Q. Please provide copies of the two previous reviews of the protection systems for the transmission lines in the Avalon Peninsula area referred to on p. 19 of Schedule 9 to Hydro's March 24, 2014 Report to the Board.

A. Hydro requested Henville Consulting to review the 230 kV line protection systems as part of its ongoing asset condition and performance assessment. The Optimho relays were anticipated to require replacement and a third party assessment was requested prior to making any changes. These were completed in two separate reports. Please see PUB-NLH-163 Attachments 1 and 2 for a copy of these reports. Please note that Appendix S to PUB-NLH-163 Attachment 1 is only viewable through proprietary (copyrighted) software and is unable to be printed.

Newfoundland and Labrador Hydro

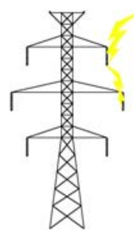
Circuits TL202, TL203, TL206, TL207 and TL237

Transmission line protection performance and settings Review

Prepared by

Charles F. Henville

Henville Consulting Inc



Prepared for

Final Report

Prepared December 31st, 2010

Circuits TL202, TL203, TL206, TL207 and TL237
Transmission line protection performance and settings Review

Table of Contents

Circuits TL202, TL203, TL206, TL207 and TL237
Transmission line protection performance and settings Review

1. Summary and recommendations

Summary

The performance and settings of the transmission line protection for five 230 kV circuits have been reviewed. The following components were included in the review.

a) Establishment of the performance requirements for the existing systems.
b) Review and modification of a model of the power system and the protective relays using ASPEN OneLiner short circuit and coordination program.
c) Review of the historical performance of the existing protection systems.
d) Detailed review of the existing settings using the ASPEN computer model mentioned above.
e) Preparation of proposed revised settings for the existing protection systems.
f) Recommendation of modifications to the existing protection systems including teleprotection equipment.

It was found that various adjustments could be made to the design and settings of the protection systems to improve the performance. The use of modern computer tools to model power systems and protective relays can result in improved settings compared to those developed earlier with more limited modeling capability.

It was found that the existing sharing of a common teleprotection function by “A” and “B” protection systems could contribute to reduced performance of the systems.

It was concluded that the use of monitoring facilities available with modern protective relays and teleprotection systems can greatly aid disturbance analysis to allow earliest possible identification and mitigation of system disturbances.

Some additional settings or teleprotection revisions may be required to protect against breaker failure in some locations.

Recommendations

As a result of the review the following recommendations are made:

a) Zero sequence mutual coupling impedances between parallel transmission lines sharing a right of way should be modeled during future line protection settings calculations.
b) Separate permissive trip communications facilities should be provided for each of the “A” and “B” protection systems so that coordination is obtained between forward and reverse looking measuring elements. This coordination is important

when the permissive trip echo function is used (as is proposed for the SEL321 relays for improved speed and sensitivity).

c) For future applications, where suitable auxiliary contacts are available on circuit breakers, the discrete status of each pole of each breaker should be connected into the SEL 321 relays instead of a single contact that cannot differentiate between a single pole open and all three poles open.
d) The transient performance of the Trench CVTs used at Sunnyside for TL202 and TL206 protection should be checked (by comparison with other CVT outputs during faults) to determine whether these CVTs need to be repaired or replaced or whether normal Zone 1 distance protection settings can be applied to these line protections. In particular, records collected during the 21 July 2010 disturbance should be analysed in more depth to check CVT accuracy.
e) During disturbance analysis, unfiltered event reports from SEL relays should be captured and retained in addition to the filtered event reports. The unfiltered reports are helpful in analyzing transient phenomena and high speed events.
f) Several adjustments of the protection settings are proposed, some more important than others. The most significant adjustments to be recommended are as follows:
   i) The permissive trip echo function should be enabled on SEL 321 relays on all lines after implementation of recommendation 1.2 b) above. The echo function is especially important at Come By Chance for the TL207 and TL237 protection systems to provide fast clearing of faults near Come by Chance under the single contingency of one 230 kV line to Come By Chance being out of service. The echo function is also important to obtain complete sensitivity for single line to ground faults with resistance of up to 100 ohms on the complete circuit.
   ii) The resistive reach of the zone 1 ground distance elements of the SEL 321 relays on circuit TL207 should be reduced significantly to increase the security of these functions.
   iii) The overreaching Zone 2 ground distance functions of all line protections except TL207 should be increased to provide dependable coverage of single line to ground faults near the remote terminals in the presence of zero sequence mutual coupling from parallel lines.
   iv) The current supervision elements of all distance protection functions (except perhaps the zone 1 function) should be set at minimum to increase the dependability and to reduce the need to continuously check the relationship between maximum load and minimum fault conditions to determine a setting for these elements.
   v) Setting adjustments should be made to the ground time overcurrent protection systems on TL203, TL207 and TL237 so they may coordinate with each other. These setting adjustments also require reduction in the tripping delays (from 1.0 s to 0.6 or 0.3 s) of the zone 2 distance elements on the P1 relays and the zone 2 ground distance elements on the P2 relays on both terminals of TL203, and TL207 and the CBC terminal of TL237.
g) Consideration should be given to the following items

i) Replacing some or all of the existing optimho distance protection systems to improve flexibility of settings and monitoring facilities for disturbance analysis. Maintenance issues due to lack of availability of spare parts for these systems are now becoming a concern.
ii) Removal of the electromechanical ground time overcurrent relays in the P2 protection systems since they add little value to the ground time overcurrent function built into the SEL 321 relays. A more independent ground time overcurrent function would be available in the new P1 protection systems if they were replaced.
iii) Modification of the dead line check function of the existing automatic reclosing system to increase the security of the 230 kV supply
iv) Replacing all pneumatic timers used for automatic reclosing or transfer trip auxiliaries with modern digital timers and configurable logic systems.
v) Use of the monitoring functions available in the new relays for steady state current and voltage balance checks. These functions could provide an alarm of steady state unbalances that could indicate a problem in the current or voltage sensing to the relays.
vi) Retrieving event records from relays and teleprotection systems in the highest possible resolution to supplement the sequence of events records, particularly in the case of questionable operations.

2. Introduction and Scope

This report is prepared in response to Newfoundland and Labrador Hydro acceptance of Henville Consulting Inc. proposal no. QNLH004 dated February 15th 2010. The work is to review the performance of protection of five 230 kV transmission lines and make recommendations for changes to settings and/or upgrades to existing protection and teleprotection systems. The transmission circuits involved are TL202, TL203, TL206, TL207, and TL237 connected as shown in Figure 1.

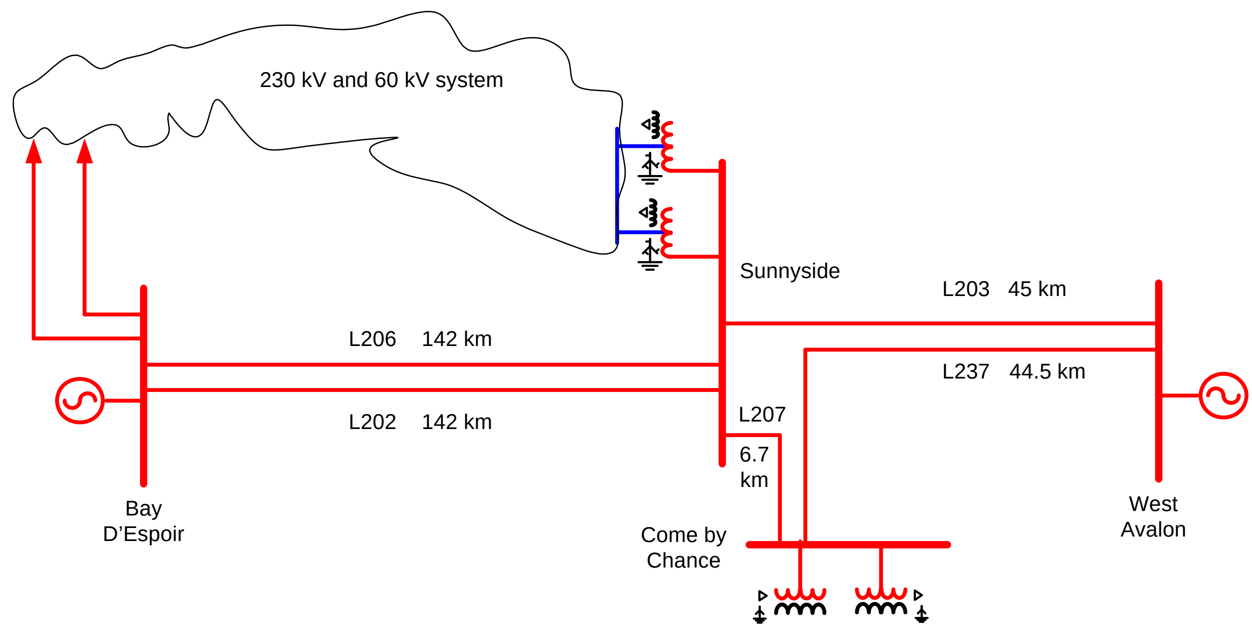


Figure 1 - Simplified System Diagram of Five 230 kV Transmission Circuits.

The existing protection systems for the five circuits are similar to each other. Consistent with industry wide practice, they consist of (almost) independent "A" and "B" systems using permissive overreaching transfer trip (POTT) logic.

Protection systems on equipment adjacent to the circuits are not included in the scope of this review except insofar as they may interact with the line protection systems.

3. Performance requirements

- **Reliability and Availability** Redundant "A" and "B" systems are provided to reduce the probability of common mode failure. Where practical, redundant teleprotection facilities are provided.
- **Loadability** Protection systems must carry the twice the maximum load (under normal conditions), without tripping, even with one pole open. The rated load is double the peak load under normal conditions in order to allow for the single contingency of the parallel line out of service. In the event of a sudden outage of

a parallel circuit, a given circuit will carry twice the load at least for a short time until operators can adjust the loading to rated values.

- **Speed** Critical clearing time for these circuits has been established as 6 cycles or less With a three cycle breaker clearing time, assume 3 cycle maximum tripping time for all faults including communications time for faults not sensed by instantaneous tripping elements.
- **Sensitivity** Must operate under minimum fault conditions and assuming a maximum fault resistance of 100 ohms for single line to ground faults. Transmission lines are not shielded for most of their length beyond the first 1.5 km from the line terminals. Backup of remote protections is not required.
- **Automatic Reclosing** Single phase tripping and reclosing is required for single line to ground faults for circuits TL202, TL203 and TL206. Three phase tripping and reclosing is applied for circuits TL207 and TL237. Reclosing will be provided by an external controller.
- **Operating procedures** Protection on TL207 and TL237 presently provide backup protection for the two 230 kV transformers at Come By Chance Station. Special operating procedures (Detailed in System Operating Instruction T-076) describe the process for removing either of these two transmission lines from service.

4. System Modeling

Basic model provided immediately after start up meeting.

The existing Newfoundland and Labrador Hydro ASPEN OneLiner model "**Hydro Interconnected System (2010-08-13) V10.olr**" was used as a starting point to represent the system. This model was provided as part of the start up information (Reference [1]).

It was noted that the existing model does not include zero sequence mutual coupling between circuits sharing the same right of way. TL202 and TL206 share the same right of way for 100% of their length, and TL203 and TL237 share the same right of way for 88% of the length of TL237 and 89% of the length of TL203. This zero sequence mutual coupling will have a significant effect on the reaches of ground distance protection functions, causing underreach in some cases and overreach in others.

The model was modified as follows:

1. Zero sequence mutual coupling between circuits sharing a common right of way was included (for the five lines under study).

2. More detailed and accurate models of the SEL 321 distance relays were used to replace the generic models. These detailed models have only recently become

available in OneLiner and provide more realistic modeling than the previously available generic models.

3. Several other changes to transformer phase shifts and generator reference angles were made to avoid power flows in the model that would not be present in the real system.

5. Historical performance

Outage records for the last 10 years were reviewed. Significant findings are presented in the following.

Circuit TL202.

This circuit has experienced 17 forced outages since 2001. In two of those incidents failure of the protection and control equipment was reported.

1. Surge ID 3312 on 8th August 2001 (defect was reported as “Refusal of switchgear to close”. It is assumed that the automatic reclose equipment failed)
2. Surge ID 4593 on 22nd August 2006 (Cause of failure is not known)

The other 15 forced outages had no significant protection problems reported. Detailed event records were available for a TL202 fault on 21 July 2010. Although the protection operation was reported as being correct, the performance was reviewed in detail. The detailed analysis is provided in **Appendix A**.

The detailed analysis concludes that there is a discrepancy between the reported location of the fault, and the observed relay performance. The reported location was 600 metres from the Bay D’Espoir terminal of the line, and the Zone 1 element of the Sunnyside terminal was observed to have operated sequentially for this fault after the Bay D’Espoir terminal opened. When the fault was simulated in the ASPEN OneLiner model, it was observed that the Zone 1 element as reported to have been set, could not have operated for a fault at the reported location.

It is possible that the reason for the discrepancy is incorrect transient response of the TL202 CVTs at Sunnyside. These CVTs are similar to the CVTs that caused a protection misoperation on 4th March 2003 at the Buchans terminal of TL205 for a TL232 fault at Stony Brook.

The possibility that the ASPEN OneLiner model might be incorrect was also considered, but the analysis of the 2 December 2007 fault on TL203 confirms the approximately correct transmission line impedances for TL202 and TL206, and the approximately correct estimate of the zero sequence mutual coupling between these two circuits.

It is concluded that either the Sunnyside TL202 CVTs transient response caused overreach of the zone 1 function, or the reported location of the fault may not have been correct.

Detailed event records were available for a series of TL202 faults on 24th August 2009 (Surge ID 5479 and 5484). These faults were high resistance and eventually cleared by three phase tripping initiated by ground time overcurrent functions. The event reports show ground fault currents in the range of less than 200 A, and no significant depression on the faulted phase voltage (see Figure 2). Therefore these faults had little impact (apart from some small frequency excursions) on the power system itself.

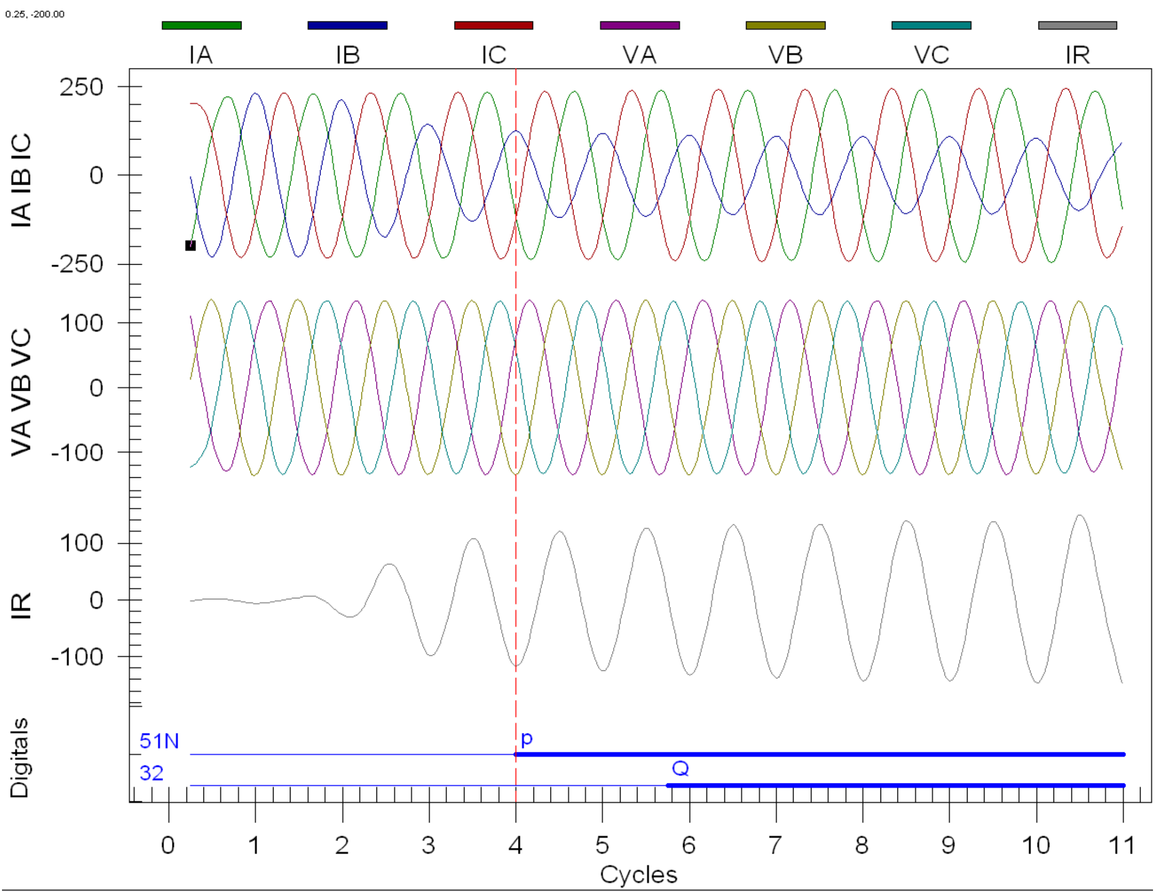


Figure 2 - Fault record from SSD Terminal of TL202 on 24th August 2010.

This incident demonstrates that trees can cause faults with significantly high resistance that will normally only be cleared by ground time overcurrent functions.

Analysis of the TL203 fault on 2 December 2007 revealed that the existing settings of the zone 2 ground distance protections are not sufficiently dependable to ensure prompt operation during single line to ground faults near the remote terminal.

Circuit TL203

This circuit has experienced 11 forced outages since 2001. In none of those incidents was failure of the protection and control equipment reported. However, on 2 December 2007, a single line to ground fault occurred that escalated to a large disturbance due to an incorrect operation of the TL237 protection to cause a separation of the 230 kV system between Western Avalon and Sunnyside (Surge ID 4955). Therefore this fault was analysed in some detail (see **Appendix B**).

The analysis of this fault supported the following conclusions from separate studies.

1. The existing settings on the TL202 and TL206 protection systems are not sufficiently dependable to be sure of detecting single line to ground faults near the remote terminals.
2. The cause of the misoperation of the TL237 protection at the Avalon terminal could not be conclusively determined, but some setting adjustments on the teleprotection systems will improve security.

Details of a TL203 C phase fault on 28 August 2009 (Surge ID 5480) were also reviewed. In this incident an insulator broke, and the conductor fell down and caused a short circuit. All protection operated properly for this fault. The SEL-321 protection operated a few milliseconds faster than the optimho protection at each end. The fault was closer to West Avalon Substation which cleared the fault in about 4.5 cycles. Sunnyside was a little slower, clearing the fault in about 5.25 cycles. The sequence of events recorder resolution was only 10 milliseconds for this event, and no additional information was obtained.

Circuit TL206

This circuit has not experienced any forced outages since 2001. No failure of the protection and control equipment has been reported.

Similar to the case of TL202 protection, analysis of the 2 December 2007 fault on TL203 revealed marginal dependability for sensing single line to ground faults of the existing protection settings.

Circuit TL207

This circuit has experienced 11 forced outages since 2001. In none of those incidents was failure of the protection and control equipment reported.

Circuit TL237

This circuit has experienced 10 forced outages since 2001. In four of those incidents failure of the protection and control equipment was reported.

1. Surge ID 3241 on 25th April 2001 (defect was reported as “False or inadvertent operation”)

2. Surge ID 3528 on 18th November 2002 (defect was reported as "False or inadvertent operation")
3. Surge ID 4555 on 3rd July 2006 (defect was reported as "False or inadvertent operation")
4. Surge ID 4955 on 2nd December 2007 (defect was reported as "False or inadvertent operation")

Details of the causes of problems on incidents in surge IDs 3241, 3528, and 4555 are not available. However the incident of Surge ID 4955 was investigated in detail (see Appendix B). The problem was an unexpected operation of the optimho relay, with an "Aided trip" target. The results of the investigation indicate as much probability of teleprotection insecurity as optimho insecurity.

6. General comments on Line Protection Reviews

Teleprotection issues

Sharing Channels

The existing teleprotection channels are shared between the P1 and P2 protection systems. Thus a teleprotection signal keyed by a P1 protection at one terminal will be received by both the P1 and P2 protections at the other terminal. The SEL 321 permissive overreaching transfer trip (POTT) protection scheme includes a reverse looking distance element to add security by blocking keying of permissive trip for a short time after a reverse looking element operates. The Optimho scheme logic POR1 does not include this security enhancement.

The keying and blocking functions in the SEL-321 POTT logic are supposed to work in tandem with each other. For any external fault, the blocking function nearest the fault will pick up and block permissive tripping and also block keying even for a short while after the reverse fault has been cleared. Thus in the event of a current reversal (which can be caused by sequential clearing of a fault on a parallel line) there will be no race between reset of the forward looking element at one end and sequential pickup of the forward looking element at the other end. If the permissive trip channel is shared with the optimho that does not have the same logic or measuring elements, there will be a danger of permissive trip from the optimho not coordinating with reset of the permissive trip from the SEL321.

It is recommended that the permissive trip teleprotection signals between the P1 and P2 systems be maintained independent of each other so that P1 teleprotection works only with P1 relays and P2 teleprotection works only with P2 relays.

Bearing in mind the comments about redundancy of teleprotection to follow, it is possible (but not preferable) to share a teleprotection facility between the P1 and P2 systems as long as independence is maintained between the permissive trip signals of the two systems. However, sharing a teleprotection facility between the two systems may complicate maintenance practices, and complete separation of the facilities is preferable.

Redundancy

It is noted that two circuits (TL202 and TL206) have redundant teleprotection facilities, but the other three do not. Since protection performance requirements require redundant facilities and the teleprotection systems form part of the facilities, redundancy should be added to the teleprotection systems of TL203, TL207 and TL237.

For the case of TL202 and TL206, it is recommended to separate the existing teleprotection facilities. If independent microwave based RFL/IMUX microwave radio systems are readily available, independent teleprotection modules should be used for each of the P1 and P2 systems. If independent modules are not available, then the P1 (optimho) systems should use the microwave system only, and the P2 systems should use the power line carrier based teleprotection only. If redundant microwave systems are available, the P1 systems can use the microwave and the power line carrier and the P2 systems should use only the independent redundant microwave system.

For the case of circuits TL203, TL207 and TL237, redundant teleprotection facilities are presently not provided. These should be provided, with care being taken to avoid possible common mode failures. If independent microwave teleprotection modules have no credible common mode failure mechanisms, then these may be used for separate P1 and P2 protection systems. If it is not possible to avoid common mode failure points in the microwave system, then use of powerline carrier for independent teleprotection facilities should be considered.

Security

The existing teleprotection systems are faster than necessary to meet overall protection performance requirements. Operating times in the range of 3-5 ms have been observed. Typical relay operating times of 17-25 ms produce an overall protection time of less than 30 ms (just less than two cycles). Protection operating times of up to three cycles are acceptable from a performance point of view. Therefore, the teleprotection could be slowed down for increased security and still retain acceptable performance.

It is not known if the existing teleprotection systems use solid state outputs or contact outputs. If they use solid state outputs it is recommended that they be replaced with contact outputs that are inherently more secure.

It is observed that the existing teleprotection systems have no intentional security delays. It is recommended that a 6-8 ms security delay be added to these systems to provide an overall teleprotection end to end time of 10-12 ms.

Monitoring

The microwave based teleprotection systems maintain logs of operations. These logs are not routinely retained as part of disturbance analysis information. It is recommended that these logs be retrieved – at least after unexpected protection operations, and retained as part of archive information about disturbance analyses.

Ground Distance Protection Issues

Zone 1 Underreaching and Overreaching

The zero sequence mutual coupling between lines sharing the same right of way for a significant distance will affect the performance of the ground distance protection functions. The major impact on the Zone 1 elements is that they will underreach under normal conditions when both parallel lines between two busses are in service. For ground faults near one end of the line, the zero sequence current flow in both lines will reduce the current in both lines and cause the ground distance function to underreach. This can be demonstrated by considering the response of the Zone 1 element to a fault at the remote bus. Without considering mutual coupling, (i.e. parallel line out of service) the apparent impedance will be equal to the line impedance as expected as shown in Figure 3. The apparent impedance is close to 8.6 ohms, which is the actual line impedance.

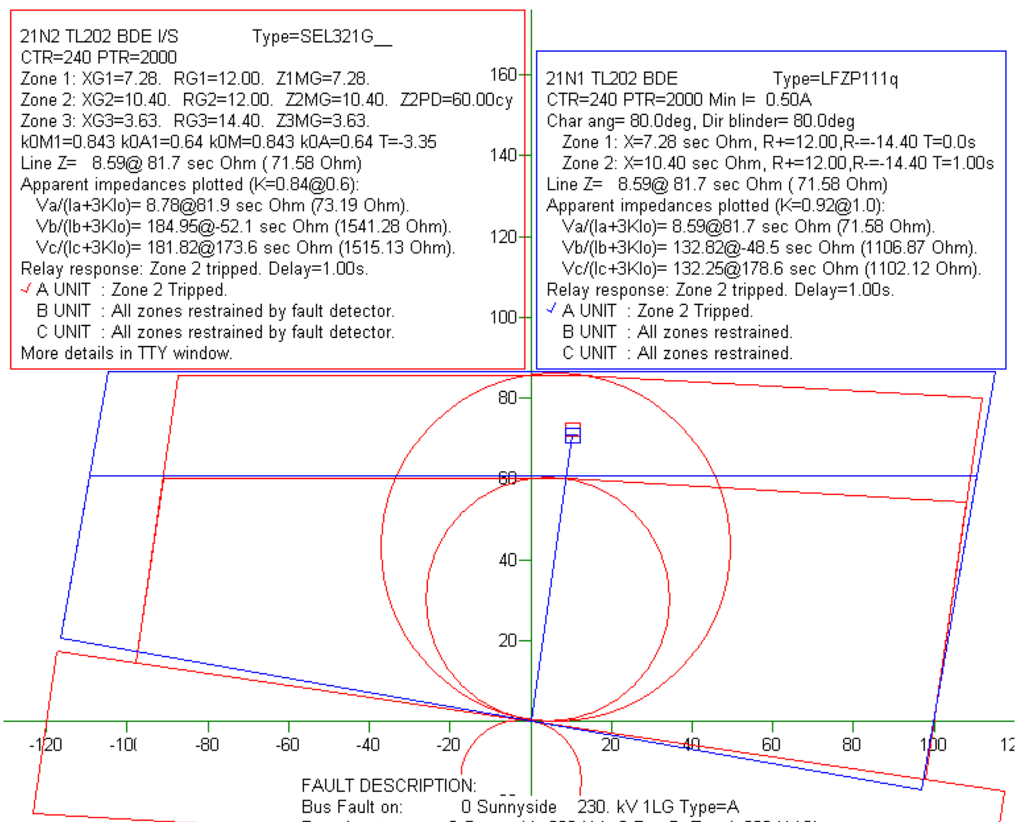


Figure 3 - Fault at remote bus with parallel line out of service but not grounded (mutual coupling has no effect).

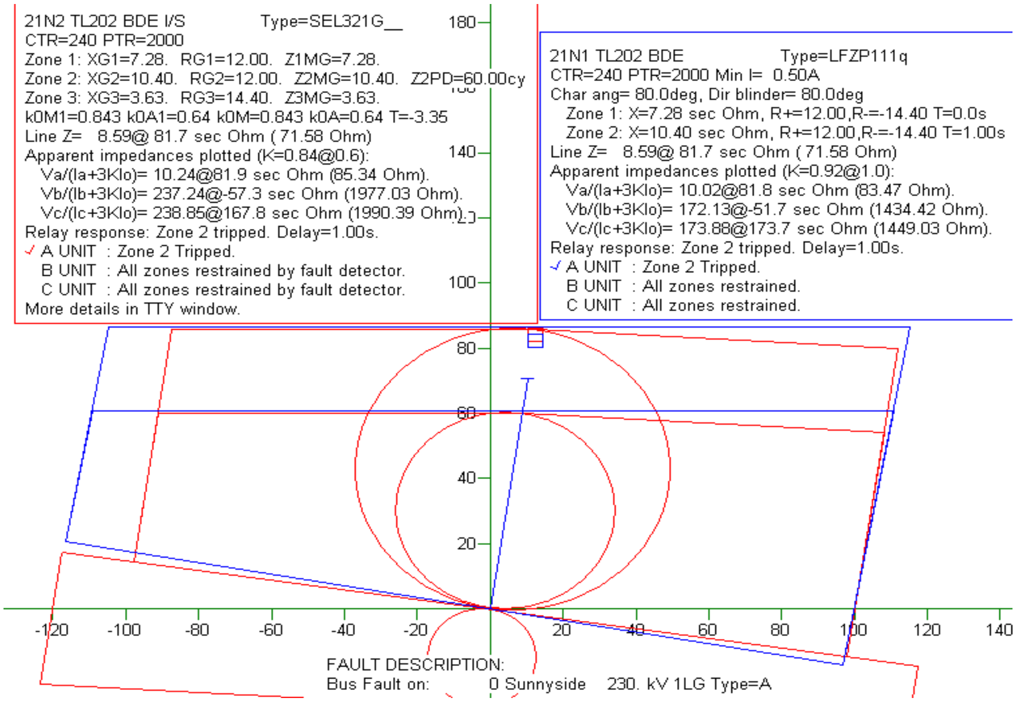


Figure 4 - Remote bus fault with mutually coupled parallel line in service

When the mutual coupling is considered, the apparent impedance is increased significantly, and the existing zone 2 reaches are barely adequate as shown in Figure 4. In Figure 4, the fault has been simulated with the mutually coupled line in service.
On the other hand, if the mutually coupled parallel line is out of service and grounded at both ends, the apparent impedance is reduced and the Zone 1 function will tend to overreach. Figure 5 shows the reduction in apparent impedance is about 10% (from a nominal 8.6 ohms secondary to 7.7 or 7.9 ohms. The security margin of a zone 1 element set at 85% of the line is not sufficient under these conditions. Zone 1 functions of lines with mutually coupled parallel lines for a significant portion should be reduced to reach less than 85% of the nominal line impedance. In the case of TL202 and TL206, settings of about 80% of the line impedance would give a comfortable security margin for the contingency of the parallel line out of service and grounded at both ends.

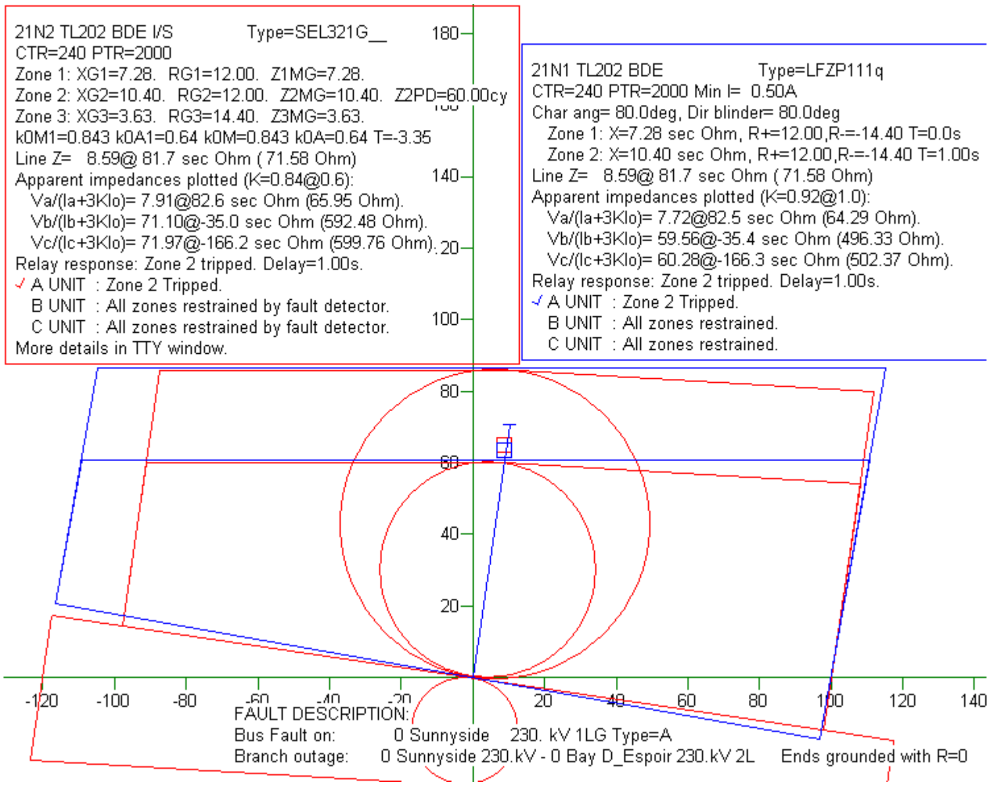


Figure 5 -Remote bus fault with parallel line out of service and grounded at both ends.

Zone 2 Underreaching

The underreaching effect shown in Figure 5 is more important for the zone 2 ground distance functions which need to overreach all of the protected line. Figure 4 shows that the reach of the zone 2 ground distance elements is quite marginal for a fault near the remote terminal of TL202. TL206 will be similar. In fact, the 2 December 2007 disturbance, demonstrated that the TL202 zone 2 elements did not see a single line to ground fault close to Sunnyside.

The reaches of the zone 2 distance elements should be increased on circuits TL202, TL203, TL206 and TL237 to improve their dependability.

Sensitivity to resistive SLG Faults and use of the Echo function.

The performance specifications require the protection to operate for fault resistances of up to 100 ohms and to provide single phase tripping and reclosing for such faults. It is found that the SEL-321 relays cannot meet this performance requirement without the use of very high resistive reach settings on the quadrilateral elements. In order to avoid the need for such high resistive reach settings, it is recommended that the echo function be enabled on all schemes using SEL relays.

It is noted on the settings calculations for Sunnyside terminal of TL207 that the use of the echo function was considered, but not adopted, with the note that this function is “set to OFF due to experience problems with the Echo feature”. It is not known what the experience problems are, but other utility experiences with this feature have been satisfactory. It is possible that the sharing of permissive trip functions between P1 and P2 protection systems may have caused poor experience. This is because the echo function depends on coordinated operation of forward looking elements at one end, and reverse looking elements at the other. If the permissive trip channel is shared between P1 and P2 systems, then this coordination is lost.

It is recommended that the echo feature is enabled on most of the SEL-321 systems only after the P1 and P2 permissive trip channels have been separated from each other as recommended in earlier discussion in this report on teleprotection systems.

The echo function is not available on the Optimho POR1 permissive tripping logic. It is available on the POR 2 logic, but that logic is not used by Newfoundland and Labrador Hydro.

Performance of the Optimho Line Protection Systems

The existing P1 protection systems are Areva type LZFP111 static distance protection systems. These systems are approximately 18-20 years old. Typical service lives for this generation of equipment is in the range of 20-25 years. This generation of protection system used hybrid analogue/digital technology. It is no longer manufactured because it has been superseded by “all digital” protection systems.

The optimho relay performance includes some important limitations when compared with more modern technology. These limitations are discussed in the following paragraphs.

a) Analogue and event recording functionality is not available for this device. Such functionality is key for successful disturbance analysis to identify actions required to avoid or minimize future reoccurrence of undesirable behavior. The lack of recording capability resulted in an inability to conclusively identify whether the teleprotection system, or the optimho relay, or the interface between them was responsible for the misoperation of the relay to trip the Western Avalon terminal of unfaulted circuit TL237 on 2 December 2007. As protection systems are recognized as major contributors to the exacerbation of system disturbances recording functionality is an important part of determining their performance during any specific event. Since the transmission lines within the scope of this report are a key part of the Newfoundland and Labrador Hydro backbone transmission, identification of problems is important for continued high performance of the power system.

b) The reactive reaches of the phase and ground distance elements have to be set the same as each other. This limitation affects the ability to optimize the reaches of these elements in the presence of zero sequence mutual coupling. In the analysis of mutual coupling issues in this report, it is noted that it is desirable to set the zone 1 ground distance functions on lines with significant mutual coupling to lower values than the phase distance functions. It is not possible to have separate reach settings on the optimho; so the zone 1 phase distance function will be set to 80% instead of 85% on some circuits.
c) The resistive reaches of the distance elements on all zones have to be set the same as each other. This means that on the short line TL207, the zone 1 trip function has to be blocked. The resistive reach of the Zone 2 element has to be set to a minimum value to meet the sensitivity performance requirements noted in Section 3 of this report. This minimum value is too high to ensure security of the zone 1 element, so tripping has to be disabled on this element.
d) The weak source echo function is not available in the permissive overreaching transfer trip logic scheme POR1 that is used by Newfoundland and Labrador Hydro. Without this logic, the specified sensitivity of 100 ohms for single line to ground faults will not be met for all fault locations. However, sensitivity close to this level will be met for all locations.

Given the age and limitations of the optimho relays, their replacement may be considered. Greatest value would likely be realized by replacing the relays on Circuit TL207 first since this short line would benefit most from a line current differential protection application.

Reclosing and auxiliary logic

It was observed that on the 2 December 2007 disturbance that the Circuit TL237 was automatically reclosed after tripping undesirably. Since the line was still closed at Come By Chance, and the Western Avalon system was separated from the Sunnyside system, the systems were reconnected out of synchronism. The problem was caused by lack of phase B line voltage. Lack of this voltage resulted in the reclosing logic considering the line to be dead, when it was not. Consideration should be given to modifying automatic reclosing logic so that all three phases have to demonstrate low voltage before the line can be considered dead.

Some transmission lines use pneumatic (Agastat) timers for automatic reclosing and auxiliary transfer trip functions. These timers suffer from lack of repeatability due to dust and temperature changes that affect their performance. They need to be tested and maintained regularly to ensure their performance is retained. Consideration should be given to replacing these timers with modern alternatives that provide better performance with improved monitoring and require significantly less maintenance.

Single Pole Open Status to SEL 321 relays

On most breakers, the existing breaker status inputs to SEL321 relays consists of a single input per breaker which is set in each relay to show the status of all three poles of the breaker. The ground distance measuring elements in this relay are each controlled by the status of its pole (see Figure 6). All quadrilateral elements are disabled during SPO conditions and the mho distance element on the open phase is also disabled (see Figure 7).

It was first recommended for TL202, TL206 and TL203 that the breaker status inputs be modified so that the relay may know the status of each pole of each breaker in order to properly disable and enable the appropriate internal measuring elements. However, it was later discovered that segregated pole auxiliary switches are not available on the majority of older (air blast) breakers. Therefore the ideal breaker status connections cannot be achieved. On the air blast breakers "52b" auxiliary switches are available, and assuming that these contacts close when any single pole is closed, it is probable that these switches will provide adequate information to the relays.

Detailed event records from the relays during open pole conditions need to be reviewed to confirm whether the existing status connections are adequate. Recommended settings changes to increase the resistive reaches of quadrilateral elements should not be implemented before this additional review is completed and the existing auxiliary switch connections are confirmed to be adequate.

In addition, some typographical errors (with respect to the use of 52b or 52bb auxiliary contacts) appear on some of the drawings that should be corrected.

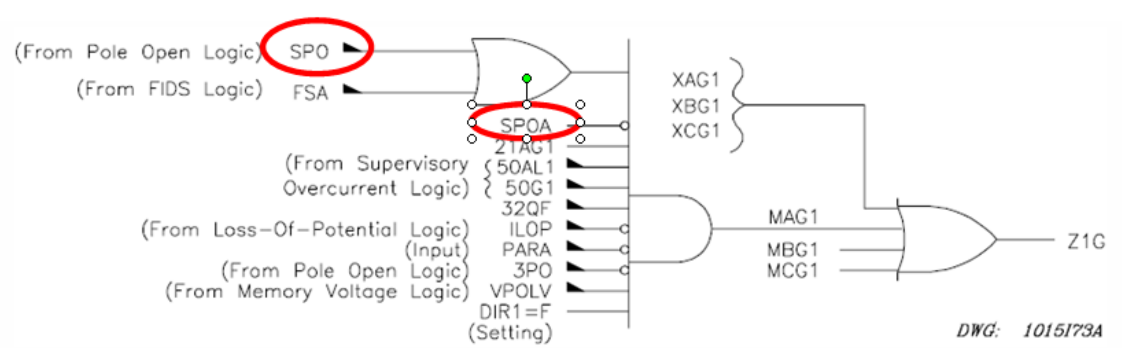


Figure 2.10: Zone 1 Mho Ground Distance Element Logic

Figure 6 - Example Mho Ground Distance Logic

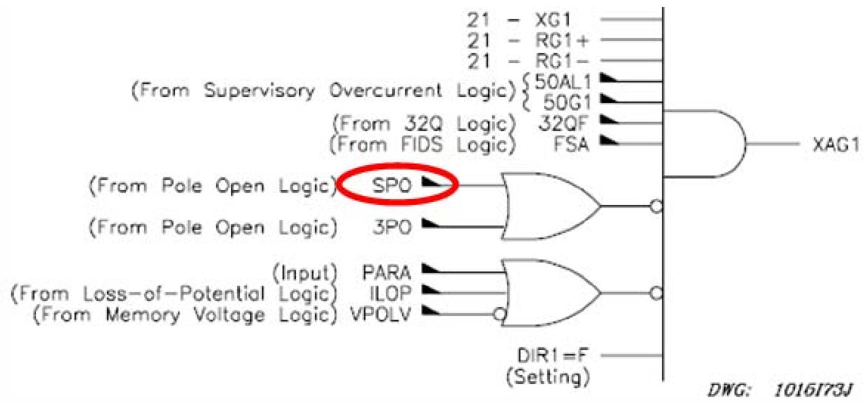


Figure 2.14: Zone 1 Quadrilateral Ground Distance Element Logic

Figure 7 - Example Quadrilateral Distance Logic

Ground time overcurrent protection.

Need for ground time overcurrent protection

Protection by ground time overcurrent functions is helpful for high resistance faults such as might result from a tree growing too close to the conductor. This was the case on 28th August 2009 when TL202 suffered such a fault. The ground time overcurrent protection could be considered backup for faults with resistance higher than 100 ohms. For faults with resistance lower than 100 ohms, redundant protection is required, as specified in Section 3 of this report.

For all line protection systems in this study, ground time overcurrent protection is provided in two places within the P2 protection system. One function is built into the SEL321 relay, and the other is a discrete external electromechanical relay. The discrete electromechanical relay is not allowed to trip by itself. Its tripping output is connected in series (though OUT6) with the ground time overcurrent function built into the SEL321 relay. The reason for this connection is not known, but it appears to have little value, considering the SEL321 internal ground time overcurrent function trips directly (through OUT5) anyway.

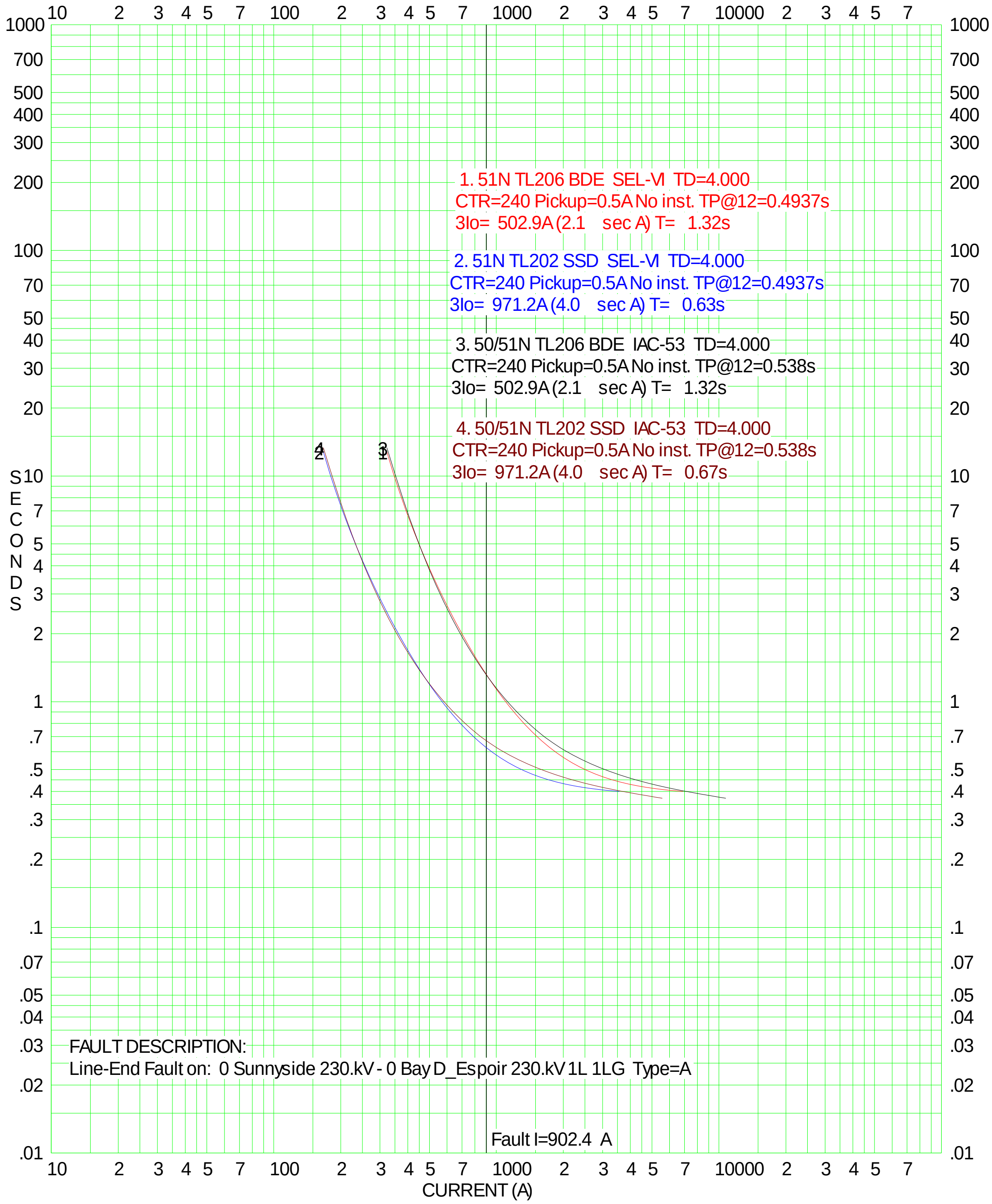
It is recommended that consideration be given to removing the discrete electromechanical time ground overcurrent relay from the P2 protection since it adds little value. If the primary (optimho) protection is not to be replaced in the near future, consideration could be given to reconnecting this discrete electromechanical relay into the P1 protection to provide redundant sensitive ground overcurrent protection. However, since the ground distance functions available in the P1 and P2 systems are set to cover single line to ground faults with resistance up to 100 ohms to meet the performance specification, redundant ground time overcurrent protection is not required.

Coordination of ground time overcurrent protection functions

The coordination of the backup ground time overcurrent functions will be made more difficult by the presence of zero sequence mutual coupling. The response of the primary and backup relays will be most critical for line end faults when the end closest to the fault is open. Such faults would be expected to be cleared sequentially. Figure 8 and Figure 9 show that coordination is achieved for such faults with the existing settings on TL202 and TL206. There will likely be no need for settings changes to these elements.

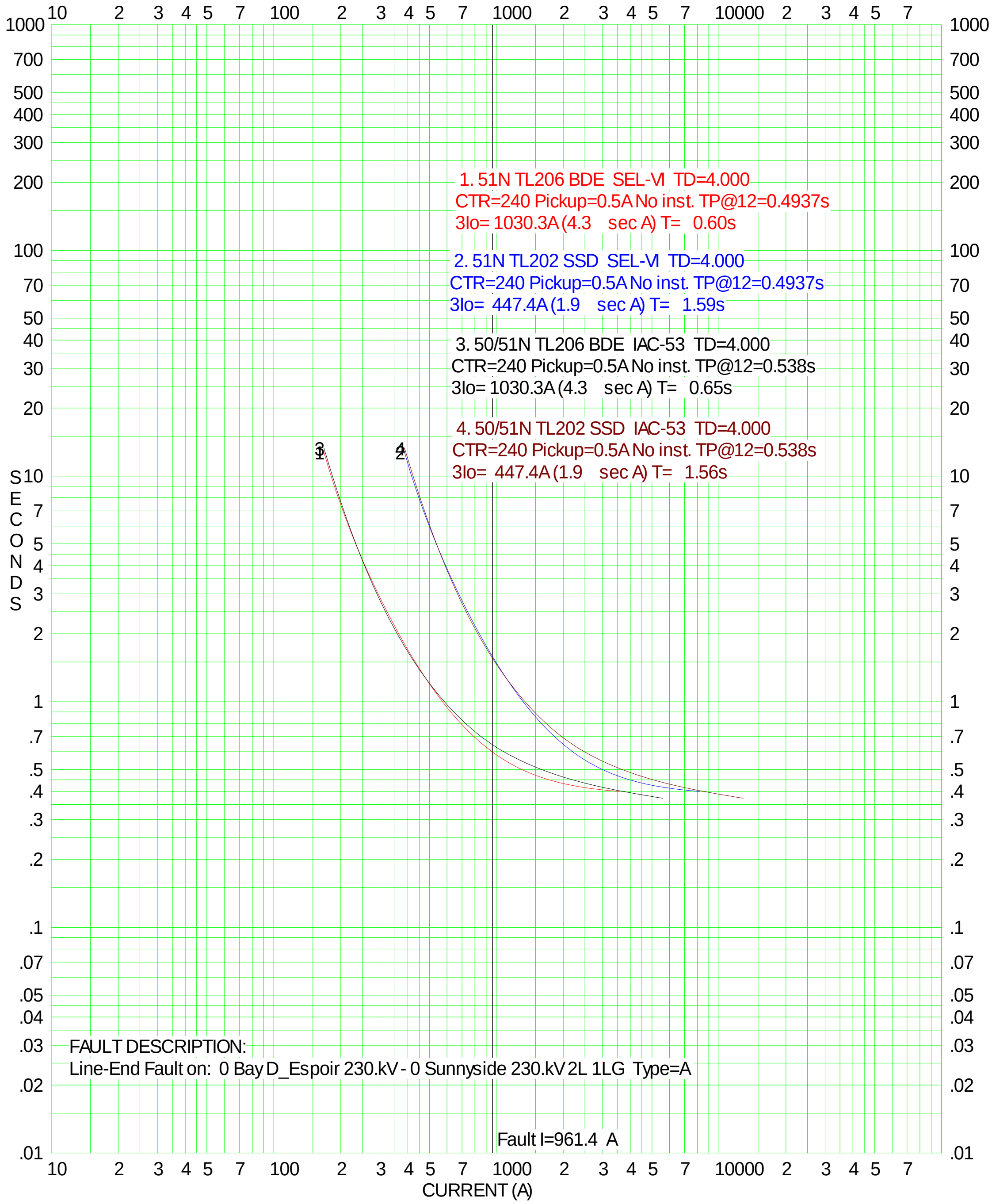
The TL237 ground time overcurrent protection will not coordinate with the TL207 ground time overcurrent protection because all relays are set the same (see curves 2 and 3 on Figure 10). This means that for any high resistance fault that needs the ground time overcurrent protection to operate, both lines will likely trip together and the CBC station will go black. Setting adjustments are required for these relays.

Note that the TL203, TL207 and TL237 will all need to have their ground distance functions time delays reduced from the existing 1 second to 0.3 or 0.6 seconds in order to ensure coordination of ground time overcurrent functions. **This recommendation is a deviation from common Newfoundland and Labrador practice and needs careful consideration by Newfoundland and Labrador Hydro before acceptance.** The alternative is to accept larger changes (than proposed in this report) in the settings of the ground time overcurrent functions on the TL203, TL207 and TL237 loop.



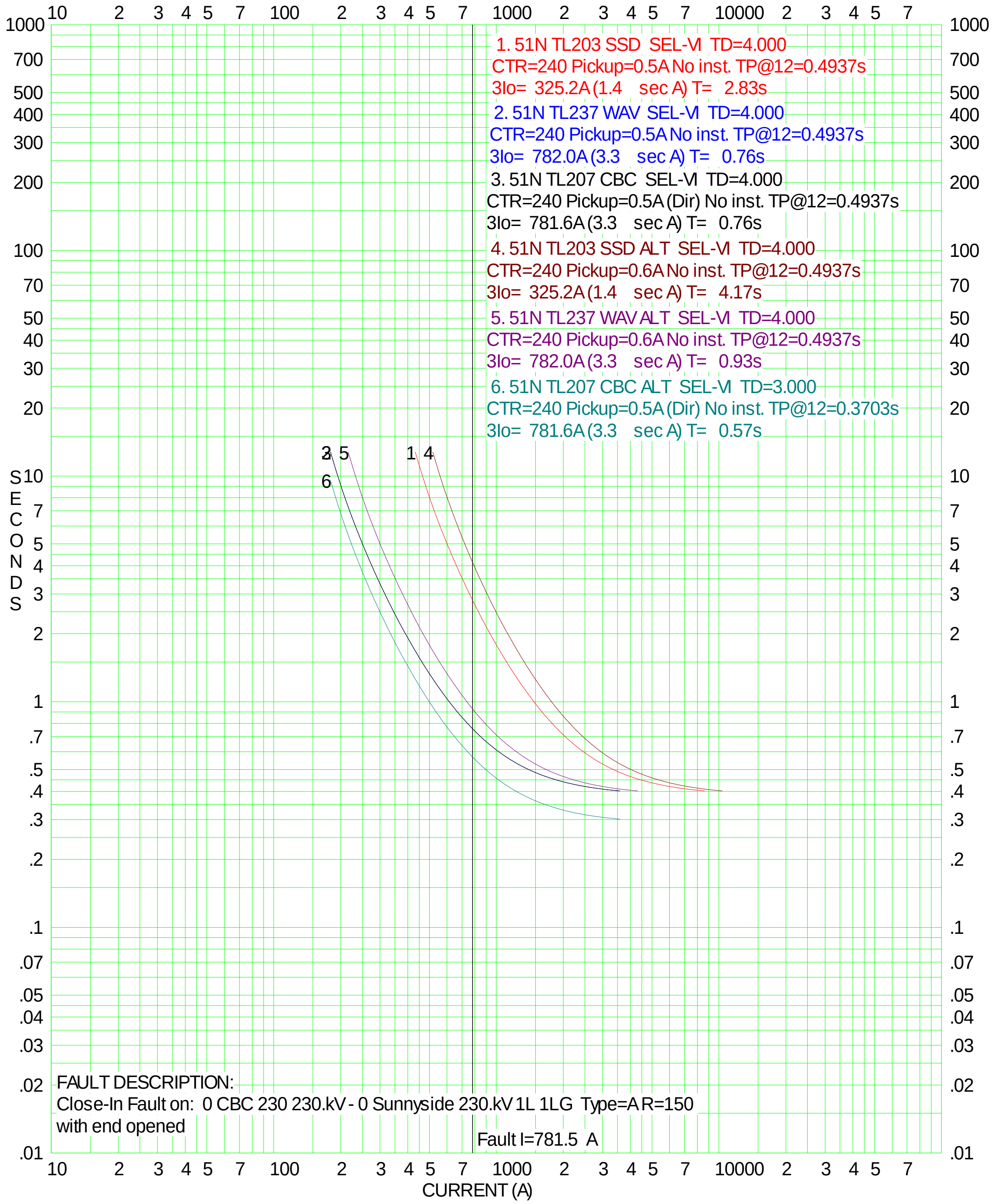
TIME-CURRENT CURVES @ Voltage 230 kV	By
For Coordination of ground time overcurrent elements	No.
Comment With mutual coupling taken into consideration.	Date

Figure 8 - coordination of ground time overcurrent elements for line end fault on TL202 close to BDE



TIME-CURRENT CURVES @ Voltage 230 kV		By
For	Coordination of ground time overcurrent elements	No.
Comment	With mutual coupling taken into consideration.	Date

Figure 9 - coordination of ground time overcurrent elements for line end fault on TL206 close to SSD



SSD3	TIME-CURRENT CURVES @ Voltage 230	By CFH
For	TL203 TL207 and TL237 CW coordination	No. SSD3
Comment	150 High Resistance SLG	Date 5 Nov. 2010

Figure 10 - Coordination of "ALT" settings on ground time overcurrent elements for close-in 150 ohm resistive SLG fault on TL207 close to CBC

Transient Response of Sunnyside TL202 and TL206 CVTs

The TL202 and TL206 CVTs at Sunnyside are suspected of having improper transient response. These CVTs are the same type of CVT as was at the Buchans terminal of TL205 on 4th March 2003, when the zone 1 functions at that terminal overreached and operated for an external fault. As a result of this the CVTs at Buchan TL205 were replaced. The zone 1 elements at the Sunnyside terminal of TL202 and TL206 had their reach reduced to 75% of the line length, instead of being set at the normal reach of 85% of the line length. This setting change is due to the uncertainty of the transient performance of the Sunnyside CVTs.

The problem with the CVTs was never resolved, and the reduced reach setting of the Zone 1 elements is still retained. As noted in Section 5, it is suspected that improper transient performance may have caused transient overreach of the TL202 zone 1 elements during a fault near BDE on 21 July 2010. It would be possible to establish the transient performance of these CVTs by comparing their voltage during a fault with the voltage of other CVTs on the same bus. It is recommended that this comparison be made during the analysis of future faults.

Distance element current supervision

It is noted that Newfoundland and Labrador Hydro practice is to set distance current supervision elements (where such elements are adjustable) above load if it is possible to do so. It should be noted that many modern relays and even some existing older relays like the Optimho) do not have settable current supervision elements. It is recommended that at least for all zones higher than zone 1, that the current supervision elements be set at minimum, and the loss of potential function be depended upon to block the distance elements from operating on load currents if the potential source should be lost. This practice eliminates the need to check loads and fault currents to set the current supervision elements. **This is a departure from Newfoundland and Labrador Hydro normal practice.** For Zone 1, it is acceptable to retain present practice if desired since the dependability of the zone 1 function is not critical for communications assisted schemes.

Monitoring of fault Records

As noted above, the transient response of two sets of CVTs at Sunnyside is suspect. It would be possible to compare the response of these CVTs to that of other CVTs on the same bus during faults. If digital fault recorder records are available, this comparison can be done with past faults. If they are not available, it should be done with future faults. If this comparison shows undesirable transient response, it would be possible to determine a course of action (repair, replace, or retain) for these CVTs.

It is noted that event records captured by SEL relays are filtered quantities sampled four times per cycle. While this sample rate is sufficient for many purposes, it is not adequate for some important phenomena, such as the transient response of CVTs. The slow sample rate may also have caused failure to detect an undesirable transient receipt of permissive trip signal at the West Avalon terminal of TL237 during the 7 December 2007 disturbance. It is recommended that in future disturbances both filtered and unfiltered (8 samples per cycle) reports be retrieved from SEL relays to assist in disturbance analysis. These reports are retrieved by using the commands “Event *x* C” and “Event *x* U” commands on the SEL321 relay communications program (where “*x*” is the event number).

Breaker Failure

All transmission lines in this study terminate at stations with breakers that are shared by one or two adjacent transmission lines. In the event of a failure of a shared breaker to clear a fault on a transmission line, local breaker failure protection will clear local infeed to the faulted line. However, there appears to be no provision to specifically remove remote infeed from the remote terminal of the unfaulted adjacent line. Ground time overcurrent protection at the remote terminal will remove infeed to single line to ground faults, but no provision is made to remove remote infeed to multiphase faults.

If all breakers at a transmission line terminal have independently controlled poles, it may be assumed to be non credible that more than one pole would fail to interrupt a single multiphase fault so that a multiphase fault involving ground would be cleared remotely by the ground time overcurrent protection. It is recommended that Newfoundland and Labrador Hydro explicitly acknowledge this assumption.

Of the five transmission circuits reviewed in this study, three have single phase tripping and reclosing in service. Two (TL207 and TL237) have three phase tripping and reclosing. It is assumed possible that circuit breaker B1/B2 at Come By Chance may fail to trip all three poles simultaneously. If this if verified, then it will be recommended to add a zone 3 function at the SSD terminal of TL207, and to extend the zone 2 at the WAV terminal of TL237 to provide remote breaker failure coverage for faults on either of TL207 or TL237.

7. TL202 review comments

Detailed calculations and comments are provided in Appendices C,D, E and F. Several minor changes are proposed. Apart from the general items noted in Section 6, the specific major changes to this line terminal include the following:

1. Increase the reach of the zone 2 distance elements in the P1 protection and the ground distance elements in the P2 protection (both terminals)

2. Decrease the reach of the zone 1 distance elements in the P1 protection and the ground distance elements in the P2 protection (BDE terminals only)
3. Increase the resistive reach of the zone 1, zone 2 and zone 3 ground distance elements in the P2 protection (both terminals). This should only be done after phase segregated breaker status inputs are connected to the relay so that the relay can know when the line has a single pole open.
4. Increase the time delay for tripping of the BDE zone 2 phase distance elements to coordinate with SSD TL207 Zone 2 protection. Consider adding a zone 4 function to the BDE P2 protection to provide faster zone 2 communications independent protection for most of the section near the remote terminal.
5. Add the echo function to the P2 protection at both terminals to increase the sensitivity to resistive faults near one end or the other. This should only be done after the P1 teleprotection is separated from the P2 protection.
6. Add unbalance monitoring functions to the P2 protection and connect them to the existing loss of potential alarm output.
7. Replace the automatic reclosing logic using Agastat timers with a modern alternative. When this is done, there will be sufficient spare input contacts on the SEL321 relay to wire individual poles of each breaker to the relay to allow the relay to know when breakers have a single pole open.

8. TL206 review comments

Except as noted below, detailed calculations and comments are provided in Appendices C,D, E and F and are identical to those calculations and comments for TL202. The only difference with protection for TL206 is that the circuit breakers at the Bay D'Espoir terminal are not air blast breakers. They are SF6 circuit breakers. The breaker auxiliary switches are segregated phase by phase. The auxiliary switch connections into the scheme logic for the 52X/bb auxiliary relay are not correct, and need to be modified to achieve the same effect for the P1 protection as on other lines.

9. TL203 review comments

Detailed calculations and comments are provided in Appendices G,H,I, J. Several minor changes are proposed. Apart from the general items noted in Section 6, the specific major changes to this line terminal include the following:

1. Increase the reach of the zone 2 distance elements in the P1 protection and the ground distance elements in the P2 protection (both terminals)
2. Decrease the reach of the zone 1 distance elements in the P1 and P2 protections (both terminals)
3. Increase the resistive reach of the zone 1, zone 2 and zone 3 ground distance elements in the P1 and P2 protections (both terminals). This should only be done

after phase segregated breaker status inputs are connected to the P2 relay so that the relay can know when the line has a single pole open.

4. Add the echo function to the P2 protection at both terminals to increase the sensitivity to resistive faults near one end or the other. This should only be done after the P1 teleprotection is separated from the P2 protection.
5. Add unbalance monitoring functions to the P2 protection and connect them to the existing loss of potential alarm output.
6. Add phase segregated breaker status inputs to the P2 protection so that it will know which phase is open during single pole open conditions.
7. With the existing setting of the TL203 ground time overcurrent protection, it could operate in about 1 second during heavy load flow and single pole open. It is recommended that the existing settings on this protection on TL203 be desensitized slightly to make them more secure (operating time 1.3 seconds) when a single pole is open during heavy load flow.

10. TL207 review comments

Detailed calculations and comments are provided in Appendices K,L,M,N. Several minor, and some significant changes are proposed. This is a very short line. Considering the “length” of a transmission line to be dependent on the ratio of the source impedance to the line impedance, the line is actually shorter looking from the CBC terminal than from the SSD terminal. In fact, it is so short looking from the CBC terminal that special security measures are taken with the P2 zone 1 functions to add a short delay to increase their security. The P1 zone 1 functions at both terminals are blocked from tripping. Apart from the general items noted in Section 6, the specific major changes to this line terminal include the following:

1. Significantly reduce the resistive reach of the zone 1 quadrilateral element in the P2 protection at both terminals. This is required to increase the security.
2. Add a 1 cycle delay to the tripping time of the zone 1 elements in the P2 protection at the CBC terminal. This is required to increase the security due to possible CVT transient errors and measuring errors in the relay during severe short circuits on other lines out of SSD.
3. Increase the reach of the zone 2 distance elements in the P1 protection and the ground distance elements in the P2 protection (both terminals)
4. Decrease the reach of the zone 1 distance elements in the P1 and P2 protections (both terminals)
5. Increase the resistive reach of the zone 2 and zone 3 ground distance elements in the P2 protections (both terminals)
6. Add the echo function to the P2 protection at both terminals to increase the sensitivity to resistive faults near one end or the other. This should only be done after the P1 teleprotection is separated from the P2 protection.

7. Add unbalance monitoring functions to the P2 protection and connect them to the existing loss of potential alarm output.
8. Modify the settings of the ground time overcurrent protection at CBC. Modify the settings of the trip time delays of the ground distance elements in the P1 and P2 protections to improve coordination of the communications independent ground protection in the TL203, TL207 and TL237 loop.

11. TL237 review comments

Detailed calculations and comments are provided in Appendices O,P, Q, R. Several minor changes are proposed. Apart from the general items noted in Section 6, the specific major changes to this line terminal include the following:

1. Increase the reach of the zone 2 distance elements in the P1 and P2 protections (both terminals)
2. Decrease the reach of the zone 1 distance elements in the P1 and P2 protections (both terminals)
3. Increase the resistive reach of the zone 1, 2 and zone 3 ground distance elements in the P1 and P2 protections (both terminals)
4. Enable the current reversal logic in the P1 POR 1 scheme to increase the security in the light of known security concerns from the 2 December 2007 disturbance.
5. Add the echo function to the P2 protection at both terminals to increase the sensitivity to resistive faults near one end or the other. This should only be done after the P1 teleprotection is separated from the P2 protection.
6. Add unbalance monitoring functions to the P2 protection and connect them to the existing loss of potential alarm output.
7. Modify the settings of the ground time overcurrent protection at CBC and WAV. Modify the settings of the trip time delays of the ground distance elements in the P1 and P2 protections to improve coordination of the communications independent ground protection in the TL203, TL207 and TL237 loop.

12. Conclusions

The past performance and existing settings of the protection on five 230 kV transmission lines have been reviewed. Possible improvements to sensitivity and security have been identified.

The performance so far has been good, with one known improper operation that exacerbated a disturbance on 2 December, 2007. The reason for the improper operation cannot be conclusively identified. However the recommended changes to settings of the system that misoperated and recommended changes to the teleprotection system will improve the security. Recommendations have been made for more detailed monitoring that would improve the ability to identify the causes of misoperation in the future.

The recommended improvements to the protection systems include adjustment of settings on the P1 and P2 protections and modifications to the existing teleprotection systems. In addition, the limitations of the existing P1 (optimho based) protection systems have been identified so that consideration may be given to replacing these systems with more modern systems.

13. Appendices

Appendix A – Detailed Analysis of TL202 Fault 21 July 2010

On 21 July 2010 a single line to ground fault occurred on this circuit. A resistive fault occurred close (600 m) to the Bay D'Espoir (BDE) terminal and the faulted phase was cleared sequentially, first from the BDE terminal, then from the Sunnyside (SSD) terminal. Reclose was successful. Relay operation was correct for this fault, but the opportunity was taken to check the OneLiner "**Hydro Interconnected System (2010-08-13) V10.olr**" model and compare the actual performance of the relays to the model performance.

A single line to ground fault with 35 ohms of resistance was simulated at the reported location. It was noted that with all BDE generators in service, the ratio of negative sequence current from the BDE terminal to the negative sequence current from the SSD terminal was significantly higher than the ratio of negative sequence currents recorded by the SEL relays.

For the initial fault, recorded by SEL relays BDE I2 = 960A, SSD I2= 117 A ratio = 8.2
For the initial fault calculated by ASPEN OneLiner BDE=1082A SSD= 96 A ratio = 11.3

Note that the ratio of negative sequence current contributions is not dependent on the fault resistance, but only on the fault location and the negative sequence impedances behind the line terminals. The difference in ratio noted above means that either the location is different from the simulated location or there is an error in the model. A large impact on source impedances is the number of generators on line at BDE. In order to get a closer match with the ratio, three generators were simulated off line in the OneLiner model. With the revised model and the same fault location and resistance, the following negative sequence currents were calculated by OneLiner.
For the initial fault calculated by OneLiner BDE=1018 A SSD= 118 A ratio = 8.6

Further studies were carried out with three units simulated off line at BDE. With the "**Hydro Interconnected System (2010-08-13) V10.olr**" model of the system (with three units offline at BDE) and the relays, the initial fault was sensed by the BDE terminal only, as shown in Figure 11.

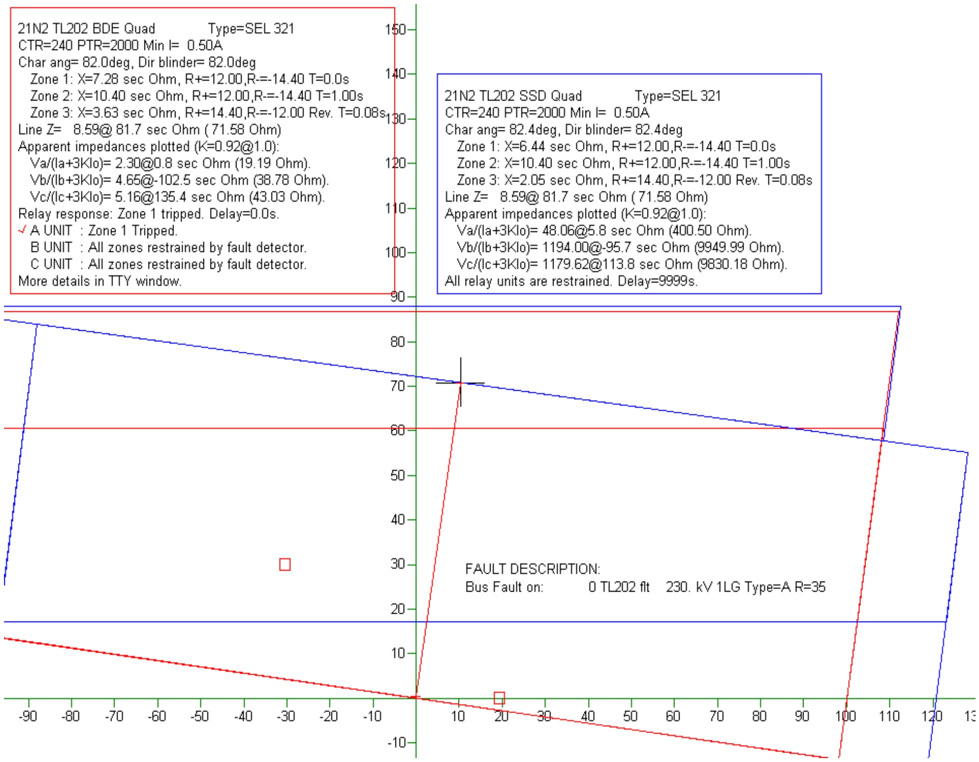


Figure 11 - Initial response of existing model relays to 21 July 2010 fault

In Figure 11 it can be seen that the BDE terminal Zone 1 element operates instantaneously while none of the SSD distance elements sense the fault. This matches the observation of the actual relay performance. After the BDE terminal opens, the SSD relays can see the fault as shown in Figure 12.

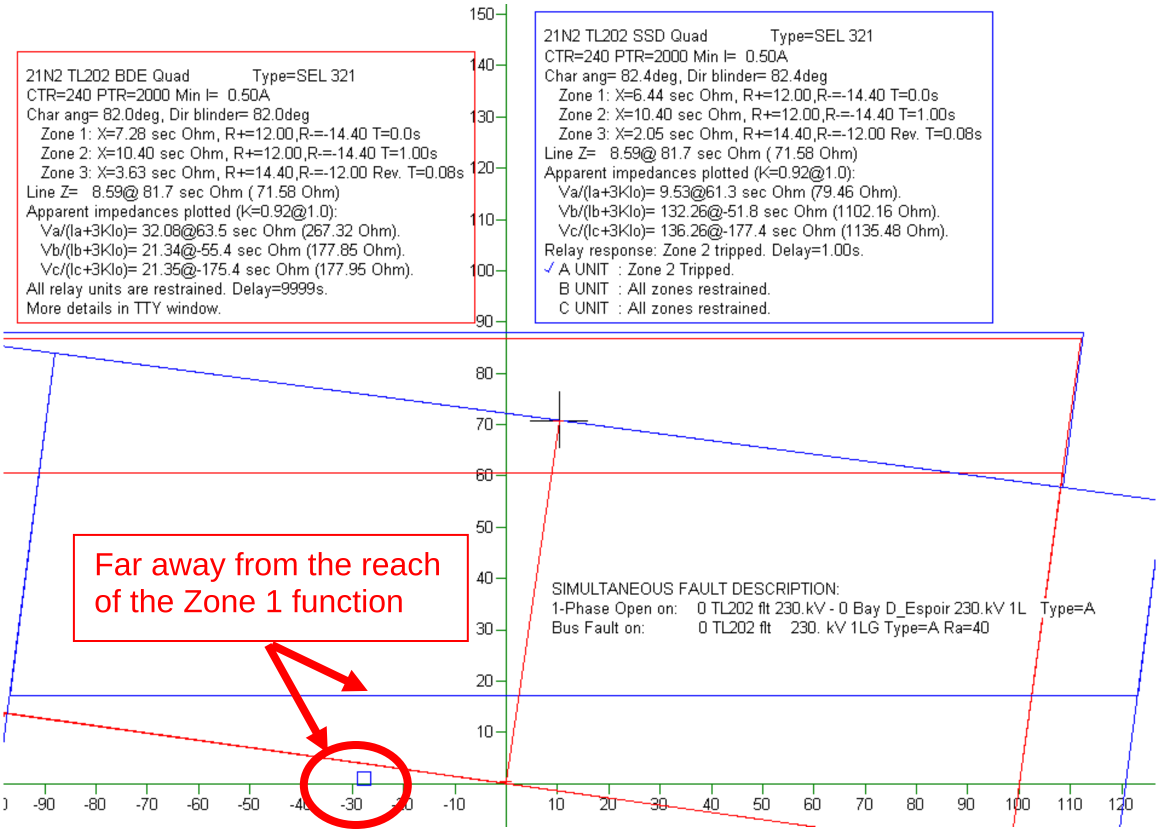


Figure 12 - Sequential response of existing model relays to 21 July 2010 fault

Note however, that in Figure 12, the zone 2 element of the SSD relay operates, while the Zone 1 element operated in the actual event (as shown in Figure 13). Thus there is a mismatch between the modeled event and the actual event.

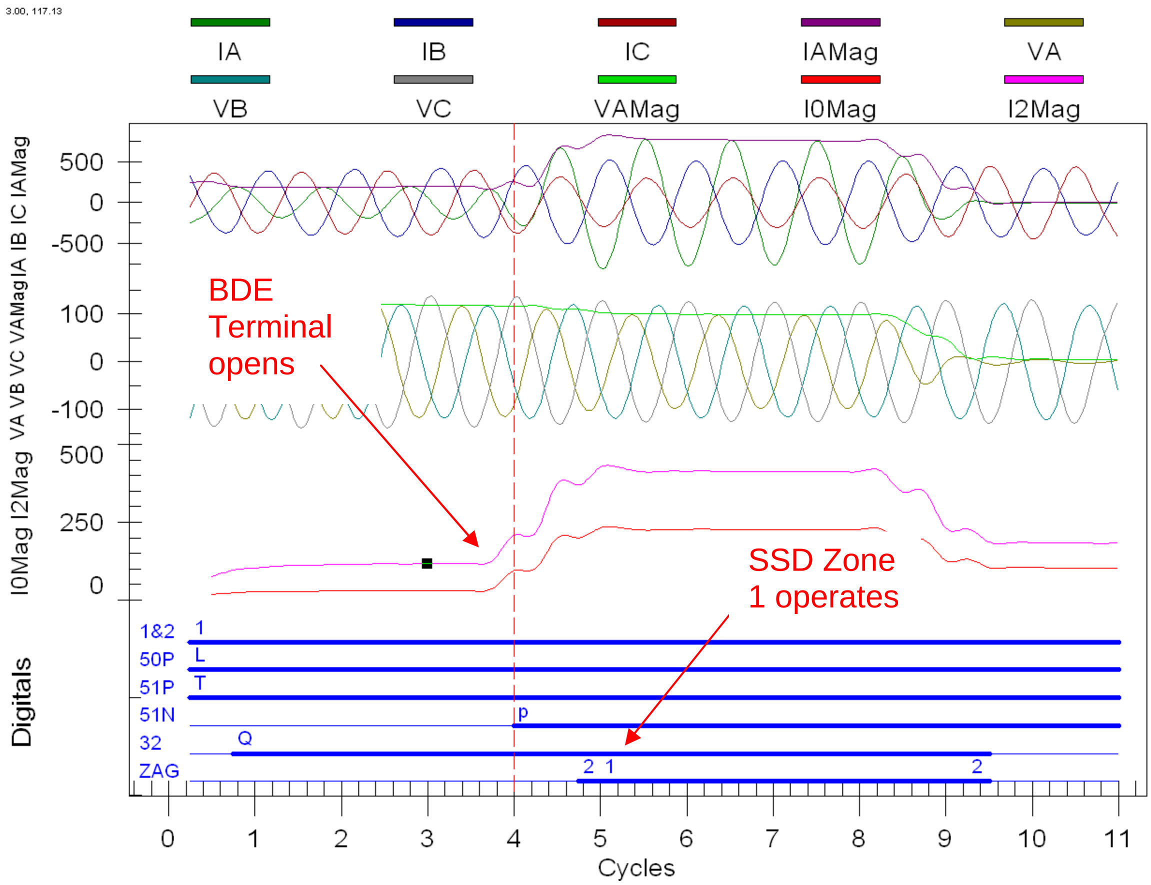


Figure 13 - Sequential operation of the SSD TL202 protection.

The cause of this mismatch is not known. It could be that the reported fault location is not the actual location. It was noted that the relay estimated a fault location of 6.5 km from the BDE terminal instead of the reported location of 600m from BDE. It could also be that the model is not sufficiently accurate. The model "**Hydro Interconnected System (2010-08-13) V10.olr**" does not include any zero sequence mutual coupling. The line data indicates a significant amount of zero sequence mutual coupling between TL202 and TL206 and lesser amounts of coupling with circuits TL212 and TL219. These additional couplings were added to the model "**Hydro Interconnected System (2010-08-13) V10.olr**".

In addition, a recent update of the OneLiner program has included a more detailed model of the SEL relays. This model is more accurate than the generic model available in earlier versions of the program. The model "**Hydro Interconnected System (2010-08-13) V10.olr**" was also modified to include the updated relay model.

The simulated faults before and after the BDE terminal opens are shown in Figure 14 and Figure 15.

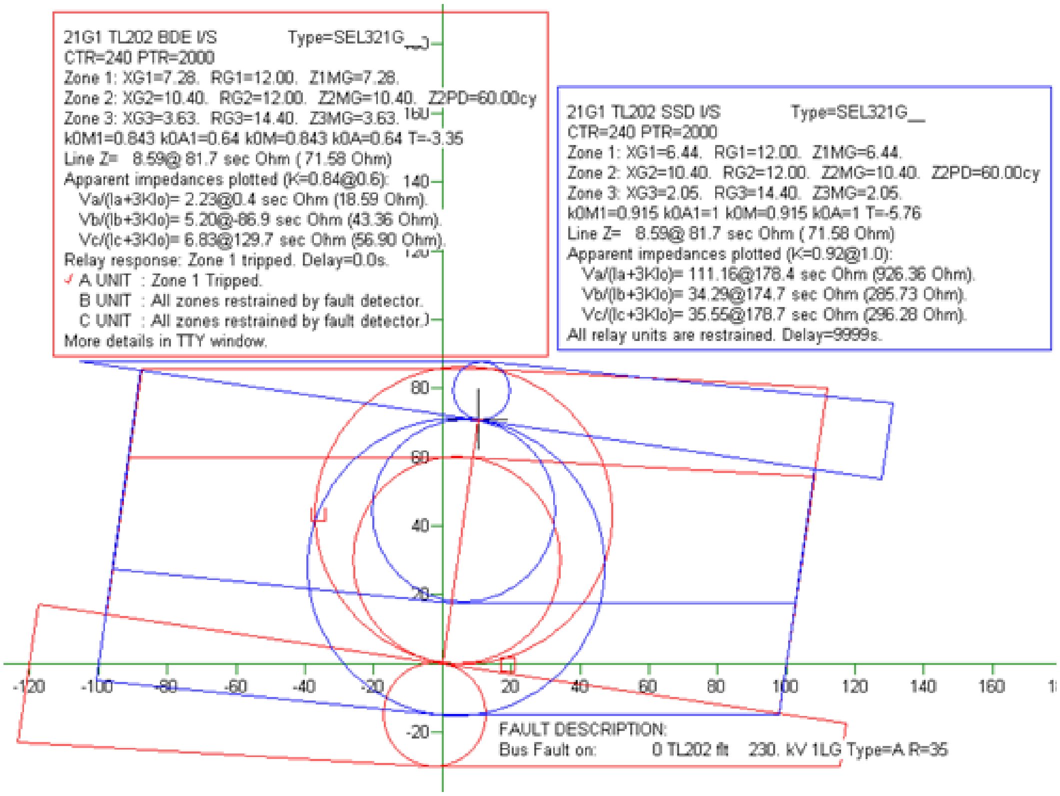


Figure 14 - Initial response of improved model relays to 21 July 2010 fault

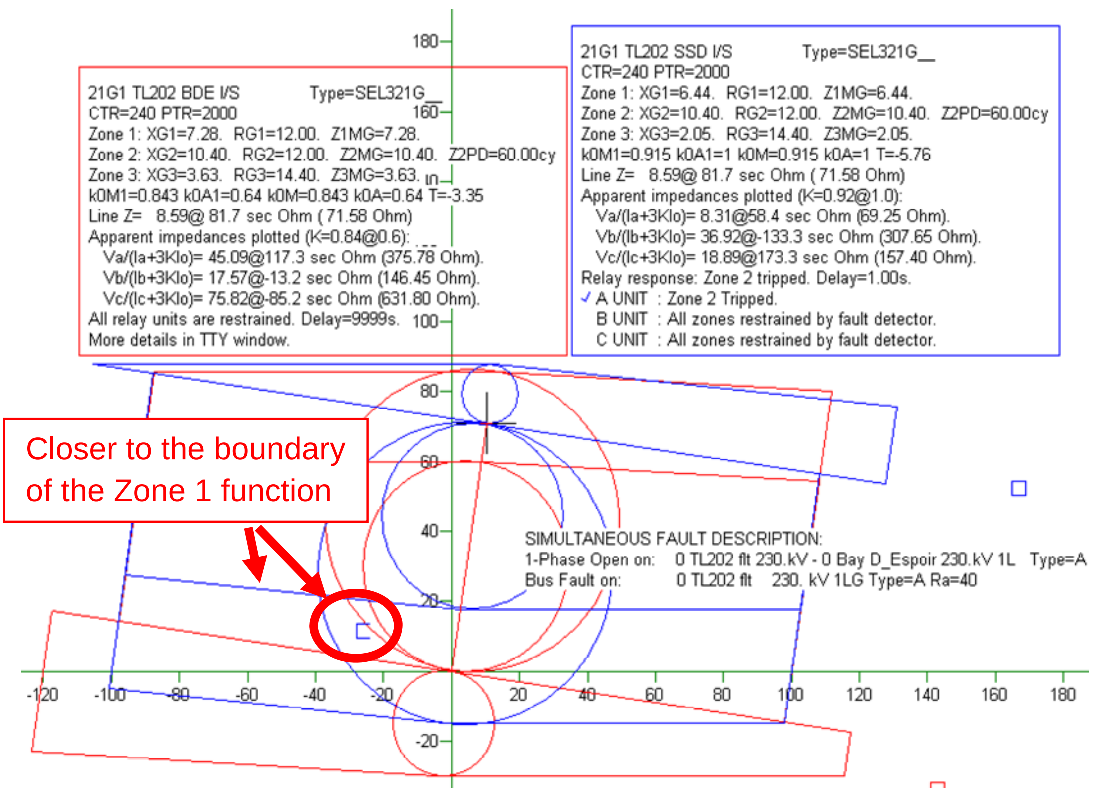


Figure 15 - Sequential response of improved model relays to 21 July 2010 fault

Figure 14 shows the same result as Figure 11 and Figure 15 shows the same result as Figure 12. However, it can be seen that the apparent impedance of the sequentially cleared fault in Figure 15 is closer to the reactive reach of the Zone 1 quadrilateral element than in Figure 14.

Therefore, although the simulation of mutual coupling causes the model response of the Sunnyside TL202 distance relay to be closer to the observed response, it is still not the same. Thus it is concluded that one of the following problems exist.

1. The transient response of the CVTs was not correct.
2. The fault was not at the reported location
3. The model is not sufficiently accurate

Analysis of the 2 December 2007 fault (described in Appendix B) shows that the response of BDE TL202 and TL206 protection systems shows good correlation between the model and observed performance. Therefore it is concluded that the model of these two lines is accurate enough to place less credibility on problem possibility No 3 above. Considering the suspect transient performance of these CVTs, it is possible that this was the cause of the overreach. Considering the calculated distance from the BDE terminal is actually 6.5 km, while the burnt trees were observed only 600 m from BDE, it is possible that the fault was actually further away from BDE than the location of the burnt trees.

Appendix B – Detailed Analysis of TL203 Fault 2 December 2007

On 2 December 2007 a single line to ground fault occurred on this circuit (Surge ID 4955). The faulted phase was cleared promptly and reclosed automatically at the Sunnyside terminal. However the fault was permanent (a ground wire had fallen on to the C Phase conductor) so upon reclose, all three phases tripped at Sunnyside, with no further reclose. The Western Avalon terminal correctly tripped all three terminals and did not reclose.

During the reclose of the Sunnyside terminal, the Western Avalon terminal of TL237 tripped undesirably. As designed, only three phase tripping and reclosing is applied on Circuit TL237. With both TL203 and TL237 tripped on all three phases, there was a system separation between Western Avalon and Sunnyside. The Western Avalon terminal of TL237 automatically reclosed, but since Western Avalon and Sunnyside were not synchronized, the reclose was not successful, and the complete system East of Western Avalon collapsed due to insufficient generation to match the load.

The validity of the ASPEN OneLiner model was tested with the known fault location by comparing the measured source impedances behind the Sunnyside and Western Avalon terminals of TL203 with the source impedances calculated by ASPEN OneLiner.

Bus	Z2s		Z0s (ohms primary)	
Cycle 4 of fault	Mag(ohms pri)	Angle (deg.)	Mag(ohms pri)	Angle (deg.)
SSD Measured	38.77	79	35.25	84.5
SSD Modeled	35.35	72.8	35.44	84.8
WAV Meas.	91.1	71.1	58.5	83.7
WAV Modeled	70.1	84.1	49.8	85.8

The comparison indicates that the Western Avalon terminal was considerably weaker (significantly higher negative and zero sequence source impedances) during this incident than modeled. This is not unexpected, since the model represents all generation in the Avalon Peninsula in service, though this was probably not the case at the time of the disturbance. In addition, modeling of zero sequence mutual coupling between circuits TL201 and TL217 would cause the modeled zero sequence impedance to be closer to the measured value. The model behind the Sunnyside terminal matches the observed data well (with worst case 9% discrepancy in the negative sequence impedance magnitude).

It was noted from the sequence of events report during this disturbance that during the initial fault, a permissive trip signal was received from the BDE terminal of TL206, but not from the BDE terminal of the parallel TL202. This confirms that at least one of the Zone 2 functions of the protections at the BDE terminal of TL206 was able to sense this fault, but neither of the same functions at the BDE terminal of TL202 was able to sense the fault. Since the impedances of the two circuits are almost identical to each other and the settings of the relays are similar (though not identical), it appears that the existing settings of the zone 2 elements of the protections at BDE are only marginal for coverage of the whole of the protected circuits for single line to ground faults. This marginal coverage is confirmed by the ASPEN OneLiner simulation of the same fault and responses of the BDE relays as shown in Figure 16.

Figure 16 shows that the apparent impedance presented to the protection at the BDE terminal of TL202 is marginal (note the red square at the boundary of reach of the TL202 relay), although the model shows the relay operating for the fault. The same figure shows that the margin of dependability is greater for the protection at the BDE terminal of TL206, but still not as large a margin as would be desirable.

It is concluded that the zero sequence mutual coupling significantly reduces the dependability of the overreaching ground distance elements on circuits TL202 and TL206. The settings of the zone 2 elements need to be increased to provide more dependable coverage.

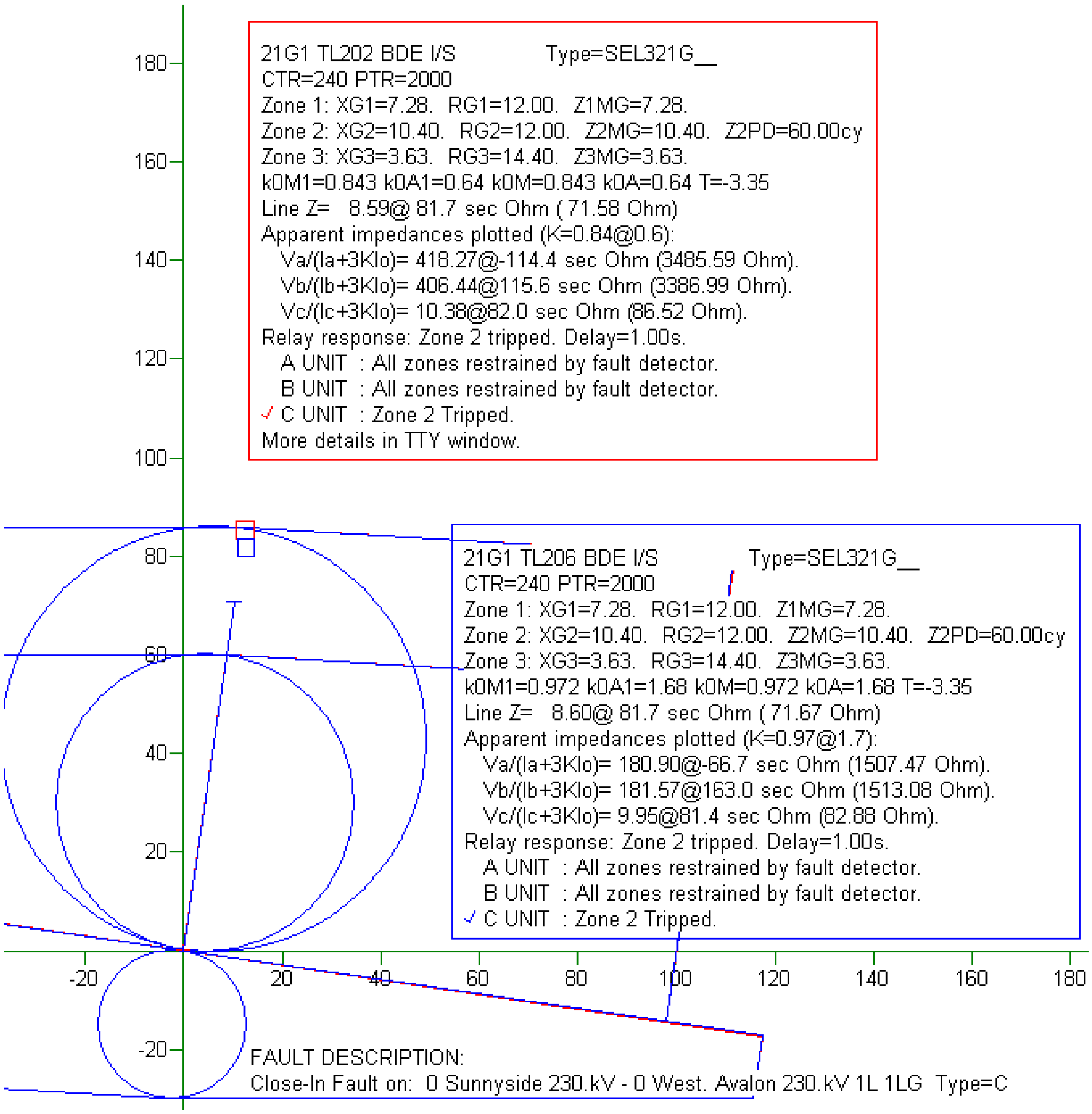


Figure 16 - Apparent impedance of TL203 close-in SLG fault to BDE protections

Figure 17 shows the operation of the SEL321 relay on the faulted line for the initial fault. It can be seen that the record shows that the permissive trip signal was received 17 ms after the SSD terminal issued the trip signal. This observation matches the sequence of events record that shows a 13 ms gap between assertion of trip signal at SSD and receipt of permissive trip from WAV. The difference is due to input/output delays in the SEL-321 relay.

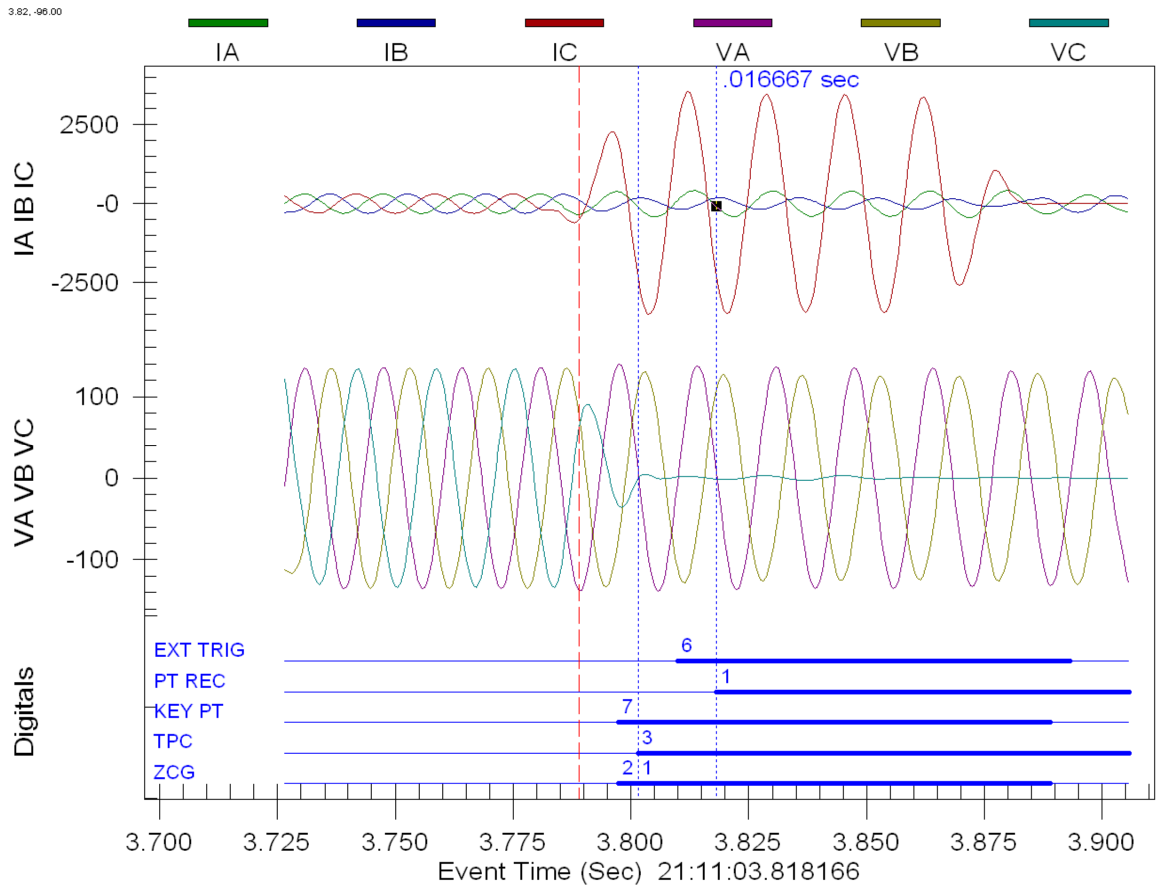


Figure 17 - TL203 SEL-321 Record of initial fault

It was noticed from the sequence of events record (Figure 18) that during the initial fault, that the permissive trip received from the CBC terminal of TL207 occurred at the same time as the local trip (both at 21:11:03.805).

.

2007-12-02 21:11:03.805	Sunnyside	21P1/P2-TL203	TRIP
2007-12-02 21:11:03.805	Sunnyside	85-2/TL207	RECEIVED
2007-12-02 21:11:03.808	Sunnyside	94C1-TL203	TRIP
2007-12-02 21:11:03.808	Sunnyside	94C2-TL203	TRIP
2007-12-02 21:11:03.815	Western Avalon	21P1/P2-TL203	FAIL
2007-12-02 21:11:03.818	Sunnyside	85-TL203	RECEIVED

Figure 18 - SOE record during initial fault

Further, the sequence of events record indicates that during the fault on reclose at Sunnyside (Figure 19), the permissive trip received from the CBC terminal of TL207 was received at 21:11:04.554, which was 4 ms before the local trip at 21:11:04.558. In both cases, the permissive trip signal was keyed about 25 ms after the fault initiation, at almost exactly the same time as the zone 1 element operated at Sunnyside on the faulted line. Therefore, it can be concluded that the permissive trip signal on TL207 is very fast and probably faster than the 3-5 ms time in the performance specification. Such a fast signal is less secure against misoperation than one with a security delay of a few milliseconds.

2007-12-02 21:11:04.359	Sunnyside	B-B1L03	OPERATED
2007-12-02 21:11:04.554	Sunnyside	85-2/TL207	RECEIVED
2007-12-02 21:11:04.558	Sunnyside	21P1/P2-TL203	TRIP
2007-12-02 21:11:04.558	Sunnyside	77/TL203	SENT
2007-12-02 21:11:04.560	Sunnyside	94C2-TL203	TRIP
2007-12-02 21:11:04.560	Western Avalon	B-L01L03	OPERATED

Figure 19 - SOE Record during fault on reclose

During the fault on reclose, the optimho relay at the WAV terminal of TL237 tripped the line terminal undesirably and triggered the system separation that led to the collapse of the Avalon Peninsula. The target was "Aided Trip". Subsequent testing of this relay revealed no problems with it. It is expected that the Zone 2 distance element of the optimho relay may have operated because its setting enabled it to (marginally) see that fault (see Figure 20).

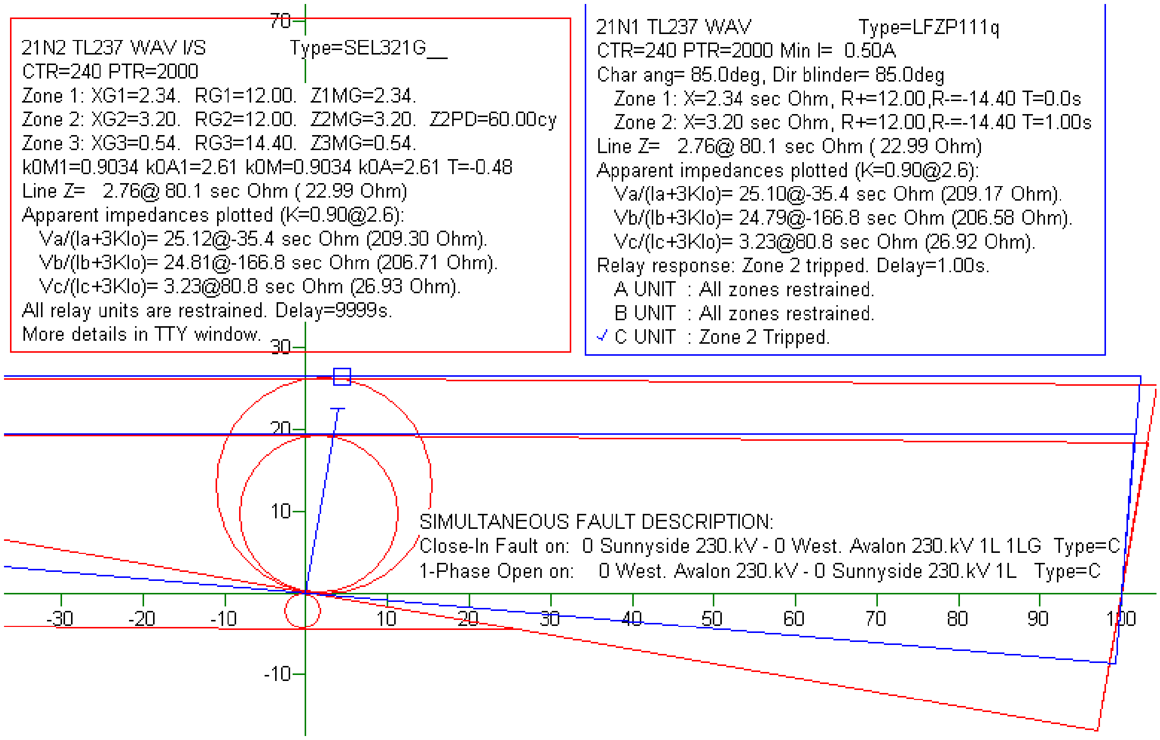


Figure 20 - Simulation of WAV TL237 Protection during SSD Reclose onto fault

As shown in Figure 20 the optimho zone 2 element may have marginally operated, and the SEL-321 marginally not. The event record from the SEL-321 relay indicates that the zone 2 function on this relay did in fact operate during this fault, but only intermittently as can be seen in Figure 21. Note in Figure 21 the instant of the “EXT TRIG” is the moment that the optimho relay issued a trip signal. Note also, that there is no indication of a permissive trip received from CBC. However, it should be borne in mind that the sampling rate of the record shown in Figure 21 is only four samples per cycle, and it is possible that a short pulse of permissive trip received may not have been captured by this record. The teleprotection equipment is so fast, that it is possible that a short output may not have been captured by recording equipment.

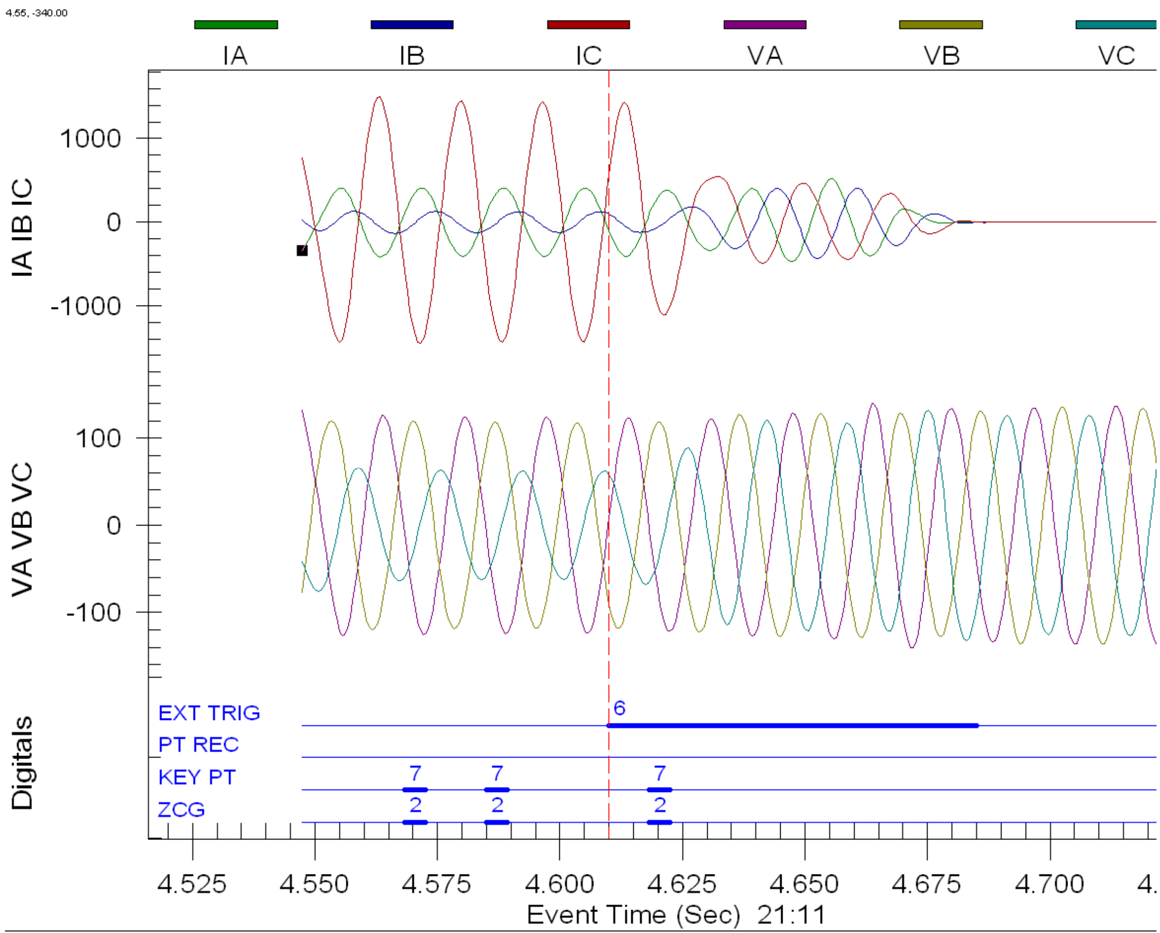


Figure 21 - Event record from WAV TL237 21P2 during fault on reclose

It can also be seen from Figure 21 that the optimho relay operated well after the start of the fault. In fact, it operated at the instant of the breaker opening to clear the fault at SSD. A few cycles of load current can be seen in Figure 21 after the fault cleared (at SSD) and before the WAV TL237 breakers opened. It would be at this moment that there would have been maximum noise on the power system and maximum threat to the security of the teleprotection.

It is concluded that the undesirable tripping by the optimho relay at WAV TL237 may not have been a relay misoperation, but an improper transient output from the teleprotection. If it was due to the incorrect keying of permissive trip by the Optimho relay at the CBC terminal, enabling of the current reversal blocking logic in the POR 1 scheme will make the P1 system more secure.

Appendix C - Detailed settings review TL202 and TL206 Protection P1 at Bay D'Espoir

- See separate .pdf printout of mathcad calculations.

Appendix D - Detailed settings review TL202 and TL206 Protection P2 at Bay D'Espoir

- See separate .pdf printout of mathcad calculations.

Appendix E - Detailed settings review TL202 and TL206 Protection P1 at Sunnyside

- See separate .pdf printout of mathcad calculations.

Appendix F - Detailed settings review TL202 and TL206 Protection P2 at Sunnyside

- See separate .pdf printout of mathcad calculations.

Appendix G - Detailed settings review TL203 Protection P1 at Sunnyside

- See separate .pdf printout of mathcad calculations.

Appendix H - Detailed settings review TL203 Protection P2 at Sunnyside

- See separate .pdf printout of mathcad calculations.

Appendix I - Detailed settings review TL203 Protection P1 at Western Avalon

- See separate .pdf printout of mathcad calculations.

Appendix J - Detailed settings review TL203 Protection P2 at Western Avalon

- See separate .pdf printout of mathcad calculations.

Appendix K - Detailed settings review TL207 Protection P1 at Sunnyside

- See separate .pdf printout of mathcad calculations.

Appendix L - Detailed settings review TL207 Protection P2 at Sunnyside

- See separate .pdf printout of mathcad calculations.

Appendix M - Detailed settings review TL207 Protection P1 at Come By Chance

- See separate .pdf printout of mathcad calculations.

Appendix N - Detailed settings review TL207 Protection P2 at Come By Chance

- See separate .pdf printout of mathcad calculations.

Appendix O - Detailed settings review TL237 Protection P1 at Come By Chance

- See separate .pdf printout of mathcad calculations.

Appendix P - Detailed settings review TL237 Protection P2 at Come By Chance

- See separate .pdf printout of mathcad calculations.

Appendix Q - Detailed settings review TL237 Protection P1 at Western Avalon

- See separate .pdf printout of mathcad calculations.

Appendix R - Detailed settings review TL237 Protection P2 at Western Avalon

- See separate .pdf printout of mathcad calculations.

Appendix S - Aspen OneLiner

- The system model with relay models is attached as an electronic file “Hydro Interconnected System (2010-08-13) V10 with mutuals.olr”

Appendix T – Report presentation

- Handout pages of the presentation of the report are provided at the end of this report.

1 Email from B. Bradbury to C Henville subject “230 kV Prot Review – Latest Files and info” dated 13th August, 2010.

Protection Review for Five 230 kV Transmission Lines

Appendix C
Detailed settings review for BDE TL202 and TL206 "P1" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador Hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Bay D'Espoir (BDE) terminals of circuits TL202 and TL206. These 230 kV transmission circuits are from BDE to Sunnyside (SSD).
The circuits run parallel to each other for most of their length. The circuit impedances are similar to each other, but not identical. However since the difference in impedance between the two circuits is less than 0.2%, the settings for both protection systems will be made identical to each other to reduce effort in testing.

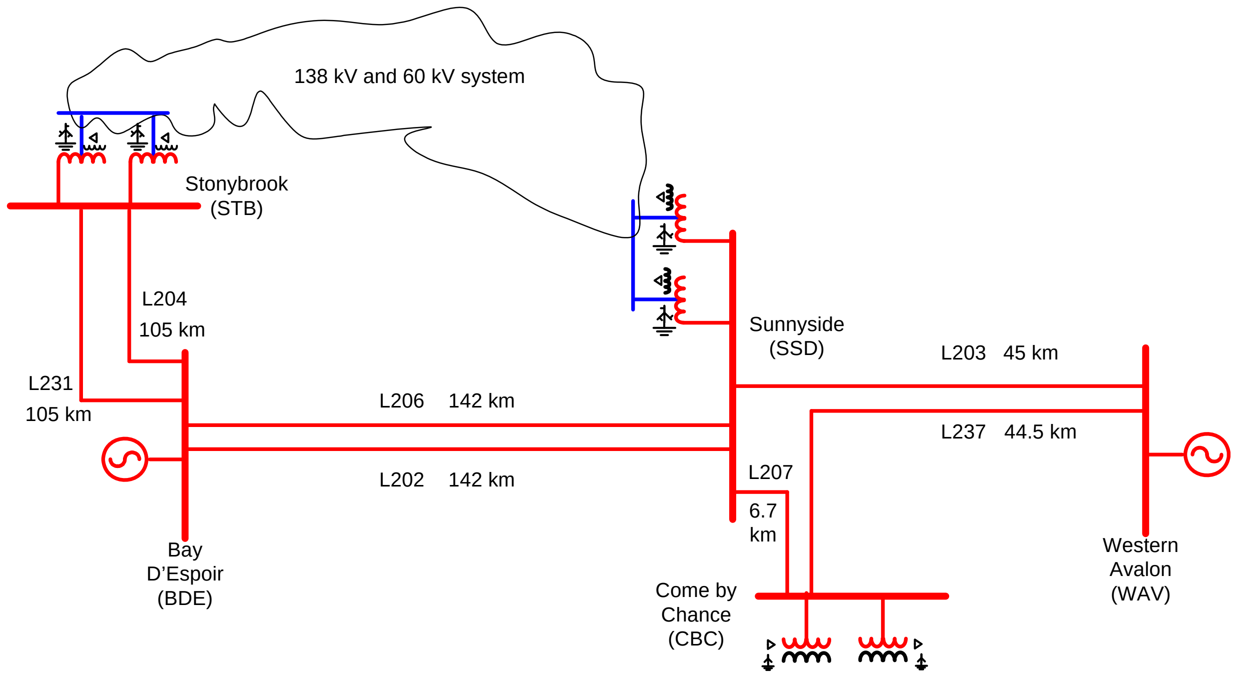


Figure 1 - System Single Line Diagram

Existing P1 protection systems are Areva LZFP111 (Optimho) systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $\quad$ $kVbase := 230$ $\quad$ $Ibase := \frac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\quad$ $Zbase := \frac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $CTR := \frac{1200}{5}$ $\quad$ VT ratio is: $VTR := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**Hydro Interconnected System (2010-08-13) V10.olr**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option.
Minimum fault current seen by each terminal (phase to phase, and SLG with 100 ohm fault resistance).

At BDE, with units 2, 4, 5, and 6 off line as under light load conditions, and both lines in service, for a fault at the remote terminal.

$ILLmin := 902$ A $\quad ISLGminPH := 838$ A $\quad ISLGmin0seq := 312$ A

The optimho current level detectors that block the distance comparators in the event of line opening are fixed at 5% of the rated current, or 0.25 A secondary, or 60 A primary. They will have no difficulty in operating for minimum fault levels. However, the ground distance elements are also supervised by a low set neutral current level detector (LDLSN that requires the neutral current to be greater than 10% of the maximum amplitude of phase difference current. This prevents the ground comparators from operating during close-in multiphase faults with CT errors. ASPEN OneLiner shows that for a bolted fault at the remote bus even under heavy load, there is sufficient neutral current (22% of maximum phase to phase fault current) that means this LDLSN function does not inhibit the ground distance comparator.

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind BDE $\quad Z2minBDE := 0.627 + j\cdot 14.85$ ohms primary

Minimum um source impedance behind SSB $\quad Z2minSSD := 4.025 + j\cdot 32.96$ ohms primary

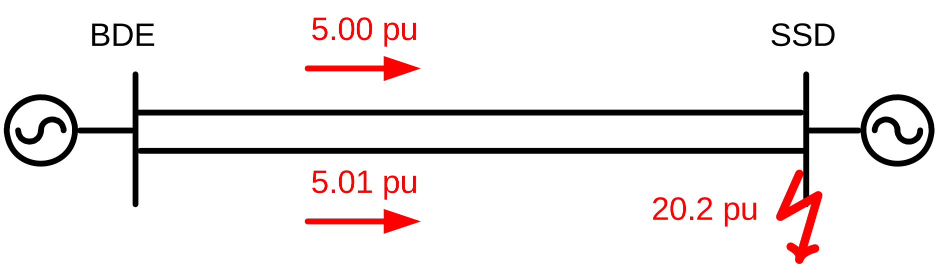


Figure 2 - 3 Phase Fault at SSD

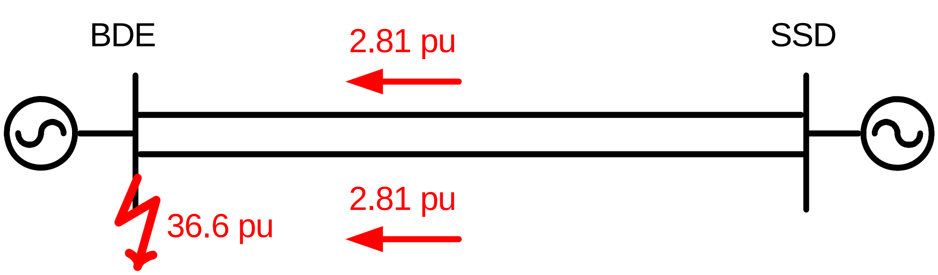


Figure 3 - 3 Phase Fault at BDE

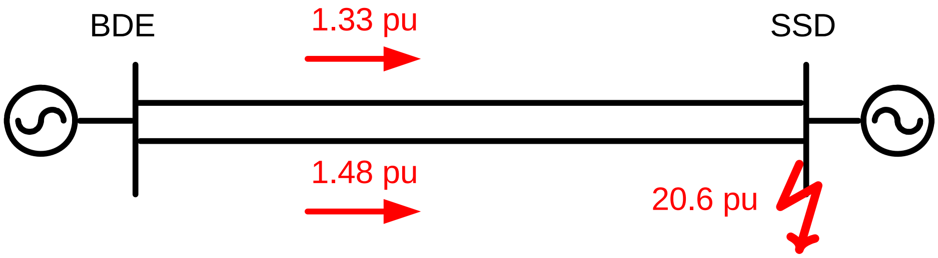


Figure 4 - SLG Fault at SSD (3I0 currents)

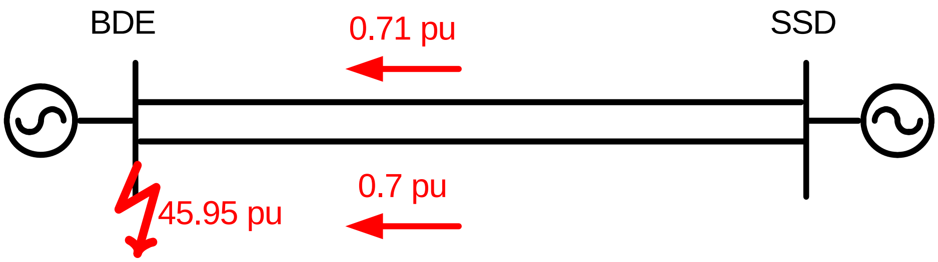


Figure 5 - SLG Fault at BDE (3I0 currents)

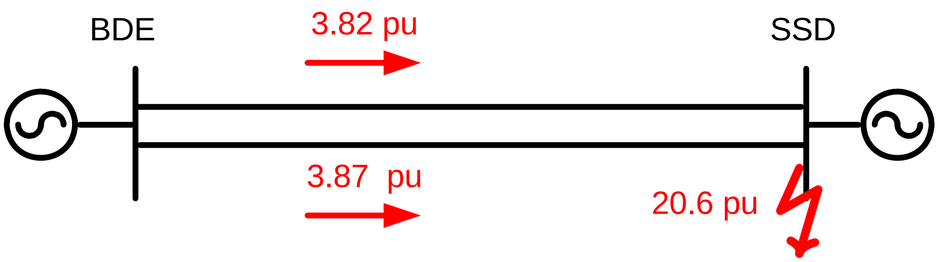


Figure 6 - SLG Fault at SSD (Phase currents)

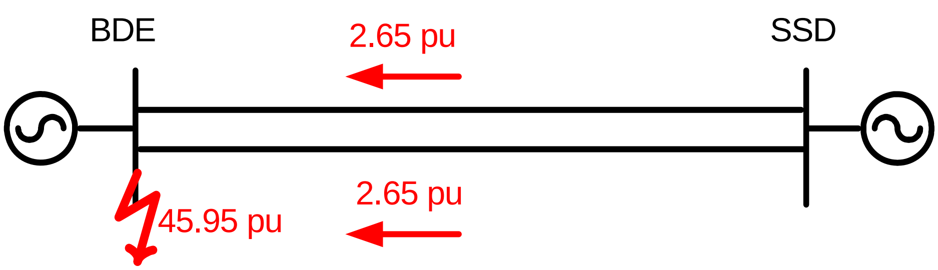


Figure 7 - SLG Fault at BDE (Phase currents)

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L202 := 0.01946 + j\cdot 0.13391$ $Z0L202 := 0.0665 + j\cdot 0.5024$

$Z1L206 := 0.01948 + j\cdot 0.13407$ $Z0L206 := 0.0668 + j\cdot 0.503$

In primary ohms

$Z1L202pri := Z1L202\cdot Zbase$ $Z0L202pri := Z0L202\cdot Zbase$

$Z1L206pri := Z1L206\cdot Zbase$ $Z0L206pri := Z0L206\cdot Zbase$

In secondary ohms

$Z1L202sec := Z1L202pri\cdot\frac{CTR}{VTR}$ $Z0L202sec := Z0L202pri\cdot\frac{CTR}{VTR}$

$Z1L206sec := Z1L206pri\cdot\frac{CTR}{VTR}$ $Z0L206sec := Z0L206pri\cdot\frac{CTR}{VTR}$

$|Z1L202sec| = 8.59$ $\arg(Z1L202sec) = 81.732\cdot deg$

$|Z1L206sec| = 8.6$ $\arg(Z1L206sec) = 81.733\cdot deg$

$|Z0L202sec| = 32.171$ $\arg(Z0L202sec) = 82.46\cdot deg$

$|Z0L206sec| = 32.211$ $\arg(Z0L206sec) = 82.435\cdot deg$

Zero sequence mutual coupling between the lines is $Z0m := 0.0466 + j\cdot 0.2347$

Use the average of these two values for line impedance for settings calculations for both lines

$Z1Line := \frac{(Z1L202 + Z1L206)}{2} = 0.019 + 0.134j$ pu $Z0Line := \frac{Z0L202 + Z0L206}{2} = 0.067 + 0.503j$ pu

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line\cdot Zbase$ $Z0Linephys := Z0Line\cdot Zbase$

$Z1Linephys = 10.3 + 70.9i$ ohms primary

$Z0Linephys = 35.3 + 265.9i$ ohms primary

Converting primary ohms to secondary ohms gives:

$Z1Linesec := Z1Linephys\cdot\frac{CTR}{VTR}$ $Z0Linesec := Z0Linephys\cdot\frac{CTR}{VTR}$

$|Z1Linesec| = 8.6$ ohms sec $\arg(Z1Linesec) = 81.7\cdot deg$

$|Z0Linesec| = 32.191$ ohms sec $\arg(Z0Linesec) = 82.4\cdot deg$

Load Data

From 2010 System peak load case provided in start up information, the peak load is given as 185 MVA (with two lines in service). In the event of sudden loss of lone line, peak load will double until operators can adjust loads. Therefore it is assumed that peak load for a short duration is 370 MVA

$Speak := 185$ MVA $\qquad Smax := 2 \cdot Speak = 370$ MVA

P1 Relay Settings

Distance element reach settings

Note that resistive reaches are forced to be the same for all zones. Reactive reaches for phase and ground distance elements must be the same as each other.

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the BDE Station bus under light load conditions with four generators at BDE off line and both TL202 and TL206 lines in service. From ASPEN OneLiner, voltage at BDE for a 3 phase fault at SSD is 0.52 per unit. So there is plenty of voltage at BDE during a fault at SSD, even under weak source conditions.

Since the voltage is higher than 20%, the line is not considered short, and a conventional Zone 1 setting is acceptable.

$Z1P := 0.85 \cdot |Z1Linesec| \qquad Z1P = 7.3$ Ohms secondary

Existing setting of 7.28 ohms is OK, and could be retained if only the phase distance functions had to be considered. However, the ground distance reach in the optimho has to be set the same as the phase distance reach; so we need to consider the ground faults too.

$Z1P := 7.28$ For phase faults only.

The reach of the ground distance element will limit the reach of the zone 1 function. It can be seen from Figure 8 that the apparent impedance presented to the relay for a fault at the remote bus when the parallel line is out of service and grounded at both ends is significantly less than the line impedance.

$Zapp\_ext := 7.95$ ohms $\qquad Zapp\_ang := 82.3deg$ This angle is close enough to the line angle to treat it as equal to the line angle.

$$\frac{Zapp\_ext}{|Z1Linesec|} = 0.925$$

The apparent impedance is reduced by about 8% due to the effect of the parallel line being out of service and grounded at both ends.

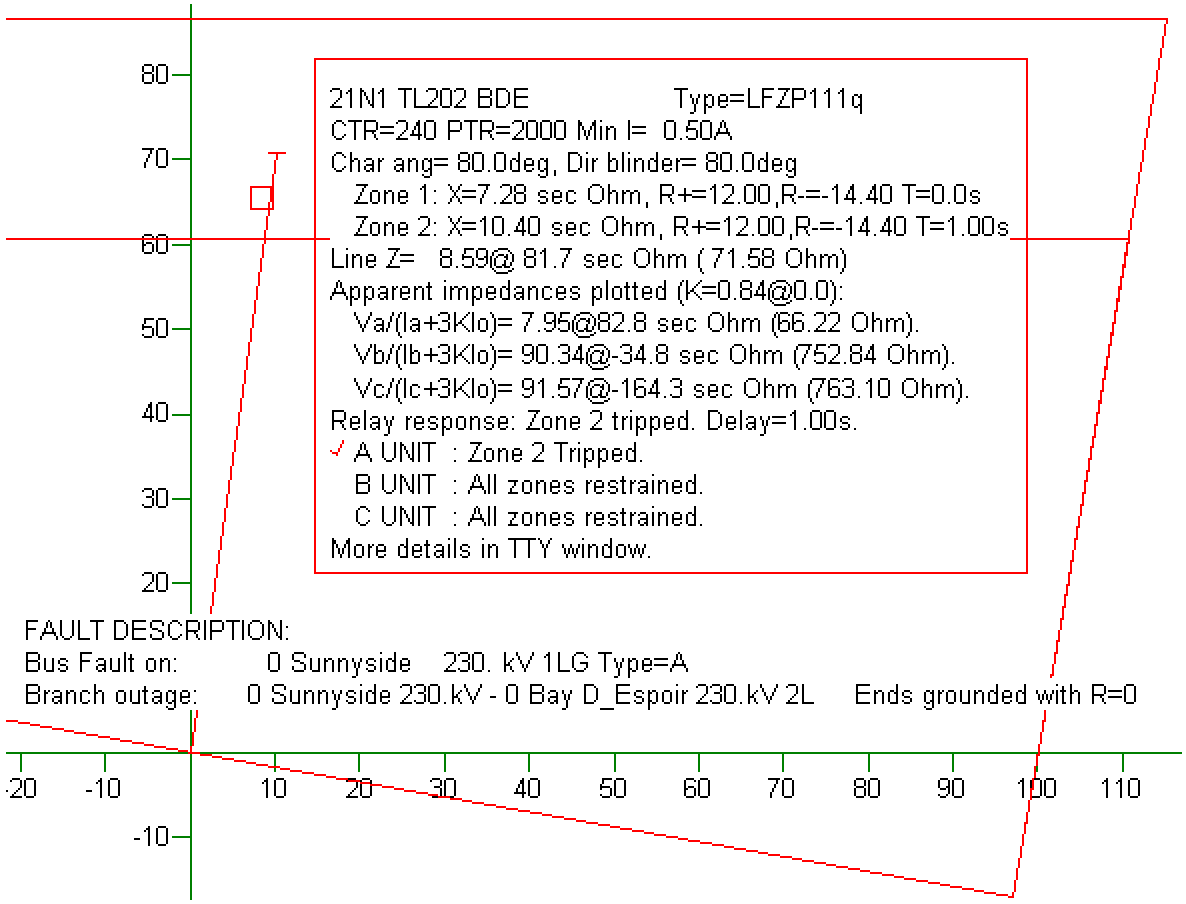


Figure 8 - Apparent impedance to a fault just beyond the remote terminal is reduced by 7.5% when parallel line is out of service and grounded at both ends. Existing relay settings modeled in this figure.

The reach of the zone 1 ground distance element should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Choose a setting of 80% of line which will underreach the remote bus by 11% when the parallel line is out of service and grounded at both ends.

Let the per unit reach of the Zone 1 function be m per unit of the line. $m := 0.8$ per unit

$Z1\_sec := m \cdot |Z1Linesec|$ $\quad Z1\_sec = 6.88$ Ohms secondary

$Z1pri := Z1\_sec \cdot \frac{VTR}{CTR} = 57.3$ Ohms primary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is just less than 10.4 ohms secondary (about 122%). However, in order to reach a single line to ground fault at the remote terminal, it will be necessary to set the reach significantly further.

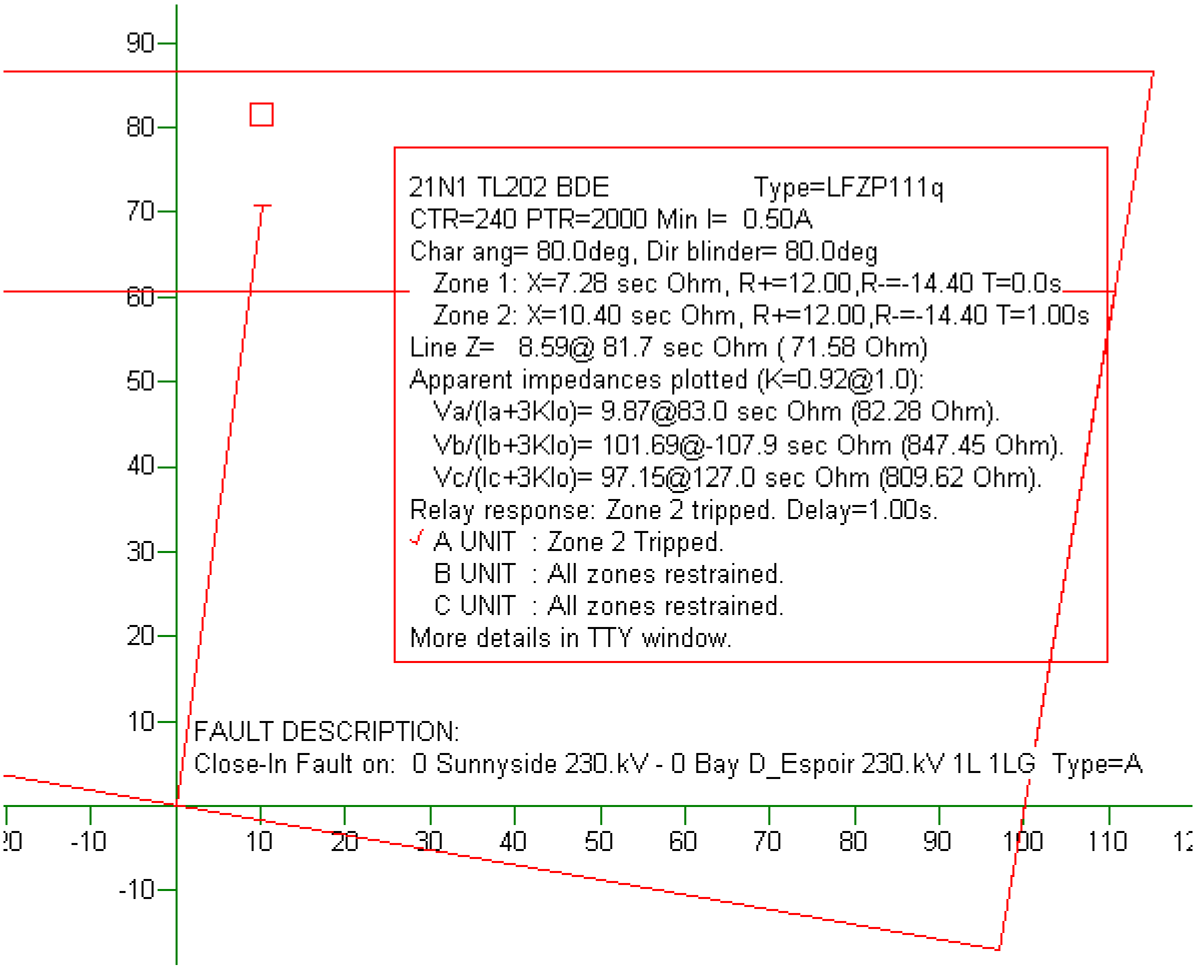


Figure 9 - Apparent impedance to a fault close to the remote terminal is increased by 15% when parallel line is in service.

As can be seen from Figure 9, the apparent impedance to a fault close to the remote terminal is increased when the parallel line is in service.

$Zapp\_int := 9.87$ Ohms secondary

$Z2\_sec := 1.25 \cdot Zapp\_int$ $Z2\_sec = 12.3$ Ohms secondary $\frac{Z2\_sec}{|Z1Linesec|} = 143.543 \cdot \%$

$Z2\_pri := Z2\_sec \cdot \frac{VTR}{CTR} = 102.813$ Ohms primary

The zone 2 timer will be enabled, and set at 1 second (to coordinate with remote ground time overcurrent functions). This long delay will have no difficulty in coordinating with the zone 2 element on the short line TL207 beyond SSD.

Zone 3

The zone 3 function is not used since the POR1 scheme does not include an echo function so there is no need for any reverse blocking function. Since the Zone 2 timer has to be set with the coordination of the ground distance element in mind, it is set at 1 second; so there is no benefit in applying a longer reaching zone 3 function.

Zone 3 element is blocked - same as existing.

Load Encroachment logic

The optimho instruction manual recommends a margin of at least 10% between the impedance of the maximum load and the resistive reach of the quadrilateral distance element.

Check loadability of the Zone 2 phase distance element assuming worst case depressed voltage of a stressed system of 0.9 per unit.

$$Zloadmin := \frac{(0.9kVbase)^2}{Smax} \qquad Zloadmin = 115.808$$ Ohms primary (assume worst case at 30 degrees)

$$Zloadmin\_sec := Zloadmin \cdot \frac{CTR}{VTR} \qquad Zloadmin\_sec = 13.897$$

A 12 ohm secondary resistive reach is less than 90% of the load impedance at unity power factor and meets the Areva criterion. Note the Areva criterion does not include worst case power factor. However it is assumed that he security factors, like zero sequence current supervision provide increased security against misoperation on heavy load at poor power factor. Figure 10 shows the apparent impedance of the load at 0.9 per unit voltage, and the characteristics of the phase and ground distance elements. The small encroachment on the quadrilateral characteristic is considered acceptable. Figure 10 also shows that the load will not encroach on the phase distance mho characteristic.

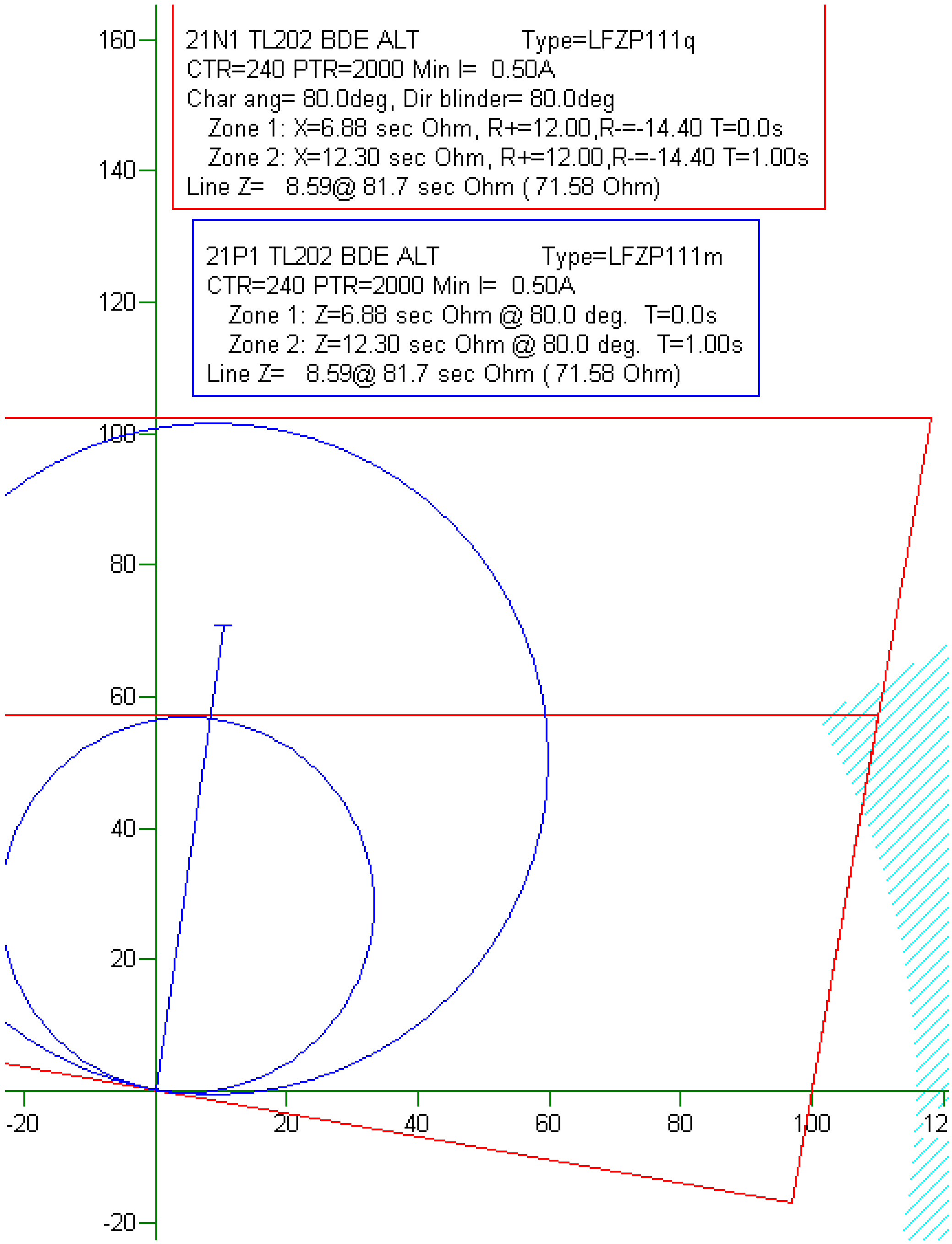


Figure 10 - Apparent impedance of load

Resistive reach of quadrilateral elements

Check the maximum fault resistance that can be sensed for a fault at a location where the current contribution from each terminal is roughly the same. From Figure 11, it can be seen that the limit of sensitivity is about 93 ohms, for a fault about 56% of the distance from BDE. This is close enough to the required sensitivity of 100 ohms.

Rquad := 12 Ohms secondary

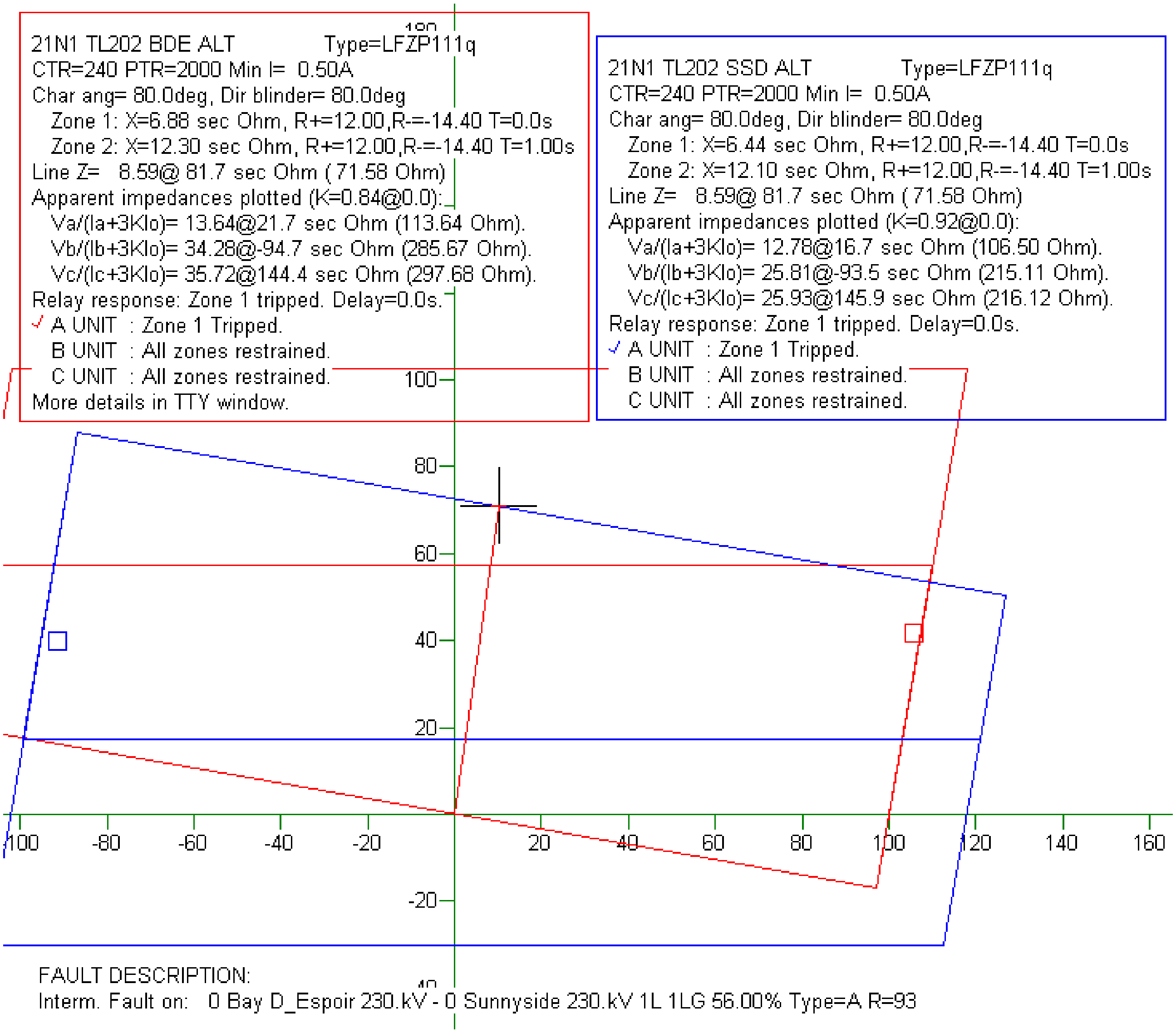


Figure 11 - Apparent impedance of a resistive fault near the mid point of the line.

Settings of K attenuators

KZPh Coarse setting common to all DISTANCE zones should be set as high as possible while below the required Zone 1 reach. The current level detectors vary inversely with KZph. Maximum setting available is 1.0

$KZPh := 1.0$

Zone 1 attenuators and angular selection

$In := 5$ $Z1\_sec = 6.88$ This is the desired secondary reach (previously calculated)

$KZ1 := \frac{Z1\_sec}{\left(KZPh \cdot \frac{5}{In}\right)}$ $KZ1 = 6.88$ $Z1sec\_reach := KZ1 \cdot KZPh \cdot \frac{5}{In}$ $Z1sec\_reach = 6.88$

$Z\theta PH := (\arg(Z1Linesec))$ $Z\theta PH = 81.732 \cdot deg$

Rounded to the nearest 5 degrees $Z\theta PH := 80$ Degrees

$Z\theta N := \arg(Z0Linesec - Z1Linesec)$ $Z\theta N = 82.708 \cdot deg$

Rounded to the nearest 5 degrees $Z\theta N := 80$ Degrees

Zone 2 attenuators selection

$Z2\_sec = 12$ This is the desired secondary reach (previously calculated)

$KZ2 := \frac{Z2\_sec}{\left(KZPh \cdot \frac{5}{In}\right)}$ $KZ2 = 12$

Zone 3 is not used

QUAD Resistive Reach setting

$Rquad = 12$ This is the desired secondary reach (previously calculated)

$KR := \frac{Rquad}{\left(\frac{5}{In}\right)}$ $KR = 12$

Residual Compensation attenuators selection

Zero sequence current compensation for ground faults is provided by the KZN factor. Zero sequence mutual compensation is not used in this application (it causes extra complexity for only moderate gain in setting accuracy).

$$KZN := \frac{Z0Linesec - Z1Linesec}{3 \cdot Z1Linesec} \cdot KZPh \qquad KZN = 0.915 + 0.016j$$

$|KZN| = 0.915$ This is a change from the existing setting of 0.843

Switch On To Fault (SOTF) Protection.

If SOTF is enabled, it can be set to 200ms or 110 s after all poles of the line have been de-energized. The 110 s setting is intended to override automatic reclosing dead time. However it makes more sense to enable after the shorter time. Once the SOTF feature has been initiated, it remains in effect for 250ms after the line has been re-energized. The SOTF tripping options are:

a) Any distance comparator.
b) Any current level detector as long as a corresponding voltage level detector has not picked up within 20ms.
c) Either current or distance, as long as a corresponding voltage level detector has not picked up within 20ms.

SOTF := "Enabled"

SOTF_TIME := 0.20 Seconds

Elements_in_SOTF := "BOTH" (Both Comparators and current level detectors).

Power Swing Detector

This element will not be used. It will be left Blocked, and if there is a power swing, the distance elements will trip naturally.

VT Supervision

Set the VT supervision to BLOCK TRIP

Set the VT fail detection to SELF RESET.

Start Indication

This function will bring up information on the LCD screen of the relay if a start event occurs. This function will not be used.

START_INDICATION := "BLOCKED"

Communications assisted logic.

The existing communications assisted logic is permissive overreaching transfer trip, scheme **POR 1**. This scheme is familiar to Newfoundland and Labrador Hydro, and even though the POR 2 scheme offers the advantage of weak infeed echo, which would help the sensitivity to resistive faults, it is not recommended to change the existing scheme logic at this stage with years of experience on a product that is nearing the end of its useful life.

The POR 1 logic is a basic permissive overreaching transfer trip scheme but it does include current reversal timers to increase security against misoperation due to current reversal when a fault on the parallel line is cleared sequentially. The current reversal logic is achieved by a timer TP which will block permissive tripping and keying of permissive trip if the local zone 2 element does not pick up within a reasonable time of receiving permissive trip. The block will be maintained for a time delay of TD after the local zone 2 element picks up, or the received permissive trip signal resets.

The application of the current reversal timers is required only if the settings of the zone 2 comparators are greater than 1.5 times the line impedance. Since the reaches of these elements are less than 1.5 times the line impedance, the current reversal logic is not required, and the recommended default settings are as existing

$TP := 98$ ms

$TD := 0$ ms

Comparison of Existing (I/S) and Proposed alternative (ALT) settings.

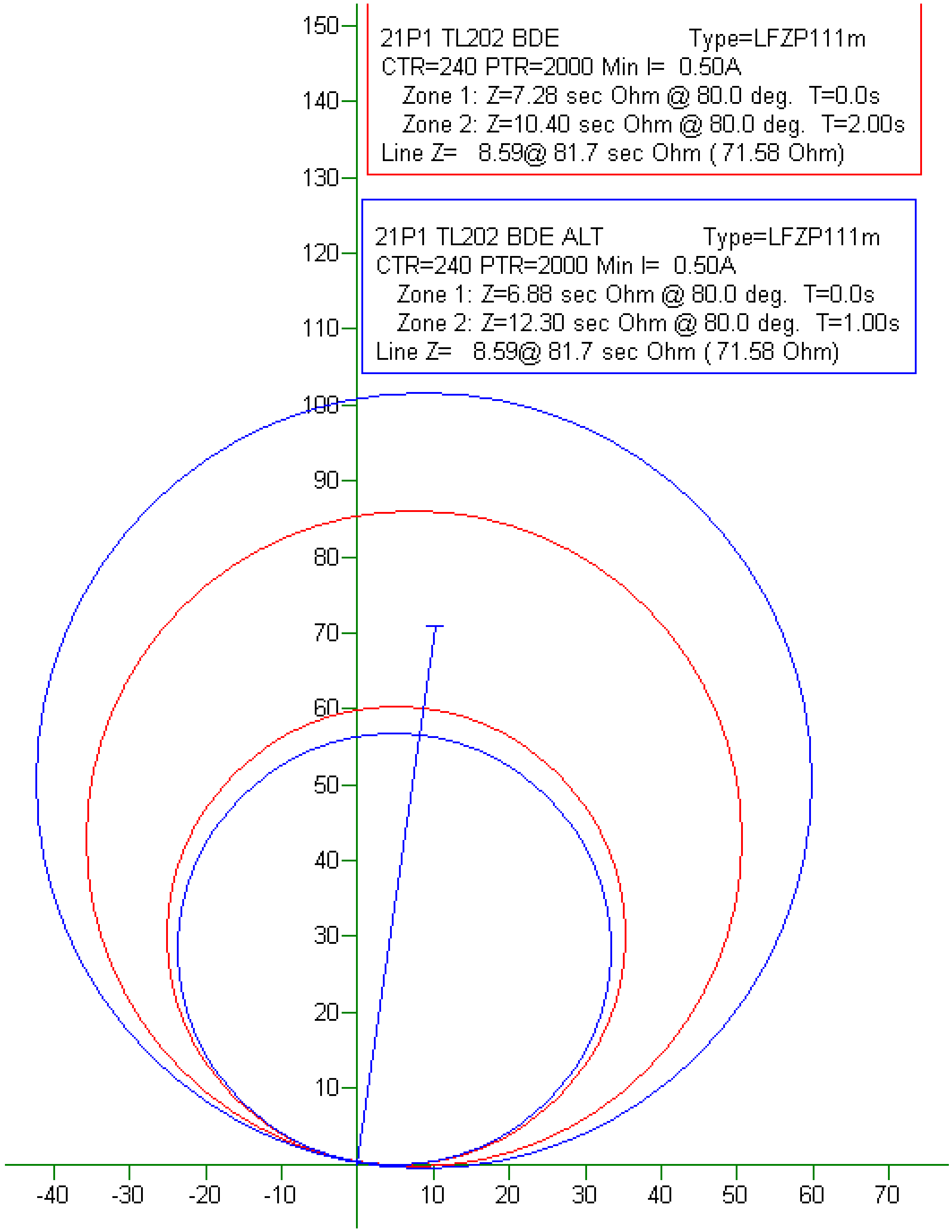


Figure 12 - Comparison of phase distance characteristics

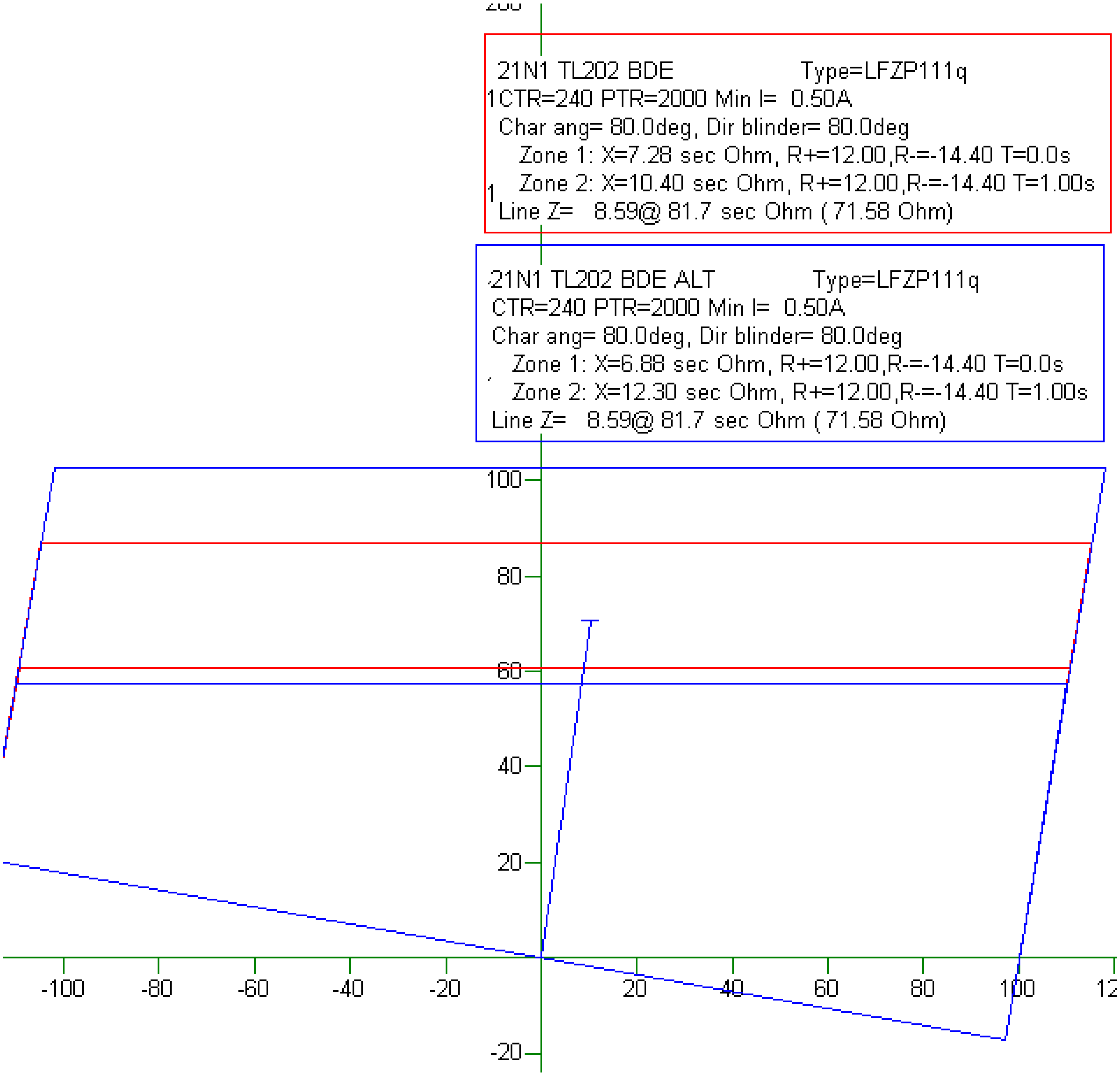


Figure 13 - Comparison of ground distance characteristics

Protection Review for Five 230 kV Transmission Lines

Appendix D
Detailed settings review for BDE TL202 and TL206 "P2" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P2 protection systems for the Bay D'Espoir (BDE) terminals of circuits TL202 and TL206. These 230 kV transmission circuits are from BDE to Sunnyside (SSD).
The circuits run parallel to each other for most of their length. The circuit impedances are similar to each other, but not identical. However since the difference in impedance between the two circuits is less than 0.2%, the settings for both protection systems will be made identical to each other to reduce effort in testing.

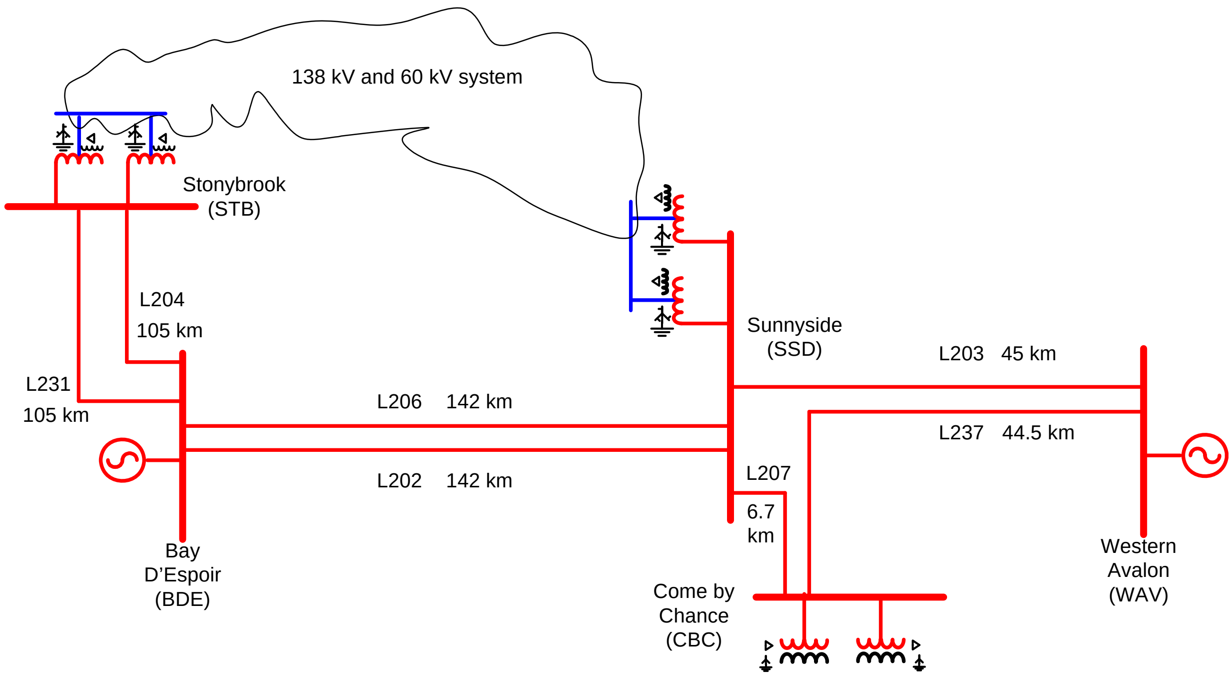


Figure 1 - System Single Line Diagram

Existing P2 protection systems are SEL321 systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$$\mathrm{MVAbase} := 100 \qquad \mathrm{kVbase} := 230 \qquad \mathrm{Ibase} := \frac{\mathrm{MVAbase}\cdot 1000}{\mathrm{kVbase}\cdot\sqrt{3}} \qquad \mathrm{Zbase} := \frac{\mathrm{kVbase}^2}{\mathrm{MVAbase}}$$

$$j := \sqrt{-1}$$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $\mathrm{CTR} := \frac{1200}{5}$ VT ratio is: $\mathrm{VTR} := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**Hydro Interconnected System (2010-08-13) V10.olr**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with all shunts ignored (unless needed for load flow simulation).

Minimum fault current seen by each terminal (phase to phase, and SLG with 100 ohm fault resistance).

At BDE, with units 2, 4, 5, and 6 off line as under light load conditions, and both lines in service, for a fault at the remote terminal.

I3Pmin := 1070 ISLGminPH := 838 ISLGmin0seq := 312

The current for a phase to phase fault would be lower, but the current supervision element of the SEL321 measures phase to phase currents, and the phase to phase current for a phase to phase fault is twice the phase current.

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind BDE	$Z2minBDE := 0.627 + j \cdot 14.85$	ohms primary
Minimum um source impedance behind SSB	$Z2minSSD := 4.025 + j \cdot 32.96$	ohms primary

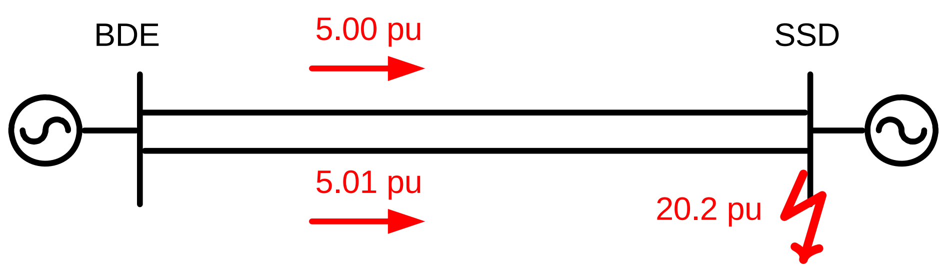


Figure 2 - 3 Phase Fault at SSD

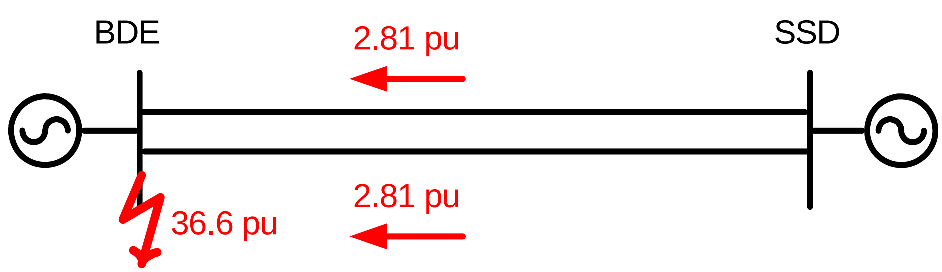


Figure 3 - 3 Phase Fault at BDE

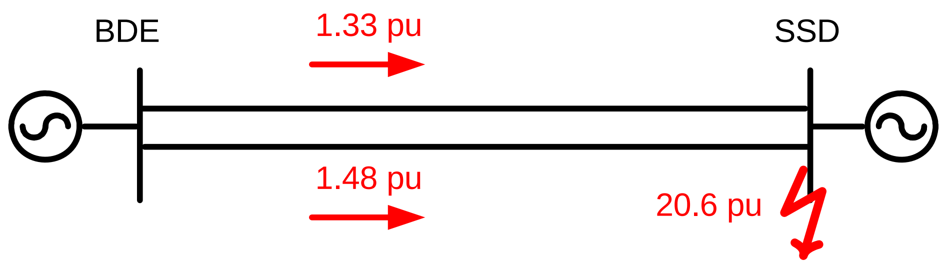


Figure 4 - SLG Fault at SSD (3I0 currents)

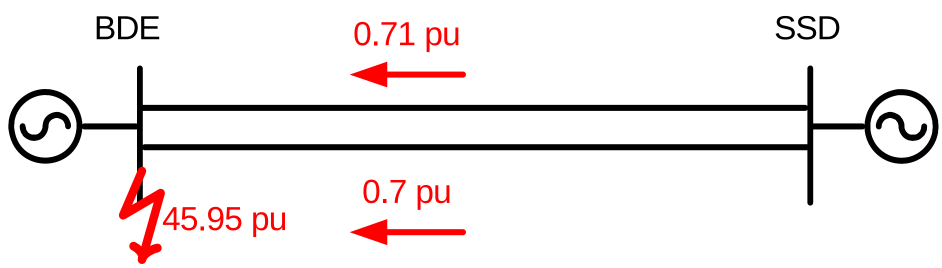


Figure 5 - SLG Fault at BDE (3I0 currents)

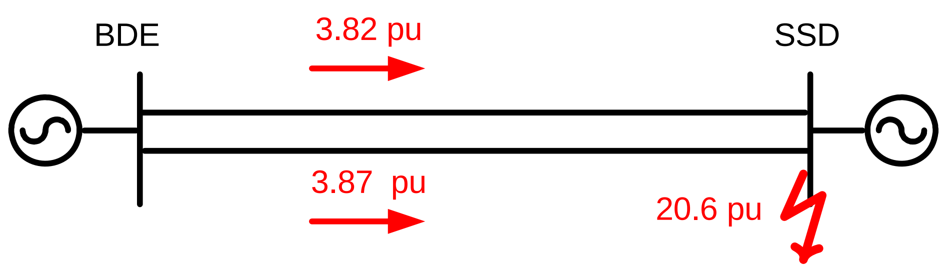


Figure 6 - SLG Fault at SSD (Phase currents)

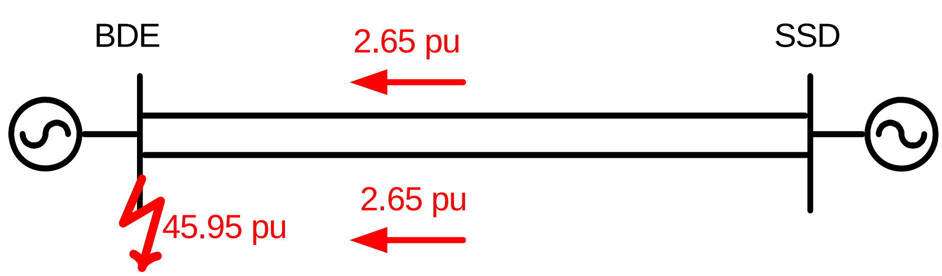


Figure 7 - SLG Fault at BDE (Phase currents)

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L202 := 0.01946 + j\cdot 0.13391$ $\quad Z0L202 := 0.0665 + j\cdot 0.5024$

$Z1L206 := 0.01948 + j\cdot 0.13407$ $\quad Z0L206 := 0.0668 + j\cdot 0.503$

In primary ohms

$Z1L202pri := Z1L202\cdot Zbase$ $\quad Z0L202pri := Z0L202\cdot Zbase$

$Z1L206pri := Z1L206\cdot Zbase$ $\quad Z0L206pri := Z0L206\cdot Zbase$

In secondary ohms

$$Z1L202sec := Z1L202pri\cdot\frac{CTR}{VTR} \qquad Z0L202sec := Z0L202pri\cdot\frac{CTR}{VTR}$$

$$Z1L206sec := Z1L206pri\cdot\frac{CTR}{VTR} \qquad Z0L206sec := Z0L206pri\cdot\frac{CTR}{VTR}$$

$|Z1L202sec| = 8.59$ $\quad arg(Z1L202sec) = 81.732\cdot deg$

$|Z1L206sec| = 8.6$ $\quad arg(Z1L206sec) = 81.733\cdot deg$

$|Z0L202sec| = 32.171$ $\quad arg(Z0L202sec) = 82.46\cdot deg$

$|Z0L206sec| = 32.211$ $\quad arg(Z0L206sec) = 82.435\cdot deg$

Zero sequence mutual coupling between the lines is $\quad Z0m := 0.0466 + j\cdot 0.2347$

Use the average of these two values for line impedance for settings calculations for both lines

$$Z1Line := \frac{(Z1L202 + Z1L206)}{2} = 0.019 + 0.134j\ pu \qquad Z0Line := \frac{Z0L202 + Z0L206}{2} = 0.067 + 0.503j\ pu$$

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line\cdot Zbase$ $\quad Z0Linephys := Z0Line\cdot Zbase$

$Z1Linephys = 10.3 + 70.9i$ ohms primary

$Z0Linephys = 35.3 + 265.9i$ ohms primary

Converting primary ohms to secondary ohms gives:

$$Z1Linesec := Z1Linephys\cdot\frac{CTR}{VTR} \qquad Z0Linesec := Z0Linephys\cdot\frac{CTR}{VTR}$$

$|Z1Linesec| = 8.6$ ohms sec $\quad arg(Z1Linesec) = 81.7\cdot deg$

$|Z0Linesec| = 32.191$ ohms sec $\quad arg(Z0Linesec) = 82.4\cdot deg$

Load Data

From 2010 System peak load case provided in start up information, the peak load is given as 185 MVA (with two lines in service). In the event of sudden loss of lone line, peak load will double until operators can adjust loads. Therefore it is assumed that peak load for a short duration is 370 MVA

$\text{Speak} := 185$ MVA $\qquad \text{Smax} := 2 \cdot \text{Speak} = 370$ MVA

P2 Relay Settings

It was considered whether to make the line lengths and impedances individual for each line. However the differences in line lengths is only 170 metres, which is only 0.1%. The accuracy of fault location will not be better than 1% so there is no point in being accurate in distinguishing between the impedances of the lines between TL202 and TL206

$\text{Z1MAG} := |\text{Z1Linesec}| \quad \text{Z1MAG} = 8.6 \qquad \text{Z1ANG} := \dfrac{\arg(\text{Z1Linesec})}{\text{deg}} \quad \text{Z1ANG} = 81.7$

$\text{Z0MAG} := |\text{Z0Linesec}| \quad \text{Z0MAG} = 32.2 \qquad \text{Z0ANG} := \dfrac{\arg(\text{Z0Linesec})}{\text{deg}} \quad \text{Z0ANG} = 82.4$

$\text{LL202} := 141.76 \qquad \text{LL206} := 141.93 \qquad \text{LL} := \dfrac{\text{LL202} + \text{LL206}}{2} = 141.8$

In order to obtain sensitivity to 100 ohm single line to ground faults, the echo function will be needed. Enable two forward and one reverse zone.

$\text{PMHOZ} := 3 \qquad \text{GMHOZ} := 3 \qquad \text{QUADZ} := 3$

$\text{DIR1} := \text{F} \qquad \text{DIR2} := \text{F} \qquad \text{DIR3} := \text{R}$

(Note, given the fact that conventional zone 2 settings need a zone 3 time delay, a reduced reach zone 4 function with zone 2 time delay could be used in addition to the extended zone 2 with longer time delay. This is to be discussed with Newfoundland and Labrador Hydro.

Mho phase distance functions

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the BDE Station bus under light load conditions with four generators at BDE off line and both TL202 and TL206 lines in service. From ASPEN OneLiner, voltage at BDE for a 3 phase fault at SSD is 0.52 per unit. So there is plenty of voltage at BDE during a fault at SSD, even under weak source conditions.

Since the voltage is higher than 20%, the line is not considered short, and a conventional Zone 1 setting is acceptable.

$\text{Z1P} := 0.85 \cdot |\text{Z1Linesec}| \qquad \text{Z1P} = 7.3$ Ohms secondary

Existing setting of 7.28 ohms is OK, and will be retained. $\text{Z1P} := 7.28$

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is just less than 10.4 ohms secondary (about 122%) and will be increased to 130%. This will give a more comfortable dependability margin.

$\text{Z2P} := 1.3 \cdot |\text{Z1Linesec}| \qquad \text{Z2P} = 11.2$ Ohms secondary

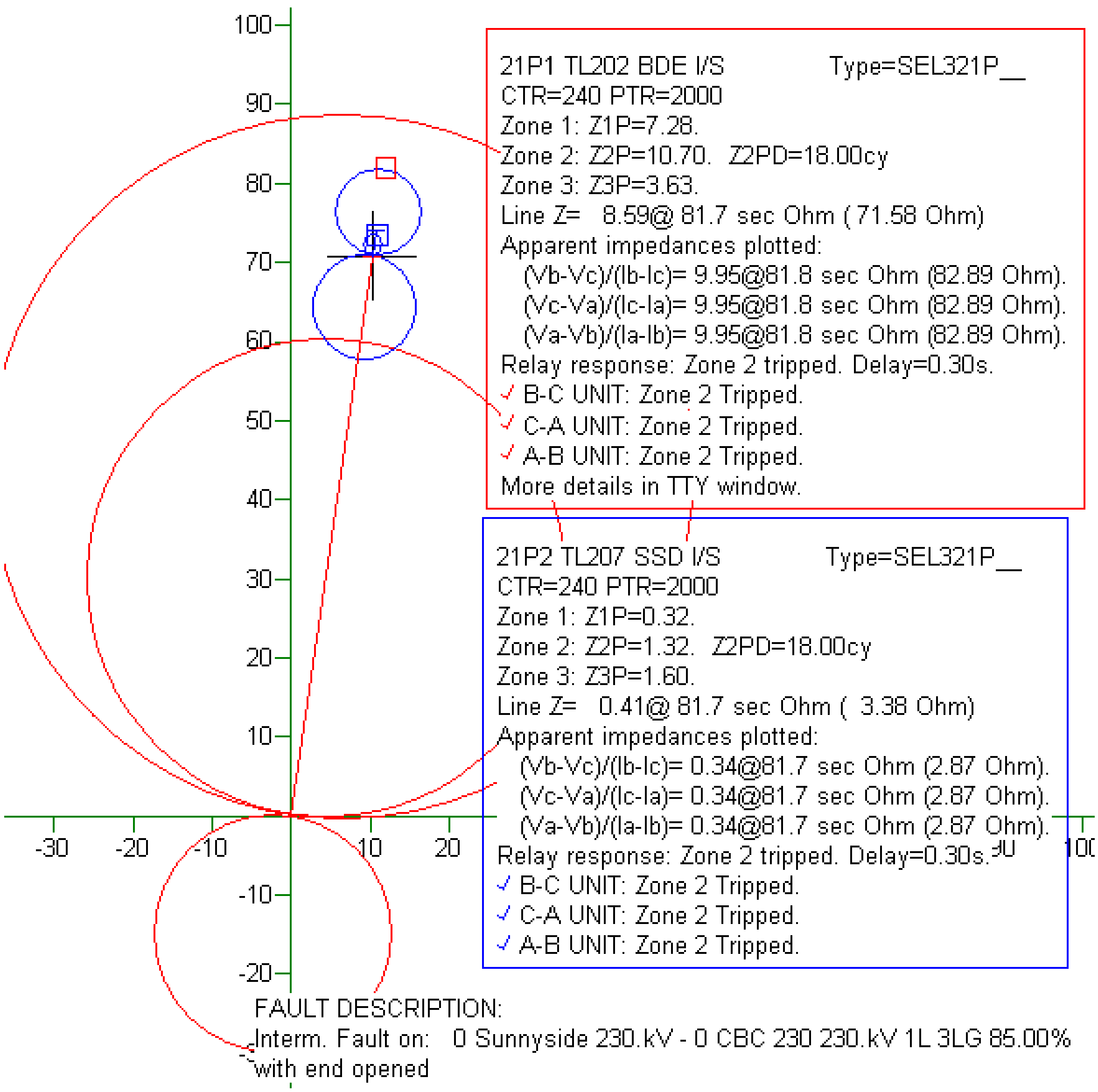
As can be seen from Figure 8, this element overreaches the zone 1 element at the SSD terminal of TL207 even with the existing setting. So we need to use a delayed zone 2 timer in order to coordinate with the SSD TL207 Zone 2 function. There is no benefit in retaining the existing setting since we should not retain the normal zone 2 time with the existing setting. Therefore, the timer setting will be increased beyond the normal zone 2.

SSD TL207 Zone 2 timer is set at 18 cycles. Assume this is Newfoundland and Labrador Hydro normal zone 2 clearing time that allows for normal breaker clearing and margin for breaker failure clearing and relay reset. To coordinate with the remote zone 2, we will need to make similar allowances.

$CBtime := 3$ cycles $Margin := 15$ cycles $Z2PDSSD\_TL207 := CBtime + Margin = 18$ cycles

Set this zone 2 at twice the remote zone 2 setting.

$Z2PD := 2Z2PDSSD\_TL207 = 36$ cycles



<u>Figure 8 - Existing BDE TL202 Zone 2 trips at the same time as the SSD TL207 for a fault 85% of the distance from SSD to CBC. Zone 3 timing is needed for the overreaching function at BDE.</u>

Zone 3

Set Zone 3 reverse element to reach further behind this terminal than the remote Zone 2. This function adds security for external faults. The element should always be more sensitive than the forward looking Zone 2 at the remote terminal. Set it the same as the remote Zone 2 overreach plus 20%

$$Z3P := Z1MAG \cdot \left(\frac{Z2P}{Z1MAG} - 1 + .2 \right)$$ $Z3P = 4.3$ Ohms secondary

$$\frac{Z3P}{|Z1MAG|} = 50 \cdot \%$$ of line length

This is a little higher than the existing setting, but provides additional security.

Mho phase distance current supervision

If the current supervision elements can be set above load, they will be secure in the event that potential is lost. However given that loss of potential logic is available, it is recommended that only the zone 1 current supervision function be set above load. If potential is lost, it will be able to block tripping by Zone 2 before it trips on time delay or receives a permissive trip from the remote terminal.

For the point of view of current supervision being above maximum load, there is no need to worry about abnormal conditions. It would be a double contingency for the VT signal to be lost while the parallel line was out of service. Therefore, consider a maximum load of 185 MVA. The current supervision elements for the phase distance functions measure phase to phase currents.

$$IPPmax\_normal := \frac{Speak \cdot 1000}{kVbase}$$ $IPPmax\_normal = 804$ A primary

The current supervision elements use phase to phase currents for supervision of the phase distance functions; so the minimum phase to phase fault current will be root three times the minim phase fault current. Choose a margin of 50% of the minimum phase to phase fault current for dependability.

$IPPmin := 0.5I3Pmin \cdot \sqrt{3}$ $IPPmin = 927$ A primary

A setting of 840 A primary for 50PP1 will ensure the Zone 1 function operates for any fault even under minimum source conditions while remaining unable to trip on load due to loss of potential under any normal maximum load conditions. This is a little lower than the existing setting, but is not insecure.

$'50PP1 := 3.5$ A Sec $'50PP1 \cdot CTR = 840$ A primary

Since Zone 2 and zone 3 elements will be blocked by LOP function, set them at minimum. This is also a little lower than the existing setting, but will be made secure by the use of LOP blocking..

$'50PP2 := 1$ A Sec $'50PP3 := 1$ A Sec

Ground Distance Protection

The reach of the ground distance functions will be affected by mutual coupling to the parallel line. These functions will tend to underreach the remote bus while the parallel line is in service, and overreach the remote bus if the parallel line is out of service and grounded at both ends. Figure 9 shows that for a remote bus fault, with the parallel line out of service and grounded, the apparent impedance of the line is reduced to about 7.9 ohms secondary instead of the nominal 8.6 ohms. This is 91% of the actual line impedance.

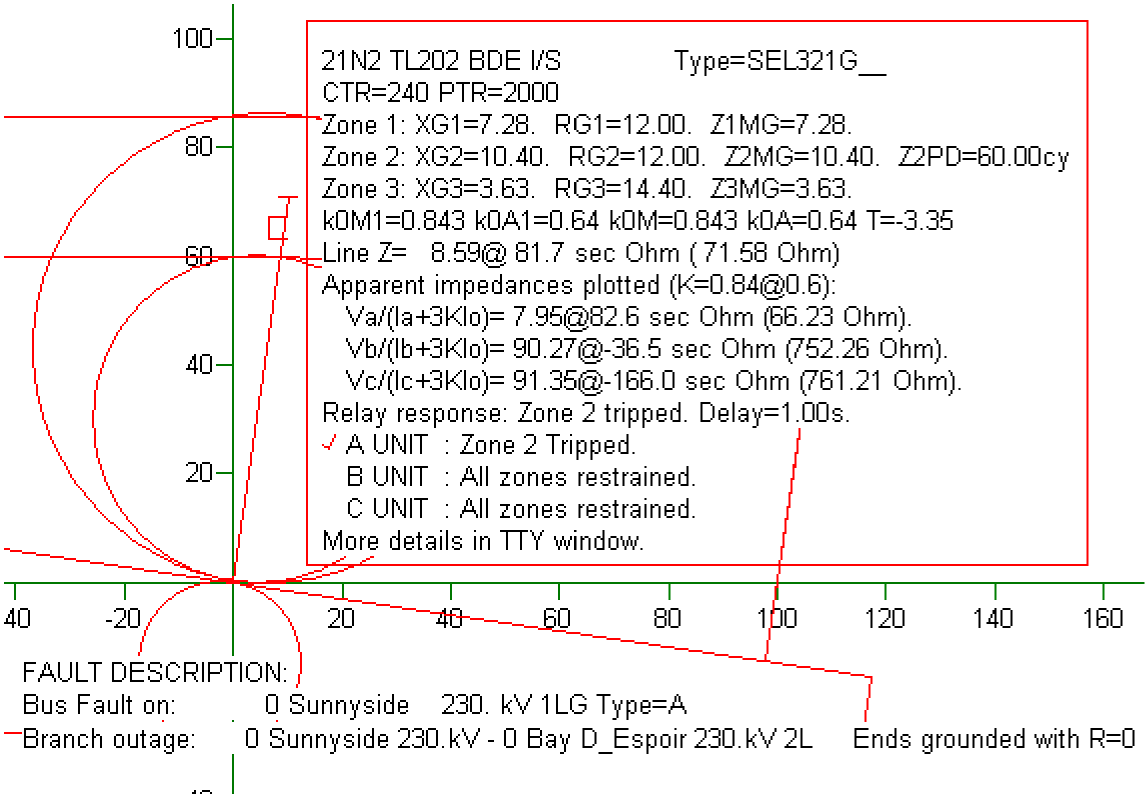


Figure 9 - Apparent impedance to a fault just beyond the remote terminal is reduced by 9% when parallel line is out of service and grounded at both ends.

The reach of the zone 1 should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Choose a setting of 80% of line which will underreach the remote bus by 11% when the parallel line is out of service and grounded at both ends.

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.8$ per unit

$Z1MG := m \cdot |Z1Linesec|$ $Z1MG = 6.88$ Ohms secondary

$XG1 := Z1MG$ $XG1 = 6.88$ Ohms secondary

Zone 1 Resistance

The resistive reach of the Zone 1 quad should provide enough sensitivity to trip the local terminal immediately without waiting for permission from the remote terminal for a severe fault that depresses the voltage significantly. Further, it should not allow the function to reach beyond the remote terminal due to errors in relay measurement or CT or VT. If possible, it should also operate for a 100 ohm SLG 25% of the distance from the local terminal. Operation for a 100 ohm resistive fault at the 25% location will ensure this function can trip for a close in fault without assistance from the remote terminal. The remote terminal zone 1 function will be set to operate sequentially for this fault.

By simulating a fault with 100 ohms fault resistance at the 25% of the distance from BDE, with the BDE terminal weak (as in light load situation) it is found that a reach of 18 ohms secondary is required to sense this fault. See Figure 10.

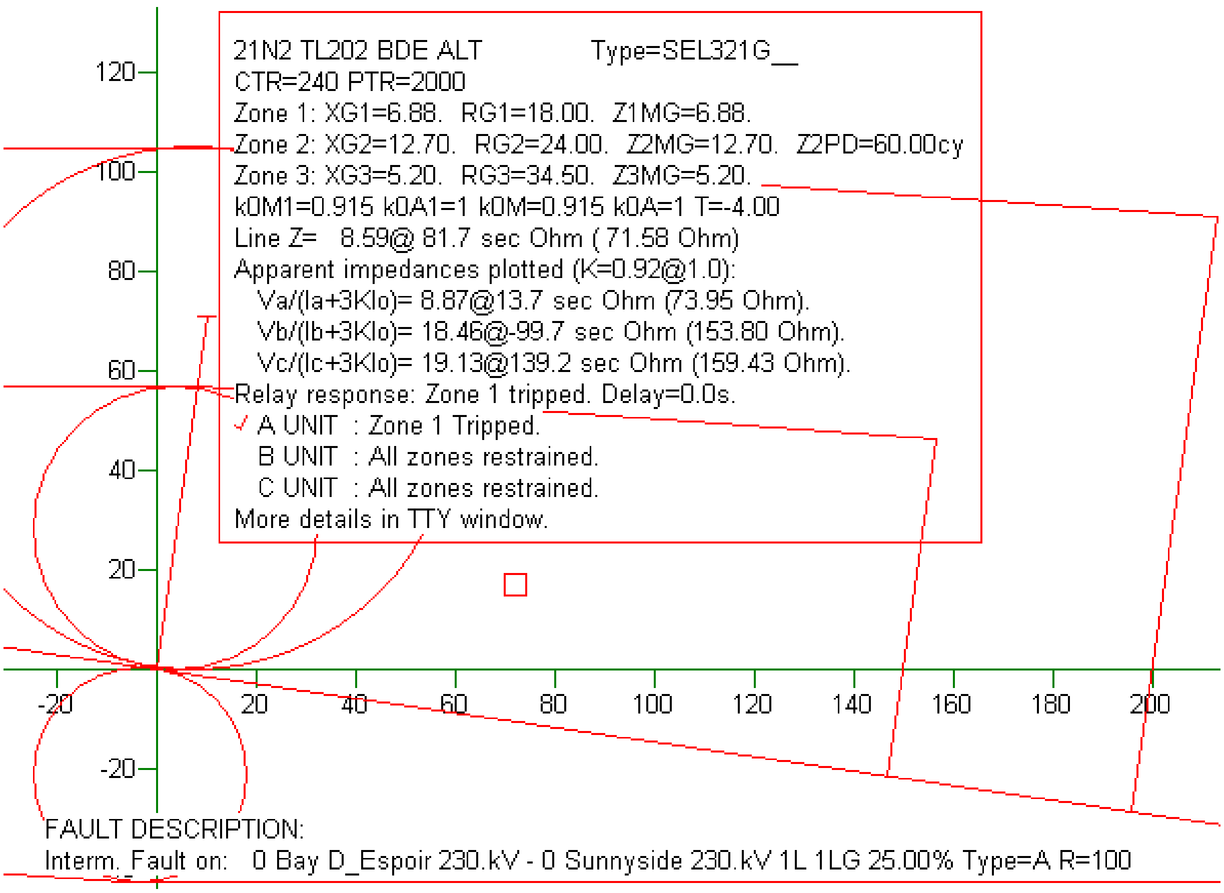


Figure 10 - BDE Zone 1 function operates for a 100 ohm SLG fault at 25% from the local terminal.

The existing 12 ohm secondary resistive reach of the zone 1 element will not sense this fault, and should be increased to 18 ohms secondary. Check whether this reach will be secure, considering possible CT and VT errors.

XG1 is set at m per unit of the transmission line. The imaginary component of the line is

$ImXG1sec := Im(Z1Linesec)$ $ImXG1sec = 8.506$ ohms

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$RG1 := round[(1 - m)\cdot 20\cdot ImXG1sec, 2]$

$RG1 = 34.02$ This is the maximum secure setting for the resistive reach and is above the proposed zone 1 resistive reach setting..

Use the proposed setting of 18 ohms for RG1 $RG1 := 18$ ohms secondary

With a resistive reach setting of 18 ohms, the BDE Zone 1 quad element will see an 80 ohm resistive SLG fault at 50% of the distance from BDE. Zone 2 protection will be depended upon to sense faults with resistance up to 100 ohms.

Zone 2 Ground Distance Protection

The Zone 2 ground distance function will need to be set longer than the Zone 2 phase distance protection function because it will tend to underreach the remote terminal while the parallel line is in service. By simulation in ASPEN OneLiner it is found that the apparent impedance to a zero ohm fault close in to the remote terminal is 10.15 ohms secondary, or 18% more than the actual line impedance. The reach of the Zone 2 ground distance element should be set at least to 1.25 times the apparent impedance.

$ZSLG\_remote := 10.15$

$Z2MG := round(1.25\cdot ZSLG\_remote, 1)$ $Z2MG = 12.7$ Ohms secondary

The quad element reactive reach will be set similarly to the mho.

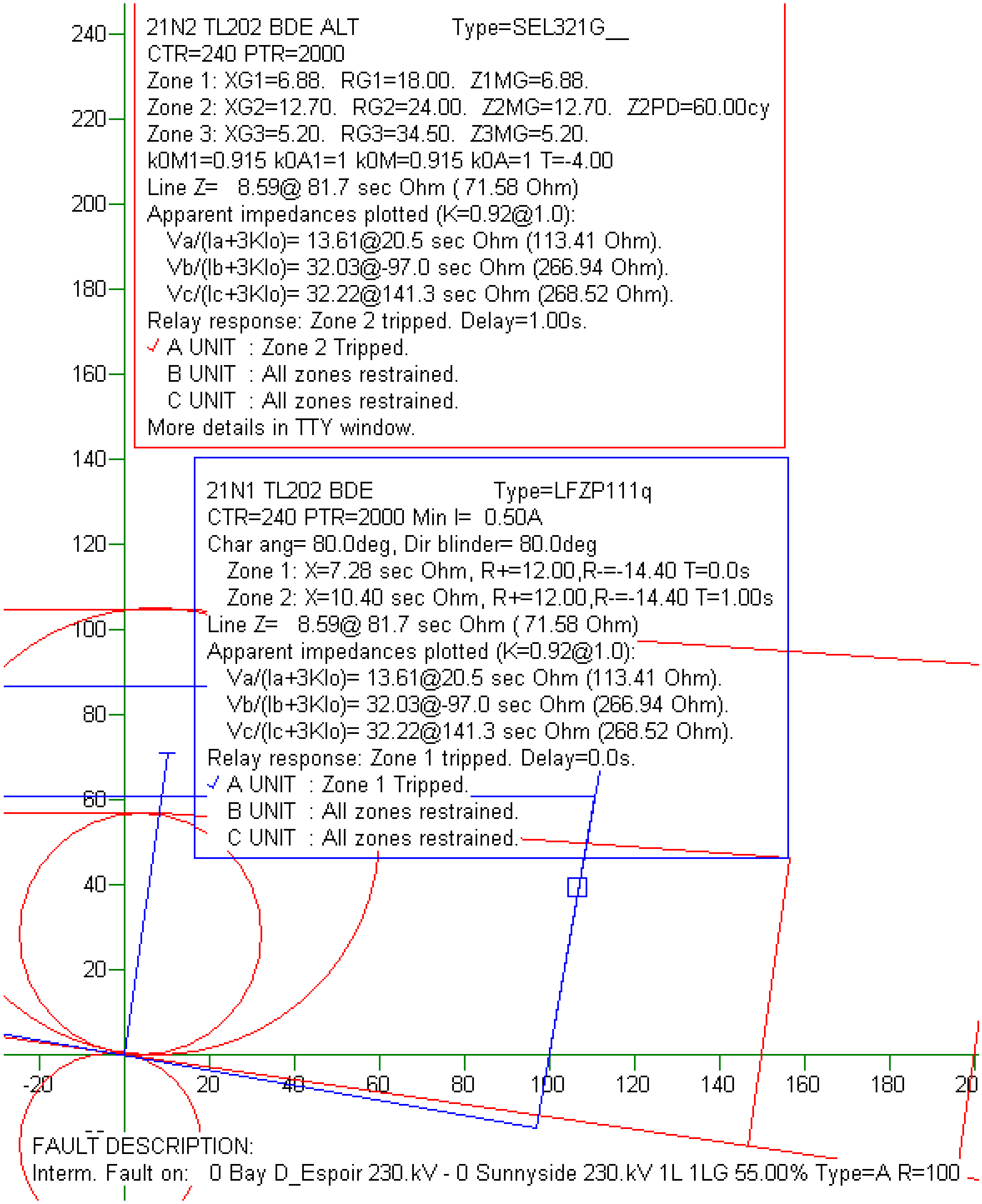
$XG2 := Z2MG$ $XG2 = 12.7$ Ohms secondary

It would be desirable to set the resistive reach of the quad element to sense a 100 ohm SLG fault at 75% of the line with the local terminal weak. This would ensure overlap with the zone 1element at the remote terminal. However, that would require too much resistive reach. Therefore choose a setting to sense a 100 ohm SLG fault just past the mid point of the line, and depend on the echo function to provide coverage for high resistance faults in the region where the remote zone 1 won't operate.

By trial and error from ASPEN it is found that a resistive reach of 24 ohms secondary will sense a 100 ohm SLG fault at a location 55% of the distance from BDE. See Figure 11. This will give positive overlap with the zone 2 element at the remote terminal. However since it will not overlap the Zone 1 element at the remote terminal, the permissive trip echo function will be required to ensure that a fault that is seen by the zone 2 element at only one terminal will still be cleared by the permissive trip logic.

Therefore, to avoid extremely large resistive reaches, and to retain sensitivity to 100 ohm resistive SLG faults, it is recommended that the echo function be enabled at both terminals.

$RG2 := 24$ Ohms secondary



<u>**Figure 11 - Quad elements operate for 100 ohm resistive SLG just past the mid line location.**</u>

Check that this resistive reach won't cause the zone 2 function to trip while the parallel line is open single phase, with heavy power flow. See Figure 12.

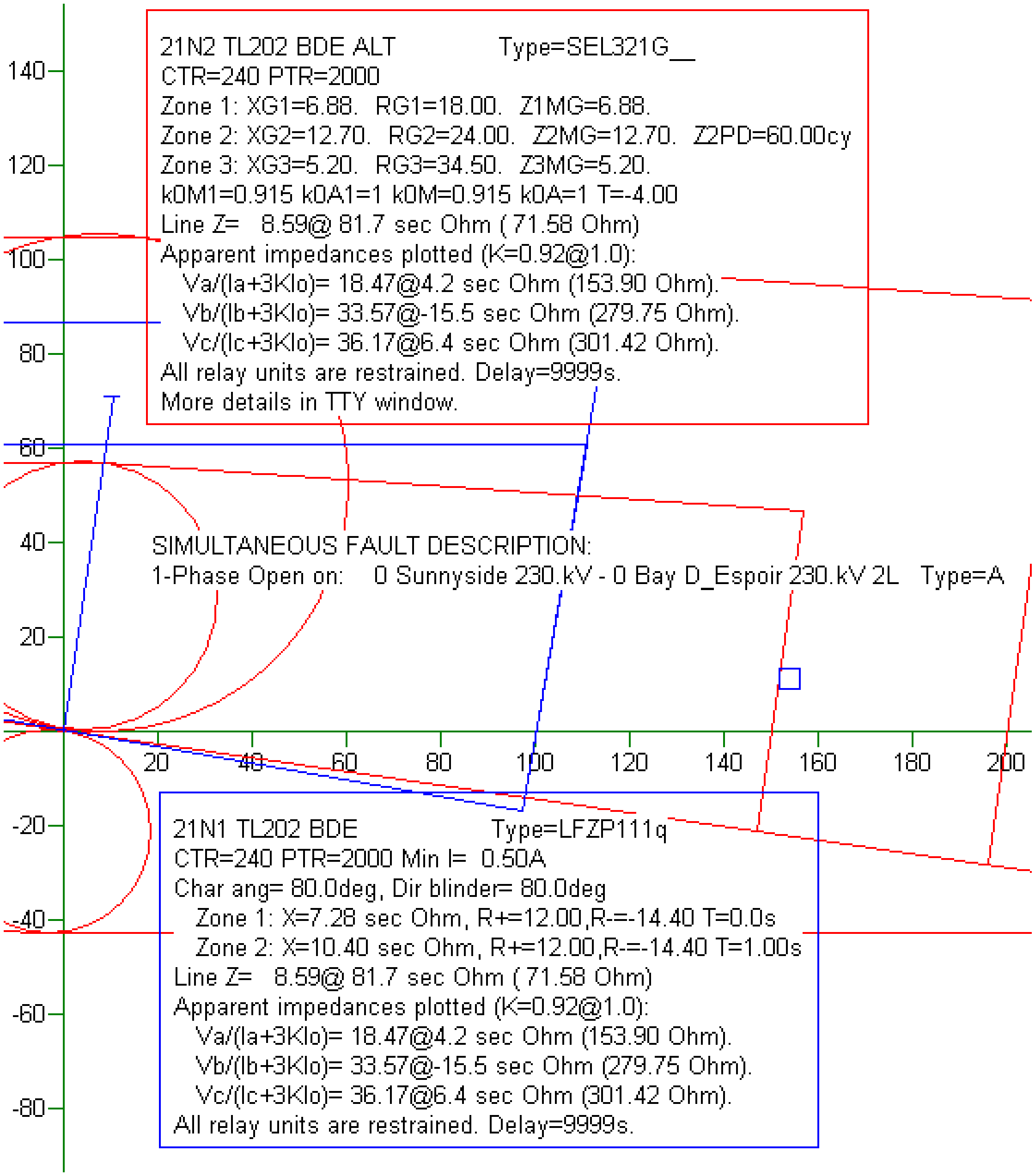


Figure 12- Quad elements are secure with heavy load flow (185 MVA in each line) while parallel line is open single pole.

The zone 3 ground mho function will be set using the same principles as the zone 3 phase distance function. The remote Z2MG will be set at 12.1 ohms

Z2MGrem := 12.1 ohms secondary

$$Z3MG := Z1MAG \cdot \left(\frac{Z2MGrem}{Z1MAG} - 1 + .2 \right)$$

Z3MG = 5.2 Ohms secondary

$\frac{Z3P}{|Z1MAG|} = 50 \cdot \%$ of line length

This is a little higher than the existing setting, but provides additional security.

$XG3 := Z3MG$ $XG3 = 5.2$ Ohms secondary

Set the Zone 3 quad resistive reach at 10% more than the remote Zone 2

$RG2rem := 30$ Ohms secondary $RG3 := RG2rem \cdot 1.1$ $RG3 = 33$ Ohms secondary

Ground distance current supervision

Since there is no concern about these elements operating on load, even with loss of potential, set all current supervision elements at minimum, for maximum sensitivity of the distance elements.

$'50L1 := 0.5$ A Sec $'50L2 := 0.5$ A Sec $'50L3 := 0.5$ A Sec

$'50G1 := 0.5$ A Sec $'50G2 := 0.5$ A Sec $'50G3 := 0.5$ A Sec

Note that due to heavy infeed of zero sequence currents from the local terminal for close-in faults, the ground overcurrent detectors will not operate for faults with more than a small amount of resistance close to the remote terminal. Therefore, we will have to rely on sequential clearing for that type of fault. However setting the current supervision at minimum allows maximum sensitivity.

Zero sequence current compensation

The zero sequence current compensation could be adjusted to compensate for the significant amount of mutual coupling. However as discussed in the settings of reaches of the ground distance elements we will accept underreach of the Zone 2 function for the normal case. Set the zero sequence current compensation as usual.

$$k01M := \left(\left| \frac{Z0Line - Z1Line}{3 \cdot Z1Line} \right| \right) \qquad k01M = 0.915$$

$$k01A := \left(\arg\left(\frac{Z0Line - Z1Line}{3 \cdot Z1Line} \right) \right) \qquad k01A = 0.976 \cdot deg$$

Say $k01A := 1deg$

Set the overreaching zones the same as zone 1 $k0M := k01M$ $k0A := k01A$

$k0M = 0.915$ $k0A = 1 \cdot deg$

Non Homogenous Angle Setting

Compare the angle of the total zero sequence current at the remote bus with the angle of the zero sequence current contribution from the local terminal to determine this setting. From ASPEN OneLiner, the worst case is under light load conditions at BDE with units 2, 4, 5 and 6 out of service. For this case, for an SLG at SSD, the angle of I0 at the fault is -114 degrees and the angle of I0 out of the BDE terminal is -110 degrees. Therefore, the total fault current leads the current contribution from BDE by 4 degrees and angle T must be set negative by the difference to ensure no overreach.

$T := -4$ degrees

Out of step blocking and tripping

Not used in this application. There is a danger of out of step conditions arising. Historically no action has been taken to provide special tripping or blocking functions. Natural tripping during swings is accepted.

Load Encroachment logic

Check loadability of the Zone 2 phase distance element assuming worst case power factor of 0.87 simultaneous with worst case depressed voltage of a stressed system of 0.85 per unit. Note that units of kV squared match units of MVA. Note that quadrilateral elements are only used for the ground distance functions that are not sensitive to balanced three phase load. Therefore no need to worry about the reach of the quadrilateral elements.

$$\mathrm{Zloadmin} := \frac{(0.85\mathrm{kVbase})^2}{\mathrm{Smax}} \qquad \mathrm{Zloadmin} = 103.298$$ Ohms primary (assume worst case at 30 degrees)

Maximum reach of the Zone 2 element is at the line angle of 81 degrees. At 30 degrees, the reach will be given by

$$\mathrm{Z2load} := \mathrm{Z2P}\cdot\cos[(\mathrm{Z1ANG} - 30)\mathrm{deg}] \qquad \mathrm{Z2load} = 6.92$$ ohms secondary

$$\mathrm{Z2load}\cdot\frac{\mathrm{VTR}}{\mathrm{CTR}} = 57.668$$ ohms primary

Since the reach of the Zone 2 element at 30 degrees is less than the apparent impedance of the maximum load, there is no need to apply load blinding logic. See Figure 13

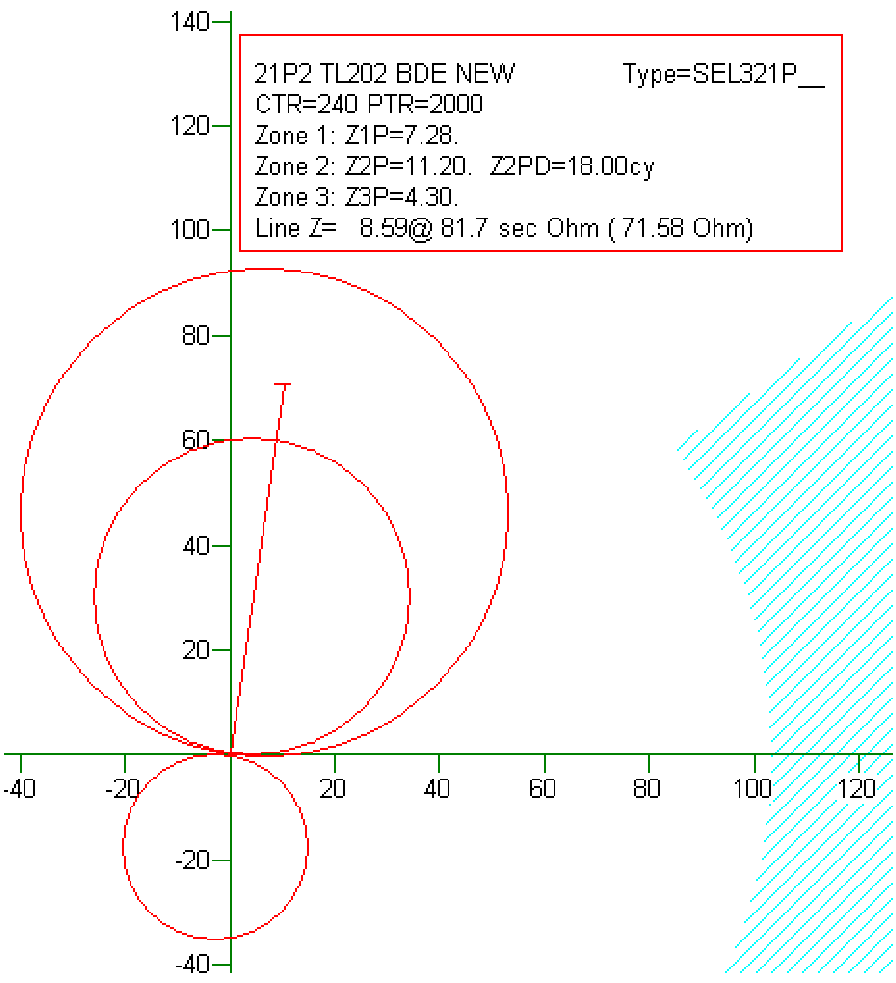


Figure 13 -Load impedance with respect to proposed new Mho function reaches.

Ground directional element

The SEL-321 application example recommends finding the minimum source impedance behind the terminal and setting the reverse and forward boundaries of the negative sequence directional element at the 1/3 and 2/3 points respectively.

In the negative sequence plane, the sum of the two source impedances and the line impedance is:

$$Z2total := Z2minBDE + Z1Linephys + Z2minSSD$$

The 1/3 point is $Z2\_1\_3 := \frac{Z2total}{3}$ The 2/3 point is $Z2\_2\_3 := \frac{2Z2total}{3}$

$Z2Rpri := Z2\_2\_3 - Z2minBDE$ $\quad |Z2Rpri| = 64.952$

$Z2Fpri := Z2\_1\_3 - Z2minBDE$ $\quad |Z2Fpri| = 25.095$

Converting the primary impedances to secondary ohms

$Z2R := Z2Rpri\cdot\frac{CTR}{VTR}$ $\quad |Z2R| = 7.794$ Ohms secondary $\quad arg(Z2R) = 81.732\cdot deg$

$Z2F := Z2Fpri\cdot\frac{CTR}{VTR}$ $\quad |Z2F| = 3.011$ Ohms secondary $\quad arg(Z2F) = 80.002\cdot deg$

Rounding up Z2F and rounding down Z2R gives:

$Z2F := 3$ Ohms secondary $\quad Z2R := 7$ Ohms secondary

These are not very different from the existing settings.

Set the current level detectors at minimum level that will allow operation of the ground distance elements.

Due to the very small zero sequence current contribution to a single line to ground fault at the remote terminal, the negative sequence current contribution will always be higher than the zero sequence. Therefore there is no point in setting the forward looking negative sequence overcurrent elements any more sensitively than the zero sequence ground overcurrent supervision of the ground distance elements.

$'50QF := '50G2$ $\quad '50QF = 0.5$ A secondary

Set the supervision function for the reverse looking element to be the same as, or a little more sensitive than the forward looking supervision element at the remote terminal.

$'50QR := 0.5$ A secondary

The positive sequence current restraint (a2) factor should be set just smaller than the ratio of the maximum load current (positive sequence) to the most sensitive current supervision element (50QR).

$I1maxpri := \frac{Smax\cdot 1000}{kVbase\cdot\sqrt{3}}$ $\quad I1maxsec := \frac{I1maxpri}{CTR}$ $\quad I1maxsec = 3.87$

Bearing in mind that the 50QR setting is in units of 3*I2

$\frac{'50QR}{3\cdot I1maxsec} = 0.043$ Choose a value of $a2 := 0.04$

The proposed new setting of a2 is a little higher than the existing setting (0.03).

Phase time overcurrent element

This element is not used

Residual time overcurrent element

This element is used to provide the most sensitive backup protection. It will be non directional element.

Set pickup to sense a higher resistance than 100 ohm SLG in the middle of the line with equal zero sequence current infeed from both ends. Choose a resistance of 200 ohms arbitrarily. Use a safety factor of 2 so that operating time is not infinity at this fault level.

$SF := 2$ Desensitization factor due to remote end infeed is $Dfactor := 2$ $Rf := 200$

$$'51NPU := round\left(\frac{kVbase \cdot 1000}{\sqrt{3} \cdot SF \cdot Dfactor \cdot Rf \cdot CTR}, 1\right) \qquad '51NPU = 0.7$$

The existing setting of 0.5 A is more sensitive than required to sense this mid line fault with arbitrary resistance. Since experience with the high resistance tree fault on 28th August 2009 has shown value in the existing setting, it will be retained.

$'51NPU := 0.5$ A secondary

Coordination checks show that existing time dial settings will coordinate with each other. See Figures 14 and 15

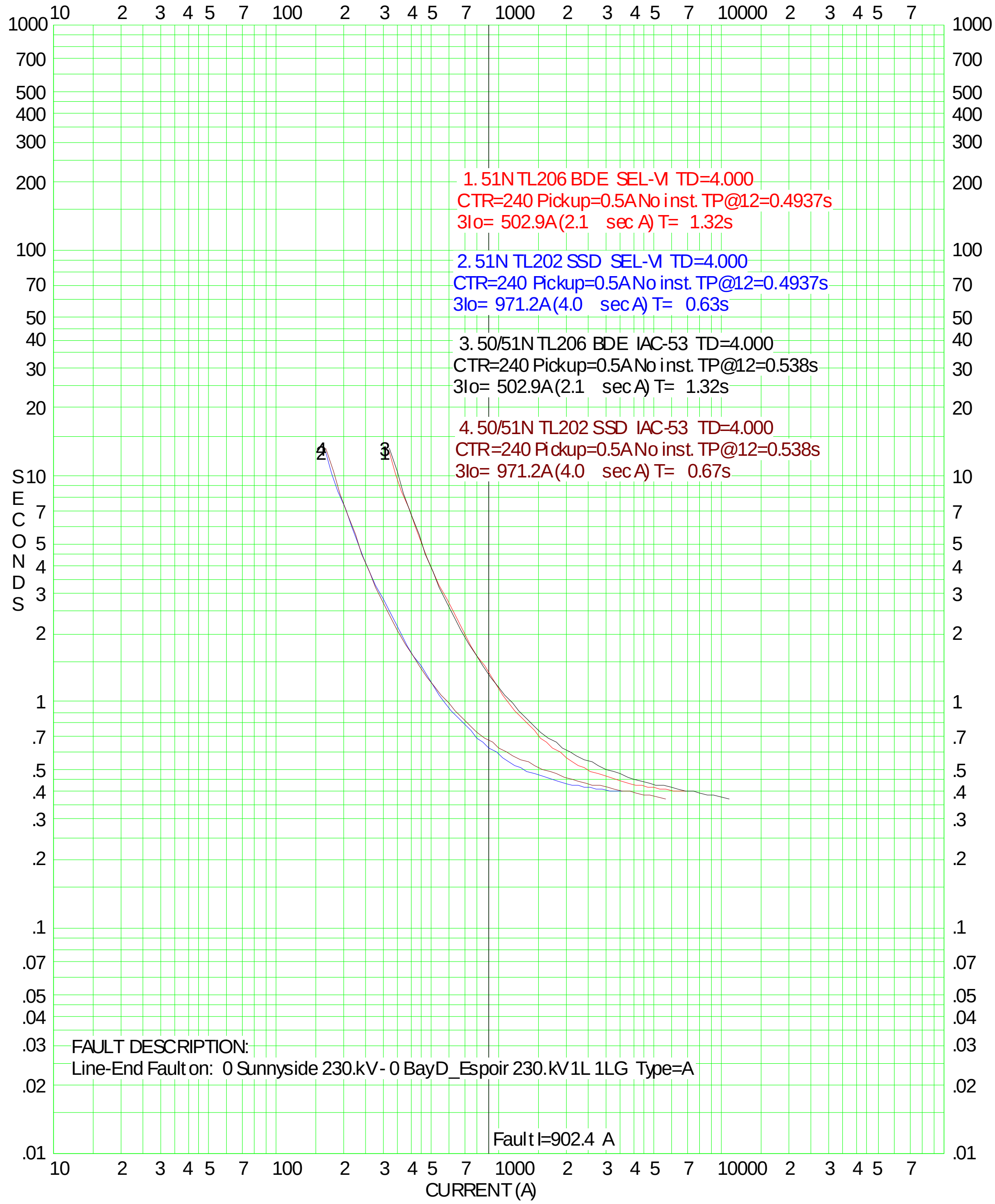
$'51NPU = 0.5$ A secondary $'51NPU \cdot CTR = 120$ A primary

$'51NTD := 4$ $'51NC := "U3"$ $'51NTC := "N"$ $'51NRS := "N"$

Checks for close-in fault show that this element will not operate in less than 0.4 seconds so there is no danger of it tripping 3 pole before the zone 1 element trips the faulted phase selectively.

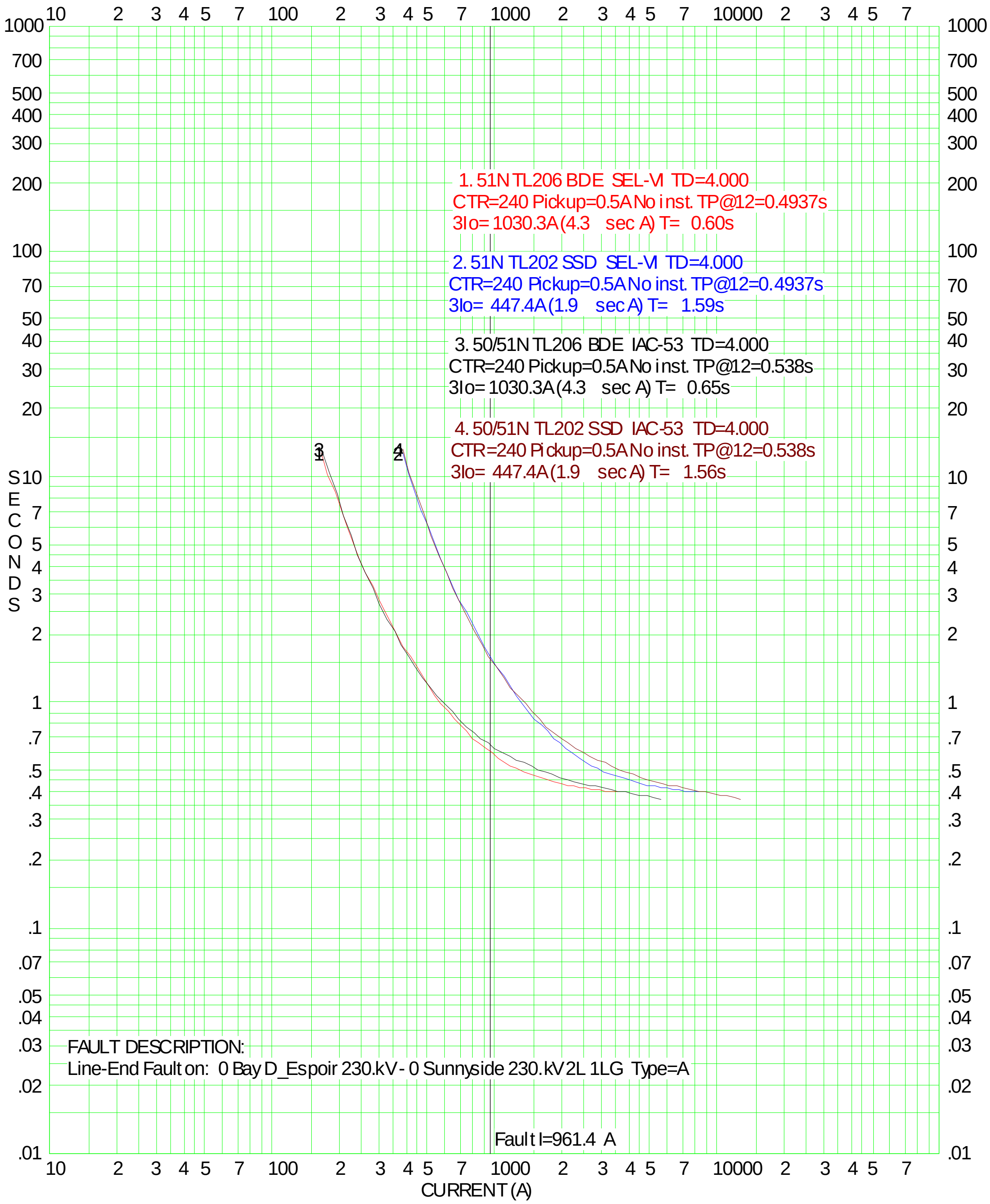
Check the coordination with the remote terminal 51N on the parallel line for a line end fault near SSD on the parallel line. due to mutual coupling, this is the type of fault that will produce the most sensitivity (least desensitization) with respect to the protection on the parallel line. see Figure 14. coordination is fine.

Worst case load unbalance with single pole open will be in the future if single pole tripping is enabled with parallel line out of service. ASPEN OneLiner shows that with 300 MVA of load on one line, and with one phase open, the 3I0 current is approximately 380 A. The 51N relay with "Alternate" settings will take approximately 3.4 seconds to operate on 380 A primary. No danger of tripping on load unbalance during SPO time.



TIME-CURRENT CURVES @Voltage 230 kV	By
For Coordination of ground time overcurrent elements	No.
Comment With mutual coupling taken into consideration.	Date

Figure 14 - coordination of ground time overcurrent elements for line end fault on TL202 close to BDE



TIME-CURRENT CURVES @Voltage 230 kV	By
For Coordination of ground time overcurrent elements	No.
Comment With mutual coupling taken into consideration.	Date

Figure 15 - coordination of ground time overcurrent elements for line end fault on TL206 close to SSD

Permissive Overreaching logic settings

EPOTT := "Y"

Z3RBD is set at remote breaker time plus channel reset time plus channel reset time plus zone 2 reset time. From review of fault records it appears that the breaker time is 3 cycles. Channel reset time is not easily determined from existing records but can conservatively be assumed to be 1 cycle, and relay reset time will also be about 1 cycle. Total time for Z3RBD is then 5 cycles.

Z3RBD := 5 cycles

Echo block delay timer blocks the echo after the local elements have picked up. This can be set relatively long since there is no significant need for the echo function shortly after the local terminal has just seen a fault but the remote terminal has not. Set at 10 cycles as per the example in the instruction manual.

EBLKD := 10 cycles

Echo time delay on pickup should be set to override noise on the communications so that it doesn't echo noise. Typical time according to the SEL application guide is 2 cycles. Since this delay only affects clearing time for relatively light (high resistance) faults that are sensed by zone 2 function at one end, the typical setting is acceptable.

ETDPU := 2 cycles

Echo duration should be long enough to ensure the permissive trip is received by the remote terminal and should also be shorter than the Z3RBD time to ensure that the reverse blocking will always be longer than any permissive trip received (including echo time stretching).

EDURD := 4 cycles

No need to enable week feed conversion to trip, since both terminals will be quite sensitive enough to detect high resistance faults after the remote terminal has cleared. Therefore we can accept sequential (or "step") clearing with no need for the added insecurity of weak infeed tripping.

EWFC := "N" **No other communications logic settings are required for this application.**

Switch on to Fault Settings

Switch on to fault logic will ensure the protection will operate when energizing the line onto a close-in three phase fault when there is no polarizing voltage available for the distance elements.

ESOTF := "Y"

The breaker close signal is not available to the relay. The 52A method of enable SOTF will be used. Therefore the Close end delay is not critical. Typical duration for enable SOTF is 10-15 cycles

ENCLO := "N" CLOEND := 0 EN52A := "Y" SOTFD := 15

Set 50H for high magnitude close-in multiphase faults with weakest source at BDE. It should be set less than 50% of the minimum close-in fault magnitude. Minimum close-in magnitude of a three phase fault with four generators out of service and TL234 also out of service is 5100 A. Therefore desired maximum setting for 50H is 2500 A.

Imin3P_close_in := 5100

$$'50H := \frac{Imin3P\_close\_in}{2CTR} \qquad '50H = 10.625 \quad \text{A secondary}$$

Choose a setting of 10 A secondary for this element. '50H := 10 A secondary

Choose a setting for 52AEND less than the shortest reclose time. '52AEND := 30 cycles

Residual overcurrent settings.

Tripping directly by instantaneous ground overcurrent is not applicable because it is not phase selective. However it would be helpful to monitor steady state unbalance, and issue an alarm for continuous unbalance. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50N := 1$ $\qquad$ $'50N1 := 0.25$

Negative Sequence overcurrent settings.

Similar to ground overcurrent, apply a negative sequence overcurrent element to initiate an alarm for steady state unbalances. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50Q := 1$ $\qquad$ $'50Q1 := 0.25$

Voltage Element Settings

Similar to unbalance current monitoring, it is helpful to have an unbalance voltage monitor to detect steady state unbalances from the voltage supply.

EVOLT := "Y"

Set the zero sequence overvoltage element at 1% of rated voltage or just at the point necessary to override normal unbalances. The zero sequence voltage element measures 3 times the zero sequence voltage.

$$'59N := 3 \cdot 0.01 \frac{kVbase \cdot 1000}{\sqrt{3} \cdot VTR} \qquad '59N = 1.992 \qquad \text{Say} \quad '59N := 2 \ \text{V secondary}$$

Loss of Potential

Enable loss of potential settings. Advanced LOP settings are not available on this model of relay.

ELOP := "Y" $\qquad$ Time delay of 1.25 cycles is commonly used. $\qquad$ $LOPD := 1.25$

The 50 M element should be set above maximum load and below minimum fault current for a fault at the remote terminal under weak source conditions. The maximum load for this case should be normal maximum, not emergency maximum which only exists for a few minutes before the operator can act to reduce load.

$$Imax\_normal := \frac{Speak \cdot 1000}{\sqrt{3} \cdot kVbase \cdot CTR} = 1.935 \ \text{A secondary}$$

Minimum fault current for a remote three phase fault is $\qquad$ $I3Pmin = 1070$ $\qquad$ A primary.

Minimum fault current for a remote phase to phase fault is 87% of the minimum three phase fault current level.

Dependability factor to be sure to operate for a minimum remote fault is chosen to be 1.6. $\qquad$ $DF := 1.6$

Maximum setting for 50M should be $\qquad \dfrac{0.87I3Pmin}{DF \cdot CTR} = 2.424$ $\qquad$ In this case a setting of 2.4 A secondary will be adequately dependable and secure.

$'50M := 2.4$ A secondary

The 59QL setting should be above normal maximum unbalance and below the level expected for a blown VT fuse. For a blown fuse, one phase voltage will be lost, and the negative sequence voltage will be roughly 33% of the nominal positive sequence voltage. Choose a setting of 15% of the nominal positive sequence voltage. This will be well above any normal unbalance.

$$'59QL := \mathrm{round}\left(\frac{0.15 \cdot kVbase \cdot 1000}{\sqrt{3} \cdot VTR}, 0\right)$$ $'59QL = 10$ V secondary

The 59PL setting should be less than the minimum voltage to be expected for a remote bus fault under weakest source conditions. There is no minimum setting (above zero) for this function. Choose a setting equal to half the voltage drop along the line impedance at the pickup setting of the 50M element.

$$'59PL := \mathrm{round}[0.5 \cdot ('50M \cdot |Z1Linesec|), 0]$$ $|'59PL| = 10$

Miscellaneous Scheme Settings

Pole discoordinance logic is not being used. EPOLD := "N" SPPDD := "N/A"

Enable single pole tripping by distance elements only ESPT := "Y"

Enable single pole open ESPO := "Y"

Set single pole open time delay for future SPO conditions SPOD := 0.25

3 Pole open reset delay to override small discrepancies in pole closing '3POD := 0.5

Stub line protection is not required ESTUB := "N" '50MFD := "N/A"

Trip unlatch logic not applied TULO := "N"

Logic variables and Miscellaneous timers

Minimum trip duration timer is set at 9 cycles as per the application example in the SEL-321 instruction manual.

TDURD := 9 Cycles

Trip during open pole time delay should be set longer than the reclose time. Existing setting is OK.

TOPD := 55 Cycles

Proposed logic for X, and Y variables is intended to create a three pole trip if a permissive trip is received any time within a period of 25 to 60 cycles after a single pole trip was asserted. This is presumably standard NL Hydro logic. It enables more sensitive protection during the open pole period, because only one terminal has to see a fault in order for the three pole trip to be implemented.

Retain existing settings except use time ZT to trigger an alarm for sustained unbalance.

LOGIC_Z := "59N+50N1+50Q1" TZPU := 1200 cycles TZDO := 0 cycles

Tripping Logic

Permissive tripping is required only for instantaneous overreaching functions. No need for any functions that trip directly. Existing 51NT word in MTCS is not required.

MTCS := "M2P+Z2G"

Unconditional tripping MTU := "M1P+Z1G+M2PT+Z2GT+51NT"

No need for existing direct tripping zone 1 functions in the switch on to fault logic.

SOTF Tripping MTO := "M2P+Z2G+50H"

Event records will be triggered automatically by all trip events. Other event record triggers should be by starting of other elements to ensure capture of all relevant events. Events should be triggered by keying or receiving permissive trips to ensure separation of relay and teleprotection issues.

MER := "M2P+Z2G+51N+LOP*52AA1+LOP*52AA2+KEY+PT+EKEY"

Outputs

Retain existing output assignments except add the continuous unbalance alarm to OUT15.

OUT15 := "LOP*50L+ZT"

Input Contact Assignment

It would be desirable to provide phase segregated inputs to the relay so that the quadrilateral functions could be disabled during single pole open conditions. However, separate inputs are not presently available for phase segregated breaker status inputs. It is recommended to replace the existing automatic reclosing logic so that additional inputs can be freed up. Alternatively an SEL2506 unit could be added to allow for additional I/O through mirrored bits.

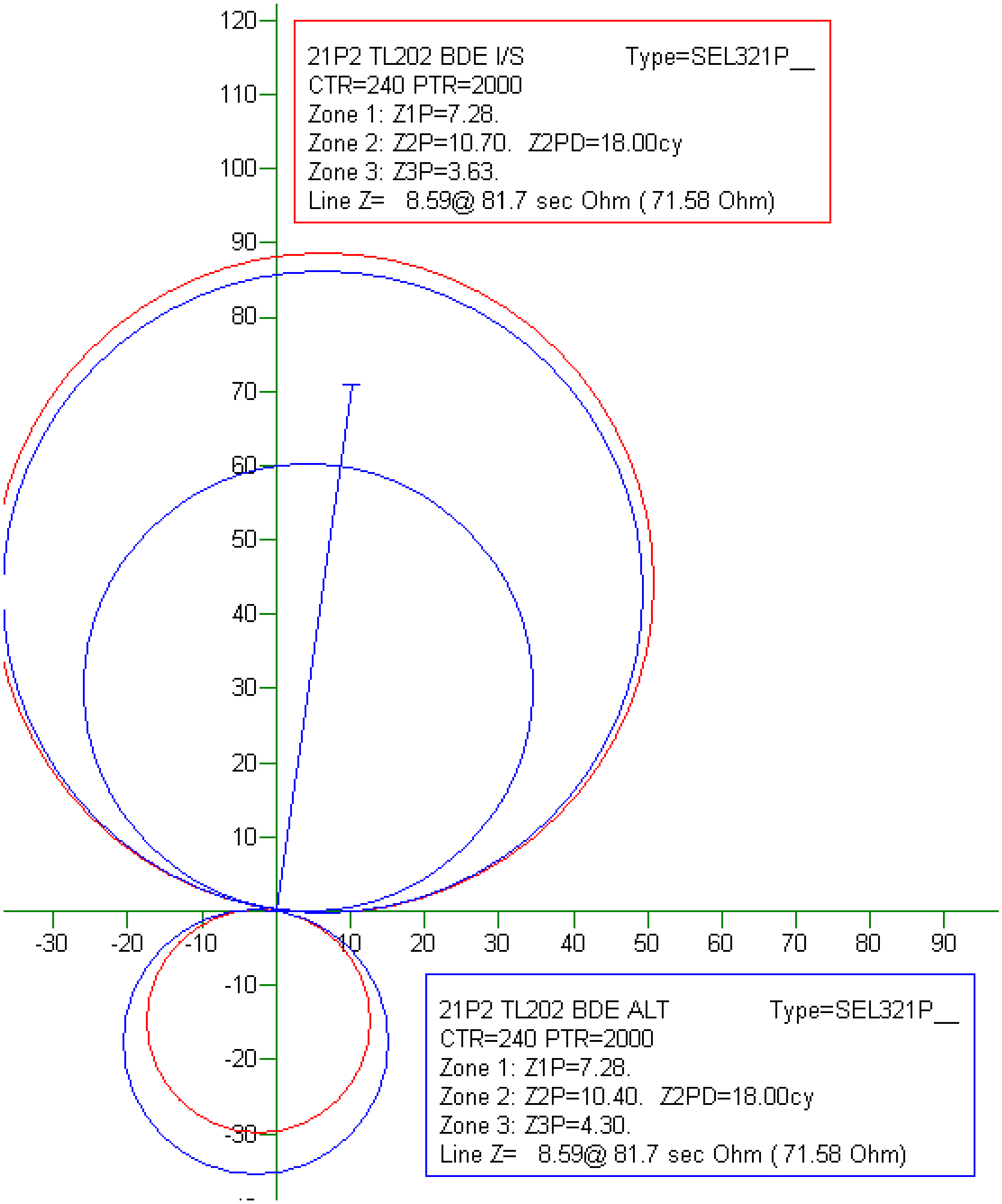


Figure 16 - Comparison between existing (red) and proposed new (blue) phase distance characteristics.

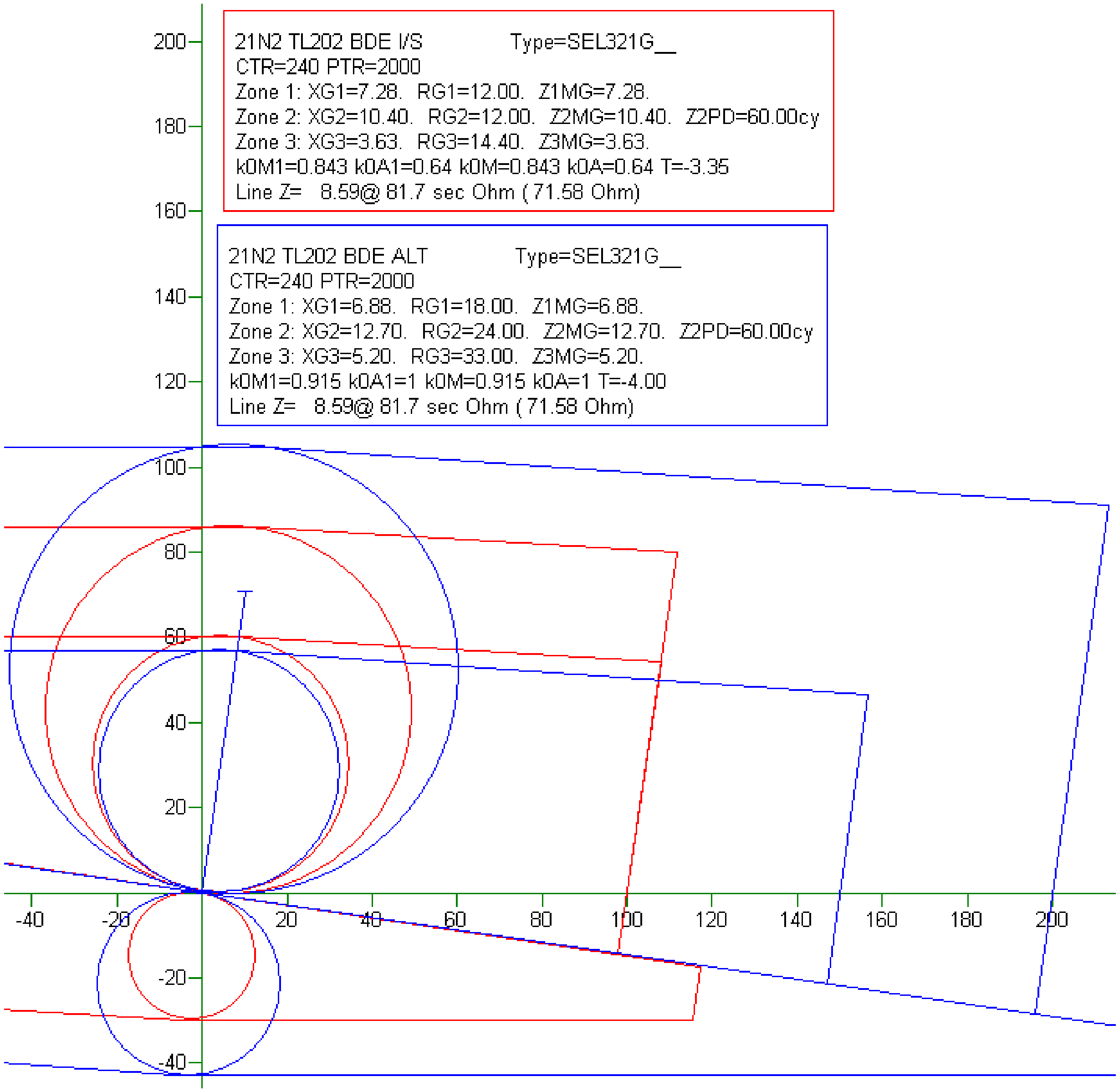


Figure 17 - Comparison between existing (red) and proposed new (blue) ground distance characteristics.

Protection Review for Five 230 kV Transmission Lines

Appendix E
Detailed settings review for SSD TL202 and TL206 "P1" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Bay D'Espoir (BDE) terminals of circuits TL202 and TL206. These 230 kV transmission circuits are from BDE to Sunnyside (SSD).
The circuits run parallel to each other for most of their length. The circuit impedances are similar to each other, but not identical. However since the difference in impedance between the two circuits is less than 0.2%, the settings for both protection systems will be made identical to each other to reduce effort in testing.

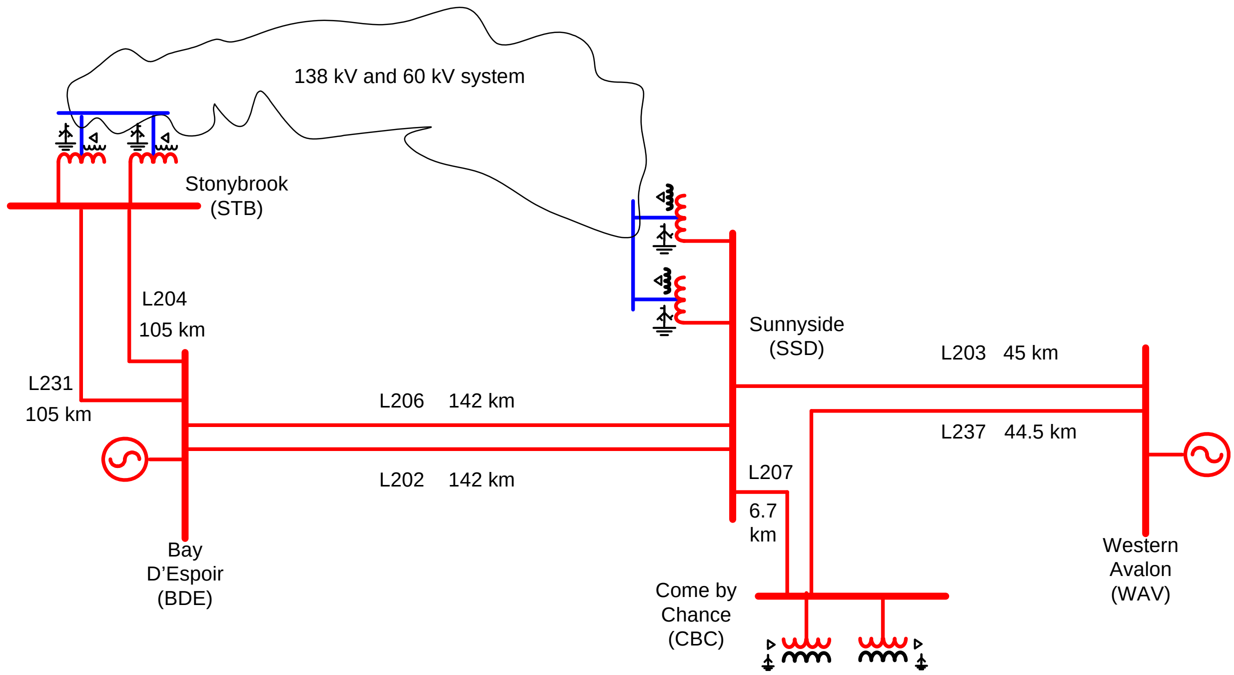


Figure 1 - System Single Line Diagram

Existing P1 protection systems are Areva LZFP111 (Optimho) systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $\quad kVbase := 230$ $\quad Ibase := \dfrac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\quad Zbase := \dfrac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $CTR := \dfrac{1200}{5}$ VT ratio is: $VTR := \dfrac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**Hydro Interconnected System (2010-08-13) V10.olr**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option.

Minimum fault current seen by each terminal (phase to phase, and SLG with 100 ohm fault resistance).

At BDE, with units 2, 4, 5, and 6 off line as under light load conditions, and both lines in service, for a fault at the remote terminal.

$ILLmin := 902$ A $ISLGminPH := 838$ A $ISLGmin0seq := 312$ A

The optimho current level detectors that block the distance comparators in the event of line opening are fixed at 5% of the rated current, or 0.25 A secondary, or 60 A primary. They will have no difficulty in operating for minimum fault levels. However, the ground distance elements are also supervised by a low set neutral current level detector (LDLSN that requires the neutral current to be greater than 10% of the maximum amplitude of phase difference current. This prevents the ground comparators from operating during close-in multiphase faults with CT errors. ASPEN OneLiner shows that for a bolted fault at the remote bus even under heavy load, there is sufficient neutral current (22% of maximum phase to phase fault current) that means this LDLSN function does not inhibit the ground distance comparator.

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind BDE $Z2minBDE := 0.627 + j \cdot 14.85$ ohms primary

Minimum um source impedance behind SSB $Z2minSSD := 4.025 + j \cdot 32.96$ ohms primary

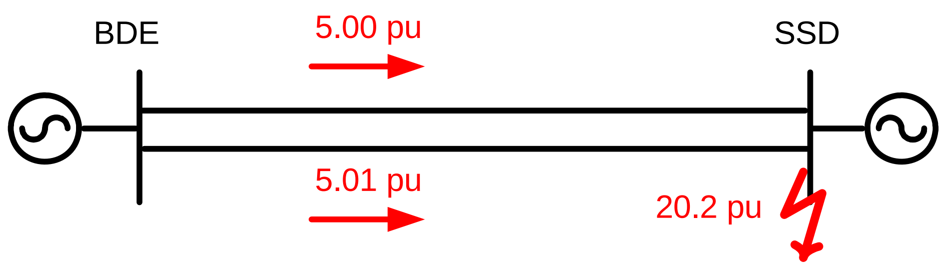


Figure 2 - 3 Phase Fault at SSD

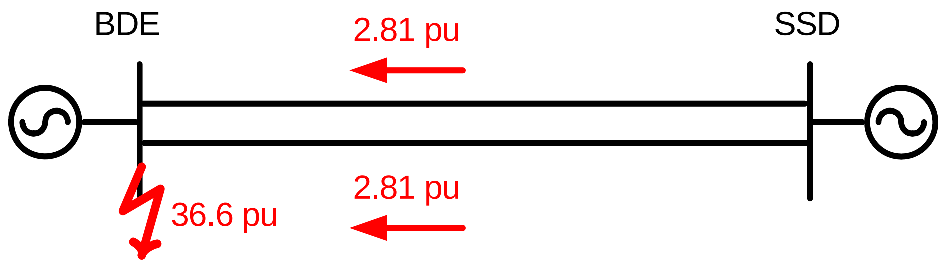


Figure 3 - 3 Phase Fault at BDE

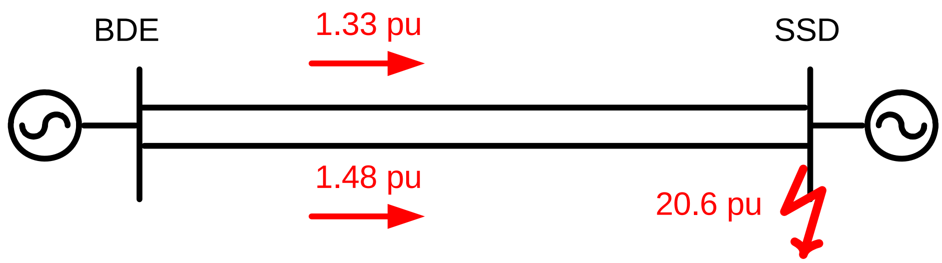


Figure 4 - SLG Fault at SSD (3I0 currents)

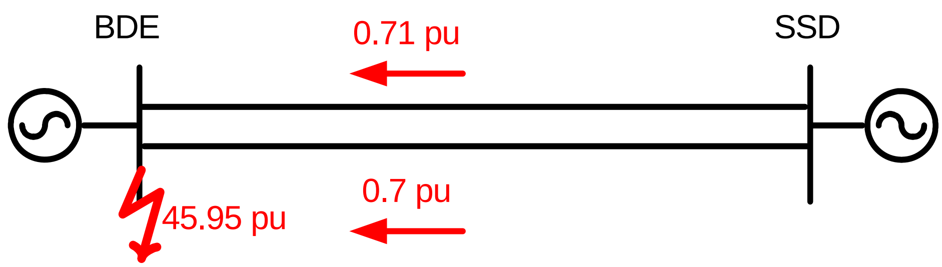


Figure 5 - SLG Fault at BDE (3I0 currents)

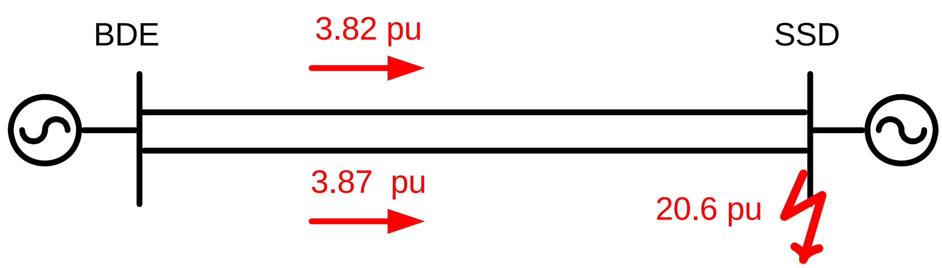


Figure 6 - SLG Fault at SSD (Phase currents)

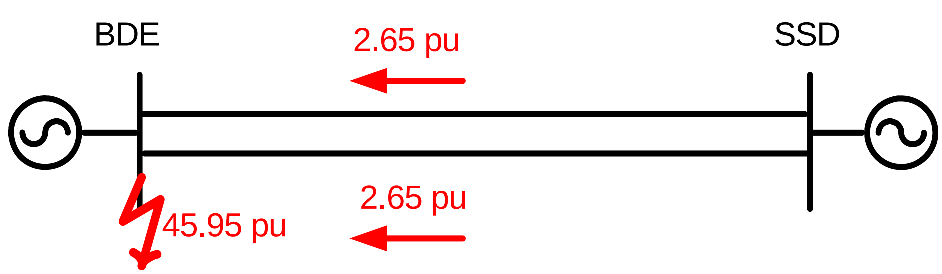


Figure 7 - SLG Fault at BDE (Phase currents)

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L202 := 0.01946 + j \cdot 0.13391$ $\quad$ $Z0L202 := 0.0665 + j \cdot 0.5024$

$Z1L206 := 0.01948 + j \cdot 0.13407$ $\quad$ $Z0L206 := 0.0668 + j \cdot 0.503$

In primary ohms

$Z1L202pri := Z1L202 \cdot Zbase$ $\quad$ $Z0L202pri := Z0L202 \cdot Zbase$

$Z1L206pri := Z1L206 \cdot Zbase$ $\quad$ $Z0L206pri := Z0L206 \cdot Zbase$

In secondary ohms

$$Z1L202sec := Z1L202pri \cdot \frac{CTR}{VTR} \qquad Z0L202sec := Z0L202pri \cdot \frac{CTR}{VTR}$$

$$Z1L206sec := Z1L206pri \cdot \frac{CTR}{VTR} \qquad Z0L206sec := Z0L206pri \cdot \frac{CTR}{VTR}$$

$|Z1L202sec| = 8.59$ $\quad$ $\arg(Z1L202sec) = 81.732 \cdot deg$

$|Z1L206sec| = 8.6$ $\quad$ $\arg(Z1L206sec) = 81.733 \cdot deg$

$|Z0L202sec| = 32.171$ $\quad$ $\arg(Z0L202sec) = 82.46 \cdot deg$

$|Z0L206sec| = 32.211$ $\quad$ $\arg(Z0L206sec) = 82.435 \cdot deg$

Zero sequence mutual coupling between the lines is $\quad$ $Z0m := 0.0466 + j \cdot 0.2347$

Use the average of these two values for line impedance for settings calculations for both lines

$$Z1Line := \frac{(Z1L202 + Z1L206)}{2} = 0.019 + 0.134j \text{ pu} \qquad Z0Line := \frac{Z0L202 + Z0L206}{2} = 0.067 + 0.503j \text{ pu}$$

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line \cdot Zbase$ $\quad$ $Z0Linephys := Z0Line \cdot Zbase$

$Z1Linephys = 10.3 + 70.9i$ $\quad$ ohms primary

$Z0Linephys = 35.3 + 265.9i$ $\quad$ ohms primary

Converting primary ohms to secondary ohms gives:

$$Z1Linesec := Z1Linephys \cdot \frac{CTR}{VTR} \qquad Z0Linesec := Z0Linephys \cdot \frac{CTR}{VTR}$$

$|Z1Linesec| = 8.6$ $\quad$ ohms sec $\quad$ $\arg(Z1Linesec) = 81.7 \cdot deg$

$|Z0Linesec| = 32.191$ $\quad$ ohms sec $\quad$ $\arg(Z0Linesec) = 82.4 \cdot deg$

Load Data

From 2010 System peak load case provided in start up information, the peak load is given as 185 MVA (with two lines in service). In the event of sudden loss of lone line, peak load will double until operators can adjust loads. Therefore it is assumed that peak load for a short duration is 370 MVA

$Speak := 185$ MVA $\quad Smax := 2 \cdot Speak = 370$ MVA

P1 Relay Settings

Distance element reach settings

Note that resistive reaches are forced to be the same for all zones. Reactive reaches for phase and ground distance elements must be the same as each other.

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the SSD Station bus under light load conditions withTL203 out of service and both TL202 and TL206 lines in service. From ASPEN OneLiner, voltage at SSD for a 3 phase fault at BDE is 0.35 per unit. So there is plenty of voltage at SSD during a fault at BDE, even under weak source conditions.

Since the voltage is higher than 20%, the line is not considered short, and a conventional Zone 1 setting is acceptable.

$Z1P := 0.85 \cdot |Z1Linesec| \quad Z1P = 7.3$ Ohms secondary

Existing setting of 7.28 ohms is OK, and could be retained if only the phase distance functions had to be considered. However, the ground distance reach in the optimho has to be set the same as the phase distance reach; so we need to consider the ground faults too.

$Z1P := 7.28$ For phase faults only.

The reach of the ground distance element will limit the reach of the zone 1 function. It can be seen from Figure 8 that the apparent impedance presented to the relay for a fault at the remote bus when the parallel line is out of service and grounded at both ends is significantly less than the line impedance.

$Zapp\_ext := 7.97$ ohms $\quad Zapp\_ang := 82.6deg$ This angle is close enough to the line angle to treat it as equal to the line angle.

$\frac{Zapp\_ext}{|Z1Linesec|} = 0.927$ The apparent impedance is reduced by about 7% due to the effect of the parallel line being out of service and grounded at both ends.

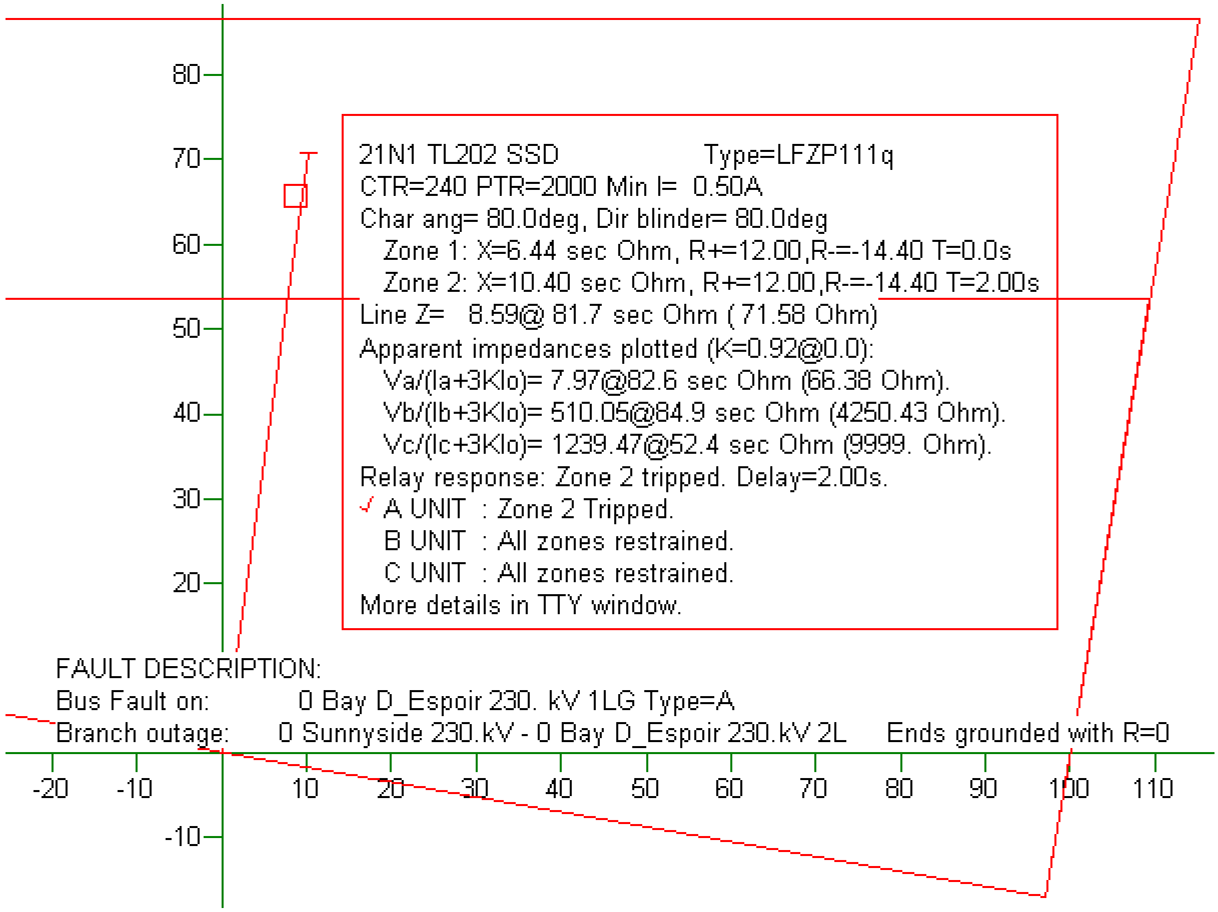


Figure 8 - Apparent impedance to a fault just beyond the remote terminal is reduced by 7% when parallel line is out of service and grounded at both ends.

The normal reach of the zone 1 should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. The existing setting of 75% of the line (applied due to uncertainty about the transient performance of the CVTs at SSD) will provide adequate security. No point in reducing the reach even further since the 75% reach was arbitrarily selected without knowledge of the transient performance of the CVTs.

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.75$ per unit

$Z1\_sec := m \cdot |Z1Linesec|$ $Z1\_sec = 6.45$ Ohms secondary

Retain the existing setting until the issue with the CVTs is resolved

$Z1\_sec := 6.44$ Ohms secondary

$Z1pri := Z1\_sec \cdot \frac{VTR}{CTR} = 53.667$ Ohms primary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is just less than 10.4 ohms secondary (about 122%). However, in order to reach a single line to ground fault at the remote terminal, it will be necessary to set the reach significantly further.

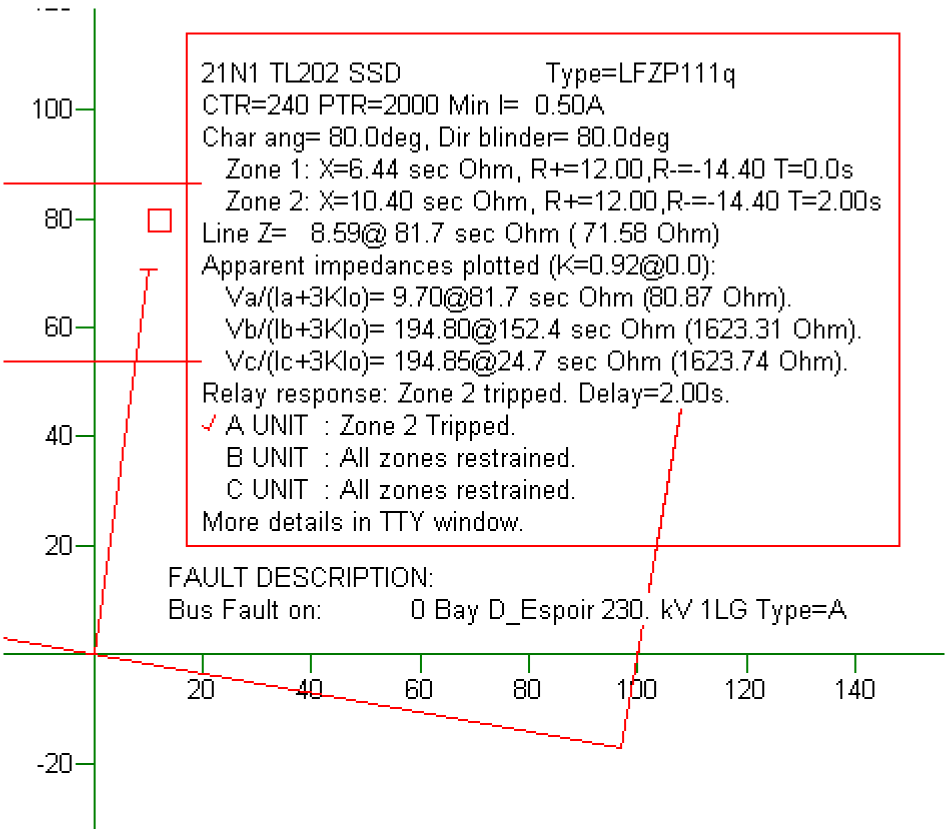


Figure 9 - Apparent impedance to a fault close to the remote terminal is increased by 15% when parallel line is in service.

As can be seen from Figure 9, the apparent impedance to a fault close to the remote terminal is increased when the parallel line is in service.

$Zapp\_int := 9.7$ Ohms secondary

$Z2\_sec := 1.25 \cdot Zapp\_int$ $\quad Z2\_sec = 12.1$ Ohms secondary $\quad \dfrac{Z2\_sec}{|Z1Linesec|} = 141.07 \cdot \%$

$Z2\_pri := Z2\_sec \cdot \dfrac{VTR}{CTR} = 101.042$ Ohms primary

The zone 2 timer will be enabled, and set as existing at 2 seconds (to coordinate with remote ground time overcurrent functions). This long delay is not necessary for the phase distance, but is for the ground distance to coordinate with remote ground time overcurrent relays. This element will not overreach the zone 1 function on the shortest line (TL234) out of BDE when infeed from BDE is taken into account.

Zone 3

The zone 3 function is not used since the POR1 scheme does not include an echo function so there is no need for any reverse blocking function. Since the Zone 2 timer has to be set with the coordination of the ground distance element in mind, it is set at 2 second; so there is no benefit in applying a longer reaching zone 3 function.

Zone 3 element is blocked - same as existing.

Load Encroachment logic

The optimho instruction manual recommends a margin of at least 10% between the impedance of the maximum load and the resistive reach of the quadrilateral distance element.

Check loadability of the Zone 2 phase distance element assuming worst case depressed voltage of a stressed system of 0.9 per unit.

$$Zloadmin := \frac{(0.9kVbase)^2}{Smax} \qquad Zloadmin = 115.808$$ Ohms primary (assume worst case at 30 degrees)

$$Zloadmin\_sec := Zloadmin \cdot \frac{CTR}{VTR} \qquad Zloadmin\_sec = 13.897$$

A 12 ohm secondary resistive reach is less than 90% of the load impedance at unity power factor and meets the Areva criterion. Note the Areva criterion does not include worst case power factor. However it is assumed that he security factors, like zero sequence current supervision provide increased security against misoperation on heavy load at poor power factor. Figure 10 shows the apparent impedance of the load at 0.9 per unit voltage, and the characteristics of the phase and ground distance elements. The small encroachment on the quadrilateral characteristic is considered acceptable. Figure 10 also shows that the load will not encroach on the phase distance mho characteristic.

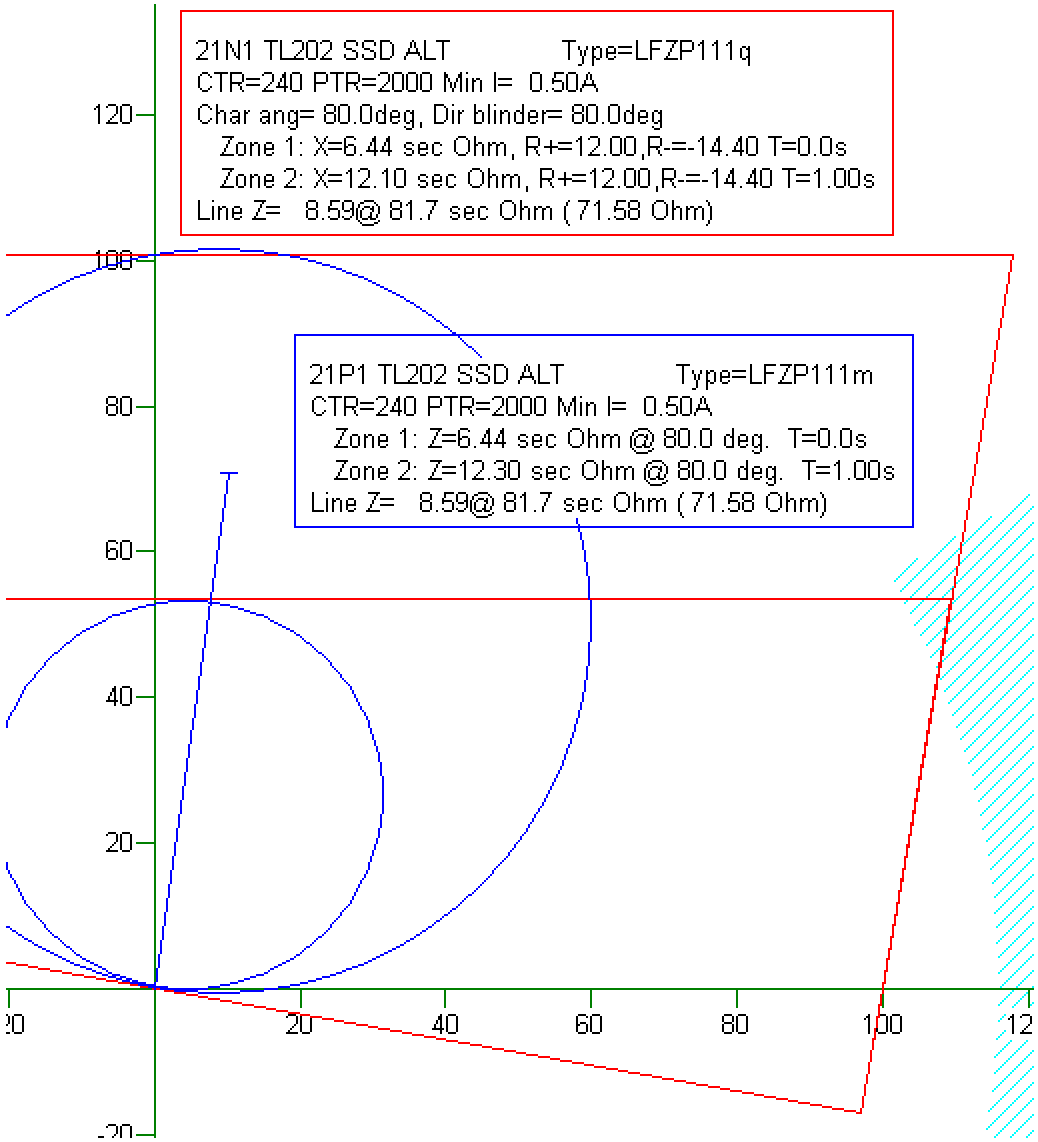


Figure 10 - Apparent impedance of load

Resistive reach of quadrilateral elements

Check the maximum fault resistance that can be sensed for a fault at a location where the current contribution from each terminal is roughly the same. From Figure 11, it can be seen that the limit of sensitivity is about 96 ohms, for a fault about 56% of the distance from BDE. This is close enough to the required sensitivity of 100 ohms.

Rquad := 12 Ohms secondary

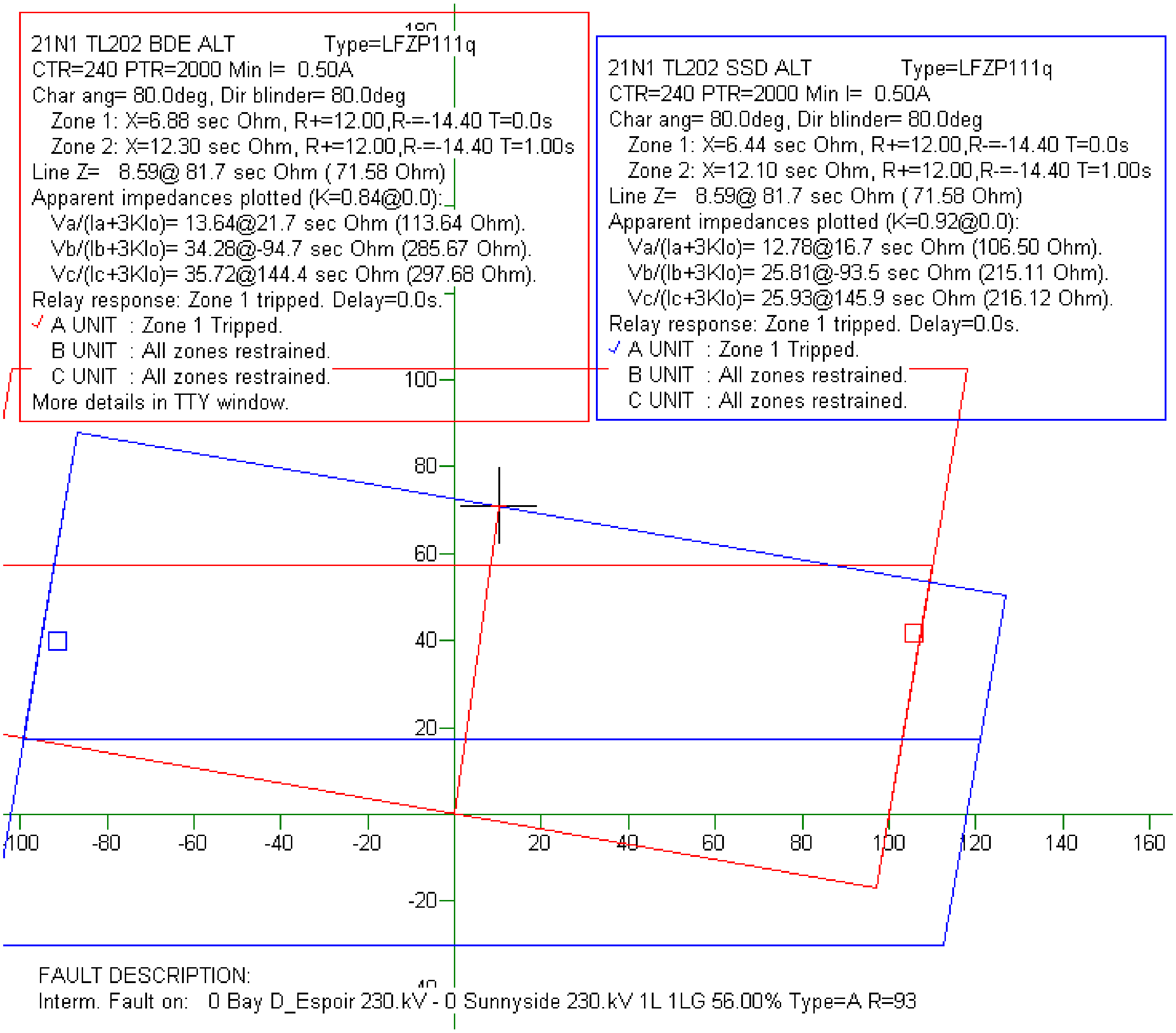


Figure 11 - Apparent impedance of a resistive fault near the mid point of the line.

Settings of K attenuators

KZPh Coarse setting common to all DISTANCE zones should be set as high as possible while below the required Zone 1 reach. The current level detectors vary inversely with KZph. Maximum setting available is 1.0

$KZPh := 1.0$

Zone 1 attenuators and angular selection

$In := 5$ $\quad Z1\_sec = 6.44$ This is the desired secondary reach (previously calculated)

$$KZ1 := \frac{Z1\_sec}{\left(KZPh\cdot\frac{5}{In}\right)} \qquad KZ1 = 6.44 \qquad Z1sec\_reach := KZ1\cdot KZPh\cdot\frac{5}{In} \qquad Z1sec\_reach = 6.44$$

$Z\theta PH := (\arg(Z1Linesec))$ $\quad Z\theta PH = 81.732\cdot deg$

Rounded to the nearest 5 degrees $\quad Z\theta PH := 80$ Degrees

$Z\theta N := \arg(Z0Linesec - Z1Linesec)$ $\quad Z\theta N = 82.708\cdot deg$

Rounded to the nearest 5 degrees $\quad Z\theta N := 80$ Degrees

Zone 2 attenuators selection

$Z2\_sec = 12.1$ This is the desired secondary reach (previously calculated)

$$KZ2 := \frac{Z2\_sec}{\left(KZPh\cdot\frac{5}{In}\right)} \qquad KZ2 = 12.1$$

Zone 3 is not used

QUAD Resistive Reach setting

$Rquad = 12$ This is the desired secondary reach (previously calculated)

$$KR := \frac{Rquad}{\left(\frac{5}{In}\right)} \qquad KR = 12$$

Residual Compensation attenuators selection

Zero sequence current compensation for ground faults is provided by the KZN factor. Zero sequence mutual compensation is not used in this application (it causes extra complexity for only moderate gain in setting accuracy).

$$KZN := \frac{Z0Linesec - Z1Linesec}{3\cdot Z1Linesec}\cdot KZPh \qquad KZN = 0.915 + 0.016j$$

$|KZN| = 0.915$ This the same as the existing setting

Switch On To Fault (SOTF) Protection.

If SOTF is enabled, it can be set to 200ms or 110 s after all poles of the line have been de-energized. The 110 s setting is intended to override automatic reclosing dead time. However it makes more sense to enable after the shorter time. Once the SOTF feature has been initiated, it remains in effect for 250ms after the line has been re-energized. The SOTF tripping options are:

a) Any distance comparator.
b) Any current level detector as long as a corresponding voltage level detector has not picked up within 20ms.
c) Either current or distance, as long as a corresponding voltage level detector has not picked up within 20ms.

SOTF := "Enabled"

SOTF_TIME := 0.20   Seconds

Elements_in_SOTF := "BOTH"   (Both Comparators and current level detectors).

Power Swing Detector

This element will not be used. It will be left Blocked, and if there is a power swing, the distance elements will trip naturally.

VT Supervision

Set the VT supervision to BLOCK TRIP

Set the VT fail detection to SELF RESET this is as existing on TL202, but different from the existing on TL206.

SELF_RESETTING := "ENABLED"

Start Indication

This function will bring up information on the LCD screen of the relay if a start event occurs. This function will not be used.

START_INDICATION := "BLOCKED"

Communications assisted logic.

The existing communications assisted logic is permissive overreaching transfer trip, scheme **POR 1**. This scheme is familiar to Newfoundland and Labrador Hydro, and even though the POR 2 scheme offers the advantage of weak infeed echo, which would help the sensitivity to resistive faults, it is not recommended to change the existing scheme logic at this stage with years of experience on a product that is nearing the end of its useful life.

The POR 1 logic is a basic permissive overreaching transfer trip scheme but it does include current reversal timers to increase security against misoperation due to current reversal when a fault on the parallel line is cleared sequentially. The current reversal logic is achieved by a timer TP which will block permissive tripping and keying of permissive trip if the local zone 2 element does not pick up within a reasonable time of receiving permissive trip. The block will be maintained for a time delay of TD after the local zone 2 element picks up, or the received permissive trip signal resets.

The application of the current reversal timers is required only if the settings of the zone 2 comparators are greater than 1.5 times the line impedance. Since the reaches of these elements are less than 1.5 times the line impedance, the current reversal logic is not required, and the recommended default settings are as existing>

$TP := 98$ ms

$TD := 0$ ms

Comparison of Existing (I/S) and Proposed alternative (ALT) settings.

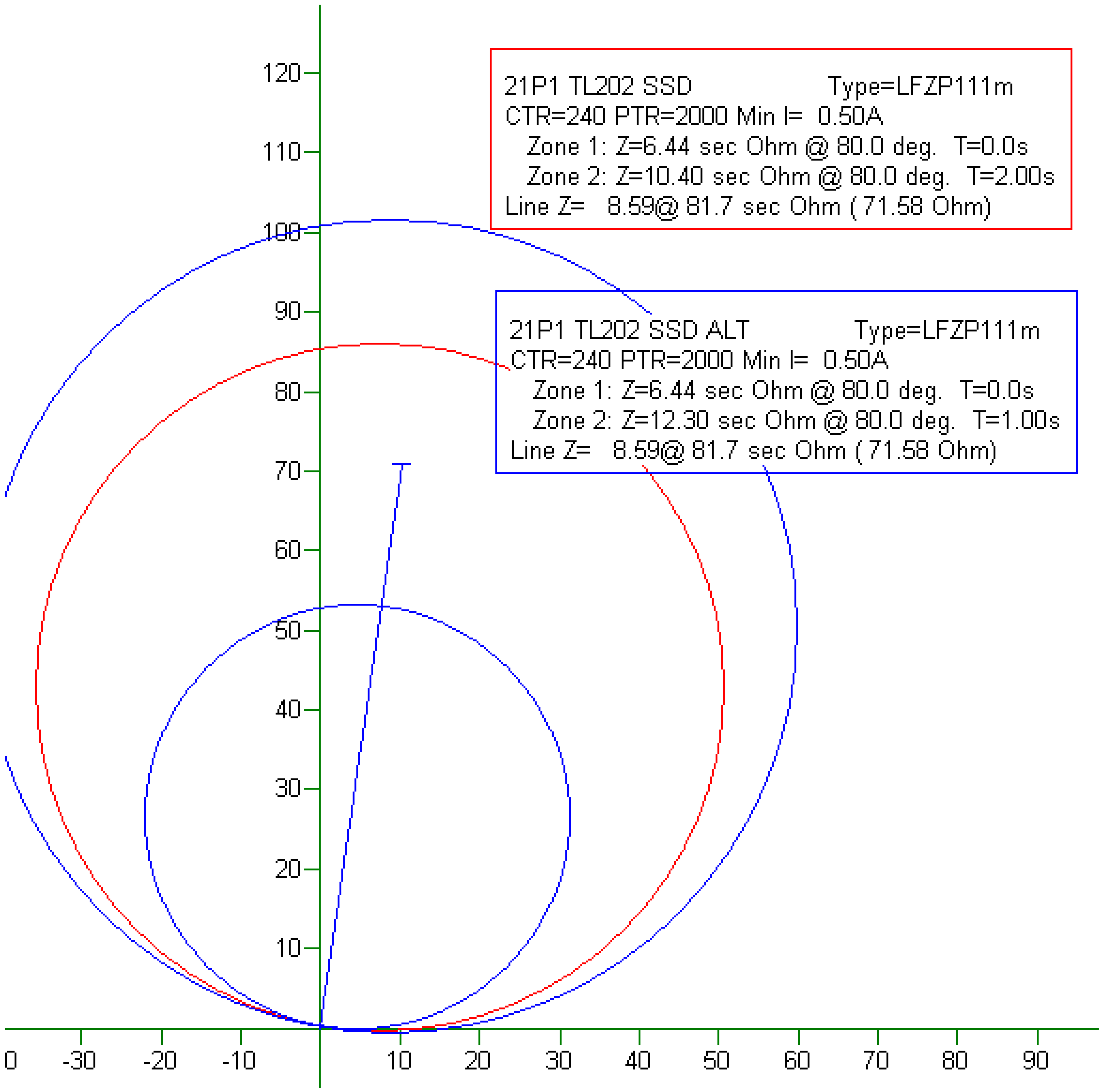


Figure 12 - Comparison of phase distance characteristics

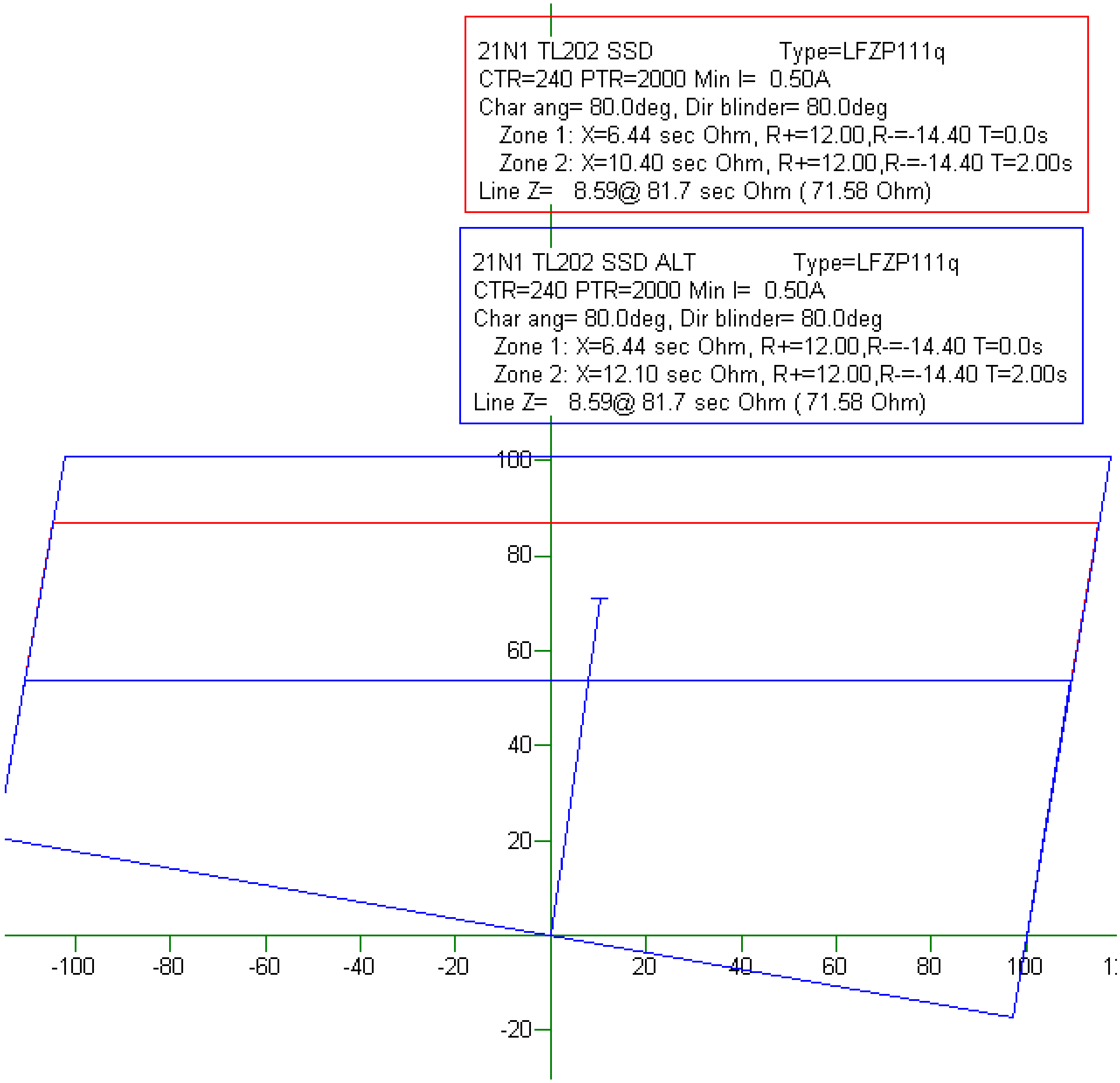


Figure 13 - Comparison of ground distance characteristics

Protection Review for Five 230 kV Transmission Lines

Appendix F
Detailed settings review for SSD TL202 and TL206 "P2" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P2 protection systems for the Sunnyside (SSD) terminals of circuits TL202 and TL206. These 230 kV transmission circuits are from Bay D'Espoir (BDE) to Sunnyside (SSD). The circuits run parallel to each other for most of their length. The circuit impedances are similar to each other, but not identical. However since the difference in impedance between the two circuits is less than 0.2%, the settings for both protection systems will be made identical to each other to reduce effort in testing.

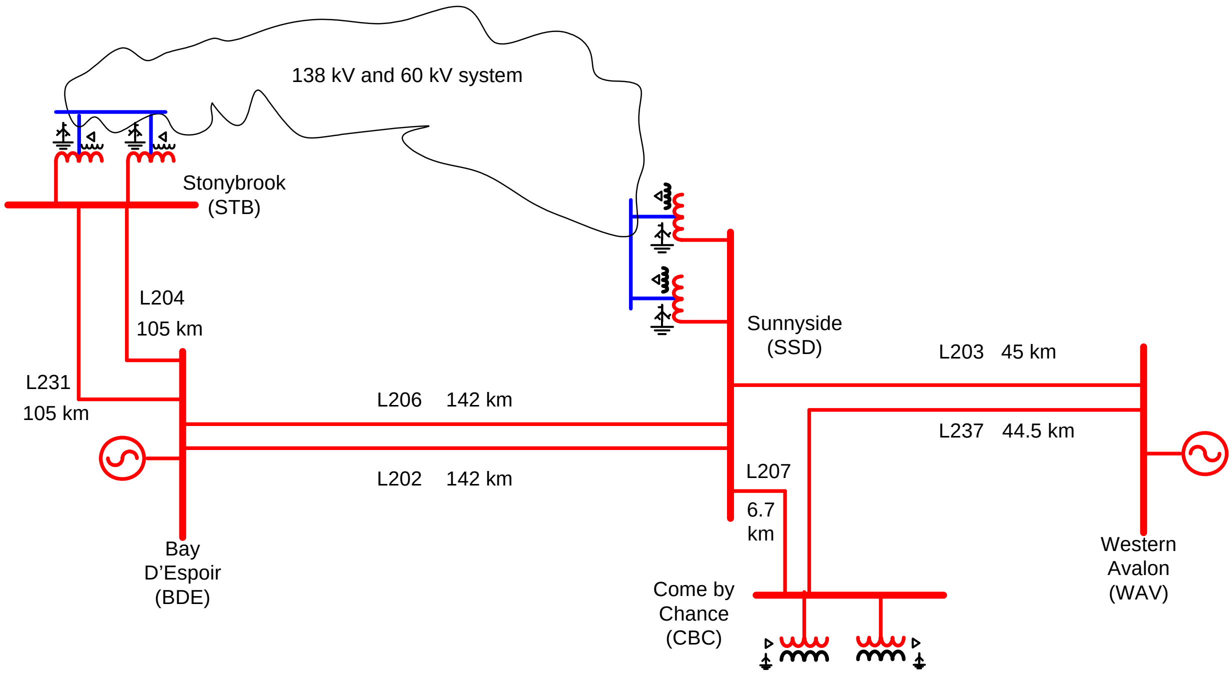


Figure 1 - System Single Line Diagram

Existing P2 protection systems are SEL321 systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $kVbase := 230$ $Ibase := \frac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $Zbase := \frac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $CTR := \frac{1200}{5}$ VT ratio is: $VTR := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**Hydro Interconnected System (2010-08-13) V10.olr**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with all shunts ignored (unless needed for load flow simulation).

Minimum fault current seen by each terminal (multiphase and SLG with 100 ohm fault resistance).

At SSD, with Circuit TL203 out of service, and TL206 in service, for a fault at the remote terminal.

$I3Pmin := 619$ $\quad ISLGminPH := 559$ A $\quad ISLGmin0seq := 165$ A

The current for a phase to phase fault would be lower, but the current supervision element of the SEL321 measures phase to phase currents, and the phase to phase current for a phase to phase fault is twice the phase current.

Calculate the minimum negative sequence source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum um source impedance behind SSB $\quad Z2minSSD := 4.025 + j \cdot 32.96$ ohms primary

Minimum source impedance behind BDE $\quad Z2minBDE := 0.627 + j \cdot 14.85$ ohms primary

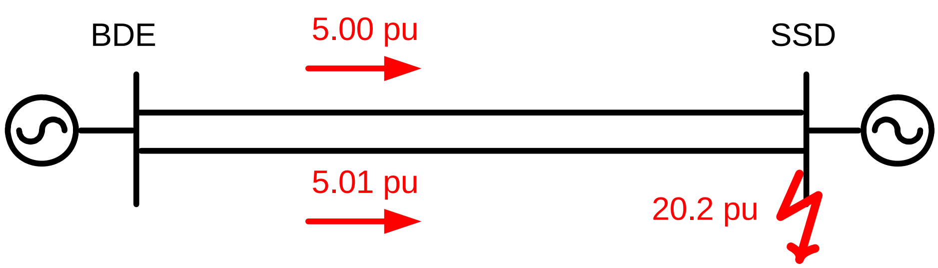


Figure 2 - 3 Phase Fault at SSD

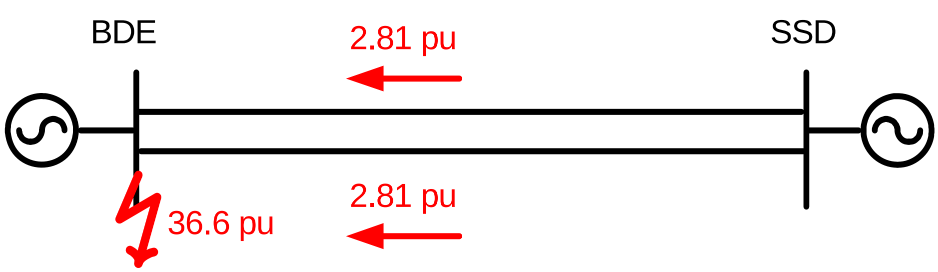


Figure 3 - 3 Phase Fault at BDE

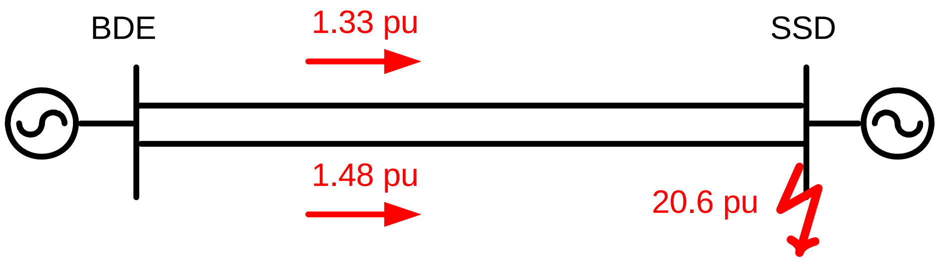


Figure 4 - SLG Fault at SSD (3I0 currents)

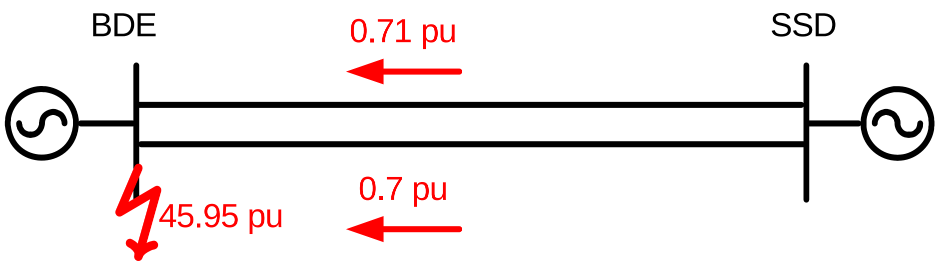


Figure 5 - SLG Fault at BDE (3I0 currents)

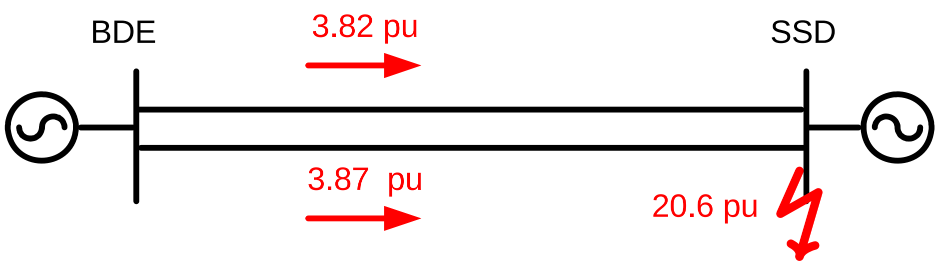


Figure 6 - SLG Fault at SSD (Phase currents)

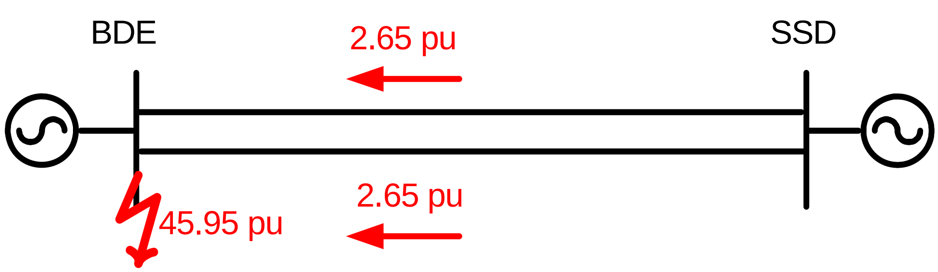


Figure 7 - SLG Fault at BDE (Phase currents)

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L202 := 0.01946 + j\cdot 0.13391$ $\quad$ $Z0L202 := 0.0665 + j\cdot 0.5024$

$Z1L206 := 0.01948 + j\cdot 0.13407$ $\quad$ $Z0L206 := 0.0668 + j\cdot 0.503$

In primary ohms

$Z1L202pri := Z1L202\cdot Zbase$ $\quad$ $Z0L202pri := Z0L202\cdot Zbase$

$Z1L206pri := Z1L206\cdot Zbase$ $\quad$ $Z0L206pri := Z0L206\cdot Zbase$

In secondary ohms

$$Z1L202sec := Z1L202pri\cdot\frac{CTR}{VTR} \qquad Z0L202sec := Z0L202pri\cdot\frac{CTR}{VTR}$$

$$Z1L206sec := Z1L206pri\cdot\frac{CTR}{VTR} \qquad Z0L206sec := Z0L206pri\cdot\frac{CTR}{VTR}$$

$|Z1L202sec| = 8.59$ $\quad$ $\arg(Z1L202sec) = 81.732\cdot deg$

$|Z1L206sec| = 8.6$ $\quad$ $\arg(Z1L206sec) = 81.733\cdot deg$

$|Z0L202sec| = 32.171$ $\quad$ $\arg(Z0L202sec) = 82.46\cdot deg$

$|Z0L206sec| = 32.211$ $\quad$ $\arg(Z0L206sec) = 82.435\cdot deg$

Zero sequence mutual coupling between the lines is $\quad Z0m := 0.0466 + j\cdot 0.2347$

Use the average of these two values for line impedance for settings calculations for both lines

$$Z1Line := \frac{(Z1L202 + Z1L206)}{2} = 0.019 + 0.134j\ pu \qquad Z0Line := \frac{Z0L202 + Z0L206}{2} = 0.067 + 0.503j\ pu$$

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line\cdot Zbase$ $\quad$ $Z0Linephys := Z0Line\cdot Zbase$

$Z1Linephys = 10.3 + 70.9i$ ohms primary

$Z0Linephys = 35.3 + 265.9i$ ohms primary

Converting primary ohms to secondary ohms gives:

$$Z1Linesec := Z1Linephys\cdot\frac{CTR}{VTR} \qquad Z0Linesec := Z0Linephys\cdot\frac{CTR}{VTR}$$

$|Z1Linesec| = 8.6$ ohms sec $\quad$ $\arg(Z1Linesec) = 81.7\cdot deg$

$|Z0Linesec| = 32.191$ ohms sec $\quad$ $\arg(Z0Linesec) = 82.4\cdot deg$

Load Data

From 2010 System peak load case provided in start up information, the peak load is given as 185 MVA (with two lines in service). In the event of sudden loss of lone line, peak load will double until operators can adjust loads. Therefore it is assumed that peak load for a short duration is 370 MVA

$\text{Speak} := 185$ MVA $\quad\quad$ $\text{Smax} := 2 \cdot \text{Speak} = 370$ MVA

P2 Relay Settings

It was considered whether to make the line lengths and impedances individual for each line. However the differences in line lengths is only 170 metres, which is only 0.1%. The accuracy of fault location will not be better than 1% so there is no point in being accurate in distinguishing between the impedances of the lines between TL202 and TL206

$\text{Z1MAG} := |\text{Z1Linesec}|$ $\quad$ $\text{Z1MAG} = 8.6$ $\quad$ $\text{Z1ANG} := \dfrac{\arg(\text{Z1Linesec})}{\text{deg}}$ $\quad$ $\text{Z1ANG} = 81.7$

$\text{Z0MAG} := |\text{Z0Linesec}|$ $\quad$ $\text{Z0MAG} = 32.2$ $\quad$ $\text{Z0ANG} := \dfrac{\arg(\text{Z0Linesec})}{\text{deg}}$ $\quad$ $\text{Z0ANG} = 82.4$

$\text{LL202} := 141.76$ $\quad$ $\text{LL206} := 141.93$ $\quad$ $\text{LL} := \dfrac{\text{LL202} + \text{LL206}}{2} = 141.8$

In order to obtain sensitivity to 100 ohm single line to ground faults, the echo function will be needed. Enable two forward and one reverse zone.

$\text{PMHOZ} := 3$ $\quad$ $\text{GMHOZ} := 3$ $\quad$ $\text{QUADZ} := 3$

$\text{DIR1} := \text{F}$ $\quad$ $\text{DIR2} := \text{F}$ $\quad$ $\text{DIR3} := \text{R}$

Mho phase distance functions

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the SSD Station bus under weak source conditions with TL203 out of service and both TL202 and TL206 lines in service. From ASPEN OneLiner, voltage at BDE for a 3 phase fault at SSD is 0.33 per unit. So there is plenty of voltage at BDE during a fault at SSD, even under weak source conditions.

Since the voltage is higher than 20%, the line is not considered short, and a conventional Zone 1 setting would normally be acceptable. However the CVTs at SSD are suspected of significant transient errors; so in 2003 the reach of the zone 1 elements were reduced to 75% of the line impedance. These reaches will be retained until the problem with the CVTs is resolved.

$\text{Z1P} := 0.75 \cdot |\text{Z1Linesec}|$ $\quad$ $\text{Z1P} = 6.45$ Ohms secondary

Say $\quad$ $\text{Z1P} := 6.44$ $\quad$ Which is the existing setting that wil lbe retained.

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 10.2 ohms secondary (about 122%) and is a little low, and will be increased.

$Z2P := 1.3 \cdot |Z1Linesec|$ $Z2P = 11.2$ Ohms secondary

As can be seen from Figure 8, this element (with the proposed new setting) slightly overreaches the zone 1 element at the BDE terminal of TL234 without infeed. However, when the effects of infeed at BDE are considered, the Zone 2 at SSD will reach no more than 10% along TL234. Therefore there is no danger of the SSD Zone 2 element overreaching the BDE TL234 Zone 1 element.

The existing Zone 2 timer setting of 18 cycles will be appropriate.

$Z2PD := 18$ cycles

Zone 3

Set Zone 3 reverse element to reach further behind this terminal than the remote Zone 2. This function adds security for external faults. The element should always be more sensitive than the forward looking Zone 2 at the remote terminal. Set it the same as the remote Zone 2 overreach plus 20%

$Z3P := Z1MAG \cdot \left(\frac{Z2P}{Z1MAG} - 1 + .2\right)$ $Z3P = 4.3$ Ohms secondary

$\frac{Z3P}{|Z1MAG|} = 50 \cdot \%$ of line length

This is a little higher than the existing setting, but provides additional security.

The reverse looking zone 3 element need not be set to trip through a timer. It is needed only for security in the POTT scheme.

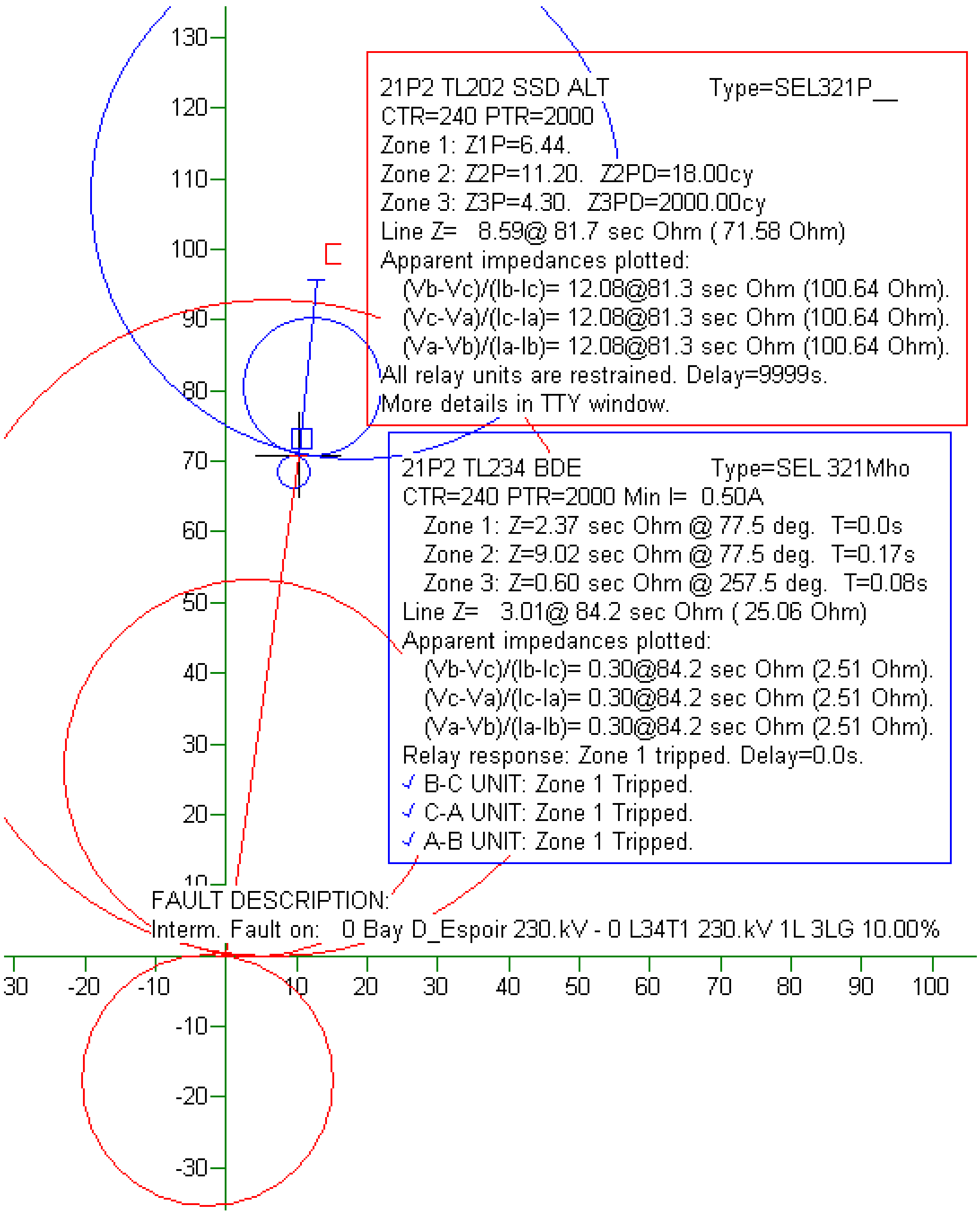


Figure 8 - Proposed new SSD TL202 Zone 2 reaches less than 10% of the distance along TL234 (shortest line out of BDE) with infeed, and coordinates with zone 1 on this line.

Mho phase distance current supervision

If the current supervision elements can be set above load, they will be secure in the event that potential is lost. However given that loss of potential logic is available, it is recommended that only the zone 1 current supervision function be set above load. If potential is lost, it will be able to block tripping by Zone 2 before it trips on time delay or receives a permissive trip from the remote terminal.

For the point of view of current supervision being above maximum load, there is no need to worry about abnormal conditions. It would be a double contingency for the VT signal to be lost while the parallel line was out of service. Therefore, consider a maximum load of 135 MVA. The current supervision elements for the phase distance functions measure phase to phase currents.

$IPPmax\_normal := \frac{Speak \cdot 1000}{kVbase}$ $\quad IPPmax\_normal = 804$ A primary

The current supervision elements use phase to phase currents for supervision of the phase distance function;. so the minimum phase to phase fault current will be root three times the minim phase fault current. Choose a margin of 50% of the minimum phase to phase fault current for dependability.

$IPPmin := 0.5I3Pmin \cdot \sqrt{3}$ $\quad IPPmin = 536$ A primary

A setting of 528 A primary for 50PP1 will ensure the Zone 1 function operates for any fault even under minimum source conditions but will be susceptible to trip on load due to loss of potential under normal maximum load conditions. This is somewhat higher than the existing setting, and adds a little more security.

$'50PP1 := 2.2$ A Sec $\quad '50PP1 \cdot CTR = 528$ A primary

Since Zone 2 and zone 3 elements will be blocked by LOP function, set them at minimum. This is lower than the existing zone 2 and zone 3 settings. The zone 3 current supervision should not be set higher than the zone 2 current supervision element at the remote terminal. In this case the remote zone 2 current supervision element will be set at 1.0 A secondary.

$'50PP2 := 1$ A Sec $\quad '50PP3 := 1$ A Sec

Ground Distance Protection

The reach of the ground distance functions will be affected by mutual coupling to the parallel line. These functions will tend to underreach the remote bus while the parallel line is in service, and overreach the remote bus if the parallel line is out of service and grounded at both ends. Figure 9 shows that for a remote bus fault, with the parallel line out of service and grounded, the apparent impedance of the line is reduced to about 7.96 ohms secondary instead of the nominal 8.59 ohms. This is 93% of the actual line impedance.

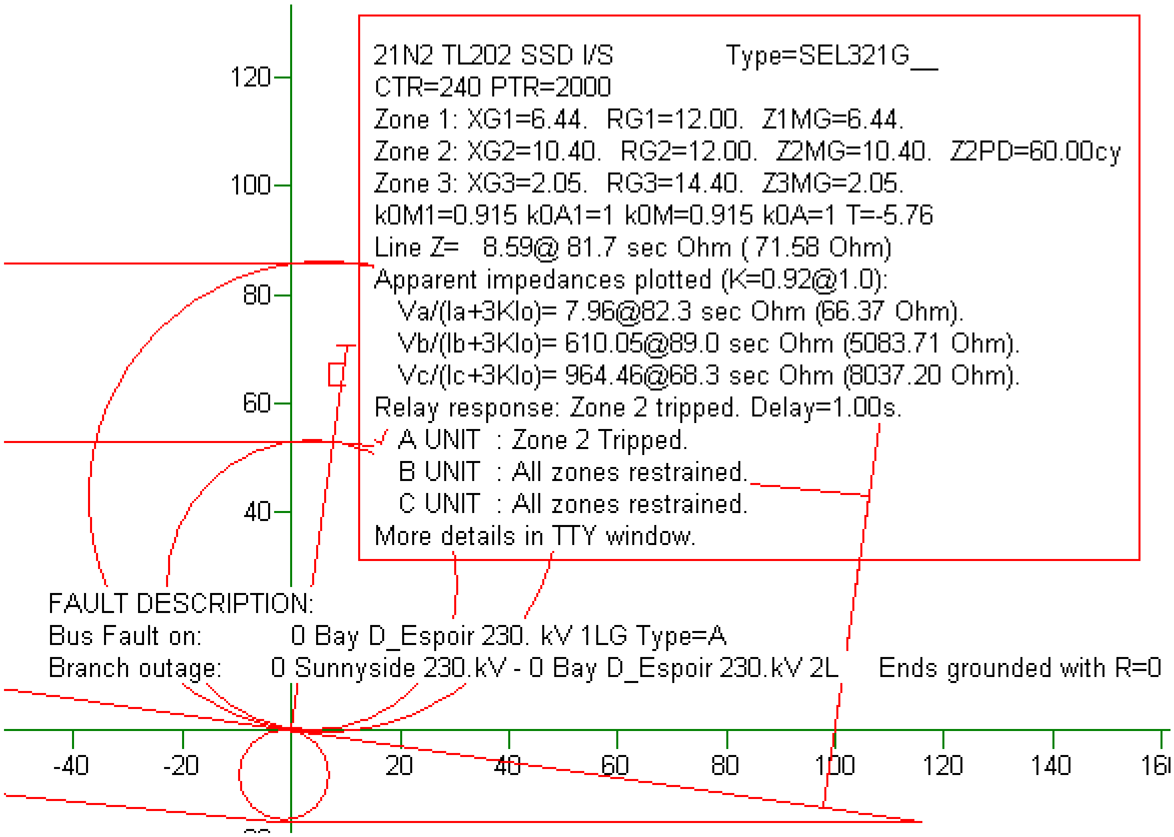


Figure 9 - Apparent impedance to a fault just beyond the remote terminal is reduced by 7% when parallel line is out of service and grounded at both ends. Existing relay settings modeled in this figure.

The normal reach of the zone 1 should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Choose a setting of 75% of the line impedance same as the phase distance element, which is same as the existing setting which is applied because of suspected improper transient performance of the CVTs.

$m := 0.75$

$Z1MG := Z1P$ $\qquad Z1MG = 6.44$

$XG1 := Z1MG$ $\qquad XG1 = 6.44$

Zone 1 Resistance

The resistive reach of the Zone 1 quad should provide enough sensitivity to trip the local terminal immediately without waiting for permission from the remote terminal for a severe fault that depresses the voltage significantly. Further, it should not allow the function to reach beyond the remote terminal due to errors in relay measurement or CT or VT. If possible, it should also operate for a 100 ohm SLG 25% of the distance from the local terminal. Operation for a 100 ohm resistive fault at the 25% location will ensure this function can trip for a close in fault without assistance from the remote terminal. The remote terminal zone 1 function will be set to operate sequentially for this fault.

By simulating a fault with 100 ohms fault resistance at the 25% of the distance from SSD, with the SSD terminal weak (as in the contingency of TL203 out of service) it is found that a reach of 20 ohms secondary is required to sense this fault. See Figure 10.

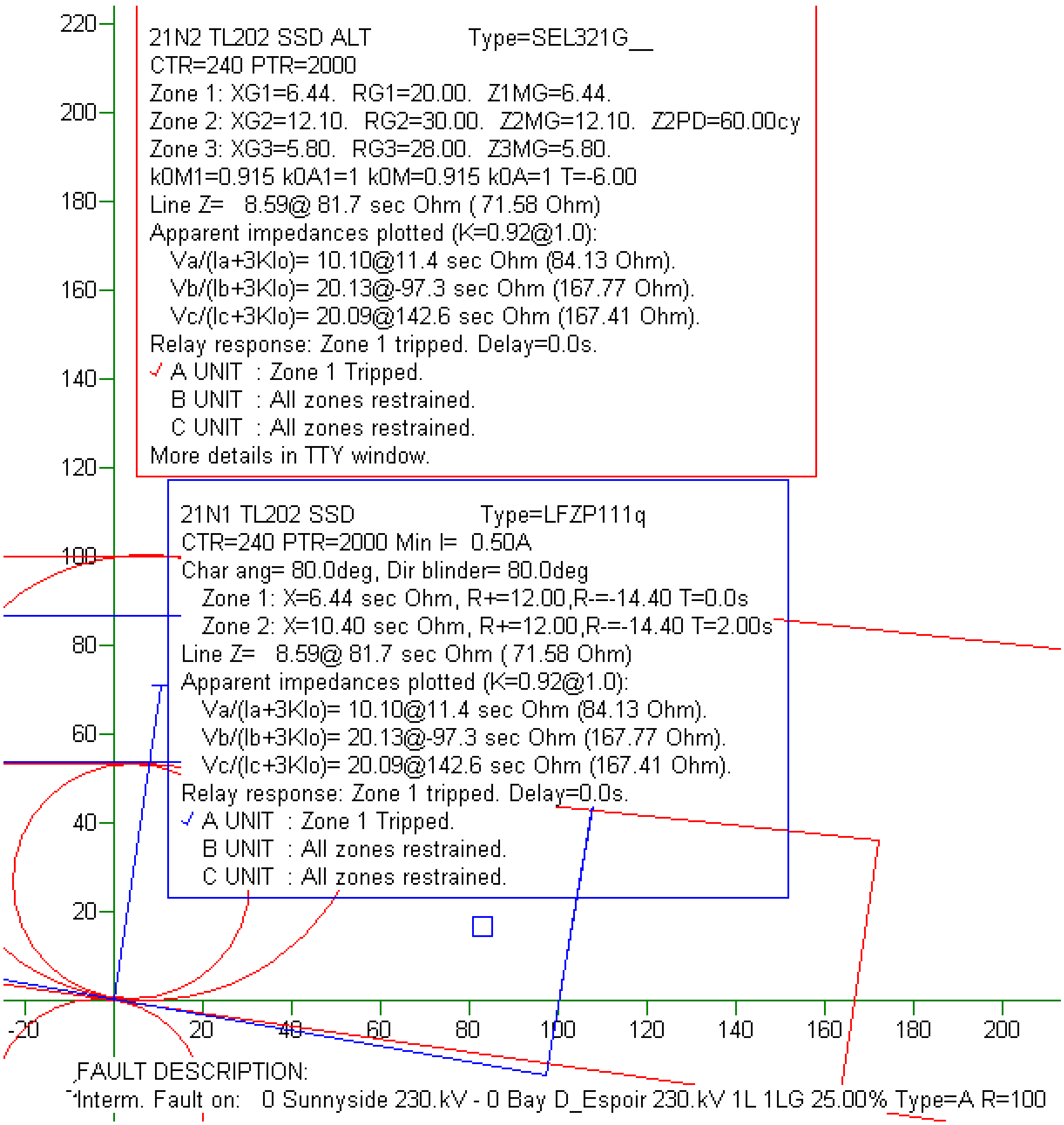


Figure 10 - SSD Zone 1 function operates for a 100 ohm SLG fault at 25% from the local terminal.

The existing 12 ohm secondary resistive reach of the zone 1 element will not sense this fault, and should be increased to 20 ohms secondary. Check whether this reach will be secure, considering possible CT and VT errors.

XG1 is set at m per unit of the transmission line. The imaginary component of the line is

$ImXG1sec := Im(Z1Linesec)$ $\quad ImXG1sec = 8.506$ ohms

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$RG1 := round[(1 - m)\cdot 20\cdot ImXG1sec, 2]$

$RG1 = 42.53$ This is the maximum secure setting for the resistive reach and is above the proposed zone 1 resistive reach setting..

Use the proposed setting of 20 ohms for RG1 $\quad RG1 := 20$ ohms secondary

With a resistive reach setting of 20 ohms, the SSD Zone 1 quad element will see an 70 ohm resistive SLG fault at 50% of the distance from SSD. Zone 2 protection will be depended upon to sense faults with resistance up to 100 ohms.

Zone 2 Ground Distance Protection

The Zone 2 ground distance function will need to be set longer than the Zone 2 phase distance protection function because it will tend to underreach the remote terminal while the parallel line is in service. By simulation in ASPEN OneLiner it is found that the apparent impedance to a zero ohm fault close in to the remote terminal is 9.7 ohms secondary, or 12% more than the actual line impedance. The reach of the Zone 2 ground distance element should be set at least to 1.25 times the apparent impedance.

$ZSLG\_remote := 9.7$

$Z2MG := round(1.25\cdot ZSLG\_remote, 1)$ $\quad Z2MG = 12.1$ Ohms secondary

The quad element reactive reach will be set similarly to the mho.

$XG2 := Z2MG$ $\quad XG2 = 12.1$ Ohms secondary

The resistive reach of the quad element is limited by the amount of negative sequence current that the SSD terminal will contribute to a resistive SLG near the BDE terminal. By trial and error it is found that the Zone 2 ground distance element cannot be set to sea a fault with 100 ohm ground fault resistance greater than 65% of the distance from SSD. Thus the negative sequence current forms a limit to the sensitivity to resistive faults. The resistive reach will be set to see a 100 ohm SLG fault 65% of the distance from SSD.

By trial and error from ASPEN it is found that a resistive reach of 30 ohms secondary will sense a 100 ohm SLG fault at a location 55% of the distance from BDE. See Figure 11. This will give positive overlap with the zone 2 element at the remote terminal. However since it will not overlap the Zone 1 element at the remote terminal, the permissive trip echo function will be required to ensure that a fault that is seen by the zone 2 element at only one terminal will still be cleared by the permissive trip logic.

Therefore, to avoid extremely large resistive reaches, and to retain sensitivity to 100 ohm resistive SLG faults, it is recommended that the echo function be enabled at both terminals.

R2G := 30   Ohms secondary

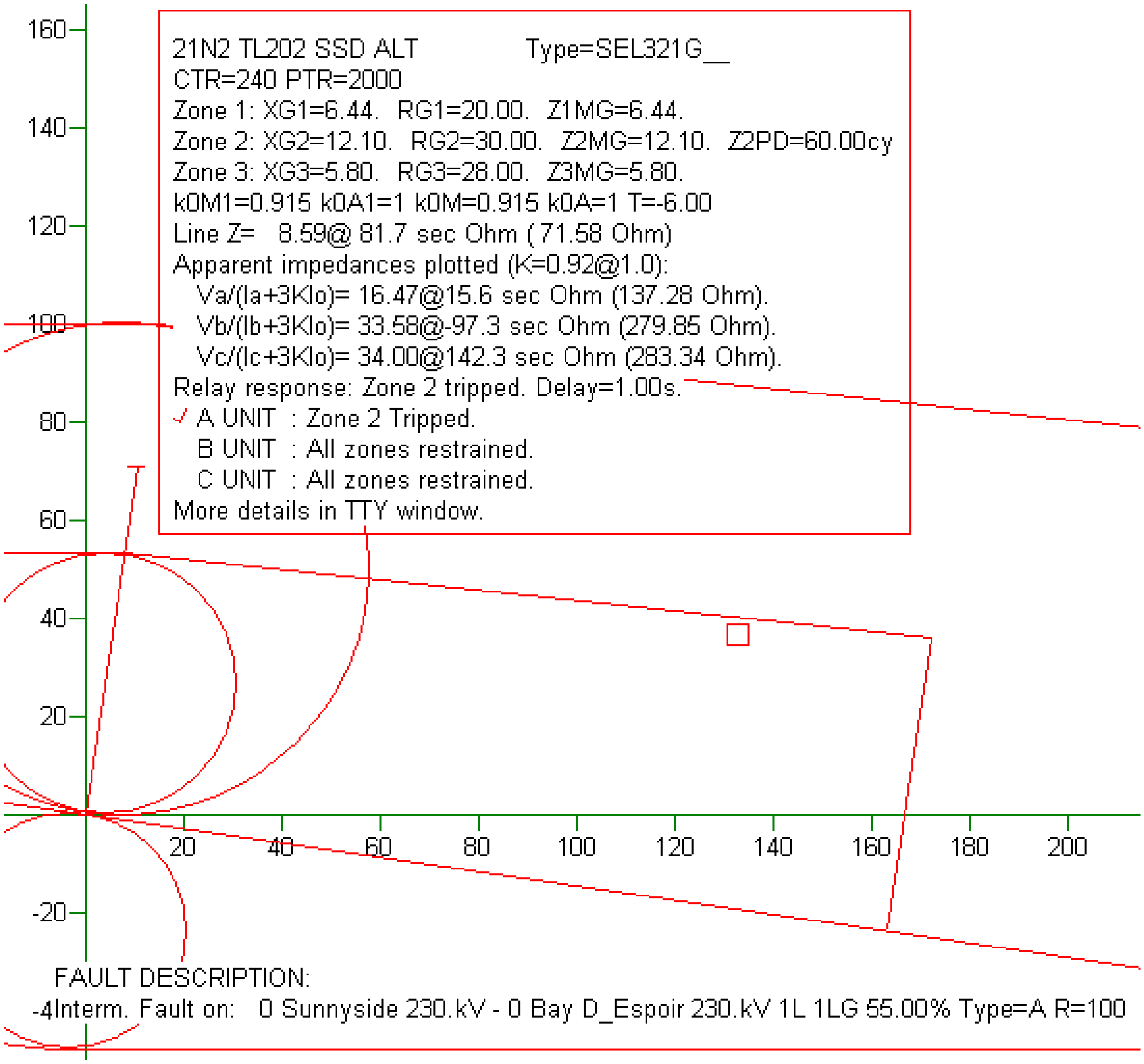


Figure 11 - Zone 2 Quad element operates for 100 ohm resistive SLG just past the mid line location.

Check that this resistive reach won't cause the zone 2 function to trip while the parallel line is open single phase, with heavy power flow. See Figure 12.

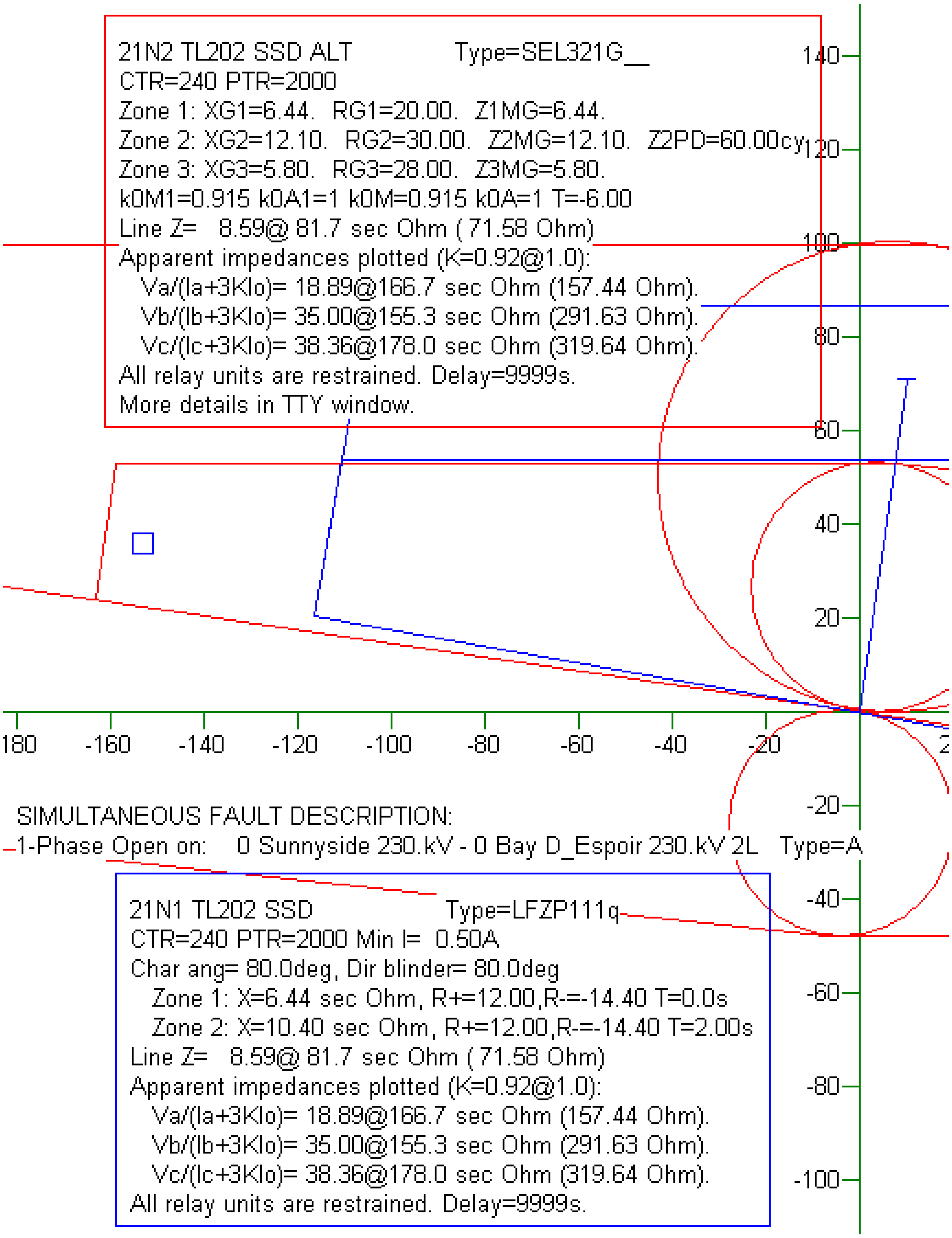


Figure 12- Quad elements are secure with heavy load flow (185 MVA in each line) while parallel line is open single pole.

The zone 3 ground mho function will be set using the same principles as the zone 3 phase distance function.

$Z2MGrem := 12.7$ ohms secondary

$Z3MG := Z1MAG\cdot\left(\frac{Z2MGrem}{Z1MAG} - 1 + .2\right)$ $Z3MG = 5.8$ Ohms secondary

$\frac{Z3P}{|Z1MAG|} = 50 \cdot \%$ of line length — This is a little higher than the existing setting, but provides additional security.

$XG3 := Z3MG$ $XG3 = 5.8$ Ohms secondary

Set the Zone 3 quad resistive reach at 15% more than the remote Zone 2

$RG2rem := 24$ Ohms secondary

$RG3 := \text{round}(RG2rem \cdot 1.1, 0)$ $RG3 = 26$ Ohms secondary

Ground distance current supervision

Since there is no concern about these elements operating on load, even with loss of potential, set all current supervision elements at minimum, for maximum sensitivity of the distance elements.

'50L1 := 0.5 A Sec   '50L2 := 0.5 A Sec   '50L3 := 0.5 A Sec

'50G1 := 0.5 A Sec   '50G2 := 0.5 A Sec   '50G3 := 0.5 A Sec

Note that due to heavy infeed of zero sequence currents from the local terminal for close-in faults, the ground overcurrent detectors will not operate for faults with more than a small amount of resistance close to the remote terminal. Therefore, we will have to rely on sequential clearing for that type of fault. However setting the current supervision at minimum allows maximum sensitivity.

Zero sequence current compensation

The zero sequence current compensation could be adjusted to compensate for the significant amount of mutual coupling. However as discussed in the settings of reaches of the ground distance elements we will accept underreach of the Zone 2 function for the normal case. Set the zero sequence current compensation as usual.

$$k01M := \left(\left| \left| \frac{Z0Line - Z1Line}{3 \cdot Z1Line} \right| \right| \right) \qquad k01M = 0.915 \qquad \left| \frac{Z0Line - Z1Line}{3 \cdot Z1Line} \right| = 0.915$$

$$k01A := \left(\arg\left(\frac{Z0Line - Z1Line}{3 \cdot Z1Line} \right) \right) \qquad k01A = 0.976 \cdot deg$$

Say $k01A := 1deg$

Set the overreaching zones the same as zone 1 $k0M := k01M$ $k0A := k01A$

$k0M = 0.915$ $k0A = 1 \cdot deg$

Non Homogenous Angle Setting

Compare the angle of the total zero sequence current at the remote bus with the angle of the zero sequence current contribution from the local terminal to determine this setting. From ASPEN OneLiner, the worst case is normal conditions. For this case, for an SLG at SSD the angle of I0 at the fault is -118 degrees and the angle of I0 out of the SSD terminal is -112 degrees. Therefore, the total fault current leads the current contribution from BDE by 6 degrees and angle T must be set negative by the difference to ensure no overreach.

$T := -6$ degrees

Out of step blocking and tripping

Not used in this application. There is a danger of out of step conditions arising. Historically no action has been taken to provide special tripping or blocking functions. Natural tripping during swings is accepted.

Load Encroachment logic

Check loadability of the Zone 2 phase distance element assuming worst case power factor of 0.87 simultaneous with worst case depressed voltage of a stressed system of 0.85 per unit. Note that units of kV squared match units of MVA. Note that quadrilateral elements are only used for the ground distance functions that are not sensitive to balanced three phase load. Therefore no need to worry about the reach of the quadrilateral elements.

$$\text{Zloadmin} := \frac{(0.85\text{kVbase})^2}{\text{Smax}} \qquad \text{Zloadmin} = 103.298$$ Ohms primary (assume worst case at 30 degrees)

Maximum reach of the Zone 2 element is at the line angle of 81 degrees. At 30 degrees, the reach will be given by

$$\text{Z2load} := \text{Z2P}\cdot\cos[(\text{Z1ANG} - 30)\text{deg}] \qquad \text{Z2load} = 6.92$$ ohms secondary

$$\text{Z2load}\cdot\frac{\text{VTR}}{\text{CTR}} = 57.668$$ ohms primary

Since the reach of the Zone 2 element at 30 degrees is less than the apparent impedance of the maximum load, there is no need to apply load blinding logic. See Figure 13

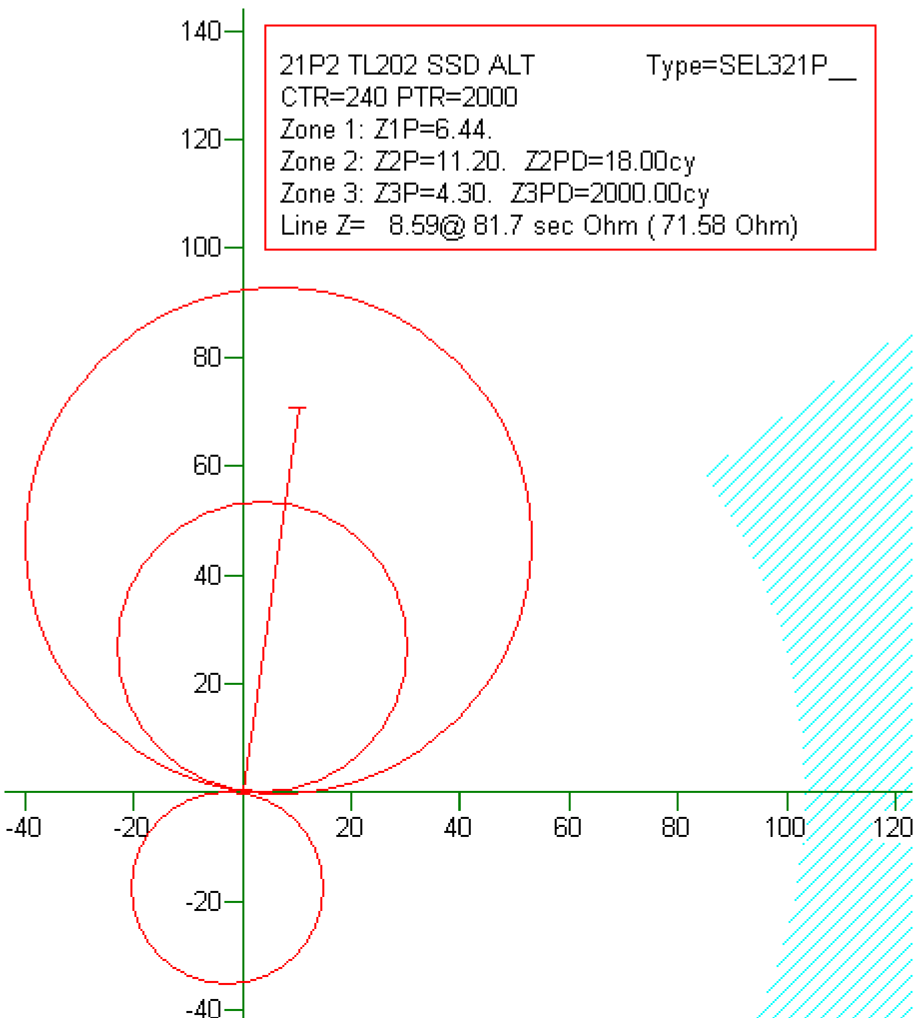


Figure 13 -Load impedance with respect to proposed new Mho function reaches.

Ground directional element

The SEL-321 application example recommends finding the minimum source impedance behind the terminal and setting the reverse and forward boundaries of the negative sequence directional element at the 1/3 and 2/3 points respectively.

In the negative sequence plane, the sum of the two source impedances and the line impedance is:

$$Z2total := Z2minSSD + Z1Linephys + Z2minBDE$$

The 1/3 point is $Z2\_1\_3 := \frac{Z2total}{3}$ The 2/3 point is $Z2\_2\_3 := \frac{2Z2total}{3}$

$Z2Rpri := Z2\_2\_3 - Z2minSSD$ $|Z2Rpri| = 46.548$

$Z2Fpri := Z2\_1\_3 - Z2minSSD$ $|Z2Fpri| = 6.673$

Converting the primary impedances to secondary ohms

$Z2R := Z2Rpri \cdot \frac{CTR}{VTR}$ $|Z2R| = 5.586$ Ohms secondary $\arg(Z2R) = 82.665 \cdot deg$

$Z2F := Z2Fpri \cdot \frac{CTR}{VTR}$ $|Z2F| = 0.801$ Ohms secondary $\arg(Z2F) = 81.738 \cdot deg$

Rounding up Z2F and rounding down Z2R gives:

$Z2F := 1$ Ohms secondary $Z2R := 5$ Ohms secondary

The proposed settings are not very different from the existing settings.

Set the current level detectors at minimum level that will allow operation of the ground distance elements.

Due to the very small zero sequence current contribution to a single line to ground fault at the remote terminal, the negative sequence current contribution will always be higher than the zero sequence. Therefore there is no point in setting the forward looking negative sequence overcurrent elements any more sensitively than the zero sequence ground overcurrent supervision of the ground distance elements.

$'50QF := '50G2$ $'50QF = 0.5$ A secondary

Set the supervision function for the reverse looking element to be the same as, or a little more sensitive than the forward looking supervision element at the remote terminal.

$'50QR := 0.5$ A secondary

The positive sequence current restraint (a2) factor should be set just smaller than the ratio of the maximum load current (positive sequence) to the most sensitive current supervision element (50QR).

$I1maxpri := \frac{Smax \cdot 1000}{kVbase \cdot \sqrt{3}}$ $I1maxsec := \frac{I1maxpri}{CTR}$ $I1maxsec = 3.87$

Bearing in mind that the 50QR setting is in units of 3*I2

$\frac{'50QR}{3 \cdot I1maxsec} = 0.043$ Choose a value of $a2 := 0.04$

Phase time overcurrent element

This element is not used

Residual time overcurrent element

This element is used to provide the most sensitive backup protection. It will be non directional element.

Set pickup to sense a higher resistance than 100 ohm SLG in the middle of the line with equal zero sequence current infeed from both ends. Choose a resistance of 200 ohms arbitrarily. Use a safety factor of 2 so that operating time is not infinity at this fault level.

$SF := 2$ Desensitization factor due to remote end infeed is $Dfactor := 2$ $Rf := 200$

$$'51NPU := round\left(\frac{kVbase \cdot 1000}{\sqrt{3} \cdot SF \cdot Dfactor \cdot Rf \cdot CTR}, 1\right) \qquad '51NPU = 0.7$$

The existing setting of 0.5 A is more sensitive than required to sense this mid line fault with arbitrary resistance. Since experience with the high resistance tree fault on 28th August 2009 has shown value in the existing setting, it will be retained.

$'51NPU := 0.5$ A secondary

Coordination checks show that existing time dial settings will coordinate with each other. See Figures 14 and 15

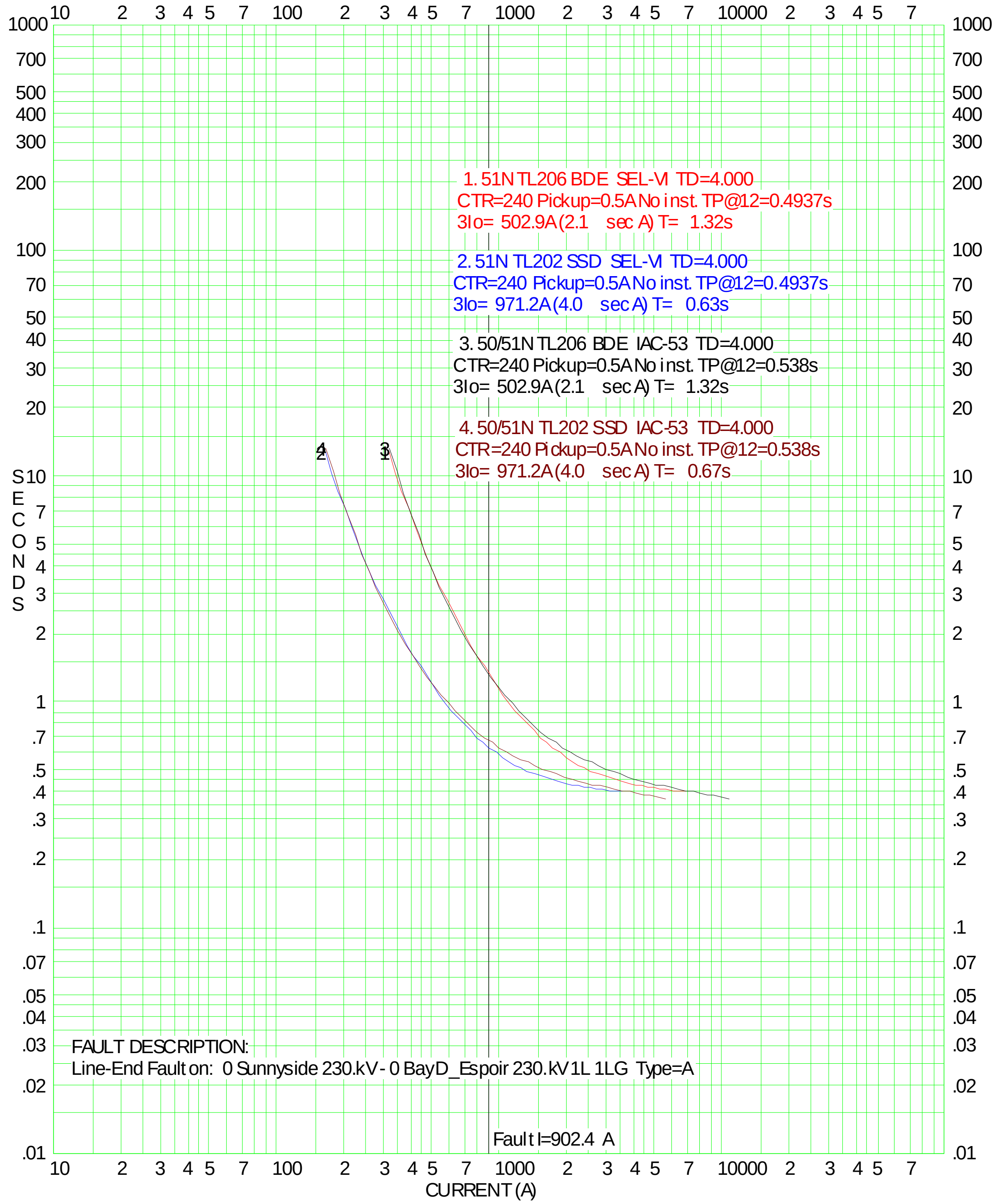
$'51NPU = 0.5$ A secondary $'51NPU \cdot CTR = 120$ A primary

$'51NTD := 4$ $'51NC := "U3"$ $'51NTC := "N"$ $'51NRS := "N"$

Checks for close-in fault show that this element will not operate in less than 0.4 seconds so there is no danger of it tripping 3 pole before the zone 1 element trips the faulted phase selectively.

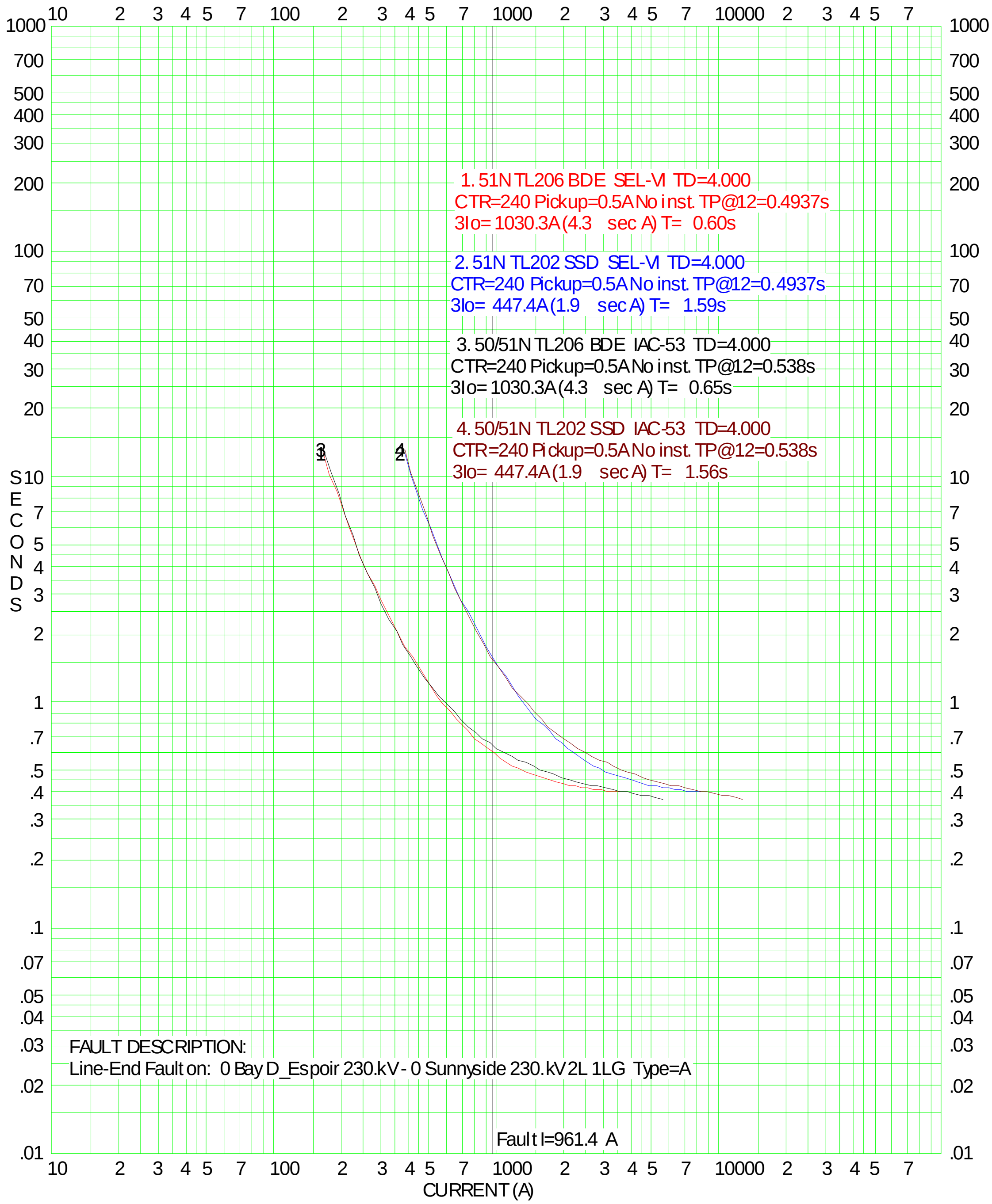
Check the coordination with the remote terminal 51N on the parallel line for a line end fault near BDE on the parallel line. due to mutual coupling, this is the type of fault that will produce the most sensitivity (least desensitization) with respect to the protection on the parallel line. see Figure 15. coordination is fine.

Worst case load unbalance with single pole open will be in the future if single pole tripping is enabled with parallel line out of service. ASPEN OneLiner shows that with 300 MVA of load on one line, and with one phase open, the 3I0 current is approximately 380 A. The 51N relay with "Alternate" settings will take approximately 3.4 seconds to operate on 380 A primary. No danger of tripping on load unbalance during SPO time.



TIME-CURRENT CURVES @Voltage 230 kV	By
For Coordination of ground time overcurrent elements	No.
Comment With mutual coupling taken into consideration.	Date

<u>Figure 14</u> - coordination of ground time overcurrent elements for line end fault on TL202 close to BDE



TIME-CURRENT CURVES @Voltage 230 kV	By
For Coordination of ground time overcurrent elements	No.
Comment With mutual coupling taken into consideration.	Date

Figure 15 - coordination of ground time overcurrent elements for line end fault on TL206 close to SSD

Permissive Overreaching logic settings

EPOTT := "Y"

Z3RBD is set at remote breaker time plus channel reset time plus channel reset time plus zone 2 reset time. From review of fault records it appears that the breaker time is 3 cycles. Channel reset time is not easily determined from existing records but can conservatively be assumed to be 1 cycle, and relay reset time will also be about 1 cycle. Total time for Z3RBD is then 5 cycles.

Z3RBD := 5 cycles

Echo block delay timer blocks the echo after the local elements have picked up. This can be set relatively long since there is no significant need for the echo function shortly after the local terminal has just seen a fault but the remote terminal has not. Set at 10 cycles as per the example in the instruction manual.

EBLKD := 10 cycles

Echo time delay on pickup should be set to override noise on the communications so that it doesn't echo noise. Typical time according to the SEL application guide is 2 cycles. Since this delay only affects clearing time for relatively light (high resistance) faults that are sensed by zone 2 function at one end, the typical setting is acceptable.

ETDPU := 2 cycles

Echo duration should be long enough to ensure the permissive trip is received by the remote terminal and should also be shorter than the Z3RBD time to ensure that the reverse blocking will always be longer than any permissive trip received (including echo time stretching).

EDURD := 4 cycles

No need to enable week feed conversion to trip, since both terminals will be quite sensitive enough to detect high resistance faults after the remote terminal has cleared. Therefore we can accept sequential (or "step") clearing with no need for the added insecurity of weak infeed tripping.

EWFC := "N" **No other communications logic settings are required for this application.**

Switch on to Fault Settings

Switch on to fault logic will ensure the protection will operate when energizing the line onto a close-in three phase fault when there is no polarizing voltage available for the distance elements.

ESOTF := "Y"

The breaker close signal is not available to the relay. The 52A method of enable SOTF will be used. Therefore the Close end delay is not critical. Typical duration for enable SOTF is 10-15 cycles

ENCLO := "N" CLOEND := 0 EN52A := "Y" SOTFD := 15

Set 50H for high magnitude close-in multiphase faults with weakest source at BDE. It should be set less than 50% of the minimum close-in fault magnitude. Minimum close-in magnitude of a three phase fault with TL203 out of service is 3300 A. Therefore desired maximum setting for 50H is 1700 A.

Imin3P_close_in := 3300

$$'50H := \frac{Imin3P\_close\_in}{2CTR} \qquad '50H = 6.875 \quad \text{A secondary}$$

Choose a setting of 6 A secondary for this element. '50H := 6 A secondary

Choose a setting for 52AEND less than the shortest reclose time. '52AEND := 30 cycles

Residual overcurrent settings.

Tripping directly by instantaneous ground overcurrent is not applicable because it is not phase selective. However it would be helpful to monitor steady state unbalance, and issue an alarm for continuous unbalance. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50N := 1$ $\quad$ $'50N1 := 0.25$

Negative Sequence overcurrent settings.

Similar to ground overcurrent, apply a negative sequence overcurrent element to initiate an alarm for steady state unbalances. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50Q := 1$ $\quad$ $'50Q1 := 0.25$

Voltage Element Settings

Similar to unbalance current monitoring, it is helpful to have an unbalance voltage monitor to detect steady state unbalances from the voltage supply.

EVOLT := "Y"

Set the zero sequence overvoltage element at 1% of rated voltage or just at the point necessary to override normal unbalances. The zero sequence voltage element measures 3 times the zero sequence voltage.

$$'59N := 3 \cdot 0.01 \frac{kVbase \cdot 1000}{\sqrt{3} \cdot VTR} \qquad '59N = 1.992 \qquad \text{Say} \quad '59N := 2 \ \text{V secondary}$$

Loss of Potential

Enable loss of potential settings. Advanced LOP settings are not available on this model of relay.

ELOP := "Y" $\quad$ Time delay of 1.25 cycles is commonly used. $\quad$ $LOPD := 1.25$

The 50 M element should be set above maximum load and below minimum fault current for a fault at the remote terminal under weak source conditions. The maximum load for this case should be normal maximum, not emergency maximum which only exists for a few minutes before the operator can act to reduce load.

$$Imax\_normal := \frac{Speak \cdot 1000}{\sqrt{3} \cdot kVbase \cdot CTR} = 1.935 \ \text{A secondary}$$

Minimum fault current for a remote three phase fault is $I3Pmin = 619$ A primary.

Minimum fault current for a remote phase to phase fault is 87% of the minimum three phase fault current level.

Dependability factor to be sure to operate for a minimum remote fault is chosen to be 1.6. $\quad$ $DF := 1.6$

Maximum setting for 50M should be $\dfrac{0.87 I3Pmin}{DF \cdot CTR} = 1.402$ $\quad$ In this case a setting of 2.4 A secondary will be adequately dependable and secure.

$'50M := 2.4$ A secondary

The 59QL setting should be above normal maximum unbalance and below the level expected for a blown VT fuse. For a blown fuse, one phase voltage will be lost, and the negative sequence voltage will be roughly 33% of the nominal positive sequence voltage. Choose a setting of 15% of the nominal positive sequence voltage. This will be well above any normal unbalance.

$'59QL := \mathrm{round}\left(\frac{0.15 \cdot kVbase \cdot 1000}{\sqrt{3} \cdot VTR}, 0\right)$ $'59QL = 10$ V secondary

The 59PL setting should be less than the minimum voltage to be expected for a remote bus fault under weakest source conditions. There is no minimum setting (above zero) for this function. Choose a setting equal to half the voltage drop along the line impedance at the pickup setting of the 50M element.

$'59PL := \mathrm{round}[0.5 \cdot ('50M \cdot |Z1Linesec|), 0]$ $|'59PL| = 10$

Miscellaneous Scheme Settings

Pole discoordinance logic is not being used. EPOLD := "N" SPPDD := "N/A"

Enable single pole tripping by distance elements only ESPT := "Y"

Enable single pole open ESPO := "Y"

Set single pole open time delay for future SPO conditions SPOD := 0.25

3 Pole open reset delay to override small discrepancies in pole closing '3POD := 0.5

Stub line protection is not required ESTUB := "N" '50MFD := "N/A"

Trip unlatch logic not applied TULO := "N"

Logic variables and Miscellaneous timers

Minimum trip duration timer is set at 9 cycles as per the application example in the SEL-321 instruction manual.

TDURD := 9 Cycles

Trip during open pole time delay should be set longer than the reclose time. Existing setting is OK.

TOPD := 55 Cycles

Proposed logic for X, and Y variables is intended to create a three pole trip if a permissive trip is received any time within a period of 25 to 60 cycles after a single pole trip was asserted. This is presumably standard NL Hydro logic. It enables more sensitive protection during the open pole period, because only one terminal has to see a fault in order for the three pole trip to be implemented.

Retain existing settings except use time ZT to trigger an alarm for sustained unbalance.

LOGIC_Z := "59N+50N1+50Q1" TZPU := 1200 cycles TZDO := 0 cycles

Tripping Logic

Permissive tripping is required only for instantaneous overreaching functions. No need for any functions that trip directly. Existing 51NT word in MTCS is not required.

MTCS := "M2P+Z2G"

Unconditional tripping MTU := "M1P+Z1G+M2PT+Z2GT+51NT"

No need for existing direct tripping zone 1 functions in the switch on to fault logic.

SOTF Tripping MTO := "M2P+Z2G+50H"

Event records will be triggered automatically by all trip events. Other event record triggers should be by starting of other elements to ensure capture of all relevant events. Events should be triggered by keying or receiving permissive trips to ensure separation of relay and teleprotection issues.

MER := "M2P+Z2G+51N+LOP*52AA1+LOP*52AA2+KEY+PT+EKEY"

Outputs

Retain existing output assignments except add the continuous unbalance alarm to OUT15.

OUT15 := "LOP*50L+ZT"

Input Contact Assignment

It would be desirable to provide phase segregated inputs to the relay so that the quadrilateral functions could be disabled during single pole open conditions. However, separate inputs are not presently available for phase segregated breaker status inputs. It is recommended to replace the existing automatic reclosing logic so that additional inputs can be freed up. Alternatively an SEL2506 unit could be added to allow for additional I/O through mirrored bits.

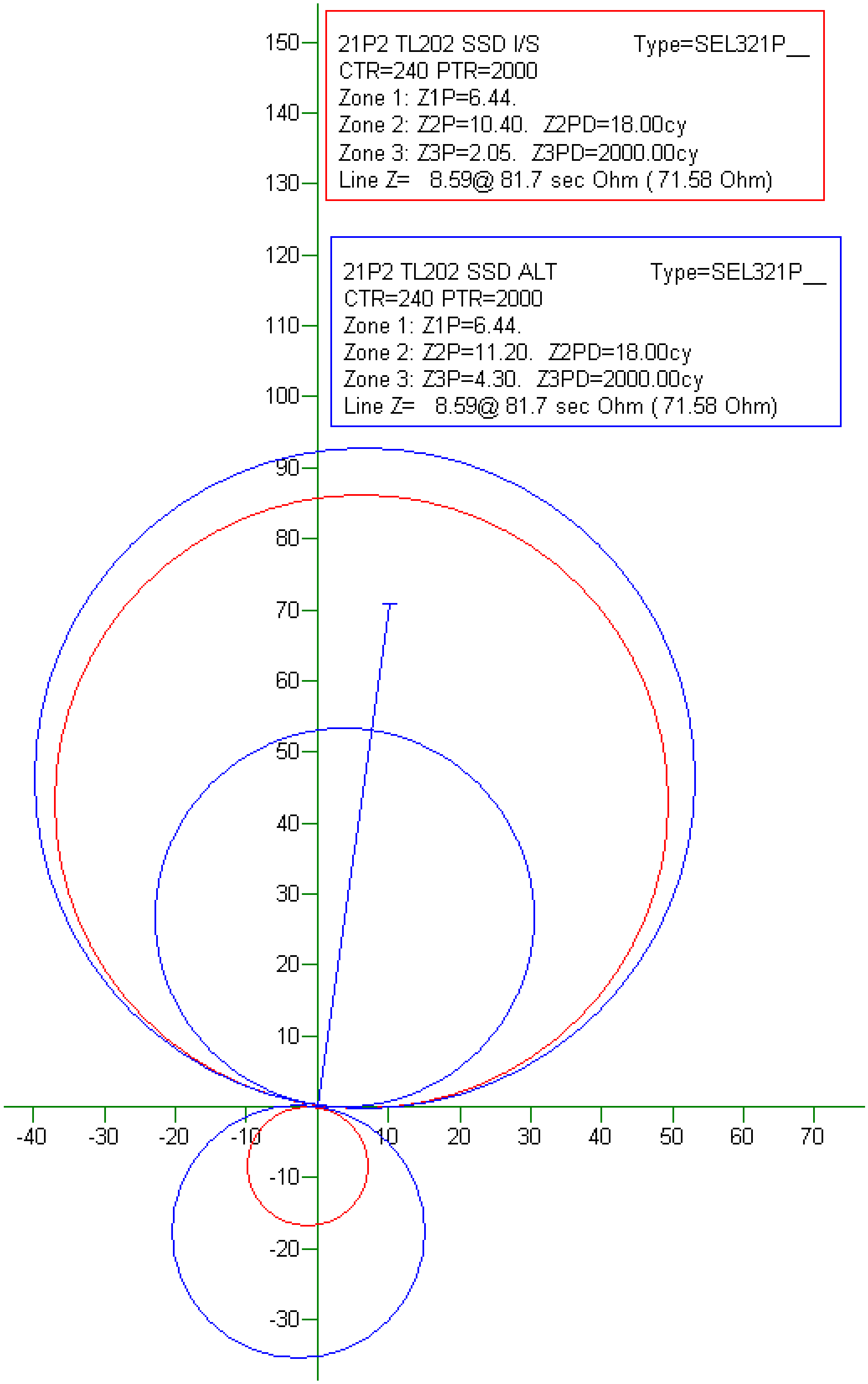


Figure 16 - Comparison between existing (red) and proposed new (blue) phase distance characteristics.

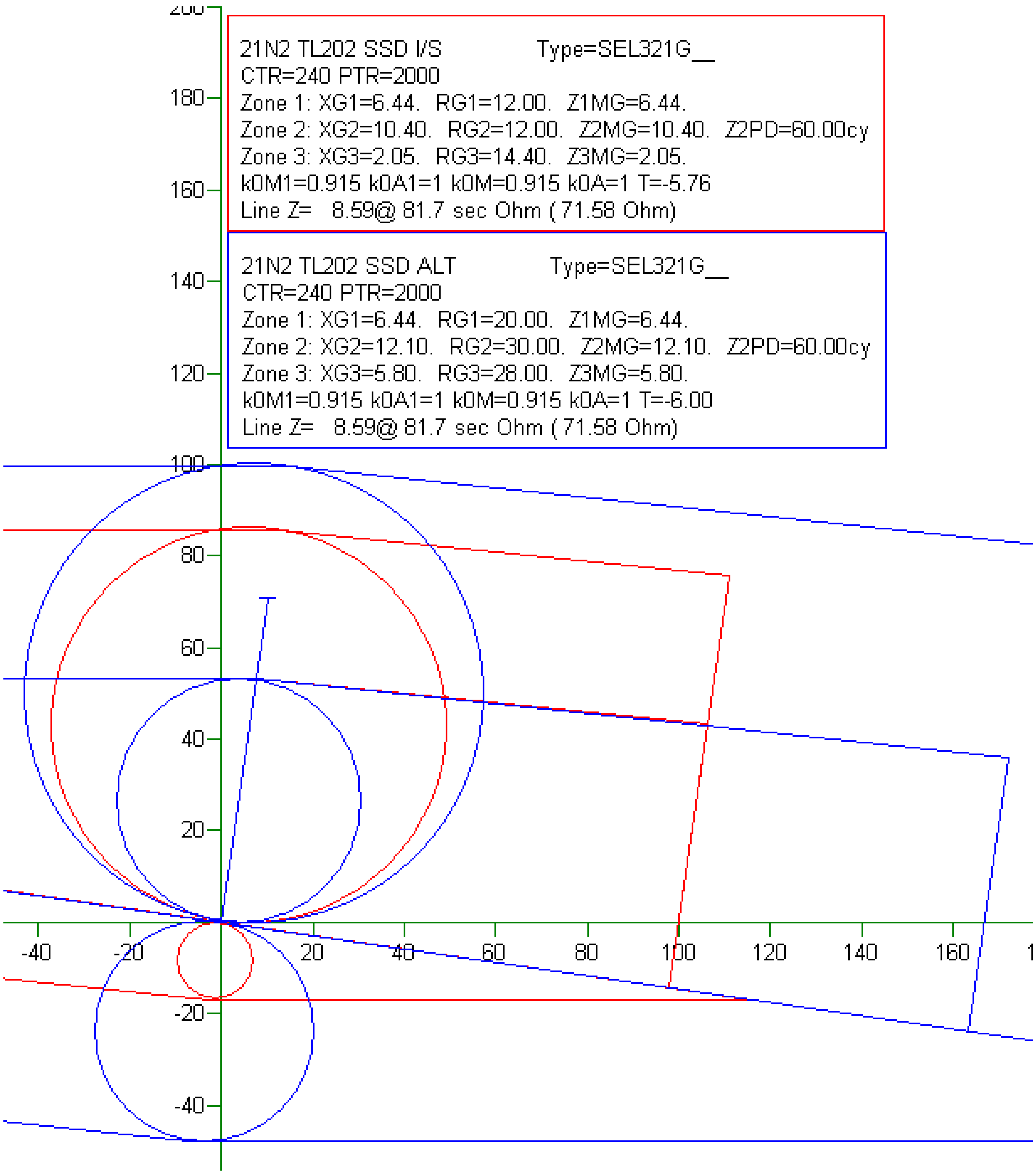


Figure 17 - Comparison between existing (red) and proposed new (blue) ground distance characteristics.

Protection Review for Five 230 kV Transmission Lines

Appendix G
Detailed settings review for SSD TL203 "P1" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Sunnyside (SSD) terminal of circuits TL203 . This 230 kV transmission circuit is from Sunnyside (SSD) to Western Avalon (WAV)
The circuit runs parallel to TL237 for most of its length.

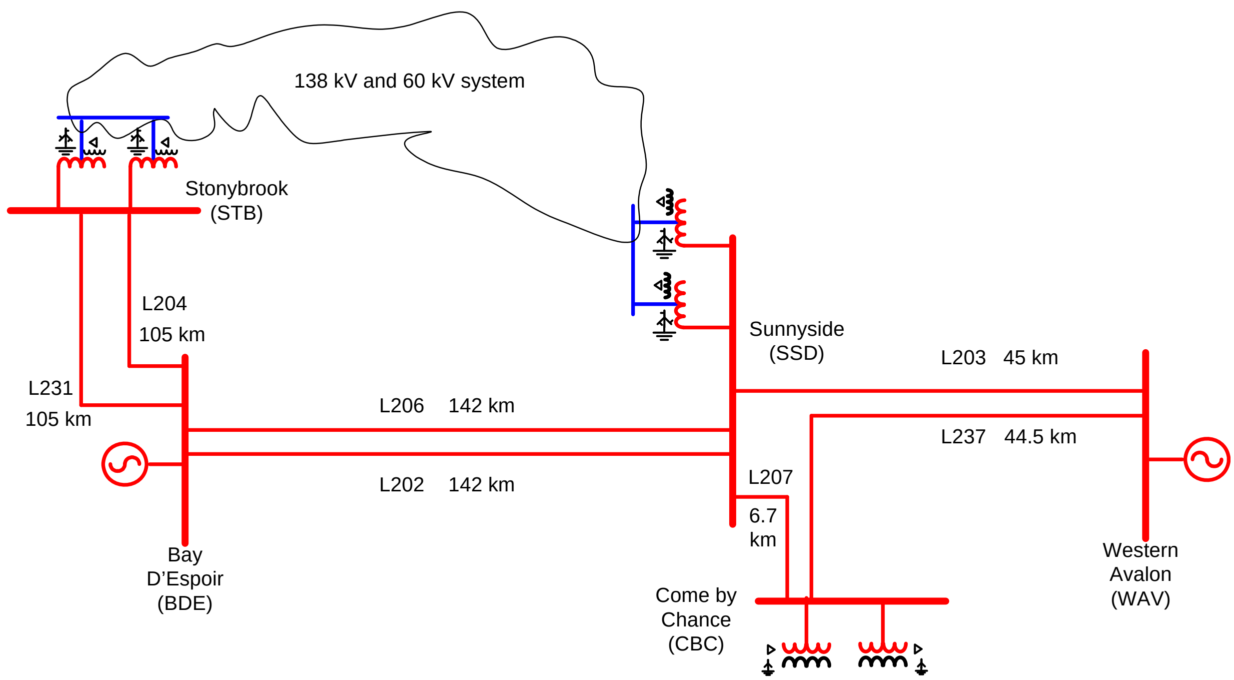


Figure 1 - System Single Line Diagram

Existing P1 protection systems are Areva LZFP111 (Optimho) systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $\quad kVbase := 230$ $\quad Ibase := \dfrac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\quad Zbase := \dfrac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $CTR := \dfrac{1200}{5}$ VT ratio is: $VTR := \dfrac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**Hydro Interconnected System (2010-08-13) V10.olr**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with all shunts ignored (unless needed for load flow simulation).

Minimum fault current seen by each terminal (phase to phase, and SLG with 100 ohm fault resistance).

At SSD, with Circuit TL202 out of service, and TL207 and TL237 lines in service, for a fault at the remote terminal.

$ILLmin := 738$ A $ISLGminPH := 811$ A $ISLGmin0seq := 556$ A

The optimho current level detectors that block the distance comparators in the event of line opening are fixed at 5% of the rated current, or 0.25 A secondary, or 60 A primary. They will have no difficulty in operating for minimum fault levels. However, the ground distance elements are also supervised by a low set neutral current level detector (LDLSN that requires the neutral current to be greater than 10% of the maximum amplitude of phase difference current. This prevents the ground comparators from operating during close-in multiphase faults with CT errors. ASPEN OneLiner shows that for a bolted fault at the remote bus even under heavy load, there is sufficient neutral current (22% of maximum phase to phase fault current) that means this LDLSN function does not inhibit the ground distance comparator.

Calculate the minimum negative sequence source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind SSD	$Z2minSSD := 3.22 + j \cdot 27.90$	ohms primary
Minimum um source impedance behind WAV	$Z2minWAV := 2.75 + j \cdot 27.64$	ohms primary

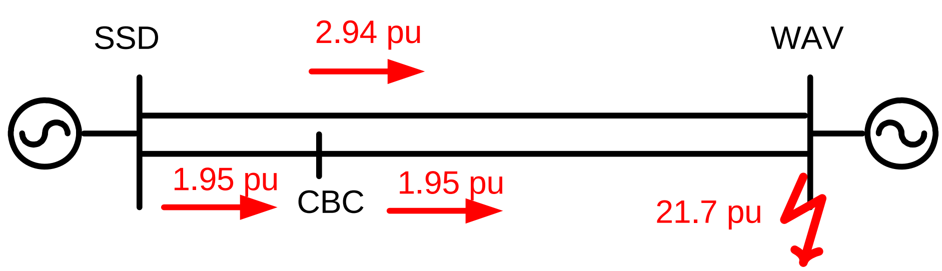


Figure 2 - 3 Phase Fault at WAV

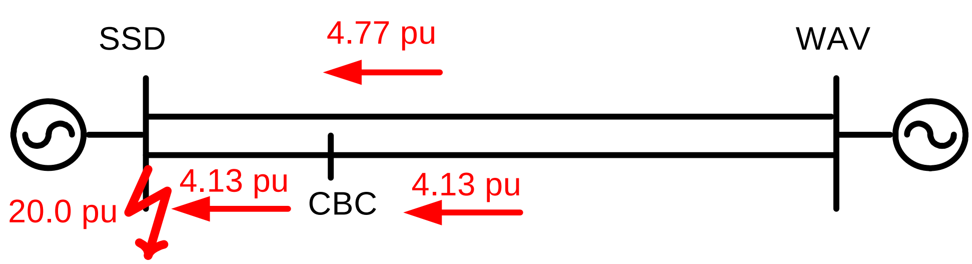


Figure 3 - 3 Phase Fault at SSD

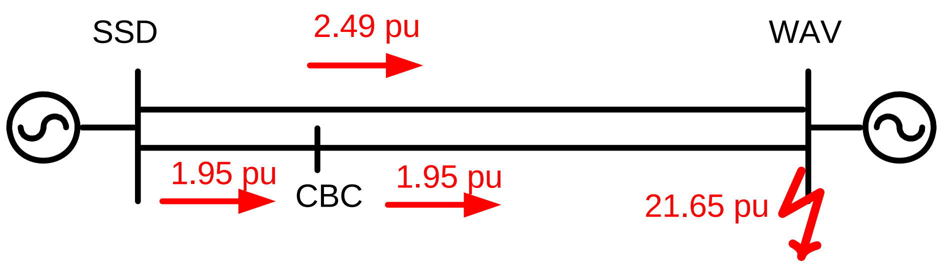


Figure 4 - SLG Fault at WAV (3I0 currents)

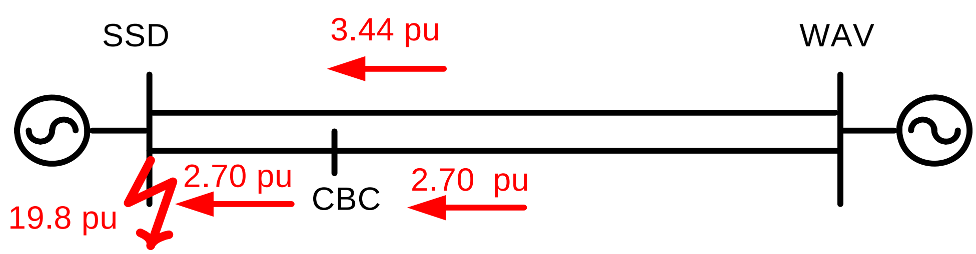


Figure 5 - SLG Fault at SSD (3I0 currents)

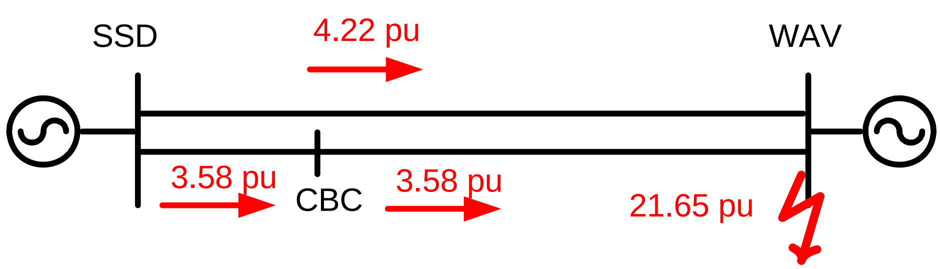


Figure 6 - SLG Fault at WAV (Phase currents)

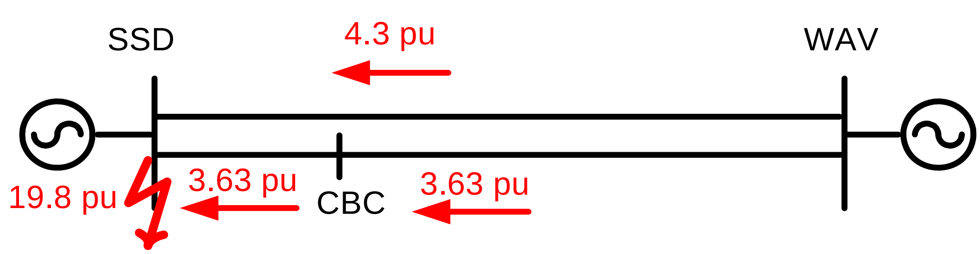


Figure 7 - SLG Fault at SSD (Phase currents)

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L203 := 0.0085 + j \cdot 0.04238$ $\quad$ $Z0L203 := 0.02337 + j \cdot 0.15876$

In primary ohms

$Z1L203pri := Z1L203 \cdot Zbase$ $\quad$ $Z0L203pri := Z0L203 \cdot Zbase$

In secondary ohms

$Z1Linesec := Z1L203pri \cdot \frac{CTR}{VTR}$ $\quad$ $Z0Linesec := Z0L203pri \cdot \frac{CTR}{VTR}$

$|Z1Linesec| = 2.744$ $\quad$ $arg(Z1Linesec) = 78.659 \cdot deg$

$|Z0Linesec| = 10.187$ $\quad$ $arg(Z0Linesec) = 81.626 \cdot deg$

Zero sequence mutual coupling between TL203 and TL237 is $Z0m := 0.0132 + j \cdot 0.0697$ (per unit)

Load Data

From 2010 System peak load case provided in start up information, the peak load is given as 132.6 MVA (with TL203, TL207 and TL237 in service). Th ehighest load of the three lines is TL207 with a load of 138.4 MVA. In the event of sudden loss of TL207. Peak load in TL203 will increase to take up the lost load through TL207. Thus the peak load in TL203 will be slightly more than double until operators can adjust loads.

$Speak\_203 := 132.6$ MVA $\quad$ $Speak\_207 := 138.4$ MVA

$Smax := Speak\_203 + Speak\_207 = 271$ MVA

P1 Relay Settings

Distance element reach settings

Note that resistive reaches are forced to be the same for all zones. Reactive reaches for phase and ground distance elements must be the same as each other.

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the SSD Station bus under weak source conditions with TL202 out of service and all of TL203. TL207 and TL237 lines in service. From ASPEN OneLiner, voltage at SSD for a 3 phase fault at WAV is 0.14 per unit. So there is less than 20% voltage at SSD during a fault at WAV under weak source conditions.

Since the voltage is not higher than 20%, the line is considered short, and a reduced Zone 1 setting is recommended to provide more security. Initially, try to choose a setting of 80% of nominal.

$Z1P := 0.8 \cdot |Z1Linesec|$ $\quad Z1P = 2.2$ Ohms secondary

Existing setting of 2.38 ohms is a little high, and should be reduced especially as the ground distance function will be subject to a little overreach if TL237 is out of service and grounded at both ends. The ground distance reach in the optimho has to be set the same as the phase distance reach; so we need to consider the ground faults too.

The reach of the ground distance element will limit the reach of the zone 1 function. It can be seen from Figure 8 that the apparent impedance presented to the relay for a fault at the remote bus when the parallel line is out of service and grounded at both ends is less than the line impedance.

$Zapp\_ext := 2.47$ ohms $\quad Zapp\_ang := 79.2deg$ This angle is close enough to the line angle to treat it as equal to the line angle.

$$\frac{Zapp\_ext}{|Z1Linesec|} = 0.9$$

The apparent impedance is reduced by about 10% due to the effect of the parallel line being out of service and grounded at both ends.

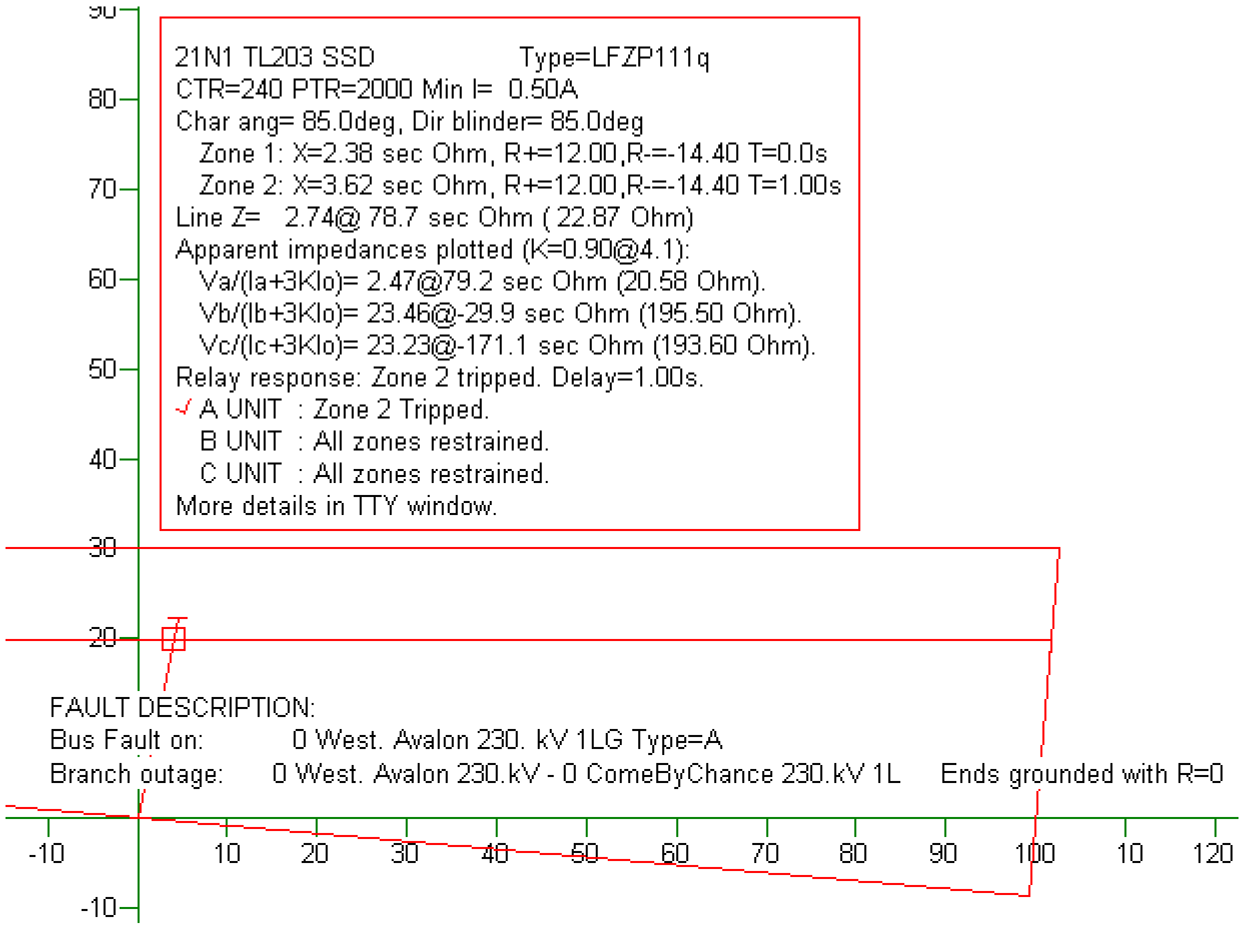


Figure 8 - Apparent impedance to a fault just beyond the remote terminal is reduced by 10% when parallel line is out of service and grounded at both ends.

The normal reach of the zone 1 should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Choose a setting of 75% of the line impedance, which is lower than the setting required to make the zone 1 element more secure for faults beyond the end of this short line. Note that as will be seen later, the reduced reactive reach is required to allow a relatively large resistive reach for sensitivity while retaining security against overreach due to CT and VT errors.

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.75$ per unit

$Z1\_sec := m \cdot |Z1Linesec|$ $Z1\_sec = 2.06$ Ohms secondary

$Z1pri := Z1\_sec \cdot \frac{VTR}{CTR} = 17.149$ Ohms primary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 3.62 ohms secondary (about 132%). However, in order to dependably reach a single line to ground fault at the remote terminal, it will be necessary to set the reach significantly further.

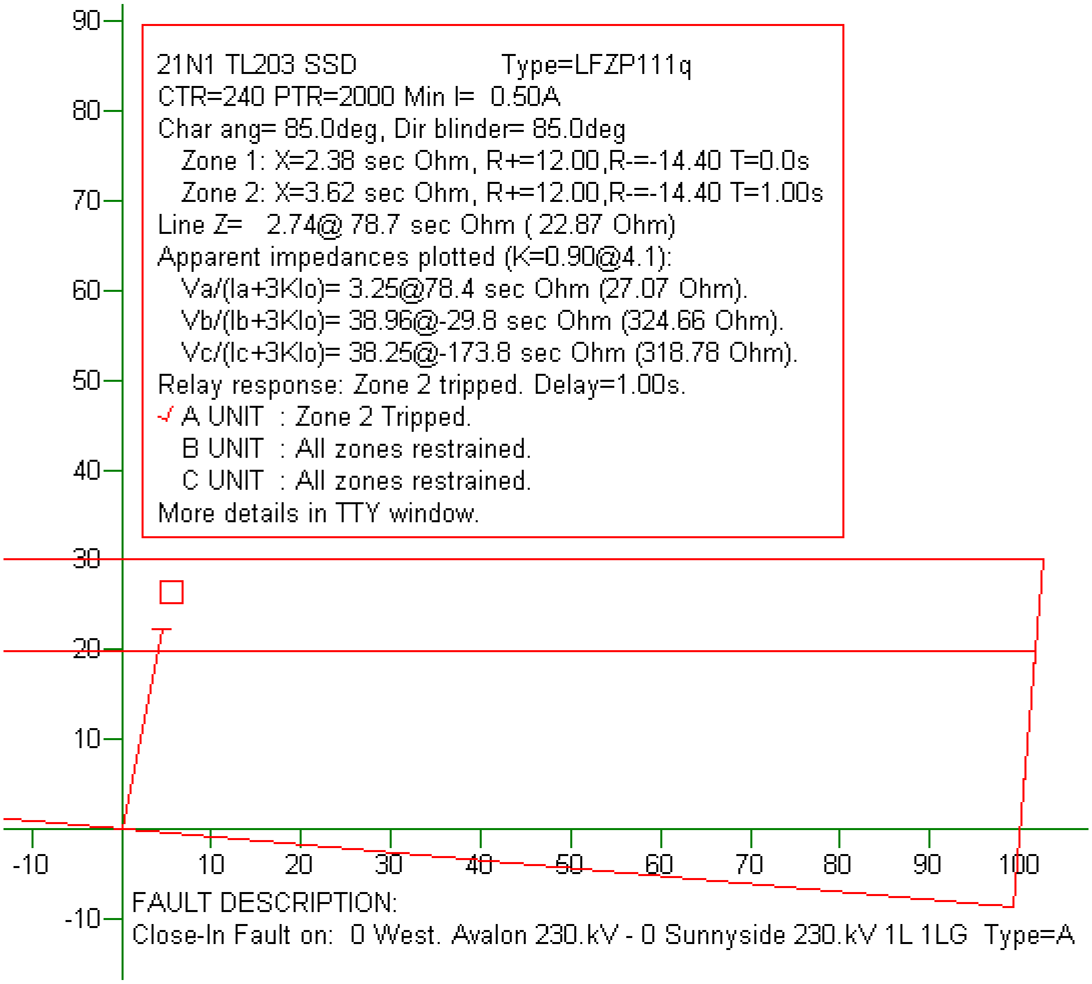


Figure 9 - Apparent impedance to a fault close to the remote terminal is increased by 19% when parallel line is in service.

As can be seen from Figure 9, the apparent impedance to a fault close to the remote terminal is increased when the parallel line is in service.

Zapp_int := 3.25 Ohms secondary

Z2_sec := 1.25·Zapp_int $\quad$ Z2_sec = 4.1 $\quad$ Ohms secondary $\quad \dfrac{\text{Z2\_sec}}{|\text{Z1Linesec}|} = 148.058\cdot\%$

$\text{Z2\_pri} := \text{Z2\_sec}\cdot\dfrac{\text{VTR}}{\text{CTR}} = 33.854$ Ohms primary

The zone 2 timer will be enabled, but with a reduced setting to 0.3 second. This reduced delay is required for coordination for severe single line to ground faults with communications assistance not available. For such faults, faster clearing than is available from the ground time overcurrent protection in the P2 protection is required.
This element will not overreach the zone 1 function on the shortest line (TL237) out of WAV when infeed from WAV is taken into account. In fact, this element reaches less than 35% of TL237 (with the CBC termnal open)

Z2T := 0.3 Seconds

Zone 3

The zone 3 function is not used since the POR1 scheme does not include an echo function so there is no need for any reverse blocking function. Since the Zone 2 timer has to be set with the coordination of the ground distance element in mind, it is set at 2 second; so there is no benefit in applying a longer reaching zone 3 function.

Zone 3 element is blocked - same as existing.

Load Encroachment logic

The optimho instruction manual recommends a margin of at least 10% between the impedance of the maximum load and the resistive reach of the quadrilateral distance element.

Check loadability of the Zone 2 phase distance element assuming worst case depressed voltage of a stressed system of 0.9 per unit.

$$Zloadmin := \frac{(0.9kVbase)^2}{Smax} \qquad Zloadmin = 158.114$$ Ohms primary (assume worst case at 30 degrees)

$$Zloadmin\_sec := Zloadmin \cdot \frac{CTR}{VTR} \qquad Zloadmin\_sec = 18.974$$

A 13 ohm secondary resistive reach is less than 90% of the load impedance at anyypower factor and meets the Areva criterion.

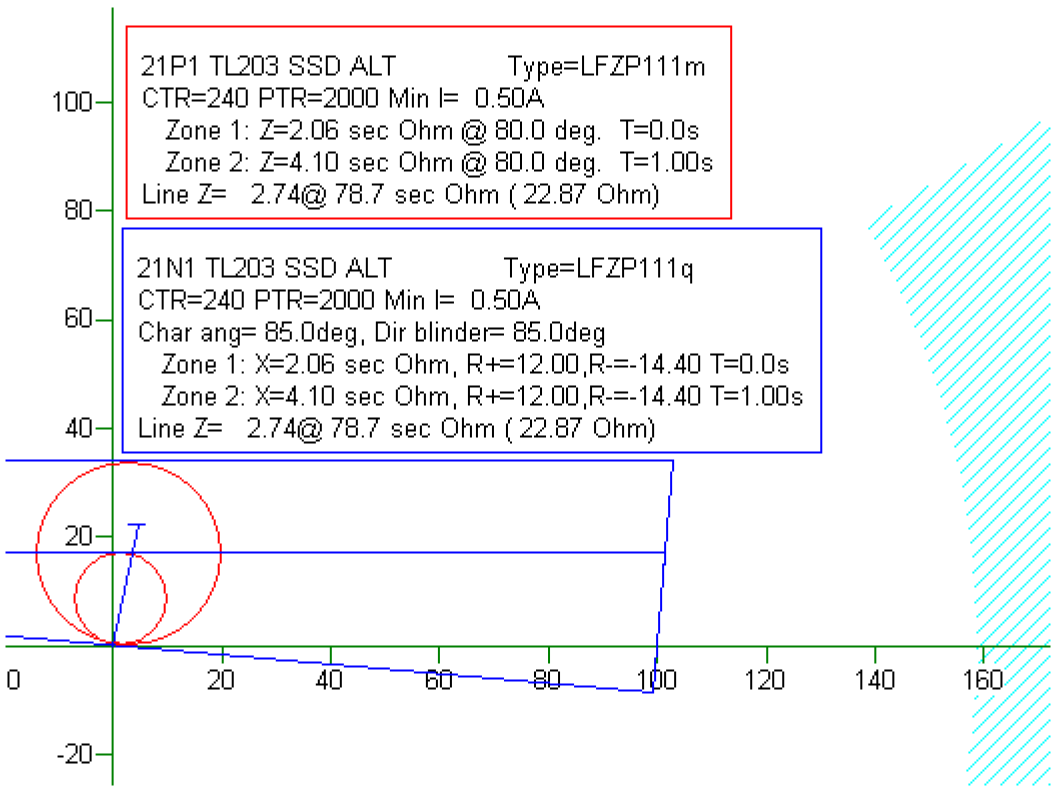


Figure 10 - Apparent impedance of load

Zone 1 Resistance - QUAD

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$R1Qmax := round[(1 - m) \cdot 20 \cdot Im(Z1Linesec), 2]\ ohm$

$R1Qmax = 13.45\,\Omega$ This is the maximum secure setting for the resistive reach and is less than the existing zone 1 resistive reach setting. The existing setting of 12 ohms will be secure enough - but will it be sensitive enough?

With the existing resistive reach setting of 12 ohms, there will be a region of 10% of the line in which neither terminal will see a 100 ohm fault. If the resistive reach is increased to 13 ohms, one or the other terminal will (just) be able to sense a 100 ohm SLG on any portion of the line.

Increase the resistive reach setting from 12 to 13 ohms $Rquad := 13$ ohms secondary.

Check the maximum fault resistance that can be sensed for a fault at a location where the current contribution from each terminal is roughly the same. From Figure 11, it can be seen that the limit of sensitivity is about 100 ohms, for a fault about 44% of the distance from SSD. This meets the required sensitivity of 100 ohms.

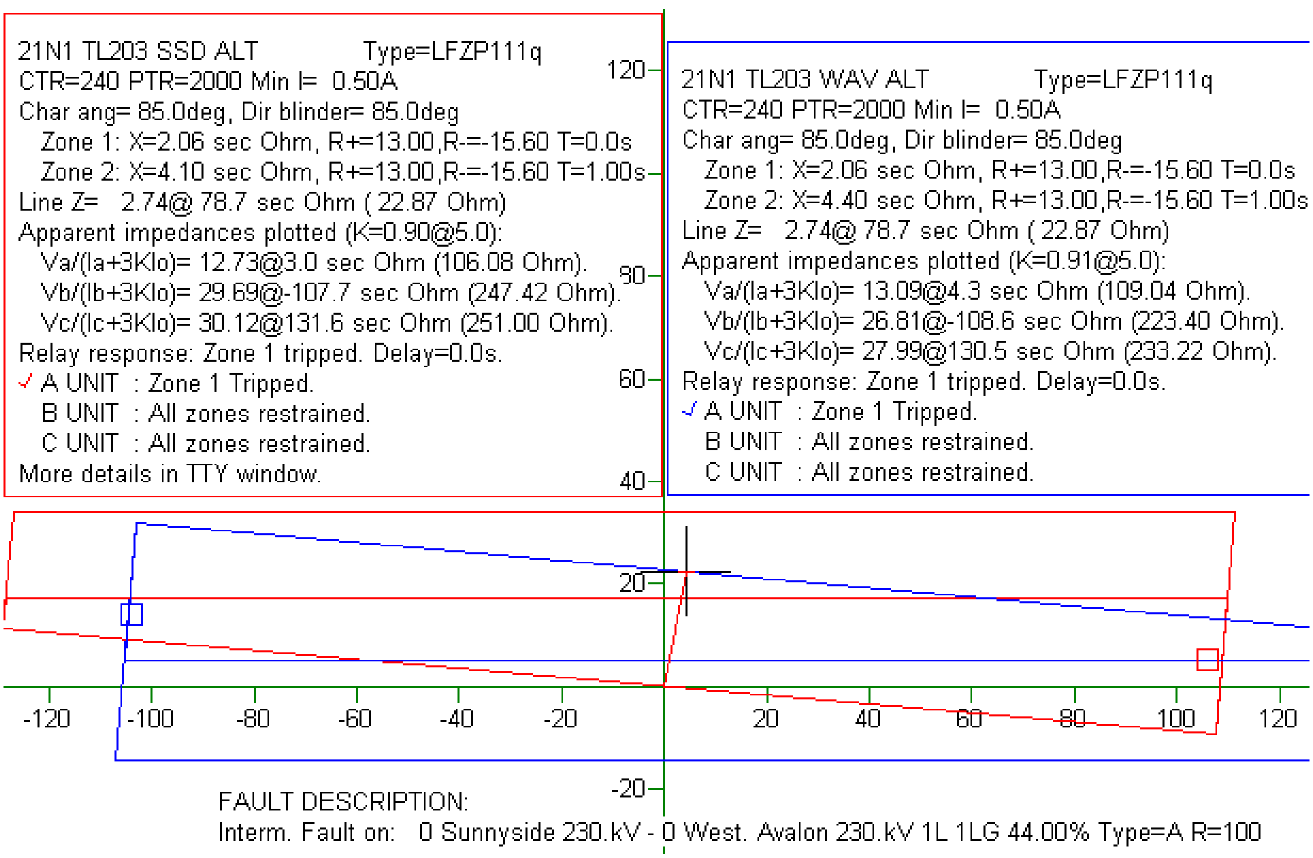


Figure 11 - Apparent impedance of a resistive fault near the mid point of the line.

Settings of K attenuators

KZPh Coarse setting common to all DISTANCE zones should be set as high as possible while below the required Zone 1 reach. The current level detectors vary inversely with KZph. Maximum setting available is 1.0

$KZPh := 1.0$

Zone 1 attenuators and angular selection

$In := 5$ $\quad Z1\_sec = 2.06$ This is the desired secondary reach (previously calculated)

$$KZ1 := \frac{Z1\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ1 = 2.06 \qquad Z1sec\_reach := KZ1 \cdot KZPh \cdot \frac{5}{In} \qquad Z1sec\_reach = 2.06$$

$Z\theta PH := (\arg(Z1Linesec))$ $\quad Z\theta PH = 78.659 \cdot deg$

Rounded to the nearest 5 degrees $\quad Z\theta PH := 80$ Degrees

$Z\theta N := \arg(Z0Linesec - Z1Linesec)$ $\quad Z\theta N = 82.7 \cdot deg$

Rounded to the nearest 5 degrees $\quad Z\theta N := 85$ Degrees

Zone 2 attenuators selection

$Z2\_sec = 4.1$ This is the desired secondary reach (previously calculated)

$$KZ2 := \frac{Z2\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ2 = 4.1$$

Zone 3 is not used

QUAD Resistive Reach setting

$Rquad = 13$ This is the desired secondary reach (previously calculated)

$$KR := \frac{Rquad}{\left(\frac{5}{In}\right)} \qquad KR = 13$$

Residual Compensation attenuators selection

Zero sequence current compensation for ground faults is provided by the KZN factor. Zero sequence mutual compensation is not used in this application (it causes extra complexity for only moderate gain in setting accuracy).

$$KZN := \frac{Z0Linesec - Z1Linesec}{3 \cdot Z1Linesec} \cdot KZPh \qquad KZN = 0.903 + 0.064j$$

$|KZN| = 0.905$ This the same as the existing setting

Switch On To Fault (SOTF) Protection.

If SOTF is enabled, it can be set to 200ms or 110 s after all poles of the line have been de-energized. The 110 s setting is intended to override automatic reclosing dead time. However it makes more sense to enable after the shorter time. Once the SOTF feature has been initiated, it remains in effect for 250ms after the line has been re-energized. The SOTF tripping options are:

a) Any distance comparator.
b) Any current level detector as long as a corresponding voltage level detector has not picked up within 20ms.
c) Either current or distance, as long as a corresponding voltage level detector has not picked up within 20ms.

SOTF := "Enabled"

SOTF_TIME := 0.20 Seconds

Elements_in_SOTF := "BOTH" (Both Comparators and current level detectors).

Power Swing Detector

This element will not be used. It will be left Blocked, and if there is a power swing, the distance elements will trip naturally.

VT Supervision

Set the VT supervision to BLOCK TRIP

Set the VT fail detection to SELF RESET this is as existing on TL202 and TL207, but different from the existing on TL203.

SELF_RESETTING := "ENABLED"

Start Indication

This function will bring up information on the LCD screen of the relay if a start event occurs. This function will not be used.

START_INDICATION := "BLOCKED"

Communications assisted logic.

The existing communications assisted logic is permissive overreaching transfer trip, scheme **POR 1**. This scheme is familiar to Newfoundland and Labrador Hydro, and even though the POR 2 scheme offers the advantage of weak infeed echo, which would help the sensitivity to resistive faults, it is not recommended to change the existing scheme logic at this stage with years of experience on a product that is nearing the end of its useful life.

The POR 1 logic is a basic permissive overreaching transfer trip scheme but it does include current reversal timers to increase security against misoperation due to current reversal when a fault on the parallel line is cleared sequentially. The current reversal logic is achieved by a timer TP which will block permissive tripping and keying of permissive trip if the local zone 2 element does not pick up within a reasonable time of receiving permissive trip. The block will be maintained for a time delay of TD after the local zone 2 element picks up, or the received permissive trip signal resets.

The application of the current reversal timers is required only if the settings of the zone 2 comparators are greater than 1.5 times the line impedance. Since the reaches of these elements are less than or equal to 1.5 times the line impedance, the current reversal logic is not required, and the recommended default settings are as existing>

TP := 98 ms
TD := 0 ms

Comparison of Existing (I/S) and Proposed alternative (ALT) settings.

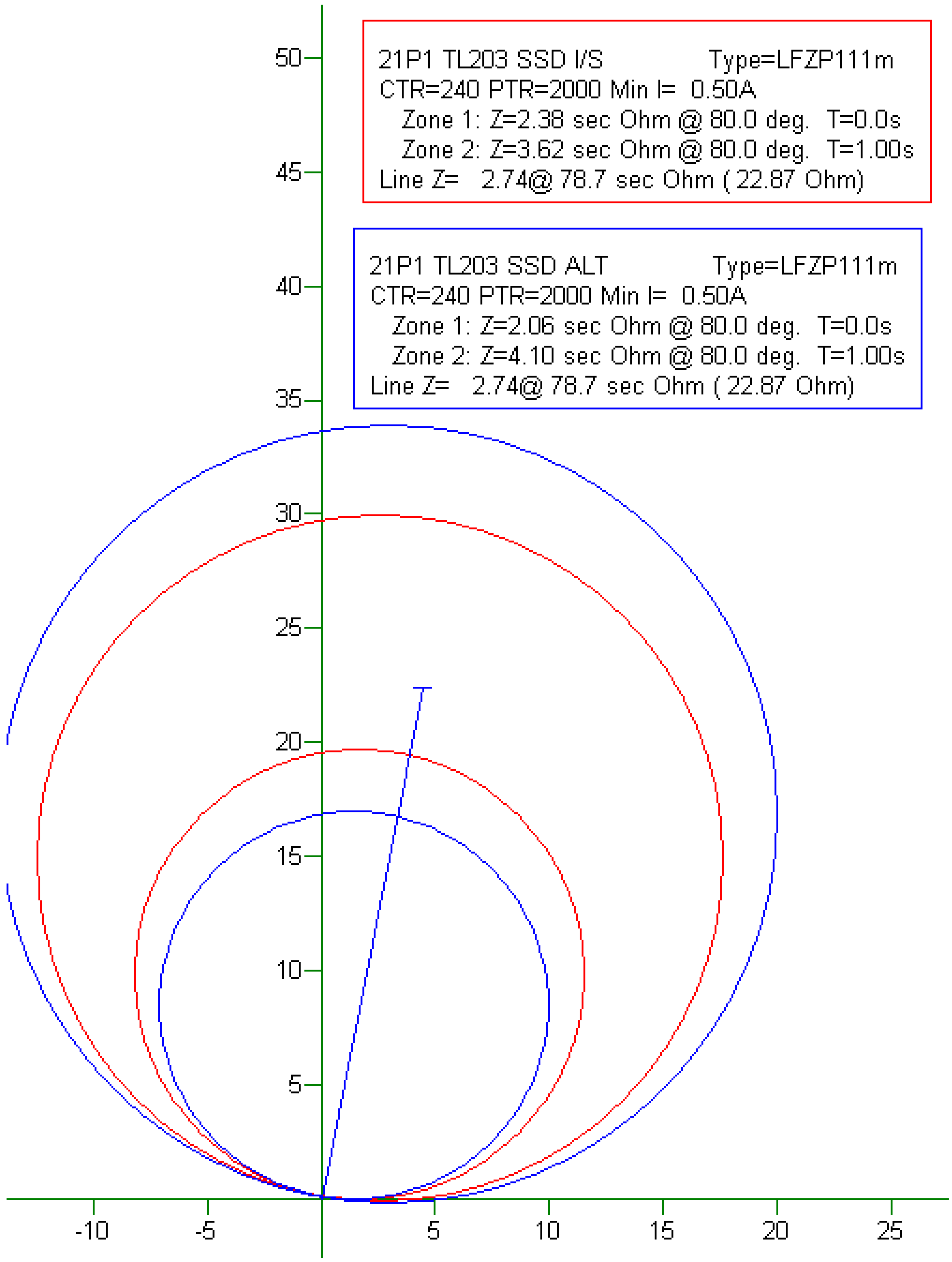


Figure 12 - Comparison of phase distance characteristics

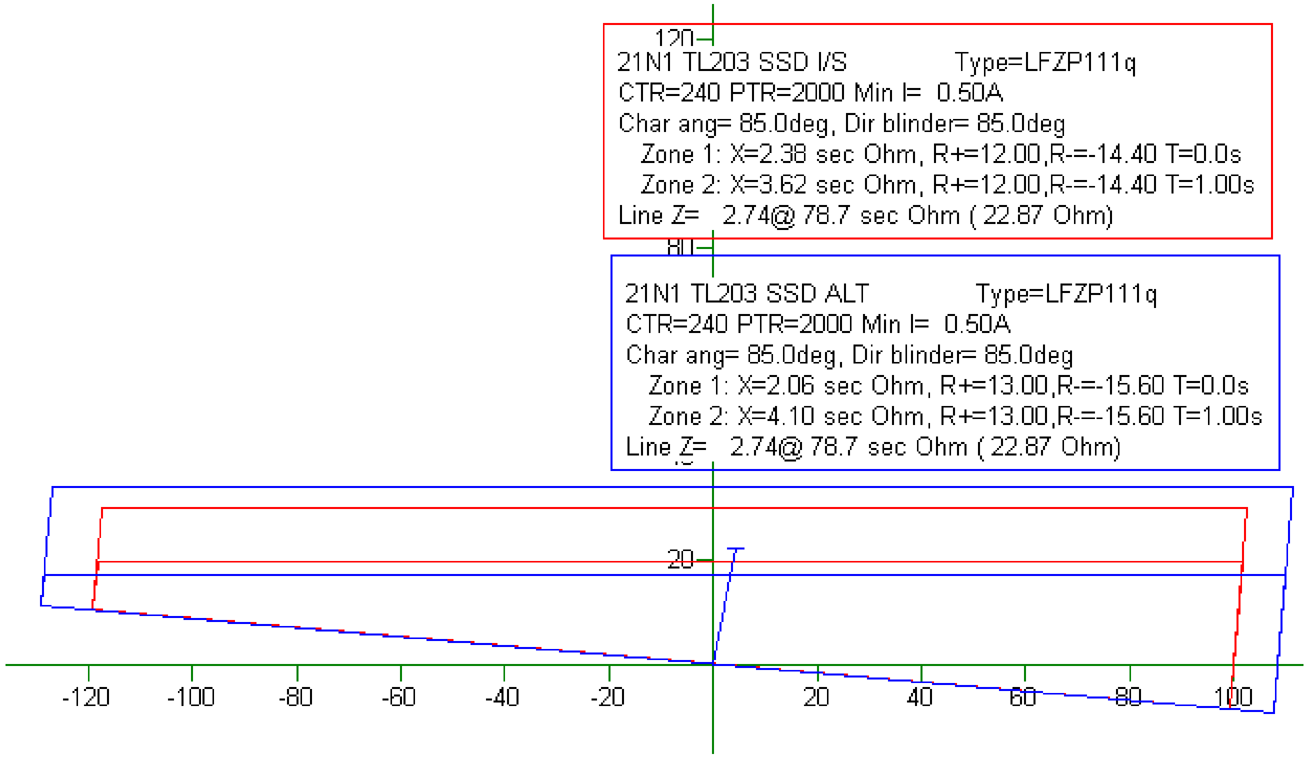


Figure 13 - Comparison of ground distance characteristics

Protection Review for Five 230 kV Transmission Lines

Appendix H
Detailed settings review for SSD TL203 "P2" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P2 protection systems for the Sunnyside (SSD) terminal of circuits TL203 .
This 230 kV transmission circuit is from Sunnyside (SSD) to Western Avalon (WAV)
The circuit runs parallel to TL237 for most of its length.

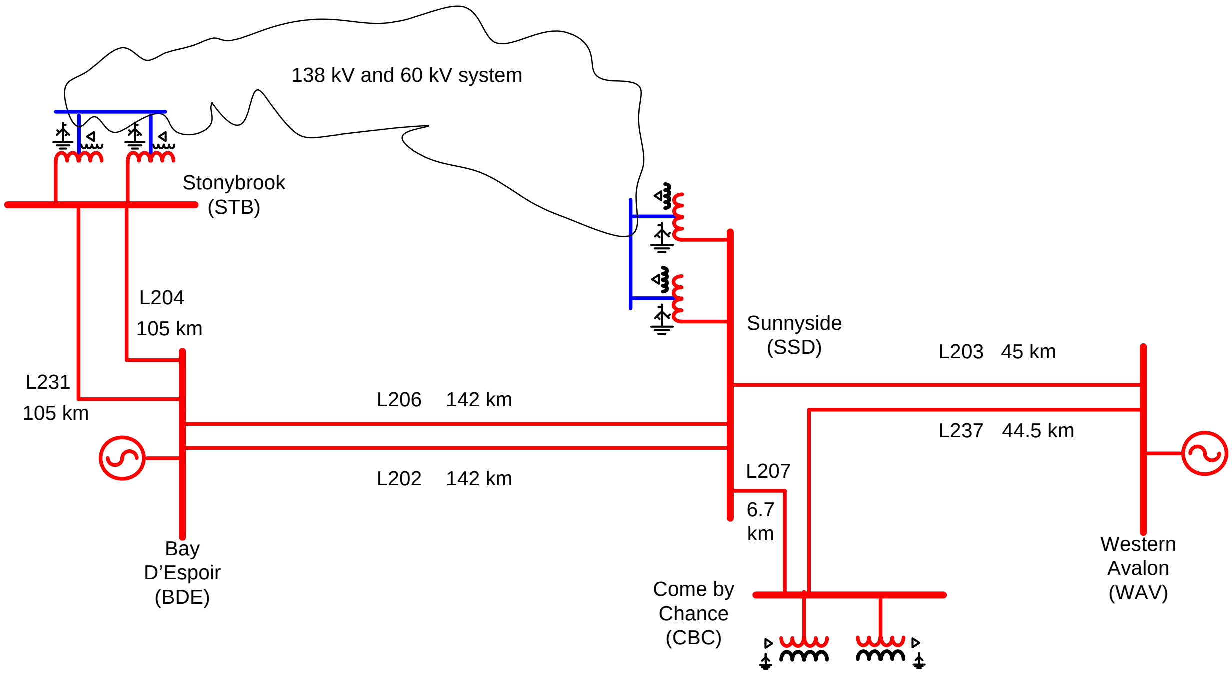


Figure 1 - System Single Line Diagram

Existing P2 protection systems are SEL321 systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$\mathrm{MVAbase} := 100$ $\quad$ $\mathrm{kVbase} := 230$ $\quad$ $\mathrm{Ibase} := \dfrac{\mathrm{MVAbase}\cdot 1000}{\mathrm{kVbase}\cdot\sqrt{3}}$ $\quad$ $\mathrm{Zbase} := \dfrac{\mathrm{kVbase}^2}{\mathrm{MVAbase}}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $\mathrm{CTR} := \dfrac{1200}{5}$ VT ratio is: $\mathrm{VTR} := \dfrac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**Hydro Interconnected System (2010-08-13) V10.olr**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with all shunts ignored (unless needed for load flow simulation).

Minimum fault current seen by each terminal (multiphase and SLG with 100 ohm fault resistance).

At SSD, with Circuit TL202 out of service, and TL207 and TL237 lines in service, for a fault at the remote terminal.

$I3Pmin := 845$ $\quad ISLGminPH := 811$ A $\quad ISLGmin0seq := 556$ A

The current for a phase to phase fault would be lower, but the current supervision element of the SEL321 measures phase to phase currents, and the phase to phase current for a phase to phase fault is twice the phase current.

Calculate the minimum negative sequence source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind SSD $\quad Z2minSSD := 3.22 + j \cdot 27.90$ ohms primary

Minimum um source impedance behind WAV $\quad Z2minWAV := 2.75 + j \cdot 27.64$ ohms primary

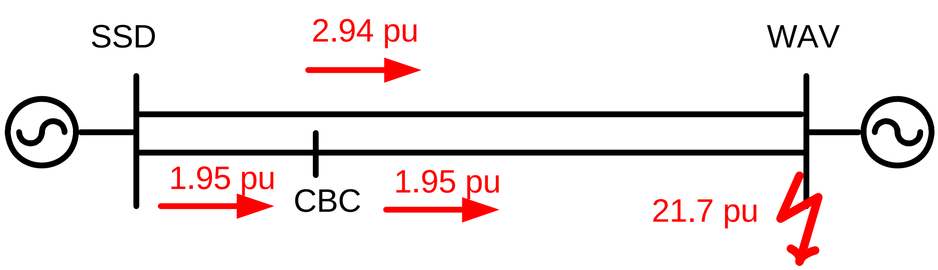


Figure 2 - 3 Phase Fault at WAV

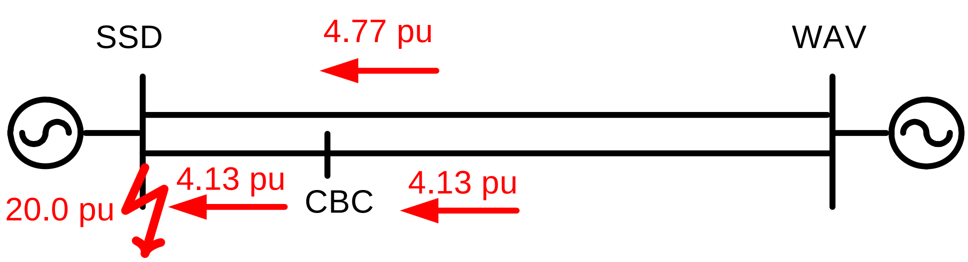


Figure 3 - 3 Phase Fault at SSD

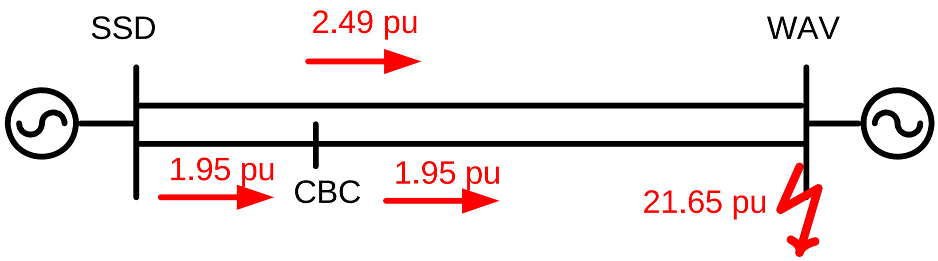


Figure 4 - SLG Fault at WAV (3I0 currents)

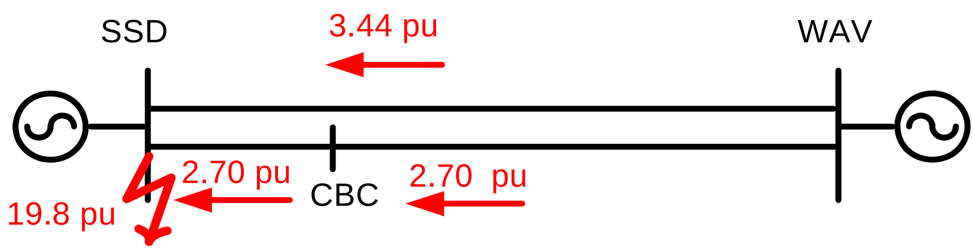


Figure 5 - SLG Fault at SSD (3I0 currents)

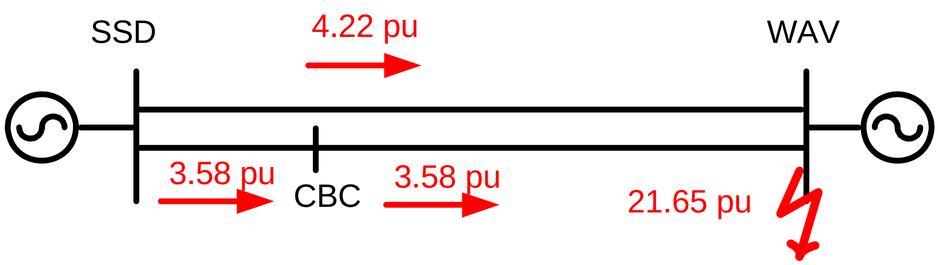


Figure 6 - SLG Fault at WAV (Phase currents)

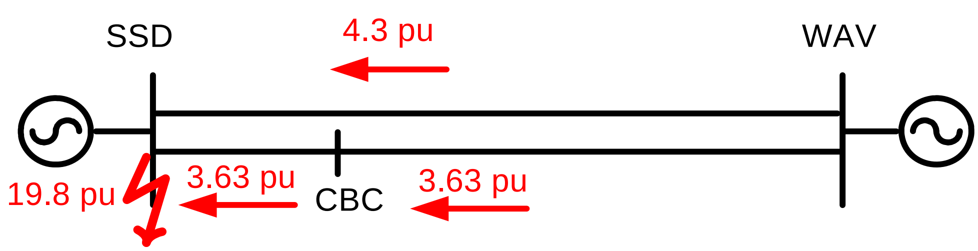


Figure 7 - SLG Fault at SSD (Phase currents)

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L203 := 0.0085 + j \cdot 0.04238$ $\quad$ $Z0L203 := 0.02337 + j \cdot 0.15876$

In primary ohms

$Z1L203pri := Z1L203 \cdot Zbase$ $\quad$ $Z0L203pri := Z0L203 \cdot Zbase$

In secondary ohms

$$Z1Linesec := Z1L203pri \cdot \frac{CTR}{VTR} \qquad Z0Linesec := Z0L203pri \cdot \frac{CTR}{VTR}$$

$|Z1Linesec| = 2.744$ $\quad$ $arg(Z1Linesec) = 78.659 \cdot deg$

$|Z0Linesec| = 10.187$ $\quad$ $arg(Z0Linesec) = 81.626 \cdot deg$

Zero sequence mutual coupling between TL203 and TL237 is $Z0m := 0.0132 + j \cdot 0.0697$

The existing line impedance settings are slightly different from the line data book. They should be adjusted to improve the accuracy of the fault location algorithm.

Load Data

From 2010 System peak load case provided in start up information, the peak load is given as 132.6 MVA (with TL203, TL207 and TL237 in service). Th ehighest load of the three lines is TL207 with a load of 138.4 MVA. In the event of sudden loss of TL207. Peak load in TL203 will increase to take up the lost load through TL207. Thus the peak load in TL203 will be slightly more than double until operators can adjust loads.

$Speak\_203 := 132.6$ MVA $\quad$ $Speak\_207 := 138.4$ MVA

$Smax := Speak\_203 + Speak\_207 = 271$ MVA

P2 Relay Settings

The existing line impedance settings are slightly different from the line data book. They should be adjusted to improve the accuracy of the fault location algorithm.

$Z1MAG := |Z1Linesec|$ $Z1MAG = 2.74$ $Z1ANG := \dfrac{\arg(Z1Linesec)}{deg}$ $Z1ANG = 78.7$

$Z0MAG := |Z0Linesec|$ $Z0MAG = 10.2$ $Z0ANG := \dfrac{\arg(Z0Linesec)}{deg}$ $Z0ANG = 81.6$

$LL203 := 44.53$

In order to obtain sensitivity to 100 ohm single line to ground faults, the echo function will be needed. Enable two forward and one reverse zone.

$PMHOZ := 3$ $GMHOZ := 3$ $QUADZ := 3$

$DIR1 := F$ $DIR2 := F$ $DIR3 := R$

Mho phase distance functions

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if the line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the SSD Station bus under weak source conditions with TL202 out of service and all of TL203, TL207 and TL237 lines in service. From ASPEN OneLiner, voltage at SSD for a 3 phase fault at WAV is 0.14 per unit. So there is less than 20% voltage at SSD during a fault at WAV under weak source conditions.

Since the voltage is not higher than 20%, the line is considered short, and a reduced Zone 1 setting is recommended to provide more security. Choose a setting of 80% of nominal.

$Z1P := 0.8 \cdot |Z1Linesec|$ $Z1P = 2.2$ Ohms secondary

Existing setting of 2.38 ohms is a little high, and will be reduced.

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 3.62 ohms secondary (about 132%) and is acceptable. No need to change.

$Z2P := 1.32 \cdot |Z1Linesec|$ $\quad Z2P = 3.62$ Ohms secondary

As can be seen from Figure 8, this element (with the proposed new setting) slightly overreaches the zone 1 element at the WAV terminal of TL237 without infeed. However, when the effects of infeed at WAV are considered, the Zone 2 at SSD will reach no more than 10% along TL237. Therefore there is no danger of the SSD Zone 2 element overreaching the WAV TL234 Zone 1 element.

The existing Zone 2 timer setting of 18 cycles will be appropriate.

$Z2PD := 18$ cycles

Zone 3

Set Zone 3 reverse element to reach further behind this terminal than the remote Zone 2. This function adds security for external faults. The element should always be more sensitive than the forward looking Zone 2 at the remote terminal. Set it the same as the remote Zone 2 overreach plus 20%

$$Z3P := Z1MAG \cdot \left(\frac{Z2P}{Z1MAG} - 1 + .2 \right) \qquad Z3P = 1.4 \quad \text{Ohms secondary}$$

$$\frac{Z3P}{|Z1MAG|} = 52 \cdot \% \quad \text{of line length}$$

This is a little higher than the existing setting, but provides additional security.

The reverse looking zone 3 element need not be set to trip through a timer. It is needed only for security in the POTT scheme.

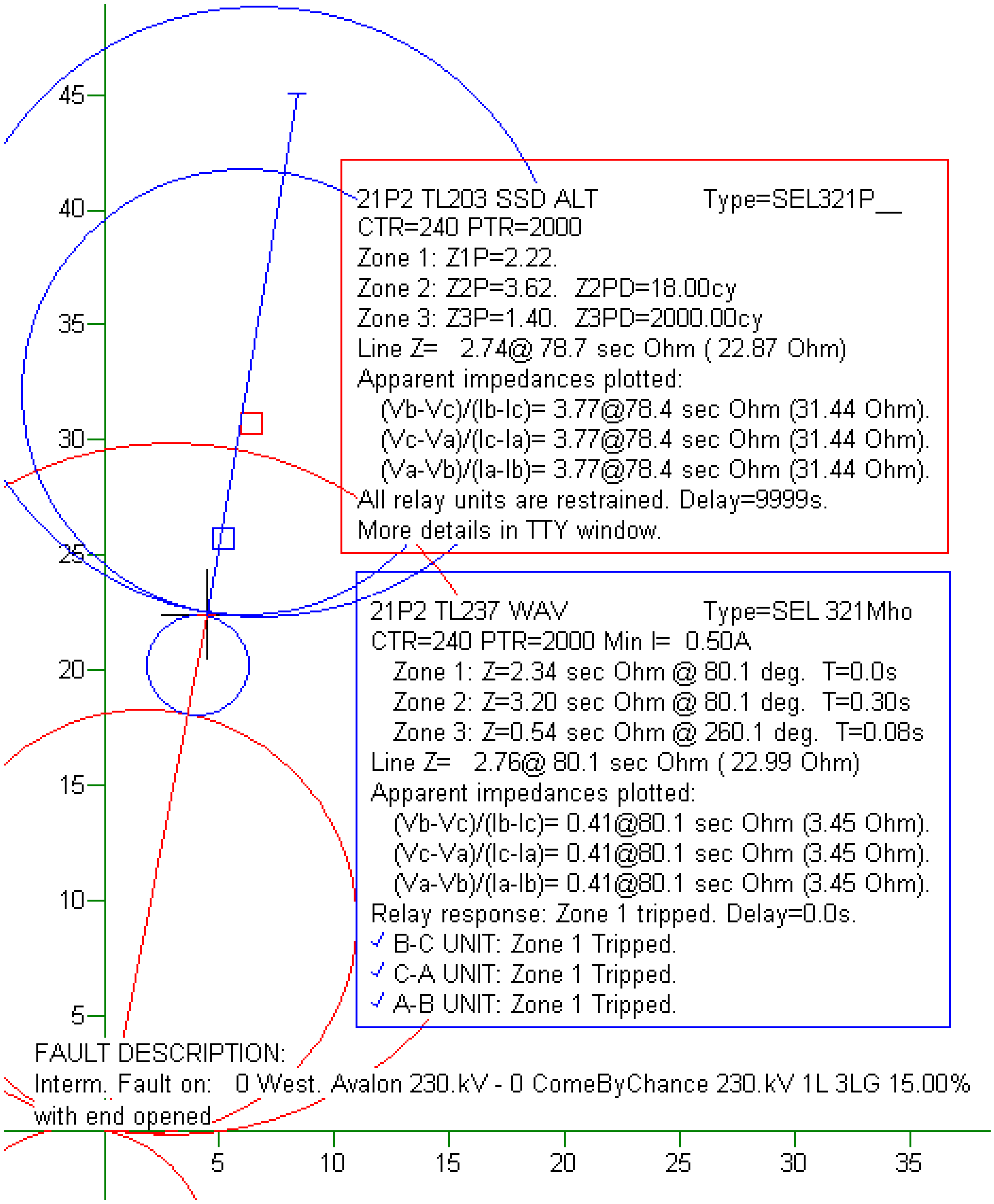


Figure 8 - Existing SSD TL203 Zone 2 reaches less than 15% of the distance along TL237 (shortest line out of WAV) with infeed, and coordinates with zone 1 on this line.

Mho phase distance current supervision

If the current supervision elements can be set above load, they will be secure in the event that potential is lost. However given that loss of potential logic is available, it is recommended that only the zone 1 current supervision function be set above load. If potential is lost, it will be able to block tripping by Zone 2 before it trips on time delay or receives a permissive trip from the remote terminal.

For the point of view of current supervision being above maximum load, there is no need to worry about abnormal conditions. It would be a double contingency for the VT signal to be lost while the parallel line was out of service. Therefore, consider a maximum load of 135 MVA. The current supervision elements for the phase distance functions measure phase to phase currents.

$IPPmax\_normal := \dfrac{Speak\_203 \cdot 1000}{kVbase}$ $IPPmax\_normal = 577$ A primary

The current supervision elements use phase to phase currents for supervision of the phase distance function;. so the minimum phase to phase fault current will be root three times the minim phase fault current. Choose a margin of 50% of the minimum phase to phase fault current for dependability.

$IPPmin := 0.5I3Pmin \cdot \sqrt{3}$ $IPPmin = 732$ A primary

A setting of 600 A primary for 50PP1 will ensure the Zone 1 function operates for any fault even under minimum source conditions but will not be susceptible to trip on load due to loss of potential under normal maximum load conditions. This is somewhat higher than the existing setting, and adds a little more security.

$'50PP1 := 2.5$ A Sec $'50PP1 \cdot CTR = 600$ A primary

Since Zone 2 and zone 3 elements will be blocked by LOP function, set them at minimum. The zone 3 current supervision should not be set higher than the zone 2 current supervision element at the remote terminal. In this case the remote zone 2 current supervision element will be set at 1.0 A secondary.

$'50PP2 := 1$ A Sec $'50PP3 := 1$ A Sec

Ground Distance Protection

The reach of the ground distance functions will be affected by mutual coupling to the parallel line. These functions will tend to underreach the remote bus while the parallel line is in service, and overreach the remote bus if the parallel line is out of service and grounded at both ends. Figure 9 shows that for a remote bus fault, with the parallel line out of service and grounded, the apparent impedance of the line is reduced to about 2.45 ohms secondary instead of the nominal 2.74 ohms. This is 89% of the actual line impedance.

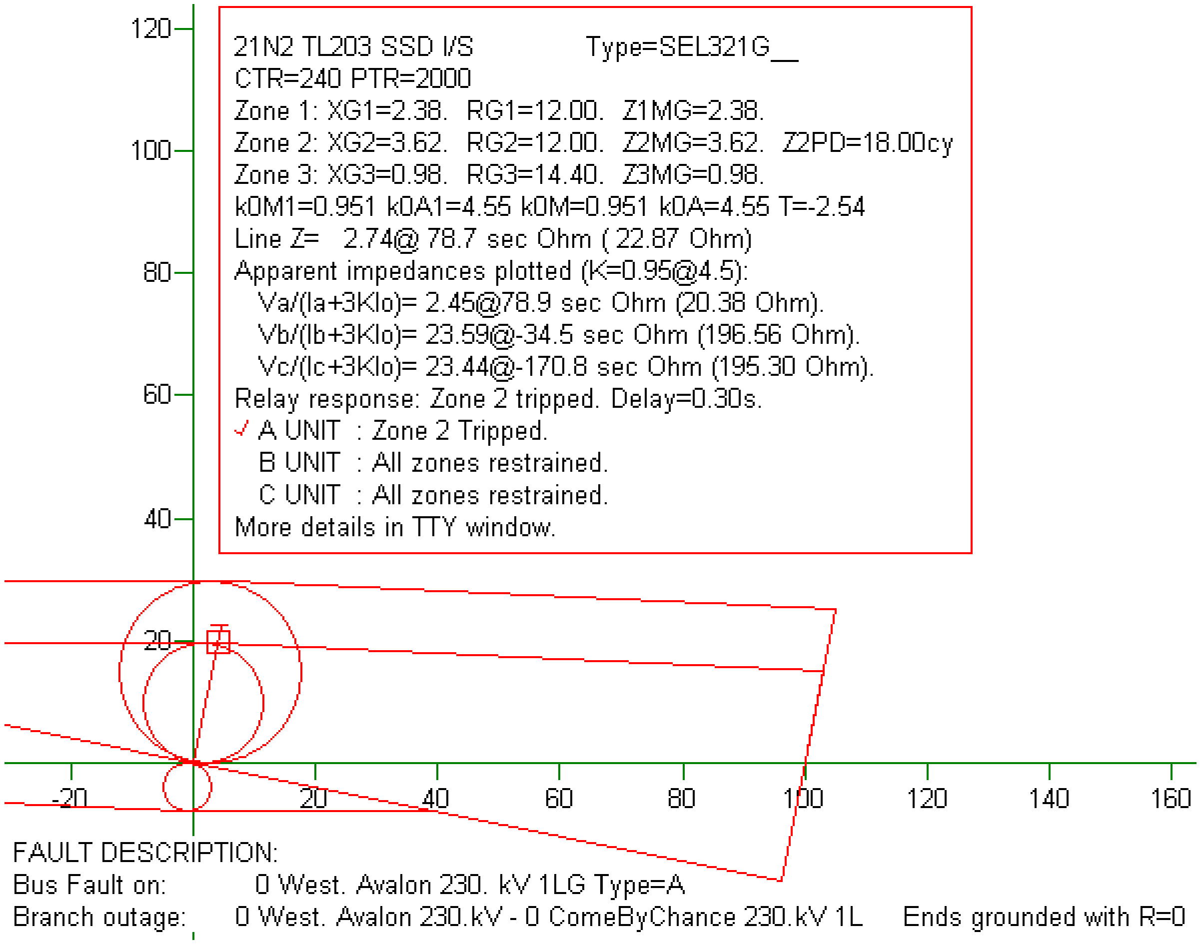


Figure 9 - Apparent impedance to a fault just beyond the remote terminal is reduced by 11% when parallel line is out of service and grounded at both ends. Existing relay settings modeled in this figure.

The normal reach of the zone 1 should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Choose a setting of 75% of the line impedance, which is lower than the setting required to make the zone 1 element more secure for faults beyond the end of this short line. Note that as will be seen later, the reduced reactive reach is required to allow a relatively large resistive reach for sensitivity while retaining security against overreach due to CT and VT errors.

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.75$ per unit

$Z1MG := m \cdot |Z1Linesec|$ $Z1MG = 2.06$

$XG1 := Z1MG$ $XG1 = 2.06$

Zone 1 Resistance

The resistive reach of the Zone 1 quad should provide enough sensitivity to trip the local terminal immediately without waiting for permission from the remote terminal for a severe fault that depresses the voltage significantly. Further, it should not allow the function to reach beyond the remote terminal due to errors in relay measurement or CT or VT. If possible, it should also operate for a 100 ohm SLG 25% of the distance from the local terminal. Operation for a 100 ohm resistive fault at the 25% location will ensure this function can trip for a close in fault without assistance from the remote terminal. The remote terminal zone 1 function will be set to operate sequentially for this fault.

By simulating a fault with 100 ohms fault resistance at the 25% of the distance from SSD, with the SSD terminal weak (as in the contingency of TL203 out of service) it is found that a reach of 12 ohms secondary will not sensethis fault. See Figure 10.

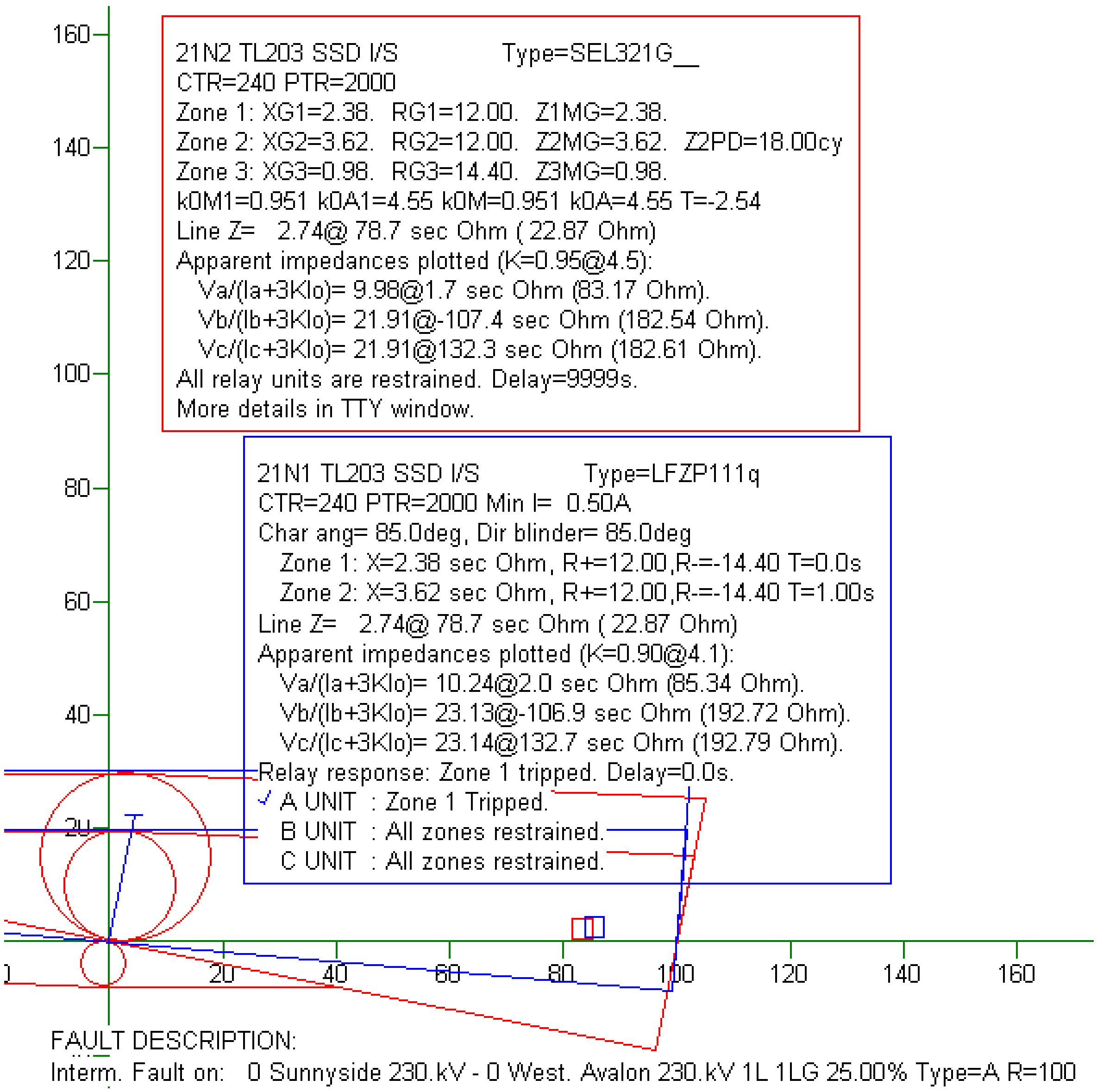


Figure 10 - SSD P2 Zone 1 function does not operate for a 100 ohm SLG fault at 25% from the local terminal (P1 function does operate)

The existing 12 ohm secondary resistive reach of the zone 1 element will not sense this fault, and would need to be increased to 20 ohms secondary. Check whether this reach will be secure, considering possible CT and VT errors.

XG1 is set at m per unit of the transmission line. The imaginary component of this is

$ImXG1sec := Im(Z1Linesec)$ $\quad ImXG1sec = 2.69$ ohms

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$RG1 := round[(1 - m) \cdot 20 \cdot ImXG1sec, 1]$

$RG1 = 13.5$ This is the maximum secure setting for the resistive reach so the desired zone 1 resistive reach setting would not be confirmed as being secure.

Use the maximum secure setting of 13 ohms for RG1 $\quad RG1 := 13$ ohms secondary

With a resistive reach setting of 13 ohms, the SSD Zone 1 quad element will see an 80 ohm resistive SLG fault immediately in front of the SSD terminal and gradually reducing resistance as the fault moves away from the terminal. Zone 2 protection will be depended upon to sense faults with resistance up to 100 ohms.

In spite of this poor sensitivity of the Zone 1 element, it should be noted that the 80 ohm resistive SLG will only depress the faulted phase voltage by about 8%; so this fault is not very severe on the system and communications assisted tripping should not have a significant negative impact on the system.

Zone 2 Ground Distance Protection

The Zone 2 ground distance function will need to be set longer than the Zone 2 phase distance protection function because it will tend to underreach the remote terminal while the parallel line is in service. By simulation in ASPEN OneLiner it is found that the apparent impedance to a zero ohm fault close in to the remote terminal is 3.2 ohms secondary, or 17% more than the actual line impedance. The reach of the Zone 2 ground distance element should be set at least to 1.25 times the apparent impedance. Choose a factor of 1.27 to make the zone 2 reach the same as the P1 protection. (Required reach is actually a little different from P1 required reach due to slightly different zero sequence current compensation factors).

$ZSLG\_remote := 3.2$

$Z2MG := round(1.27 \cdot ZSLG\_remote, 1)$ $\quad Z2MG = 4.1$ Ohms secondary

The quad element reactive reach will be set similarly to the mho.

$XG2 := Z2MG$ $\quad XG2 = 4.1$ Ohms secondary

The resistive reach of the quad will be increased to sense a 100 ohm resistive in the middle of the line with a good overlap of zone 2 elements from each end.

By trial and error from ASPEN it is found that a resistive reach of 25 ohms secondary will sense a 100 ohm SLG fault from both ends of the line between 42 to 49 percent of the distances from the SSD terminal. However since it will not overlap the Zone 1 element at the remote terminal, the permissive trip echo function will be required to ensure that a fault that is seen by the zone 2 element at only one terminal will still be cleared by the permissive trip logic.

Therefore, to avoid extremely large resistive reaches, and to retain sensitivity to 100 ohm resistive SLG faults, it is recommended that the echo function be enabled at both terminals.

R2G := 25 Ohms secondary

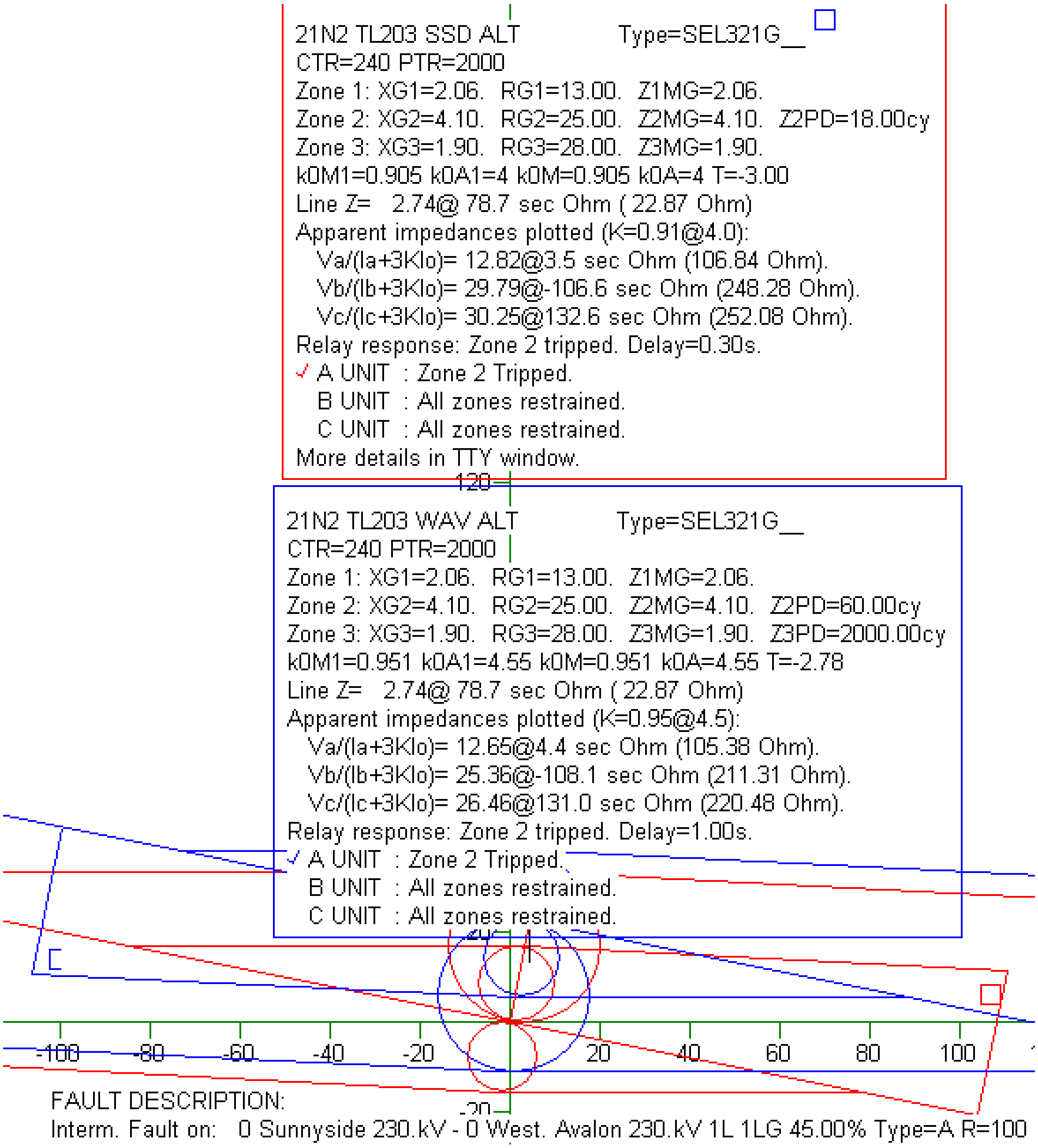


Figure 11 - Local Zone 2 Quad element operates for 100 ohm resistive SLG at 45% of the distance from the local terminal.

Since the parallel path TL207 and TL237 both trip three pole only, there is no danger of the zone 2 function tripping while the parallel line is open single phase, with heavy power flow.

The zone 2 ground distance time delay trip will need to be reduced from 60 to 18 cycles (0.3 seconds) in order to aid coordination for resistive single line to ground faults "around the loop" of TL203 TL237 and TL207 where otherwise, the ground time overcurrent functions might not have coordinated fully. Check that the Zone 2 ground distance element will not be more sensitive than the Zone 1 ground distance element on the shortest line out of SSD.

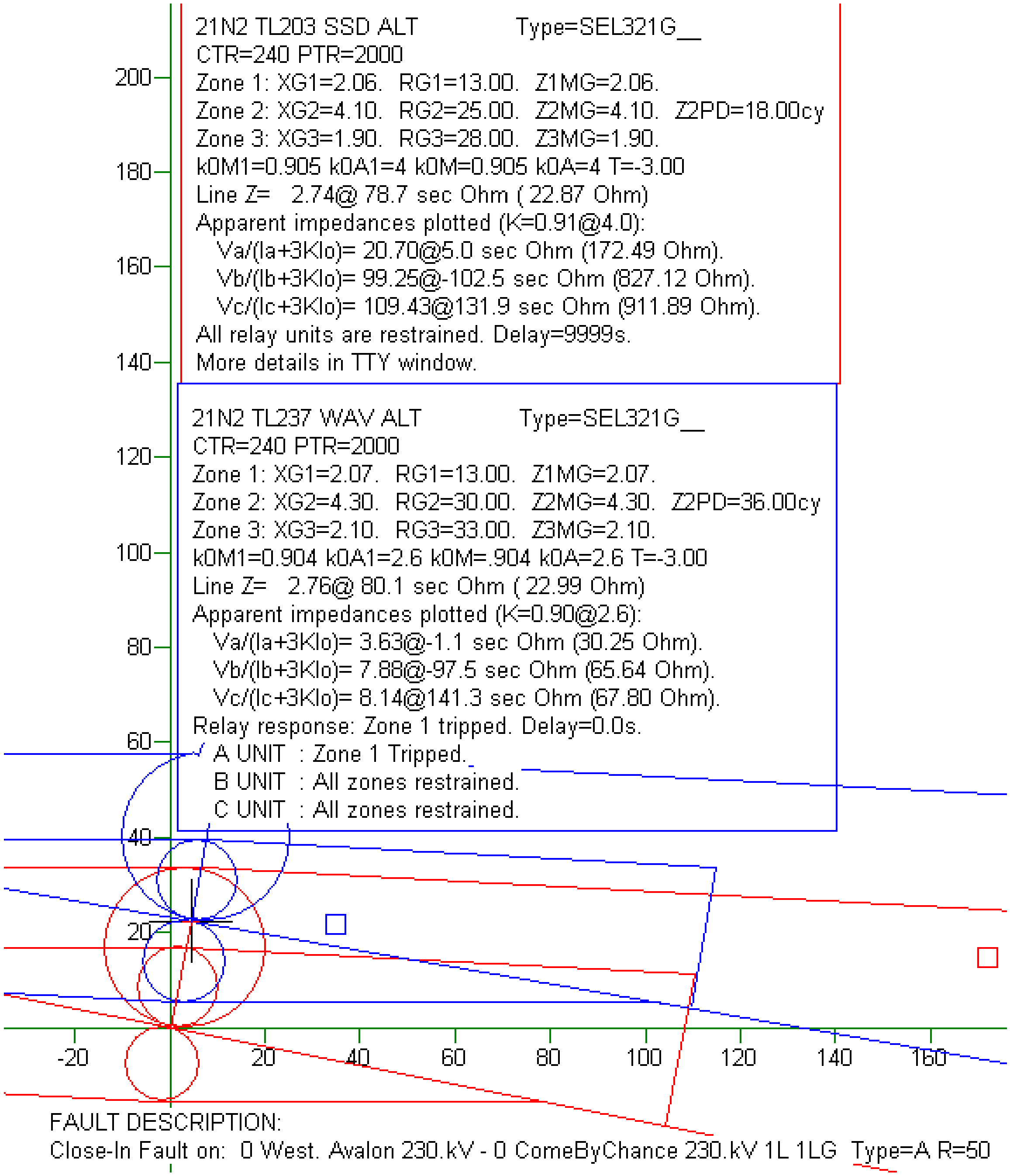


Figure 12 - Zone 2 ground distance element significantly underreaches remote Zone 1 ground distance element for resisitive faults on TL237 (other lines will be similar)

Figure 12 shows that there is no danger of the zone 2 element, even with the increased resistive reach, overreaching the zone 1 protection out of WAV. **Therefore, assuming there is not a concern with coordination with WAV transformer backup protection**, there will be no danger of miscoordination if the zone 2 ground distance function delay is reduces to 18 cycles.

Z2GD := 18 Cycles

Zone 3 Ground Distance Protection

The zone 3 ground mho function will be set using the same principles as the zone 3 phase distance function.

$Z2MGrem := 4.1$ ohms secondary

$Z3MG := Z1MAG \cdot \left(\frac{Z2MGrem}{Z1MAG} - 1 + .2 \right)$ $Z3MG = 1.9$ Ohms secondary

$\frac{Z3P}{|Z1MAG|} = 52 \cdot \%$ of line length This is a little higher than the existing setting, but provides additional security.

$XG3 := Z3MG$ $XG3 = 1.9$ Ohms secondary

Set the Zone 3 quad resistive reach at 10% more than the remote Zone 2

$R2Grem := 25$ Ohms secondary

$R3G := \mathrm{round}(R2Grem \cdot 1.1, 0)$ $R3G = 28$ Ohms secondary

Ground distance current supervision

Since there is no concern about these elements operating on load, even with loss of potential, set all current supervision elements at minimum, for maximum sensitivity of the distance elements.

$'50L1 := 0.5$ A Sec $'50L2 := 0.5$ A Sec $'50L3 := 0.5$ A Sec

$'50G1 := 0.5$ A Sec $'50G2 := 0.5$ A Sec $'50G3 := 0.5$ A Sec

Note that due to heavy infeed of zero sequence currents from the local terminal for close-in faults, the ground overcurrent detectors will not operate for faults with more than a small amount of resistance close to the remote terminal. Therefore, we will have to rely on sequential clearing for that type of fault. However setting the current supervision at minimum allows maximum sensitivity.

Zero sequence current compensation

The zero sequence current compensation could be adjusted to compensate for the significant amount of mutual coupling. However as discussed in the settings of reaches of the ground distance elements we will accept underreach of the Zone 2 function for the normal case. Set the zero sequence current compensation as usual.

$k01M := \left(\left| \frac{Z0L203 - Z1L203}{3 \cdot Z1L203} \right| \right)$ $k01M = 0.905$

$k01A := \left(\arg\left(\frac{Z0L203 - Z1L203}{3 \cdot Z1L203} \right) \right)$ $k01A = 4.06 \cdot deg$ Say $k01A := 4deg$

Set the overreaching zones the same as zone 1 $k0M := k01M$ $k0A := k01A$

$k0M = 0.905$ $k0A = 4 \cdot deg$

Non Homogenous Angle Setting

Compare the angle of the total zero sequence current at the remote bus with the angle of the zero sequence current contribution from the local terminal to determine this setting. From ASPEN OneLiner, the worst case is normal conditions. For this case, for an SLG at WAV the angle of I0 at the fault is -115 degrees and the angle of I0 out of the SSD terminal is -112 degrees. Therefore, the total fault current lags the current contribution from SSD by 3 degrees and angle T must be set negative by the difference to ensure no overreach.

$T := -3$ degrees

Out of step blocking and tripping

Not used in this application. There is a danger of out of step conditions arising. Historically no action has been taken to provide special tripping or blocking functions. Natural tripping during swings is accepted.

Load Encroachment logic

Check loadability of the Zone 2 phase distance element assuming worst case power factor of 0.87 simultaneous with worst case depressed voltage of a stressed system of 0.9 per unit. Note that units of kV squared match units of MVA. Note that quadrilateral elements are only used for the ground distance functions that are not sensitive to balanced three phase load. Therefore no need to worry about the reach of the quadrilateral elements.

$\text{Zloadmin} := \dfrac{(0.9\text{kVbase})^2}{\text{Smax}}$ $\text{Zloadmin} = 158.114$ Ohms primary (assume worst case at 30 degrees)

Maximum reach of the Zone 2 element is at the line angle of 81 degrees. At 30 degrees, the reach will be given by

$\text{Z2load} := \text{Z2P}\cdot\cos[(\text{Z1ANG} - 30)\text{deg}]$ $\text{Z2load} = 2.392$ ohms secondary

$\text{Smax} = 271$

$\text{Z2load}\cdot\dfrac{\text{VTR}}{\text{CTR}} = 19.937$ ohms primary

Since the reach of the Zone 2 element at 30 degrees is less than the apparent impedance of the maximum load, there is no need to apply load blinding logic. See Figure 13

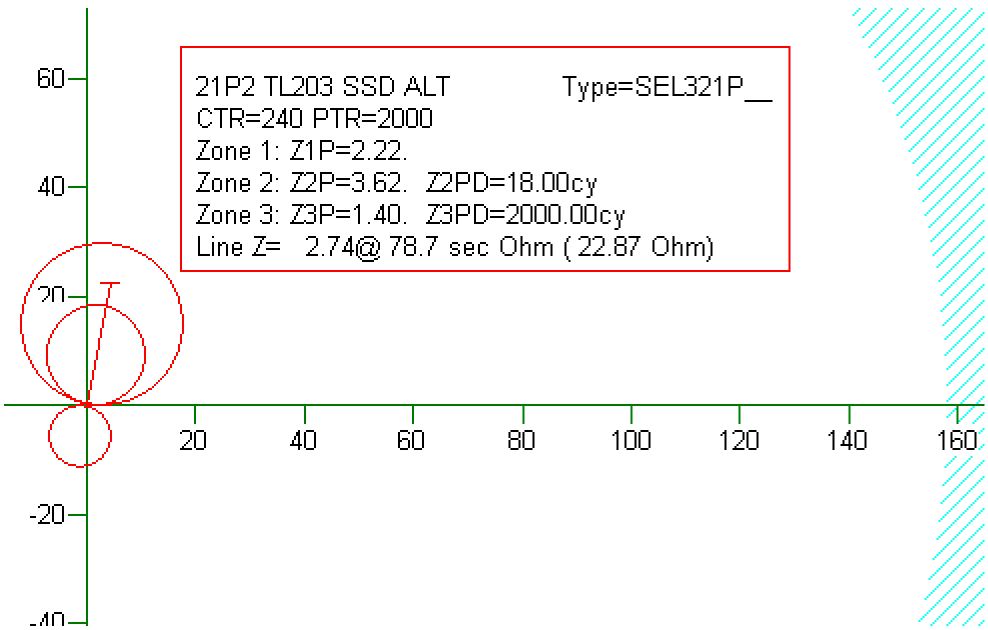


Figure 13 -Load impedance with respect to proposed new Mho function reaches.

Ground directional element

The SEL-321 application example recommends finding the minimum source impedance behind the terminal and setting the reverse and forward boundaries of the negative sequence directional element at the 1/3 and 2/3 points respectively.

In the negative sequence plane, the sum of the two source impedances and the line impedance is:

$Z2total := Z2minSSD + Z1L203pri + Z2minWAV$ $\qquad |Z2total| = 78.658$

The 1/3 point is $Z2\_1\_3 := \frac{Z2total}{3}$ $\qquad$ The 2/3 point is $Z2\_2\_3 := \frac{2Z2total}{3}$

$Z2Rpri := Z2\_2\_3 - Z2minSSD$ $\qquad |Z2Rpri| = 24.364$ $\qquad |Z1L203pri| = 22.865$

$Z2Fpri := Z2\_1\_3 - Z2minSSD$ $\qquad |Z2Fpri| = 1.932$ $\qquad |Z2minWAV| = 27.776$

$|Z2minSSD| = 28.085$

Converting the primary impedances to secondary ohms

$Z2R := Z2Rpri \cdot \frac{CTR}{VTR}$ $\qquad |Z2R| = 2.924$ Ohms secondary $\qquad arg(Z2R) = 81.128 \cdot deg$

$Z2F := Z2Fpri \cdot \frac{CTR}{VTR}$ $\qquad |Z2F| = 0.232$ Ohms secondary $\qquad arg(Z2F) = -82.003 \cdot deg$

Rounding up Z2F (note that Z2F is negative) and rounding down Z2R gives:

$Z2F := 0$ Ohms secondary $\qquad Z2R := 2$ Ohms secondary

The proposed Z2F setting is not very different from the existing settings, but the proposed Z2R setting is considerably less. The existing Z2R setting is too high.

Set the current level detectors at minimum level that will allow operation of the ground distance elements.

Due to the very small zero sequence current contribution to a single line to ground fault at the remote terminal, the negative sequence current contribution will always be higher than the zero sequence. Therefore there is no point in setting the forward looking negative sequence overcurrent elements any more sensitively than the zero sequence ground overcurrent supervision of the ground distance elements.

$'50QF := '50G2$ $\qquad '50QF = 0.5$ A secondary

Set the supervision function for the reverse looking element to be the same as, or a little more sensitive than the forward looking supervision element at the remote terminal.

$'50QR := 0.5$ A secondary

The positive sequence current restraint (a2) factor should be set just smaller than the ratio of the maximum load current (positive sequence) to the most sensitive current supervision element (50QR).

$I1maxpri := \frac{Smax \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\qquad I1maxsec := \frac{I1maxpri}{CTR}$ $\qquad I1maxsec = 2.834$

Bearing in mind that the 50QR setting is in units of 3*I2

$\frac{'50QR}{3 \cdot I1maxsec} = 0.059$ $\qquad$ Choose a value of $a2 := 0.06$

Phase time overcurrent element

This element is not used

Residual time overcurrent element

This element is used to provide the most sensitive backup protection. It will be non directional element.

Set pickup to sense a higher resistance than 100 ohm SLG in the middle of the line with equal zero sequence current infeed from both ends. Choose a resistance of 200 ohms arbitrarily. Use a safety factor of 2 so that operating time is not infinity at this fault level.

$SF := 2$ Desensitization factor due to remote end infeed is $Dfactor := 2$ $Rf := 200$

$$'51NPU := \text{round}\left(\frac{kVbase \cdot 1000}{\sqrt{3} \cdot SF \cdot Dfactor \cdot Rf \cdot CTR}, 1\right) \qquad '51NPU = 0.7$$

The existing setting of 0.5 A is more sensitive than required to sense this mid line fault with arbitrary resistance. It will be increased a little to make it more secure during SPO conditions with very heavy load.

$'51NPU := 0.6$ A secondary

Coordination checks show that existing time dial settings around the loop TL203, TL237 and TL207 (clockwise) will not coordinate, because the CBC TL207 and WAV TL237 relays are set exactly the same. Therefore if there is a fault on TL207 that has to be cleared by the ground time overcurrent relay, the WAV TL237 will trip simultaneously or not coordinate. Therefore the existing settings have to be adjusted. The ground distance elements will speed up tripping for faults with resistance up to 150 ohms fed from one end, where ground relay coordination is challenged), so coordination will be checked for faults with resistance of 150 ohms or more. Trial and error checks show that in order to achieve coordination, the existing time dial setting of CBC TL207 ground time overcurrent relay will have to have its time dial settings reduced from existing 4 to 3 and WAV TL237 pickup increased to 0.6.

Check the coordination with the other relays for three faults (all with 150 ohm resistance). Line end TL203, Close in to CBC on TL207 and 88% from WAV on TL237 (at the end of the mutually coupled section). See Figure 14 to find that existing settings (curves 2&3) do not coordinate, and Figures 14, 15 and 16 to find that revised (Curves 4, 5 and 6) settings will coordinate.

$'51NPU = 0.6$ A secondary $'51NPU \cdot CTR = 144$ A primary

$'51NTD := 4$ $'51NC := \text{"U3"}$ $'51NTC := \text{"N"}$ $'51NRS := \text{"N"}$

Checks for close-in fault show that this element will not operate in less than 0.3 seconds so there is no danger of it tripping 3 pole before the zone 1 element trips the faulted phase selectively.

Worst case load unbalance with single pole open will be in the future if single pole tripping is enabled with parallel line out of service. ASPEN OneLiner shows that with 288 MVA of load on TL203, and with one phase open, the 3I0 current is approximately 600 A. The 51N relay **with the proposed new settings** will take approximately 1.32 seconds to operate on 700 A primary. It will be (just) slow enough to override load unbalance during this SPO time with extremely heavy load.

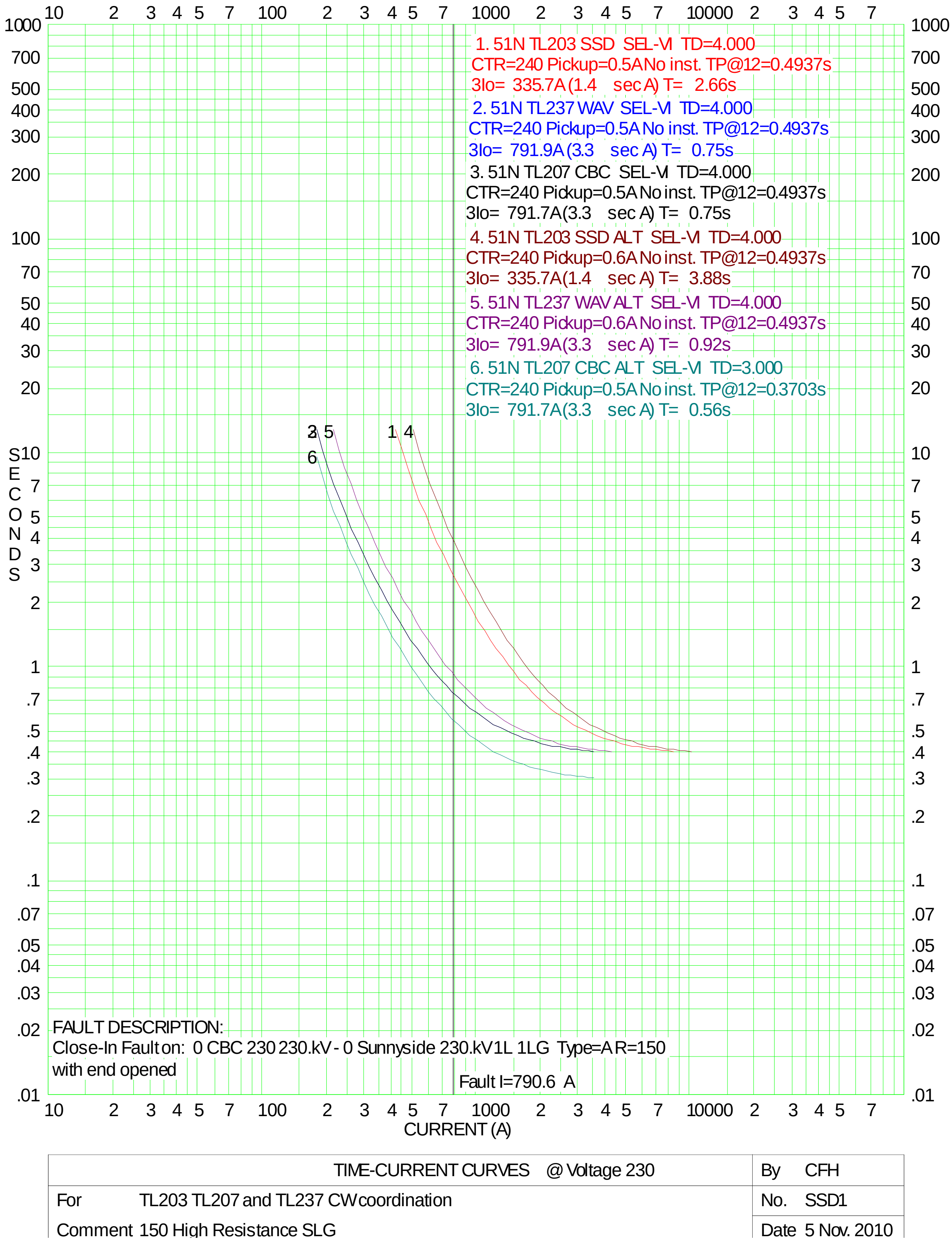
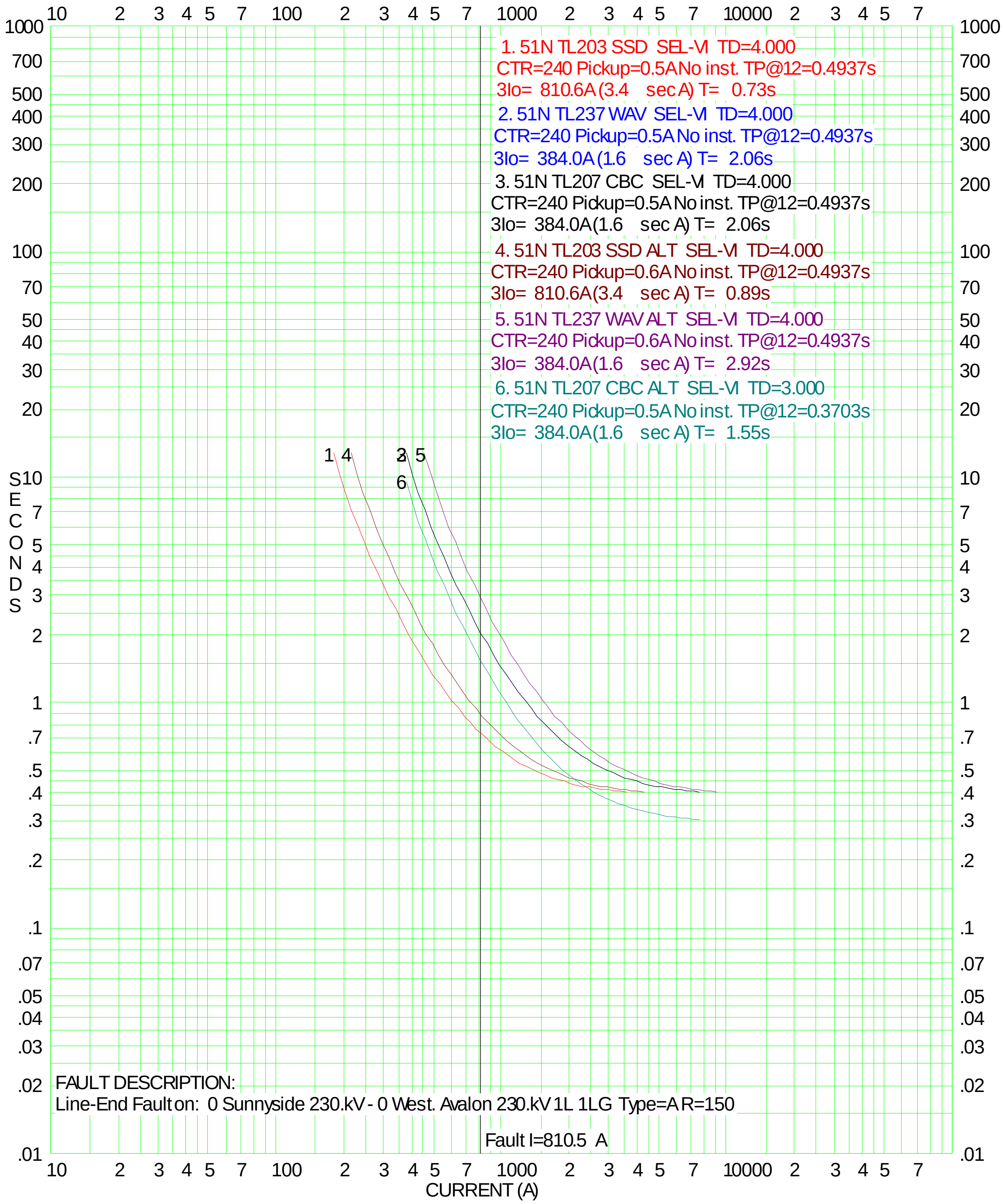
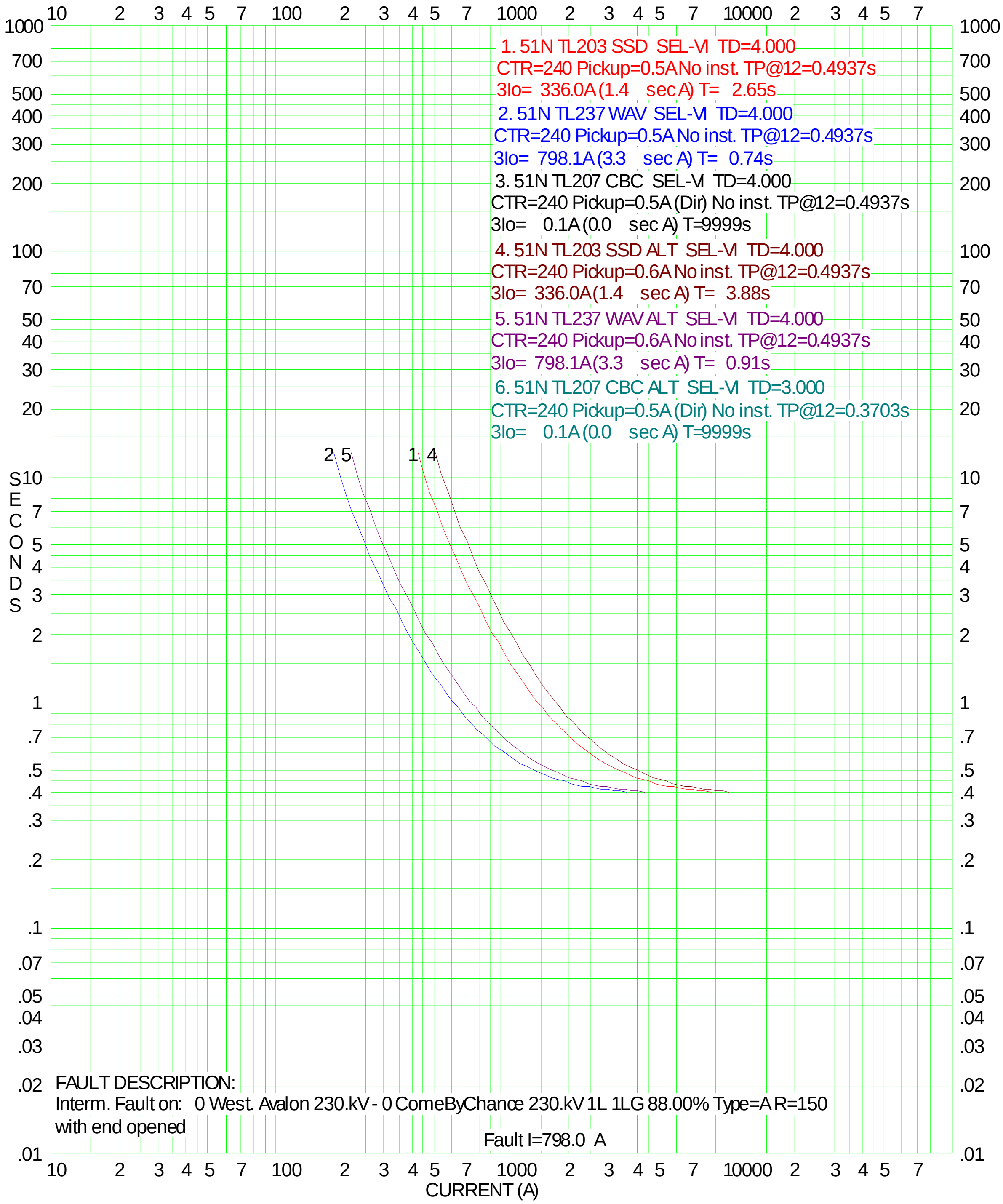


Figure 14 - coordination of ground time overcurrent elements for close-in fault on TL207 close to CBC



TIME-CURRENT CURVES @ Voltage 230	By CFH
For TL203 TL207 and TL237 CW coordination	No. SSD2
Comment 150 High Resistance SLG	Date 5 Nov. 2010

Figure 15 - coordination of ground time overcurrent elements for line end fault on TL203 close to WAV



SSD3	TIME-CURRENT CURVES @ Voltage 230	By CFH
For	TL203 TL207 and TL237 CW coordination	No. SSD3
Comment	150 High Resistance SLG	Date 5 Nov. 2010

Figure 16 - coordination of ground time overcurrent elements for intermediate fault on TL237 88% from WAV with CBC terminal open.

Permissive Overreaching logic settings

EPOTT := "Y"

Z3RBD is set at remote breaker time plus channel reset time plus channel reset time plus zone 2 reset time. From review of fault records it appears that the breaker time is 3 cycles. Channel reset time is not easily determined from existing records but can conservatively be assumed to be 1 cycle, and relay reset time will also be about 1 cycle. Total time for Z3RBD is then 5 cycles.

Z3RBD := 5 cycles

Echo block delay timer blocks the echo after the local elements have picked up. This can be set relatively long since there is no significant need for the echo function shortly after the local terminal has just seen a fault but the remote terminal has not. Set at 10 cycles as per the example in the instruction manual.

EBLKD := 10 cycles

Echo time delay on pickup should be set to override noise on the communications so that it doesn't echo noise. Typical time according to the SEL application guide is 2 cycles. Since this delay only affects clearing time for relatively light (high resistance) faults that are sensed by zone 2 function at one end, the typical setting is acceptable.

ETDPU := 2 cycles

Echo duration should be long enough to ensure the permissive trip is received by the remote terminal and should also be shorter than the Z3RBD time to ensure that the reverse blocking will always be longer than any permissive trip received (including echo time stretching).

EDURD := 4 cycles

No need to enable week feed conversion to trip, since both terminals will be quite sensitive enough to detect high resistance faults after the remote terminal has cleared. Therefore we can accept sequential (or "step") clearing with no need for the added insecurity of weak infeed tripping.

EWFC := "N" **No other communications logic settings are required for this application.**

Switch on to Fault Settings

Switch on to fault logic will ensure the protection will operate when energizing the line onto a close-in three phase fault when there is no polarizing voltage available for the distance elements.

ESOTF := "Y"

The breaker close signal is not available to the relay. The 52A method of enable SOTF will be used. Therefore the Close end delay is not critical. Typical duration for enable SOTF is 10-15 cycles

ENCLO := "N" CLOEND := 0 EN52A := "Y" SOTFD := 15

Set 50H for high magnitude close-in multiphase faults with weakest source at SSD It should be set less than 50% of the minimum close-in fault magnitude. Minimum close-in magnitude of a three phase fault with TL207 out of service is 2700 A. Therefore desired maximum setting for 50H is 1300 A.

Imin3P_close_in := 2700

$$'50H := \frac{Imin3P\_close\_in}{2CTR} \qquad '50H = 5.625 \quad \text{A secondary}$$

Choose a setting of 5 A secondary for this element. '50H := 5 A secondary

Choose a setting for 52AEND less than the shortest reclose time. '52AEND := 30 cycles

Residual overcurrent settings.

Tripping directly by instantaneous ground overcurrent is not applicable because it is not phase selective. However it would be helpful to monitor steady state unbalance, and issue an alarm for continuous unbalance. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50N := 1$ $\quad$ $'50N1 := 0.25$

Negative Sequence overcurrent settings.

Similar to ground overcurrent, apply a negative sequence overcurrent element to initiate an alarm for steady state unbalances. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50Q := 1$ $\quad$ $'50Q1 := 0.25$

Voltage Element Settings

Similar to unbalance current monitoring, it is helpful to have an unbalance voltage monitor to detect steady state unbalances from the voltage supply.

EVOLT := "Y"

Set the zero sequence overvoltage element at 1% of rated voltage or just at the point necessary to override normal unbalances. The zero sequence voltage element measures 3 times the zero sequence voltage.

$$'59N := 3 \cdot 0.01 \frac{kVbase \cdot 1000}{\sqrt{3} \cdot VTR} \qquad '59N = 1.992 \qquad \text{Say} \quad '59N := 2 \text{ V secondary}$$

Loss of Potential

Enable loss of potential settings. Advanced LOP settings are not available on this model of relay.

ELOP := "Y" $\quad$ Time delay of 1.25 cycles is commonly used. $\quad$ $LOPD := 1.25$

The 50 M element should be set above maximum load and below minimum fault current for a fault at the remote terminal under weak source conditions. The maximum load for this case should be normal maximum, not emergency maximum which only exists for a few minutes before the operator can act to reduce load.

$$Imax\_normal := \frac{Speak\_203 \cdot 1000}{\sqrt{3} \cdot kVbase \cdot CTR} = 1.387 \text{ A secondary}$$

Minimum fault current for a remote three phase fault is $\quad I3Pmin = 845 \quad$ A primary.

Minimum fault current for a remote phase to phase fault is 87% of the minimum three phase fault current level.

Dependability factor to be sure to operate for a minimum remote fault is chosen to be 1.6. $\quad DF := 1.6$

Maximum setting for 50M should be $\dfrac{0.87 I3Pmin}{DF \cdot CTR} = 1.914$ $\quad$ In this case a setting of 1.5 A secondary will be adequately dependable and secure.

$'50M := 1.5$ A secondary

The 59QL setting should be above normal maximum unbalance and below the level expected for a blown VT fuse. For a blown fuse, one phase voltage will be lost, and the negative sequence voltage will be roughly 33% of the nominal positive sequence voltage. Choose a setting of 15% of the nominal positive sequence voltage. This will be well above any normal unbalance.

$'59QL := \text{round}\left(\frac{0.15\cdot \text{kVbase}\cdot 1000}{\sqrt{3}\cdot \text{VTR}}, 0\right)$ $'59QL = 10$ V secondary

The 59PL setting should be less than the minimum voltage to be expected for a remote bus fault under weakest source conditions. There is no minimum setting (above zero) for this function. Choose a setting equal to half the voltage drop along the line impedance at the pickup setting of the 50M element.

$'59PL := \text{round}[0.5\cdot('50M\cdot|Z1Linesec|), 0]$ $|'59PL| = 2$

Miscellaneous Scheme Settings

Pole discoordinance logic is not being used. EPOLD := "N" SPPDD := "N/A"

Enable single pole tripping by distance elements only ESPT := "Y"

Enable single pole open ESPO := "Y"

Set single pole open time delay for future SPO conditions SPOD := 0.25

3 Pole open reset delay to override small discrepancies in pole closing '3POD := 0.5

Stub line protection is not required ESTUB := "N" '50MFD := "N/A"

Trip unlatch logic not applied TULO := "N"

Logic variables and Miscellaneous timers

Minimum trip duration timer is set at 9 cycles as per the application example in the SEL-321 instruction manual.

TDURD := 9 Cycles

Trip during open pole time delay should be set longer than the reclose time. Existing setting is OK.

TOPD := 55 Cycles

Proposed logic for X, and Y variables is intended to create a three pole trip if a permissive trip is received any time within a period of 25 to 60 cycles after a single pole trip was asserted. This is presumably standard NL Hydro logic. It enables more sensitive protection during the open pole period, because only one terminal has to see a fault in order for the three pole trip to be implemented.

Retain existing settings except use time ZT to trigger an alarm for sustained unbalance.

LOGIC_Z := "59N+50N1+50Q1" TZPU := 1200 cycles TZDO := 0 cycles

Tripping Logic

Permissive tripping is required only for instantaneous overreaching functions. No need for any functions that trip directly. Existing 51NT word in MTCS is not required.

MTCS := "M2P+Z2G"

Unconditional tripping MTU := "M1P+Z1G+M2PT+Z2GT+51NT"

No need for existing direct tripping zone 1 functions in the switch on to fault logic.

SOTF Tripping MTO := "M2P+Z2G+50H"

Event records will be triggered automatically by all trip events. Other event record triggers should be by starting of other elements to ensure capture of all relevant events. Events should be triggered by keying or receiving permissive trips to ensure separation of relay and teleprotection issues.

MER := "M2P+Z2G+51N+LOP*52AA1+LOP*52AA2+KEY+PT+EKEY"

Outputs

Retain existing output assignments except add the continuous unbalance alarm to OUT15.

OUT15 := "LOP*50L+ZT"

Input Contact Assignment

It would be desirable to provide phase segregated inputs to the relay so that the quadrilateral functions could be disabled during single pole open conditions. Sufficient separate inputs are presently available for phase segregated breaker status inputs. It is recommended to replace the existing 52bx breaker status inputs with phase segregated breaker status inputs.

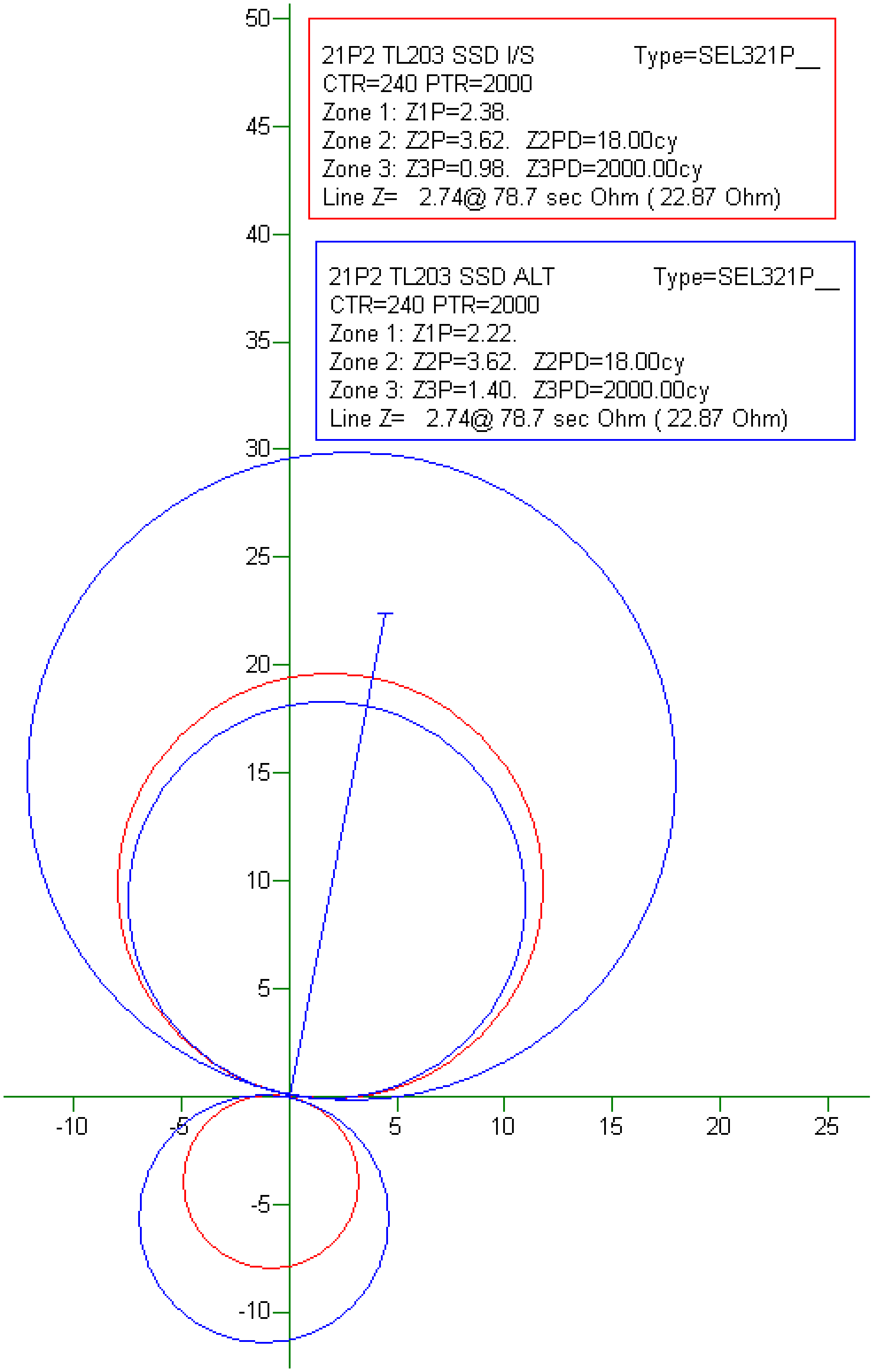


Figure 17 - Comparison of phase distance characteristics. Red is existing, blue is proposed alternative

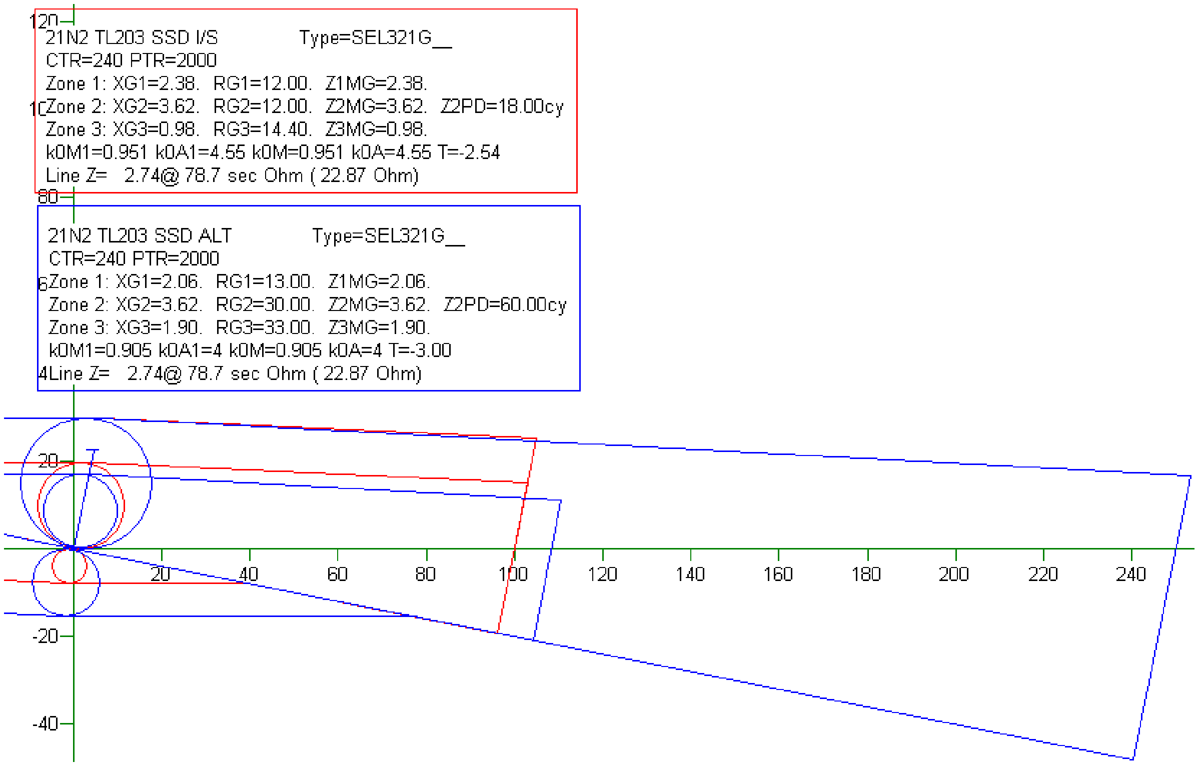


Figure 18 - Comparison of ground distance characteristics. Red is existing, blue is proposed alternative

Protection Review for Five 230 kV Transmission Lines

Appendix I
Detailed settings review for WAV TL203 "P1" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Western Avalon (WAV) terminal of circuits TL203 . This 230 kV transmission circuit is from Sunnyside (SSD) to Western Avalon (WAV)
The circuit runs parallel to TL237 for most of its length.

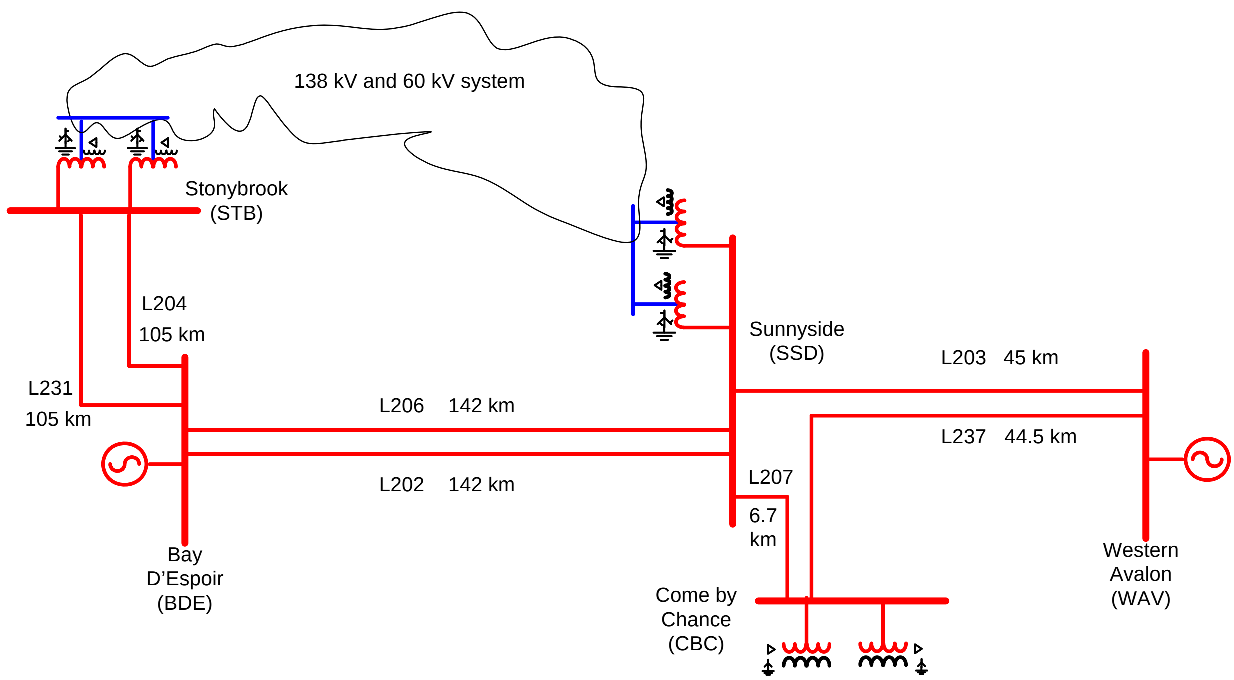


Figure 1 - System Single Line Diagram

Existing P1 protection systems are Areva LZFP111 (Optimho) systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $\quad$ $kVbase := 230$ $\quad$ $Ibase := \frac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\quad$ $Zbase := \frac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $CTR := \frac{1200}{5}$ $\quad$ VT ratio is: $VTR := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**Hydro Interconnected System (2010-08-13) V10.olr**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with all shunts ignored (unless needed for load flow simulation).
Minimum fault current seen by each terminal (phase to phase, and SLG with 100 ohm fault resistance).

At WAV with Circuit TL217 out of service, and TL207 and TL237 lines in service, for a fault at the remote terminal.

ILLmin := 814 A ISLGminPH := 768 A ISLGmin0seq := 312 A

The optimho current level detectors that block the distance comparators in the event of line opening are fixed at 5% of the rated current, or 0.25 A secondary, or 60 A primary. They will have no difficulty in operating for minimum fault levels. However, the ground distance elements are also supervised by a low set neutral current level detector (LDLSN that requires the neutral current to be greater than 10% of the maximum amplitude of phase difference current. This prevents the ground comparators from operating during close-in multiphase faults with CT errors. ASPEN OneLiner shows that for a bolted fault at the remote bus even under heavy load, there is sufficient neutral current (22% of maximum phase to phase fault current) that means this LDLSN function does not inhibit the ground distance comparator.

Calculate the minimum negative sequence source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind SSD $Z2minSSD := 3.22 + j \cdot 27.90$ ohms primary

Minimum um source impedance behind WAV $Z2minWAV := 2.75 + j \cdot 27.64$ ohms primary

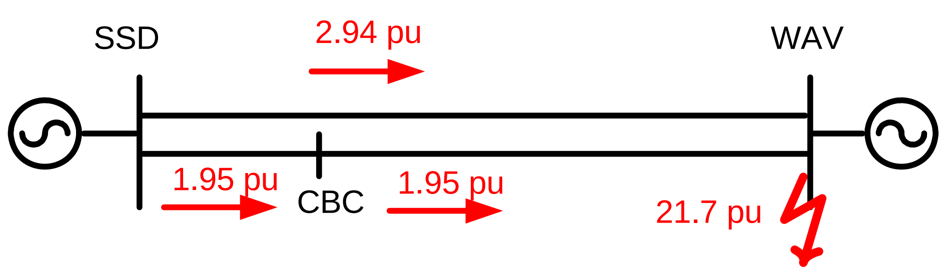


Figure 2 - 3 Phase Fault at WAV

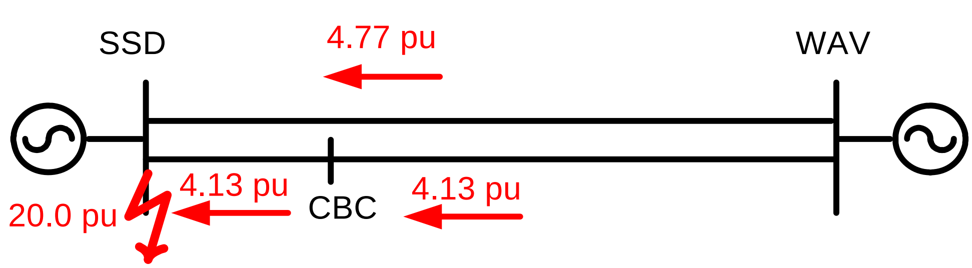


Figure 3 - 3 Phase Fault at SSD

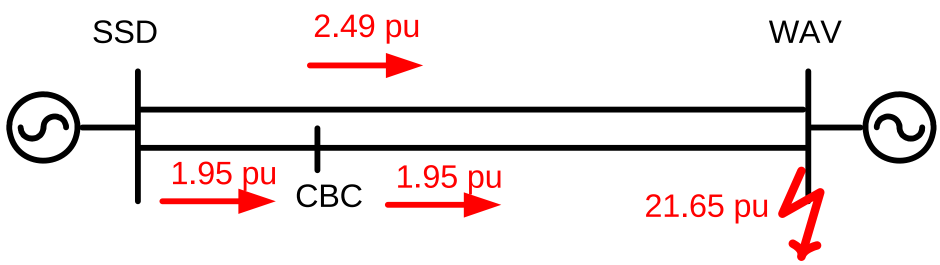


Figure 4 - SLG Fault at WAV (3I0 currents)

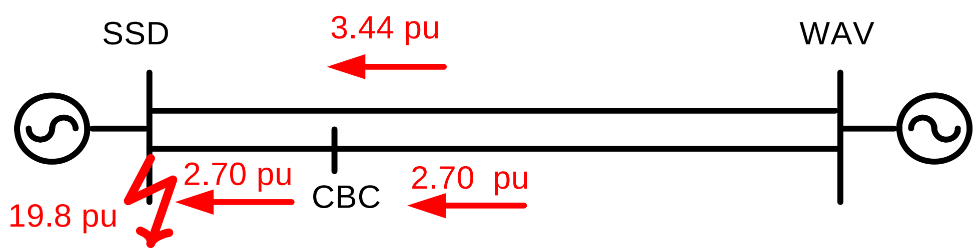


Figure 5 - SLG Fault at SSD (3I0 currents)

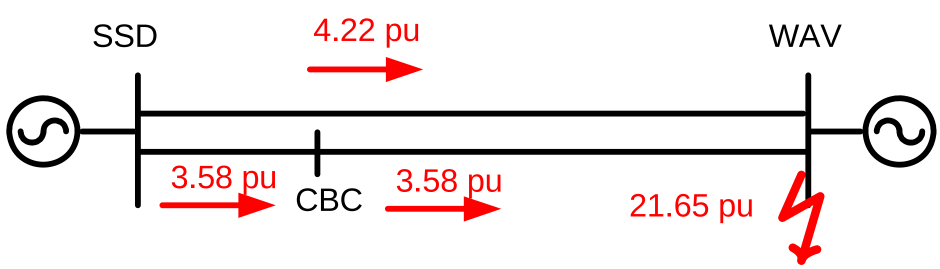


Figure 6 - SLG Fault at WAV (Phase currents)

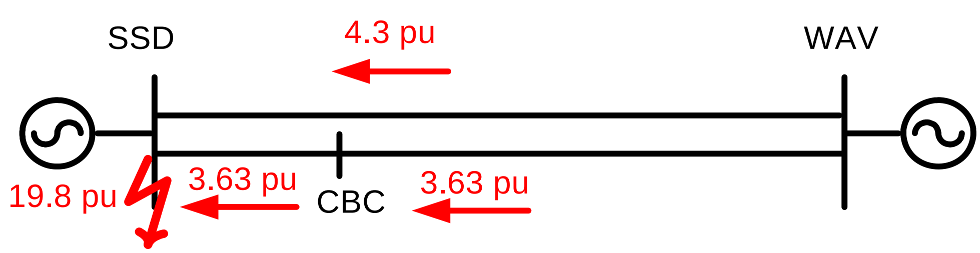


Figure 7 - SLG Fault at SSD (Phase currents)

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L203 := 0.0085 + j \cdot 0.04238$ $\quad$ $Z0L203 := 0.02337 + j \cdot 0.15876$

In primary ohms

$Z1L203pri := Z1L203 \cdot Zbase$ $\quad$ $Z0L203pri := Z0L203 \cdot Zbase$

In secondary ohms

$Z1Linesec := Z1L203pri \cdot \frac{CTR}{VTR}$ $\quad$ $Z0Linesec := Z0L203pri \cdot \frac{CTR}{VTR}$

$|Z1Linesec| = 2.744$ $\quad$ $\arg(Z1Linesec) = 78.659 \cdot deg$

$|Z0Linesec| = 10.187$ $\quad$ $\arg(Z0Linesec) = 81.626 \cdot deg$

Zero sequence mutual coupling between TL203 and TL237 is $Z0m := 0.0132 + j \cdot 0.0697$ (per unit)

Load Data

From 2010 System peak load case provided in start up information, the peak load is given as 132.6 MVA (with TL203, TL207 and TL237 in service). The highest load of the three lines is TL207 with a load of 138.4 MVA. In the event of sudden loss of TL207. Peak load in TL203 will increase to take up the lost load through TL207. Thus the peak load in TL203 will be slightly more than double until operators can adjust loads.

$Speak\_203 := 132.6$ MVA $\quad$ $Speak\_207 := 138.4$ MVA

$Smax := Speak\_203 + Speak\_207 = 271$ MVA

P1 Relay Settings

Distance element reach settings

Note that resistive reaches are forced to be the same for all zones. Reactive reaches for phase and ground distance elements must be the same as each other.

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the SSD Station bus under weak source conditions with TL202 out of service and all of TL203. TL207 and TL237 lines in service. From ASPEN OneLiner, voltage at SSD for a 3 phase fault at WAV is 0.16 per unit. So there is less than 20% voltage at WAV during a fault at SSD, under weak source conditions.

Since the voltage is not higher than 20%, the line is considered short, and a reduced Zone 1 setting is recommended to provide more security. Choose a setting of 80% of nominal.

$Z1P := 0.8 \cdot |Z1Linesec|$ $\qquad Z1P = 2.2$ $\qquad$ Ohms secondary

Existing setting of 2.38 ohms is a little high, and should be reduced especially as the ground distance function will be subject to a little overreach if TL237 is out of service and grounded at both ends. The ground distance reach in the optimho has to be set the same as the phase distance reach; so we need to consider the ground faults too.

The reach of the ground distance element will limit the reach of the zone 1 function. It can be seen from Figure 8 that the apparent impedance presented to the relay for a fault at the remote bus when the parallel line is out of service and grounded at both ends is less than the line impedance.

$Zapp\_ext := 2.44$ ohms $\qquad Zapp\_ang := 79.2deg$ $\qquad$ This angle is close enough to the line angle to treat it as equal to the line angle.

$$\frac{Zapp\_ext}{|Z1Linesec|} = 0.889$$

The apparent impedance is reduced by about 11% due to the effect of the parallel line being out of service and grounded at both ends.

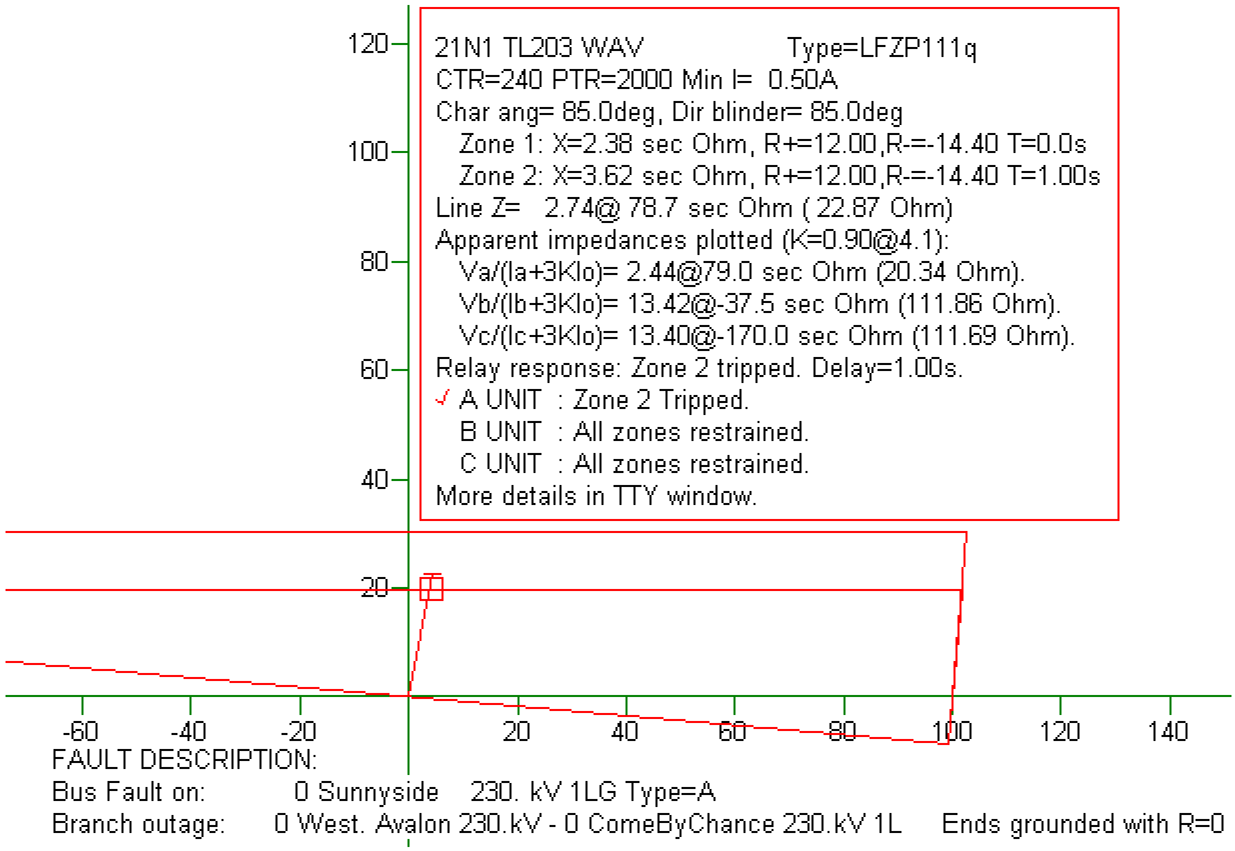


Figure 8 - Apparent impedance to a fault just beyond the remote terminal is reduced by 11% when parallel line is out of service and grounded at both ends.

The normal reach of the zone 1 should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Choose a setting of 75% of the line impedance, which is lower than the setting required to make the zone 1 element more secure for faults beyond the end of this short line. Note that as will be seen later, the reduced reactive reach is required to allow a relatively large resistive reach for sensitivity while retaining security against overreach due to CT and VT errors.

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.75$ per unit

$Z1\_sec := m \cdot |Z1Linesec|$ $Z1\_sec = 2.06$ Ohms secondary

$Z1pri := Z1\_sec \cdot \frac{VTR}{CTR} = 17.149$ Ohms primary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 3.62 ohms secondary (about 132%). However, in order to dependably reach a single line to ground fault at the remote terminal, it will be necessary to set the reach significantly further.

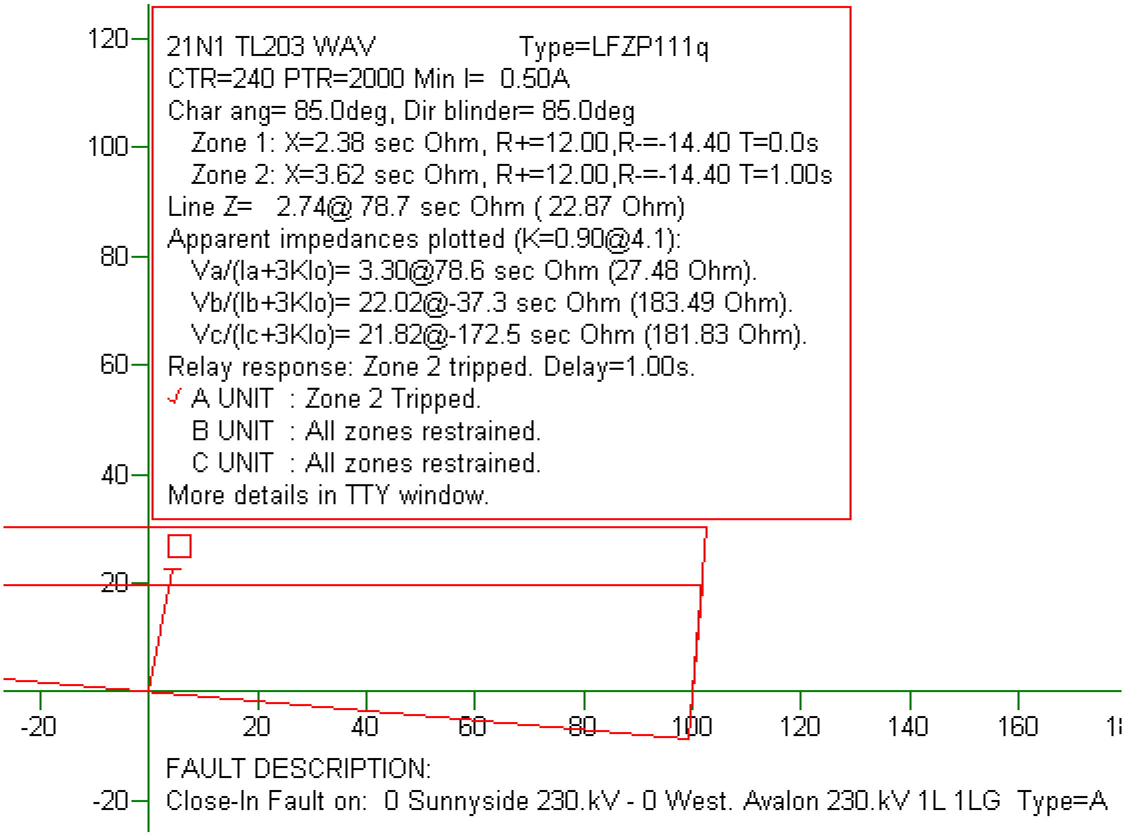


Figure 9 - Apparent impedance to a fault close to the remote terminal is increased by 20% when parallel line is in service.

As can be seen from Figure 9, the apparent impedance to a fault close to the remote terminal is increased when the parallel line is in service.

Zapp_int := 3.3 Ohms secondary

Z2_sec := 1.25·Zapp_int Z2_sec = 4.1 Ohms secondary $\frac{Z2\_sec}{|Z1Linesec|} = 150 \cdot \%$

$Z2\_pri := Z2\_sec \cdot \frac{VTR}{CTR} = 34.375$ Ohms primary

Since TL207 is very short, it is likely that the Zone 2 function will overreach the SSD TL207 P2 zone 1 element, at least under some circumstances. Indeed, from Figure 10 below, it can be seen that the Zone 2 ground distance function does overreach the SSD TL207 zone 1 element for a close in resistive fault, and trips at the same time as the SSD TL207 zone 2 element. Since the SSD TL207 zone 2 element is already set at 0.6 seconds, there is no room to reduce the existing 1 second delay on the zone 2 tripping for this IWAV TL203 function.

Z2T := 1 Second

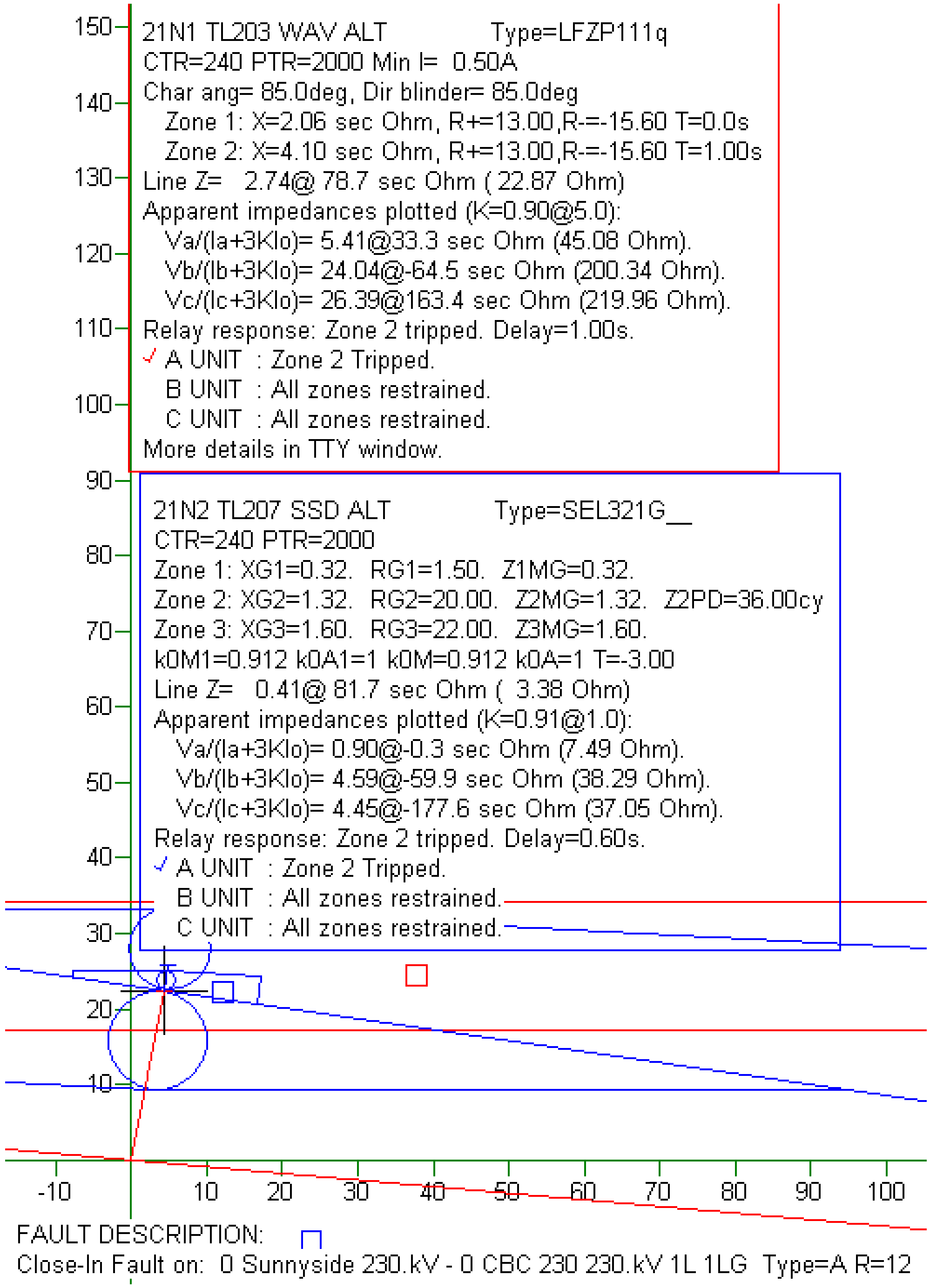


Figure 10 - WAV TL203 Zone 2 ground distance function overreaches SSD TL207 P2 zone 1 ground distance for a resistive fault near SSD.

Zone 3

The zone 3 function is not used since the POR1 scheme does not include an echo function so there is no need for any reverse blocking function. Since the Zone 2 timer has to be set with the coordination of the ground distance element in mind, it is set at 2 second; so there is no benefit in applying a longer reaching zone 3 function.

Zone 3 element is blocked - same as existing.

Load Encroachment logic

The optimho instruction manual recommends a margin of at least 10% between the impedance of the maximum load and the resistive reach of the quadrilateral distance element.

Check loadability of the Zone 2 phase distance element assuming worst case depressed voltage of a stressed system of 0.9 per unit.

$$Zloadmin := \frac{(0.9kVbase)^2}{Smax} \qquad Zloadmin = 158.114$$

Ohms primary (assume worst case at 30 degrees)

$$Zloadmin\_sec := Zloadmin \cdot \frac{CTR}{VTR} \qquad Zloadmin\_sec = 18.974$$

$Smax = 271$ MVA

A 13 ohm secondary resistive reach is less than 90% of the load impedance at anyypower factor and meets the Areva criterion.

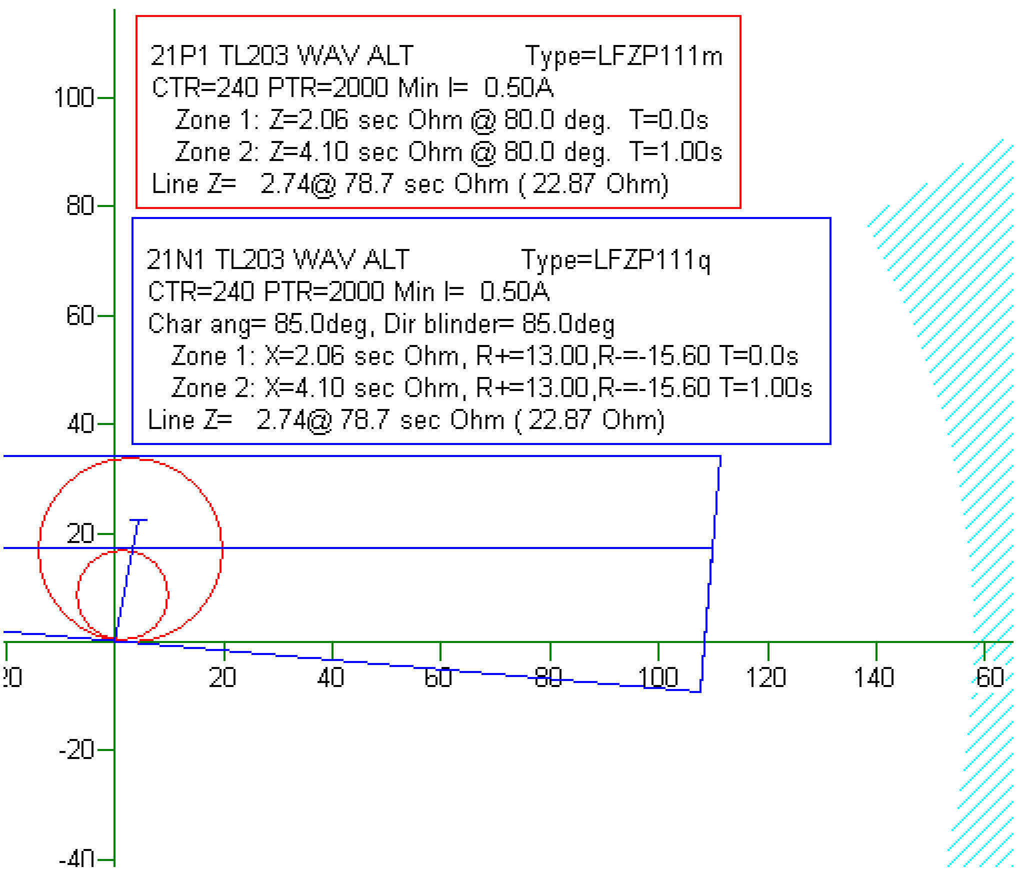


Figure 10 - Apparent impedance of load

Zone 1 Resistance - QUAD

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$R1Qmax := round[(1 - m) \cdot 20 \cdot Im(Z1Linesec), 2]$ ohm

$R1Qmax = 13.45\,\Omega$ This is the maximum secure setting for the resistive reach and is less than the existing zone 1 resistive reach setting. The existing setting of 12 ohms will be secure enough - but will it be sensitive enough?

With the existing resistive reach setting of 12 ohms, there will be a region of 10% of the line in which neither terminal will see a 100 ohm fault. If the resistive reach is increased to 13 ohms, one or the other terminal will (just) be able to sense a 100 ohm SLG on any portion of the line.

Increase the resistive reach setting from 12 to 13 ohms $Rquad := 13$ ohms secondary.

Check the maximum fault resistance that can be sensed for a fault at a location where the current contribution from each terminal is roughly the same. From Figure 11, it can be seen that the limit of sensitivity is about 100 ohms, for a fault about 56% of the distance from WAV This meets the required sensitivity of 100 ohms.

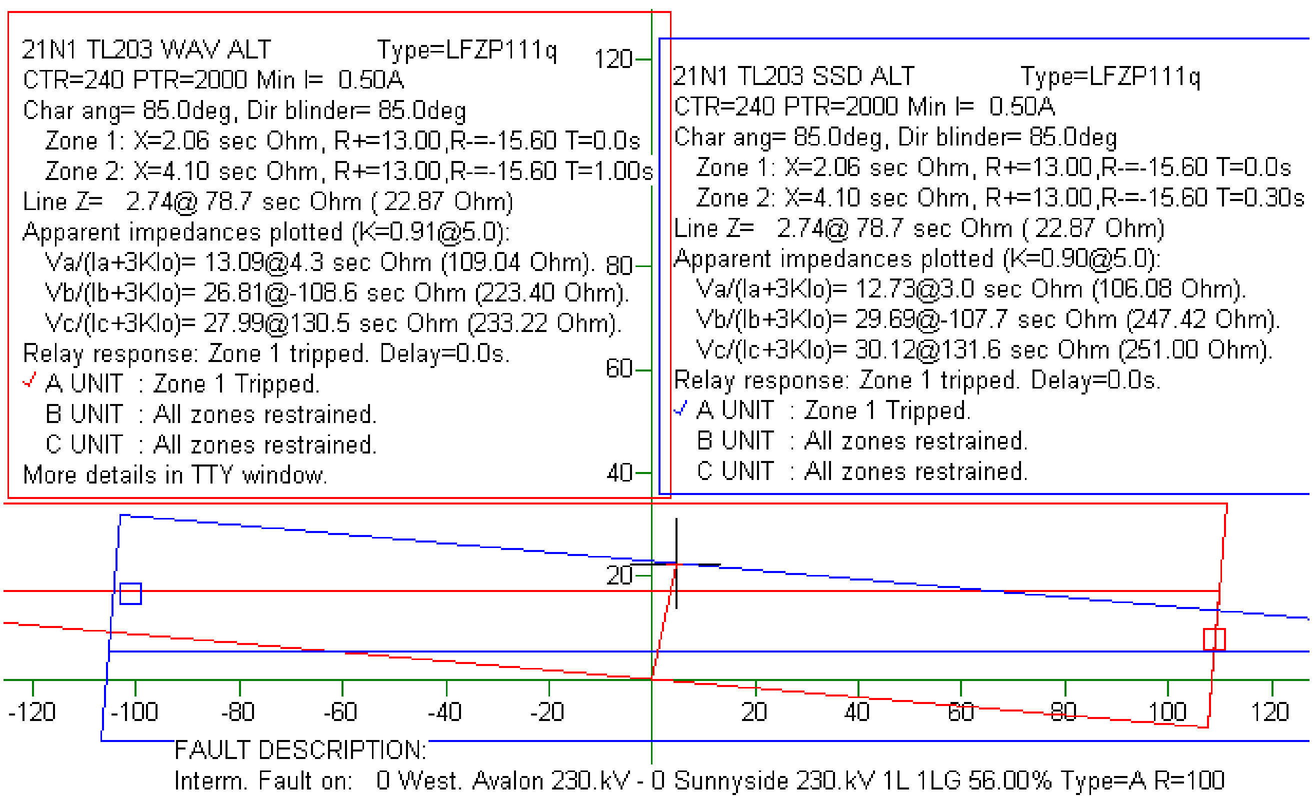


Figure 11 - Apparent impedance of a resistive fault near the mid point of the line.

Settings of K attenuators

KZPh Coarse setting common to all DISTANCE zones should be set as high as possible while below the required Zone 1 reach. The current level detectors vary inversely with KZph. Maximum setting available is 1.0

$KZPh := 1.0$

Zone 1 attenuators and angular selection

$In := 5$ $\quad Z1\_sec = 2.06$ This is the desired secondary reach (previously calculated)

$$KZ1 := \frac{Z1\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ1 = 2.06 \qquad Z1sec\_reach := KZ1 \cdot KZPh \cdot \frac{5}{In} \qquad Z1sec\_reach = 2.06$$

$Z\theta PH := (\arg(Z1Linesec))$ $\quad Z\theta PH = 78.659 \cdot deg$

Rounded to the nearest 5 degrees $\quad Z\theta PH := 80$ Degrees

$Z\theta N := \arg(Z0Linesec - Z1Linesec)$ $\quad Z\theta N = 82.7 \cdot deg$

Rounded to the nearest 5 degrees $\quad Z\theta N := 85$ Degrees

Zone 2 attenuators selection

$Z2\_sec = 4.1$ This is the desired secondary reach (previously calculated)

$$KZ2 := \frac{Z2\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ2 = 4.1$$

Zone 3 is not used

QUAD Resistive Reach setting

$Rquad = 13$ This is the desired secondary reach (previously calculated)

$$KR := \frac{Rquad}{\left(\frac{5}{In}\right)} \qquad KR = 13$$

Residual Compensation attenuators selection

Zero sequence current compensation for ground faults is provided by the KZN factor. Zero sequence mutual compensation is not used in this application (it causes extra complexity for only moderate gain in setting accuracy).

$$KZN := \frac{Z0Linesec - Z1Linesec}{3 \cdot Z1Linesec} \cdot KZPh \qquad KZN = 0.903 + 0.064j$$

$|KZN| = 0.905$ This the same as the existing setting

Switch On To Fault (SOTF) Protection.

If SOTF is enabled, it can be set to 200ms or 110 s after all poles of the line have been de-energized. The 110 s setting is intended to override automatic reclosing dead time. However it makes more sense to enable after the shorter time. Once the SOTF feature has been initiated, it remains in effect for 250ms after the line has been re-energized. The SOTF tripping options are:

a) Any distance comparator.
b) Any current level detector as long as a corresponding voltage level detector has not picked up within 20ms.
c) Either current or distance, as long as a corresponding voltage level detector has not picked up within 20ms.

SOTF := "Enabled"

SOTF_TIME := 0.20 Seconds

Elements_in_SOTF := "BOTH" (Both Comparators and current level detectors).

Power Swing Detector

This element will not be used. It will be left Blocked, and if there is a power swing, the distance elements will trip naturally.

VT Supervision

Set the VT supervision to BLOCK TRIP

Set the VT fail detection to SELF RESET this is as existing on WAV TL201 and TL237, but different from the existing on TL203.

SELF_RESETTING := "ENABLED"

Start Indication

This function will bring up information on the LCD screen of the relay if a start event occurs. This function will not be used.

START_INDICATION := "BLOCKED"

Communications assisted logic.

The existing communications assisted logic is permissive overreaching transfer trip, scheme **POR 1**. This scheme is familiar to Newfoundland and Labrador Hydro, and even though the POR 2 scheme offers the advantage of weak infeed echo, which would help the sensitivity to resistive faults, it is not recommended to change the existing scheme logic at this stage with years of experience on a product that is nearing the end of its useful life.

The POR 1 logic is a basic permissive overreaching transfer trip scheme but it does include current reversal timers to increase security against misoperation due to current reversal when a fault on the parallel line is cleared sequentially. The current reversal logic is achieved by a timer TP which will block permissive tripping and keying of permissive trip if the local zone 2 element does not pick up within a reasonable time of receiving permissive trip. The block will be maintained for a time delay of TD after the local zone 2 element picks up, or the received permissive trip signal resets.

The application of the current reversal timers is required only if the settings of the zone 2 comparators are greater than 1.5 times the line impedance. Since the reaches of these elements are less than or equal to 1.5 times the line impedance, the current reversal logic is not required, and the recommended default settings are as existing>

TP := 98 ms
TD := 0 ms

Comparison of Existing (red) and Proposed alternative (ALT) settings.

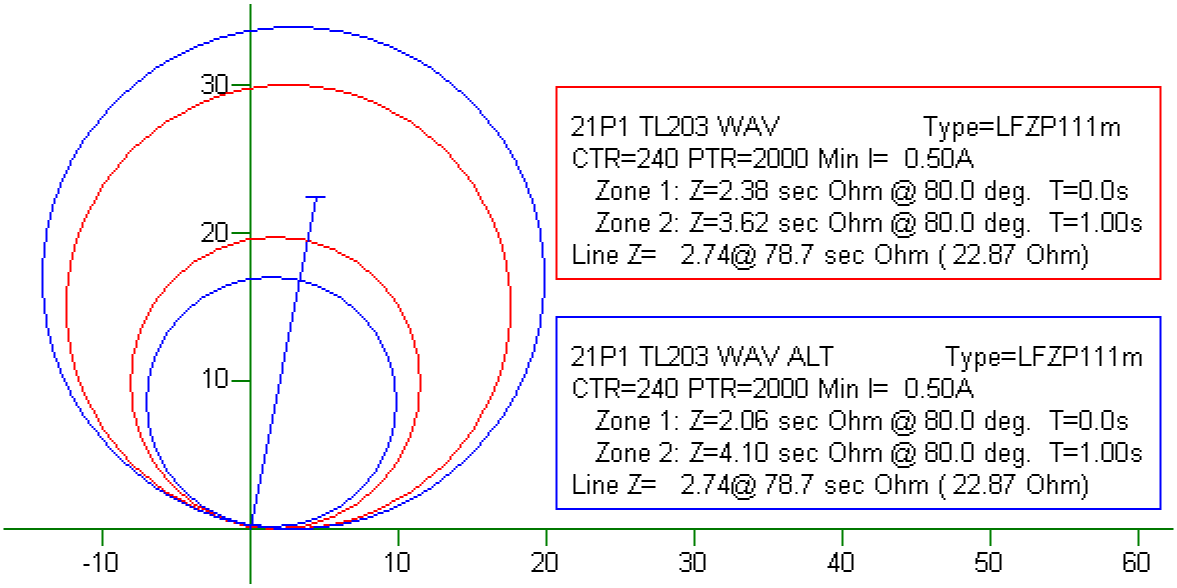


Figure 12 - Comparison of phase distance characteristics

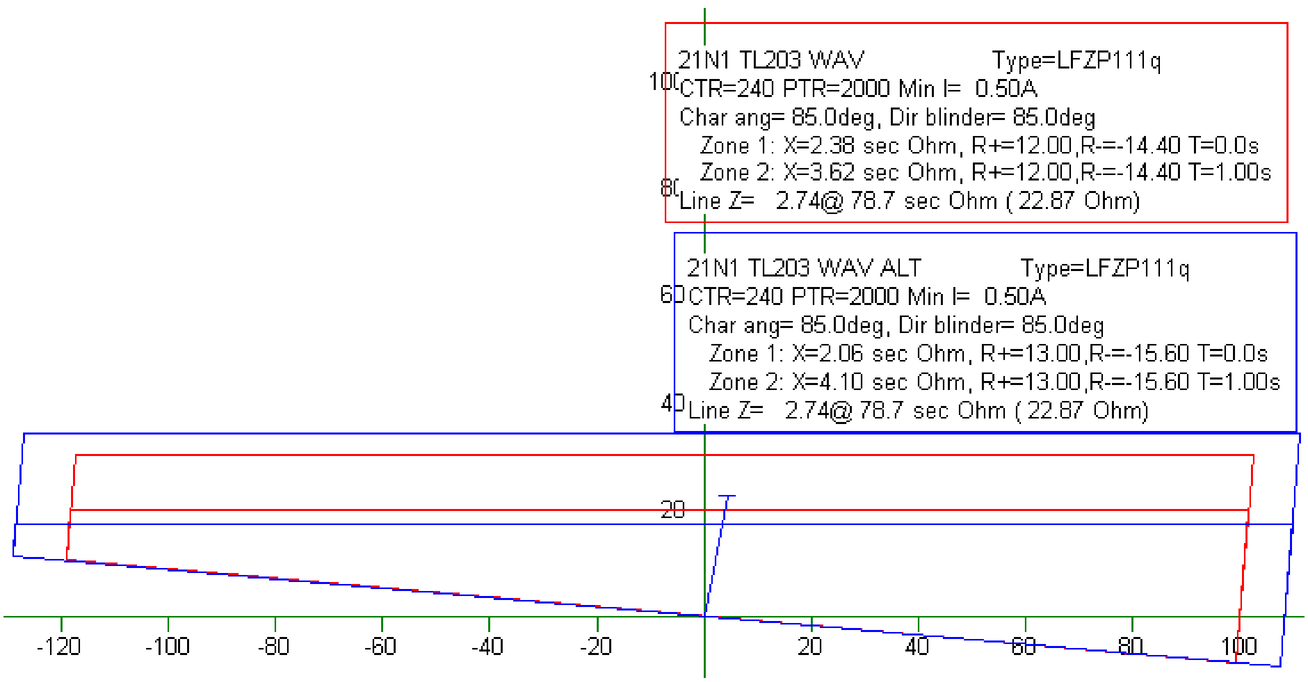


Figure 13 - Comparison of ground distance characteristics

Protection Review for Five 230 kV Transmission Lines

Appendix J
Detailed settings review for WAV TL203 "P2" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the protection systems for the Western Avalon (WAV) terminal of circuit TL203 . This 230 kV transmission circuit is from Sunnyside (SSD) to Western Avalon (WAV).
The circuit runs parallel to TL237 for most of its length.

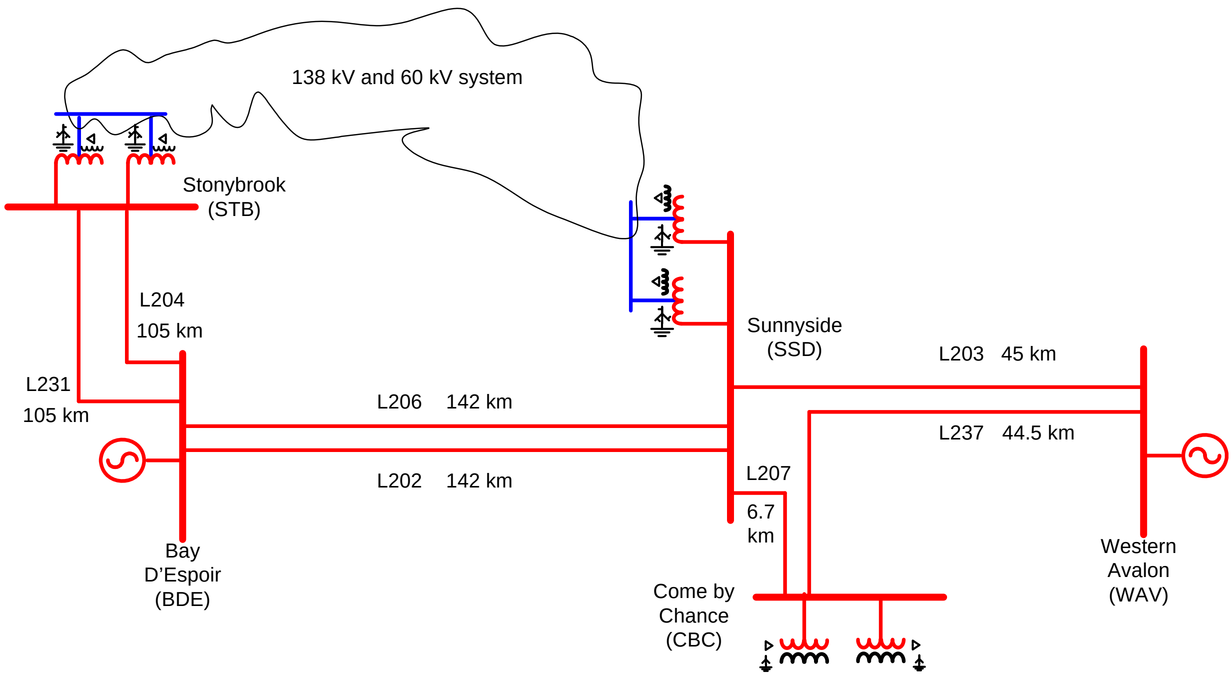


Figure 1 - System Single Line Diagram

Existing P2 protection systems are SEL321 systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$\text{MVAbase} := 100$ $\qquad$ $\text{kVbase} := 230$ $\qquad$ $\text{Ibase} := \dfrac{\text{MVAbase}\cdot 1000}{\text{kVbase}\cdot\sqrt{3}}$ $\qquad$ $\text{Zbase} := \dfrac{\text{kVbase}^2}{\text{MVAbase}}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $\text{CTR} := \dfrac{1200}{5}$ $\qquad$ VT ratio is: $\text{VTR} := \dfrac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**Hydro Interconnected System (2010-08-13) V10.olr**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with all shunts ignored (unless needed for load flow simulation).

Minimum fault current seen by each terminal (multiphase and SLG with 100 ohm fault resistance).

At WAV, with Circuit TL217 out of service, and TL207 and TL237 lines in service, for a fault at the remote terminal.

$I3Pmin := 924$ $ISLGminPH := 884$ A $ISLGmin0seq := 768$ A

The current for a phase to phase fault would be lower, but the current supervision element of the SEL321 measures phase to phase currents, and the phase to phase current for a phase to phase fault is twice the phase current.

Calculate the minimum negative sequence source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum um source impedance behind WAV $Z2minWAV := 2.75 + j \cdot 27.64$ ohms primary

Minimum source impedance behind SSD $Z2minSSD := 3.22 + j \cdot 27.90$ ohms primary

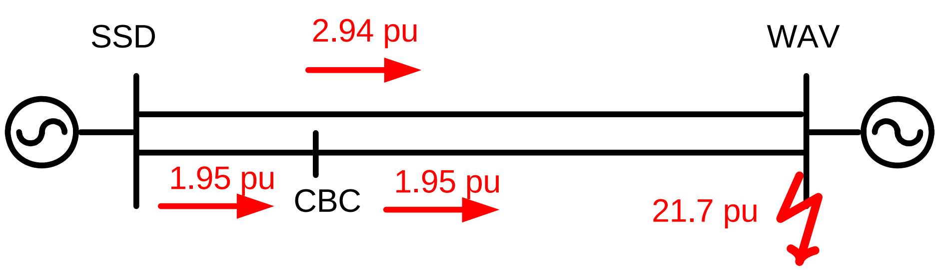


Figure 2 - 3 Phase Fault at WAV

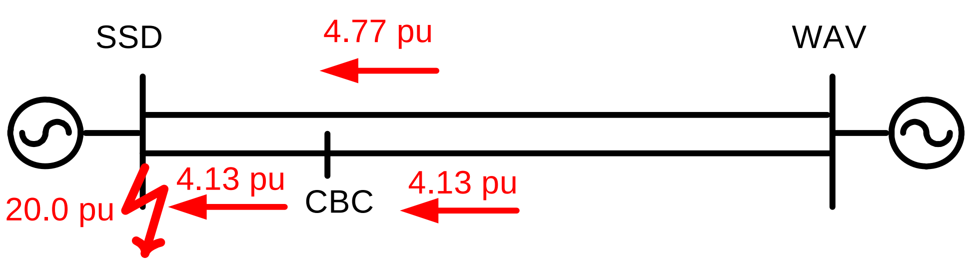


Figure 3 - 3 Phase Fault at SSD

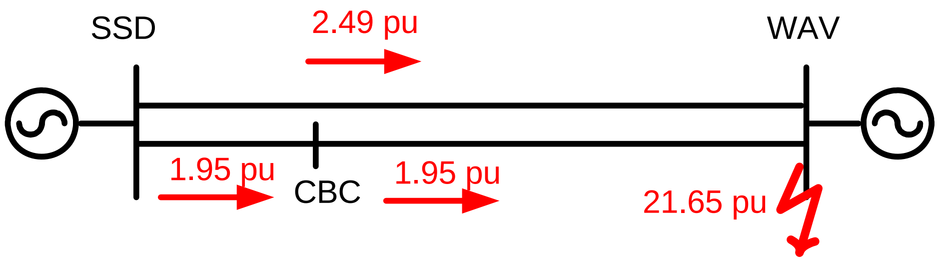


Figure 4 - SLG Fault at WAV (3I0 currents)

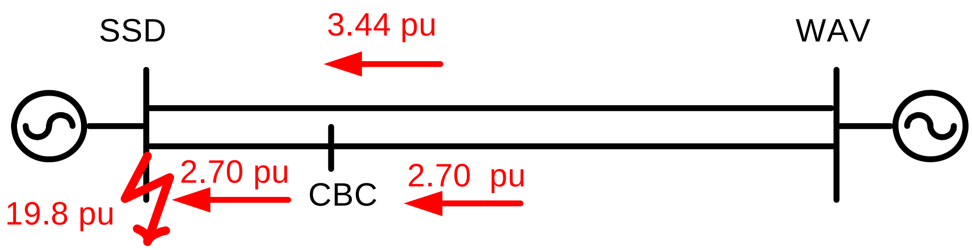


Figure 5 - SLG Fault at SSD (3I0 currents)

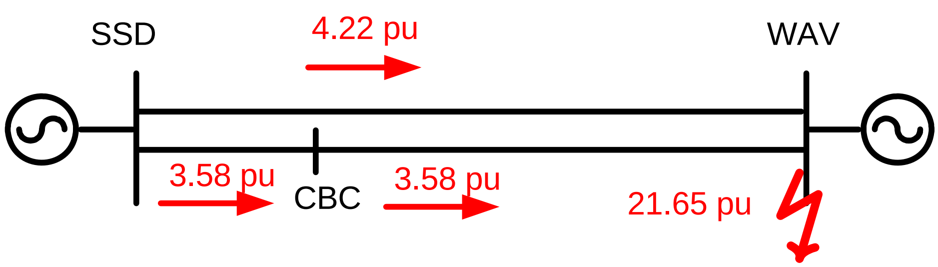


Figure 6 - SLG Fault at WAV (Phase currents)

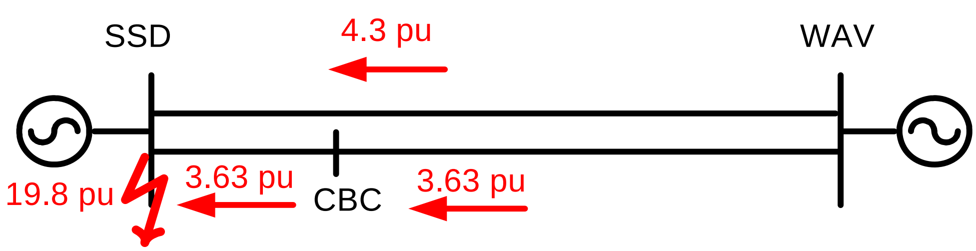


Figure 7 - SLG Fault at SSD (Phase currents)

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L203 := 0.0085 + j \cdot 0.04238$ $\qquad$ $Z0L203 := 0.02337 + j \cdot 0.15876$

In primary ohms

$Z1L203pri := Z1L203 \cdot Zbase$ $\qquad$ $Z0L203pri := Z0L203 \cdot Zbase$

In secondary ohms

$Z1Linesec := Z1L203pri \cdot \frac{CTR}{VTR}$ $\qquad$ $Z0Linesec := Z0L203pri \cdot \frac{CTR}{VTR}$

$|Z1Linesec| = 2.744$ $\qquad$ $\arg(Z1Linesec) = 78.659 \cdot deg$

$|Z0Linesec| = 10.187$ $\qquad$ $\arg(Z0Linesec) = 81.626 \cdot deg$

Zero sequence mutual coupling between TL203 and TL237 is $\quad Z0m := 0.0132 + j \cdot 0.0697$

The existing line impedance settings are slightly different from the line data book. They should be adjusted to improve the accuracy of the fault location algorithm.

Load Data

From 2010 System peak load case provided in start up information, the peak load is given as 132.6 MVA (with TL203, TL207 and TL237 in service). The highest load of the three lines is TL207 with a load of 138.4 MVA. In the event of sudden loss of TL207. Peak load in TL203 will increase to take up the lost load through TL207. Thus the peak load in TL203 will be slightly more than double until operators can adjust loads.

$Speak\_203 := 132.6$ MVA $\quad$ $Speak\_207 := 138.4$ MVA

$Smax := Speak\_203 + Speak\_207 = 271$ MVA

P2 Relay Settings

The existing line impedance settings are slightly different from the line data book. They should be adjusted to improve the accuracy of the fault location algorithm.

$Z1MAG := |Z1Linesec|$ $Z1MAG = 2.74$ $Z1ANG := \frac{arg(Z1Linesec)}{deg}$ $Z1ANG = 78.7$

$Z0MAG := |Z0Linesec|$ $Z0MAG = 10.2$ $Z0ANG := \frac{arg(Z0Linesec)}{deg}$ $Z0ANG = 81.6$

$LL203 := 44.53$

In order to obtain sensitivity to 100 ohm single line to ground faults, the echo function will be needed. Enable two forward and one reverse zone.

$PMHOZ := 3$ $GMHOZ := 3$ $QUADZ := 3$

$DIR1 := F$ $DIR2 := F$ $DIR3 := R$

Mho phase distance functions

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if the line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the SSD Station bus under weak source conditions with TL217 out of service and all of TL203, TL207 and TL237 lines in service. From ASPEN OneLiner, voltage at WAV for a 3 phase fault at SSD is 0.16 per unit. So there is less than 20% voltage at WAV during a fault at SSD under weak source conditions.

Since the voltage is not higher than 20%, the line is considered short, and a reduced Zone 1 setting is recommended to provide more security. Choose a setting of 80% of nominal.

$Z1P := 0.8 \cdot |Z1Linesec|$ $Z1P = 2.2$ Ohms secondary

Existing setting of 2.38 ohms is a little high, and will be reduced.

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 3.62 ohms secondary (about 132%) and is acceptable. No need to change.

$Z2P := 1.32 \cdot |Z1Linesec|$ $\quad Z2P = 3.62$ Ohms secondary

Since TL207 is very short, it is likely that the zone 2 element will overreach the SSD TL207 zone 1 under some circumstances. Therefore we need to use a delayed zone 2 timer in order to coordinate with the SSD TL207 Zone 2 function. Therefore, the timer setting will be increased beyond the normal zone 2.

SSD TL207 Zone 2 timer is set at 18 cycles. Assume this is Newfoundland and Labrador Hydro normal zone 2 clearing time that allows for normal breaker clearing and margin for breaker failure clearing and relay reset. To coordinate with the remote zone 2, we will need to make similar allowances.

$CBtime := 3$ cycles $\quad Margin := 15$ cycles $\quad Z2PDSSD\_TL207 := CBtime + Margin = 18$ cycles

Set this zone 2 at twice the remote zone 2 setting.

$Z2PD := 2Z2PDSSD\_TL207 = 36$ cycles

Zone 3

Set Zone 3 reverse element to reach further behind this terminal than the remote Zone 2. This function adds security for external faults. The element should always be more sensitive than the forward looking Zone 2 at the remote terminal. Set it the same as the remote Zone 2 overreach plus 20%

$Z3P := Z1MAG \cdot \left(\frac{Z2P}{Z1MAG} - 1 + .2 \right)$ $\quad Z3P = 1.4$ Ohms secondary

$\frac{Z3P}{|Z1MAG|} = 52 \cdot \%$ of line length

This is a little higher than the existing setting, but provides additional security.

The reverse looking zone 3 element need not be set to trip through a timer. It is needed only for security in the POTT scheme.

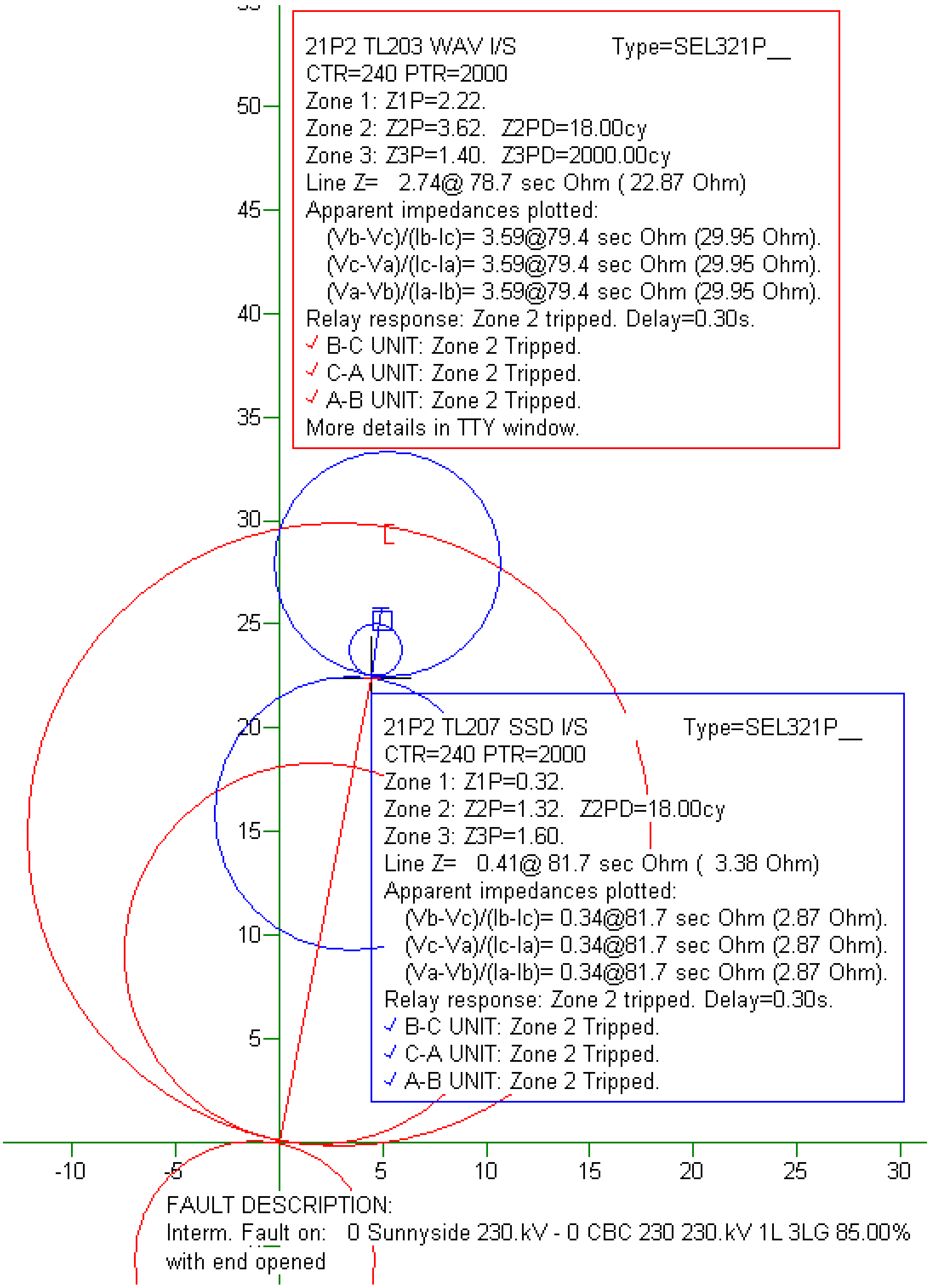


Figure 8 - Existing WAV TL203 Zone 2 overreaches SSD TL207 Zone 1(shortest line out of WAV) with infeed, and needs extended delay before tripping.

Mho phase distance current supervision

If the current supervision elements can be set above load, they will be secure in the event that potential is lost. However given that loss of potential logic is available, it is recommended that only the zone 1 current supervision function be set above load. If potential is lost, it will be able to block tripping by Zone 2 before it trips on time delay or receives a permissive trip from the remote terminal.

For the point of view of current supervision being above maximum load, there is no need to worry about abnormal conditions. It would be a double contingency for the VT signal to be lost while the parallel line was out of service. Therefore, consider a maximum load of 135 MVA. The current supervision elements for the phase distance functions measure phase to phase currents.

$IPPmax\_normal := \frac{Speak\_203 \cdot 1000}{kVbase}$ $IPPmax\_normal = 577$ A primary

The current supervision elements use phase to phase currents for supervision of the phase distance function;. so the minimum phase to phase fault current will be root three times the minim phase fault current. Choose a margin of 50% of the minimum phase to phase fault current for dependability.

$IPPmin := 0.5I3Pmin \cdot \sqrt{3}$ $IPPmin = 800$ A primary

A setting of 600 A primary for 50PP1 will ensure the Zone 1 function operates for any fault even under minimum source conditions but will not be susceptible to trip on load due to loss of potential under normal maximum load conditions. This is somewhat higher than the existing setting, and adds a little more security.

$'50PP1 := 2.5$ A Sec $'50PP1 \cdot CTR = 600$ A primary

Since Zone 2 and zone 3 elements will be blocked by LOP function, set them at minimum. The zone 3 current supervision should not be set higher than the zone 2 current supervision element at the remote terminal. In this case the remote zone 2 current supervision element will be set at 1.0 A secondary.

$'50PP2 := 1$ A Sec $'50PP3 := 1$ A Sec

Ground Distance Protection

The reach of the ground distance functions will be affected by mutual coupling to the parallel line. These functions will tend to underreach the remote bus while the parallel line is in service, and overreach the remote bus if the parallel line is out of service and grounded at both ends. Figure 9 shows that for a remote bus fault, with the parallel line out of service and grounded, the apparent impedance of the line is reduced to about 2.39 ohms secondary instead of the nominal 2.74 ohms. This is 87% of the actual line impedance.

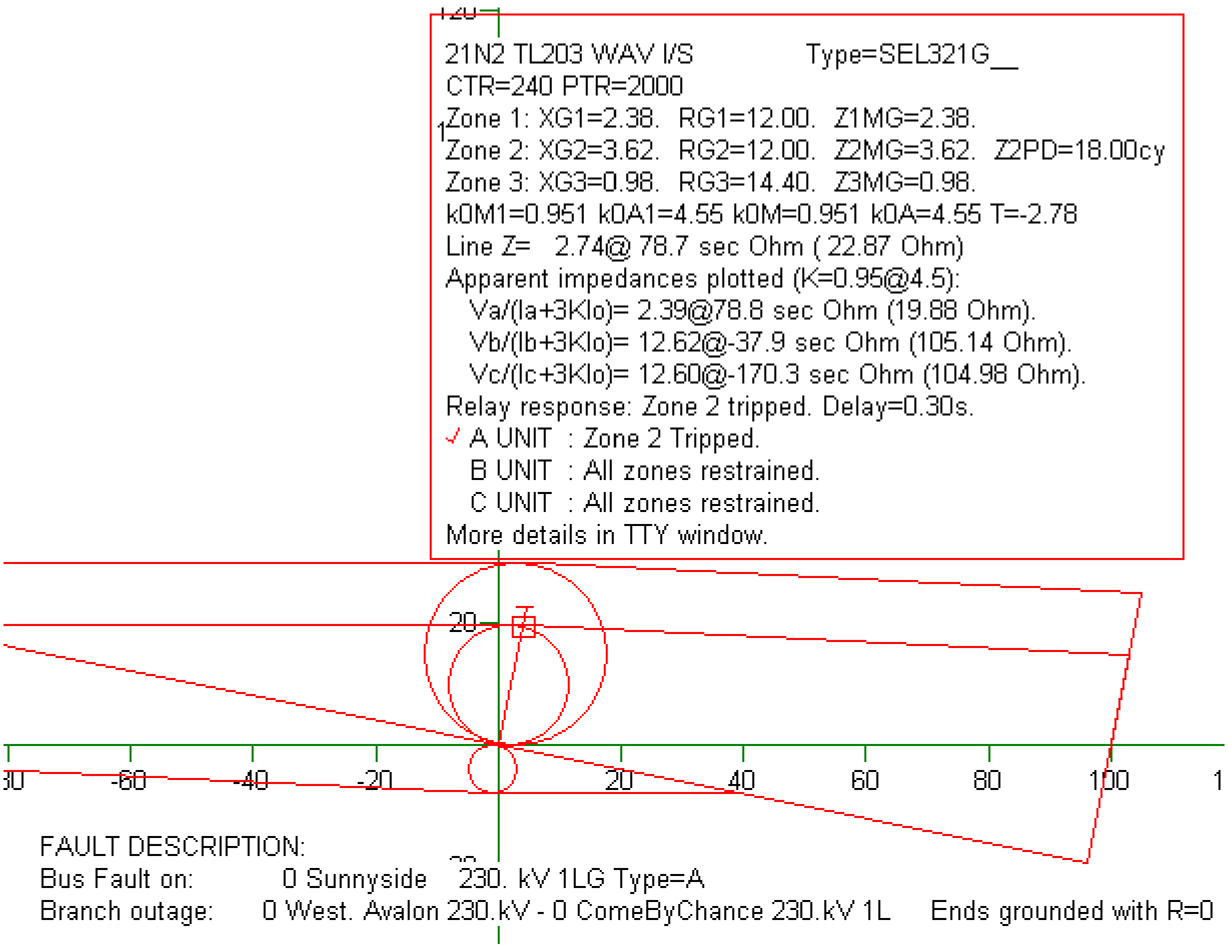


Figure 9 - Apparent impedance to a fault just beyond the remote terminal is reduced by 11% when parallel line is out of service and grounded at both ends. Existing relay settings modeled in this figure.

The normal reach of the zone 1 should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Choose a setting of 75% of the line impedance, which is lower than the setting required to make the zone 1 element more secure for faults beyond the end of this short line. Note that as will be seen later, the reduced reactive reach is required to allow a relatively large resistive reach for sensitivity while retaining security against overreach due to CT and VT errors.

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.75$ per unit

$Z1MG := m \cdot |Z1Linesec|$ $Z1MG = 2.06$

$XG1 := Z1MG$ $XG1 = 2.06$

Zone 1 Resistance

The resistive reach of the Zone 1 quad should provide enough sensitivity to trip the local terminal immediately without waiting for permission from the remote terminal for a severe fault that depresses the voltage significantly. Further, it should not allow the function to reach beyond the remote terminal due to errors in relay measurement or CT or VT. If possible, it should also operate for a 100 ohm SLG 25% of the distance from the local terminal. Operation for a 100 ohm resistive fault at the 25% location will ensure this function can trip for a close in fault without assistance from the remote terminal. The remote terminal zone 1 function will be set to operate sequentially for this fault.

By simulating a fault with 100 ohms fault resistance at the 25% of the distance from WAV, with the system normal, it is found that a reach of 13 ohms secondary will not sense this fault. See Figure 10.

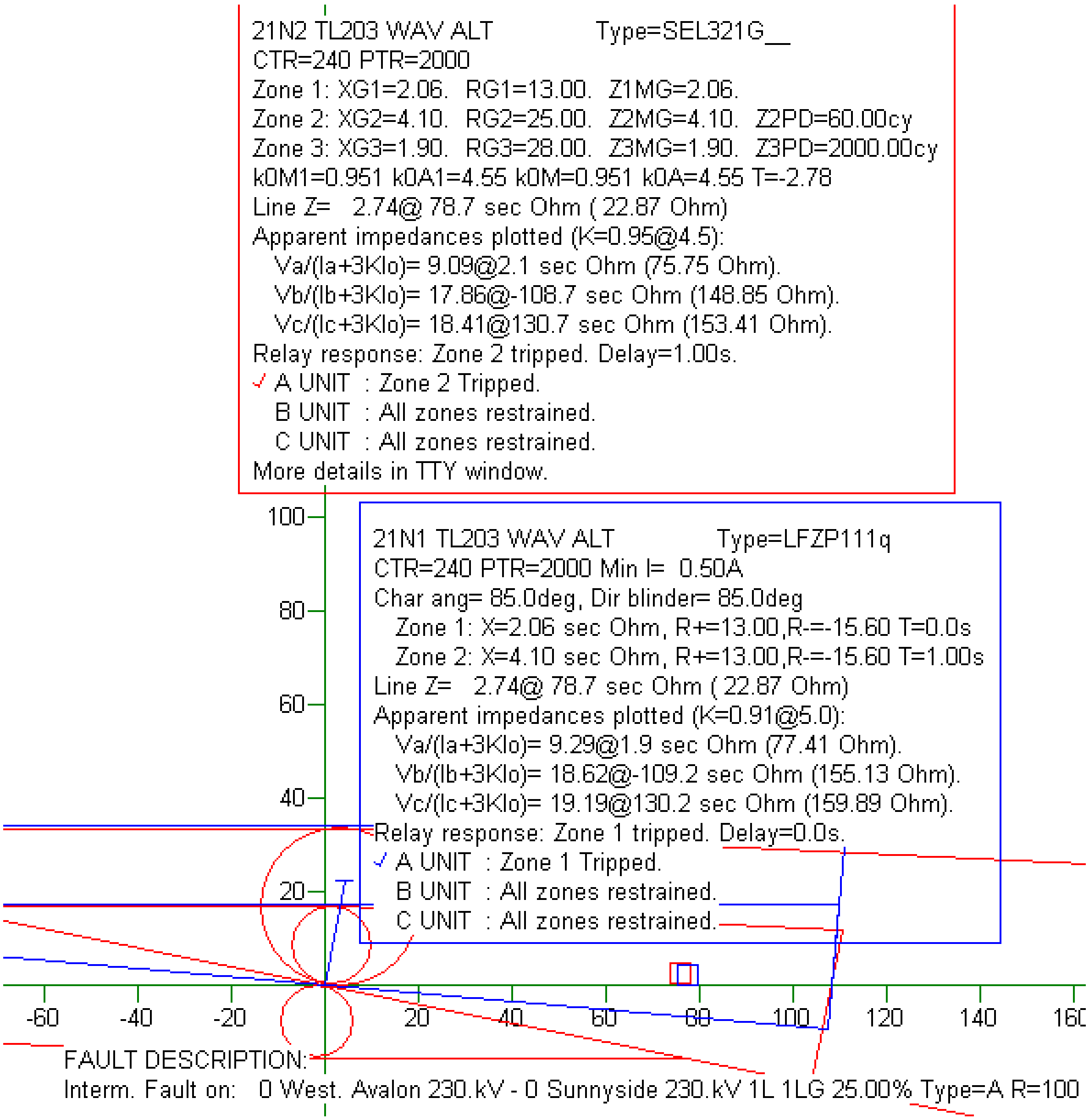


Figure 10 - WAV P2 Zone 1 function does not operate for a 100 ohm SLG fault at 25% from the local terminal. (although the P1 protection does).

The existing 12 ohm secondary resistive reach of the zone 1 element will certainly not sense this fault, and would need to be increased to 20 ohms secondary. Check whether this reach will be secure, considering possible CT and VT errors.

XG1 is set at m per unit of the transmission line. The imaginary component of this is

$ImXG1sec := Im(Z1Linesec)$ $\quad ImXG1sec = 2.69$ ohms

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$RG1 := round[(1 - m)\cdot 20\cdot ImXG1sec, 1]$

$RG1 = 13.5$ This is the maximum secure setting for the resistive reach so the desired zone 1 resistive reach setting would not be confirmed as being secure.

Use the maximum secure setting of 13 ohms for RG1 $\quad RG1 := 13$ ohms secondary

With a resistive reach setting of 13 ohms, the SSD Zone 1 quad element will see an 80 ohm resistive SLG fault immediately in from of the SSD terminal and gradually reducing resistance as the fault moves away from the terminal. Zone 2 protection will be depended upon to sense faults with resistance up to 100 ohms.

In spite of this poor sensitivity of the Zone 1 element, it should be noted that the 80 ohm resistive SLG will only depress the faulted phase voltage by about 8%; so this fault is not very severe on the system and communications assisted tripping should not have a significant negative impact on the system.

Zone 2 Ground Distance Protection

The Zone 2 ground distance function will need to be set longer than the Zone 2 phase distance protection function because it will tend to underreach the remote terminal while the parallel line is in service. By simulation in ASPEN OneLiner it is found that the apparent impedance to a zero ohm fault close in to the remote terminal is 3.22 ohms secondary, or 18% more than the actual line impedance. The reach of the Zone 2 ground distance element should be set at least to 1.25 times the apparent impedance. Choose a factor of 1.27 to make the zone 2 reach the same as the P1 protection. (Required reach is actually a little different from P1 required reach due to slightly different zero sequence current compensation factors).

$ZSLG\_remote := 3.22$

$Z2MG := round(1.27\cdot ZSLG\_remote, 1)$ $\quad Z2MG = 4.1$ Ohms secondary

The quad element reactive reach will be set similarly to the mho.

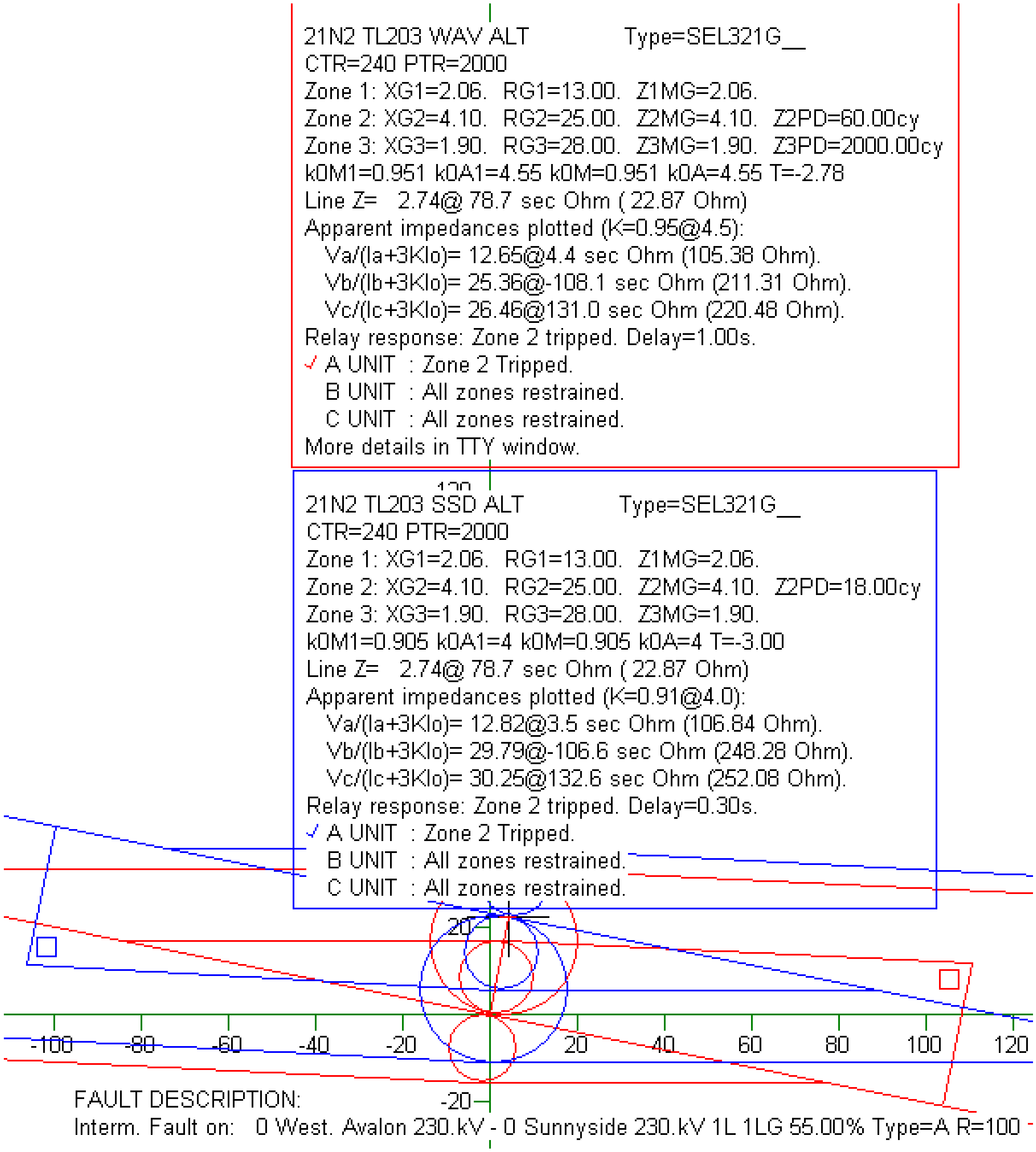
$XG2 := Z2MG$ $\quad XG2 = 4.1$ Ohms secondary

The resistive reach of the quad will be increased to sense a 100 ohm resistive in the middle of the line with a good overlap of zone 2 elements from each end.

By trial and error from ASPEN it is found that a resistive reach of 25 ohms secondary will sense a 100 ohm SLG fault from both ends of the line between 51 to 58 percent of the distances from the WAV terminal. However since it will not overlap the Zone 1 element at the remote terminal, the permissive trip echo function will be required to ensure that a fault that is seen by the zone 2 element at only one terminal will still be cleared by the permissive trip logic.

Therefore, to avoid extremely large resistive reaches, and to retain sensitivity to 100 ohm resistive SLG faults, it is recommended that the echo function be enabled at both terminals.

R2G := 25 Ohms secondary



<u>Figure 11 - Local Zone 2 Quad element operates for 100 ohm resistive SLG at 55% of the distance from the local terminal.</u>

Since the parallel path TL207 and TL237 both trip three pole only, there is no danger of the zone 2 function tripping while the parallel line is open single phase, with heavy power flow.

It would be desired to reduce the zone 2 ground distance time delay trip in order to aid coordination for resistive single line to ground faults "around the loop" of TL203 TL237 and TL207 where otherwise, the ground time overcurrent functions might not have coordinated fully. Unfortunately, since this element senses faults with higher resistance than the short reaching zone 1 element at the SSD terminal of TL207, it has to be set to coordinate with the SSD TL207 zone 2 element which already has its time delay set at 0.6 seconds. Therefore it will not be possible to reduce the zone 2 ground distance time delay below the existing 1 second..

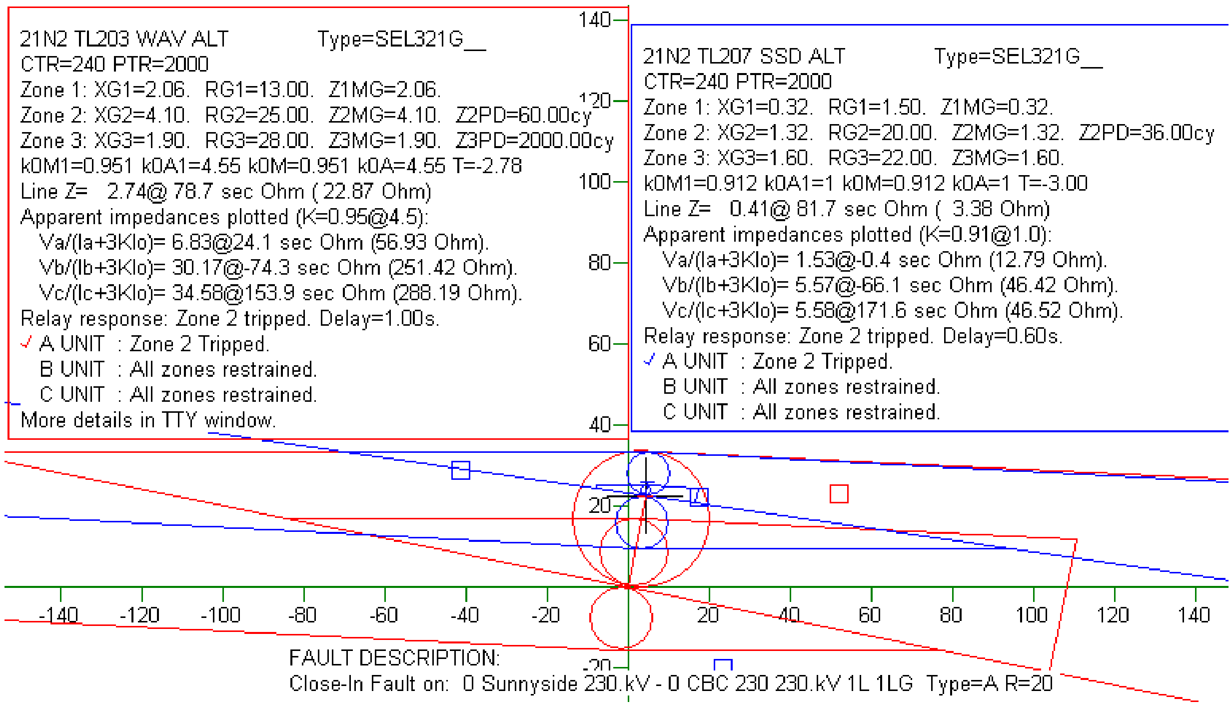


Figure 12 - Zone 2 ground distance element senses a 20 ohm resistive fault on TL207 that the SSD TL207 Zone 1 element does not sense.

$Z2GD := 60$ Cycles (same as existing)

Zone 3 Ground Distance Protection

The zone 3 ground mho function will be set using the same principles as the zone 3 phase distance function.

$Z2MGrem := 4.1$ ohms secondary

$Z3MG := Z1MAG \cdot \left(\frac{Z2MGrem}{Z1MAG} - 1 + .2\right)$ $Z3MG = 1.9$ Ohms secondary

$\frac{Z3P}{|Z1MAG|} = 52 \cdot \%$ of line length This is a little higher than the existing setting, but provides additional security.

$XG3 := Z3MG$ $XG3 = 1.9$ Ohms secondary

Set the Zone 3 quad resistive reach at 10% more than the remote Zone 2

$R2Grem := 25$ Ohms secondary

$R3G := round(R2Grem \cdot 1.1, 0)$ $R3G = 28$ Ohms secondary

Ground distance current supervision

Since there is no concern about these elements operating on load, even with loss of potential, set all current supervision elements at minimum, for maximum sensitivity of the distance elements.

'50L1 := 0.5 A Sec '50L2 := 0.5 A Sec '50L3 := 0.5 A Sec

'50G1 := 0.5 A Sec '50G2 := 0.5 A Sec '50G3 := 0.5 A Sec

Note that due to heavy infeed of zero sequence currents from the local terminal for close-in faults, the ground overcurrent detectors will not operate for faults with more than a small amount of resistance close to the remote terminal. Therefore, we will have to rely on sequential clearing for that type of fault. However setting the current supervision at minimum allows maximum sensitivity.

Zero sequence current compensation

The zero sequence current compensation could be adjusted to compensate for the significant amount of mutual coupling. However as discussed in the settings of reaches of the ground distance elements we will accept underreach of the Zone 2 function for the normal case. Set the zero sequence current compensation as usual.

$$k01M := \left(\left|\frac{Z0L203 - Z1L203}{3 \cdot Z1L203}\right|\right) \qquad k01M = 0.905$$

$$k01A := \left(\arg\left(\frac{Z0L203 - Z1L203}{3 \cdot Z1L203}\right)\right) \qquad k01A = 4.06 \cdot deg$$

Say $k01A := 4deg$

Set the overreaching zones the same as zone 1 $k0M := k01M$ $k0A := k01A$

$k0M = 0.905$ $k0A = 4 \cdot deg$

Non Homogenous Angle Setting

Compare the angle of the total zero sequence current at the remote bus with the angle of the zero sequence current contribution from the local terminal to determine this setting. From ASPEN OneLiner, the worst case is normal conditions. For this case, for an SLG at WAV the angle of I0 at the fault is -115 degrees and the angle of I0 out of the SSD terminal is -112 degrees. Therefore, the total fault current lags the current contribution from SSD by 3 degrees and angle T must be set negative by the difference to ensure no overreach.

$T := -3$ degrees

Out of step blocking and tripping

Not used in this application. There is a danger of out of step conditions arising. Historically no action has been taken to provide special tripping or blocking functions. Natural tripping during swings is accepted.

Load Encroachment logic

Check loadability of the Zone 2 phase distance element assuming worst case power factor of 0.87 simultaneous with worst case depressed voltage of a stressed system of 0.9 per unit. Note that units of kV squared match units of MVA. Note that quadrilateral elements are only used for the ground distance functions that are not sensitive to balanced three phase load. Therefore no need to worry about the reach of the quadrilateral elements.

$$\text{Zloadmin} := \frac{(0.9\text{kVbase})^2}{\text{Smax}} \qquad \text{Zloadmin} = 158.114$$ Ohms primary (assume worst case at 30 degrees)

Maximum reach of the Zone 2 element is at the line angle of 81 degrees. At 30 degrees, the reach will be given by

$$\text{Z2load} := \text{Z2P}\cdot\cos[(\text{Z1ANG} - 30)\text{deg}] \qquad \text{Z2load} = 2.392$$ ohms secondary

$$\text{Z2load}\cdot\frac{\text{VTR}}{\text{CTR}} = 19.937$$ ohms primary

Since the reach of the Zone 2 element at 30 degrees is less than the apparent impedance of the maximum load, there is no need to apply load blinding logic. See Figure 13

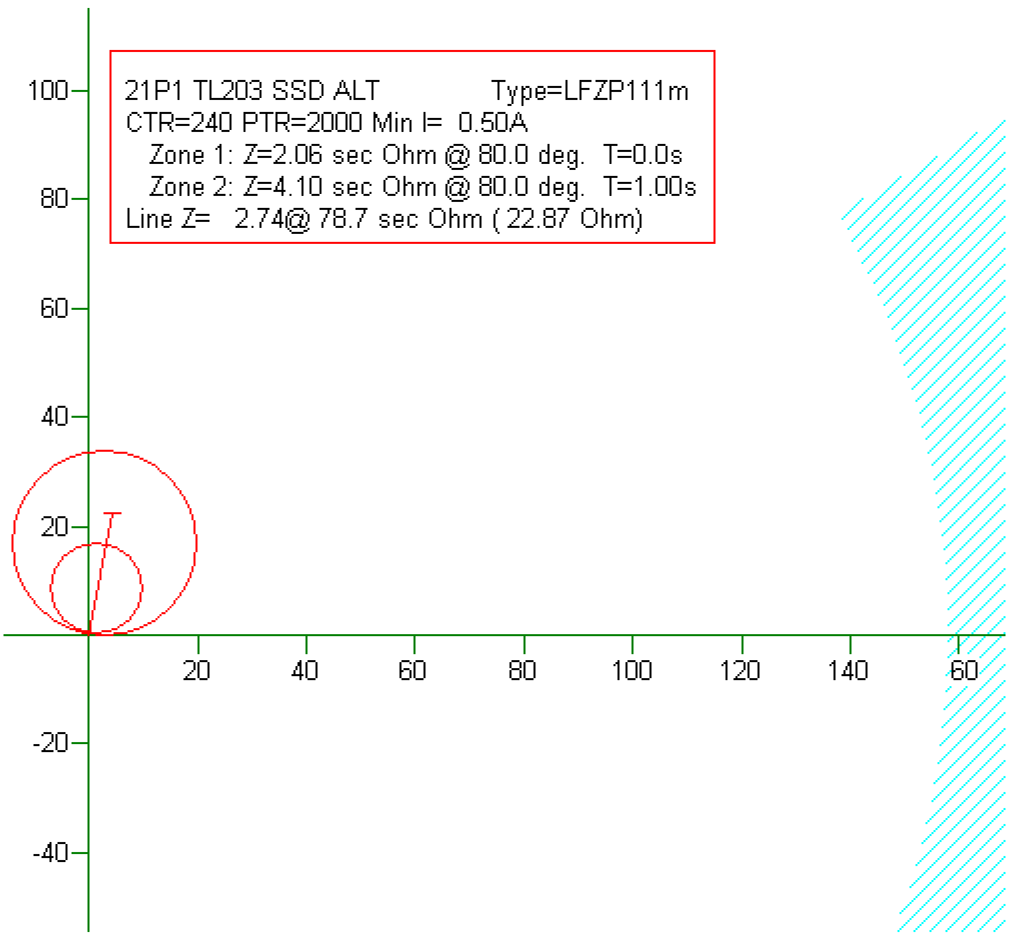


Figure 13 -Load impedance with respect to proposed new Mho function reaches.

Ground directional element

The SEL-321 application example recommends finding the minimum source impedance behind the terminal and setting the reverse and forward boundaries of the negative sequence directional element at the 1/3 and 2/3 points respectively.

In the negative sequence plane, the sum of the two source impedances and the line impedance is:

$Z2total := Z2minWAV + Z1L203pri + Z2minSSD$ $\qquad |Z2total| = 78.658$

The 1/3 point is $Z2\_1\_3 := \frac{Z2total}{3}$ $\qquad$ The 2/3 point is $Z2\_2\_3 := \frac{2Z2total}{3}$

$Z2Rpri := Z2\_2\_3 - Z2minWAV$ $\qquad |Z2Rpri| = 24.697$ $\qquad |Z1L203pri| = 22.865$

$Z2Fpri := Z2\_1\_3 - Z2minWAV$ $\qquad |Z2Fpri| = 1.811$ $\qquad |Z2minWAV| = 27.776$

$|Z2minSSD| = 28.085$

Converting the primary impedances to secondary ohms

$Z2R := Z2Rpri \cdot \frac{CTR}{VTR}$ $\qquad |Z2R| = 2.964$ Ohms secondary $\qquad arg(Z2R) = 80.144 \cdot deg$

$Z2F := Z2Fpri \cdot \frac{CTR}{VTR}$ $\qquad |Z2F| = 0.217$ Ohms secondary $\qquad arg(Z2F) = -65.926 \cdot deg$

Rounding up Z2F (note that Z2F is negative) and rounding down Z2R gives:

$Z2F := 0$ Ohms secondary $\qquad Z2R := 2$ Ohms secondary

The proposed Z2F setting is not very different from the existing settings, but the proposed Z2R setting is considerably less. The existing Z2R setting is too high.

Set the current level detectors at minimum level that will allow operation of the ground distance elements.

Due to the very small zero sequence current contribution to a single line to ground fault at the remote terminal, the negative sequence current contribution will always be higher than the zero sequence. Therefore there is no point in setting the forward looking negative sequence overcurrent elements any more sensitively than the zero sequence ground overcurrent supervision of the ground distance elements.

$'50QF := '50G2$ $\qquad '50QF = 0.5$ $\qquad$ A secondary

Set the supervision function for the reverse looking element to be the same as, or a little more sensitive than the forward looking supervision element at the remote terminal.

$'50QR := 0.5$ $\qquad$ A secondary

The positive sequence current restraint (a2) factor should be set just smaller than the ratio of the maximum load current (positive sequence) to the most sensitive current supervision element (50QR).

$I1maxpri := \frac{Smax \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\qquad I1maxsec := \frac{I1maxpri}{CTR}$ $\qquad I1maxsec = 2.834$

Bearing in mind that the 50QR setting is in units of 3*I2

$\frac{'50QR}{3 \cdot I1maxsec} = 0.059$ $\qquad$ Choose a value of $\qquad a2 := 0.06$

Phase time overcurrent element

This element is not used

Residual time overcurrent element

This element is used to provide the most sensitive backup protection. It will be non directional element.

Set pickup to sense a higher resistance than 100 ohm SLG in the middle of the line with equal zero sequence current infeed from both ends. Choose a resistance of 200 ohms arbitrarily. Use a safety factor of 2 so that operating time is not infinity at this fault level.

$SF := 2$ Desensitization factor due to remote end infeed is $Dfactor := 2$ $Rf := 200$

$$'51NPU := round\left(\frac{kVbase \cdot 1000}{\sqrt{3} \cdot SF \cdot Dfactor \cdot Rf \cdot CTR}, 1\right) \qquad '51NPU = 0.7$$

The existing setting of 0.5 A is more sensitive than required to sense this mid line fault with arbitrary resistance. It will be increased a little to make it more secure during SPO conditions with very heavy load.

$'51NPU := 0.6$ A secondary

Coordination checks show that existing time dial settings around the loop TL203, TL237 and TL207 will not coordinate, because the CBC TL237 and SSD TL207 relays do not have enough difference in their settings. Therefore if there is a fault on TL237 that has to be cleared by the ground time overcurrent relay, SSD TL207 will not coordinate. Therefore the existing time dial settings have to be adjusted. The ground distance elements will speed up tripping for faults with resistance up to 150 ohms fed from one end, where ground relay coordination is challenged), so coordination will be checked for faults with resistance of 150 ohms or more. Trial and error checks show that in order to achieve coordination, the existing time dial setting of CBC TL237 ground time overcurrent relay will have to have its time dial settings reduced from existing 4 to 3.

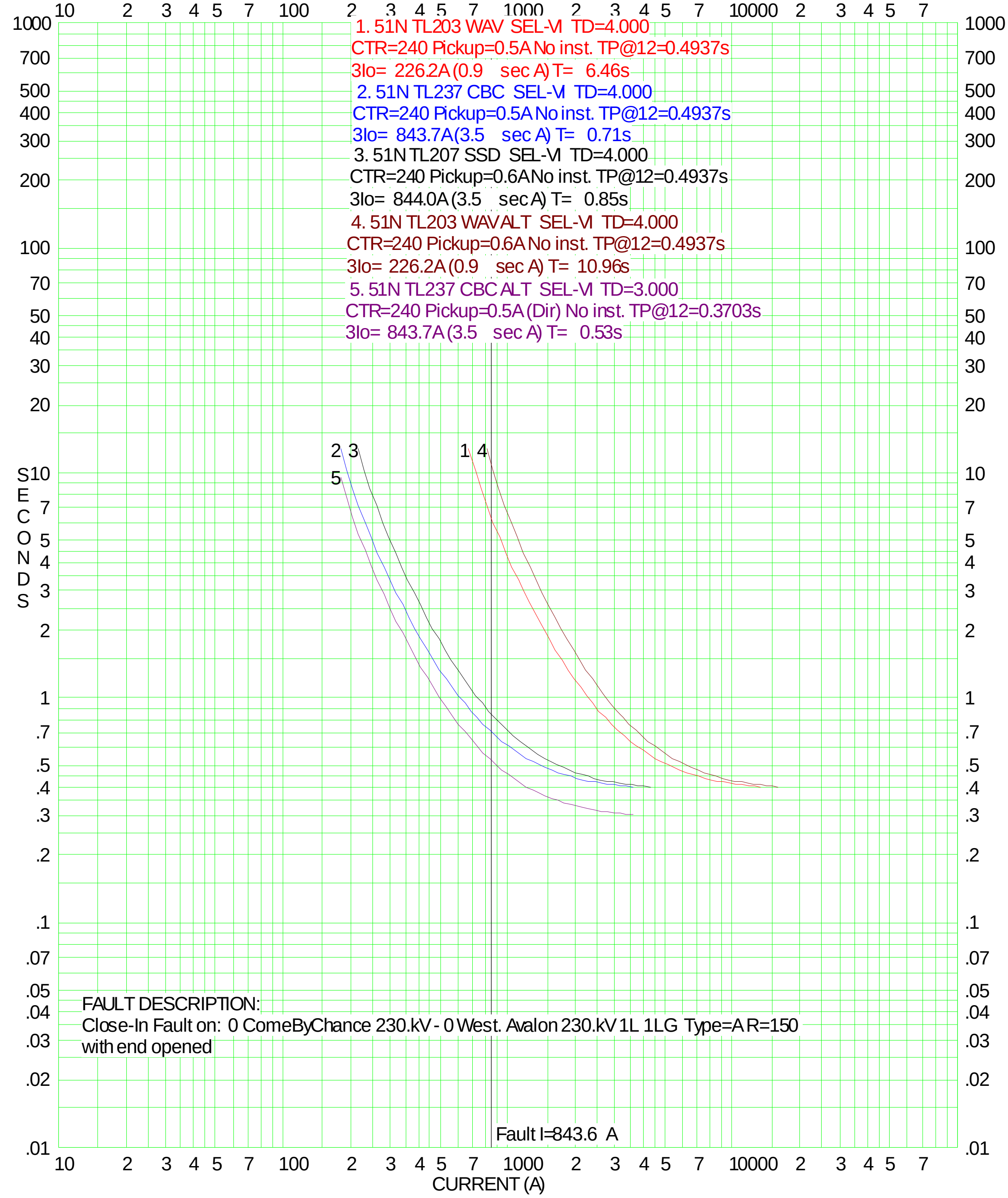
Check the coordination with the other relays for three faults (all with 150 ohm resistance). Intermediate on TL203 89% from WAV with SSD end open. LE on TL237 with WAV open and close-in to SSD on TL207 with CBC terminal open. See Figure 14 to find that existing settings (curves 2&3) do not coordinate, and Figures 14, 15 and 16 to find that Curve 3 and revised curves 4 and 6 settings will coordinate.

$'51NPU = 0.6$ A secondary $'51NPU \cdot CTR = 144$ A primary

$'51NTD := 4$ $'51NC := "U3"$ $'51NTC := "N"$ $'51NRS := "N"$

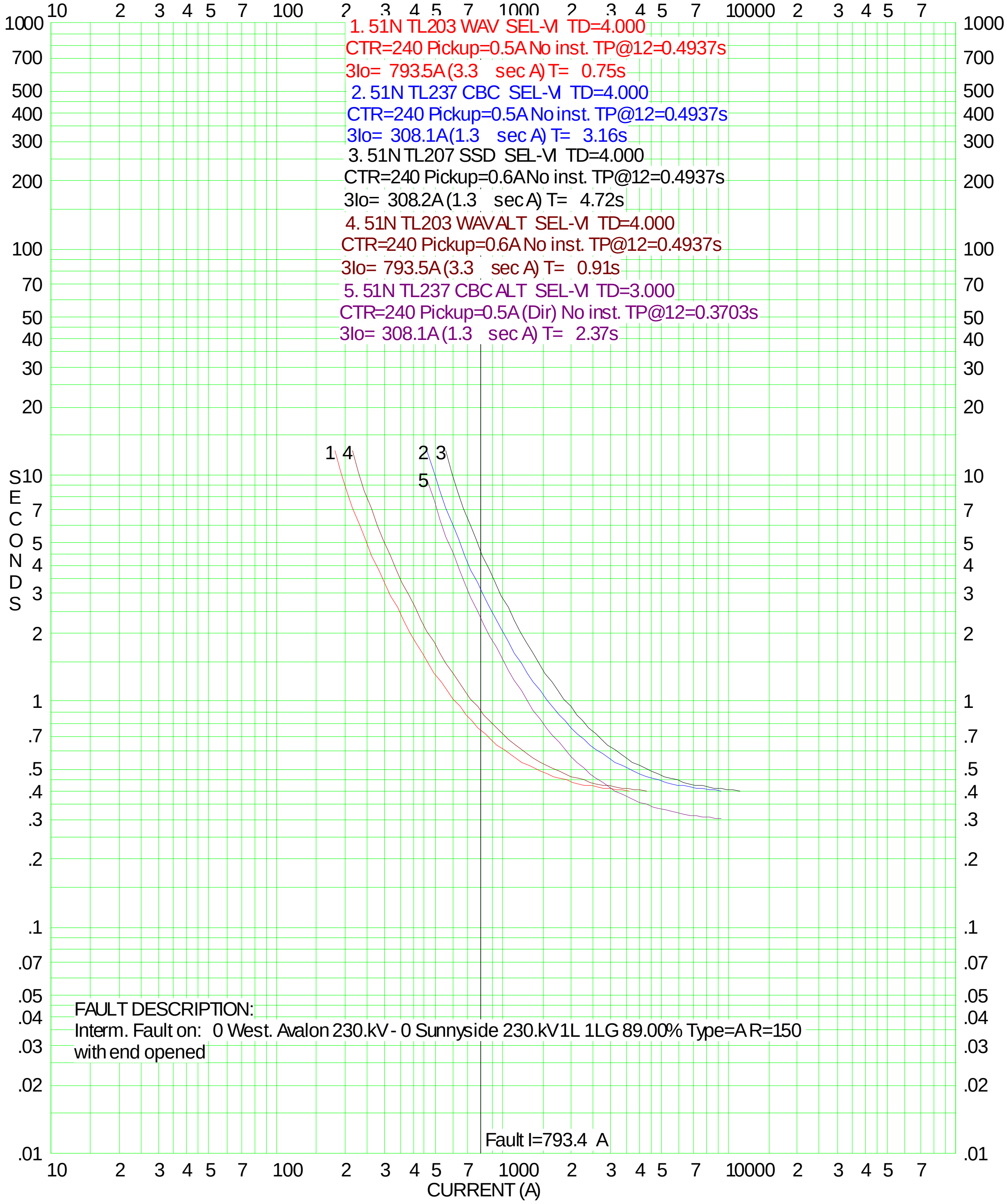
Checks for close-in fault show that this element will not operate in less than 0.3 seconds so there is no danger of it tripping 3 pole before the zone 1 element trips the faulted phase selectively.

Worst case load unbalance with single pole open will be in the future if single pole tripping is enabled with parallel line out of service. ASPEN OneLiner shows that with 288 MVA of load on TL203, and with one phase open, the 3I0 current is approximately 600 A. The 51N relay **with the proposed new settings** will take approximately 1.32 seconds to operate on 700 A primary. It will be (just) slow enough to override load unbalance during this SPO time with extremely heavy load.



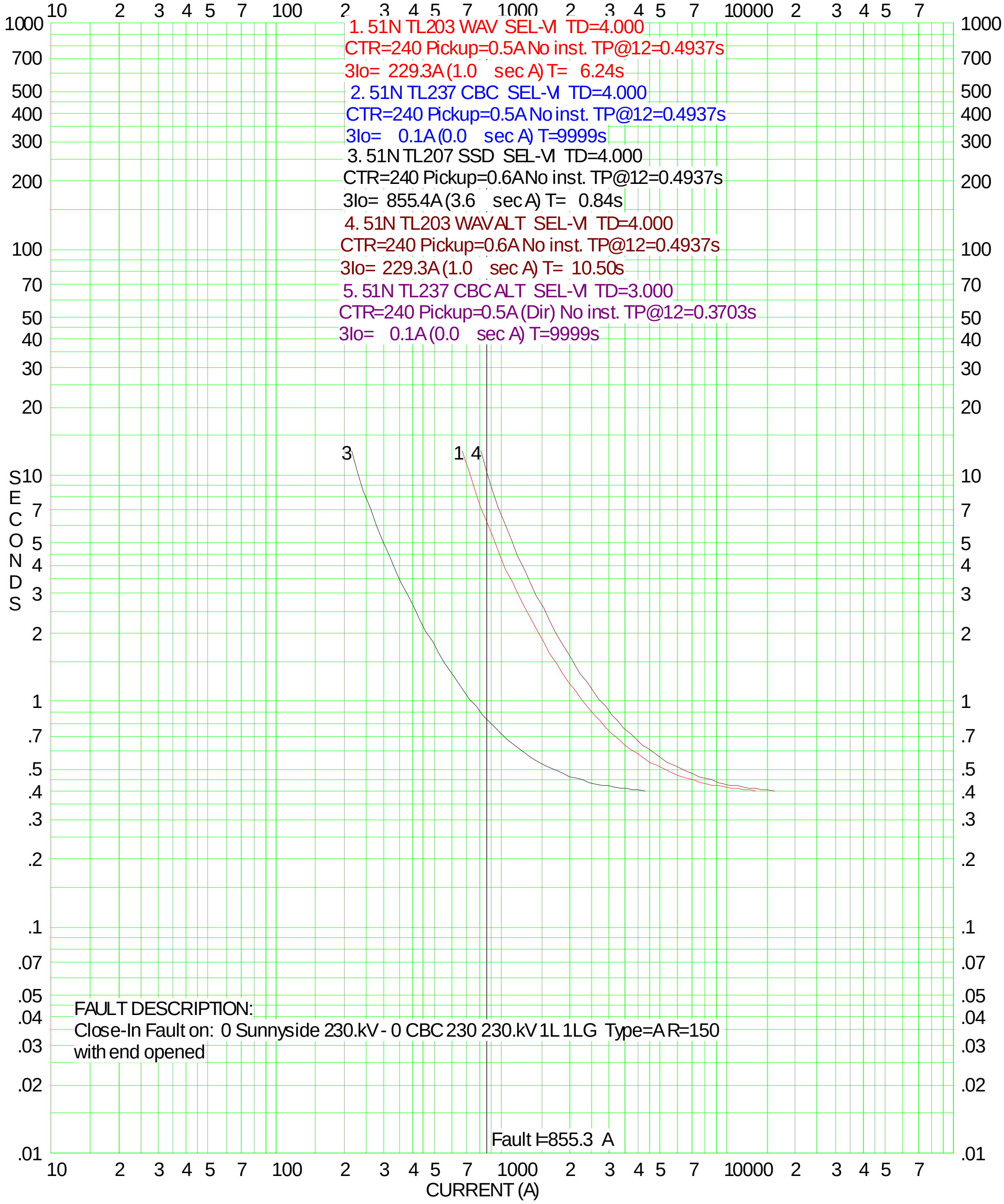
TIME-CURRENT CURVES @ Voltage 230	By CFH
For CCW Coordination of TL203, TL207, TL37 Ground O/C PN	No. WAV1
Comment 150 ohm SLG faults	Date 7 Nov. 2010

<u>Figure 14</u> - coordination of ground time overcurrent elements for close-in fault on TL237 close to CBC



TIME-CURRENT CURVES @ Voltage 230	By CFH
For CCW Coordination of TL203, TL207, TL37 Ground O/C PN	No. WAV2
Comment 150 ohm SLG faults	Date 7 Nov. 2010

Figure 15 - coordination of ground time overcurrent elements for fault on TL203 89% of distance from WAV with SSD terminal open



WAV 2	TIME-CURRENT CURVES @ Voltage 230	By CFH
For	CCW Coordination of TL203, TL207, TL37 Ground O/C PN	No. WAV3
Comment 150 ohm SLG faults		Date 7 Nov. 2010

<u>Figure 16</u> - coordination of ground time overcurrent elements for close-in fault on TL207 at SSD with CBC terminal open

Permissive Overreaching logic settings

EPOTT := "Y"

Z3RBD is set at remote breaker time plus channel reset time plus channel reset time plus zone 2 reset time. From review of fault records it appears that the breaker time is 3 cycles. Channel reset time is not easily determined from existing records but can conservatively be assumed to be 1 cycle, and relay reset time will also be about 1 cycle. Total time for Z3RBD is then 5 cycles.

Z3RBD := 5 cycles

Echo block delay timer blocks the echo after the local elements have picked up. This can be set relatively long since there is no significant need for the echo function shortly after the local terminal has just seen a fault but the remote terminal has not. Set at 10 cycles as per the example in the instruction manual.

EBLKD := 10 cycles

Echo time delay on pickup should be set to override noise on the communications so that it doesn't echo noise. Typical time according to the SEL application guide is 2 cycles. Since this delay only affects clearing time for relatively light (high resistance) faults that are sensed by zone 2 function at one end, the typical setting is acceptable.

ETDPU := 2 cycles

Echo duration should be long enough to ensure the permissive trip is received by the remote terminal and should also be shorter than the Z3RBD time to ensure that the reverse blocking will always be longer than any permissive trip received (including echo time stretching).

EDURD := 4 cycles

No need to enable week feed conversion to trip, since both terminals will be quite sensitive enough to detect high resistance faults after the remote terminal has cleared. Therefore we can accept sequential (or "step") clearing with no need for the added insecurity of weak infeed tripping.

EWFC := "N" **No other communications logic settings are required for this application.**

Switch on to Fault Settings

Switch on to fault logic will ensure the protection will operate when energizing the line onto a close-in three phase fault when there is no polarizing voltage available for the distance elements.

ESOTF := "Y"

The breaker close signal is not available to the relay. The 52A method of enable SOTF will be used. Therefore the Close end delay is not critical. Typical duration for enable SOTF is 10-15 cycles

ENCLO := "N" CLOEND := 0 EN52A := "Y" SOTFD := 15

Set 50H for high magnitude close-in multiphase faults with weakest source at WAV It should be set less than 50% of the minimum close-in fault magnitude. Minimum close-in magnitude of a three phase fault with TL217 out of service is 2800 A. Therefore desired maximum setting for 50H is 1400 A.

Imin3P_close_in := 2800

$$'50H := \frac{Imin3P\_close\_in}{2CTR} \qquad '50H = 5.833 \quad \text{A secondary}$$

Choose a setting of 5 A secondary for this element. '50H := 5 A secondary

Choose a setting for 52AEND less than the shortest reclose time. '52AEND := 30 cycles

Residual overcurrent settings.

Tripping directly by instantaneous ground overcurrent is not applicable because it is not phase selective. However it would be helpful to monitor steady state unbalance, and issue an alarm for continuous unbalance. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50N := 1$ $\quad$ $'50N1 := 0.25$

Negative Sequence overcurrent settings.

Similar to ground overcurrent, apply a negative sequence overcurrent element to initiate an alarm for steady state unbalances. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50Q := 1$ $\quad$ $'50Q1 := 0.25$

Voltage Element Settings

Similar to unbalance current monitoring, it is helpful to have an unbalance voltage monitor to detect steady state unbalances from the voltage supply.

EVOLT := "Y"

Set the zero sequence overvoltage element at 1% of rated voltage or just at the point necessary to override normal unbalances. The zero sequence voltage element measures 3 times the zero sequence voltage.

$$'59N := 3 \cdot 0.01 \frac{kVbase \cdot 1000}{\sqrt{3} \cdot VTR} \qquad '59N = 1.992$$

Say $'59N := 2$ V secondary

Loss of Potential

Enable loss of potential settings. Advanced LOP settings are not available on this model of relay.

ELOP := "Y" $\quad$ Time delay of 1.25 cycles is commonly used. $\quad$ $LOPD := 1.25$

The 50 M element should be set above maximum load and below minimum fault current for a fault at the remote terminal under weak source conditions. The maximum load for this case should be normal maximum, not emergency maximum which only exists for a few minutes before the operator can act to reduce load.

$$Imax\_normal := \frac{Speak\_203 \cdot 1000}{\sqrt{3} \cdot kVbase \cdot CTR} = 1.387$$ A secondary

Minimum fault current for a remote three phase fault is $I3Pmin = 924$ A primary.

Minimum fault current for a remote phase to phase fault is 87% of the minimum three phase fault current level.

Dependability factor to be sure to operate for a minimum remote fault is chosen to be 1.6. $\quad$ $DF := 1.6$

Maximum setting for 50M should be $\dfrac{0.87 I3Pmin}{DF \cdot CTR} = 2.093$ $\quad$ In this case a setting of 1.5 A secondary will be adequately dependable and secure.

$'50M := 1.5$ A secondary

The 59QL setting should be above normal maximum unbalance and below the level expected for a blown VT fuse. For a blown fuse, one phase voltage will be lost, and the negative sequence voltage will be roughly 33% of the nominal positive sequence voltage. Choose a setting of 15% of the nominal positive sequence voltage. This will be well above any normal unbalance.

$'59QL := \mathrm{round}\left(\frac{0.15 \cdot kVbase \cdot 1000}{\sqrt{3} \cdot VTR}, 0\right)$ $'59QL = 10$ V secondary

The 59PL setting should be less than the minimum voltage to be expected for a remote bus fault under weakest source conditions. There is no minimum setting (above zero) for this function. Choose a setting equal to half the voltage drop along the line impedance at the pickup setting of the 50M element.

$'59PL := \mathrm{round}[0.5 \cdot ('50M \cdot |Z1Linesec|), 0]$ $|'59PL| = 2$

Miscellaneous Scheme Settings

Pole discoordinance logic is not being used. EPOLD := "N" SPPDD := "N/A"

Enable single pole tripping by distance elements only ESPT := "Y"

Enable single pole open ESPO := "Y"

Set single pole open time delay for future SPO conditions SPOD := 0.25

3 Pole open reset delay to override small discrepancies in pole closing '3POD := 0.5

Stub line protection is not required ESTUB := "N" '50MFD := "N/A"

Trip unlatch logic not applied TULO := "N"

Logic variables and Miscellaneous timers

Minimum trip duration timer is set at 9 cycles as per the application example in the SEL-321 instruction manual.

TDURD := 9 Cycles

Trip during open pole time delay should be set longer than the reclose time. Existing setting is OK.

TOPD := 55 Cycles

No logic variable settings are used in the existing settings. A new setting for Zt will be added to provide an alarm for a sustained unbalance.

Retain existing settings except use time ZT to trigger an alarm for sustained unbalance.

LOGIC_Z := "59N+50N1+50Q1" TZPU := 1200 cycles TZDO := 0 cycles

Tripping Logic

Permissive tripping is required only for instantaneous overreaching functions. No need for any functions that trip directly. Existing 51NT word in MTCS is not required.

MTCS := "M2P+Z2G"

Unconditional tripping MTU := "M1P+Z1G+M2PT+Z2GT+51NT"

No need for existing direct tripping zone 1 functions in the switch on to fault logic.

SOTF Tripping MTO := "M2P+Z2G+50H"

Event records will be triggered automatically by all trip events. Other event record triggers should be by starting of other elements to ensure capture of all relevant events. Events should be triggered by keying or receiving permissive trips to ensure separation of relay and teleprotection issues.

MER := "M2P+Z2G+51N+LOP*52AA1+LOP*52AA2+KEY+PT+EKEY"

Outputs

Retain existing output assignments except add the continuous unbalance alarm to OUT15.

OUT15 := "LOP*50L+ZT"

Input Contact Assignment

It would be desirable to provide phase segregated inputs to the relay so that the quadrilateral functions could be disabled during single pole open conditions. Sufficient separate inputs are presently available for phase segregated breaker status inputs. It is recommended to replace the existing 52bx breaker status inputs with phase segregated breaker status inputs.

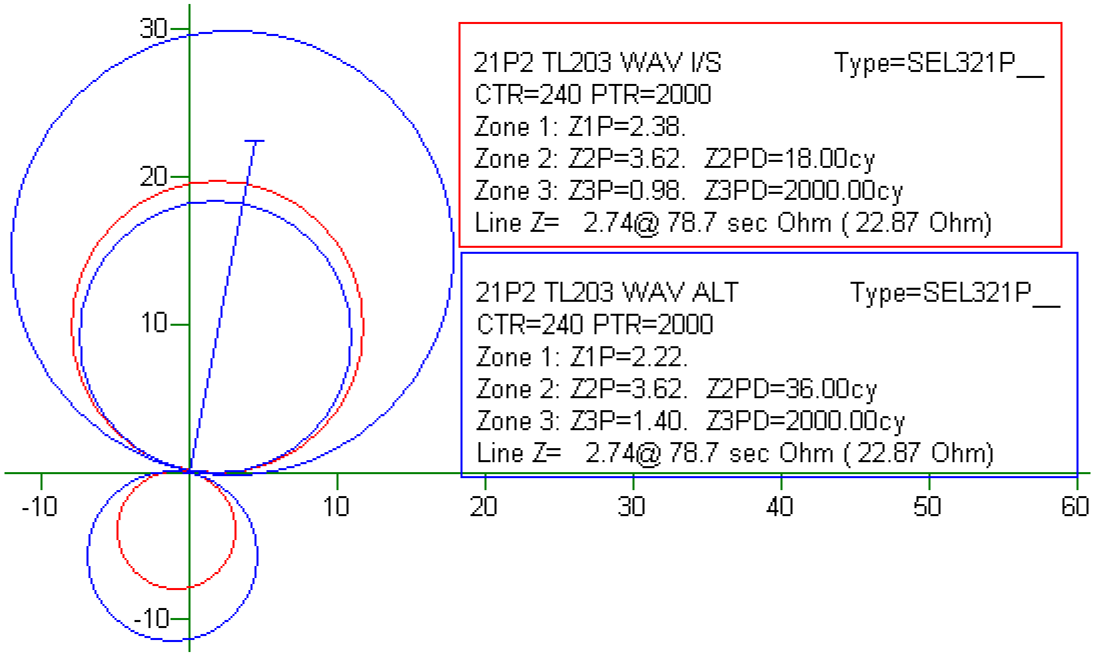


Figure 17 - Comparison of phase distance characteristics. Red is existing, blue is proposed alternative

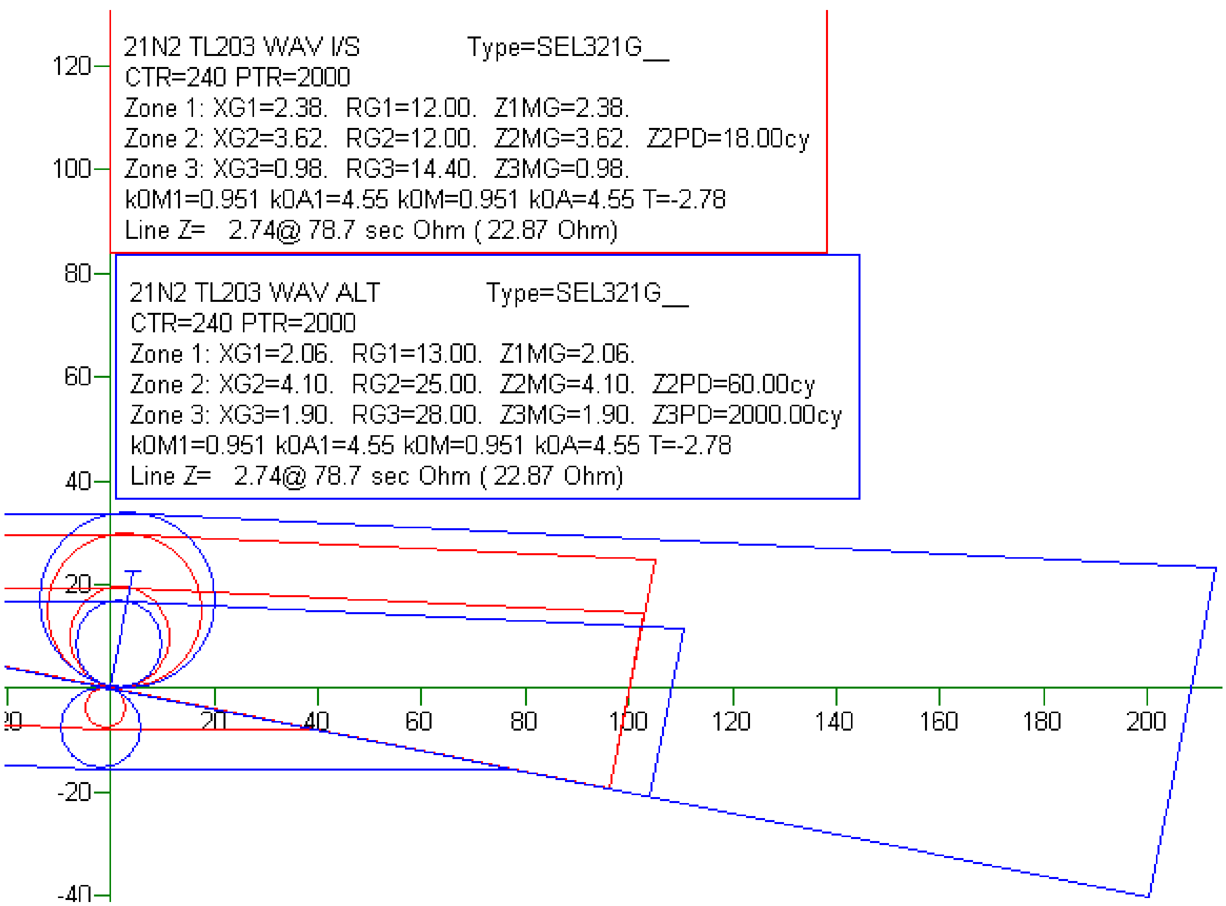


Figure 18 - Comparison of ground distance characteristics. Red is existing, blue is proposed alternative

Protection Review for Five 230 kV Transmission Lines

Appendix K
Detailed settings review for SSD TL207 "P1" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1protection systems for the Sunnyside (SSD) terminal of circuit TL207 .
This 230 kV transmission circuit is from Sunnyside (SSD) to Come By Chance(CBC)
The circuit does not run parallel to any other circuit for any significant portion of its length.

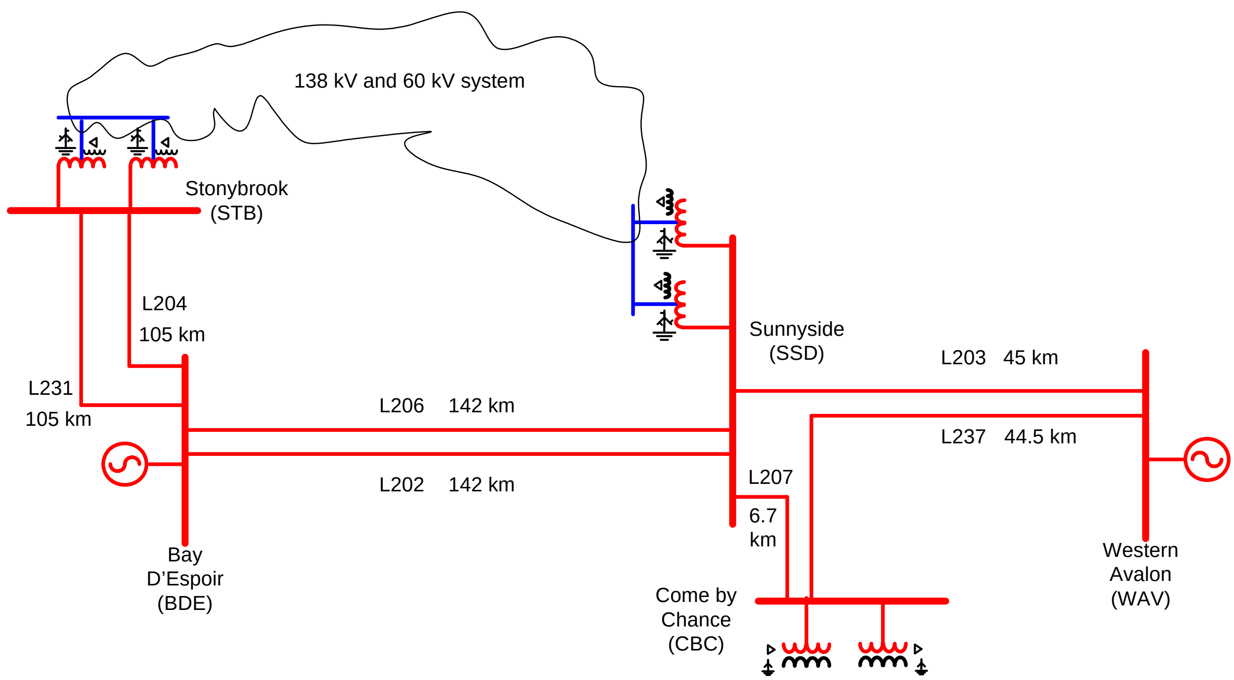


Figure 1 - System Single Line Diagram

Existing P1 protection systems are Areva LZFP111 (Optimho) systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $kVbase := 230$ $Ibase := \frac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $Zbase := \frac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $CTR := \frac{1200}{5}$ VT ratio is: $VTR := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**Hydro Interconnected System (2010-08-13) V10.olr**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with all shunts ignored (unless needed for load flow simulation).

Minimum fault current seen by each terminal (phase to phase, and SLG with 100 ohm fault resistance).

At SSD, with Circuit TL202 out of service, and TL207 and TL237 lines in service, for a fault at the remote terminal.

$ILLmin := 738$ A $ISLGminPH := 811$ A $ISLGmin0seq := 556$ A

The optimho current level detectors that block the distance comparators in the event of line opening are fixed at 5% of the rated current, or 0.25 A secondary, or 60 A primary. They will have no difficulty in operating for minimum fault levels. However, the ground distance elements are also supervised by a low set neutral current level detector (LDLSN that requires the neutral current to be greater than 10% of the maximum amplitude of phase difference current. This prevents the ground comparators from operating during close-in multiphase faults with CT errors. ASPEN OneLiner shows that for a bolted fault at the remote bus even under heavy load, there is sufficient neutral current (22% of maximum phase to phase fault current) that means this LDLSN function does not inhibit the ground distance comparator.

Calculate the minimum negative sequence source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind SSD $Z2minSSD := 3.23 + j \cdot 27.31$ ohms primary

Minimum um source impedance behind CBC $Z2minCBC := 6.76 + j \cdot 49.82$ ohms primary

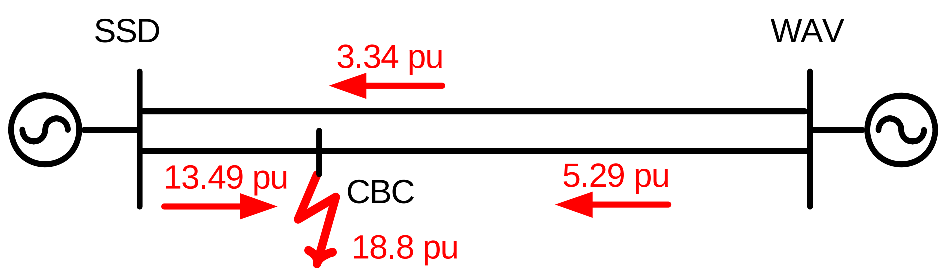


Figure 2 - 3 Phase Fault at CBC

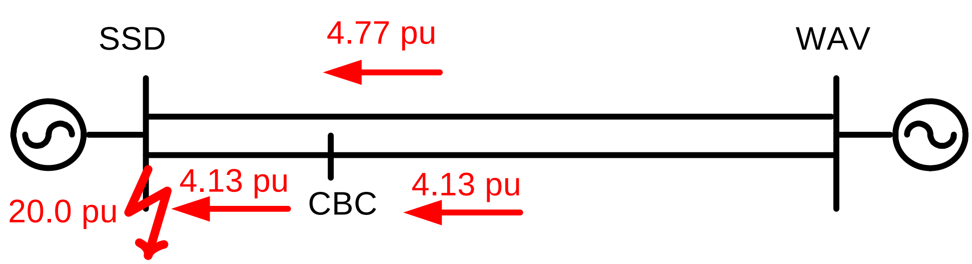


Figure 3 - 3 Phase Fault at SSD

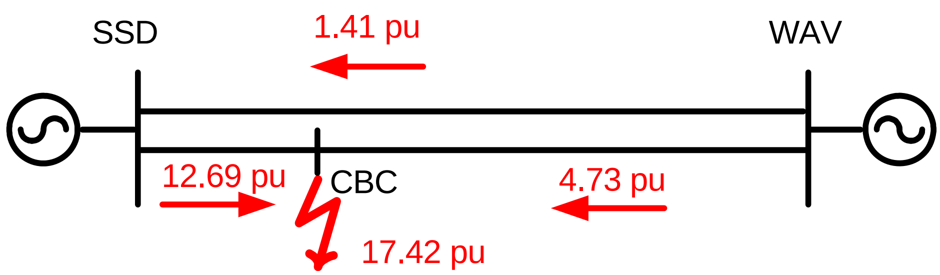


Figure 4 - SLG Fault at CBC (3I0 currents)

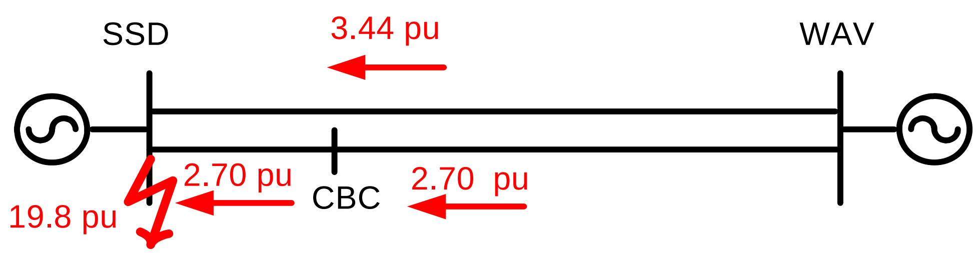


Figure 5 - SLG Fault at SSD (3I0 currents)

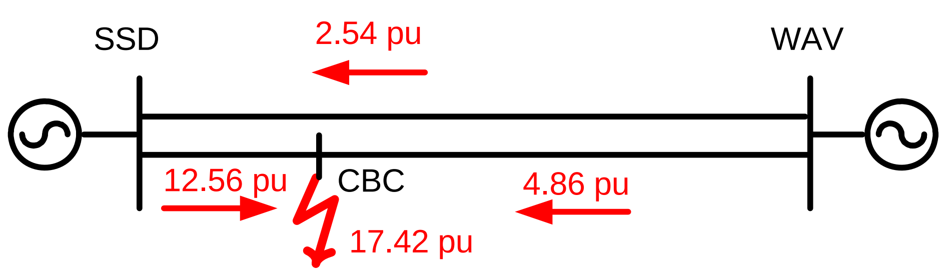


Figure 6 - SLG Fault at CBC (Phase currents)

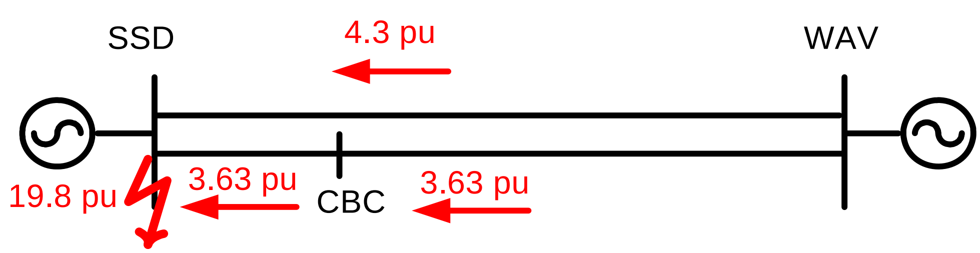


Figure 7 - SLG Fault at SSD (Phase currents)

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L207 := 0.00092 + j \cdot 0.00632$ $\quad$ $Z0L207 := 0.00314 + j \cdot 0.02366$

In primary ohms

$Z1L207pri := Z1L207 \cdot Zbase$ $\quad$ $Z0L207pri := Z0L207 \cdot Zbase$

In secondary ohms

$Z1Linesec := Z1L207pri \cdot \frac{CTR}{VTR}$ $\quad$ $Z0Linesec := Z0L207pri \cdot \frac{CTR}{VTR}$

$|Z1Linesec| = 0.405$ $\quad$ $arg(Z1Linesec) = 81.718 \cdot deg$

$|Z0Linesec| = 1.515$ $\quad$ $arg(Z0Linesec) = 82.44 \cdot deg$

Load Data

From 2010 System peak load case provided in start up information, the peak load is given as 138.4 MVA (with TL203, TL207 and TL237 in service). The highest load of the three lines is TL207 with a load of 138.4 MVA. In the event of sudden loss of TL203. Peak load in TL207 will increase to take up the lost load through TL207. Thus the peak load in TL207 will be slightly less than double until operators can adjust loads.

$Speak\_207 := 138.4$ MVA $\quad$ $Speak\_203 := 132.6$ MVA

$Smax := Speak\_203 + Speak\_207 = 271$ MVA

P1 Relay Settings

Distance element reach settings

Note that resistive reaches are forced to be the same for all zones. Reactive reaches for phase and ground distance elements must be the same as each other.

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the SSD Station bus under weak source conditions with TL202 out of service and all of TL203. TL207 and TL237 lines in service. From ASPEN OneLiner, voltage at SSD for a 3 phase fault at CBC is 0.07 per unit. So there is less than 20% voltage at SSD during a fault at WAV under weak source conditions.

Since the voltage is not higher than 20%, the line is considered short, and a reduced Zone 1 setting is recommended to provide more security. Choose a setting of 80% of nominal.

$Z1P := 0.8 \cdot |Z1Linesec|$ $\quad Z1P = 0.32$ Ohms secondary

This is the same as the existing setting. However, note that direct tripping by zone 1 will be blocked, because it is desired to use a higher resistive reach for the quadrilateral element than could be secure with such a short zone 1 setting. This is a limitation of the optimho relay that the resistive reach for all zones has to be set the same.

$Z1pri := Z1P \cdot \frac{VTR}{CTR} = 2.703$ Ohms primary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

However, for such a short line, it is preferable to set a longer reach so the relay may operate faster. Existing setting is about 360% of the line, and this is a reasonable number that could be retained. For consistency with the P2 protection, the setting could be changed to 400% of the line. Check that as setting of 400% will not reach beyond the LV bus at CBC without infeed and also that it will not reach past the zone 1 element of the CBC TL237 protection. 400% reach is OK, see "ALT" setting in Figure 9.

$Z2\_sec := 4 \cdot |Z1Linesec|$ $\quad Z2\_sec = 1.6$ Ohms secondary $\quad \frac{Z2\_sec}{|Z1Linesec|} = 400 \cdot \%$

$Z2\_pri := Z2\_sec \cdot \frac{VTR}{CTR} = 13.514$ Ohms primary

$|Z1Linesec| \cdot \frac{VTR}{CTR} = 3.379$

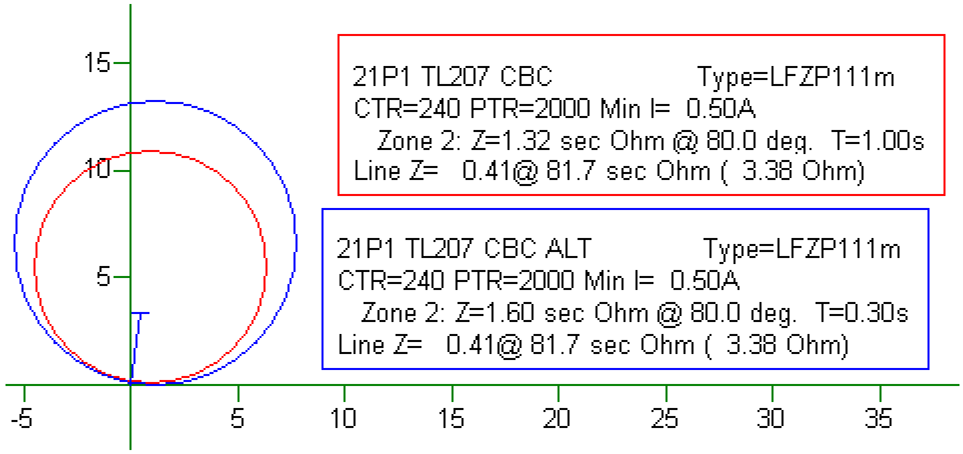


Figure 8 -Alternate Zone 2 setting is slightly longer than existing.

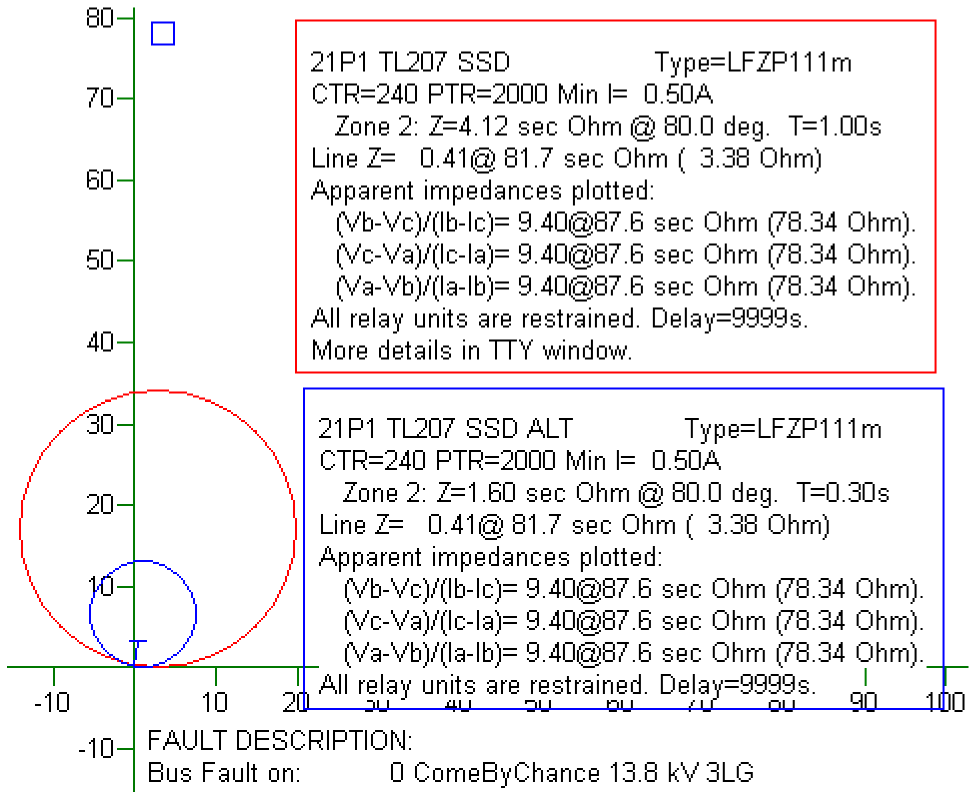


Figure 9 - Apparent impedance to a fault on the CBC 13.8 kV bus without infeed from WAV

The zone 2 timer will be enabled, and set as existing at 1 second. This long delay is not necessary for coordination with remote primary protection but may be helpful for coordination with the CBC backup protection. This element will not overreach the zone 1 function on the shortest line (TL237) out of CBC.

Zone 3

The zone 3 function is not used since the POR1 scheme does not include an echo function so there is no need for any reverse blocking function. Since the Zone 2 timer has to be set with the coordination of the ground distance element in mind, it is set at 2 second; so there is no benefit in applying a longer reaching zone 3 function.

Zone 3 element is blocked - same as existing.

Load Encroachment logic

The optimho instruction manual recommends a margin of at least 10% between the impedance of the maximum load and the resistive reach of the quadrilateral distance element.

Check loadability of the Zone 2 phase distance element assuming worst case depressed voltage of a stressed system of 0.9 per unit.

$$\mathrm{Zloadmin} := \frac{(0.9\mathrm{kVbase})^2}{\mathrm{Smax}} \qquad \mathrm{Zloadmin} = 158.114$$ Ohms primary (assume worst case at 30 degrees)

$$\mathrm{Zloadmin\_sec} := \mathrm{Zloadmin}\cdot\frac{\mathrm{CTR}}{\mathrm{VTR}} \qquad \mathrm{Zloadmin\_sec} = 18.974$$

A 12 ohm secondary resistive reach is less than 90% of the load impedance at anyypower factor and meets the Areva criterion. Anyway there is no difficulty with load encroachment as can be seen in Figure 10.

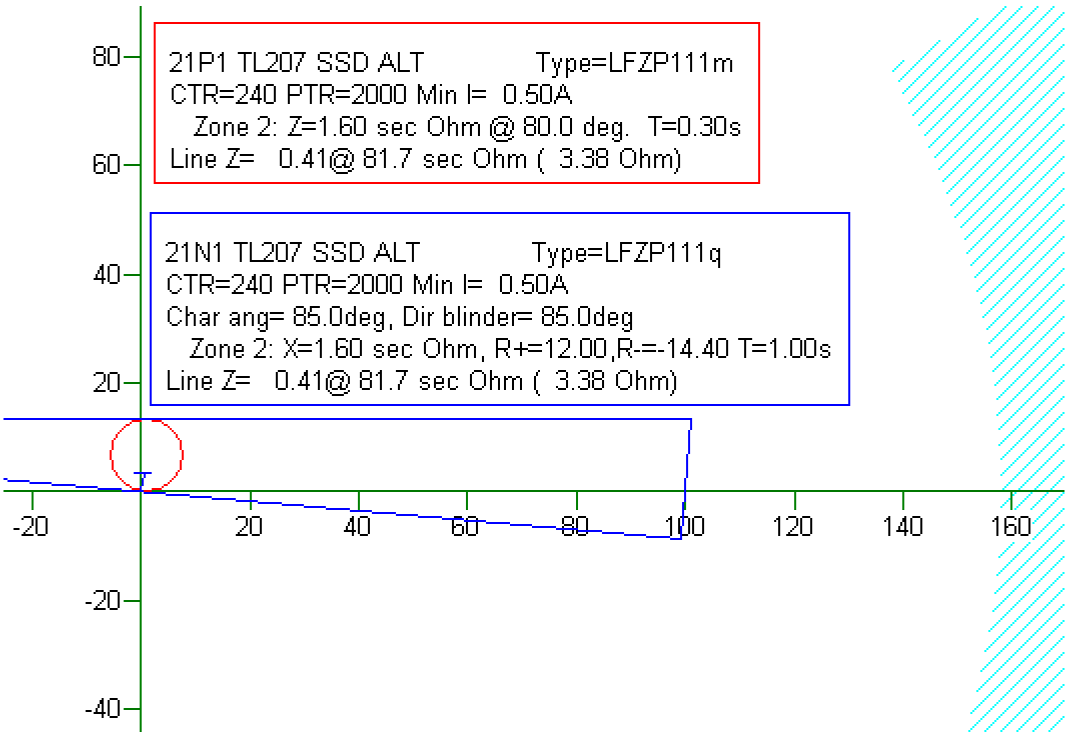


Figure 10 - Apparent impedance of load

Zone 1 Resistance - QUAD

If a quad element was provided for Zone 1, a secure setting would need to have such a small resistive reach that it would not be much use for a resistive single line to ground fault. In order to get a reasonable setting for the resistive reach for the zone 2 function, the zone 1 function will be blocked from tripping.

Zone 2 Resistance - QUAD

The existing setting is 1.32 ohms secondary. From Figure 11, it can be seen that this will be sufficient to sense a 100 ohm single line to ground fault close to the CBC terminal.

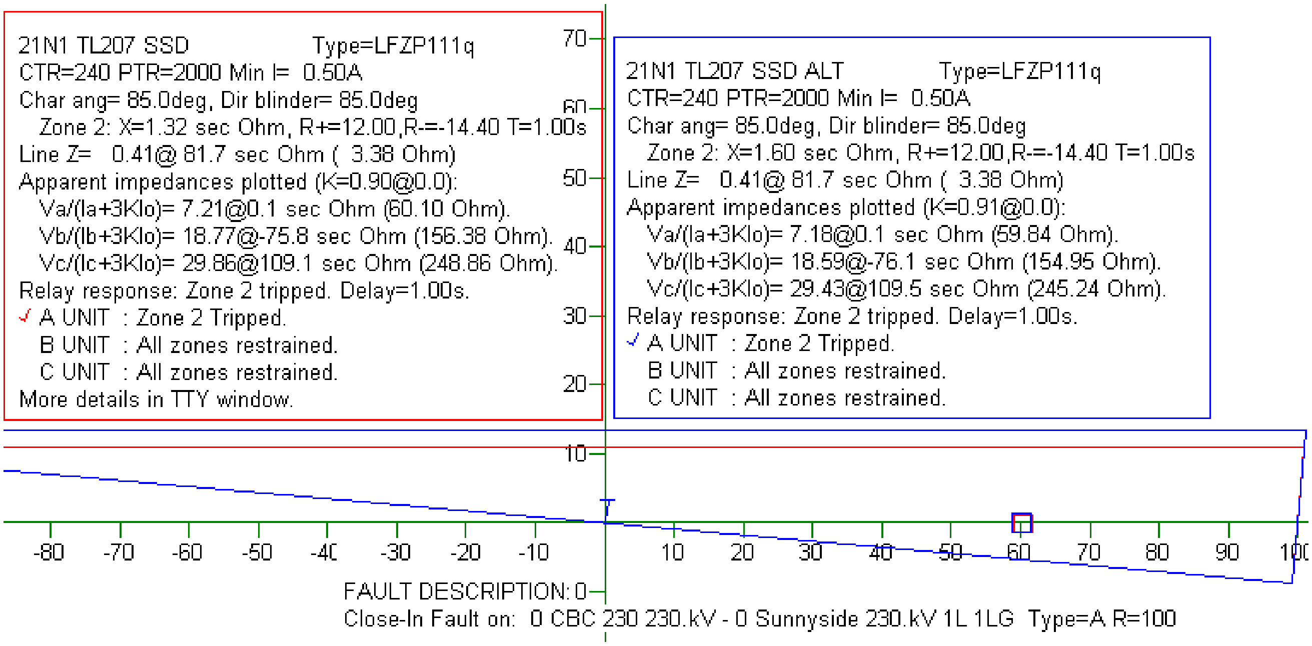


Figure 11 - Sensitivity for 100 ohm SLG fault near CBC

Retain the existing setting of resistive reach. Rquad := 12 ohms secondary

Settings of K attenuators

KZPh Coarse setting common to all DISTANCE zones should be set as high as possible while below the required Zone 1 reach. The current level detectors vary inversely with KZph. Maximum setting available is 1.0. However, the minimum setting on KZ1 is 1, therefore for this short line, KZPh has to be set less than 1.

$KZPh := 0.32$

Zone 1 attenuators and angular selection

$In := 5$ $\quad Z1P = 0.32$ This is the desired secondary reach (previously calculated)

$$KZ1 := \frac{Z1P}{\left(KZPh\cdot\frac{5}{In}\right)} \qquad KZ1 = 1 \qquad Z1sec\_reach := KZ1\cdot KZPh\cdot\frac{5}{In} \qquad Z1sec\_reach = 0.32$$

Tripping by the zone 1 function is disabled - same as existing.

$Z\theta PH := (\arg(Z1Linesec))$ $\quad Z\theta PH = 81.718\cdot deg$

Rounded to the nearest 5 degrees $\quad Z\theta PH := 80$ Degrees

$Z\theta N := \arg(Z0Linesec - Z1Linesec)$ $\quad Z\theta N = 82.7\cdot deg$

Rounded to the nearest 5 degrees $\quad Z\theta N := 85$ Degrees

Zone 2 attenuators selection

$Z2\_sec = 1.6$ This is the desired secondary reach (previously calculated)

$$KZ2 := \frac{Z2\_sec}{\left(KZPh\cdot\frac{5}{In}\right)} \qquad KZ2 = 5.1$$

Zone 3 is not used

QUAD Resistive Reach setting

$Rquad = 12$ ohms secondary. This reach will be required to sense a 100 ohm SLG fault anywhere on the line.

$$KR := \frac{Rquad}{\left(\frac{5}{In}\right)} \qquad KR = 12$$

Residual Compensation attenuators selection

Zero sequence current compensation for ground faults is provided by the KZN factor. Zero sequence mutual compensation is not used in this application (it causes extra complexity for only moderate gain in setting accuracy).

$$KZN := \frac{Z0Linesec - Z1Linesec}{3\cdot Z1Linesec}\cdot KZPh \qquad KZN = 0.292 + 5.027j \times 10^{-3}$$

$|KZN| = 0.292$ $\quad$ This close to the existing setting

Switch On To Fault (SOTF) Protection.

If SOTF is enabled, it can be set to 200ms or 110 s after all poles of the line have been de-energized. The 110 s setting is intended to override automatic reclosing dead time. However it makes more sense to enable after the shorter time. Once the SOTF feature has been initiated, it remains in effect for 250ms after the line has been re-energized. The SOTF tripping options are:

a) Any distance comparator.
b) Any current level detector as long as a corresponding voltage level detector has not picked up within 20ms.
c) Either current or distance, as long as a corresponding voltage level detector has not picked up within 20ms.

SOTF := "Enabled"

SOTF_TIME := 0.20 Seconds

Elements_in_SOTF := "BOTH" (Both Comparators and current level detectors).

Power Swing Detector

This element will not be used. It will be left Blocked, and if there is a power swing, the distance elements will trip naturally.

VT Supervision

Set the VT supervision to BLOCK TRIP

Set the VT fail detection to SELF RESET this is as existing .

SELF_RESETTING := "ENABLED"

Start Indication

This function will bring up information on the LCD screen of the relay if a start event occurs. This function will not be used.

START_INDICATION := "BLOCKED"

Communications assisted logic.

The existing communications assisted logic is permissive overreaching transfer trip, scheme **POR 1**. This scheme is familiar to Newfoundland and Labrador Hydro, and even though the POR 2 scheme offers the advantage of weak infeed echo, which would help the sensitivity to resistive faults, it is not recommended to change the existing scheme logic at this stage with years of experience on a product that is nearing the end of its useful life.

The POR 1 logic is a basic permissive overreaching transfer trip scheme but it does include current reversal timers to increase security against misoperation due to current reversal when a fault on the parallel line is cleared sequentially. The current reversal logic is achieved by a timer TP which will block permissive tripping and keying of permissive trip if the local zone 2 element does not pick up within a reasonable time of receiving permissive trip. The block will be maintained for a time delay of TD after the local zone 2 element picks up, or the received permissive trip signal resets.

The application of the current reversal timers is required only if the settings of the zone 2 comparators are greater than 1.5 times the line impedance. Since the reaches of these elements are less than or equal to 1.5 times the line impedance, the current reversal logic is not required, and the recommended default settings are as existing>

$TP := 98$ ms

$TD := 0$ ms

Comparison of Existing and Proposed alternative (ALT) settings.

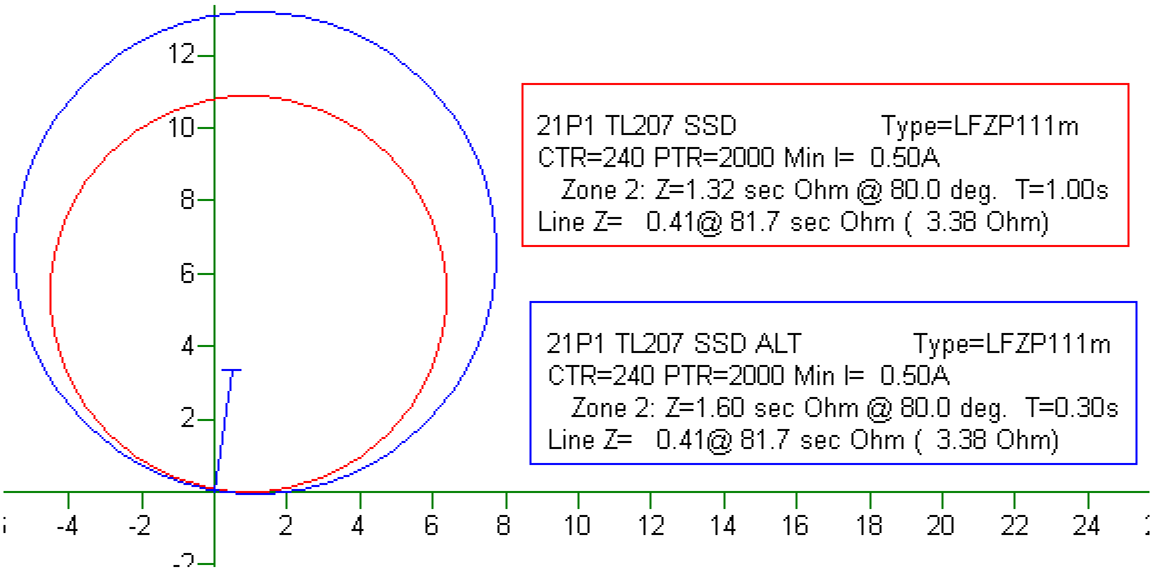


Figure 12 - Comparison of phase distance characteristics

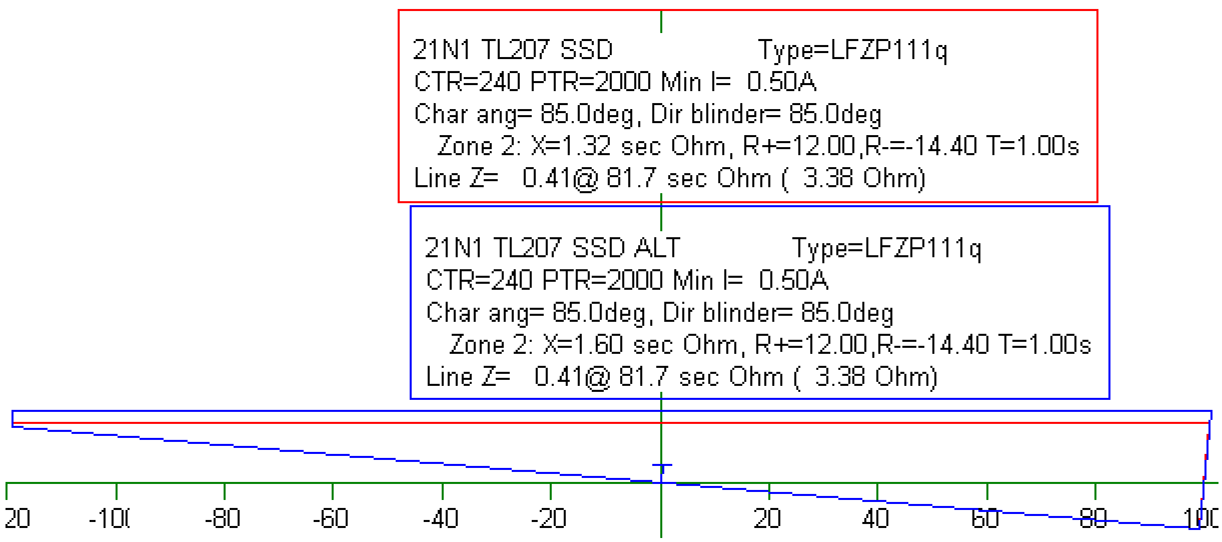


Figure 13 - Comparison of ground distance characteristics

Protection Review for Five 230 kV Transmission Lines

Appendix L
Detailed settings review for SSD TL207 "P2" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P2 protection systems for the Sunnyside (SSD) terminal of circuits TL207 .
This 230 kV transmission circuit is from Sunnyside (SSD) to Come By Chance (CBC)
The circuit does not run parallel to any other circuit for any significant distance.

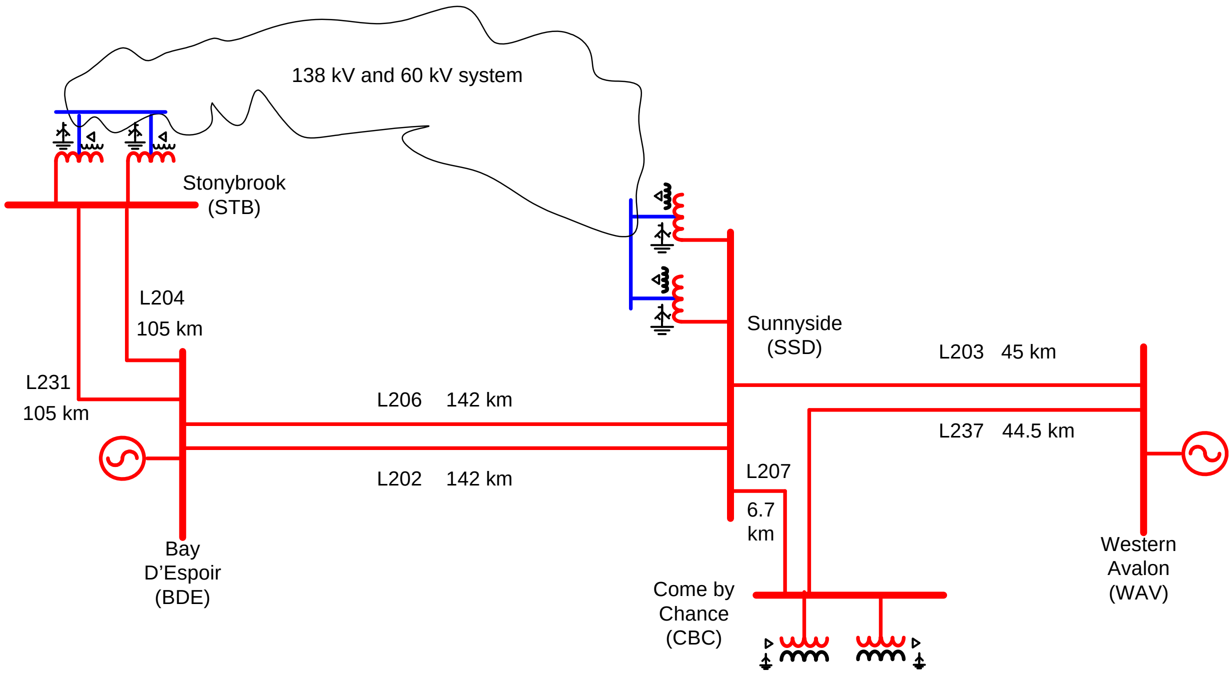


Figure 1 - System Single Line Diagram

Existing P2 protection systems are SEL321 systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$\text{MVAbase} := 100 \qquad \text{kVbase} := 230 \qquad \text{Ibase} := \frac{\text{MVAbase}\cdot 1000}{\text{kVbase}\cdot\sqrt{3}} \qquad \text{Zbase} := \frac{\text{kVbase}^2}{\text{MVAbase}}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $\text{CTR} := \frac{1200}{5}$ VT ratio is: $\text{VTR} := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**Hydro Interconnected System (2010-08-13) V10.olr**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with all shunts ignored (unless needed for load flow simulation).

Minimum fault current seen by each terminal (multiphase and SLG with 100 ohm fault resistance).

At SSD, with Circuit TL202 out of service, and TL207 and TL237 lines in service, for a fault at the remote terminal.

$I3Pmin := 2624$ $ISLGminPH := 780$ A $ISLGmin0seq := 893$ A

The current for a phase to phase fault would be lower, but the current supervision element of the SEL321 measures phase to phase currents, and the phase to phase current for a phase to phase fault is twice the phase current.

Calculate the minimum negative sequence source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open. **For this calculation only, simulate 50 MVA of generation (i.e., simulating motor load) at CBC to minimize source impedance.**

Minimum source impedance behind SSD $Z2minSSD := 3.23 + j \cdot 27.31$ ohms primary

Minimum um source impedance behind CBC $Z2minCBC := 4.68 + j \cdot 41.16$ ohms primary

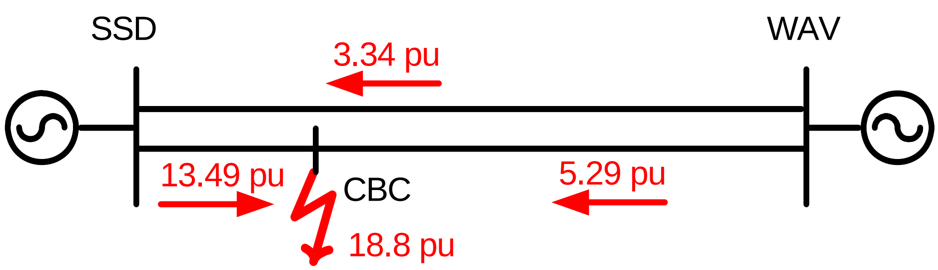


Figure 2 - 3 Phase Fault at CBC

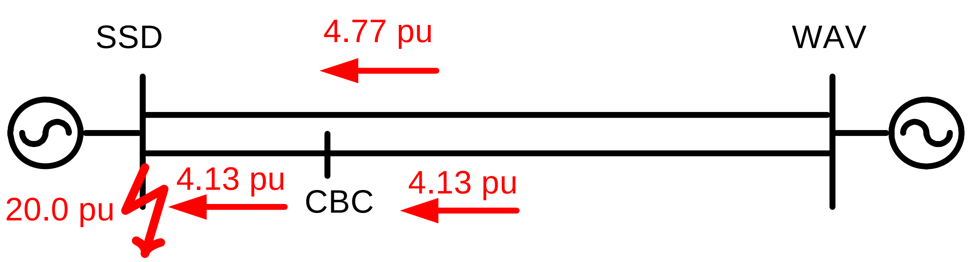


Figure 3 - 3 Phase Fault at SSD

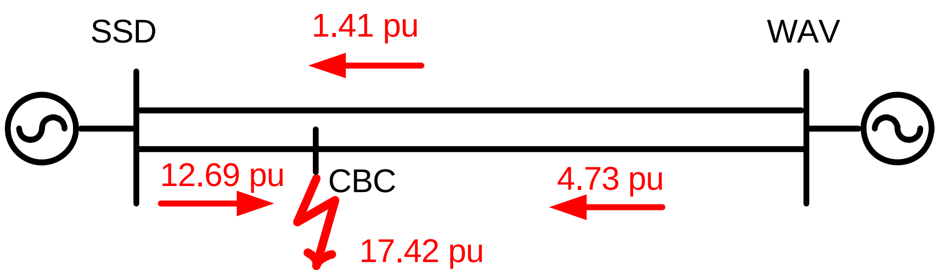


Figure 4 - SLG Fault at CBC (3I0 currents)

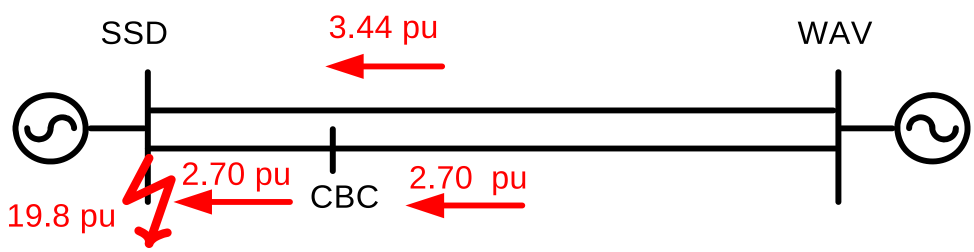


Figure 5 - SLG Fault at SSD (3I0 currents)

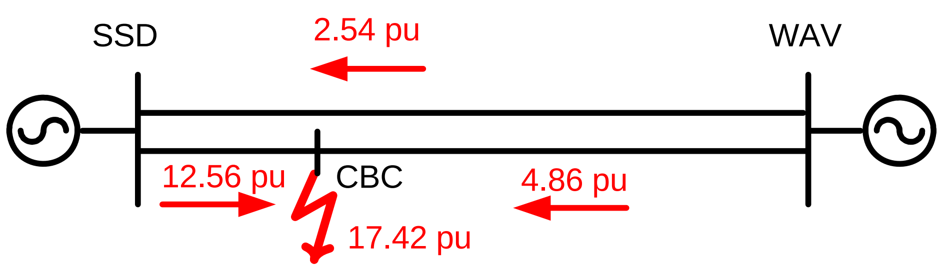


Figure 6 - SLG Fault at CBC (Phase currents)

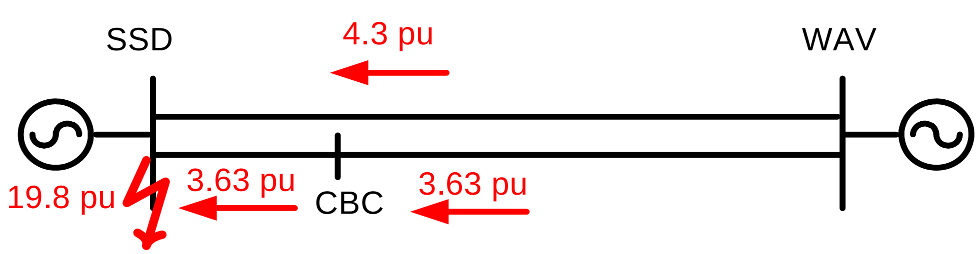


Figure 7 - SLG Fault at SSD (Phase currents)

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L207 := 0.00092 + j \cdot 0.00632$ $\quad$ $Z0L207 := 0.00314 + j \cdot 0.02366$

In primary ohms

$Z1L207pri := Z1L207 \cdot Zbase$ $\quad$ $Z0L207pri := Z0L207 \cdot Zbase$

In secondary ohms

$$Z1Linesec := Z1L207pri \cdot \frac{CTR}{VTR} \qquad Z0Linesec := Z0L207pri \cdot \frac{CTR}{VTR}$$

$|Z1Linesec| = 0.405$ $\quad$ $\arg(Z1Linesec) = 81.718 \cdot deg$

$|Z0Linesec| = 1.515$ $\quad$ $\arg(Z0Linesec) = 82.44 \cdot deg$

These impedances match the existing settings in the P2 relay no need for changes.

Load Data

From 2010 System peak load case provided in start up information, the peak load is given as 138.4 MVA (with TL203, TL207 and TL237 in service). The highest load of the three lines is TL207 with a load of 138.4 MVA. In the event of sudden loss of TL203. Peak load in TL207 will increase to take up the lost load through TL207. Thus the peak load in TL207 will be slightly less than double until operators can adjust loads.

$Speak\_207 := 138.4$ MVA $\quad$ $Speak\_203 := 132.6$ MVA

$Smax := Speak\_203 + Speak\_207 = 271$ MVA

P2 Relay Settings

The existing line impedance settings are slightly different from the line data book. They should be adjusted to improve the accuracy of the fault location algorithm.

$Z1MAG := |Z1Linesec| \quad Z1MAG = 0.41 \qquad Z1ANG := \frac{arg(Z1Linesec)}{deg} \qquad Z1ANG = 81.7$

$Z0MAG := |Z0Linesec| \quad Z0MAG = 1.5 \qquad Z0ANG := \frac{arg(Z0Linesec)}{deg} \qquad Z0ANG = 82.4$

$LL207 := 6.7$

In order to obtain sensitivity to 100 ohm single line to ground faults, the echo function will be needed. Enable two forward and one reverse zone.

$PMHOZ := 3 \qquad GMHOZ := 3 \qquad QUADZ := 3$

$DIR1 := F \qquad DIR2 := F \qquad DIR3 := R$

Mho phase distance functions

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if the line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the SSD Station bus under weak source conditions with TL202 out of service and all of TL203, TL207 and TL237 lines in service. From ASPEN OneLiner, voltage at SSD for a 3 phase fault at CBC is 0.07 per unit. So there is less than 20% voltage at SSD during a fault at CBC under weak source conditions.

Since the voltage is not higher than 20%, the line is considered short, and a reduced Zone 1 setting is recommended to provide more security. Choose a setting of 80% of nominal.

$Z1P := 0.8 \cdot |Z1Linesec| \qquad Z1P = 0.32$ Ohms secondary

This is the same as the existing setting.

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

However, for such a short line, it is preferable to set a longer reach so the relay may operate faster. Existing setting is about 320% of the line, and this is a reasonable number that could be retained, however for consistency with the P1 protection it recommended to increase this setting to 400% of the line.

$Z2P := \mathrm{round}(4\cdot|Z1Linesec|, 1)$ $\quad\quad$ $Z2P = 1.6$ $\quad$ Ohms secondary

As can be seen from Figure 8, this element (with the proposed new setting) does not overreach the zone 1 element at the CBC terminal of TL237 even without infeed.

The existing Zone 2 timer setting of 18 cycles will be appropriate.

$Z2PD := 18$ $\quad$ cycles

Zone 3

Set Zone 3 reverse element to reach further behind this terminal than the remote Zone 2. This function adds security for external faults. The element should always be more sensitive than the forward looking Zone 2 at the remote terminal. Set it the same as the remote Zone 2 overreach plus 100%. This higher margin than used on other lines is desirable considering the short line does not provide much margin in itself.

$$Z3P := Z1MAG\cdot\left(\frac{Z2P}{Z1MAG} - 1 + 1\right)$$

$Z3P = 1.6$ $\quad$ Ohms secondary (as existing)

$$\frac{Z3P}{|Z1MAG|} = 394.65\cdot\% \quad \text{of line length}$$

The reverse looking zone 3 element need not be set to trip through a timer. It is needed only for security in the POTT scheme.

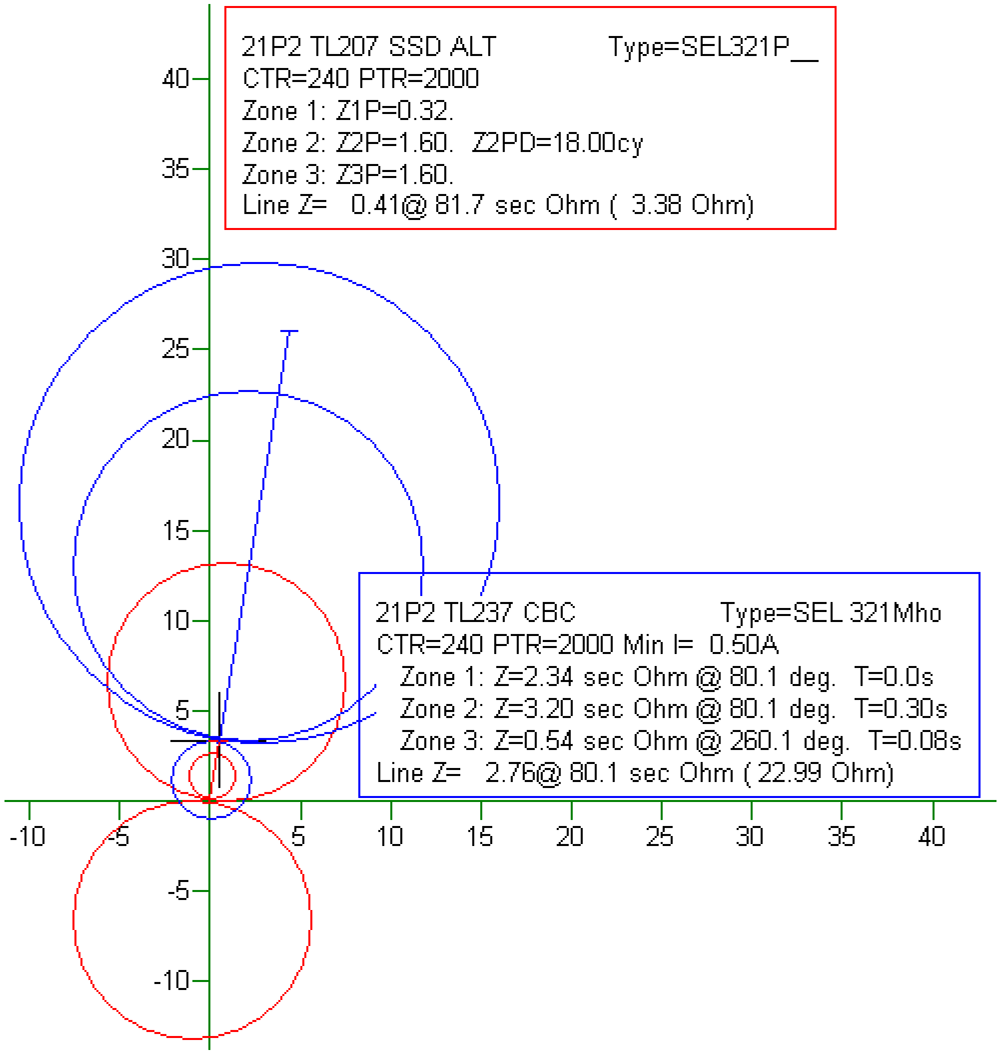


Figure 8 - Existing SSD TL207 Zone 2 underreaches CBC TL237zone 1 without infeed, and coordinates with zone 1 on this line.

Mho phase distance current supervision

If the current supervision elements can be set above load, they will be secure in the event that potential is lost. However given that loss of potential logic is available, it is recommended that only the zone 1 current supervision function be set above load. If potential is lost, it will be able to block tripping by Zone 2 before it trips on time delay or receives a permissive trip from the remote terminal.

For the point of view of current supervision being above maximum load, there is no need to worry about abnormal conditions. It would be a double contingency for the VT signal to be lost while the parallel line was out of service. Therefore, consider a maximum load of 135 MVA. The current supervision elements for the phase distance functions measure phase to phase currents.

$$IPPmax\_normal := \frac{Speak\_207 \cdot 1000}{kVbase} \qquad IPPmax\_normal = 602$$ A primary

The current supervision elements use phase to phase currents for supervision of the phase distance function;. so the minimum phase to phase fault current will be root three times the minim phase fault current. Choose a margin of 50% of the minimum phase to phase fault current for dependability.

$$IPPmin := 0.5I3Pmin \cdot \sqrt{3} \qquad IPPmin = 2272$$ A primary

A setting of 720 A primary for 50PP1 will ensure the Zone 1 function operates for any fault even under minimum source conditions but will not be susceptible to trip on load due to loss of potential under normal maximum load conditions. This is somewhat lower than the existing setting but there is no need for any higher setting.

$'50PP1 := 3$ A Sec $\qquad '50PP1 \cdot CTR = 720$ A primary

Since Zone 2 and zone 3 elements will be blocked by LOP function, set them at minimum. The zone 3 current supervision should not be set higher than the zone 2 current supervision element at the remote terminal. In this case the remote zone 2 current supervision element will be set at 1.0 A secondary.

$'50PP2 := 1$ A Sec $\qquad '50PP3 := 1$ A Sec

Ground Distance Protection

Since there are no parallel lines there is no impact from mutual coupling. However, on this short line, it is important to be aware of the possibility of incorrect measurement of a fault beyond the remote terminal due to a high resistive reach on the zone 1 quadrilateral. Choose a setting of 80% of the line impedance and find the maximum resistive reach that should be set using the guideline provided by SEL.

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.8$ per unit

$Z1MG := m \cdot |Z1Linesec|$ $Z1MG = 0.32$

$XG1 := Z1MG$ $XG1 = 0.32$ These are the same as existing settings.

Zone 1 Resistance

XG1 is set at m per unit of the transmission line. The imaginary component of this is

$ImXG1sec := Im(Z1Linesec)$ $ImXG1sec = 0.401$ ohms

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$RG1 := round[(1 - m) \cdot 20 \cdot ImXG1sec, 1]$

$RG1 = 1.6$ This is the maximum secure setting for the resistive reach so the desired zone 1 resistive reach setting would not be confirmed as being secure.

Use the maximum secure setting of 1.5 ohms for RG1 $RG1 := 1.5$ ohms secondary

With a resistive reach setting of 1.5 ohms, the SSD Zone 1 quad element will see a maximum 10 ohm resistive SLG fault 25% of the distance from of the SSD terminal (see Figure 9) and gradually reducing resistance as the fault moves away from the terminal. Zone 2 protection will be depended upon to sense faults with resistance up to 100 ohms.

It should be noted that the 10 ohm resistive SLG at 25% of the distance from SSD will depress the faulted phase voltage by about 66%; so this fault is fairly severe on the system and communications assisted tripping will be required to maintain reasonable performance from the protection.

Communications assistance becomes of increasing importance in protecting a short line such as this. The zone 2 and permissive trip echo function is important on this line.

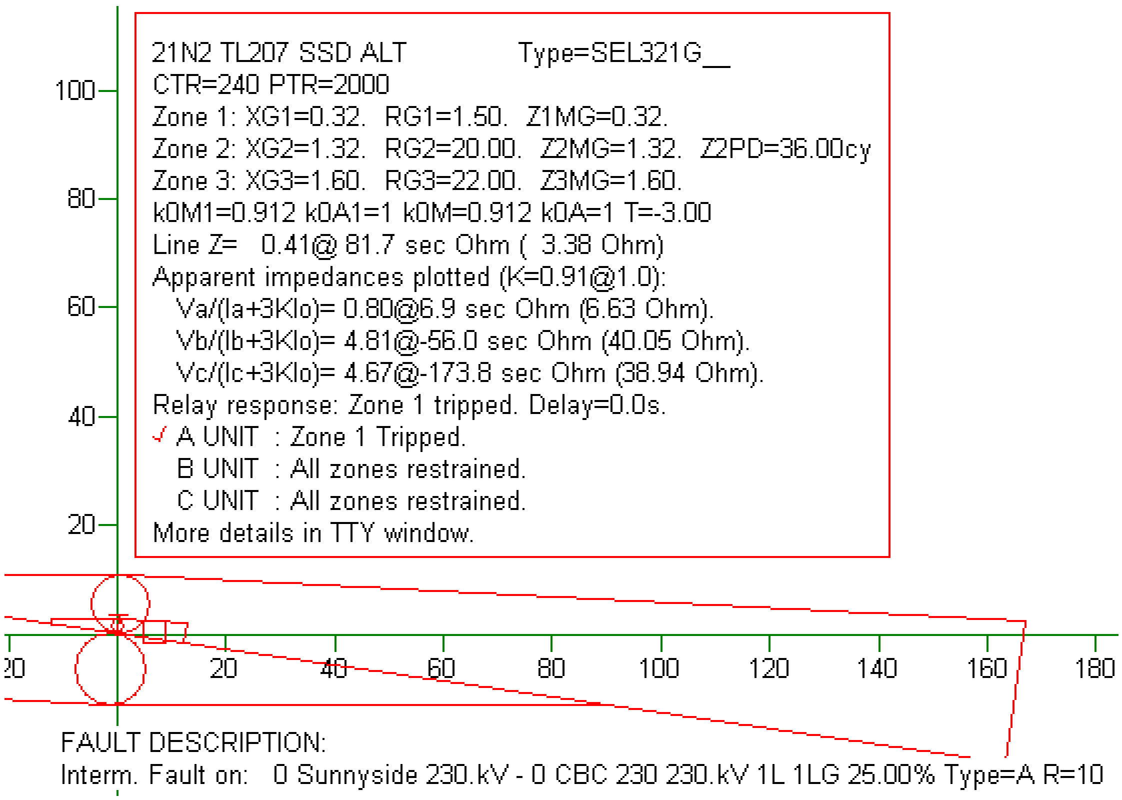


Figure 9 - Proposed reduced resistive reach of Zone 1 quadrilateral reduces sensitivity to resistive faults considerably.

Zone 2 Ground Distance Protection

The Zone 2 ground distance function will set the same as the Zone 2 phase distance protection function because there are no significant mutual coupling effects from parallel lines. In any case, the phase distance function is set at 400% of the line impedance.

Z2MG := Z2P Z2MG = 1.6 Ohms secondary

The quad element reactive reach will be set similarly to the mho.

XG2 := Z2MG XG2 = 1.6 Ohms secondary

The resistive reach of the quad will be increased to sense a 100 ohm resistive close to the CBC terminal of the line so it will operate without the need for any assistance from the CBC terminal (with permissive trip echo if necessary because of lack of sensitivity of the CBC terminal).

By trial and error from ASPEN it is found that a resistive reach of 20 ohms secondary will sense a 100 ohm SLG fault close in to the CBC terminal. However the permissive trip echo function will be required to ensure that a fault that is seen by the zone 2 element at only the SSD terminal will still be cleared by the permissive trip logic.

Therefore, to avoid extremely large resistive reaches, and to retain sensitivity to 100 ohm resistive SLG faults, it is recommended that the echo function be enabled at both terminals.

R2G := 20 Ohms secondary

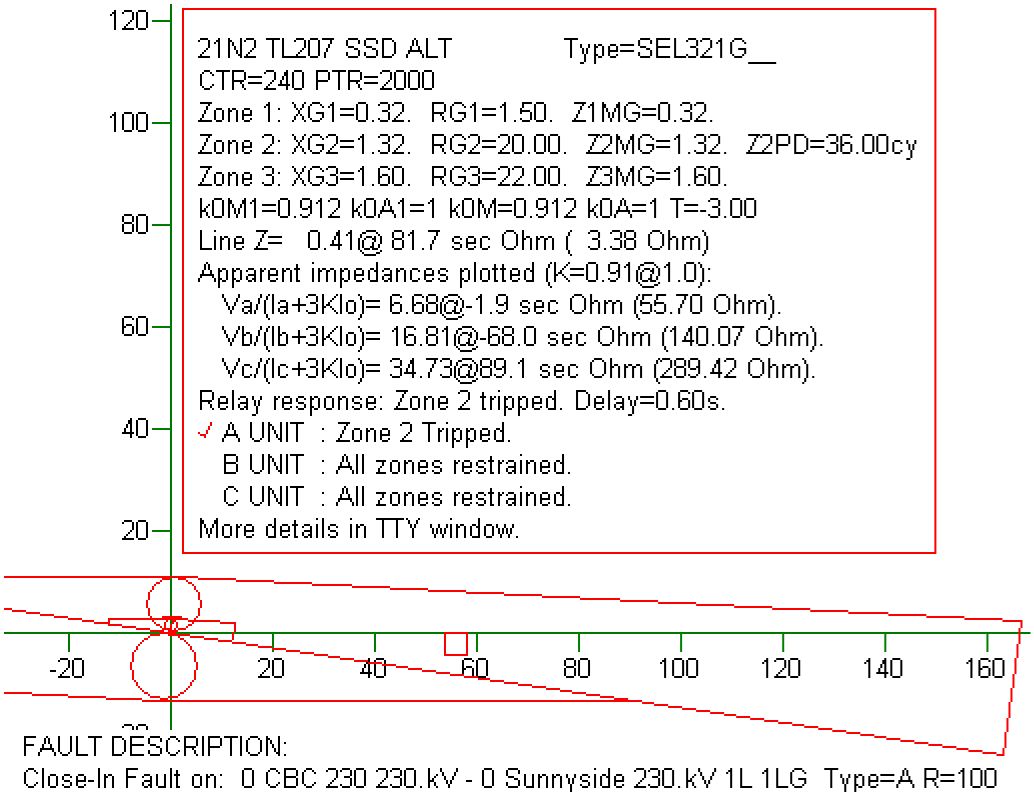


Figure 10 - Local Zone 2 Quad element operates for 100 ohm resistive SLG close to the remote (CBC) terminal.

With very heavy prefault load flow (220 MVA in TL203 and 240 MVA in TL207) if TL203 trips single pole, the ground distance elements with the increased resistive reach on the P2 protection will remain secure. See Figure 11

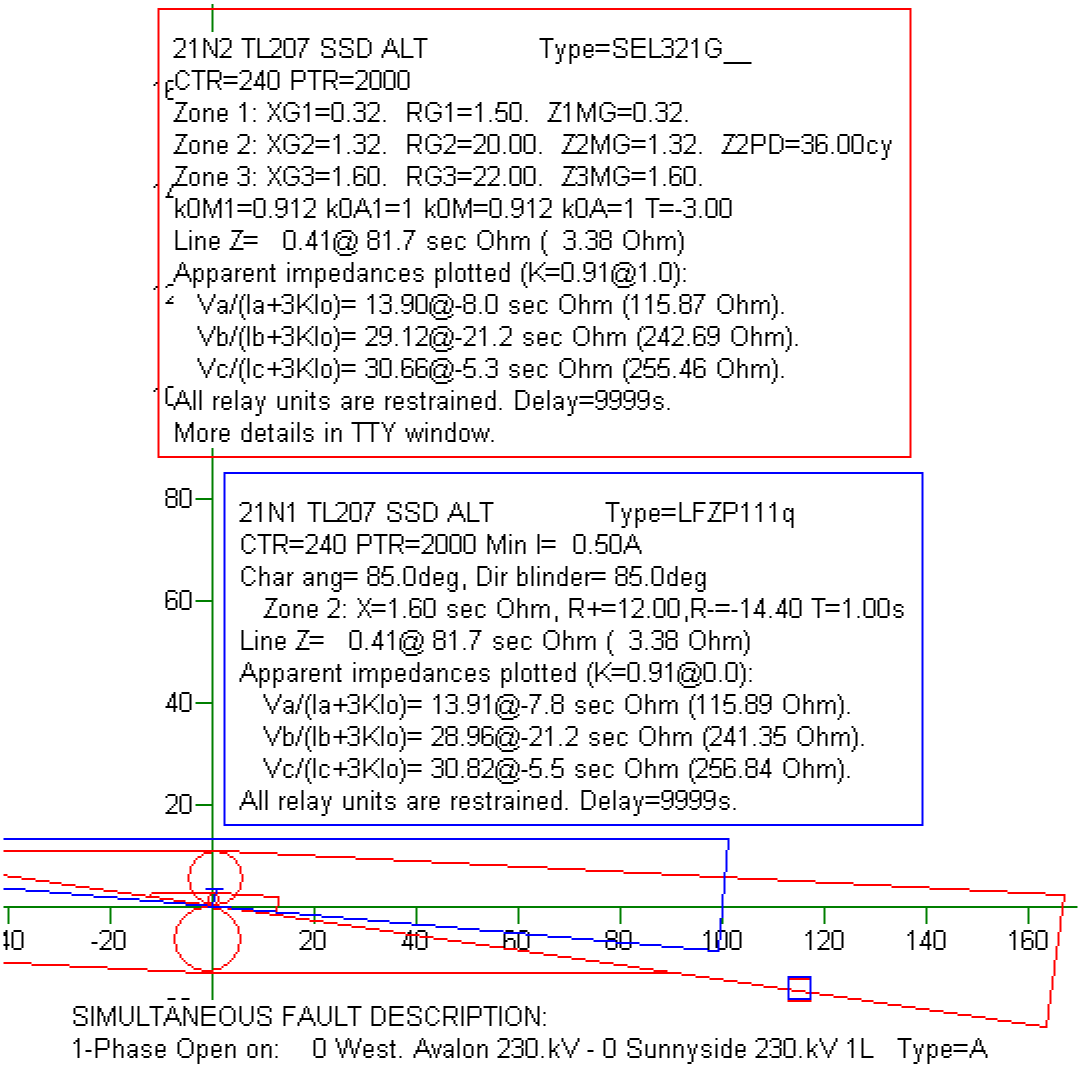


Figure 11 - Ground distance elements remain secure during heavy load flow with one phase open on TL203

The zone 2 ground distance time delay trip will need to be reduced from 60 to 36 cycles (0.6 seconds) in order to aid coordination for resistive single line to ground faults "around the loop" of TL203 TL237 and TL207 where otherwise, the ground time overcurrent functions might not have coordinated fully. A setting of 0.6 seconds is proposed to aid coordination with the CBC TL237 zone 1 ground distance protection since there is no fault current infeed at CBC to aid this coordination.

$Z2GD := 36$ Cycles

Zone 3 Ground Distance Protection

The zone 3 ground mho function will be set the same as the zone 3 phase distance function.

$Z3MG := Z3P$ $Z3MG = 1.6$ Ohms secondary

$\frac{Z3P}{|Z1MAG|} = 394.65 \cdot \%$ of line length This is the same as the existing setting,

$XG3 := Z3MG$ $XG3 = 1.6$ Ohms secondary

Set the Zone 3 quad resistive reach at 10% more than the remote Zone 2

$R2Grem := 20$ Ohms secondary

$R3G := \mathrm{round}(R2Grem \cdot 1.1, 0)$ $R3G = 22$ Ohms secondary

Ground distance current supervision

Since there is no concern about these elements operating on load, even with loss of potential, set all current supervision elements at minimum, for maximum sensitivity of the distance elements.

$'50L1 := 0.5$ A Sec $'50L2 := 0.5$ A Sec $'50L3 := 0.5$ A Sec

$'50G1 := 0.5$ A Sec $'50G2 := 0.5$ A Sec $'50G3 := 0.5$ A Sec

Zero sequence current compensation

Set the zero sequence current compensation as usual.

$$k01M := \left(\left|\frac{Z0L207 - Z1L207}{3 \cdot Z1L207}\right|\right) \qquad k01M = 0.912$$

$$k01A := \left(\arg\left(\frac{Z0L207 - Z1L207}{3 \cdot Z1L207}\right)\right) \qquad k01A = 0.987 \cdot deg \qquad \text{Say} \qquad k01A := 1deg$$

Set the overreaching zones the same as zone 1 $k0M := k01M$ $k0A := k01A$

$k0M = 0.912$ $k0A = 1 \cdot deg$

These settings are only slightly different from the existing settings.

Non Homogenous Angle Setting

Compare the angle of the total zero sequence current at the remote bus with the angle of the zero sequence current contribution from the local terminal to determine this setting. From ASPEN OneLiner, the worst case is normal conditions. For this case, for an SLG at CBC the angle of I0 at the fault is -114 degrees and the angle of I0 out of the SSD terminal is -114 degrees. Therefore, the total fault current lags the current contribution from SSD by 0 degrees and angle T may be set at zero and ensure no overreach. However, because this is such a short line, the angle T should be set at the default angle of -3 degrees for extra security.

$T := -3$ degrees

Out of step blocking and tripping

Not used in this application. There is a danger of out of step conditions arising. Historically no action has been taken to provide special tripping or blocking functions. Natural tripping during swings is accepted.

Load Encroachment logic

Check loadability of the Zone 2 phase distance element assuming worst case power factor of 0.87 simultaneous with worst case depressed voltage of a stressed system of 0.9 per unit. Note that units of kV squared match units of MVA. Note that quadrilateral elements are only used for the ground distance functions that are not sensitive to balanced three phase load. Therefore no need to worry about the reach of the quadrilateral elements.

$$\text{Zloadmin} := \frac{(0.9\text{kVbase})^2}{\text{Smax}} \qquad \text{Zloadmin} = 158.114$$

Ohms primary (assume worst case at 30 degrees)

Maximum reach of the Zone 2 element is at the line angle of 81 degrees. At 30 degrees, the reach will be given by

$$\text{Z2load} := \text{Z2P}\cdot\cos[(\text{Z1ANG} - 30)\text{deg}] \qquad \text{Z2load} = 0.991$$

ohms secondary

$$\text{Z2load}\cdot\frac{\text{VTR}}{\text{CTR}} = 8.26$$

ohms primary

Since the reach of the Zone 2 element at 30 degrees is less than the apparent impedance of the maximum load, there is no need to apply load blinding logic. See Figure 12

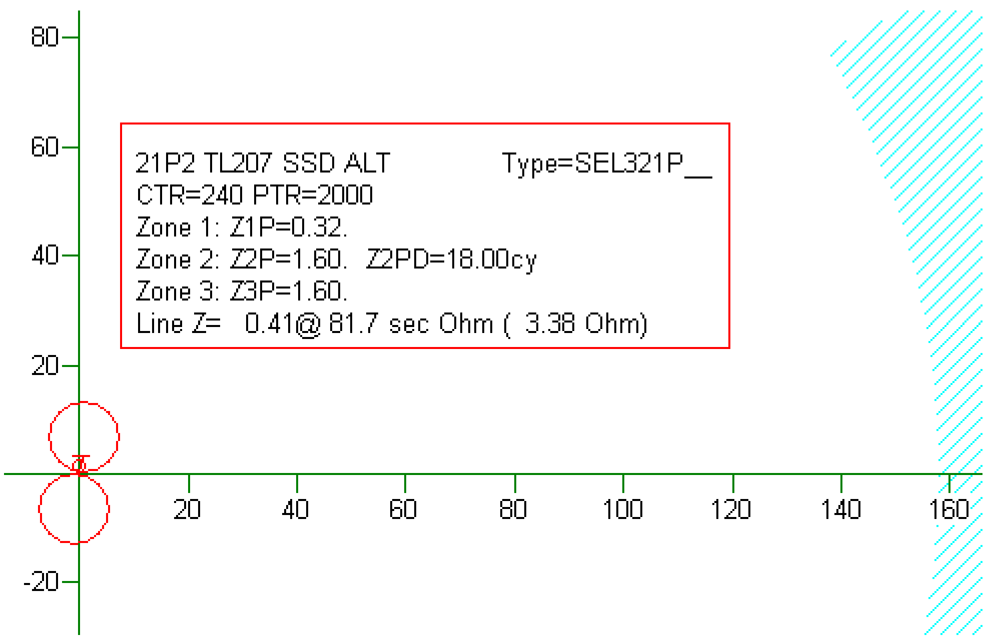


Figure 12 -Load impedance with respect to proposed new Mho function reaches.

Ground directional element

The SEL-321 application example recommends finding the minimum source impedance behind the terminal and setting the reverse and forward boundaries of the negative sequence directional element at the 1/3 and 2/3 points respectively.

In the negative sequence plane, the sum of the two source impedances and the line impedance is:

$Z2total := Z2minSSD + Z1L207pri + Z2minCBC$ $\quad |Z2total| = 72.302$

The 1/3 point is $Z2\_1\_3 := \frac{Z2total}{3}$ The 2/3 point is $Z2\_2\_3 := \frac{2Z2total}{3}$

$Z2Rpri := Z2\_2\_3 - Z2minSSD$ $\quad |Z2Rpri| = 20.701$ $\quad |Z1L207pri| = 3.379$

$Z2Fpri := Z2\_1\_3 - Z2minSSD$ $\quad |Z2Fpri| = 3.4$ $\quad |Z2minCBC| = 41.425$

$|Z2minSSD| = 27.5$

Converting the primary impedances to secondary ohms

$Z2R := Z2Rpri \cdot \frac{CTR}{VTR}$ $\quad |Z2R| = 2.484$ Ohms secondary $\quad arg(Z2R) = 83.432 \cdot deg$

$Z2F := Z2Fpri \cdot \frac{CTR}{VTR}$ $\quad |Z2F| = 0.408$ Ohms secondary $\quad arg(Z2F) = -97.285 \cdot deg$

Rounding up Z2F (note that Z2F is negative) and rounding down Z2R gives:

$Z2F := 0$ Ohms secondary $\quad Z2R := 2$ Ohms secondary

The proposed Z2F and Z2R settings are considerably less than existing, reflecting the addition of motor load as generation at CBC. This will move the thresholds closer to SSD.

Set the current level detectors at minimum level that will allow operation of the ground distance elements.

Due to the very small zero sequence current contribution to a single line to ground fault at the remote terminal, the negative sequence current contribution will always be higher than the zero sequence. Therefore there is no point in setting the forward looking negative sequence overcurrent elements any more sensitively than the zero sequence ground overcurrent supervision of the ground distance elements.

$'50QF := '50G2$ $\quad '50QF = 0.5$ A secondary

Set the supervision function for the reverse looking element to be the same as, or a little more sensitive than the forward looking supervision element at the remote terminal.

$'50QR := 0.5$ A secondary

The positive sequence current restraint (a2) factor should be set just smaller than the ratio of the maximum load current (positive sequence) to the most sensitive current supervision element (50QR).

$I1maxpri := \frac{Smax \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\quad I1maxsec := \frac{I1maxpri}{CTR}$ $\quad I1maxsec = 2.834$

Bearing in mind that the 50QR setting is in units of 3*I2

$\frac{'50QR}{3 \cdot I1maxsec} = 0.059$ Choose a value of $a2 := 0.06$

This a2 factor is lower than existing setting because of higher maximum load current used.

Phase time overcurrent element

This element is not used

Residual time overcurrent element

This element is used to provide the most sensitive backup protection. It will be non directional element. Minimum pickup needed to sense a higher resistance than 100 ohm SLG near the CBC terminal. Choose 200 ohm arbitrarily. Note that this terminal contributes 3 times more zero sequence current to a fault near CBC than the CBC terminal. However choose a desensitization factor of 2 for most conservative requirement for sensitivity.

$SF := 2$ Desensitization factor due to remote end infeed is $Dfactor := 2$ $Rf := 200$

$$'51NPU := round\left(\frac{kVbase \cdot 1000}{\sqrt{3} \cdot SF \cdot Dfactor \cdot Rf \cdot CTR}, 1\right) \qquad '51NPU = 0.7$$

The existing setting of 0.6 A is more sensitive than required to sense this fault with arbitrary resistance. However, it will coordinate OK with the CBC TL237 51N for resistive SLG faults. Therefore it will be retained.

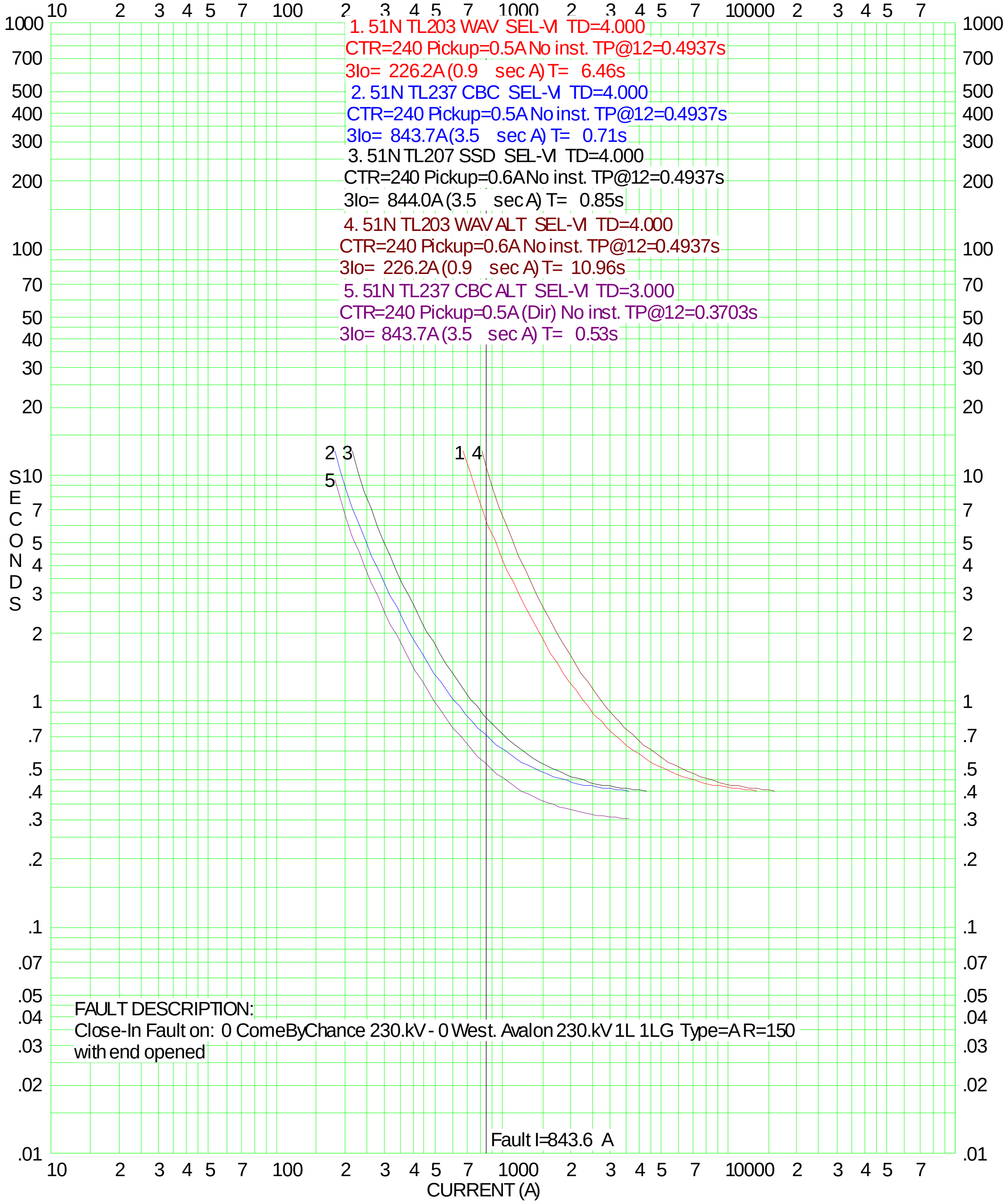
$'51NPU := 0.6$ A secondary

Coordination checks show that existing time dial settings around the loop TL203, TL237 and TL207 (counter clockwise) will not coordinate, because the CBC TL237 relays with a time dial setting of 4 are too slow. Therefore if there is a fault on TL237 that has to be cleared by the ground time overcurrent relay at CBC, the SSD TL207 will trip simultaneously or not coordinate. Therefore the existing time dial settings on CBC TL237 have to be adjusted. The ground distance elements will speed up tripping for faults with resistance up to 150 ohms fed from one end, where ground relay coordination is challenged), so coordination will be checked for faults with resistance of 150 ohms or more. Trial and error checks show that in order to achieve coordination, the existing time dial setting of CBC TL237 ground time overcurrent relay will have to have its time dial settings reduced from existing 4 to 3. The WAV terminal of TL203 already is going to have its pickup increased from 0.5 to 0.6 A sec.

Check the coordination with the other relays for three faults (all with 150 ohm resistance). Line end TL237, Close in to CBC on TL237 and 89% from WAV on TL203 (at the end of the mutually coupled section). See Figure 14 to find that existing settings (curves 2&3) do not coordinate, and Figures 14, 15 and 16 to find that Curve 3 and revised curves 4 and 5 settings will coordinate.

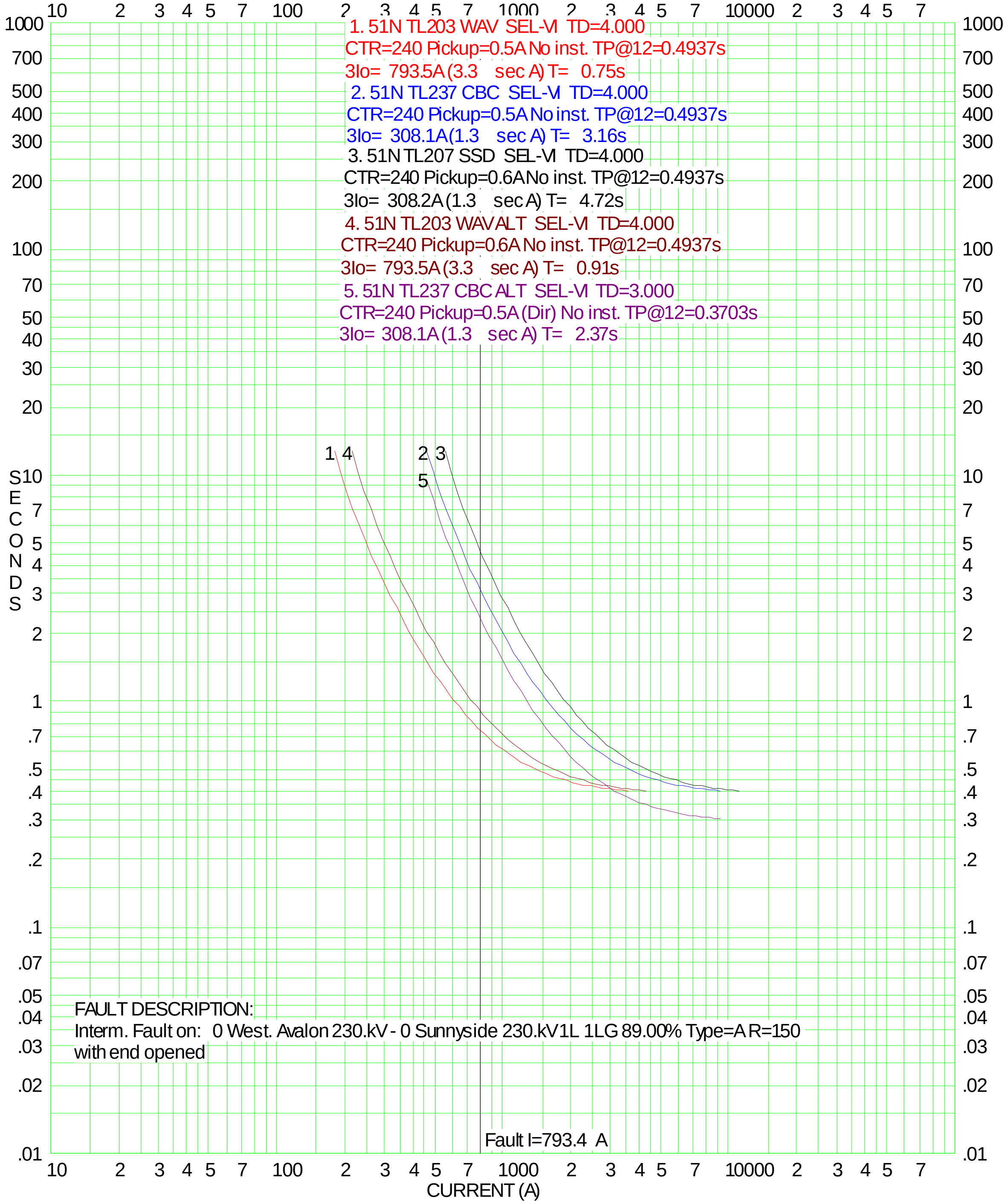
$'51NPU = 0.6$ A secondary $'51NPU \cdot CTR = 144$ A primary

$'51NTD := 4$ $'51NC := "U3"$ $'51NTC := "N"$ $'51NRS := "N"$



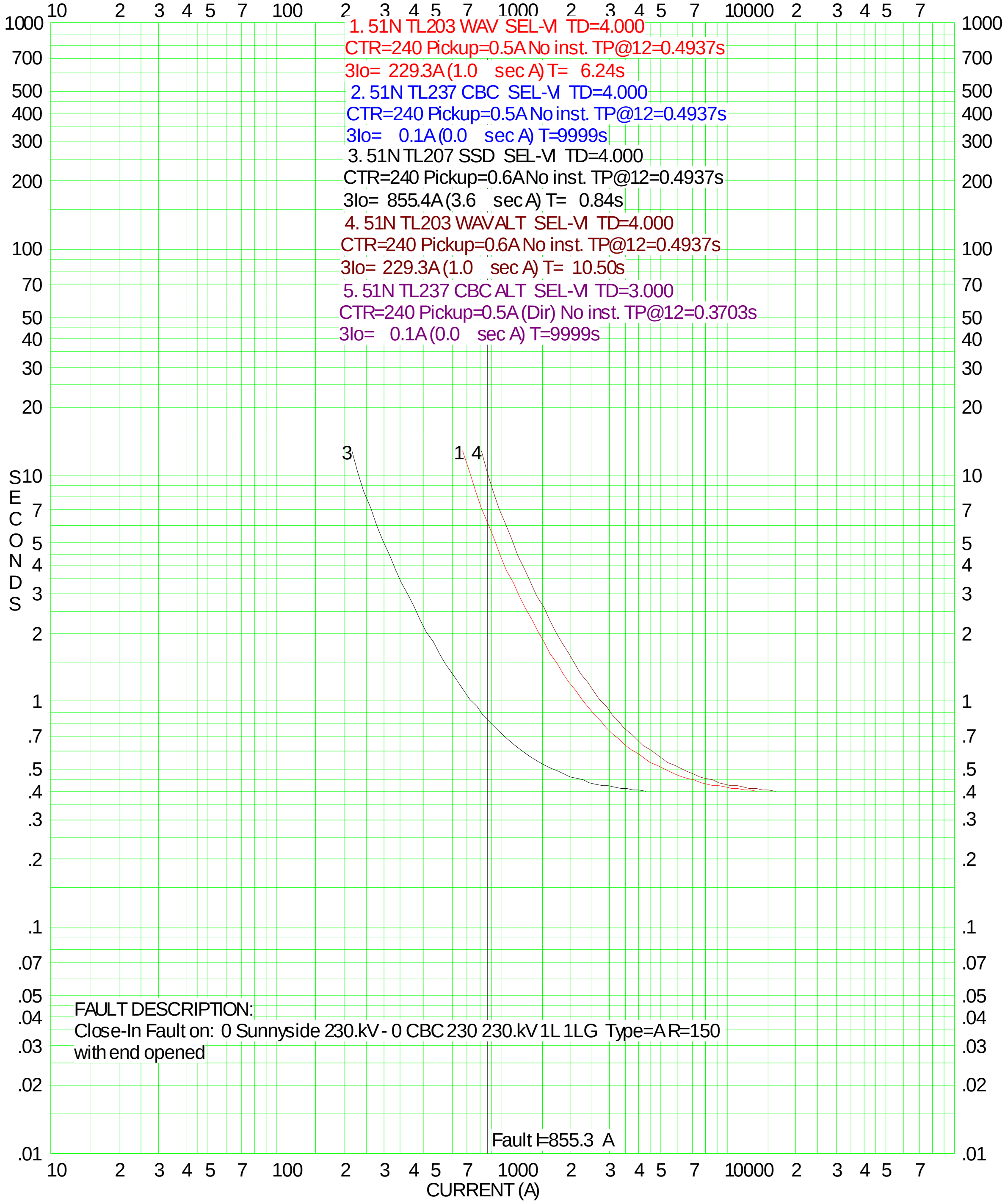
WAV 1	TIME-CURRENT CURVES @ Voltage 230	By CFH
For	CCW Coordination of TL203, TL207, TL37 Ground O/C PN	No. WAV1
Comment 150 ohm SLG faults		Date 7 Nov. 2010

Figure 14 - coordination of ground time overcurrent elements for close-in fault on TL237 close to CBC



WAV 2	TIME-CURRENT CURVES @ Voltage 230	By CFH
For	CCW Coordination of TL203, TL207, TL37 Ground O/C PN	No. WAV2
Comment 150 ohm SLG faults		Date 7 Nov. 2010

<u>Figure 15</u> - coordination of ground time overcurrent elements for fault 89% on TL203 from WAV with SSD terminal open.



WAV3	TIME-CURRENT CURVES @ Voltage 230	By CFH
For	CCW Coordination of TL203, TL207, TL37 Ground O/C PN	No. WAV3
Comment 150 ohm SLG faults		Date 7 Nov. 2010

Figure 16 - coordination of ground time overcurrent elements for close in fault on TL207 at SSD with CBC terminal open.

Permissive Overreaching logic settings

EPOTT := "Y"

Z3RBD is set at remote breaker time plus channel reset time plus channel reset time plus zone 2 reset time. From review of fault records it appears that the breaker time is 3 cycles. Channel reset time is not easily determined from existing records but can conservatively be assumed to be 1 cycle, and relay reset time will also be about 1 cycle. Total time for Z3RBD is then 5 cycles.

Z3RBD := 5 cycles

Echo block delay timer blocks the echo after the local elements have picked up. This can be set relatively long since there is no significant need for the echo function shortly after the local terminal has just seen a fault but the remote terminal has not. Set at 10 cycles as per the example in the instruction manual.

EBLKD := 10 cycles

Echo time delay on pickup should be set to override noise on the communications so that it doesn't echo noise. Typical time according to the SEL application guide is 2 cycles. Since this delay only affects clearing time for relatively light (high resistance) faults that are sensed by zone 2 function at one end, the typical setting is acceptable.

ETDPU := 2 cycles

Echo duration should be long enough to ensure the permissive trip is received by the remote terminal and should also be shorter than the Z3RBD time to ensure that the reverse blocking will always be longer than any permissive trip received (including echo time stretching).

EDURD := 4 cycles

No need to enable week feed conversion to trip, since both terminals will be quite sensitive enough to detect high resistance faults after the remote terminal has cleared. Therefore we can accept sequential (or "step") clearing with no need for the added insecurity of weak infeed tripping.

EWFC := "N" **No other communications logic settings are required for this application.**

Switch on to Fault Settings

Switch on to fault logic will ensure the protection will operate when energizing the line onto a close-in three phase fault when there is no polarizing voltage available for the distance elements.

ESOTF := "Y"

The breaker close signal is not available to the relay. The 52A method of enable SOTF will be used. Therefore the Close end delay is not critical. Typical duration for enable SOTF is 10-15 cycles

ENCLO := "N" CLOEND := 0 EN52A := "Y" SOTFD := 15

Set 50H for high magnitude close-in multiphase faults with weakest source at SSD It should be set less than 50% of the minimum close-in fault magnitude. Minimum close-in magnitude of a three phase fault with TL207 out of service is 2800 A. Therefore desired maximum setting for 50H is 1400 A. This is considerably lower than existing.

Imin3P_close_in := 2800

$$'50H := \frac{Imin3P\_close\_in}{2CTR} \qquad '50H = 5.833 \quad \text{A secondary}$$

Choose a setting of 5 A secondary for this element. '50H := 5 A secondary

Choose a setting for 52AEND less than the shortest reclose time. '52AEND := 30 cycles

Residual overcurrent settings.

Tripping directly by instantaneous ground overcurrent is not necessary because the zone 1 ground distance is more selective on this short line. However it would be helpful to monitor steady state unbalance, and issue an alarm for continuous unbalance. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50N := 1$ $\quad$ $'50N1 := 0.25$

Negative Sequence overcurrent settings.

Similar to ground overcurrent, apply a negative sequence overcurrent element to initiate an alarm for steady state unbalances. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50Q := 1$ $\quad$ $'50Q1 := 0.25$

Voltage Element Settings

Similar to unbalance current monitoring, it is helpful to have an unbalance voltage monitor to detect steady state unbalances from the voltage supply.

EVOLT := "Y"

Set the zero sequence overvoltage element at 1% of rated voltage or just at the point necessary to override normal unbalances. The zero sequence voltage element measures 3 times the zero sequence voltage.

$$'59N := 3 \cdot 0.01 \frac{kVbase \cdot 1000}{\sqrt{3} \cdot VTR} \qquad '59N = 1.992 \qquad \text{Say} \quad '59N := 2 \quad \text{V secondary}$$

Loss of Potential

Enable loss of potential settings. Advanced LOP settings are not available on this model of relay.

ELOP := "Y" $\quad$ Time delay of 1.25 cycles is commonly used. $\quad$ $LOPD := 1.25$

The 50 M element should be set above maximum load and below minimum fault current for a fault at the remote terminal under weak source conditions. The maximum load for this case should be normal maximum, not emergency maximum which only exists for a few minutes before the operator can act to reduce load.

$$Imax\_normal := \frac{Speak\_207 \cdot 1000}{\sqrt{3} \cdot kVbase \cdot CTR} = 1.448 \text{ A secondary}$$

Minimum fault current for a remote three phase fault is $\quad I3Pmin = 2624 \quad$ A primary.

Minimum fault current for a remote phase to phase fault is 87% of the minimum three phase fault current level.

Dependability factor to be sure to operate for a minimum remote fault is chosen to be 1.6. $\quad DF := 1.6$

Maximum setting for 50M should be $\quad \dfrac{0.87 I3Pmin}{DF \cdot CTR} = 5.945 \quad$ In this case a setting of 2 A secondary will be adequately dependable and secure.

$'50M := 2$ A secondary

The 59QL setting should be above normal maximum unbalance and below the level expected for a blown VT fuse. For a blown fuse, one phase voltage will be lost, and the negative sequence voltage will be roughly 33% of the nominal positive sequence voltage. Choose a setting of 15% of the nominal positive sequence voltage. This will be well above any normal unbalance.

$$'59QL := \mathrm{round}\left(\frac{0.15\cdot kVbase\cdot 1000}{\sqrt{3}\cdot VTR}, 0\right) \qquad '59QL = 10 \quad \text{V secondary}$$

The 59PL setting should be less than the minimum voltage to be expected for a remote bus fault under weakest source conditions. There is no minimum setting (above zero) for this function. Since this is a short line, choose a setting equal to half the voltage drop along the line impedance at the minimum fault current.

$$'59PL := \mathrm{round}\left[0.5\cdot\left(\frac{0.87I3Pmin}{CTR}\cdot\left|Z1Linesec\right|\right), 0\right] \qquad \left|'59PL\right| = 2$$

Miscellaneous Scheme Settings

Pole discoordinance logic is not being used. EPOLD := "N" SPPDD := "N/A"

Enable single pole tripping by distance elements only ESPT := "Y"

Enable single pole open ESPO := "Y"

Set single pole open time delay for future SPO conditions SPOD := 0.25

3 Pole open reset delay to override small discrepancies in pole closing '3POD := 0.5

Stub line protection is not required ESTUB := "N" '50MFD := "N/A"

Trip unlatch logic not applied TULO := "N"

Logic variables and Miscellaneous timers

Minimum trip duration timer is set at 9 cycles as per the application example in the SEL-321 instruction manual.

TDURD := 9 Cycles

Trip during open pole time delay should be set longer than the reclose time. Existing setting is OK.

TOPD := 55 Cycles

Retain existing settings except use time ZT to trigger an alarm for sustained unbalance.

LOGIC_Z := "59N+50N1+50Q1" TZPU := 1200 cycles TZDO := 0 cycles

Tripping Logic

Permissive tripping is required only for instantaneous overreaching functions. No need for any functions that trip directly. Existing 51NT word in MTCS is not required.

MTCS := "M2P+Z2G"

Unconditional tripping MTU := "M1P+Z1G+M2PT+Z2GT+51NT"

No need for existing direct tripping zone 1 functions in the switch on to fault logic.

SOTF Tripping MTO := "M2P+Z2G+50H"

Event records will be triggered automatically by all trip events. Other event record triggers should be by starting of other elements to ensure capture of all relevant events. Events should be triggered by keying or receiving permissive trips to ensure separation of relay and teleprotection issues.

MER := "M2P+Z2G+51N+LOP*52AA1+LOP*52AA2+KEY+PT+EKEY"

Outputs

Retain existing output assignments except add the continuous unbalance alarm to OUT15.

OUT15 := "LOP*50L+ZT"

Input Contact Assignment

Retain existing input assignments.

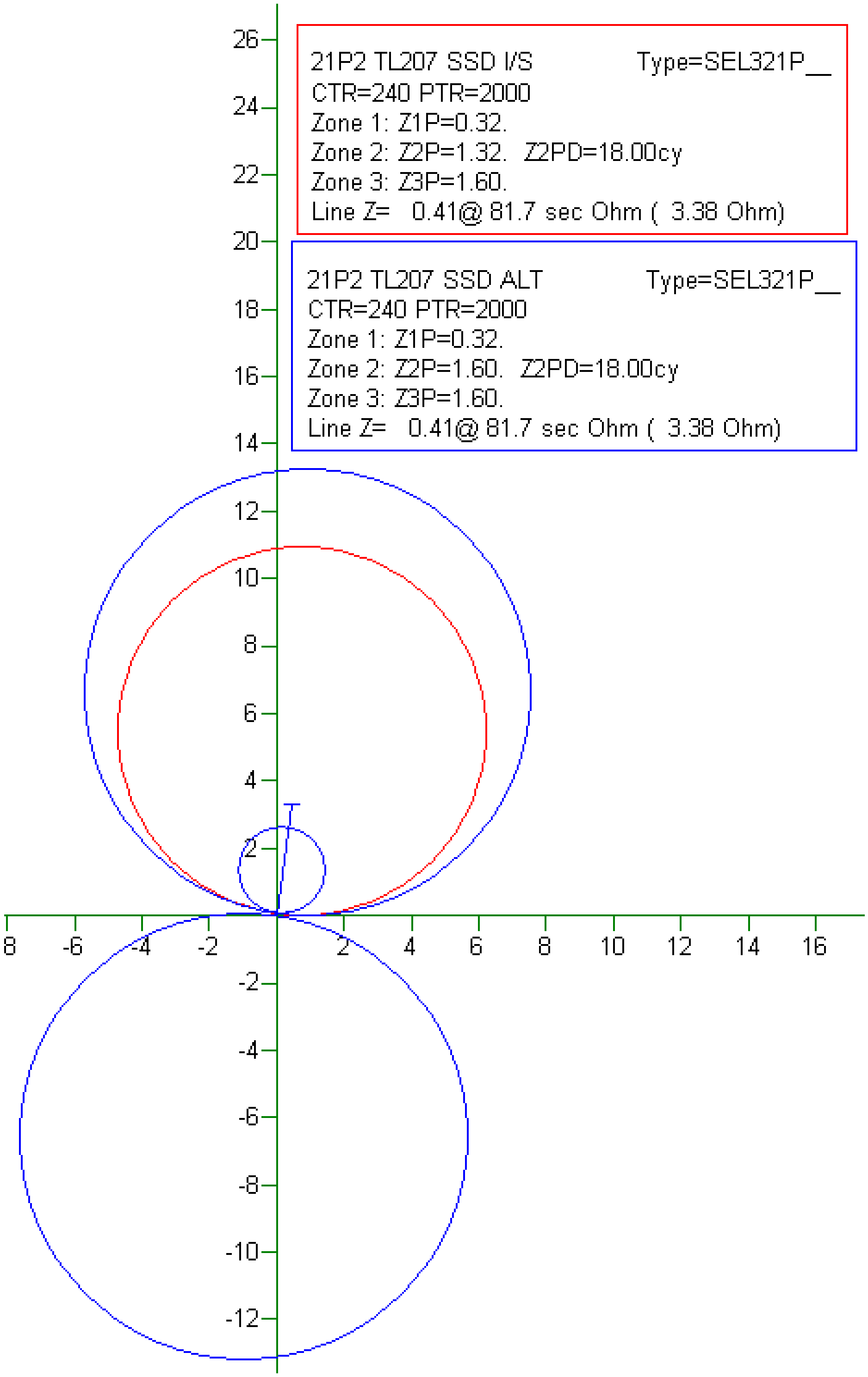


Figure 17 - Comparison of phase distance characteristics. Red is existing, blue is proposed alternative

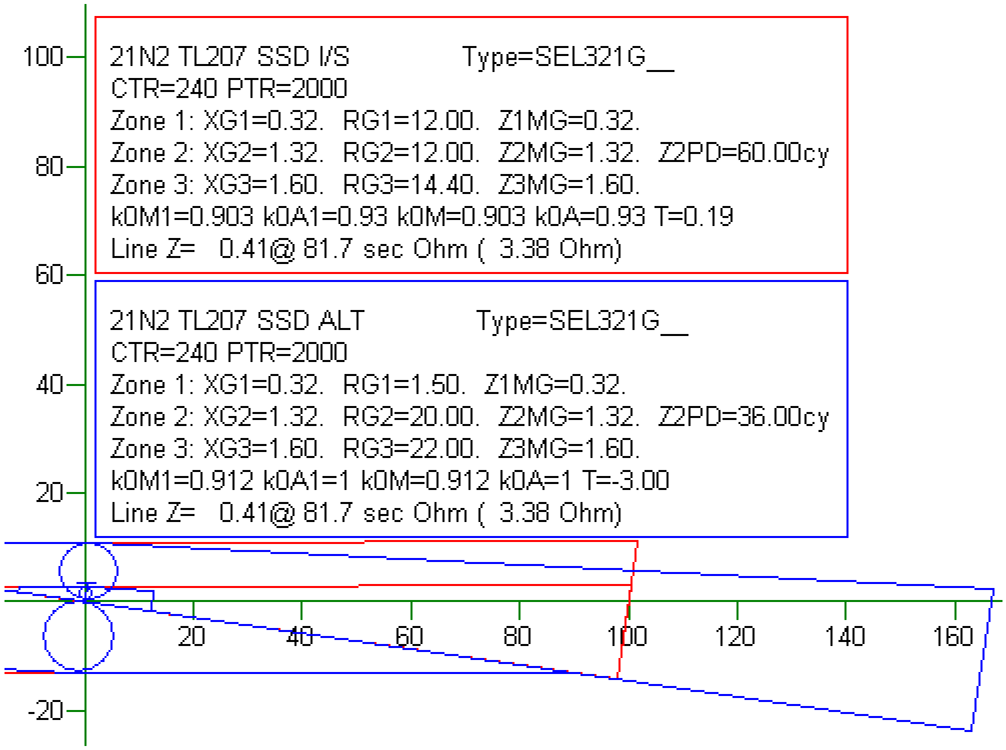


Figure 18 - Comparison of ground distance characteristics. Red is existing, blue is proposed alternative

Protection Review for Five 230 kV Transmission Lines

Appendix M
Detailed settings review for CBC TL207 "P1" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc

Scope

To review the existing settings of the P1 protection systems for the Come By Chance(CBC) terminal of circuit TL207 . This 230 kV transmission circuit is from Sunnyside (SSD) to Come By Chance(CBC)
The circuit does not run parallel to any other circuit for any significant portion of its length.

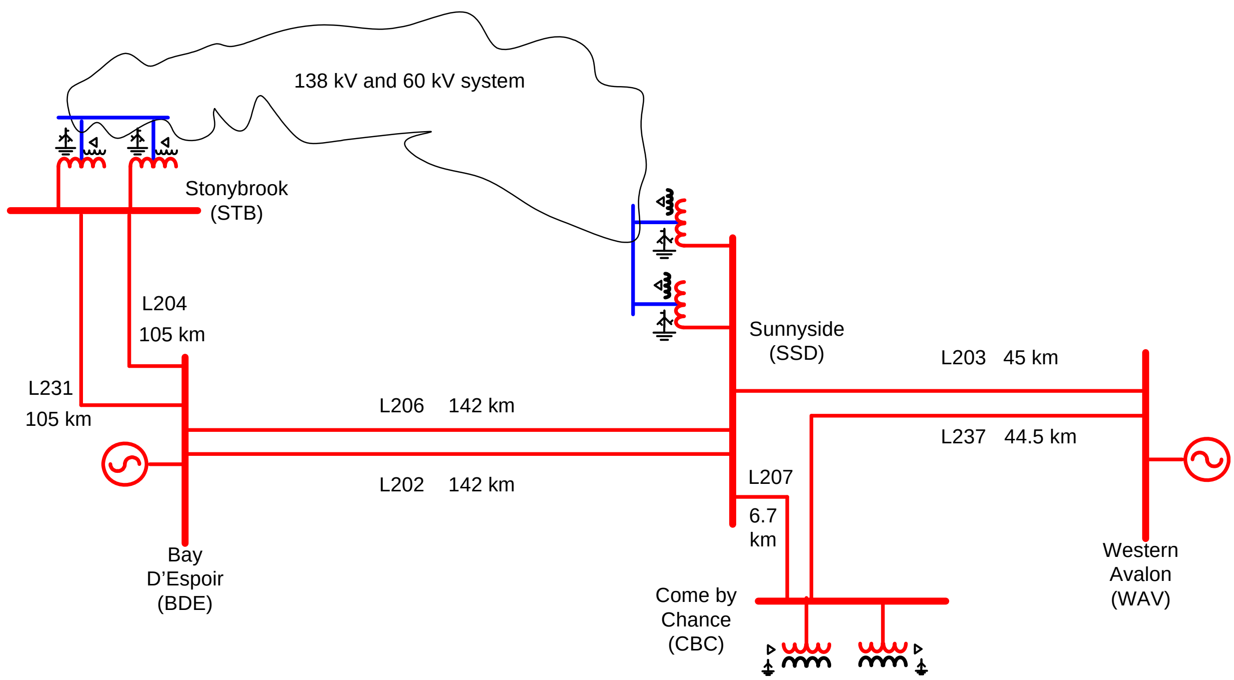


Figure 1 - System Single Line Diagram

Existing P1 protection systems are Areva LZFP111 (Optimho) systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$$MVAbase := 100 \qquad kVbase := 230 \qquad Ibase := \frac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}} \qquad Zbase := \frac{kVbase^2}{MVAbase}$$

$$j := \sqrt{-1}$$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $CTR := \frac{1200}{5}$ VT ratio is: $VTR := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**Hydro Interconnected System (2010-08-13) V10.olr**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with all shunts ignored (unless needed for load flow simulation).

Minimum fault current seen by each terminal (phase to phase, and SLG with 100 ohm fault resistance).

At CBC with Circuit TL237 out of service this terminal will not be a significant source of fault current to the TL207 line protection. A permissive trip echo function would be desirable to cater for the case when TL237 is out of service. However the echo function is not available with the POR 1 scheme that is normally used by Newfoundland and Labrador Hydro. Under normal conditions, for a fault near SSD

ILLmin := 916 A ISLGminPH := 911 A ISLGmin0seq := 677 A

The optimho current level detectors that block the distance comparators in the event of line opening are fixed at 5% of the rated current, or 0.25 A secondary, or 60 A primary. They will have no difficulty in operating for normal fault levels. However, the ground distance elements are also supervised by a low set neutral current level detector (LDLSN that requires the neutral current to be greater than 10% of the maximum amplitude of phase difference current. This prevents the ground comparators from operating during close-in multiphase faults with CT errors. ASPEN OneLiner shows that for a bolted fault at the remote bus even under heavy load, there is sufficient neutral current (22% of maximum phase to phase fault current) that means this LDLSN function does not inhibit the ground distance comparator.

Calculate the minimum negative sequence source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum um source impedance behind CBC $Z2minCBC := 6.76 + j \cdot 49.82$ ohms primary

Minimum source impedance behind SSD $Z2minSSD := 3.23 + j \cdot 27.31$ ohms primary

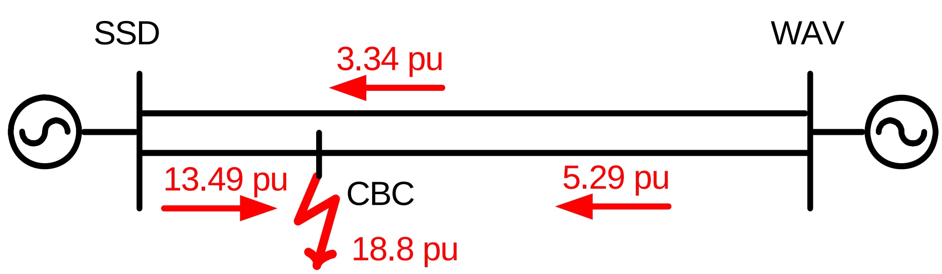


Figure 2 - 3 Phase Fault at CBC

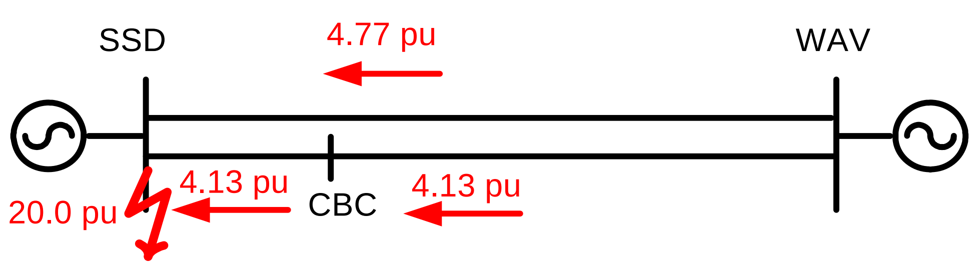


Figure 3 - 3 Phase Fault at SSD

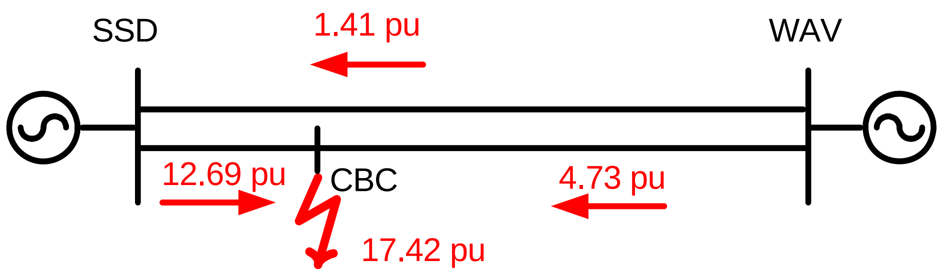


Figure 4 - SLG Fault at CBC (3I0 currents)

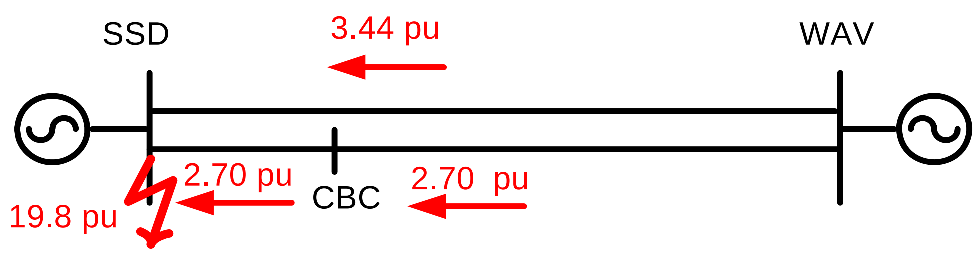


Figure 5 - SLG Fault at SSD (3I0 currents)

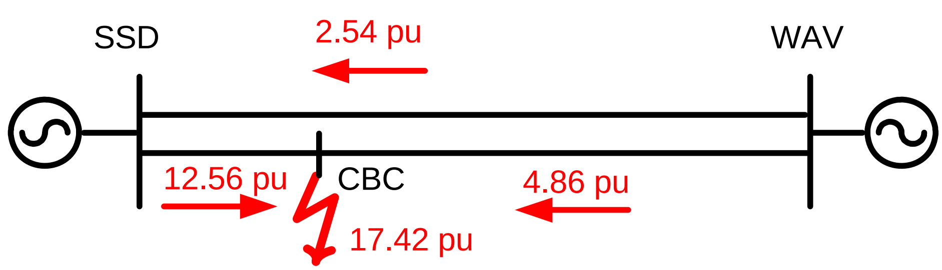


Figure 6 - SLG Fault at CBC (Phase currents)

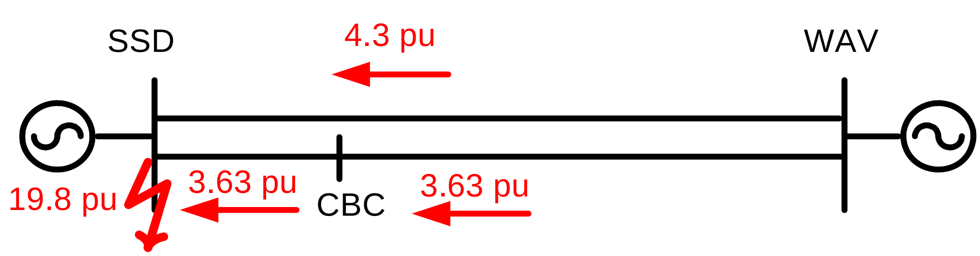


Figure 7 - SLG Fault at SSD (Phase currents)

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L207 := 0.00092 + j \cdot 0.00632$ $\qquad$ $Z0L207 := 0.00314 + j \cdot 0.02366$

In primary ohms

$Z1L207pri := Z1L207 \cdot Zbase$ $\qquad$ $Z0L207pri := Z0L207 \cdot Zbase$

In secondary ohms

$Z1Linesec := Z1L207pri \cdot \frac{CTR}{VTR}$ $\qquad$ $Z0Linesec := Z0L207pri \cdot \frac{CTR}{VTR}$

$|Z1Linesec| = 0.405$ $\qquad$ $\arg(Z1Linesec) = 81.718 \cdot deg$

$|Z0Linesec| = 1.515$ $\qquad$ $\arg(Z0Linesec) = 82.44 \cdot deg$

Load Data

From 2010 System peak load case provided in start up information, the peak load is given as 138.4 MVA (with TL203, TL207 and TL237 in service). The highest load of the three lines is TL207 with a load of 138.4 MVA. In the event of sudden loss of TL203. Peak load in TL207 will increase to take up the lost load through TL207. Thus the peak load in TL207 will be slightly less than double until operators can adjust loads.

$Speak\_207 := 138.4$ MVA $\qquad$ $Speak\_203 := 132.6$ MVA

$Smax := Speak\_203 + Speak\_207 = 271$ MVA

P1 Relay Settings

Distance element reach settings

Note that resistive reaches are forced to be the same for all zones. Reactive reaches for phase and ground distance elements must be the same as each other.

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the SSD Station bus under weak source conditions with TL202 out of service and all of TL203. TL207 and TL237 lines in service. From ASPEN OneLiner, voltage at CBC for a 3 phase fault at SSD is 0.026 per unit. So there is less than 20% voltage at SSD during a fault at WAV under weak source conditions.

Since the voltage is not higher than 20%, the line is considered short, and a reduced Zone 1 setting is recommended to provide more security. Choose a setting of 80% of nominal.

$Z1P := 0.8 \cdot |Z1Linesec|$ $Z1P = 0.32$ Ohms secondary

This is the same as the existing setting. However, note that direct tripping by zone 1 will be blocked, because it is desired to use a higher resistive reach for the quadrilateral element than could be secure with such a short zone 1 setting. This is a limitation of the optimho relay that the resistive reach for all zones has to be set the same.

$Z1pri := Z1P \cdot \frac{VTR}{CTR} = 2.703$ Ohms primary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

However, for such a short line, it is preferable to set a longer reach so the relay may operate faster. Existing setting is about 360% of the line, and this is a reasonable number that could be retained. For consistency with the P2 protection, the setting could be changed to 400% of the line. Check that as setting of 400% will not reach beyond the LV bus at CBC without infeed and also that it will not reach past the zone 1 element of the CBC TL237 protection. 400% reach is OK, see "ALT" setting in Figure 9.

$Z2\_sec := 4 \cdot |Z1Linesec|$ $Z2\_sec = 1.6$ Ohms secondary $\frac{Z2\_sec}{|Z1Linesec|} = 400 \cdot \%$

$Z2\_pri := Z2\_sec \cdot \frac{VTR}{CTR} = 13.514$ Ohms primary

$|Z1Linesec| \cdot \frac{VTR}{CTR} = 3.379$

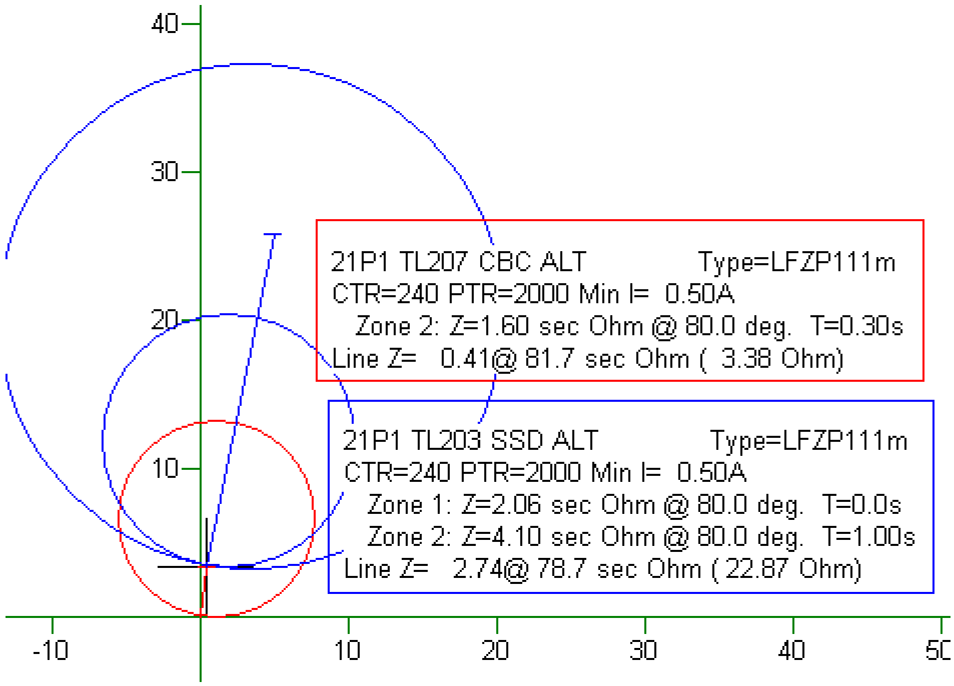


Figure 8 - Proposed Zone 2 Setting underreaches SSD TL203 Zone 1 without infeed.

The zone 2 timer will be enabled, but with a reduced setting to 0.3 second. This reduced delay is required for coordination for severe single line to ground faults with communications assistance not available. For such faults, faster clearing than is available from the ground time overcurrent protection in the P2 protection is required.

$Z2T := 0.3$ Seconds

Zone 3

The zone 3 function is not used since the POR1 scheme does not include an echo function so there is no need for any reverse blocking function. Since the Zone 2 timer has to be set with the coordination of the ground distance element in mind, it is set at 2 second; so there is no benefit in applying a longer reaching zone 3 function.

Zone 3 element is blocked - same as existing.

Load Encroachment logic

The optimho instruction manual recommends a margin of at least 10% between the impedance of the maximum load and the resistive reach of the quadrilateral distance element.

Check loadability of the Zone 2 phase distance element assuming worst case depressed voltage of a stressed system of 0.9 per unit.

$Zloadmin := \frac{(0.9kVbase)^2}{Smax}$ $Zloadmin = 158.114$ Ohms primary (assume worst case at 30 degrees)

$Zloadmin\_sec := Zloadmin \cdot \frac{CTR}{VTR}$ $Zloadmin\_sec = 18.974$

A 12 ohm secondary resistive reach is less than 90% of the load impedance at anyypower factor and meets the Areva criterion. Anyway there is no difficulty with load encroachment as can be seen in Figure 9.

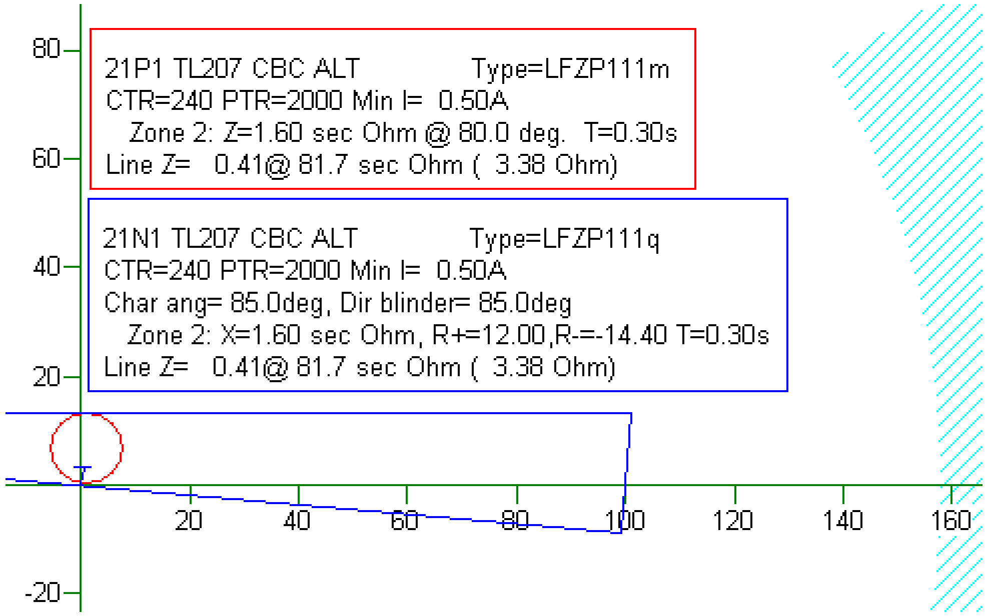


Figure 9 - Apparent impedance of load

Zone 1 Resistance - QUAD

If a quad element was provided for Zone 1, a secure setting would need to have such a small resistive reach that it would not be much use for a resistive single line to ground fault. In order to get a reasonable setting for the resistive reach for the zone 2 function, the zone 1 function will be blocked from tripping.

Zone 2 Resistance - QUAD

The existing setting is 12 ohms secondary. From Figure 10, it can be seen that this is not sufficient to sense a 100 ohm single line to ground fault anywhere on the line, even close to the CBC terminal.

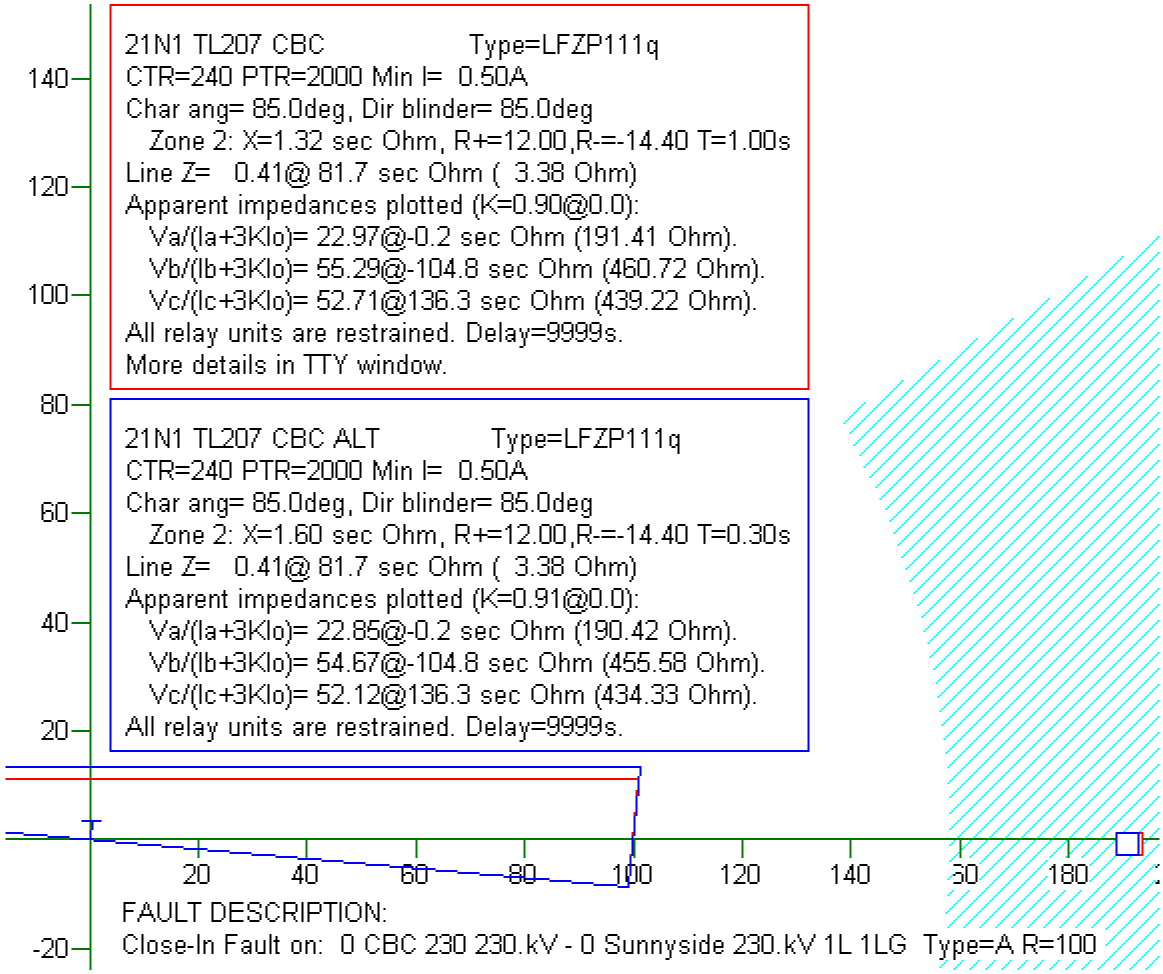


Figure 10 - Lack of Sensitivity for 100 ohm SLG fault near CBC

It was found that the maximum fault resistance that could be covered for a close-in fault was 50 ohms. This will still be of some value because many faults will have a resistance of less than 50 ohms. However, the P1 protection without the echo function will not be nearly as sensitive as the P2 protection for resistive single line to ground faults.

Retain the existing setting of resistive reach. Rquad := 12 ohms secondary

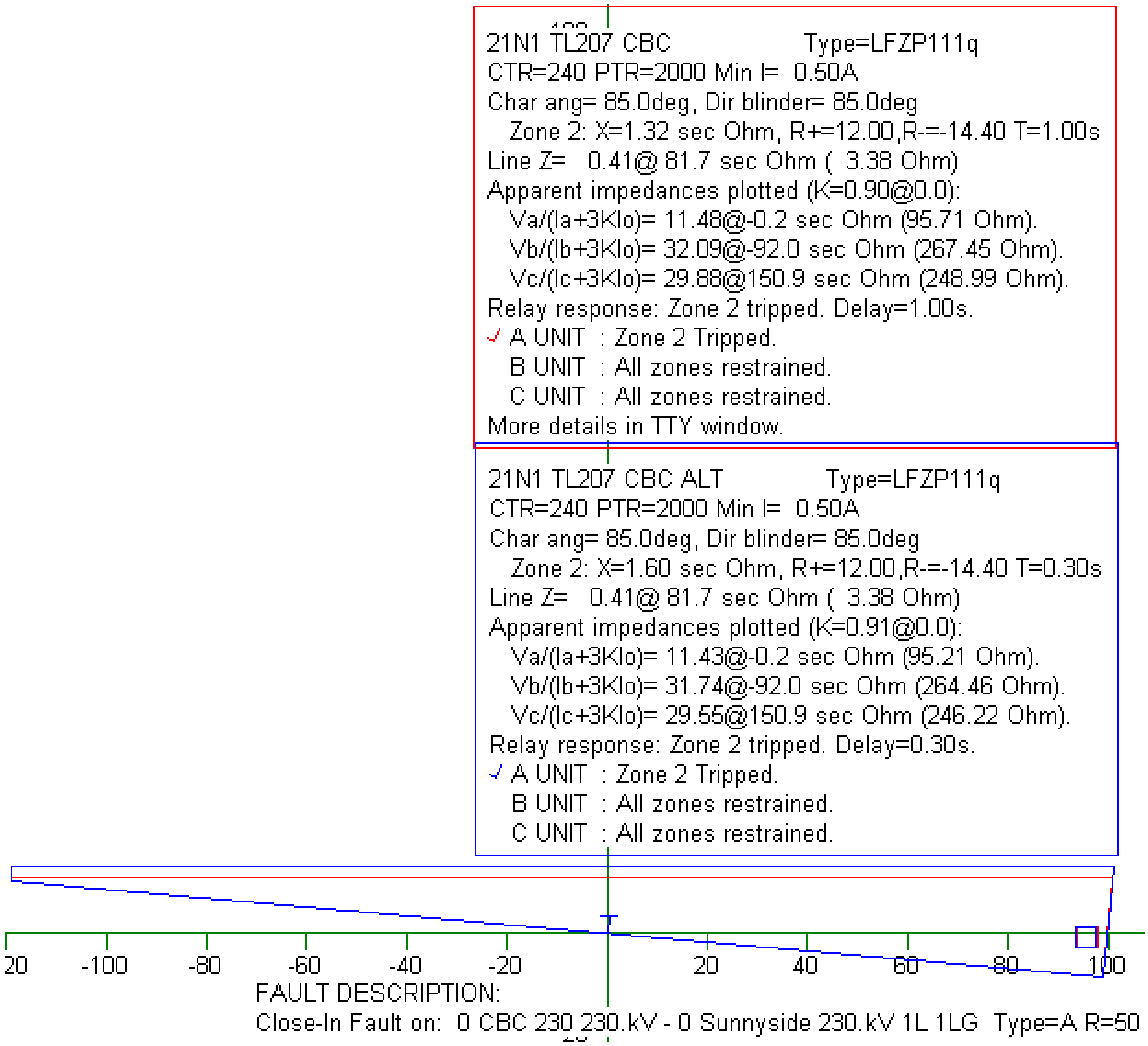


Figure 11 - Sensitivity for 50 ohm resistive fault close to CBC

Settings of K attenuators

KZPh Coarse setting common to all DISTANCE zones should be set as high as possible while below the required Zone 1 reach. The current level detectors vary inversely with KZph. Maximum setting available is 1.0. However, the minimum setting on KZ1 is 1, therefore for this short line, KZPh has to be set less than 1.

$KZPh := 0.32$

Zone 1 attenuators and angular selection

$In := 5$ $Z1P = 0.32$ This is the desired secondary reach (previously calculated)

$$KZ1 := \frac{Z1P}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ1 = 1 \qquad Z1sec\_reach := KZ1 \cdot KZPh \cdot \frac{5}{In} \qquad Z1sec\_reach = 0.32$$

Tripping by the zone 1 function is disabled - same as existing.

$Z\theta PH := (\arg(Z1Linesec))$ $Z\theta PH = 81.718 \cdot deg$

Rounded to the nearest 5 degrees $Z\theta PH := 80$ Degrees

$Z\theta N := \arg(Z0Linesec - Z1Linesec)$ $Z\theta N = 82.7 \cdot deg$

Rounded to the nearest 5 degrees $Z\theta N := 85$ Degrees

Zone 2 attenuators selection

$Z2\_sec = 1.6$ This is the desired secondary reach (previously calculated)

$$KZ2 := \frac{Z2\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ2 = 5.1$$

Zone 3 is not used

QUAD Resistive Reach setting

$Rquad = 12$ ohms secondary. This reach will be required to sense a 100 ohm SLG fault anywhere on the line.

$$KR := \frac{Rquad}{\left(\frac{5}{In}\right)} \qquad KR = 12$$

Residual Compensation attenuators selection

Zero sequence current compensation for ground faults is provided by the KZN factor. Zero sequence mutual compensation is not used in this application (it causes extra complexity for only moderate gain in setting accuracy).

$$KZN := \frac{Z0Linesec - Z1Linesec}{3 \cdot Z1Linesec} \cdot KZPh \qquad KZN = 0.292 + 5.027j \times 10^{-3}$$

$|KZN| = 0.292$ This close to the existing setting

Switch On To Fault (SOTF) Protection.

If SOTF is enabled, it can be set to 200ms or 110 s after all poles of the line have been de-energized. The 110 s setting is intended to override automatic reclosing dead time. However it makes more sense to enable after the shorter time. Once the SOTF feature has been initiated, it remains in effect for 250ms after the line has been re-energized. The SOTF tripping options are:

a) Any distance comparator.
b) Any current level detector as long as a corresponding voltage level detector has not picked up within 20ms.
c) Either current or distance, as long as a corresponding voltage level detector has not picked up within 20ms.

SOTF := "Enabled"

SOTF_TIME := 0.20 Seconds

Elements_in_SOTF := "BOTH" (Both Comparators and current level detectors).

Power Swing Detector

This element will not be used. It will be left Blocked, and if there is a power swing, the distance elements will trip naturally.

VT Supervision

Set the VT supervision to BLOCK TRIP

Set the VT fail detection to SELF RESET this is as existing .

SELF_RESETTING := "ENABLED"

Start Indication

This function will bring up information on the LCD screen of the relay if a start event occurs. This function will not be used.

START_INDICATION := "BLOCKED"

Communications assisted logic.

The existing communications assisted logic is permissive overreaching transfer trip, scheme **POR 1**. This scheme is familiar to Newfoundland and Labrador Hydro, and even though the POR 2 scheme offers the advantage of weak infeed echo, which would help the sensitivity to resistive faults, it is not recommended to change the existing scheme logic at this stage with years of experience on a product that is nearing the end of its useful life.

The POR 1 logic is a basic permissive overreaching transfer trip scheme but it does include current reversal timers to increase security against misoperation due to current reversal when a fault on the parallel line is cleared sequentially. The current reversal logic is achieved by a timer TP which will block permissive tripping and keying of permissive trip if the local zone 2 element does not pick up within a reasonable time of receiving permissive trip. The block will be maintained for a time delay of TD after the local zone 2 element picks up, or the received permissive trip signal resets.

The application of the current reversal timers is required only if the settings of the zone 2 comparators are greater than 1.5 times the line impedance. Since the reaches of these elements are less than or equal to 1.5 times the line impedance, the current reversal logic is not required, and the recommended default settings are as existing>

TP := 98 ms
TD := 0 ms

Comparison of Existing and Proposed alternative (ALT) settings.

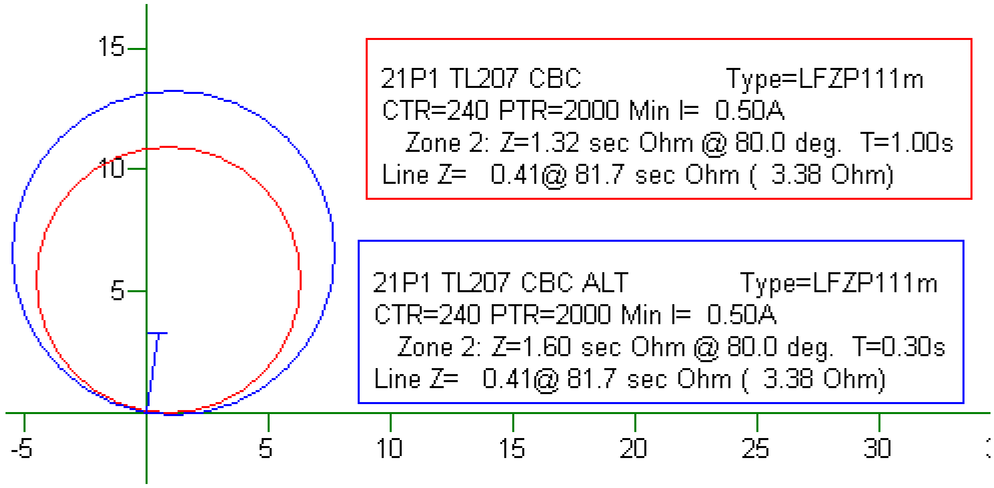


Figure 12 - Comparison of phase distance characteristics

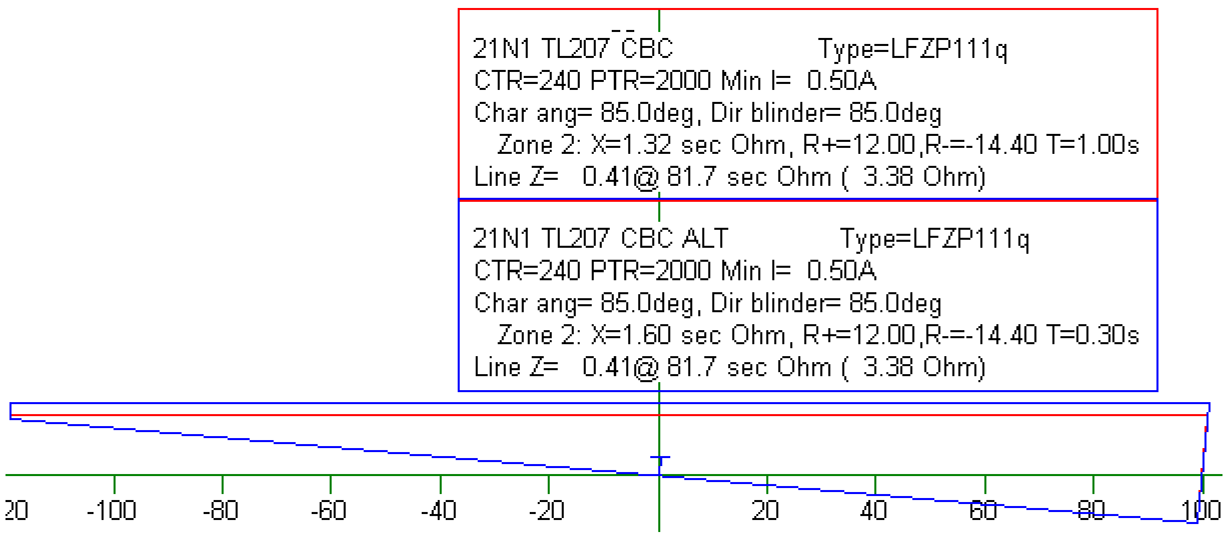


Figure 13 - Comparison of ground distance characteristics

Protection Review for Five 230 kV Transmission Lines

Appendix N
Detailed settings review for CBC TL207 "P2" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P2 protection systems for the Come By Chance (CBC) terminal of circuits TL207 . This 230 kV transmission circuit is from Sunnyside (SSD) to Come By Chance (CBC)
The circuit does not run parallel to any other circuit for any significant distance.

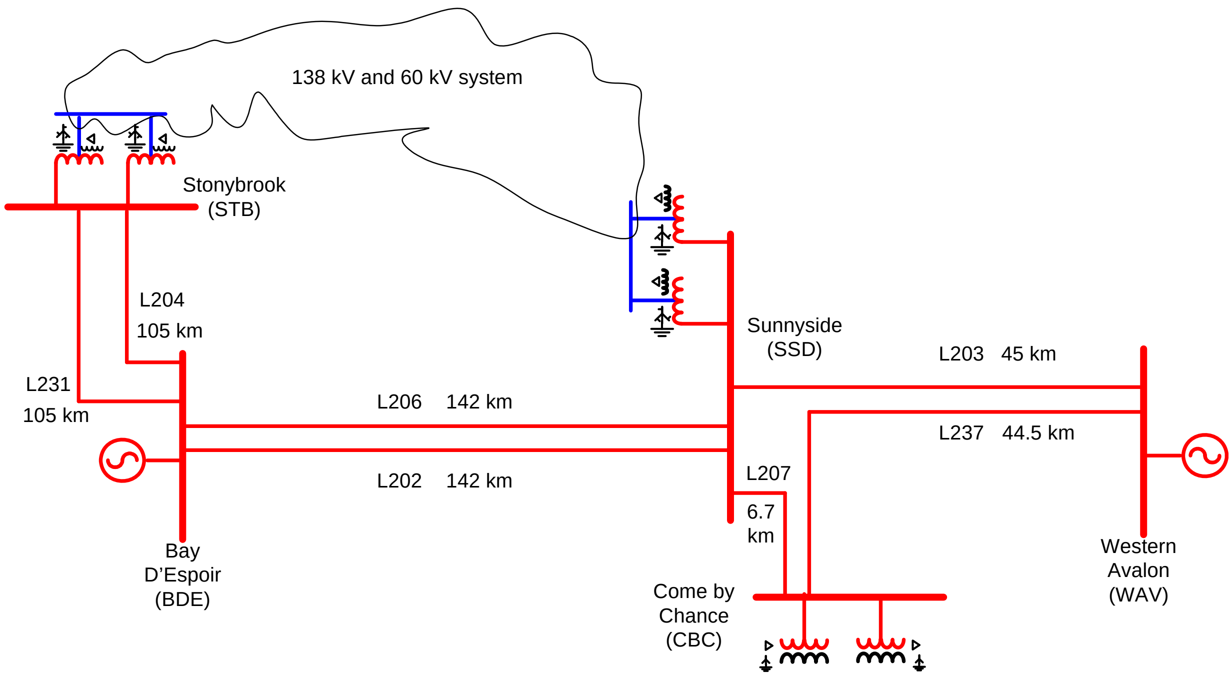


Figure 1 - System Single Line Diagram

Existing P2 protection systems are SEL321 systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$\text{MVAbase} := 100$ $\quad$ $\text{kVbase} := 230$ $\quad$ $\text{Ibase} := \dfrac{\text{MVAbase}\cdot 1000}{\text{kVbase}\cdot\sqrt{3}}$ $\quad$ $\text{Zbase} := \dfrac{\text{kVbase}^2}{\text{MVAbase}}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $\text{CTR} := \dfrac{1200}{5}$ $\quad$ VT ratio is: $\text{VTR} := \dfrac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**Hydro Interconnected System (2010-08-13) V10.olr**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with all shunts ignored (unless needed for load flow simulation).

Minimum fault current seen by each terminal (multiphase and SLG with 100 ohm fault resistance).

At CBC, with Circuit TL217 out of service, and TL207 and TL237 lines in service, for a fault at the remote terminal.

$I3Pmin := 800$ $\quad$ $ISLGminPH := 290$ A $\quad$ $ISLGmin0seq := 172$ A

The current for a phase to phase fault would be lower, but the current supervision element of the SEL321 measures phase to phase currents, and the phase to phase current for a phase to phase fault is twice the phase current.

Calculate the minimum negative sequence source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open. **For this calculation only, simulate 50 MVA of generation (i.e., simulating motor load) at CBC to minimize source impedance.**

Minimum um source impedance behind CBC $\quad$ $Z2minCBC := 4.68 + j \cdot 41.16$ ohms primary

Minimum source impedance behind SSD $\quad$ $Z2minSSD := 3.23 + j \cdot 27.31$ ohms primary

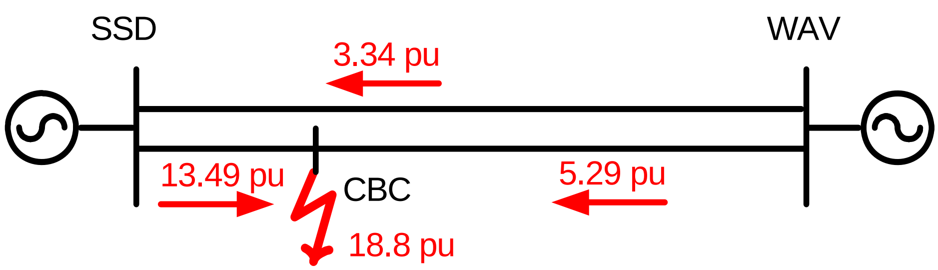


Figure 2 - 3 Phase Fault at CBC

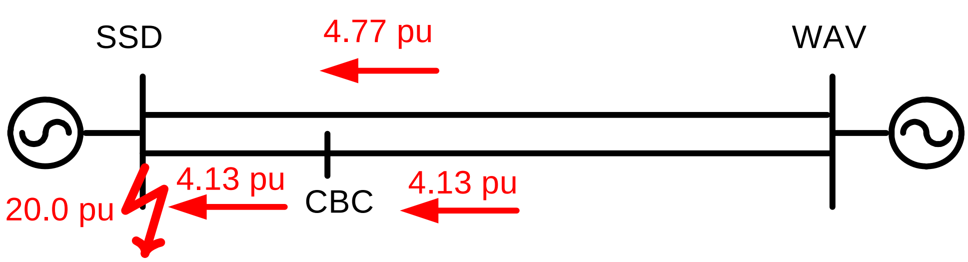


Figure 3 - 3 Phase Fault at SSD

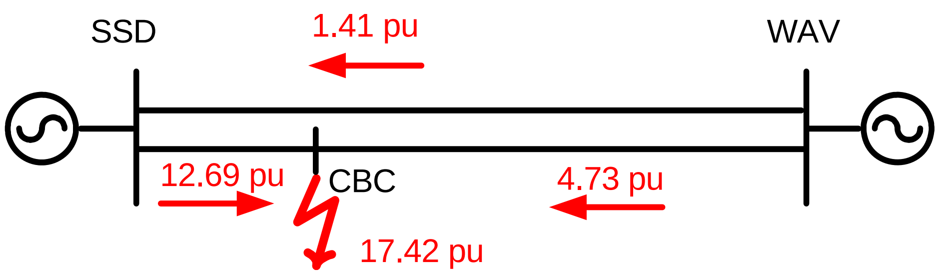


Figure 4 - SLG Fault at CBC (3I0 currents)

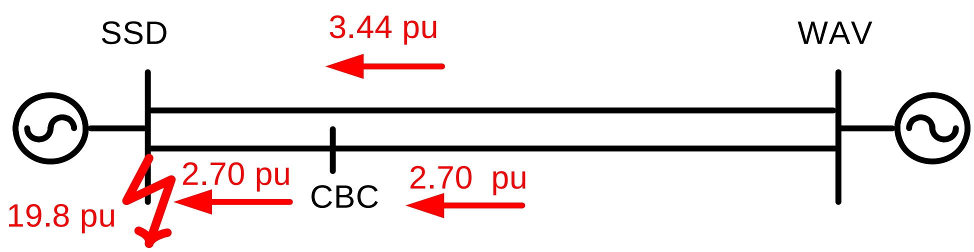


Figure 5 - SLG Fault at SSD (3I0 currents)

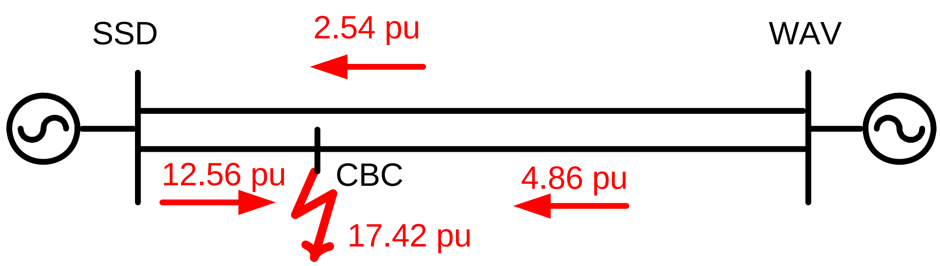


Figure 6 - SLG Fault at CBC (Phase currents)

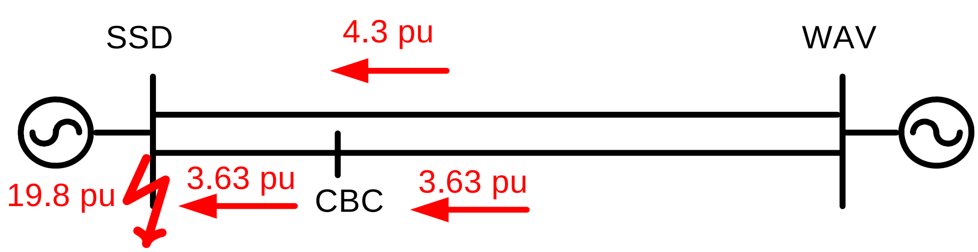


Figure 7 - SLG Fault at SSD (Phase currents)

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L207 := 0.00092 + j\cdot 0.00632$ $\quad$ $Z0L207 := 0.00314 + j\cdot 0.02366$

In primary ohms

$Z1L207pri := Z1L207\cdot Zbase$ $\quad$ $Z0L207pri := Z0L207\cdot Zbase$

In secondary ohms

$$Z1Linesec := Z1L207pri\cdot\frac{CTR}{VTR} \qquad Z0Linesec := Z0L207pri\cdot\frac{CTR}{VTR}$$

$|Z1Linesec| = 0.405$ $\quad$ $\arg(Z1Linesec) = 81.718\cdot deg$

$|Z0Linesec| = 1.515$ $\quad$ $\arg(Z0Linesec) = 82.44\cdot deg$

These impedances match the existing settings in the P2 relay no need for changes.

Load Data

From 2010 System peak load case provided in start up information, the peak load is given as 138.4 MVA (with TL203, TL207 and TL237 in service). The highest load of the three lines is TL207 with a load of 138.4 MVA. In the event of sudden loss of TL203. Peak load in TL207 will increase to take up the lost load through TL207. Thus the peak load in TL207 will be slightly less than double until operators can adjust loads.

$Speak\_207 := 138.4$ MVA $\qquad$ $Speak\_203 := 132.6$ MVA

$Smax := Speak\_203 + Speak\_207 = 271$ MVA

P2 Relay Settings

The existing line impedance settings are close to the line data book. No need for adjustment

$$Z1MAG := |Z1Linesec| \quad Z1MAG = 0.41 \qquad Z1ANG := \frac{\arg(Z1Linesec)}{deg} \quad Z1ANG = 81.7$$

$$Z0MAG := |Z0Linesec| \quad Z0MAG = 1.5 \qquad Z0ANG := \frac{\arg(Z0Linesec)}{deg} \quad Z0ANG = 82.4$$

$LL207 := 6.7$

In order to obtain sensitivity to 100 ohm single line to ground faults, the echo function will be needed. Enable two forward and one reverse zone.

$PMHOZ := 3$ $\quad$ $GMHOZ := 3$ $\quad$ $QUADZ := 3$

$DIR1 := F$ $\quad$ $DIR2 := F$ $\quad$ $DIR3 := R$

Mho phase distance functions

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if the line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the SSD Station bus under weak source conditions with TL217 out of service and all of TL203, TL207 and TL237 lines in service. From ASPEN OneLiner, voltage at CBC for a 3 phase fault at SSD is 0.02 per unit. So there is less than 20% voltage at CBC during a fault at SSD under weak source conditions.

Since the voltage is not higher than 20%, the line is considered short, and a reduced Zone 1 setting is recommended to provide more security. Choose a setting of 80% of nominal.

$Z1P := 0.8 \cdot |Z1Linesec|$ $\quad$ $Z1P = 0.32$ Ohms secondary

This is the same as the existing setting.

In addition, because this voltage is so low, the zone 1 function is exposed to a risk of misoperation due to measuring error and/or CVT transient performance problems. Therefore, a 1 cycle security delay is proposed to be added to tripping by this element. The delay will be added by SEL logic variable timer YT.

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

However, for such a short line, it is preferable to set a longer reach so the relay may operate faster. Existing setting is about 320% of the line, and this is a reasonable number that could be retained, however for consistency with the P1 protection it recommended to increase this setting to 400% of the line.

$Z2P := \text{round}(4 \cdot |Z1Linesec|, 1)$ $\quad$ $Z2P = 1.6$ Ohms secondary

As can be seen from Figure 8, this element (with the proposed new setting) does not overreach the zone 1 element at the SSD terminal of TL203 even without infeed.

The existing Zone 2 timer setting of 18 cycles will be appropriate.

$Z2PD := 18$ cycles

Zone 3

Set Zone 3 reverse element to reach further behind this terminal than the remote Zone 2. This function adds security for external faults. The element should always be more sensitive than the forward looking Zone 2 at the remote terminal. Set it the same as the remote Zone 2 overreach plus 100%. This higher margin than used on other lines is desirable considering the short line does not provide much margin in itself.

$$Z3P := Z1MAG \cdot \left(\frac{Z2P}{Z1MAG} - 1 + 1 \right)$$

$Z3P = 1.6$ Ohms secondary
(slightly different from existing but set the same as at SSD for consistency)

$$\frac{Z3P}{|Z1MAG|} = 394.65 \cdot \% \quad \text{of line length}$$

The reverse looking zone 3 element need not be set to trip through a timer. It is needed only for security in the POTT scheme.

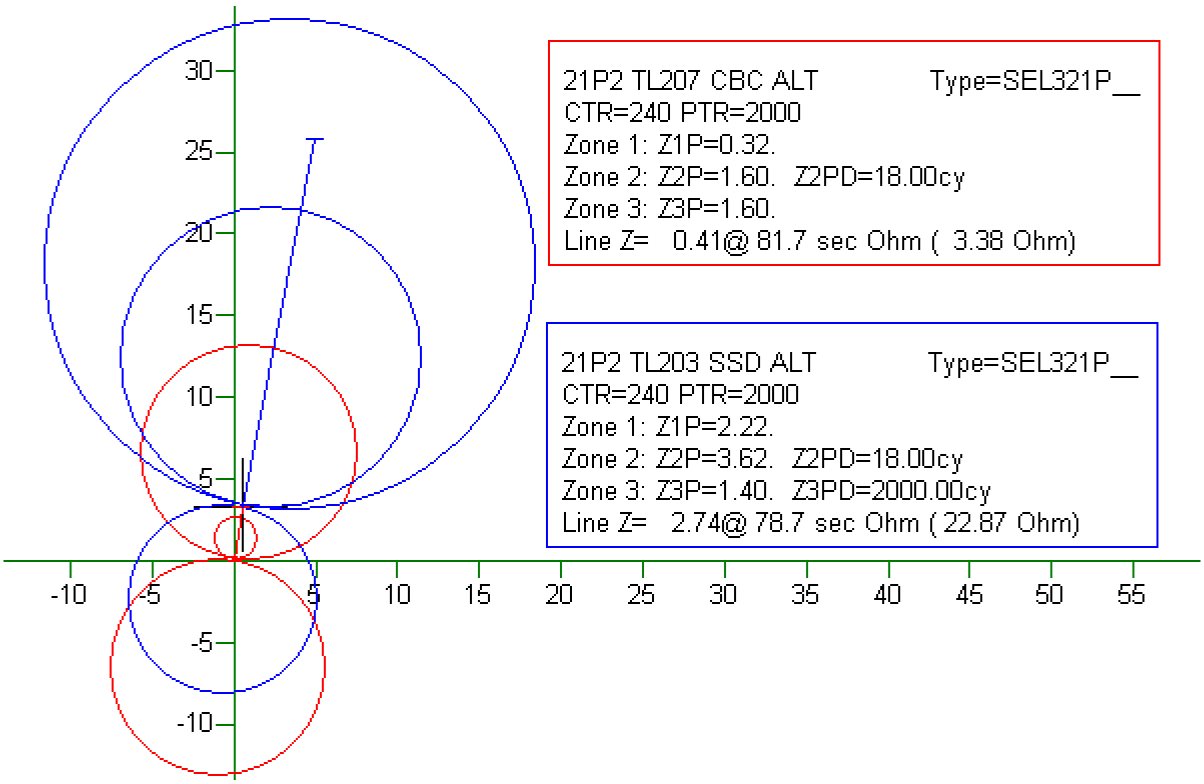


Figure 8 - Proposed new CBC TL207 Zone 2 underreaches SSD TL203 zone 1 without infeed, and coordinates with zone 1 on this line.

Mho phase distance current supervision

If the current supervision elements can be set above load, they will be secure in the event that potential is lost. However given that loss of potential logic is available, it is recommended that only the zone 1 current supervision function be set above load. If potential is lost, it will be able to block tripping by Zone 2 before it trips on time delay or receives a permissive trip from the remote terminal.

For the point of view of current supervision being above maximum load, there is no need to worry about abnormal conditions. It would be a double contingency for the VT signal to be lost while the parallel line was out of service. Therefore, consider a maximum load of 135 MVA. The current supervision elements for the phase distance functions measure phase to phase currents.

$$IPPmax\_normal := \frac{Speak\_207 \cdot 1000}{kVbase} \qquad IPPmax\_normal = 602$$ A primary

The current supervision elements use phase to phase currents for supervision of the phase distance function;. so the minimum phase to phase fault current will be root three times the minim phase fault current. Choose a margin of 50% of the minimum phase to phase fault current for dependability.

$$IPPmin := 0.5I3Pmin \cdot \sqrt{3} \qquad IPPmin = 693$$ A primary

A setting of 648 A primary for 50PP1 will ensure the Zone 1 function operates for any fault even under minimum source conditions but will not be susceptible to trip on load due to loss of potential under normal maximum load conditions. This is somewhat lower than the existing setting but there is no need for any higher setting.

$'50PP1 := 2.7$ A Sec $\qquad '50PP1 \cdot CTR = 648$ A primary

50PP1 is higher than the existing zone 2 settings but is sensitive enough, and offers better security. Since Zone 2 and zone 3 elements will be blocked by LOP function, set them at minimum. The zone 3 current supervision should not be set higher than the existing zone 2 current supervision element at the remote terminal. In this case the remote zone 2 current supervision element will be set at 1.0 A secondary.

$'50PP2 := 1$ A Sec $\qquad '50PP3 := 1$ A Sec

Ground Distance Protection

Since there are no parallel lines there is no impact from mutual coupling. However, on this short line, it is important to be aware of the possibility of incorrect measurement of a fault beyond the remote terminal due to a high resistive reach on the zone 1 quadrilateral. Choose a setting of 80% of the line impedance and find the maximum resistive reach that should be set using the guideline provided by SEL.

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.8$ per unit

$Z1MG := m \cdot |Z1Linesec|$ $\quad Z1MG = 0.32$

$XG1 := Z1MG$ $\quad XG1 = 0.32$ These are the same as existing settings.

Zone 1 Resistance

XG1 is set at m per unit of the transmission line. The imaginary component of this is

$ImXG1sec := Im(Z1Linesec)$ $\quad ImXG1sec = 0.401$ ohms

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$RG1 := round[(1 - m) \cdot 20 \cdot ImXG1sec, 1]$

$RG1 = 1.6$ This is the maximum secure setting for the resistive reach so the desired zone 1 resistive reach setting would not be confirmed as being secure.

Use the maximum secure setting of 1.5 ohms for RG1 $RG1 := 1.5$ ohms secondary

With a resistive reach setting of 1.5 ohms, the SSD Zone 1 quad element will not be much use. The mho element will be more sensitive than it due to expansion of the characteristic due to cross polarizing. The mho zone 1 element will see a maximum of 5 ohm fault resistance for a close - in fault (see Figure 9) and gradually reducing resistance as the fault moves away from the terminal. Zone 2 protection will be depended upon to sense faults with higher resistance.

It should be noted that the 5 ohm resistive SLG close in to CBC will depress the faulted phase voltage by about 85%; so this fault is fairly severe on the system and communications assisted tripping will be required to maintain reasonable performance from the protection.

Communications assistance becomes of increasing importance in protecting a short line such as this. The zone 2 and permissive trip echo function is important on this line.

Similar to the phase distance element, the zone 1 ground distance element will be configured to trip through a 1 cycle delay (using SEL Logic variable YT) to increase security on this very short line.

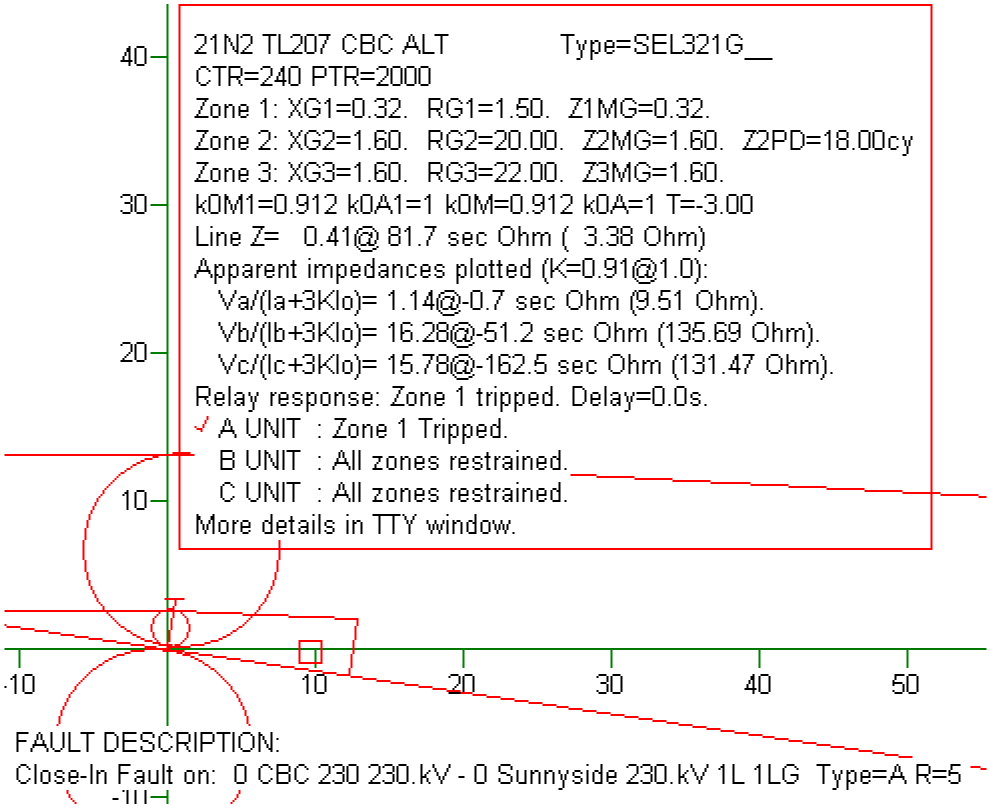


Figure 9 - Proposed reduced resistive reach of Zone 1 quadrilateral reduces sensitivity to resistive faults considerably.

Zone 2 Ground Distance Protection

The Zone 2 ground distance function will set the same as the Zone 2 phase distance protection function because there are no significant mutual coupling effects from parallel lines. In any case, the phase distance function is set at 400% of the line impedance.

Z2MG := Z2P Z2MG = 1.6 Ohms secondary

The quad element reactive reach will be set similarly to the mho.

XG2 := Z2MG XG2 = 1.6 Ohms secondary

The resistive reach of the quad will be increased to 20 ohms similar to the SSD terminal. This will not sense a 100 ohm resistive SLG fault close to the CBC terminal of the line so it will only operate sequentially after the CBC terminal opens (with permissive trip echo if necessary because of lack of sensitivity of the CBC terminal). However, there is no point in increasing the sensitivity any more.

By trial and error from ASPEN it is found that a resistive reach of 20 ohms secondary will sense a 40 ohm SLG fault close in to the CBC terminal and 25 ohm SLG close to the SSD terminal, therefore it will still be useful. However the permissive trip echo function will be required to ensure that a fault that is seen by the zone 2 element at only the SSD terminal will still be cleared by the permissive trip logic.

Therefore, to avoid extremely large resistive reaches, and to retain sensitivity to 100 ohm resistive SLG faults, it is recommended that the echo function be enabled at both terminals.

R2G := 20 Ohms secondary

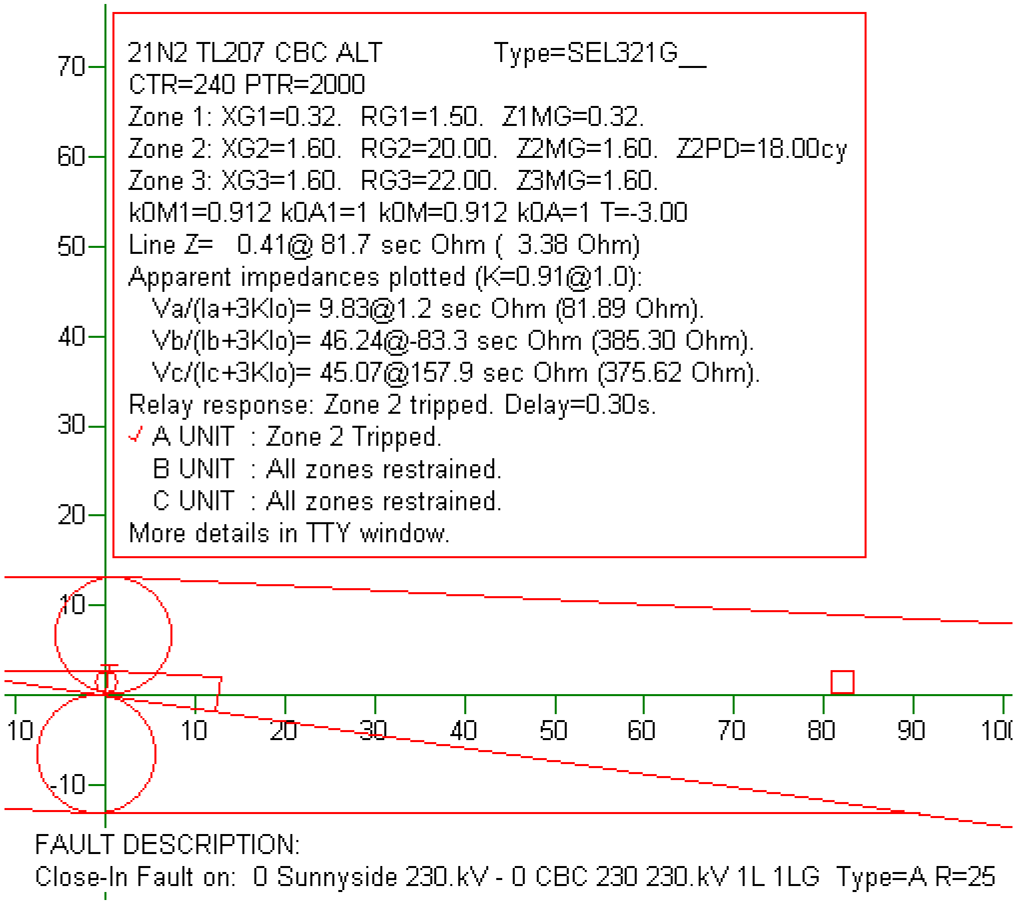
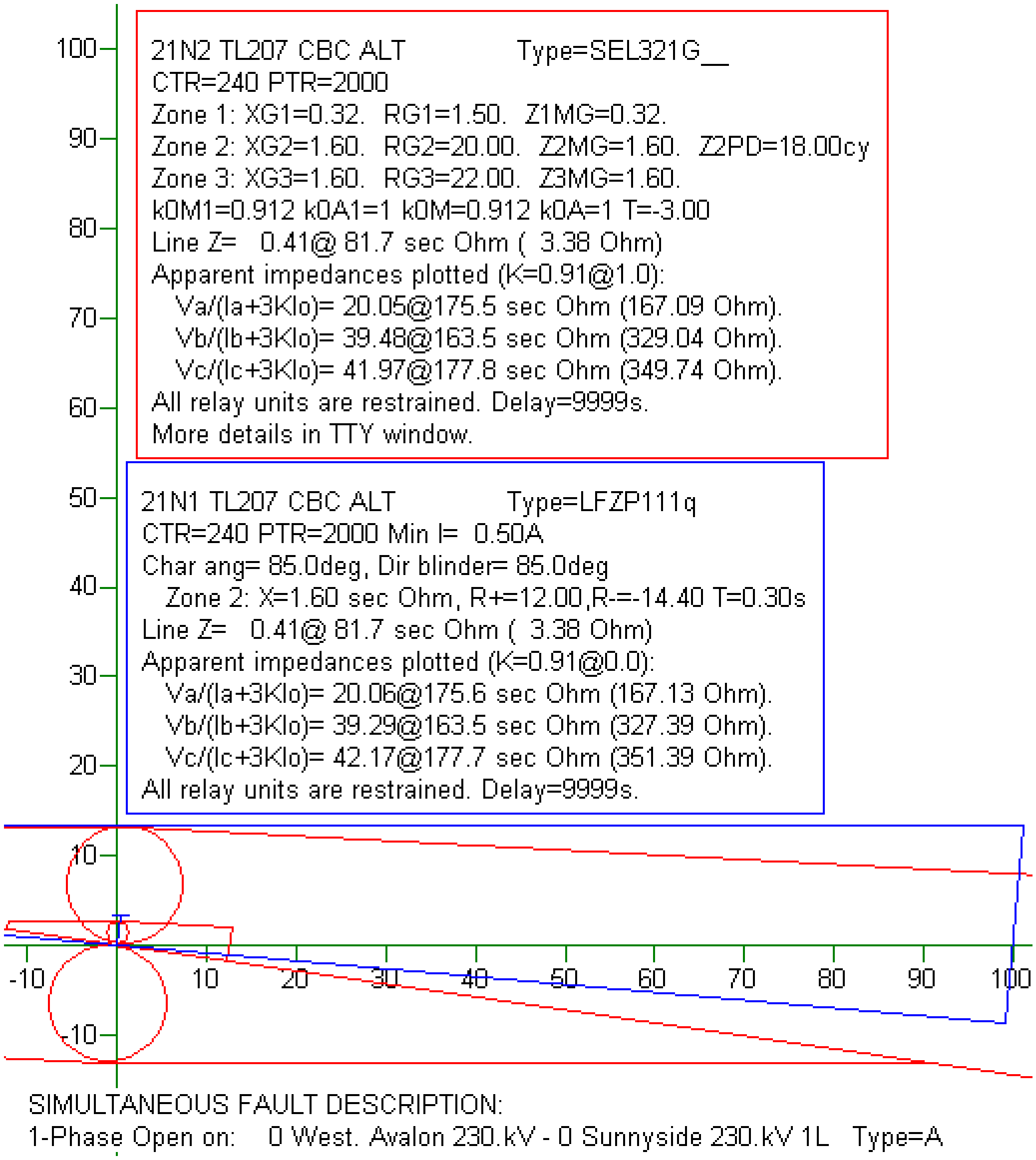


Figure 10 - Local Zone 2 Quad element operates for 25 ohm resistive SLG close to the remote (SSD) terminal.

With very heavy prefault load flow (170 MVA in TL203 and 177 MVA in TL207) if TL203 trips single pole, the ground distance elements with the increased resistive reach on the P2 protection will remain secure. See Figure 11



<u>Figure 11 - Ground distance elements remain secure during heavy load flow with one phase open on TL203</u>

The zone 2 ground distance time delay trip will need to be reduced from 60 to 18 cycles (0.3 seconds) in order to aid coordination for resistive single line to ground faults "around the loop" of TL203 TL237 and TL207 where otherwise, the ground time overcurrent functions might not have coordinated fully. A setting of 0.3 seconds is proposed to aid coordination below the WAV TL237 zone 1 ground distance protection since there is no fault current infeed at CBC to aid this coordination.

Z2GD := 18 Cycles

Zone 3 Ground Distance Protection

The zone 3 ground mho function will be set the same as the zone 3 phase distance function.

$Z3MG := Z3P$ $\quad Z3MG = 1.6$ Ohms secondary

$\frac{Z3P}{|Z1MAG|} = 394.65 \cdot \%$ of line length

This is not exactly the same as the existing setting but is set the same as zone 3 at SSD for consistency.

$XG3 := Z3MG$ $\quad XG3 = 1.6$ Ohms secondary

Set the Zone 3 quad resistive reach at 10% more than the remote Zone 2

$R2Grem := 20$ Ohms secondary

$R3G := \mathrm{round}(R2Grem \cdot 1.1, 0)$ $\quad R3G = 22$ Ohms secondary

Ground distance current supervision

Since there is no concern about these elements operating on load, even with loss of potential, set all current supervision elements at minimum, for maximum sensitivity of the distance elements.

$'50L1 := 0.5$ A Sec $\quad '50L2 := 0.5$ A Sec $\quad '50L3 := 0.5$ A Sec

$'50G1 := 0.5$ A Sec $\quad '50G2 := 0.5$ A Sec $\quad '50G3 := 0.5$ A Sec

Zero sequence current compensation

Set the zero sequence current compensation as usual.

$$k01M := \left(\left| \frac{Z0L207 - Z1L207}{3 \cdot Z1L207} \right| \right) \qquad k01M = 0.912$$

$$k01A := \left(\arg\left(\frac{Z0L207 - Z1L207}{3 \cdot Z1L207} \right) \right) \qquad k01A = 0.987 \cdot deg \qquad \text{Say} \quad k01A := 1deg$$

Set the overreaching zones the same as zone 1 $\quad k0M := k01M$ $\quad k0A := k01A$

$k0M = 0.912$ $\quad k0A = 1 \cdot deg$

These settings are only slightly different from the existing settings.

Non Homogenous Angle Setting

Compare the angle of the total zero sequence current at the remote bus with the angle of the zero sequence current contribution from the local terminal to determine this setting. From ASPEN OneLiner, the worst case is normal conditions. For this case, for an SLG at SSD the angle of I0 at the fault is -114 degrees and the angle of I0 out of the CBC terminal is -112 degrees. Therefore, the total fault current lags the current contribution from SSD by 2 degrees and angle T may be set at -2 and ensure no overreach. However, because this is such a short line, the angle T should be set at the default angle of -3 degrees for extra security.

$T := -3$ degrees

Out of step blocking and tripping

Not used in this application. There is a danger of out of step conditions arising. Historically no action has been taken to provide special tripping or blocking functions. Natural tripping during swings is accepted.

Load Encroachment logic

Check loadability of the Zone 2 phase distance element assuming worst case power factor of 0.87 simultaneous with worst case depressed voltage of a stressed system of 0.9 per unit. Note that units of kV squared match units of MVA. Note that quadrilateral elements are only used for the ground distance functions that are not sensitive to balanced three phase load. Therefore no need to worry about the reach of the quadrilateral elements.

$$\text{Zloadmin} := \frac{(0.9\text{kVbase})^2}{\text{Smax}} \qquad \text{Zloadmin} = 158.114$$ Ohms primary (assume worst case at 30 degrees)

Maximum reach of the Zone 2 element is at the line angle of 81 degrees. At 30 degrees, the reach will be given by

$$\text{Z2load} := \text{Z2P}\cdot\cos[(\text{Z1ANG} - 30)\text{deg}] \qquad \text{Z2load} = 0.991$$ ohms secondary

$$\text{Z2load}\cdot\frac{\text{VTR}}{\text{CTR}} = 8.26$$ ohms primary

Since the reach of the Zone 2 element at 30 degrees is less than the apparent impedance of the maximum load, there is no need to apply load blinding logic. See Figure 12

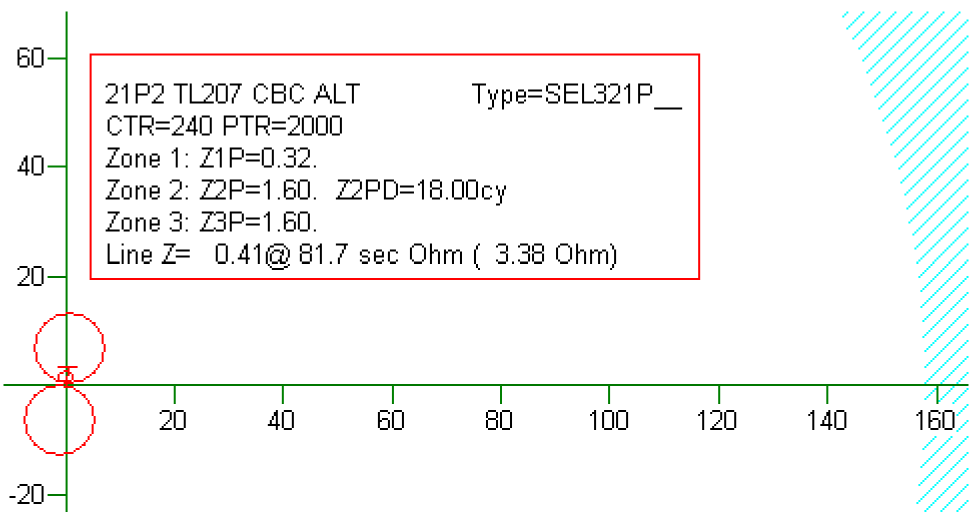


Figure 12 -Load impedance with respect to proposed new Mho function reaches.

Ground directional element

The SEL-321 application example recommends finding the minimum source impedance behind the terminal and setting the reverse and forward boundaries of the negative sequence directional element at the 1/3 and 2/3 points respectively.

In the negative sequence plane, the sum of the two source impedances and the line impedance is:

$Z2total := Z2minCBC + Z1L207pri + Z2minSSD$ $\qquad |Z2total| = 72.302$

The 1/3 point is $Z2\_1\_3 := \frac{Z2total}{3}$ $\qquad$ The 2/3 point is $Z2\_2\_3 := \frac{2Z2total}{3}$

$Z2Rpri := Z2\_2\_3 - Z2minCBC$ $\qquad |Z2Rpri| = 6.778$ $\qquad |Z1L207pri| = 3.379$

$Z2Fpri := Z2\_1\_3 - Z2minCBC$ $\qquad |Z2Fpri| = 17.325$ $\qquad |Z2minCBC| = 41.425$

$|Z2minSSD| = 27.5$

Converting the primary impedances to secondary ohms

$Z2R := Z2Rpri \cdot \frac{CTR}{VTR}$ $\qquad |Z2R| = 0.813$ Ohms secondary $\qquad arg(Z2R) = 82.218 \cdot deg$

$Z2F := Z2Fpri \cdot \frac{CTR}{VTR}$ $\qquad |Z2F| = 2.079$ Ohms secondary $\qquad arg(Z2F) = -96.233 \cdot deg$

Rounding up Z2F (note that Z2F is negative) and rounding down Z2R gives:

$Z2F := -2$ Ohms secondary $\qquad Z2R := 0$ Ohms secondary

The proposed Z2F and Z2R settings are considerably higher than existing, reflecting the addition of motor load as generation at CBC. This will move the thresholds closer to SSD.

Set the current level detectors at minimum level that will allow operation of the ground distance elements.

Due to the very small zero sequence current contribution to a single line to ground fault at the remote terminal, the negative sequence current contribution will always be higher than the zero sequence. Therefore there is no point in setting the forward looking negative sequence overcurrent elements any more sensitively than the zero sequence ground overcurrent supervision of the ground distance elements.

$'50QF := '50G2$ $\qquad '50QF = 0.5$ $\qquad$ A secondary

Set the supervision function for the reverse looking element to be the same as, or a little more sensitive than the forward looking supervision element at the remote terminal.

$'50QR := 0.5$ $\qquad$ A secondary

The positive sequence current restraint (a2) factor should be set just smaller than the ratio of the maximum load current (positive sequence) to the most sensitive current supervision element (50QR).

$I1maxpri := \frac{Smax \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\qquad I1maxsec := \frac{I1maxpri}{CTR}$ $\qquad I1maxsec = 2.834$

Bearing in mind that the 50QR setting is in units of 3*I2

$\frac{'50QR}{3 \cdot I1maxsec} = 0.059$ $\qquad$ Choose a value of $\qquad a2 := 0.06$

This a2 factor is lower than existing setting because of higher maximum load current used.

Phase time overcurrent element

This element is not used

Residual time overcurrent element

This element is used to provide the most sensitive backup protection. It will be a directional element. Minimum pickup needed to sense a higher resistance than 100 ohm SLG near the CBC terminal. Choose 200 ohm arbitrarily. Note that this terminal contributes 1/3 of the zero sequence current to a fault near CBC than the CBC terminal. Choose a desensitization factor of 4 for sensitivity.

$SF := 2$ Desensitization factor due to remote end infeed is $Dfactor := 4$ $Rf := 200$

$$'51NPU := round\left(\frac{kVbase \cdot 1000}{\sqrt{3} \cdot SF \cdot Dfactor \cdot Rf \cdot CTR}, 1\right) \qquad '51NPU = 0.3$$

The existing setting of 0.5 A is less sensitive than required to sense this fault with arbitrary resistance. However, it is the minimum setting available. Therefore it will be retained.

$'51NPU := 0.5$ A secondary

Coordination checks show that existing time dial settings around the loop TL203, TL237 and TL207 (clockwise) will not coordinate, because the CBC TL207 and WAV TL237 relays are set exactly the same. Therefore if there is a fault on TL207 that has to be cleared by the ground time overcurrent relay at CBC, the WAV TL237 will trip simultaneously or not coordinate. Therefore the existing time dial settings on CBC TL207 have to be adjusted. The ground distance elements will speed up tripping for faults with resistance up to 150 ohms fed from one end, where ground relay coordination is challenged), so coordination will be checked for faults with resistance of 150 ohms or more. Trial and error checks show that in order to achieve coordination, the existing time dial setting of CBC TL207 ground time overcurrent relay will have to have its time dial settings reduced from existing 4 to 3. The WAV terminal of TL203 already is going to have its pickup increased from 0.5 to 0.6 A sec.

Check the coordination with the other relays for three faults (all with 150 ohm resistance). Line end TL237, Close in to CBC on TL237 and 89% from WAV on TL203 (at the end of the mutually coupled section). See Figure 14 to find that existing settings (curves 2&3) do not coordinate, and Figures 14, 15 and 16 to find that revised (Curves 4, 5 and 6) settings will coordinate.

$'51NPU = 0.5$ A secondary $'51NPU \cdot CTR = 120$ A primary

$'51NTD := 3$ $'51NC := "U3"$ $'51NTC := "N"$ $'51NRS := "N"$

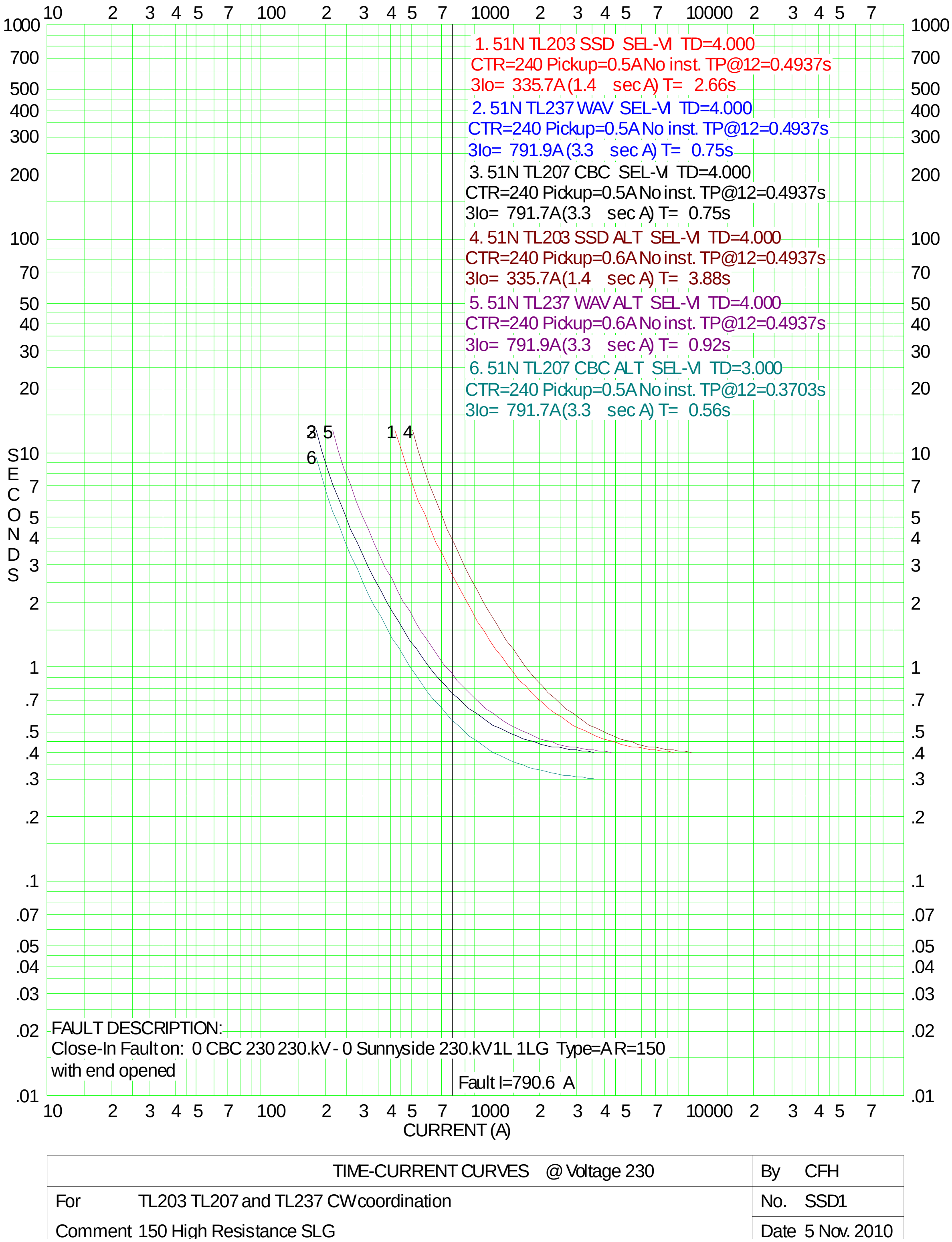
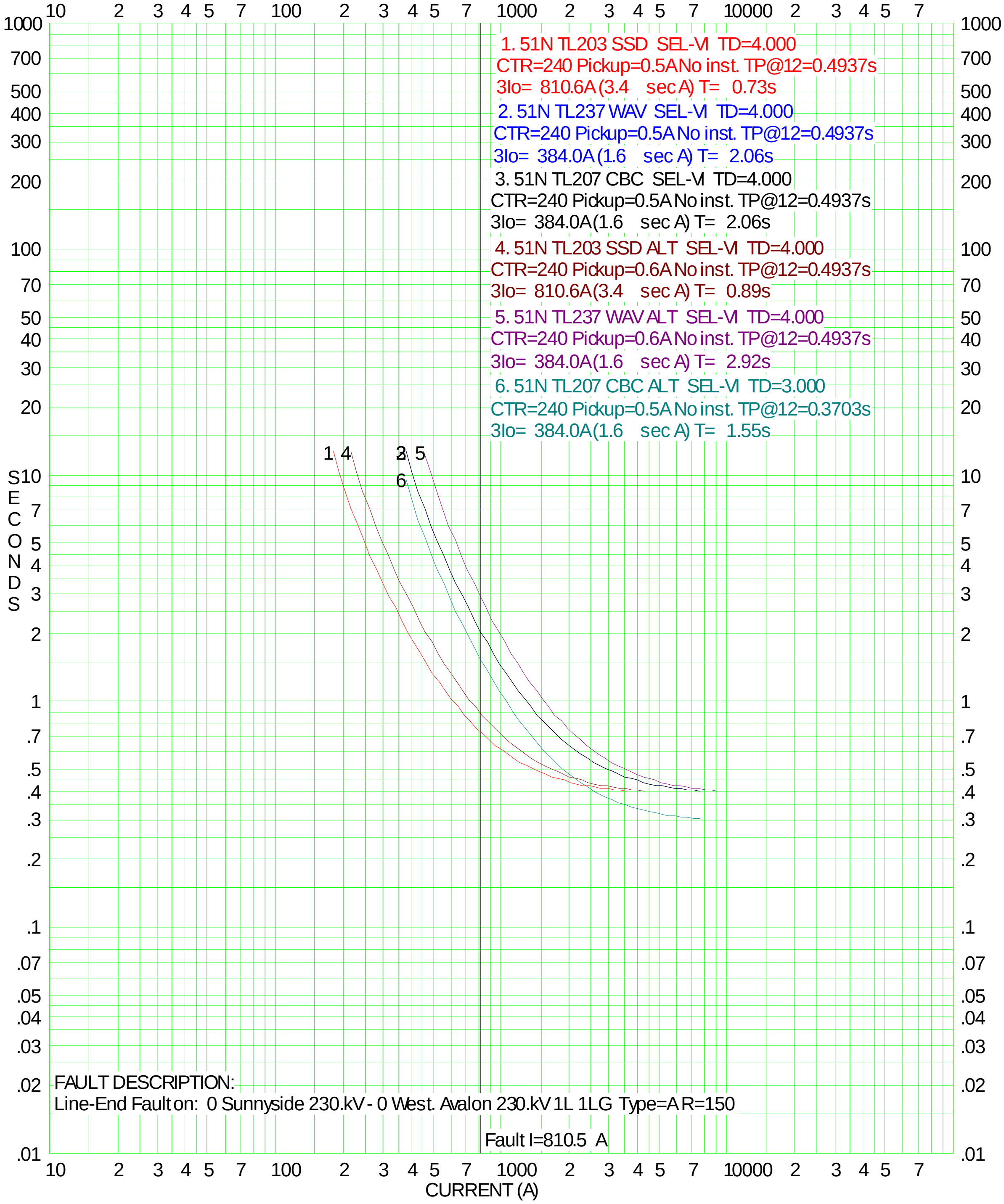
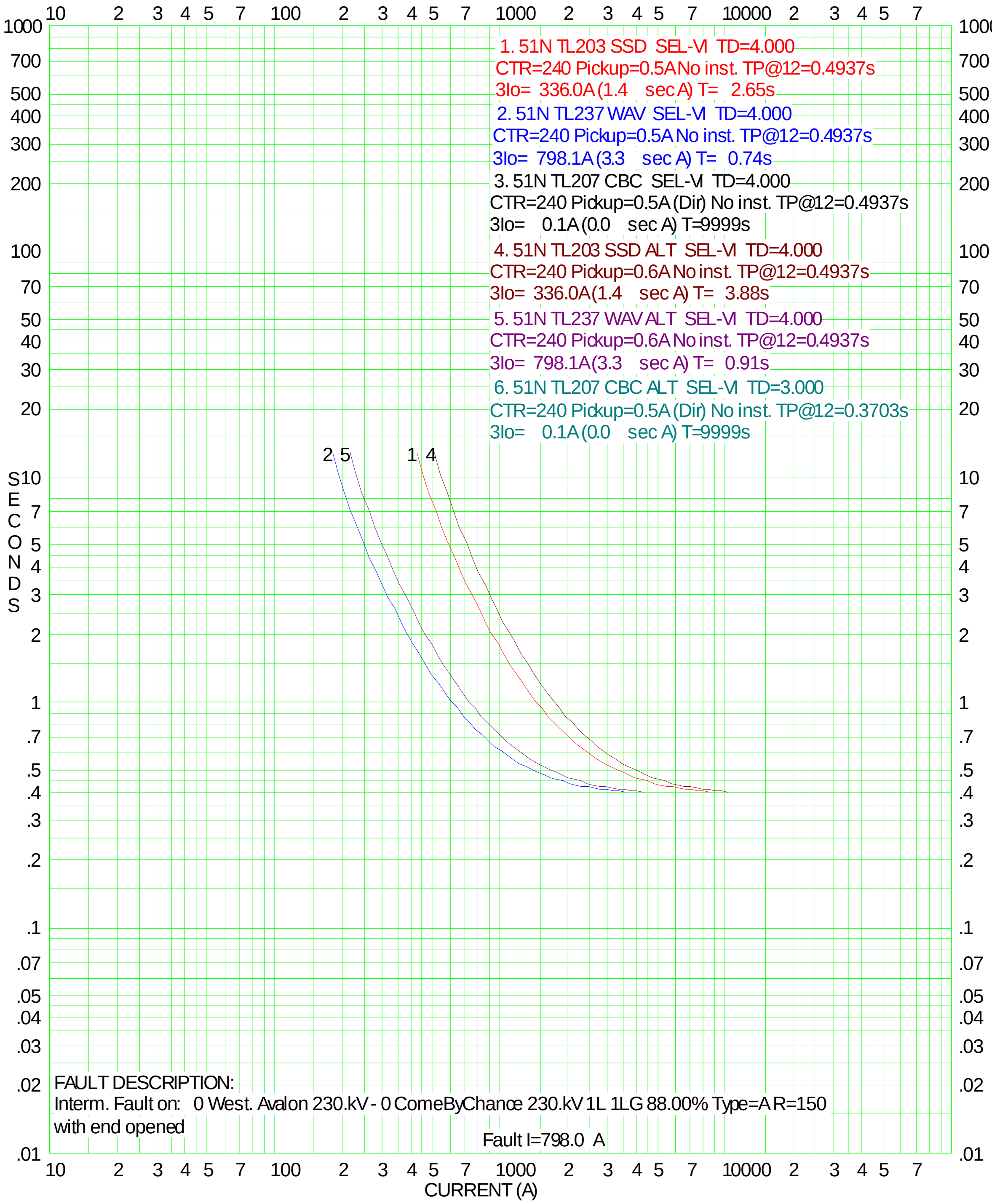


Figure 14 - coordination of ground time overcurrent elements for close-in fault on TL207 close to CBC



TIME-CURRENT CURVES @ Voltage 230	By CFH
For TL203 TL207 and TL237 CW coordination	No. SSD2
Comment 150 High Resistance SLG	Date 5 Nov. 2010

Figure 15 - coordination of ground time overcurrent elements for line end fault on TL203 close to WAV



SSD3	TIME-CURRENT CURVES @ Voltage 230	By CFH
For	TL203 TL207 and TL237 CW coordination	No. SSD3
Comment	150 High Resistance SLG	Date 5 Nov. 2010

<u>Figure 16</u> - coordination of ground time overcurrent elements for intermediate fault on TL237 88% from WAV with CBC terminal open.

Permissive Overreaching logic settings

EPOTT := "Y"

Z3RBD is set at remote breaker time plus channel reset time plus channel reset time plus zone 2 reset time. From review of fault records it appears that the breaker time is 3 cycles. Channel reset time is not easily determined from existing records but can conservatively be assumed to be 1 cycle, and relay reset time will also be about 1 cycle. Total time for Z3RBD is then 5 cycles.

Z3RBD := 5 cycles

Echo block delay timer blocks the echo after the local elements have picked up. This can be set relatively long since there is no significant need for the echo function shortly after the local terminal has just seen a fault but the remote terminal has not. Set at 10 cycles as per the example in the instruction manual.

EBLKD := 10 cycles

Echo time delay on pickup should be set to override noise on the communications so that it doesn't echo noise. Typical time according to the SEL application guide is 2 cycles. Since this delay only affects clearing time for relatively light (high resistance) faults that are sensed by zone 2 function at one end, the typical setting is acceptable.

ETDPU := 2 cycles

Echo duration should be long enough to ensure the permissive trip is received by the remote terminal and should also be shorter than the Z3RBD time to ensure that the reverse blocking will always be longer than any permissive trip received (including echo time stretching).

EDURD := 4 cycles

No need to enable week feed conversion to trip, since both terminals will be quite sensitive enough to detect high resistance faults after the remote terminal has cleared. Therefore we can accept sequential (or "step") clearing with no need for the added insecurity of weak infeed tripping.

EWFC := "N" **No other communications logic settings are required for this application.**

Switch on to Fault Settings

Switch on to fault logic will ensure the protection will operate when energizing the line onto a close-in three phase fault when there is no polarizing voltage available for the distance elements.

ESOTF := "Y"

The breaker close signal is not available to the relay. The 52A method of enable SOTF will be used. Therefore the Close end delay is not critical. Typical duration for enable SOTF is 10-15 cycles

ENCLO := "N" CLOEND := 0 EN52A := "Y" SOTFD := 15

Set 50H for high magnitude close-in multiphase faults with weakest source at CBC It should be set less than 50% of the minimum close-in fault magnitude. Minimum close-in magnitude of a three phase fault with TL203 out of service is 1890 A. Therefore desired maximum setting for 50H is 900 A. This is lower than existing.

Imin3P_close_in := 900

$$'50H := \frac{\text{Imin3P\_close\_in}}{2CTR} \qquad '50H = 1.875 \quad \text{A secondary}$$

Choose a setting of 1.8. A secondary for this element. This is considerably lower than existing, but is necessary for good dependability. Also, there is no concern with unequal saturation of CTs in a stub bus for an external fault because there will only be one line CT for this terminal

'50H := 1.8 A secondary

Choose a setting for 52AEND less than the shortest reclose time. '52AEND := 30 cycles

Residual overcurrent settings.

Tripping directly by instantaneous ground overcurrent is not necessary because the zone 1 ground distance is more selective on this short line. However it would be helpful to monitor steady state unbalance, and issue an alarm for continuous unbalance. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50N := 1$ $'50N1 := 0.25$

Negative Sequence overcurrent settings.

Similar to ground overcurrent, apply a negative sequence overcurrent element to initiate an alarm for steady state unbalances. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50Q := 1$ $'50Q1 := 0.25$

Voltage Element Settings

Similar to unbalance current monitoring, it is helpful to have an unbalance voltage monitor to detect steady state unbalances from the voltage supply.

$EVOLT := "Y"$

Set the zero sequence overvoltage element at 1% of rated voltage or just at the point necessary to override normal unbalances. The zero sequence voltage element measures 3 times the zero sequence voltage.

$$'59N := 3 \cdot 0.01 \frac{kVbase \cdot 1000}{\sqrt{3} \cdot VTR} \qquad '59N = 1.992 \qquad \text{Say} \quad '59N := 2 \quad \text{V secondary}$$

Loss of Potential

Enable loss of potential settings. Advanced LOP settings are not available on this model of relay.

$ELOP := "Y"$ Time delay of 1.25 cycles is commonly used. $LOPD := 1.25$

The 50 M element should be set above maximum load and below minimum fault current for a fault at the remote terminal under weak source conditions. The maximum load for this case should be normal maximum, not emergency maximum which only exists for a few minutes before the operator can act to reduce load.

$$Imax\_normal := \frac{Speak\_207 \cdot 1000}{\sqrt{3} \cdot kVbase \cdot CTR} = 1.448 \text{ A secondary}$$

Minimum fault current for a remote three phase fault is $I3Pmin = 800$ A primary.

Minimum fault current for a remote phase to phase fault is 87% of the minimum three phase fault current level.

Dependability factor to be sure to operate for a minimum remote fault is chosen to be 1.6. $DF := 1.6$

Maximum setting for 50M should be $\frac{0.87I3Pmin}{DF \cdot CTR} = 1.813$ In this case a setting of 1.5 A secondary will be adequately dependable and secure.

$'50M := 1.5$ A secondary

The 59QL setting should be above normal maximum unbalance and below the level expected for a blown VT fuse. For a blown fuse, one phase voltage will be lost, and the negative sequence voltage will be roughly 33% of the nominal positive sequence voltage. Choose a setting of 15% of the nominal positive sequence voltage. This will be well above any normal unbalance.

$$'59QL := \mathrm{round}\left(\frac{0.15 \cdot kVbase \cdot 1000}{\sqrt{3} \cdot VTR}, 0\right) \qquad '59QL = 10 \text{ V secondary}$$

The 59PL setting should be less than the minimum voltage to be expected for a remote bus fault under weakest source conditions. There is no minimum setting (above zero) for this function. Since this is a very short line, choose a setting equal to half the voltage drop along the line impedance at the minimum fault current.

$$'59PL := \mathrm{round}\left[0.5 \cdot \left(\frac{0.87I3Pmin}{CTR} \cdot |Z1Linesec|\right), 0\right] \qquad |'59PL| = 1$$

Miscellaneous Scheme Settings

Pole discoordinance logic is not being used. EPOLD := "N" SPPDD := "N/A"

Enable single pole tripping by distance elements only ESPT := "Y"

Enable single pole open ESPO := "Y"

Set single pole open time delay for future SPO conditions SPOD := 0.25

3 Pole open reset delay to override small discrepancies in pole closing '3POD := 0.5

Stub line protection is not required ESTUB := "N" '50MFD := "N/A"

Trip unlatch logic not applied TULO := "N"

Logic variables and Miscellaneous timers

Minimum trip duration timer is set at 9 cycles as per the application example in the SEL-321 instruction manual.

TDURD := 9 Cycles

Trip during open pole time delay should be set longer than the reclose time. Existing setting is OK.

TOPD := 55 Cycles

Add a new use for timer YT to delay tripping by the zone 1 elements for extra security on this very short line.

LOGIC_Y := "M1P+Z1G" TYPU := 1 cycle TZDO := 0 cycles

Retain existing settings except use time ZT to trigger an alarm for sustained unbalance.

LOGIC_Z := "59N+50N1+50Q1" TZPU := 1200 cycles TZDO := 0 cycles

Tripping Logic

Permissive tripping is required only for instantaneous overreaching functions. No need for any functions that trip directly. Existing 51NT word in MTCS is not required.

MTCS := "M2P+Z2G"

Unconditional tripping MTU := "YT+M2PT+Z2GT+51NT"

No need for existing direct tripping zone 1 functions in the switch on to fault logic.

The revised tripping logic includes the timer YT to add a 1 cycle delay to the zone 1 tripping elements.

SOTF Tripping MTO := "M2P+Z2G+50H"

Event records will be triggered automatically by all trip events. Other event record triggers should be by starting of other elements to ensure capture of all relevant events. Events should be triggered by keying or receiving permissive trips to ensure separation of relay and teleprotection issues.

MER := "M2P+Z2G+51N+LOP*52AA1+LOP*52AA2+KEY+PT+EKEY"

Outputs

Retain existing output assignments except add the continuous unbalance alarm to OUT15.

OUT15 := "LOP*50L+ZT"

Input Contact Assignment

Retain existing input assignments.

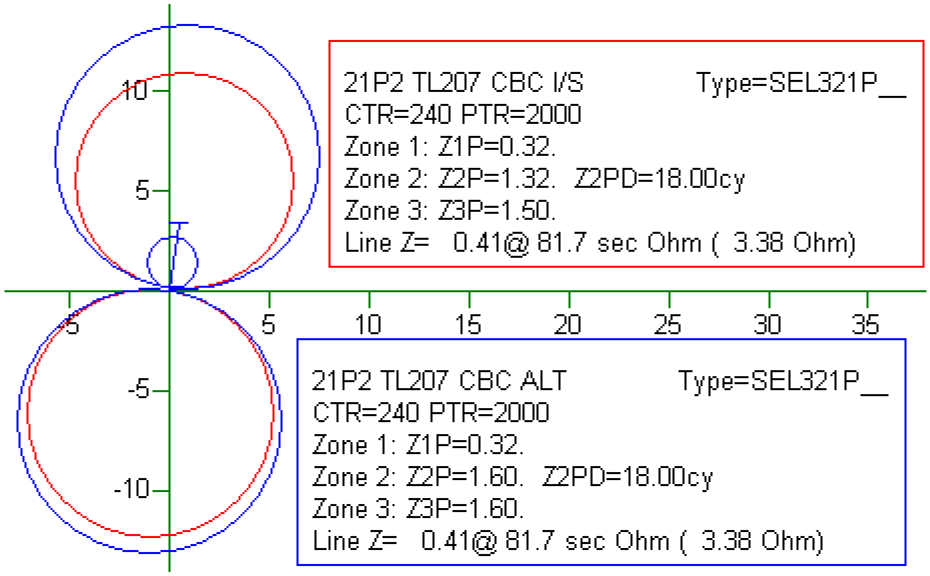


Figure 17 - Comparison of phase distance characteristics. Red is existing, blue is proposed alternative

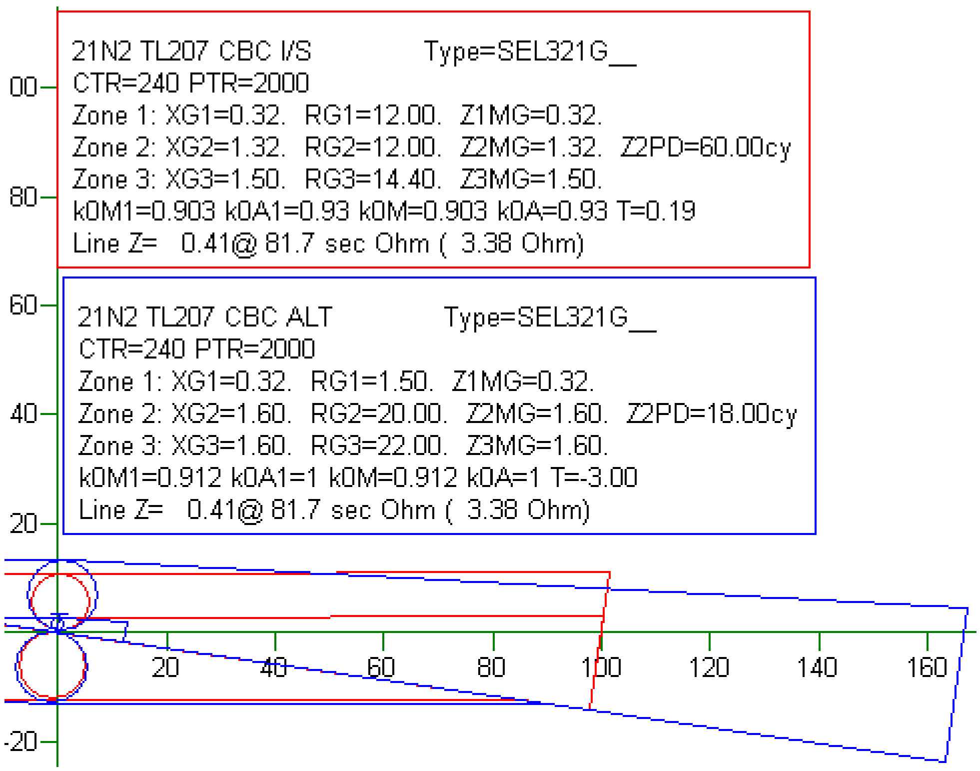


Figure 18 - Comparison of ground distance characteristics. Red is existing, blue is proposed alternative

Protection Review for Five 230 kV Transmission Lines

Appendix O
Detailed settings review for CBC TL237 "P1" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the protection systems for the Come By Chance(CBC) terminal of circuit TL237 . This 230 kV transmission circuit is from Sunnyside (SSD) to Western Avalon (WAV)
The circuit runs parallel to TL203 for 88% of its length.

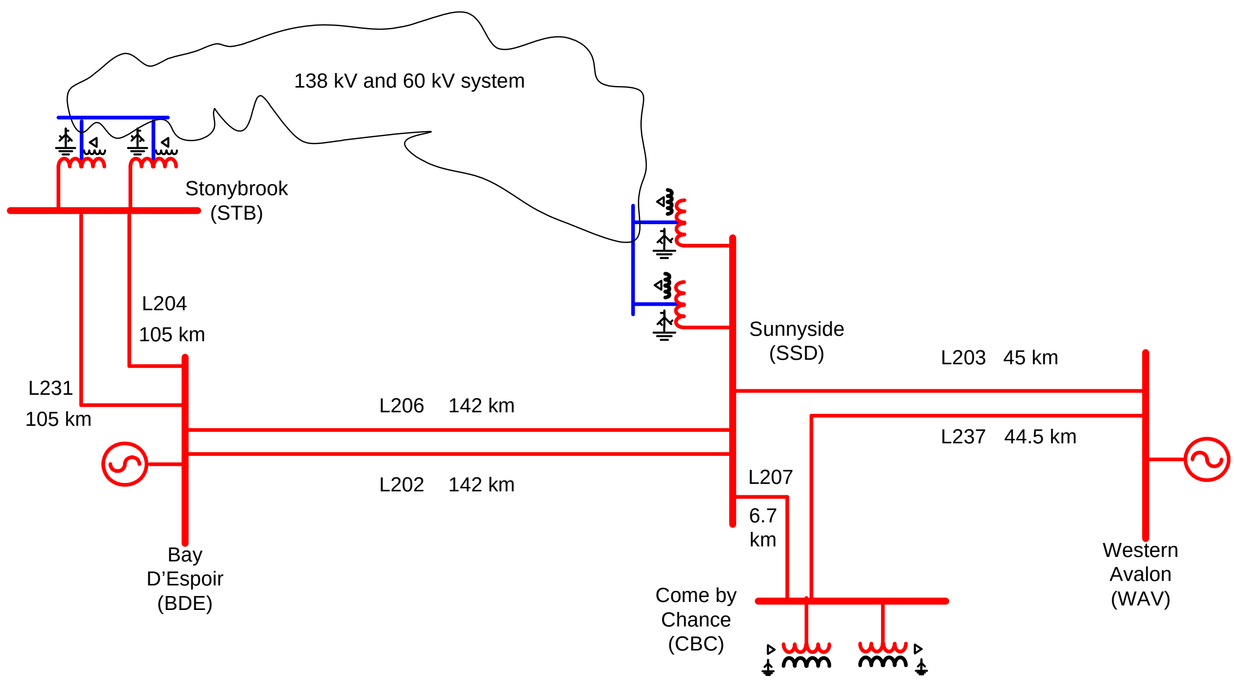


Figure 1 - System Single Line Diagram

Existing P1 protection systems are Areva LZFP111 (Optimho) systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $kVbase := 230$ $Ibase := \frac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $Zbase := \frac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $CTR := \frac{1200}{5}$ VT ratio is: $VTR := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**Hydro Interconnected System (2010-08-13) V10.olr**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with all shunts ignored (unless needed for load flow simulation).

Minimum fault current seen by each terminal (phase to phase, and SLG with 100 ohm fault resistance).

At CBC with Circuit TL207 out of service this terminal will not be a significant source of fault current to the TL207 line protection. A permissive trip echo function would be desirable to cater for the case when TL207 is out of service. However the echo function is not available with the POR 1 scheme that is normally used by Newfoundland and Labrador Hydro. With TL202 out of service, for a fault near WAV

$IPPmin := 639$ A $ISLGminPH := 175$ A $ISLGmin0seq := 111$ A

The optimho current level detectors that block the distance comparators in the event of line opening are fixed at 5% of the rated current, or 0.25 A secondary, or 60 A primary. They will have no difficulty in operating for normal fault levels. However, the ground distance elements are also supervised by a low set neutral current level detector (LDLSN that requires the neutral current to be greater than 10% of the maximum amplitude of phase difference current. This prevents the ground comparators from operating during close-in multiphase faults with CT errors. ASPEN OneLiner shows that for a bolted fault at the remote bus even under heavy load, there is sufficient neutral current (22% of maximum phase to phase fault current) that means this LDLSN function does not inhibit the ground distance comparator.

Calculate the minimum negative sequence source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum um source impedance behind CBC $Z2minCBC := 2.94 + j \cdot 27.18$ ohms primary

Minimum source impedance behind WAV $Z2minWAV := 2.64 + j \cdot 25.85$ ohms primary

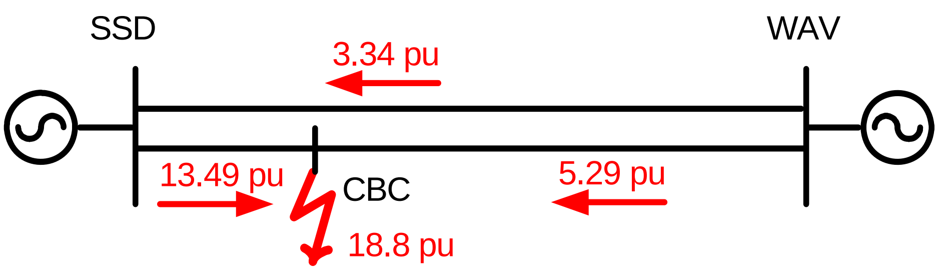


Figure 2 - 3 Phase Fault at CBC

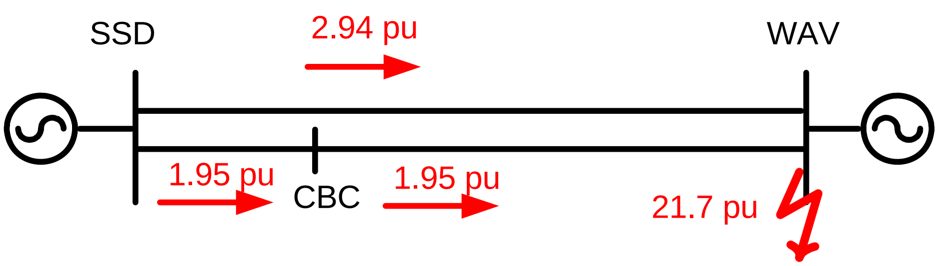


Figure 3 - 3 Phase Fault at WAV

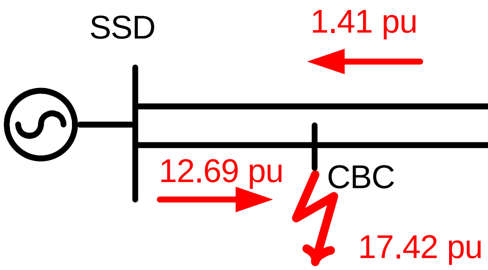


Figure 4 - SLG Fault at CBC (3I0 currents)

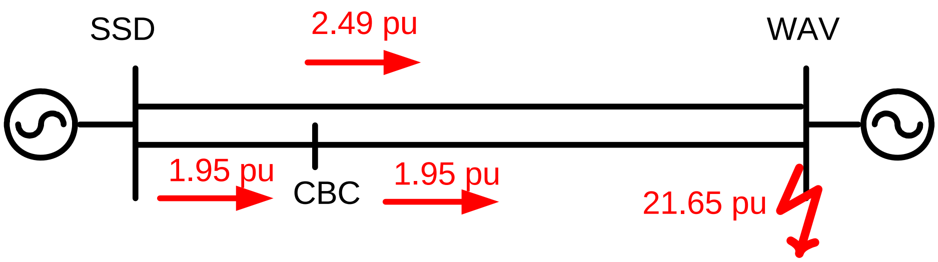


Figure 5 - SLG Fault at WAV (3I0 currents)

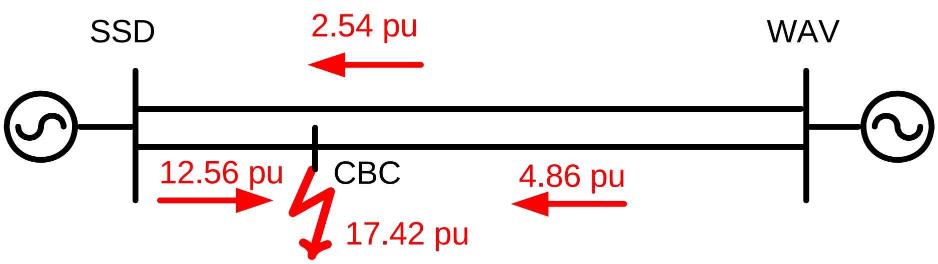


Figure 6 - SLG Fault at CBC (Phase currents)

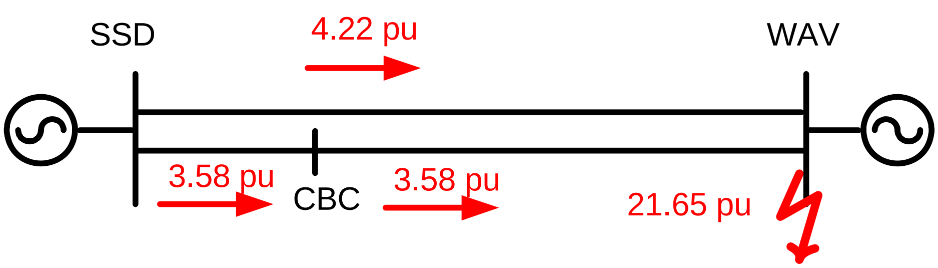


Figure 7 - SLG Fault at WAV (Phase currents)

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L237 := 0.00748 + j\cdot 0.04282$ $\quad Z0L237 := 0.02245 + j\cdot 0.15972$

In primary ohms

$Z1L237pri := Z1L237\cdot Zbase$ $\quad Z0L237pri := Z0L237\cdot Zbase$

In secondary ohms

$Z1Linesec := Z1L237pri\cdot\frac{CTR}{VTR}$ $\quad Z0Linesec := Z0L237pri\cdot\frac{CTR}{VTR}$

$|Z1Linesec| = 2.759$ $\quad arg(Z1Linesec) = 80.091\cdot deg$

$|Z0Linesec| = 10.239$ $\quad arg(Z0Linesec) = 81.999\cdot deg$

These impedances match the existing settings in the P2 relay no need for changes.

Zero sequence mutual coupling between TL237 and TL203 is $Z0m := 0.0132 + j\cdot 0.0697$

Load Data

From 2010 System peak load case provided in start up information, the peak load is given as 110.3 MVA (with TL203, TL207 and TL237 in service). The load in TL203 is 132.6 MVA. In the event of sudden loss of TL203. Peak load in TL207 will increase to take up the lost load through TL203. Thus the peak load in TL207 will be slightly more than double until operators can adjust loads.

$Speak\_237 := 110.3$ MVA $\quad Speak\_203 := 132.6$ MVA

$Smax := Speak\_203 + Speak\_237 = 242.9$ MVA

P1 Relay Settings

Distance element reach settings

Note that resistive reaches are forced to be the same for all zones. Reactive reaches for phase and ground distance elements must be the same as each other.

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if the line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the WAV Station bus under weak source conditions with TL202 out of service and all of TL203, TL207 and TL237 lines in service. From ASPEN OneLiner, voltage at CBC for a 3 phase fault at WAV is 0.16 per unit. So there is less than 20% voltage at CBC during a fault at WAV under weak source conditions.

Since the voltage is not higher than 20%, the line is considered short, and a reduced Zone 1 setting is recommended to provide more security. Initially, try to choose a setting of 80% of nominal.

$Z1P := \mathrm{round}(0.8 \cdot |Z1Linesec|, 1)$ $\quad Z1P = 2.2$ Ohms secondary

Existing setting of 2.34 ohms is a little high, and should be reduced especially as the ground distance function will be subject to a little overreach if TL203 is out of service and grounded at both ends. The ground distance reach in the optimho has to be set the same as the phase distance reach; so we need to consider the ground faults too.

The reach of the ground distance element will limit the reach of the zone 1 function. It can be seen from Figure 8 that the apparent impedance presented to the relay for a fault at the remote bus when the parallel line is out of service and grounded at both ends is less than the line impedance.

$Zapp\_ext := 2.51$ ohms $\quad Zapp\_ang := 80.5deg$ This angle is close enough to the line angle to treat it as equal to the line angle.

$\frac{Zapp\_ext}{|Z1Linesec|} = 0.91$ The apparent impedance is reduced by about 9% due to the effect of the parallel line being out of service and grounded at both ends.

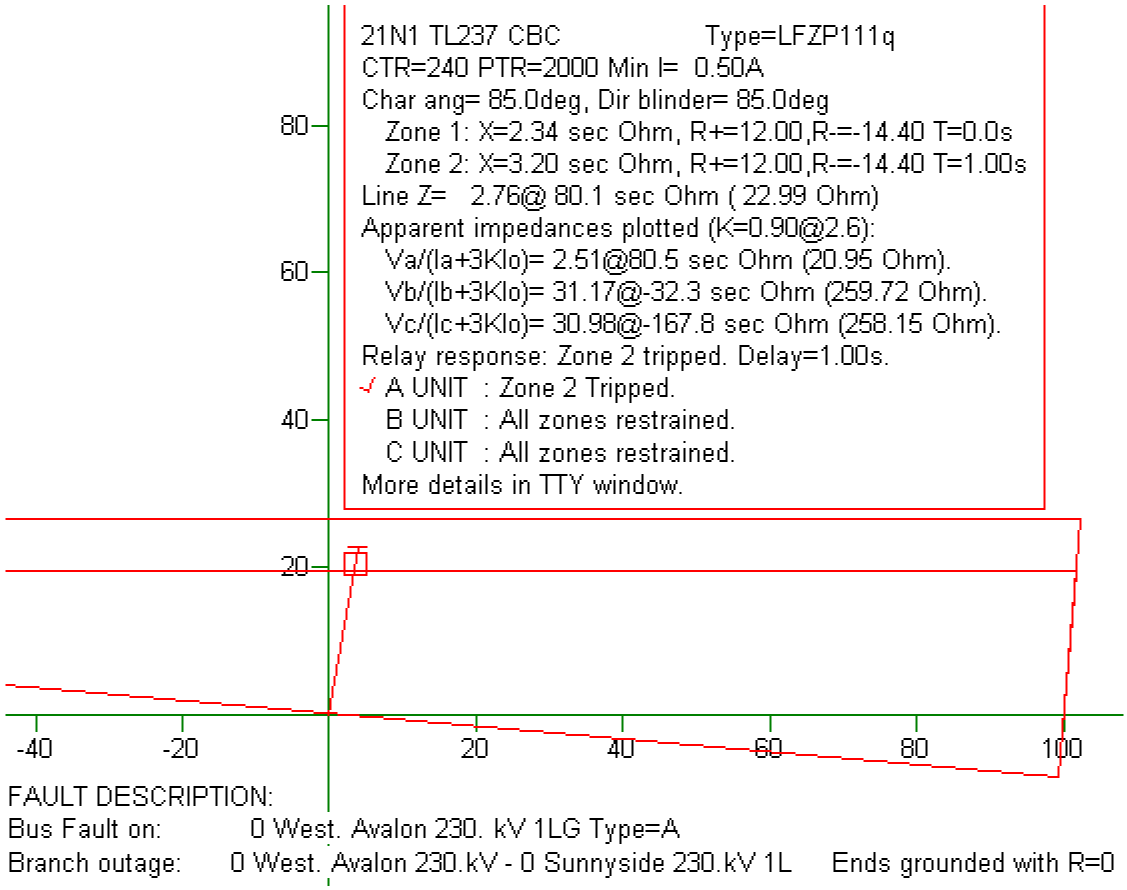


Figure 8 - Apparent impedance to a fault just beyond the remote terminal is reduced by 10% when parallel line is out of service and grounded at both ends.

The normal reach of the zone 1 should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Choose a setting of 75% of the line impedance, which is lower than the setting required to make the zone 1 element more secure for faults beyond the end of this short line. Note that as will be seen later, the reduced reactive reach is required to allow a relatively large resistive reach for sensitivity while retaining security against overreach due to CT and VT errors.

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.75$ per unit

$Z1\_sec := m \cdot |Z1Linesec|$ $Z1\_sec = 2.07$ Ohms secondary

$Z1pri := Z1\_sec \cdot \frac{VTR}{CTR} = 17.246$ Ohms primary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 3.2 ohms secondary (about 117%). However, in order to dependably reach a single line to ground fault at the remote terminal, it will be necessary to set the reach significantly further.

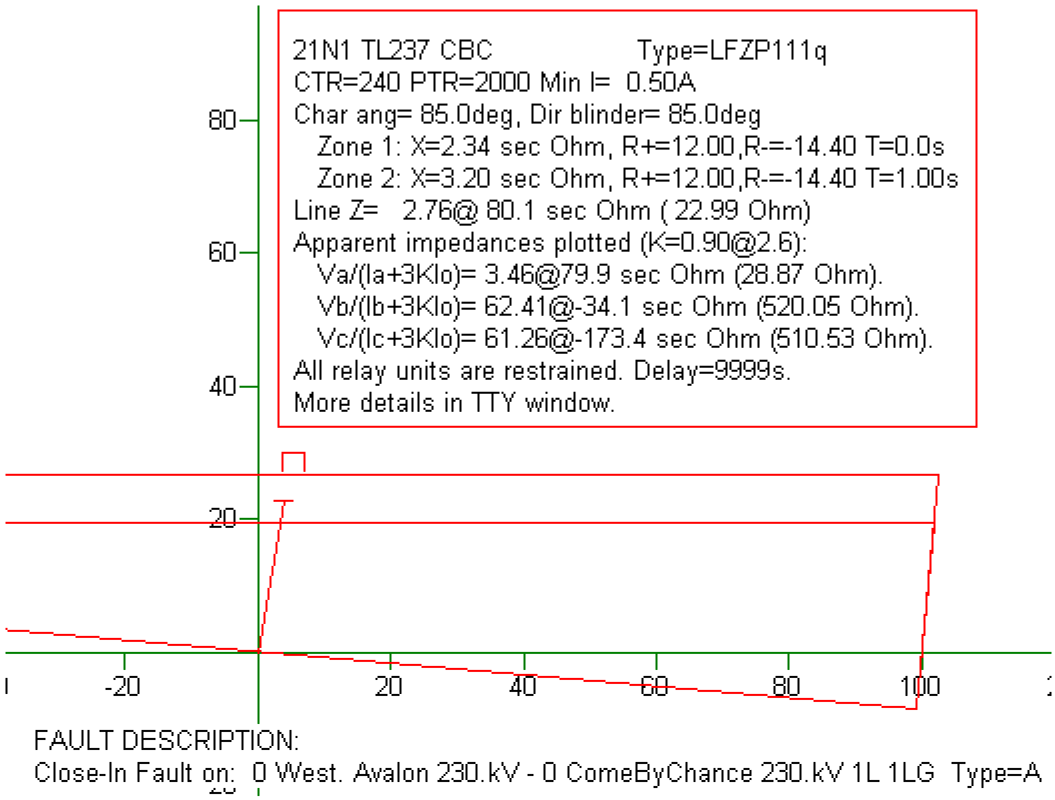


Figure 9 - Apparent impedance to a fault close to the remote terminal is increased by 25% when parallel line is in service. Relay will not operate with existing settings for this fault.

As can be seen from Figure 9, the apparent impedance to a fault close to the remote terminal is increased by so much when the parallel line is in service that the P1 protection will not sense this fault.

$Zapp\_int := 3.46$ Ohms secondary

$Z2\_sec := 1.25 \cdot Zapp\_int$ $\quad Z2\_sec = 4.3$ Ohms secondary $\quad \frac{Z2\_sec}{|Z1Linesec|} = 156.738 \cdot \%$

$Z2\_pri := Z2\_sec \cdot \frac{VTR}{CTR} = 36.042$ Ohms primary

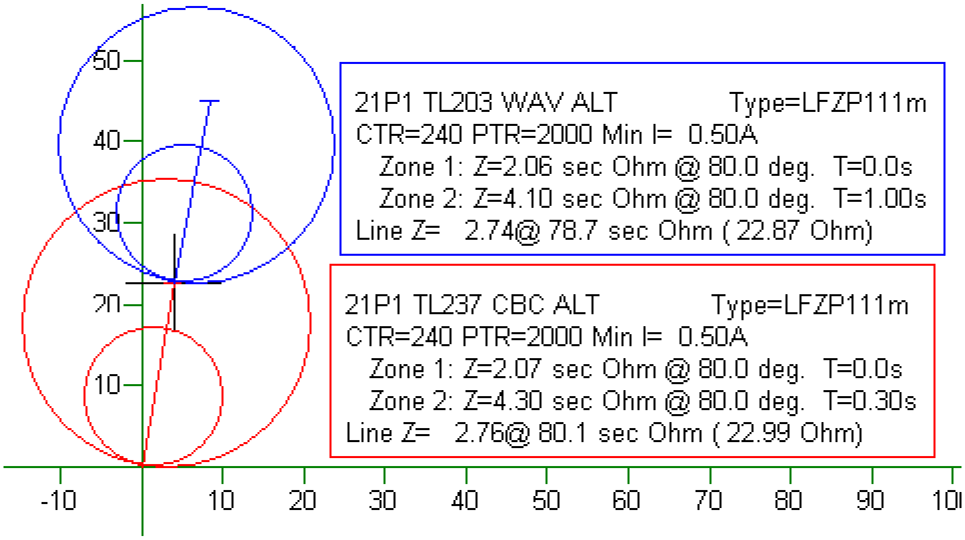


Figure 8 - Proposed Zone 2 Setting underreaches WAV TL203 Zone 1 without infeed.

The zone 2 timer will be enabled, but with a reduced setting to 0.3 second. This reduced delay is required for coordination for severe single line to ground faults with communications assistance not available. For such faults, faster clearing than is available from the ground time overcurrent protection in the P2 protection is required.

$Z2T := 0.3$ Seconds

Zone 3

The zone 3 function is not used since the POR1 scheme does not include an echo function so there is no need for any reverse blocking function. Since the Zone 2 timer has to be set with the coordination of the ground distance element in mind, it is set at 2 second; so there is no benefit in applying a longer reaching zone 3 function.

Zone 3 element is blocked - same as existing.

Load Encroachment logic

The optimho instruction manual recommends a margin of at least 10% between the impedance of the maximum load and the resistive reach of the quadrilateral distance element.

Check loadability of the Zone 2 phase distance element assuming worst case depressed voltage of a stressed system of 0.9 per unit.

$$Zloadmin := \frac{(0.9kVbase)^2}{Smax} \qquad Zloadmin = 176.406$$ Ohms primary (assume worst case at 30 degrees)

$Smax = 242.9$

$$Zloadmin\_sec := Zloadmin \cdot \frac{CTR}{VTR} \qquad Zloadmin\_sec = 21.169$$

A 12 ohm secondary resistive reach is less than 90% of the load impedance at anyypower factor and meets the Areva criterion. Anyway there is no difficulty with load encroachment as can be seen in Figure 9.

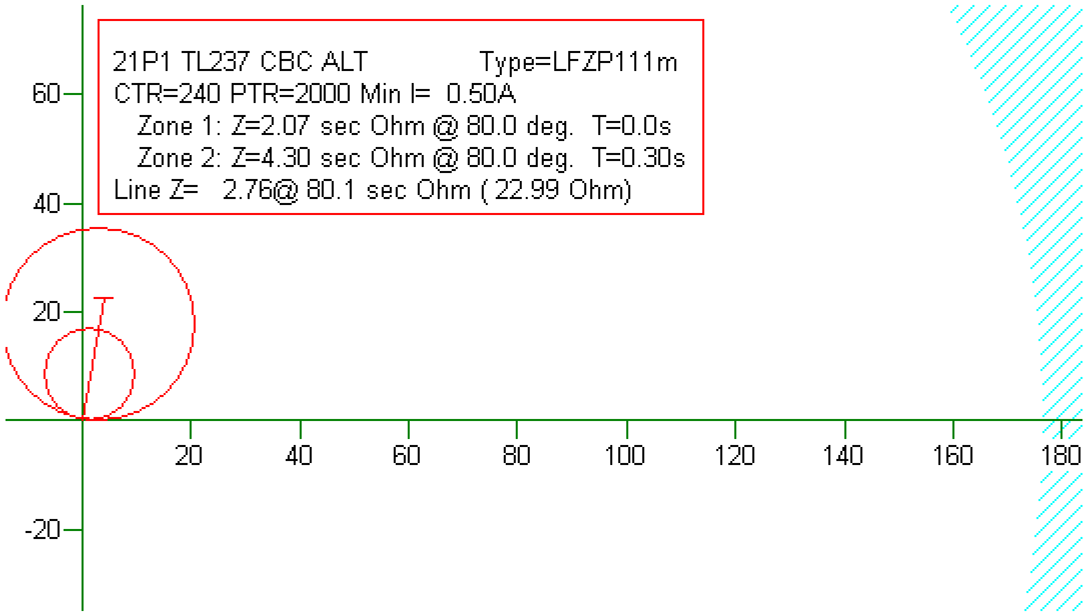


Figure 9 - Apparent impedance of load

Zone 1 Resistance - QUAD

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$R1Qmax := \mathrm{round}[(1-m)\cdot 20\cdot \mathrm{Im}(Z1Linesec), 2]\ \mathrm{ohm}$

$R1Qmax = 13.59\,\Omega$ This is the maximum secure setting for the resistive reach and is less than the existing zone 1 resistive reach setting. The existing setting of 12 ohms will be secure enough - but will it be sensitive enough?

With the existing resistive reach setting of 12 ohms, there will be a region of 10% of the line in which neither terminal will see a 100 ohm fault. If the resistive reach is increased to 13 ohms, one or the other terminal will (just) be able to sense a 100 ohm SLG on any portion of the line.

Increase the resistive reach setting from 12 to 13 ohms $Rquad := 13$ ohms secondary.

Check the maximum fault resistance that can be sensed for a fault at a location where the current contribution from each terminal is roughly the same. From Figure 11, it can be seen that the limit of sensitivity is about 100 ohms, for a fault about 34% of the distance from CBC. This meets the required sensitivity of 100 ohms.

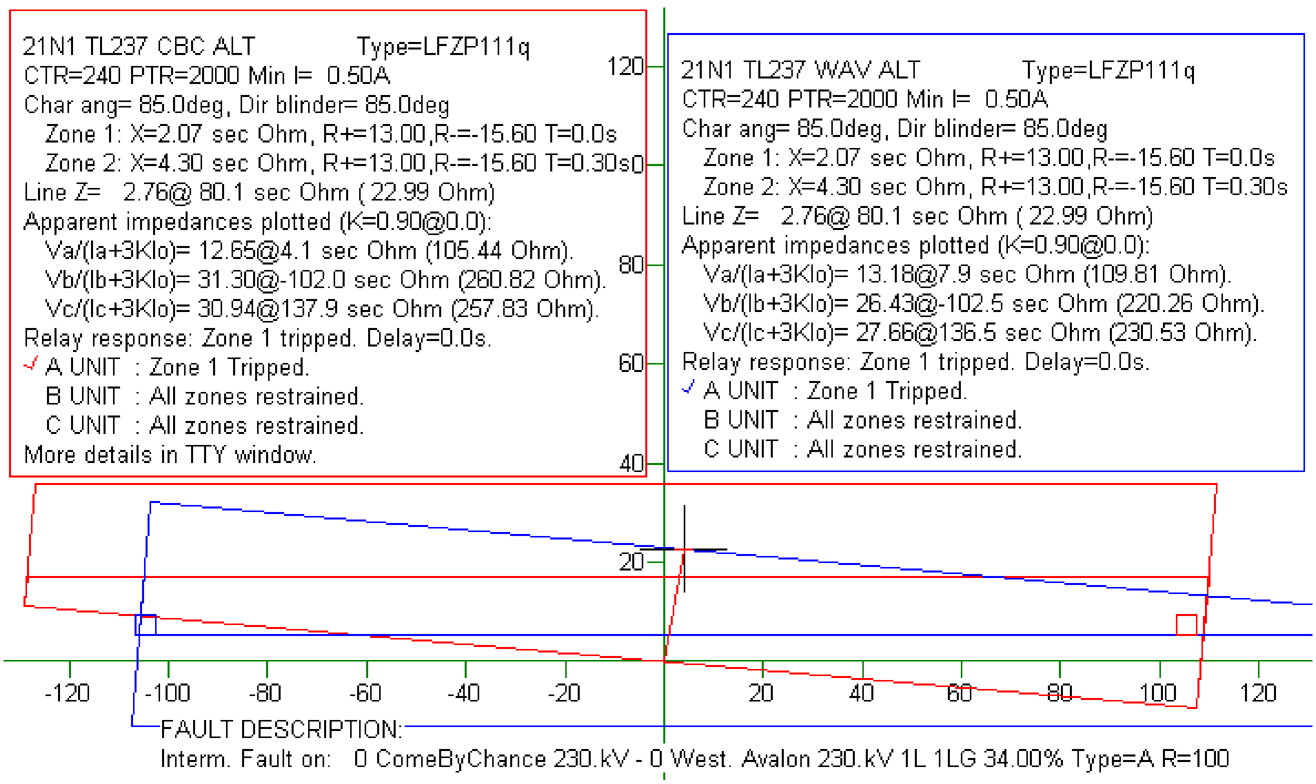


Figure 11 - Apparent impedance of a resistive fault near the mid point of the line.

Settings of K attenuators

KZPh Coarse setting common to all DISTANCE zones should be set as high as possible while below the required Zone 1 reach. The current level detectors vary inversely with KZph. Maximum setting available is 1.0

$KZPh := 1.0$

Zone 1 attenuators and angular selection

$In := 5$ $\quad Z1P = 2.2$ This is the desired secondary reach (previously calculated)

$$KZ1 := \frac{Z1\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ1 = 2.07 \qquad Z1sec\_reach := KZ1 \cdot KZPh \cdot \frac{5}{In} \qquad Z1sec\_reach = 2.07$$

Tripping by the zone 1 function is disabled - same as existing.

$Z\theta PH := (\arg(Z1Linesec)) \qquad Z\theta PH = 80.091 \cdot deg$

Rounded to the nearest 5 degrees $\qquad Z\theta PH := 80$ Degrees

$Z\theta N := \arg(Z0Linesec - Z1Linesec) \qquad Z\theta N = 82.7 \cdot deg$

Rounded to the nearest 5 degrees $\qquad Z\theta N := 85$ Degrees

Zone 2 attenuators selection

$Z2\_sec = 4.3$ This is the desired secondary reach (previously calculated)

$$KZ2 := \frac{Z2\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ2 = 4.3$$

Zone 3 is not used

QUAD Resistive Reach setting

$Rquad = 13$ ohms secondary. This reach will be required to sense a 100 ohm SLG fault anywhere on the line.

$$KR := \frac{Rquad}{\left(\frac{5}{In}\right)} \qquad KR = 13$$

Residual Compensation attenuators selection

Zero sequence current compensation for ground faults is provided by the KZN factor. Zero sequence mutual compensation is not used in this application (it causes extra complexity for only moderate gain in setting accuracy).

$$KZN := \frac{Z0Linesec - Z1Linesec}{3 \cdot Z1Linesec} \cdot KZPh \qquad KZN = 0.903 + 0.041j$$

$|KZN| = 0.904$ This is very close, but not identical to the existing setting

Switch On To Fault (SOTF) Protection.

If SOTF is enabled, it can be set to 200ms or 110 s after all poles of the line have been de-energized. The 110 s setting is intended to override automatic reclosing dead time. However it makes more sense to enable after the shorter time. Once the SOTF feature has been initiated, it remains in effect for 250ms after the line has been re-energized. The SOTF tripping options are:

a) Any distance comparator.
b) Any current level detector as long as a corresponding voltage level detector has not picked up within 20ms.
c) Either current or distance, as long as a corresponding voltage level detector has not picked up within 20ms.

SOTF := "Enabled"

SOTF_TIME := 0.20 Seconds

Elements_in_SOTF := "BOTH" (Both Comparators and current level detectors).

Power Swing Detector

This element will not be used. It will be left Blocked, and if there is a power swing, the distance elements will trip naturally.

VT Supervision

Set the VT supervision to BLOCK TRIP

Set the VT fail detection to SELF RESET this is as existing .

SELF_RESETTING := "ENABLED"

Start Indication

This function will bring up information on the LCD screen of the relay if a start event occurs. This function will not be used.

START_INDICATION := "BLOCKED"

Communications assisted logic.

The existing communications assisted logic is permissive overreaching transfer trip, scheme **POR 1**. This scheme is familiar to Newfoundland and Labrador Hydro, and even though the POR 2 scheme offers the advantage of weak infeed echo, which would help the sensitivity to resistive faults, it is not recommended to change the existing scheme logic at this stage with years of experience on a product that is nearing the end of its useful life.

The POR 1 logic is a basic permissive overreaching transfer trip scheme but it does include current reversal timers to increase security against misoperation due to current reversal when a fault on the parallel line is cleared sequentially. The current reversal logic is achieved by a timer TP which will block permissive tripping and keying of permissive trip if the local zone 2 element does not pick up within a reasonable time of receiving permissive trip. The block will be maintained for a time delay of TD after the local zone 2 element picks up, or the received permissive trip signal resets.

The application of the current reversal timers is required only if the settings of the zone 2 comparators are greater than 1.5 times the line impedance. Since the reaches of these elements are less than or equal to 1.5 times the line impedance or if current reversals are not possible, the current reversal logic is not theoretically not required. However, given the fact that the WAV terminal of this protection tripped undesirably during the 7 December 2007 fault on TL203, and noting that the current reversal logic could have prevented this misoperation (if indeed an incorrect permissive trip signal was issued from CBC) it is recommended that this logic be enabled on this circuit.

Recommended setting for TP is 30 ms - minimum signalling channel time. It has been found that the minimum signalling channel time is approximately 3 ms. Therefore, unless this time is changed.

$CS\_Min := 3$ $\quad$ $TP := 30 - CS\_Min$ $\quad$ $TP = 27$ ms

Recommended setting for TC is Maximum signalling channel reset time +35 ms. The maximum signalling channel reset time will always be less than 10 ms.

$CR\_Max := 10$ $\quad$ $TD := 35 + CR\_Max$ $\quad$ $TD = 45$ ms

These new times will increase the security of the communications assisted scheme.

Comparison of Existing (red) and Proposed alternative (ALT) settings.

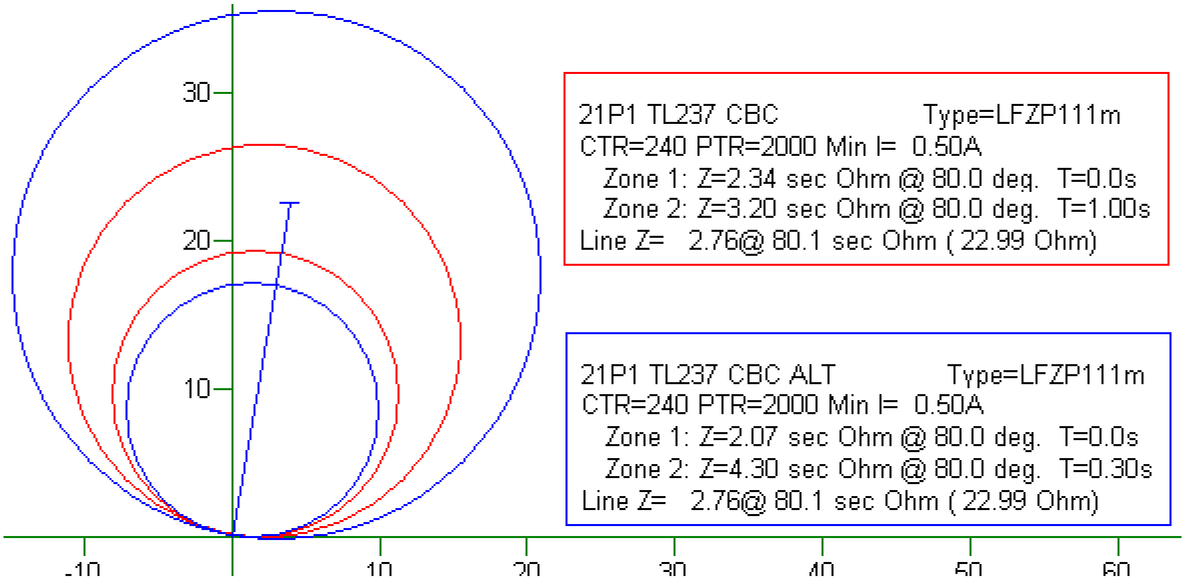


Figure 12 - Comparison of phase distance characteristics

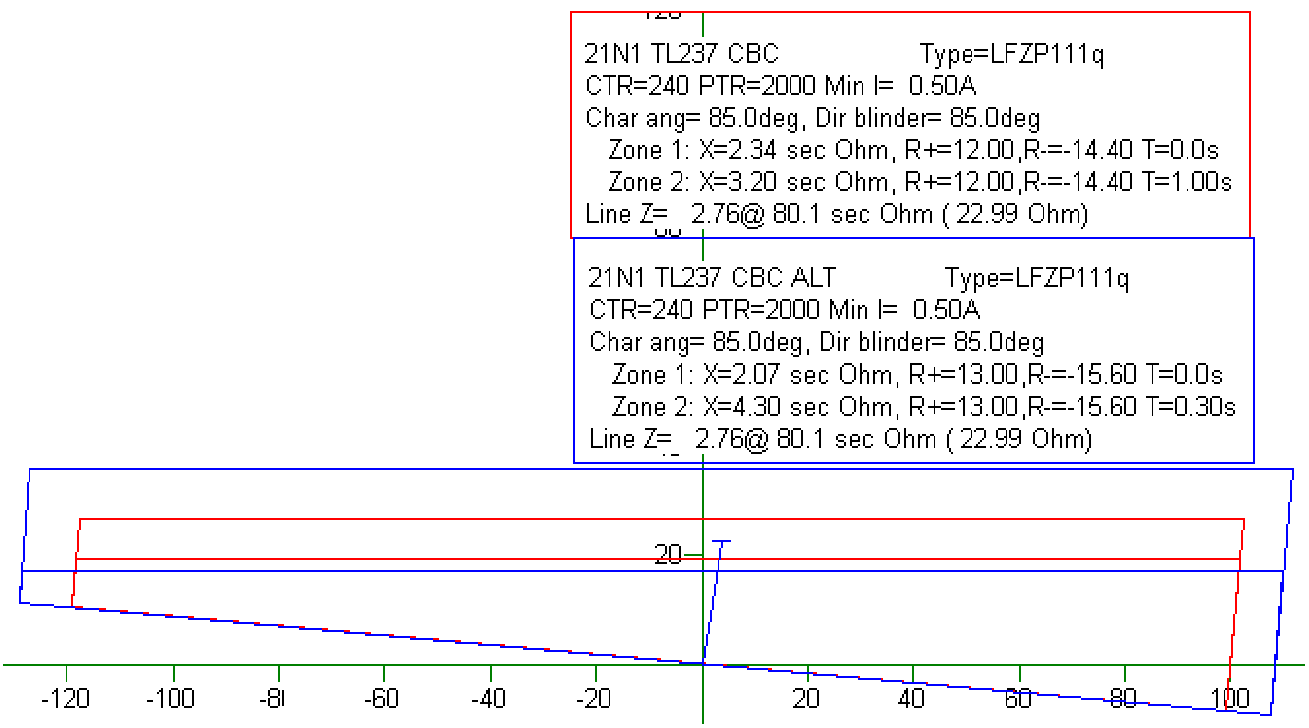


Figure 13 - Comparison of ground distance characteristics

Protection Review for Five 230 kV Transmission Lines

Appendix P
Detailed settings review for CBC TL237 "P2" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P2 protection systems for the Come By Chance (CBC) terminal of circuit TL237 . This 230 kV transmission circuit is from Come By Chance (CBC) to Western Avalon (WAV)
The circuit runs parallel to TL203 for 88% of its length.

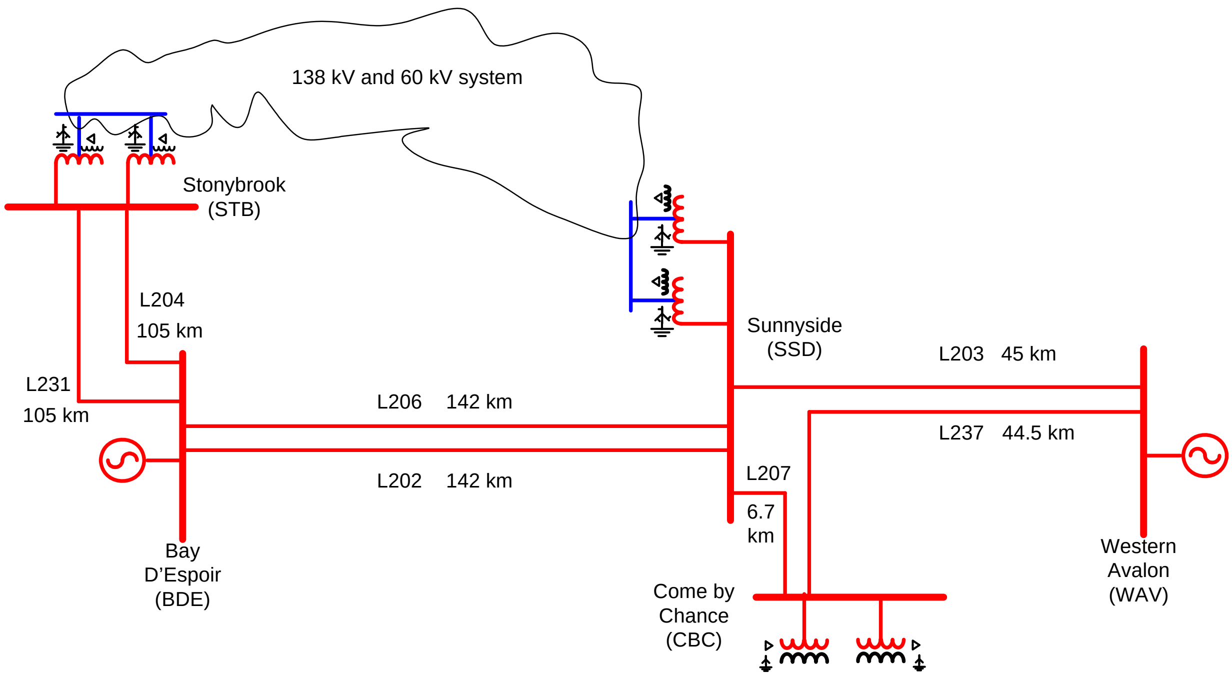


Figure 1 - System Single Line Diagram

Existing P2 protection systems are SEL321 systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$$\text{MVAbase} := 100 \qquad \text{kVbase} := 230 \qquad \text{Ibase} := \frac{\text{MVAbase}\cdot 1000}{\text{kVbase}\cdot\sqrt{3}} \qquad \text{Zbase} := \frac{\text{kVbase}^2}{\text{MVAbase}}$$

$$j := \sqrt{-1}$$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $\text{CTR} := \frac{1200}{5}$ VT ratio is: $\text{VTR} := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**Hydro Interconnected System (2010-08-13) V10.olr**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with all shunts ignored (unless needed for load flow simulation).

Minimum fault current seen by each terminal (multiphase and SLG with 100 ohm fault resistance).

At CBC, with Circuit TL202 out of service, and TL207 and TL203 lines in service, for a fault at the remote terminal.

$I3Pmin := 730$ A $ISLGminPH := 175$ A $ISLGmin0seq := 111$ A

The current for a phase to phase fault would be lower, but the current supervision element of the SEL321 measures phase to phase currents, and the phase to phase current for a phase to phase fault is twice the phase current.

Calculate the minimum negative sequence source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open. **For this calculation only, simulate 50 MVA of generation (i.e., simulating motor load) at CBC to minimize source impedance.**

Minimum um source impedance behind CBC $Z2minCBC := 2.94 + j \cdot 27.18$ ohms primary

Minimum source impedance behind WAV $Z2minWAV := 2.64 + j \cdot 25.85$ ohms primary

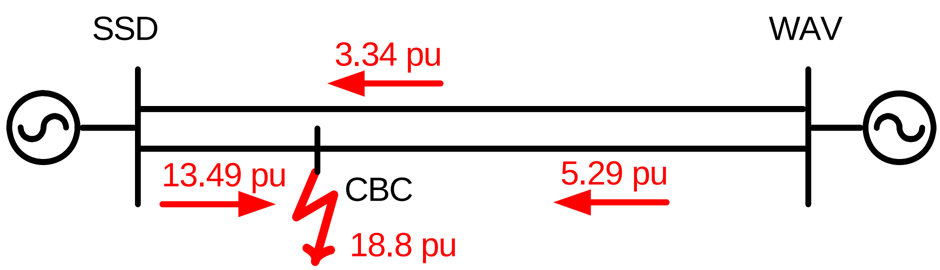


Figure 2 - 3 Phase Fault at CBC

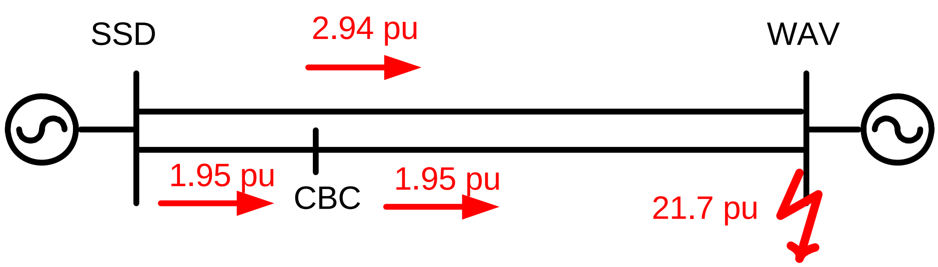


Figure 3 - 3 Phase Fault at WAV

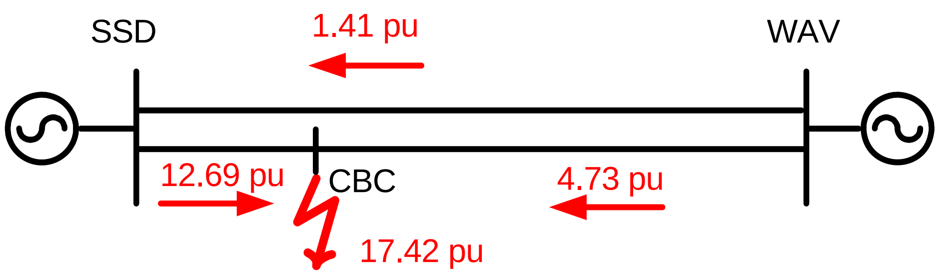


Figure 4 - SLG Fault at CBC (3I0 currents)

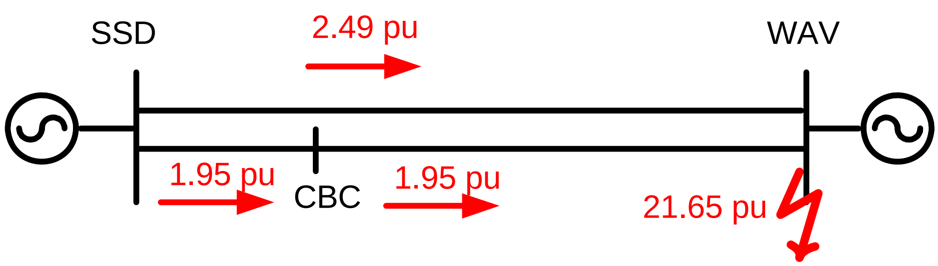


Figure 5 - SLG Fault at WAV (3I0 currents)

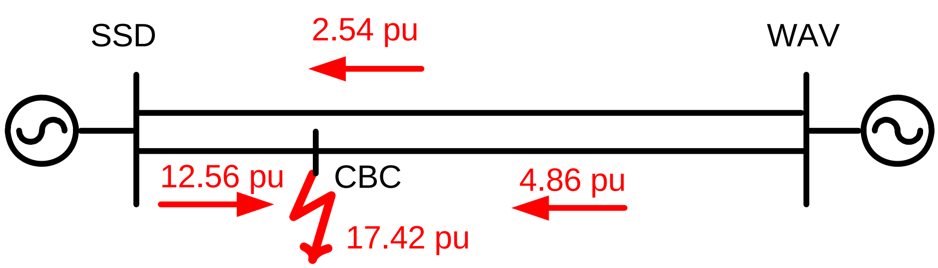


Figure 6 - SLG Fault at CBC (Phase currents)

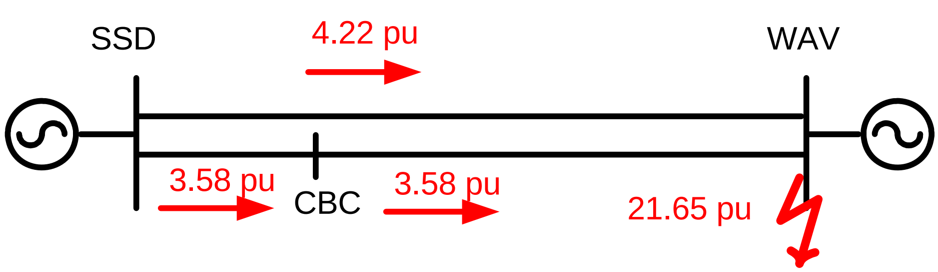


Figure 7 - SLG Fault at WAV (Phase currents)

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L237 := 0.00748 + j \cdot 0.04282 \qquad Z0L237 := 0.02245 + j \cdot 0.15972$

In primary ohms

$Z1L237pri := Z1L237 \cdot Zbase \qquad Z0L237pri := Z0L237 \cdot Zbase$

In secondary ohms

$$Z1Linesec := Z1L237pri \cdot \frac{CTR}{VTR} \qquad Z0Linesec := Z0L237pri \cdot \frac{CTR}{VTR}$$

$|Z1Linesec| = 2.759 \qquad \arg(Z1Linesec) = 80.091 \cdot deg$

$|Z0Linesec| = 10.239 \qquad \arg(Z0Linesec) = 81.999 \cdot deg$

These impedances match the existing settings in the P2 relay no need for changes.

Zero sequence mutual coupling between TL237 and TL203 is $Z0m := 0.0132 + j \cdot 0.0697$

Load Data

From 2010 System peak load case provided in start up information, the peak load is given as 110.3 MVA (with TL203, TL207 and TL237 in service). The load in TL203 is 132.6 MVA. In the event of sudden loss of TL203. Peak load in TL207 will increase to take up the lost load through TL203. Thus the peak load in TL207 will be slightly more than double until operators can adjust loads.

$Speak\_237 := 110.3$ MVA $\qquad Speak\_203 := 132.6$ MVA

$Smax := Speak\_203 + Speak\_237 = 242.9$ MVA

P2 Relay Settings

The existing line impedance settings are close to the line data book. No need for adjustment

$Z1MAG := |Z1Linesec|$ $Z1MAG = 2.76$ $Z1ANG := \frac{arg(Z1Linesec)}{deg}$ $Z1ANG = 80.09$

$Z0MAG := |Z0Linesec|$ $Z0MAG = 10.24$ $Z0ANG := \frac{arg(Z0Linesec)}{deg}$ $Z0ANG = 82$

$LL237 := 44.95$ km

In order to obtain sensitivity to 100 ohm single line to ground faults, the echo function will be needed. Enable two forward and one reverse zone.

$PMHOZ := 3$ $GMHOZ := 3$ $QUADZ := 3$

$DIR1 := F$ $DIR2 := F$ $DIR3 := R$

Mho phase distance functions

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if the line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the WAV Station bus under weak source conditions with TL202 out of service and all of TL203, TL207 and TL237 lines in service. From ASPEN OneLiner, voltage at CBC for a 3 phase fault at WAV is 0.16 per unit. So there is less than 20% voltage at CBC during a fault at WAV under weak source conditions.

Since the voltage is not higher than 20%, the line is considered short, and a reduced Zone 1 setting is recommended to provide more security. Choose a setting of 80% of nominal.

$Z1P := round(0.8 \cdot |Z1Linesec|, 1)$ $Z1P = 2.2$ Ohms secondary

This is a little lower than the existing setting.

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 3.2 ohms secondary (about 116%) and is too short. It should be increased.

$Z2P := \mathrm{round}(1.3 \cdot |Z1Linesec|, 1)$ $\quad Z2P = 3.6$ Ohms secondary

As can be seen from Figure 8, this element (with the proposed new setting) does not overreach the zone 1 element at the WAV terminal of TL203 even without infeed.

The existing Zone 2 timer setting of 18 cycles will be appropriate.

$Z2PD := 18$ cycles

Zone 3

Set Zone 3 reverse element to reach further behind this terminal than the remote Zone 2. This function adds security for external faults. The element should always be more sensitive than the forward looking Zone 2 at the remote terminal. Set it the same as the remote Zone 2 overreach plus 20%

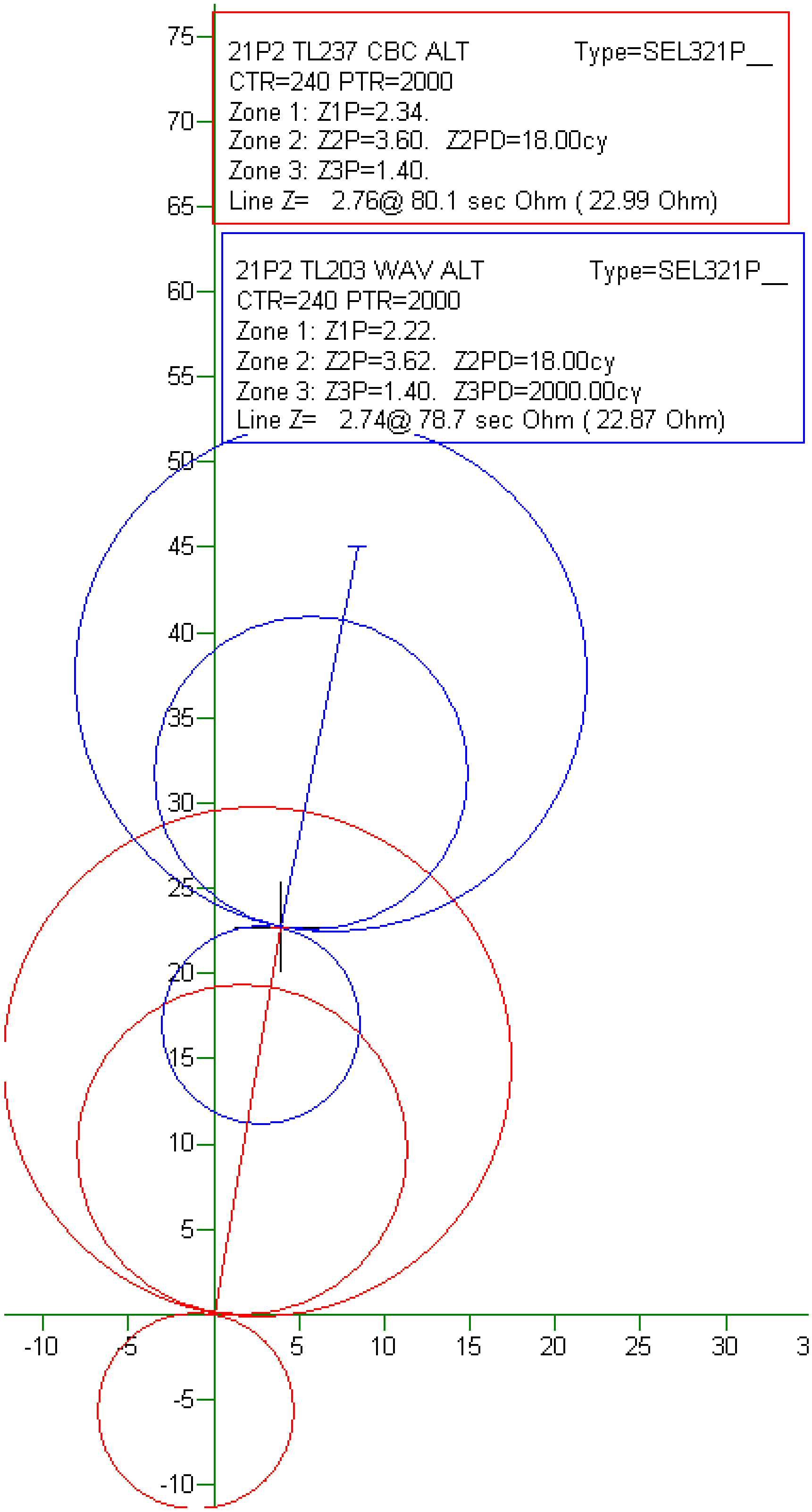
$$Z3P := Z1MAG \cdot \left(\frac{Z2P}{Z1MAG} - 1 + .2 \right)$$

$Z3P = 1.4$ Ohms secondary

$\frac{Z3P}{|Z1MAG|} = 50.464 \cdot \%$ of line length

This is a little higher than the existing setting, but provides additional security.

The reverse looking zone 3 element need not be set to trip through a timer. It is needed only for security in the POTT scheme.



<u>Figure 8 - Proposed new CBC TL237 Zone 2 underreaches WAV TL203 zone 1 without infeed, and coordinates with zone 1 on this line.</u>

Mho phase distance current supervision

If the current supervision elements can be set above load, they will be secure in the event that potential is lost. However given that loss of potential logic is available, it is recommended that only the zone 1 current supervision function be set above load. If potential is lost, it will be able to block tripping by Zone 2 before it trips on time delay or receives a permissive trip from the remote terminal.

For the point of view of current supervision being above maximum load, there is no need to worry about abnormal conditions. It would be a double contingency for the VT signal to be lost while the parallel line was out of service. Therefore, consider a maximum load of 110 MVA. The current supervision elements for the phase distance functions measure phase to phase currents.

$$IPPmax\_normal := \frac{Speak\_237 \cdot 1000}{kVbase} \qquad IPPmax\_normal = 480 \text{ A primary}$$

The current supervision elements use phase to phase currents for supervision of the phase distance function;. so the minimum phase to phase fault current will be root three times the minim phase fault current. Choose a margin of 50% of the minimum phase to phase fault current for dependability.

$$IPPmin := 0.5I3Pmin \cdot \sqrt{3} \qquad IPPmin = 632 \text{ A primary}$$

A setting of 528 A primary for 50PP1 will ensure the Zone 1 function operates for any fault even under minimum source conditions but will not be susceptible to trip on load due to loss of potential under normal maximum load conditions. This is a little higher than the existing setting and will give better security without compromising dependability.

$'50PP1 := 2.2$ A Sec $'50PP1 \cdot CTR = 528$ A primary

Since Zone 2 and zone 3 elements will be blocked by LOP function, set them at minimum. This is lower than the existing settings but will not affect the security under loss of potential conditions. The zone 3 current supervision should not be set higher than the zone 2 current supervision element at the remote terminal. In this case the remote zone 2 current supervision element will be set at 1.0 A secondary.

$'50PP2 := 1$ A Sec $'50PP3 := 1$ A Sec

Ground Distance Protection

The reach of the ground distance functions will be affected by mutual coupling to the parallel line. These functions will tend to underreach the remote bus while the parallel line is in service, and overreach the remote bus if the parallel line is out of service and grounded at both ends. Figure 9 shows that for a remote bus fault, with the parallel line out of service and grounded, the apparent impedance of the line is reduced to about 2.52 ohms secondary instead of the nominal 2.74 ohms. This is 91% of the actual line impedance.

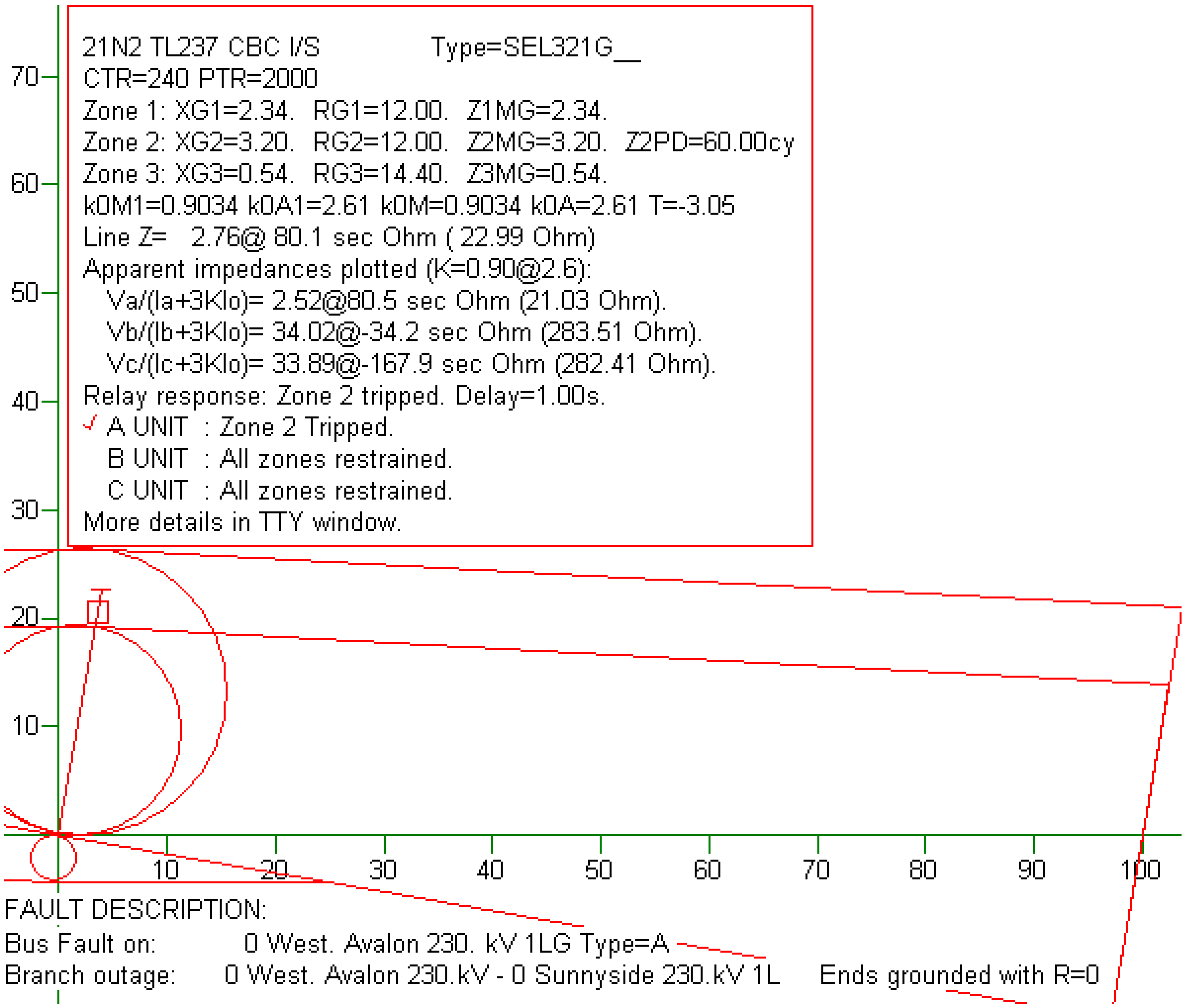


Figure 9 - Apparent impedance to a fault just beyond the remote terminal is reduced by 11% when parallel line is out of service and grounded at both ends. Existing relay settings modeled in this figure.

The normal reach of the zone 1 should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Choose a setting of 75% of the line impedance, which is lower than the setting required to make the zone 1 element more secure for faults beyond the end of this short line. Note that as will be seen later, the reduced reactive reach is required to allow a relatively large resistive reach for sensitivity while retaining security against overreach due to CT and VT errors.

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.75$ per unit

$Z1MG := m \cdot |Z1Linesec|$ $Z1MG = 2.07$

$XG1 := Z1MG$ $XG1 = 2.07$

Zone 1 Resistance

The resistive reach of the Zone 1 quad should provide enough sensitivity to trip the local terminal immediately without waiting for permission from the remote terminal for a severe fault that depresses the voltage significantly. Further, it should not allow the function to reach beyond the remote terminal due to errors in relay measurement or CT or VT. If possible, it should also operate for a 100 ohm SLG 25% of the distance from the local terminal. Operation for a 100 ohm resistive fault at the 25% location will ensure this function can trip for a close in fault without assistance from the remote terminal. The remote terminal zone 1 function will be set to operate sequentially for this fault.

However, with a resistive reach of 12 ohms, the quadrilateral characteristic cannot even sense a 100 ohm SLG close in to the CBC terminal. Therefore the desired sensitivity for the P2 zone 1 function cannot be achieved. However, it can be seen that the P1 zone 1 function will operate for this fault.

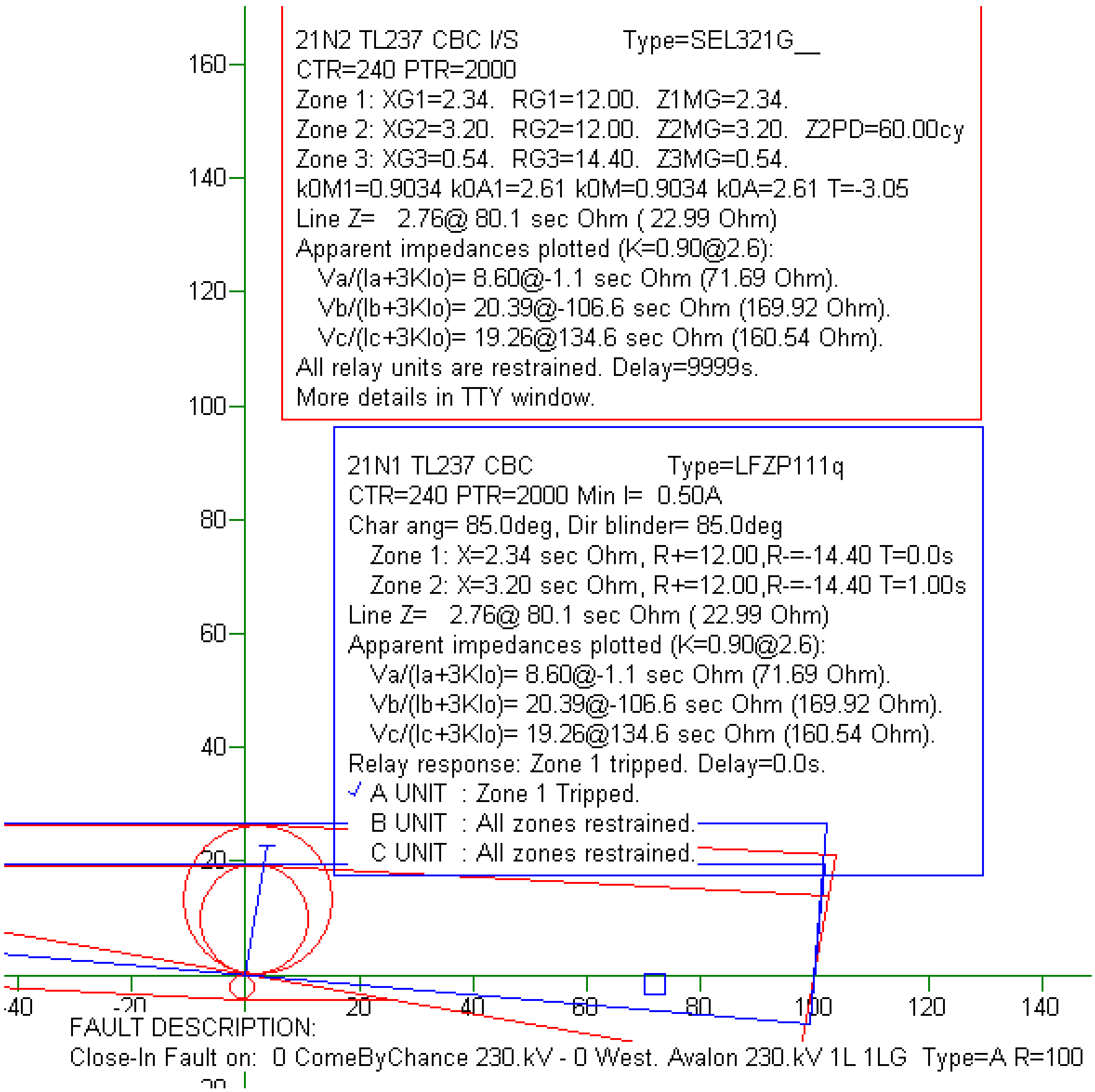


Figure 10 - CBC P1 but not P2 Zone 1 function operates for a 100 ohm SLG fault close in to the local terminal.

The existing 12 ohm secondary resistive reach of the zone 1 element will not sense this fault, and would need to be increased to 20 ohms secondary. Check whether this reach will be secure, considering possible CT and VT errors.

XG1 is set at m per unit of the transmission line. The imaginary component of this is

$ImXG1sec := Im(Z1Linesec)$ $\qquad ImXG1sec = 2.718$ ohms

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$RG1 := round[(1 - m)\cdot 20\cdot ImXG1sec, 1]$

$RG1 = 13.6$ This is the maximum secure setting for the resistive reach so the desired zone 1 resistive reach setting would not be confirmed as being secure.

Use the maximum secure setting of 13 ohms for RG1 $\qquad RG1 := 13$ ohms secondary

With a resistive reach setting of 13 ohms, the SSD Zone 1 quad element will see a 75 ohm resistive SLG fault immediately in front of the SSD terminal and gradually reducing resistance as the fault moves away from the terminal. Zone 2 protection will be depended upon to sense faults with resistance up to 100 ohms.

In spite of this poor sensitivity of the Zone 1 element, it should be noted that the 75 ohm resistive SLG will only depress the faulted phase voltage by about 10%; so this fault is not very severe on the system and communications assisted tripping (slightly slower than zone 1 communications independent tripping) should not have a significant negative impact on the system.

Zone 2 Ground Distance Protection

The Zone 2 ground distance function will need to be set longer than the Zone 2 phase distance protection function because it will tend to underreach the remote terminal while the parallel line is in service. By simulation in ASPEN OneLiner it is found that the apparent impedance to a zero ohm fault close in to the remote terminal is 3.42 ohms secondary, or 23% more than the actual line impedance. In fact, as can be seen from Figure 11, the existing setting of the zone 2 protection will not reach a zero ohm fault close to the remote terminal. The reach of the Zone 2 ground distance element should be set at least to 1.25 times the apparent impedance.

$ZSLG\_remote := 3.42$

$Z2MG := round(1.25\cdot ZSLG\_remote, 1)$ $\qquad Z2MG = 4.3$ Ohms secondary

The quad element reactive reach will be set similarly to the mho.

$XG2 := Z2MG$ $\qquad XG2 = 4.3$ Ohms secondary

The resistive reach of the quad will be increased to sense a 100 ohm resistive in the middle of the line with a good overlap of zone 2 elements from each end.

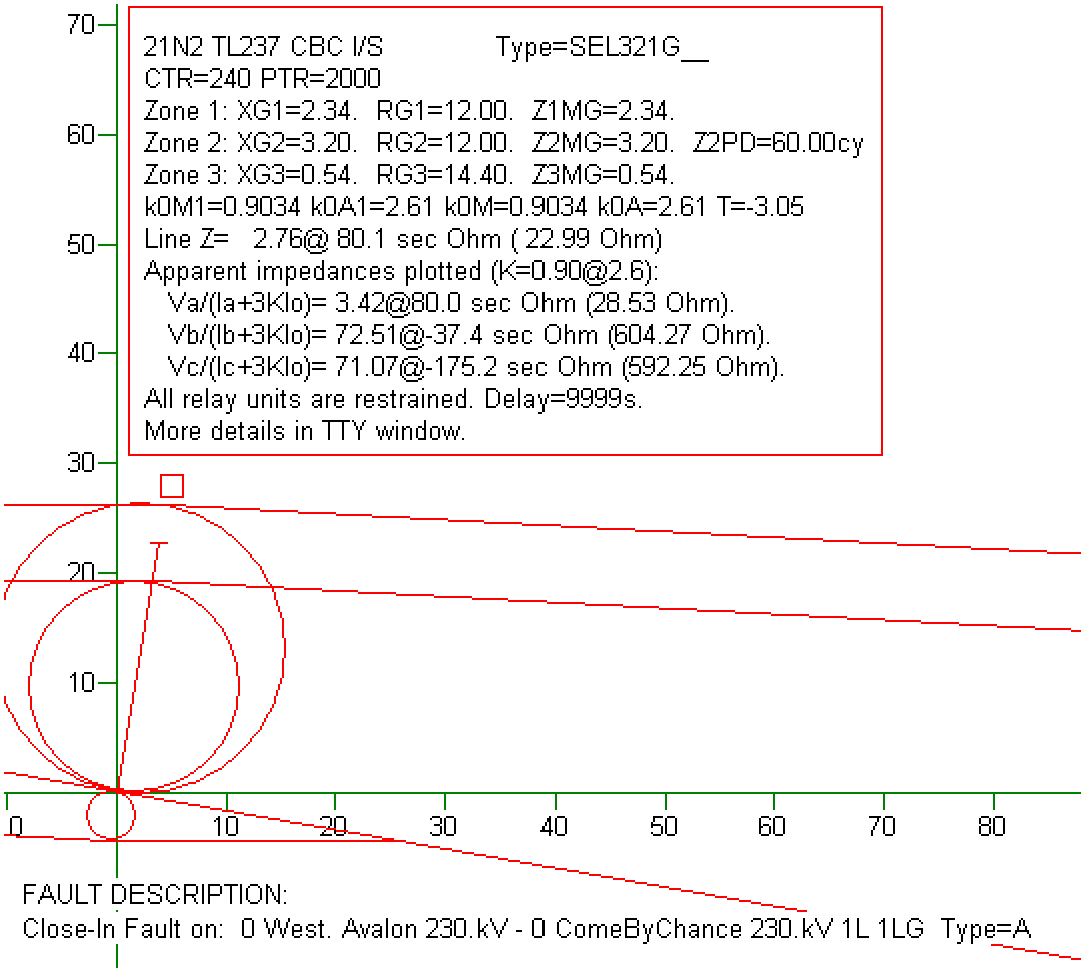


Figure 11 - Existing Zone 2 distance function is set too short to see a fault close to the remote terminal.

By trial and error from ASPEN it is found that a resistive reach of 25 ohms secondary will sense a 100 ohm SLG fault from both ends of the line between 32 to 39 percent of the distance from the CBC terminal. However since it will not overlap the Zone 1 element at the remote terminal, the permissive trip echo function will be required to ensure that a fault that is seen by the zone 2 element at only one terminal will still be cleared by the permissive trip logic.

Therefore, to avoid extremely large resistive reaches, and to retain sensitivity to 100 ohm resistive SLG faults, it is recommended that the echo function be enabled at both terminals.

The zone 2 ground distance time delay trip will need to be reduced from 60 to 18 cycles (0.3 seconds) in order to aid coordination for resistive single line to ground faults "around the loop" of TL203 TL237 and TL207 where otherwise, the ground time overcurrent functions might not have coordinated fully. Check that the Zone 2 ground distance element will not be more sensitive than the Zone 1 ground distance element on the shortest line out of SSD.

Figure 13 shows that there is no danger of the zone 2 element, even with the increased resistive reach, overreaching the zone 1 protection out of WAV. **Therefore, assuming there is not a concern with coordination with WAV transformer backup protection**, there will be no danger of miscoordination if the zone 2 ground distance function delay is reduces to 18 cycles.

$Z2GD := 18$ Cycles

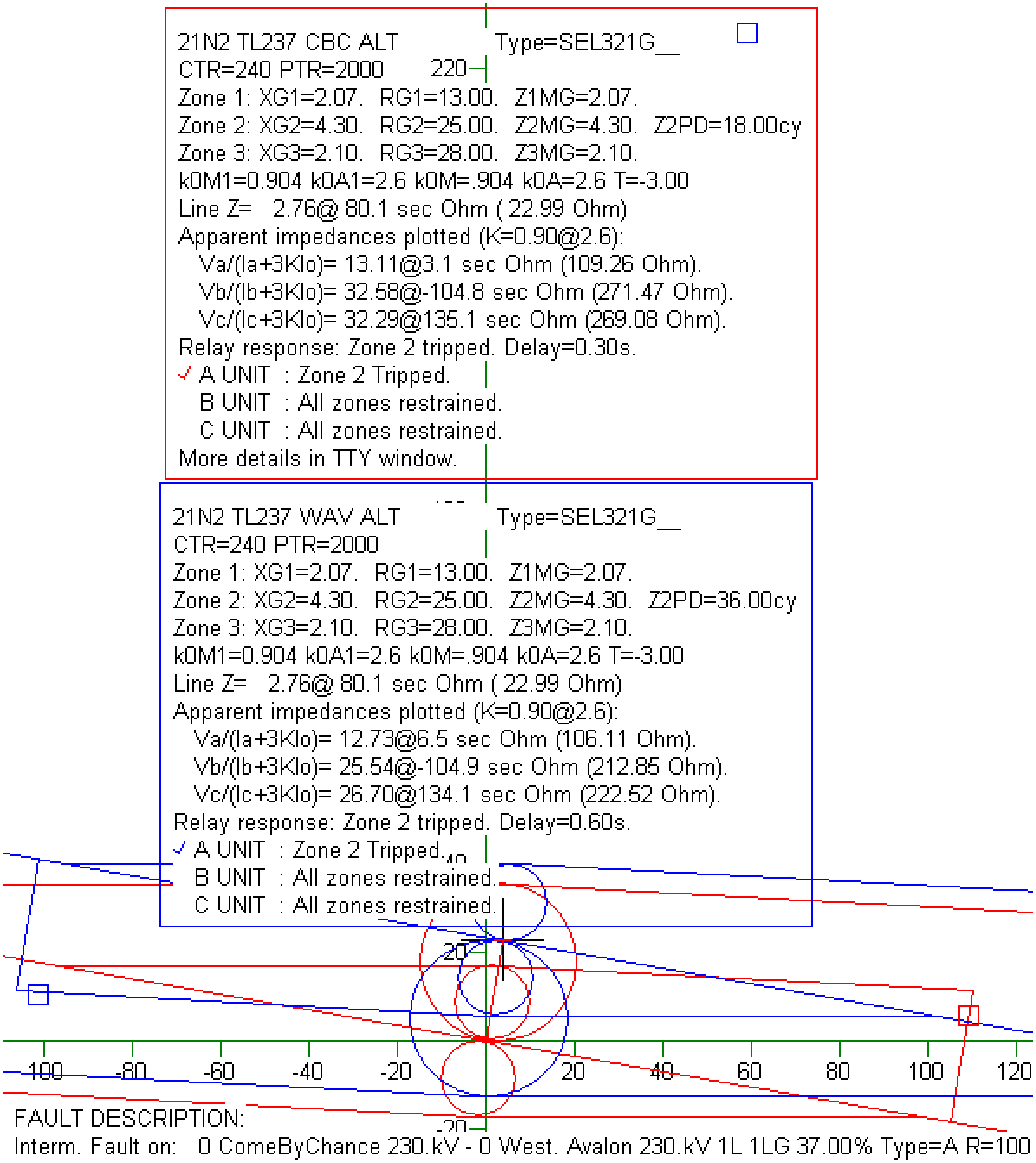


Figure 12 - Local Zone 2 Quad element operates for 100 ohm resistive SLG at 54% of the distance from the local terminal.

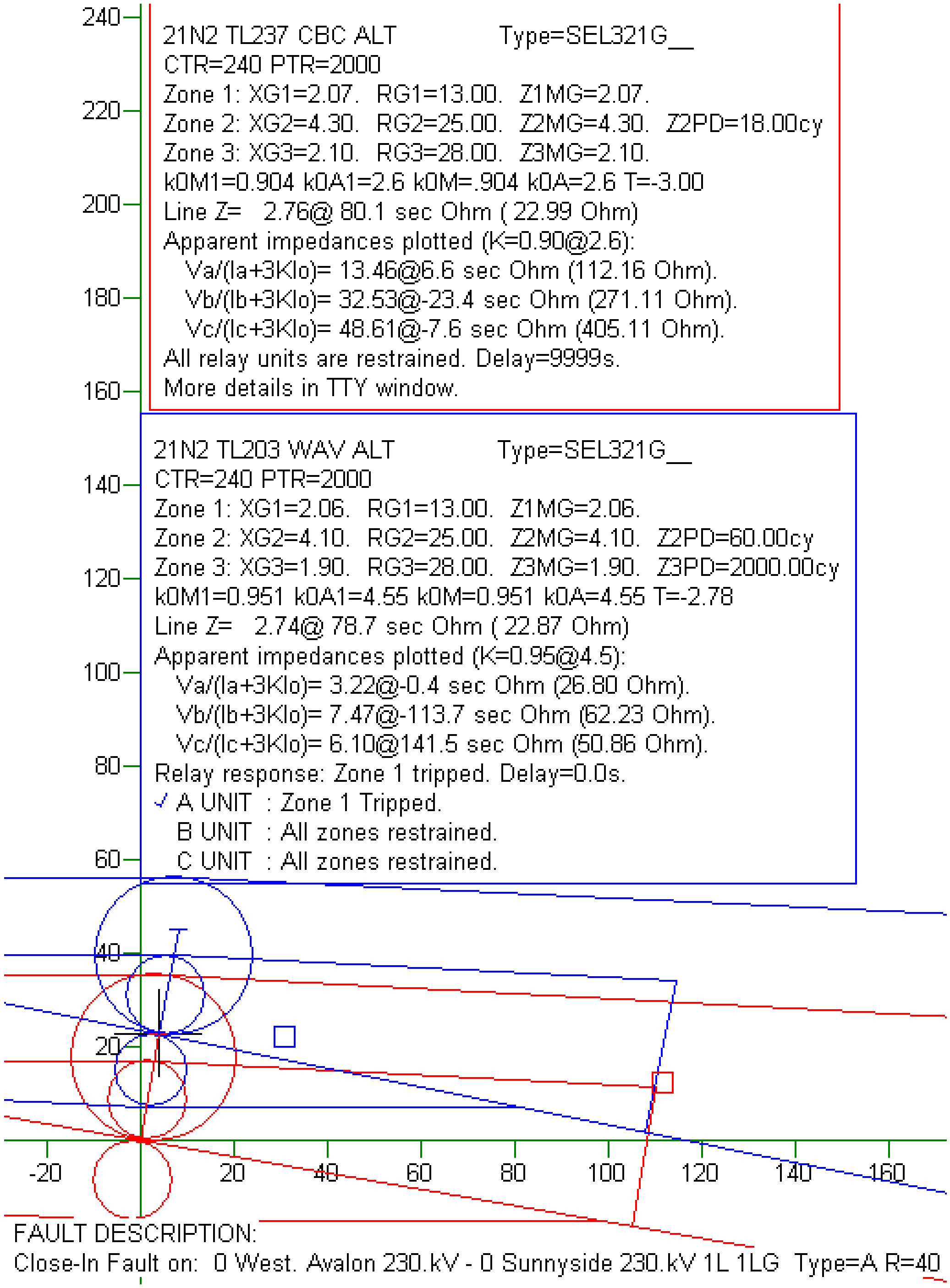


Figure 13 - Zone 2 quad with 25 ohm resistive reach will not operate for 40 ohm fault on TL203 that WAV TL203 Zone 1 sees comfortably.

Zone 3 Ground Distance Protection

The zone 3 ground mho function will be set using the same principles as the zone 3 phase distance function.

$Z2MGrem := 4.3$ ohms secondary

$$Z3MG := Z1MAG \cdot \left(\frac{Z2MGrem}{Z1MAG} - 1 + .2 \right)$$ $Z3MG = 2.1$ Ohms secondary

$$\frac{Z3P}{|Z1MAG|} = 50.464 \cdot \%$$ of line length

This is a little higher than the existing setting, but provides additional security.

$XG3 := Z3MG$ $XG3 = 2.1$ Ohms secondary

Set the Zone 3 quad resistive reach at 10% more than the remote Zone 2

$R2Grem := 30$ Ohms secondary

$R3G := \mathrm{round}(R2Grem \cdot 1.1, 0)$ $R3G = 33$ Ohms secondary

With very heavy prefault load flow (220 MVA in TL203 and 180 MVA in TL237) if TL203 trips single pole, the ground distance elements with the increased resistive reach on the P2 protection will remain secure. See Figure 14

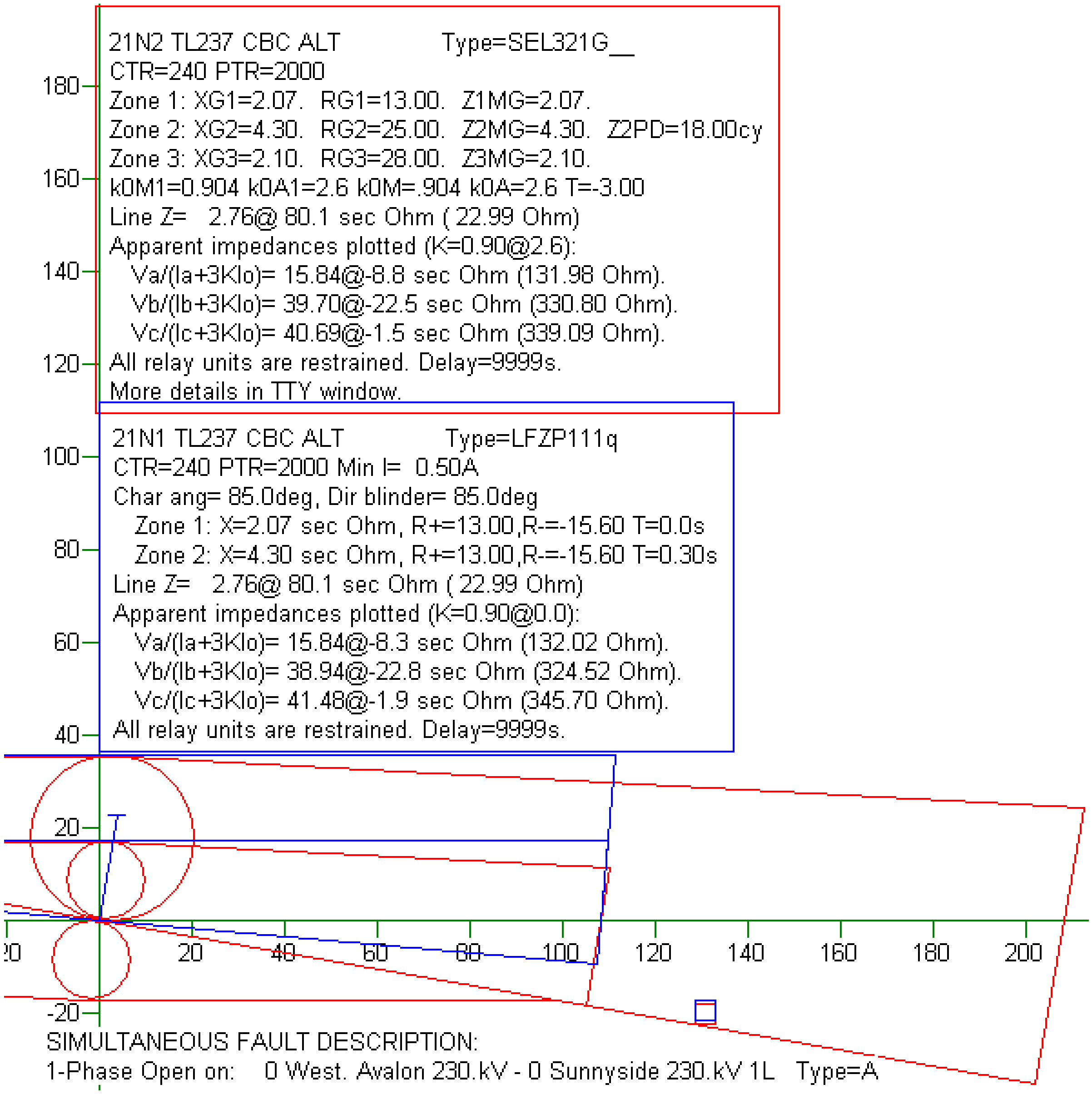


Figure 14 - Ground distance elements remain secure during heavy load flow with one phase open on TL203

The zone 2 ground distance time delay trip will need to be reduced from 60 to 18 cycles (0.3 seconds) in order to aid coordination for resistive single line to ground faults "around the loop" of TL203 TL237 and TL207 where otherwise, the ground time overcurrent functions might not have coordinated fully. A setting of 0.3 seconds is proposed to aid coordination below the WAV TL237 zone 1 ground distance protection since there is no fault current infeed at CBC to aid this coordination.

Z2GD := 18 Cycles

Zone 3 Ground Distance Protection

The zone 3 ground mho function will be set using the same principles as the zone 3 phase distance function.

$Z2MGrem := 4.3$ ohms secondary

$$Z3MG := Z1MAG\cdot\left(\frac{Z2MGrem}{Z1MAG} - 1 + .2\right) \qquad Z3MG = 2.1$$ Ohms secondary

$$\frac{Z3P}{|Z1MAG|} = 50.464\cdot\%$$ of line length

This is a little higher than the existing setting, but provides additional security.

$XG3 := Z3MG \qquad XG3 = 2.1$ Ohms secondary

Set the Zone 3 quad resistive reach at 10% more than the remote Zone 2

$R2Grem := 30$ Ohms secondary

$R3G := round(R2Grem\cdot 1.1, 0) \qquad R3G = 33$ Ohms secondary

Ground distance current supervision

Since there is no concern about these elements operating on load, even with loss of potential, set all current supervision elements at minimum, for maximum sensitivity of the distance elements.

$'50L1 := 0.5$ A Sec $\quad '50L2 := 0.5$ A Sec $\quad '50L3 := 0.5$ A Sec

$'50G1 := 0.5$ A Sec $\quad '50G2 := 0.5$ A Sec $\quad '50G3 := 0.5$ A Sec

Zero sequence current compensation

Set the zero sequence current compensation as usual.

$$k01M := \left(\left|\frac{Z0L237 - Z1L237}{3\cdot Z1L237}\right|\right) \qquad k01M = 0.904$$

$$k01A := \left(arg\left(\frac{Z0L237 - Z1L237}{3\cdot Z1L237}\right)\right) \qquad k01A = 2.611\cdot deg$$

Say $k01A := 1deg$

Set the overreaching zones the same as zone 1 $\quad k0M := k01M \quad k0A := k01A$

$k0M = 0.904 \quad k0A = 1\cdot deg$

These settings are only slightly different from the existing settings.

Non Homogenous Angle Setting

Compare the angle of the total zero sequence current at the remote bus with the angle of the zero sequence current contribution from the local terminal to determine this setting. From ASPEN OneLiner, the worst case is normal conditions. For this case, for an SLG at WAV the angle of I0 at the fault is -115 degrees and the angle of I0 out of the CBC terminal is -113 degrees. Therefore, the total fault current lags the current contribution from SSD by 2 degrees and angle T may be set at -2 and ensure no overreach. However, because this is such a short line, the angle T should be set at the default angle of -3 degrees for extra security.

$T := -3$ degrees

Out of step blocking and tripping

Not used in this application. There is a danger of out of step conditions arising. Historically no action has been taken to provide special tripping or blocking functions. Natural tripping during swings is accepted.

Load Encroachment logic

Check loadability of the Zone 2 phase distance element assuming worst case power factor of 0.87 simultaneous with worst case depressed voltage of a stressed system of 0.9 per unit. Note that units of kV squared match units of MVA. Note that quadrilateral elements are only used for the ground distance functions that are not sensitive to balanced three phase load. Therefore no need to worry about the reach of the quadrilateral elements.

$$\mathrm{Zloadmin} := \frac{(0.9\mathrm{kVbase})^2}{\mathrm{Smax}} \qquad \mathrm{Zloadmin} = 176.406$$ Ohms primary (assume worst case at 30 degrees)

Maximum reach of the Zone 2 element is at the line angle of 81 degrees. At 30 degrees, the reach will be given by

$$\mathrm{Z2load} := \mathrm{Z2P}\cdot\cos[(\mathrm{Z1ANG} - 30)\mathrm{deg}] \qquad \mathrm{Z2load} = 2.31$$ ohms secondary

$$\mathrm{Z2load}\cdot\frac{\mathrm{VTR}}{\mathrm{CTR}} = 19.247$$ ohms primary

Since the reach of the Zone 2 element at 30 degrees is less than the apparent impedance of the maximum load, there is no need to apply load blinding logic. See Figure 15

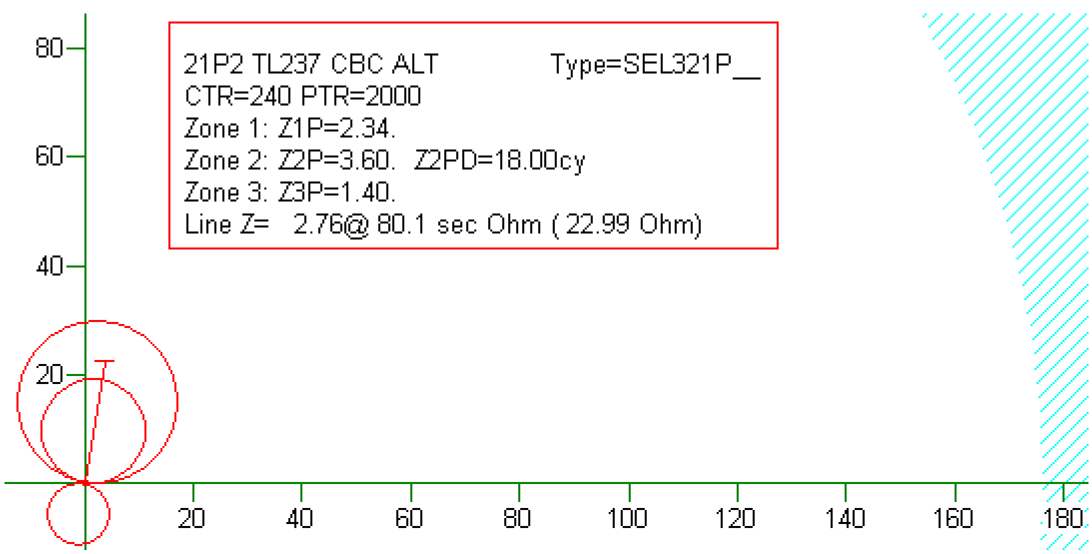


Figure 15 -Load impedance with respect to proposed new Mho function reaches.

Ground directional element

The SEL-321 application example recommends finding the minimum source impedance behind the terminal and setting the reverse and forward boundaries of the negative sequence directional element at the 1/3 and 2/3 points respectively.

In the negative sequence plane, the sum of the two source impedances and the line impedance is:

$Z2total := Z2minCBC + Z1L237pri + Z2minWAV$ $\qquad |Z2total| = 76.28$

The 1/3 point is $Z2\_1\_3 := \dfrac{Z2total}{3}$ $\qquad$ The 2/3 point is $Z2\_2\_3 := \dfrac{2Z2total}{3}$

$Z2Rpri := Z2\_2\_3 - Z2minCBC$ $\qquad |Z2Rpri| = 23.524$ $\qquad |Z1L237pri| = 22.995$

$Z2Fpri := Z2\_1\_3 - Z2minCBC$ $\qquad |Z2Fpri| = 1.967$ $\qquad |Z2minCBC| = 27.339$

$|Z2minWAV| = 25.984$

Converting the primary impedances to secondary ohms

$Z2R := Z2Rpri \cdot \dfrac{CTR}{VTR}$ $\qquad |Z2R| = 2.823$ Ohms secondary $\qquad arg(Z2R) = 81.646 \cdot deg$

$Z2F := Z2Fpri \cdot \dfrac{CTR}{VTR}$ $\qquad |Z2F| = 0.236$ Ohms secondary $\qquad arg(Z2F) = -83.023 \cdot deg$

Rounding up Z2F (note that Z2F is negative) and rounding down Z2R gives:

$Z2F := 0$ Ohms secondary $\qquad Z2R := 2$ Ohms secondary

The proposed Z2F is close to existing, and Z2R is a little lower than existing.

Set the current level detectors at minimum level that will allow operation of the ground distance elements.

Due to the very small zero sequence current contribution to a single line to ground fault at the remote terminal, the negative sequence current contribution will always be higher than the zero sequence. Therefore there is no point in setting the forward looking negative sequence overcurrent elements any more sensitively than the zero sequence ground overcurrent supervision of the ground distance elements.

$'50QF := '50G2$ $\qquad '50QF = 0.5$ A secondary

Set the supervision function for the reverse looking element to be the same as, or a little more sensitive than the forward looking supervision element at the remote terminal.

$'50QR := 0.5$ A secondary

The positive sequence current restraint (a2) factor should be set just smaller than the ratio of the maximum load current (positive sequence) to the most sensitive current supervision element (50QR).

$I1maxpri := \dfrac{Smax \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\qquad I1maxsec := \dfrac{I1maxpri}{CTR}$ $\qquad I1maxsec = 2.541$

Bearing in mind that the 50QR setting is in units of 3*I2

$\dfrac{'50QR}{3 \cdot I1maxsec} = 0.066$ $\qquad$ Choose a value of $a2 := 0.07$

This a2 factor is lower than existing setting because of higher maximum load current used.

Phase time overcurrent element

This element is not used

Residual time overcurrent element

This element is used to provide the most sensitive backup protection. It will be a directional element. Minimum pickup needed to sense a higher resistance than 100 ohm SLG near the CBC terminal. Choose 200 ohm arbitrarily. Choose a desensitization factor of 2 to reflect half the total fault current coming from each end.

$SF := 2$ Desensitization factor due to remote end infeed is $Dfactor := 2$ $Rf := 200$

$$'51NPU := \mathrm{round}\left(\frac{kVbase\cdot 1000}{\sqrt{3}\cdot SF\cdot Dfactor\cdot Rf\cdot CTR}, 1\right) \qquad '51NPU = 0.7$$

The existing setting of 0.5 A is more sensitive than required to sense this fault with arbitrary resistance. However, we need speed and sensitivity at this terminal. Therefore it will be retained.

$'51NPU := 0.5$ A secondary

Coordination checks show that existing time dial settings around the loop TL203, TL237 and TL207 (counter clockwise) will not coordinate, because the CBC TL237 relays time dial setting is too high. Therefore if there is a fault on TL237 that has to be cleared by the ground time overcurrent relay at CBC, the SSD TL207 will not coordinate. Therefore the existing time dial settings on CBC TL237 have to be adjusted. The ground distance elements will speed up tripping for faults with resistance up to 150 ohms fed from one end, where ground relay coordination is challenged), so coordination will be checked for faults with resistance of 150 ohms or more. Trial and error checks show that in order to achieve coordination, the existing time dial setting of CBC TL237 ground time overcurrent relay will have to have its time dial settings reduced from existing 4 to 3. The SSD terminal of TL207 already has a suitable pickup of 0.6 A sec.

Check the coordination with the other relays for three faults (all with 150 ohm resistance). Line end TL237, Close in to CBC on TL237 and 89% from WAV on TL203 (at the end of the mutually coupled section). See Figure 16 to find that existing settings (curves 2&3) do not coordinate, and Figures 16, 17 and 18 to find that Curve 3 and revised curves 4 and 5 settings will coordinate.

$'51NPU = 0.5$ A secondary $'51NPU\cdot CTR = 120$ A primary

$'51NTD := 3$ $'51NC := "U3"$ $'51NTC := "N"$ $'51NRS := "N"$

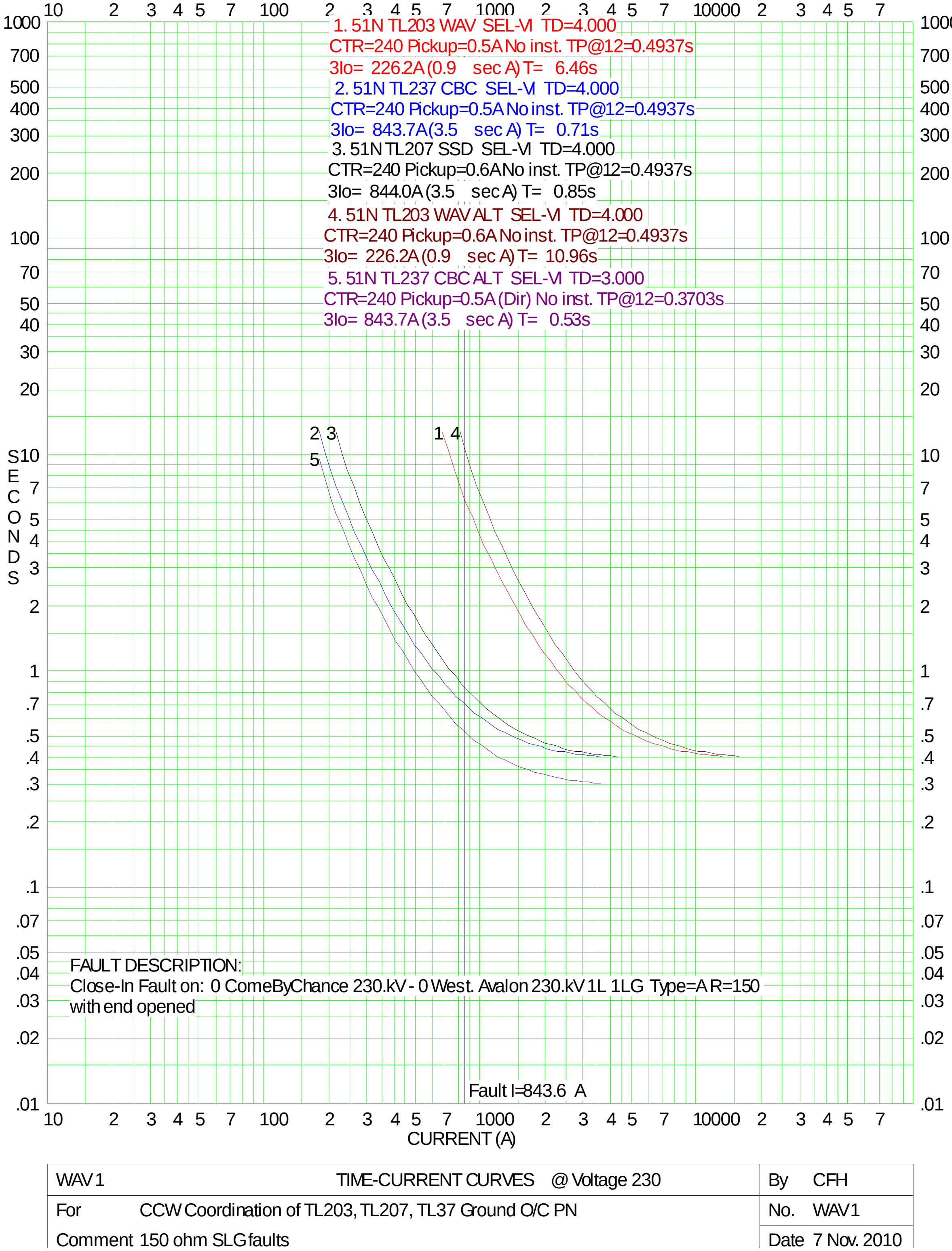
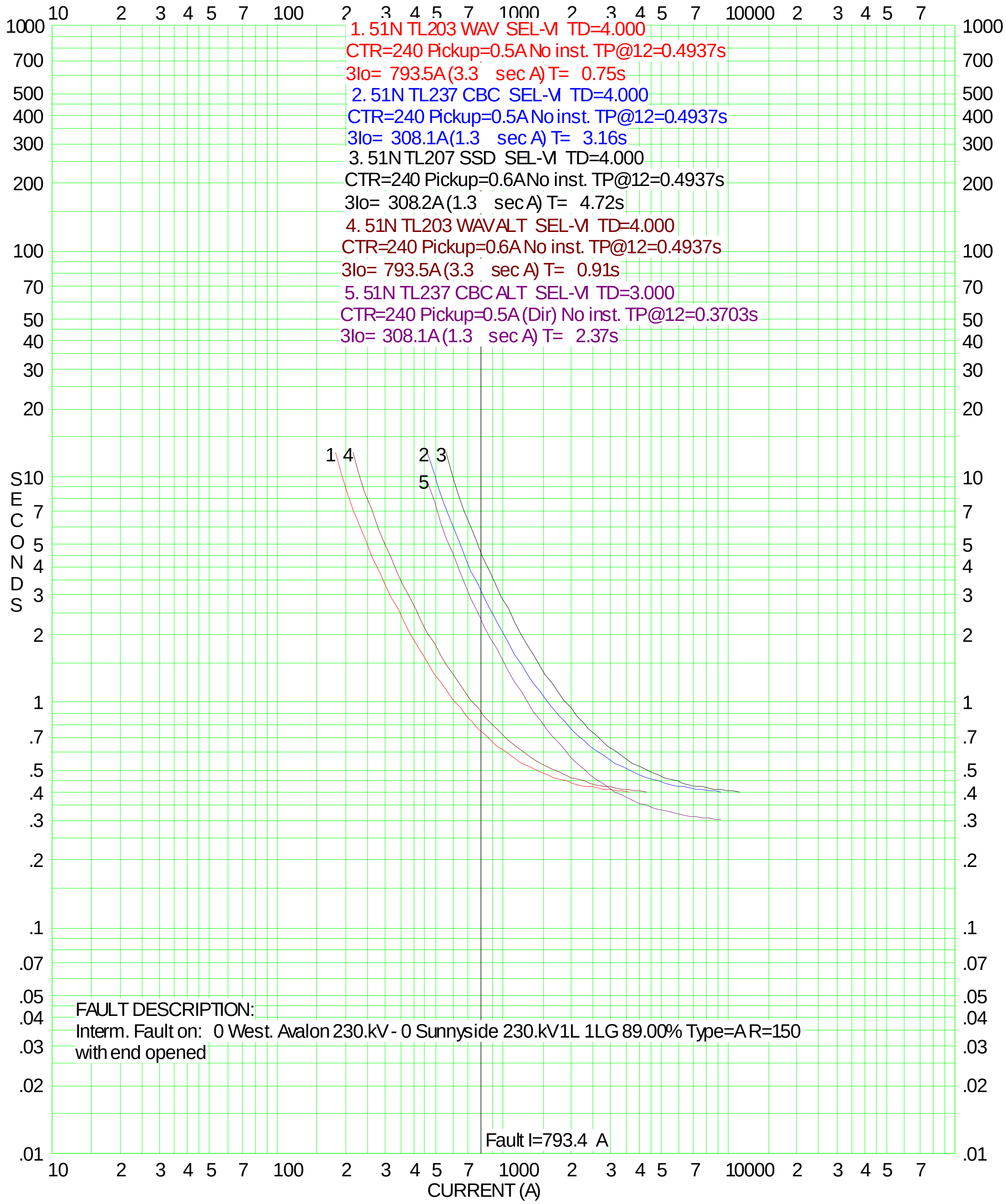
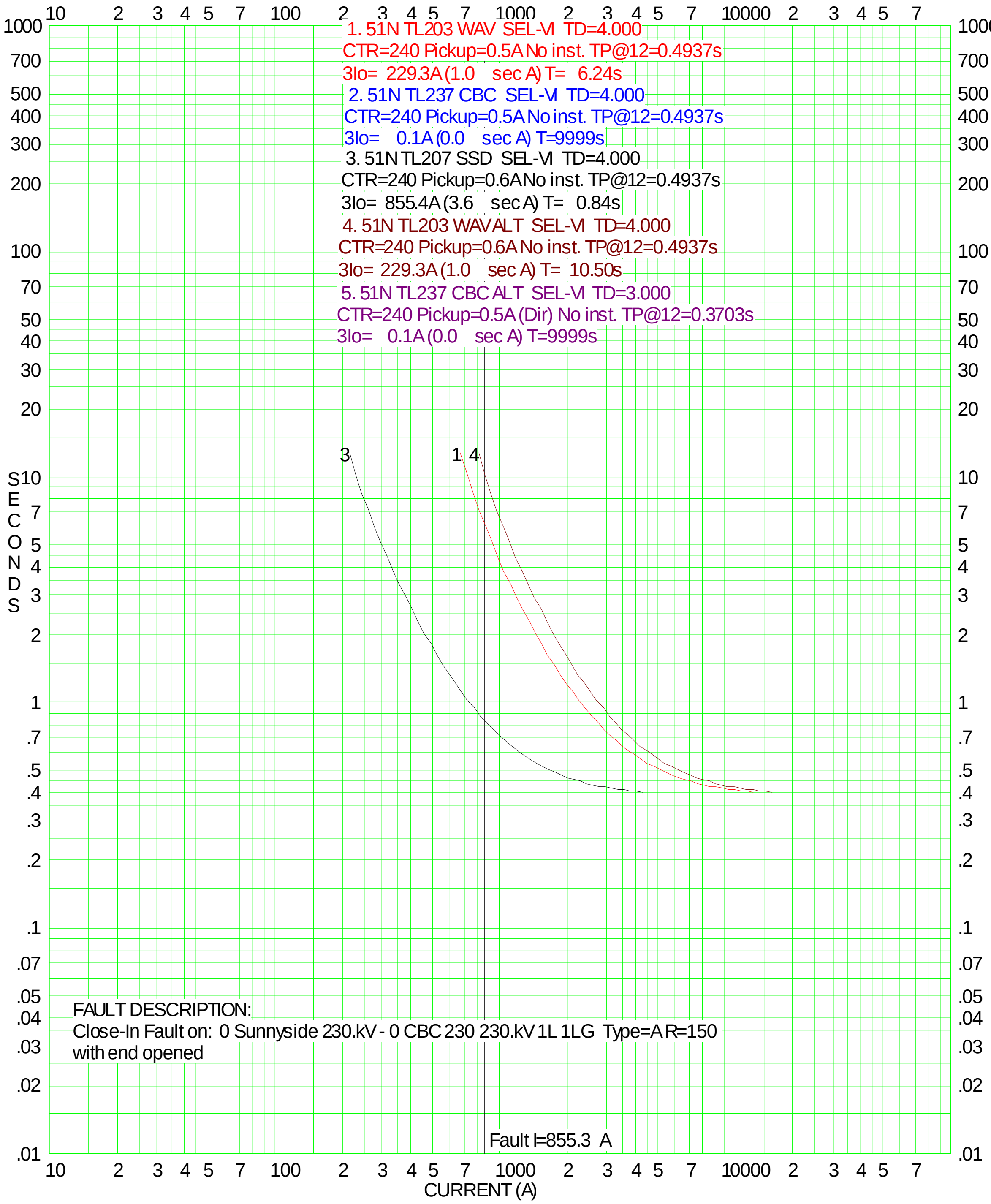


Figure 16 - coordination of ground time overcurrent elements for close-in fault on TL237 close to CBC



WAV 2	TIME-CURRENT CURVES @ Voltage 230	By CFH
For CCW Coordination of TL203, TL207, TL37 Ground O/C PN		No. WAV2
Comment 150 ohm SLG faults		Date 7 Nov. 2010

Figure 17 - coordination of ground time overcurrent elements for fault 89% on TL203 from WAV with SSD terminal open.



WAV3	TIME-CURRENT CURVES @ Voltage 230	By CFH
For	CCW Coordination of TL203, TL207, TL37 Ground O/C PN	No. WAV3
Comment 150 ohm SLG faults		Date 7 Nov. 2010

Figure 18 - coordination of ground time overcurrent elements for close in fault on TL207 at SSD with CBC terminal open.

Permissive Overreaching logic settings

EPOTT := "Y"

Z3RBD is set at remote breaker time plus channel reset time plus channel reset time plus zone 2 reset time. From review of fault records it appears that the breaker time is 3 cycles. Channel reset time is not easily determined from existing records but can conservatively be assumed to be 1 cycle, and relay reset time will also be about 1 cycle. Total time for Z3RBD is then 5 cycles.

Z3RBD := 5 cycles

Echo block delay timer blocks the echo after the local elements have picked up. This can be set relatively long since there is no significant need for the echo function shortly after the local terminal has just seen a fault but the remote terminal has not. Set at 10 cycles as per the example in the instruction manual.

EBLKD := 10 cycles

Echo time delay on pickup should be set to override noise on the communications so that it doesn't echo noise. Typical time according to the SEL application guide is 2 cycles. Since this delay only affects clearing time for relatively light (high resistance) faults that are sensed by zone 2 function at one end, the typical setting is acceptable.

ETDPU := 2 cycles

Echo duration should be long enough to ensure the permissive trip is received by the remote terminal and should also be shorter than the Z3RBD time to ensure that the reverse blocking will always be longer than any permissive trip received (including echo time stretching).

EDURD := 4 cycles

No need to enable week feed conversion to trip, since both terminals will be quite sensitive enough to detect high resistance faults after the remote terminal has cleared. Therefore we can accept sequential (or "step") clearing with no need for the added insecurity of weak infeed tripping.

EWFC := "N" **No other communications logic settings are required for this application.**

Switch on to Fault Settings

Switch on to fault logic will ensure the protection will operate when energizing the line onto a close-in three phase fault when there is no polarizing voltage available for the distance elements.

ESOTF := "Y"

The breaker close signal is not available to the relay. The 52A method of enable SOTF will be used. Therefore the Close end delay is not critical. Typical duration for enable SOTF is 10-15 cycles

ENCLO := "N" CLOEND := 0 EN52A := "Y" SOTFD := 15

Set 50H for high magnitude close-in multiphase faults with weakest source at CBC. It should be set less than 50% of the minimum close-in fault magnitude. Minimum close-in magnitude of a three phase fault with TL203 out of service is 2600 A. Therefore desired maximum setting for 50H is 1300 A. This is lower than existing.

Imin3P_close_in := 2600

$$'50H := \frac{Imin3P\_close\_in}{2CTR} \qquad '50H = 5.417 \text{ A secondary}$$

Choose a setting of 4 A secondary for this element. With a single CT on this breaker, there is no concern about CT saturation for an external fault through CTs on a ring bus.

'50H := 4 A secondary

Choose a setting for 52AEND less than the shortest reclose time. '52AEND := 30 cycles

Residual overcurrent settings.

Tripping directly by instantaneous ground overcurrent is not applicable because the zone 1 ground distance is more selective. However it would be helpful to monitor steady state unbalance, and issue an alarm for continuous unbalance. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50N := 1$ $'50N1 := 0.25$

Negative Sequence overcurrent settings.

Similar to ground overcurrent, apply a negative sequence overcurrent element to initiate an alarm for steady state unbalances. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50Q := 1$ $'50Q1 := 0.25$

Voltage Element Settings

Similar to unbalance current monitoring, it is helpful to have an unbalance voltage monitor to detect steady state unbalances from the voltage supply.

$EVOLT := "Y"$

Set the zero sequence overvoltage element at 1% of rated voltage or just at the point necessary to override normal unbalances. The zero sequence voltage element measures 3 times the zero sequence voltage.

$'59N := 3 \cdot 0.01 \frac{kVbase \cdot 1000}{\sqrt{3} \cdot VTR}$ $'59N = 1.992$ Say $'59N := 2$ V secondary

Loss of Potential

Enable loss of potential settings. Advanced LOP settings are not available on this model of relay.

$ELOP := "Y"$ Time delay of 1.25 cycles is commonly used. $LOPD := 1.25$

The 50 M element should be set above maximum load and below minimum fault current for a fault at the remote terminal under weak source conditions. The maximum load for this case should be normal maximum, not emergency maximum which only exists for a few minutes before the operator can act to reduce load.

$Imax\_normal := \frac{Speak\_237 \cdot 1000}{\sqrt{3} \cdot kVbase \cdot CTR} = 1.154$ A secondary

Minimum fault current for a remote three phase fault is $I3Pmin = 730$ A primary.

Minimum fault current for a remote phase to phase fault is 87% of the minimum three phase fault current level.

Dependability factor to be sure to operate for a minimum remote fault is chosen to be 1.6. $DF := 1.6$

Maximum setting for 50M should be $\frac{0.87 I3Pmin}{DF \cdot CTR} = 1.654$ In this case a setting of 1.5 A secondary will be adequately dependable and secure.

$'50M := 1.5$ A secondary

The 59QL setting should be above normal maximum unbalance and below the level expected for a blown VT fuse. For a blown fuse, one phase voltage will be lost, and the negative sequence voltage will be roughly 33% of the nominal positive sequence voltage. Choose a setting of 15% of the nominal positive sequence voltage. This will be well above any normal unbalance.

$$'59QL := \mathrm{round}\left(\frac{0.15 \cdot kVbase \cdot 1000}{\sqrt{3} \cdot VTR}, 0\right) \qquad '59QL = 10 \text{ V secondary}$$

The 59PL setting should be less than the minimum voltage to be expected for a remote bus fault under weakest source conditions. There is no minimum setting (above zero) for this function. Choose a setting equal to half the voltage drop along the line impedance at the pickup setting of the 50M element.

$$'59PL := \mathrm{round}[0.5 \cdot ('50M \cdot |Z1Linesec|), 0] \qquad |'59PL| = 2$$

Miscellaneous Scheme Settings

Pole discoordinance logic is not being used. EPOLD := "N" SPPDD := "N/A"

Enable single pole tripping by distance elements only ESPT := "Y"

Enable single pole open ESPO := "Y"

Set single pole open time delay for future SPO conditions SPOD := 0.25

3 Pole open reset delay to override small discrepancies in pole closing '3POD := 0.5

Stub line protection is not required ESTUB := "N" '50MFD := "N/A"

Trip unlatch logic not applied TULO := "N"

Logic variables and Miscellaneous timers

Minimum trip duration timer is set at 9 cycles as per the application example in the SEL-321 instruction manual.

TDURD := 9 Cycles

Trip during open pole time delay should be set longer than the reclose time. Existing setting is OK.

TOPD := 55 Cycles

Retain existing settings except use time ZT to trigger an alarm for sustained unbalance.

LOGIC_Z := "59N+50N1+50Q1" TZPU := 1200 cycles TZDO := 0 cycles

Tripping Logic

Permissive tripping is required only for instantaneous overreaching functions. No need for any functions that trip directly. Existing 51NT word in MTCS is not required.

MTCS := "M2P+Z2G"

Unconditional tripping MTU := "M1P+Z1G+M2PT+Z2GT+51NT"

No need for existing direct tripping zone 1 functions in the switch on to fault logic.

The revised tripping logic includes the timer YT to add a 1 cycle delay to the zone 1 tripping elements.

SOTF Tripping MTO := "M2P+Z2G+50H"

Event records will be triggered automatically by all trip events. Other event record triggers should be by starting of other elements to ensure capture of all relevant events. Events should be triggered by keying or receiving permissive trips to ensure separation of relay and teleprotection issues.

MER := "M2P+Z2G+51N+LOP*52AA1+LOP*52AA2+KEY+PT+EKEY"

Outputs

Retain existing output assignments except add the continuous unbalance alarm to OUT15.

OUT15 := "LOP*50L+ZT"

Input Contact Assignment

Retain existing input assignments.

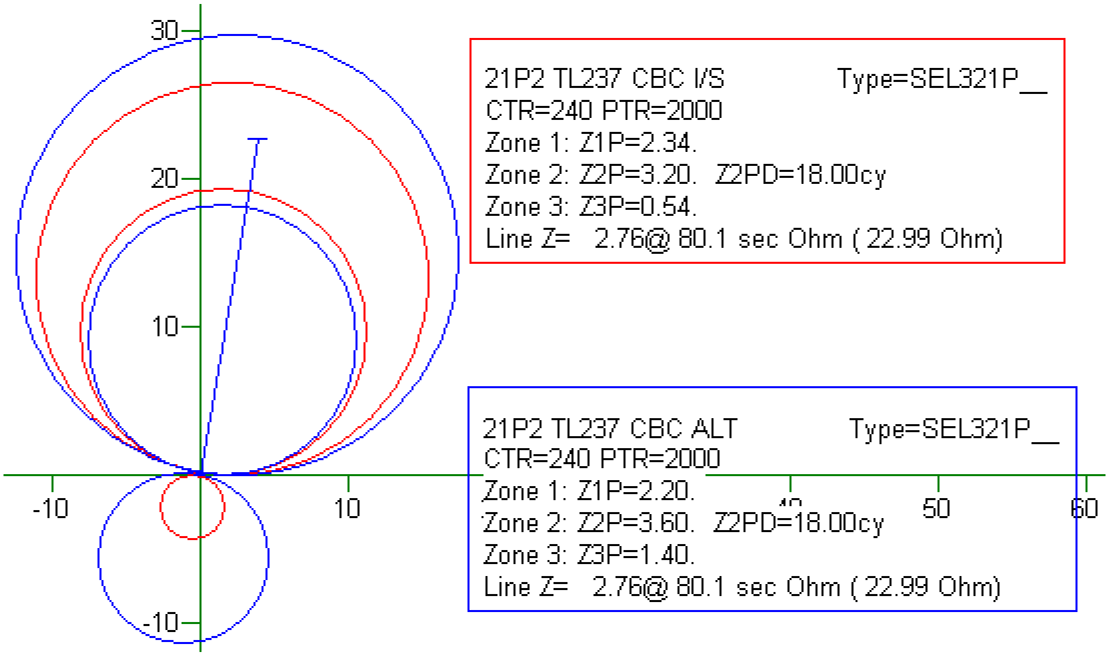


Figure 19 - Comparison of phase distance characteristics. Red is existing, blue is proposed alternative

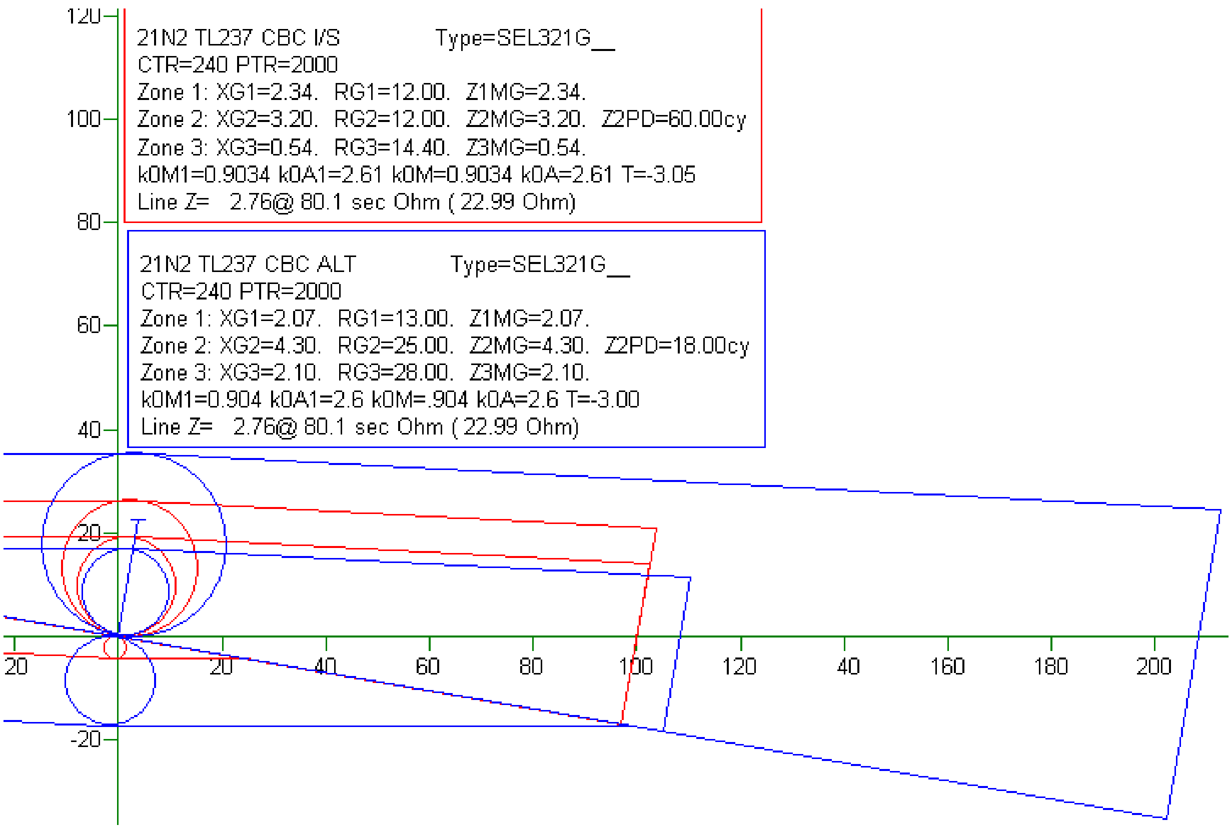


Figure 20 - Comparison of ground distance characteristics. Red is existing, blue is proposed alternative

Protection Review for Five 230 kV Transmission Lines

Appendix Q
Detailed settings review for WAV TL237 "P1" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Western Avalon (WAV) terminal of circuit TL237 . This 230 kV transmission circuit is from Sunnyside (SSD) to Western Avalon (WAV)
The circuit runs parallel to TL203 for 88% of its length.

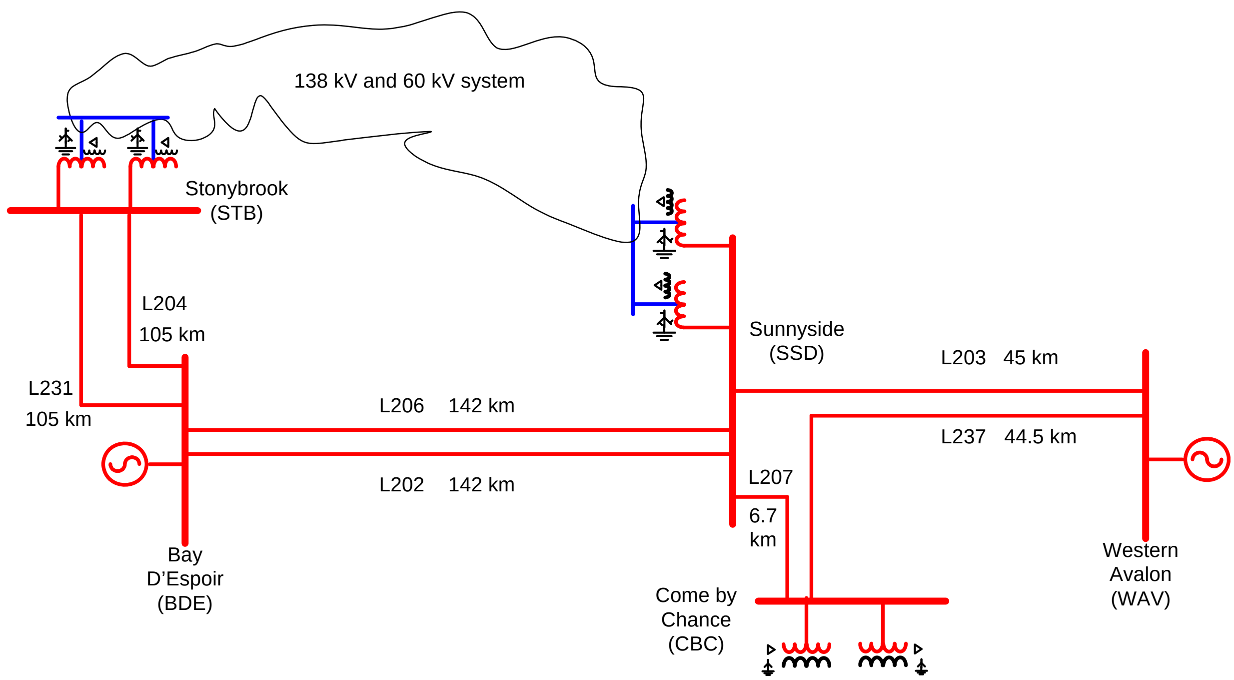


Figure 1 - System Single Line Diagram

Existing P1 protection systems are Areva LZFP111 (Optimho) systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $\qquad kVbase := 230$ $\qquad Ibase := \frac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\qquad Zbase := \frac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $CTR := \frac{1200}{5}$ $\qquad$ VT ratio is: $VTR := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**Hydro Interconnected System (2010-08-13) V10.olr**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with all shunts ignored (unless needed for load flow simulation).

Minimum fault current seen by each terminal (phase to phase, and SLG with 100 ohm fault resistance).

With TL217 out of service, for a fault near CBC

$IPPmin := 941$ $ISLGminPH := 315$ A $ISLGmin0seq := 326$ A

The optimho current level detectors that block the distance comparators in the event of line opening are fixed at 5% of the rated current, or 0.25 A secondary, or 60 A primary. They will have no difficulty in operating for normal fault levels. However, the ground distance elements are also supervised by a low set neutral current level detector (LDLSN that requires the neutral current to be greater than 10% of the maximum amplitude of phase difference current. This prevents the ground comparators from operating during close-in multiphase faults with CT errors. ASPEN OneLiner shows that for a bolted fault at the remote bus even under heavy load, there is sufficient neutral current (22% of maximum phase to phase fault current) that means this LDLSN function does not inhibit the ground distance comparator.

Calculate the minimum negative sequence source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind WAV $Z2minWAV := 2.64 + j \cdot 25.85$ ohms primary

Minimum um source impedance behind CBC $Z2minCBC := 2.94 + j \cdot 27.18$ ohms primary

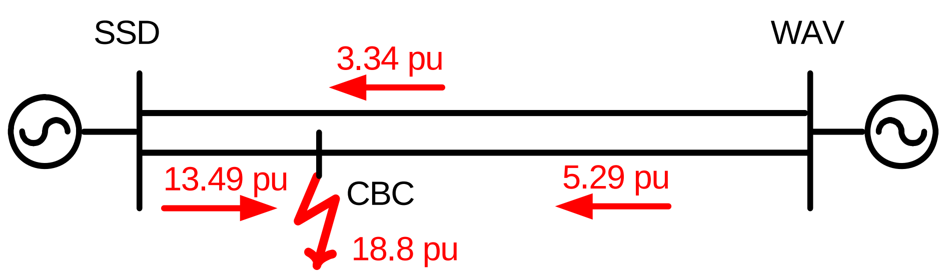


Figure 2 - 3 Phase Fault at CBC

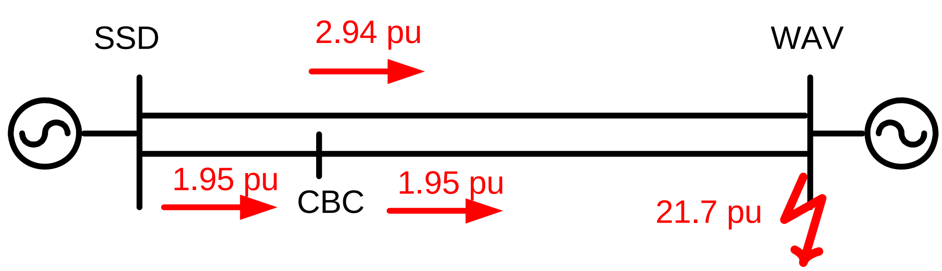


Figure 3 - 3 Phase Fault at WAV

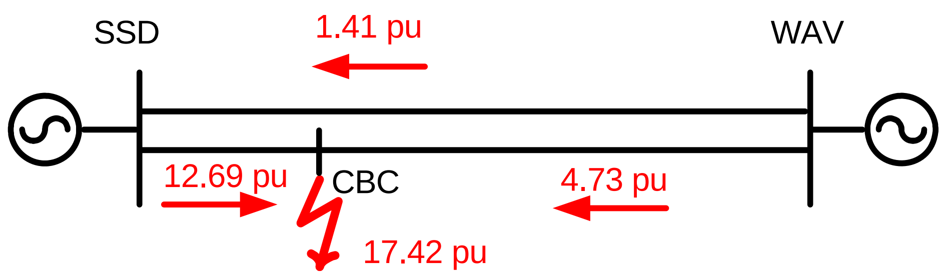


Figure 4 - SLG Fault at CBC (3I0 currents)

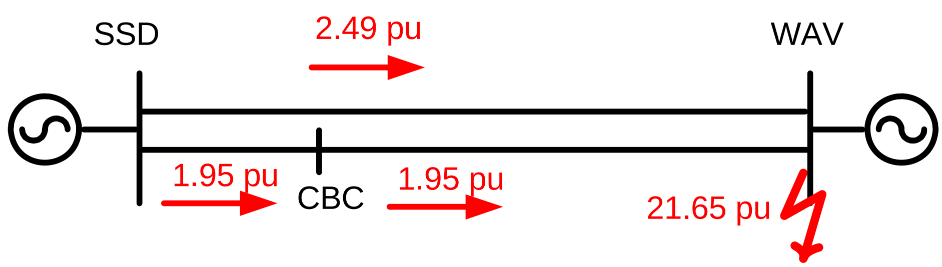


Figure 5 - SLG Fault at WAV (3I0 currents)

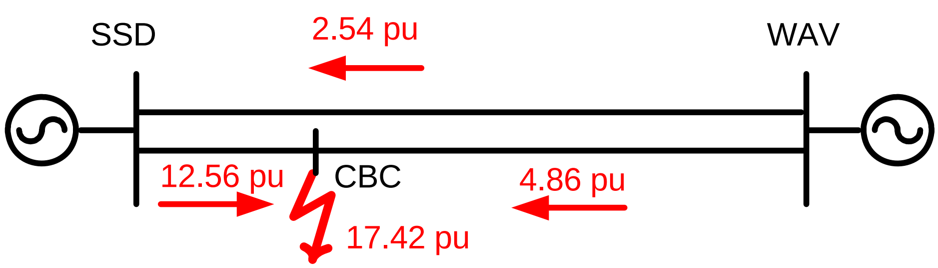


Figure 6 - SLG Fault at CBC (Phase currents)

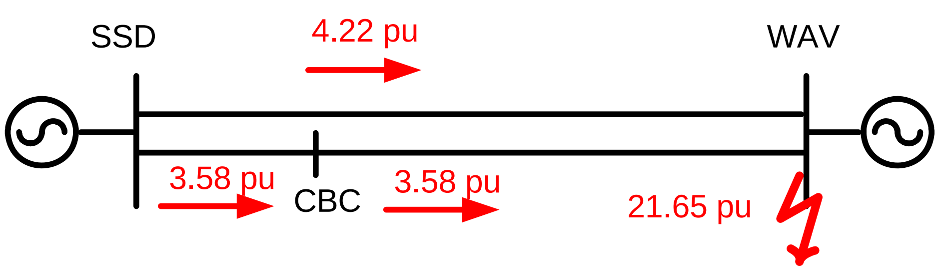


Figure 7 - SLG Fault at WAV (Phase currents)

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L237 := 0.00748 + j \cdot 0.04282$ $\quad$ $Z0L237 := 0.02245 + j \cdot 0.15972$

In primary ohms

$Z1L237pri := Z1L237 \cdot Zbase$ $\quad$ $Z0L237pri := Z0L237 \cdot Zbase$

In secondary ohms

$Z1Linesec := Z1L237pri \cdot \frac{CTR}{VTR}$ $\quad$ $Z0Linesec := Z0L237pri \cdot \frac{CTR}{VTR}$

$|Z1Linesec| = 2.759$ $\quad$ $arg(Z1Linesec) = 80.091 \cdot deg$

$|Z0Linesec| = 10.239$ $\quad$ $arg(Z0Linesec) = 81.999 \cdot deg$

These impedances match the existing settings in the P2 relay no need for changes.

Zero sequence mutual coupling between TL237 and TL203 is $\quad$ $Z0m := 0.0132 + j \cdot 0.0697$

Load Data

From 2010 System peak load case provided in start up information, the peak load is given as 110.3 MVA (with TL203, TL207 and TL237 in service). The load in TL203 is 132.6 MVA. In the event of sudden loss of TL203. Peak load in TL207 will increase to take up the lost load through TL203. Thus the peak load in TL207 will be slightly more than double until operators can adjust loads.

$Speak\_237 := 110.3$ MVA $\quad$ $Speak\_203 := 132.6$ MVA

$Smax := Speak\_203 + Speak\_237 = 242.9$ MVA

P1 Relay Settings

Distance element reach settings

Note that resistive reaches are forced to be the same for all zones. Reactive reaches for phase and ground distance elements must be the same as each other.

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if the line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the CBC Station bus under weak source conditions with TL217 out of service and all of TL203, TL207 and TL237 lines in service. From ASPEN OneLiner, voltage at WAV for a 3 phase fault at CBC is 0.185 per unit. So there is less than 20% voltage at CBC during a fault at WAV under weak source conditions.

Since the voltage is not higher than 20%, the line is considered short, and a reduced Zone 1 setting is recommended to provide more security. Initially, try to choose a setting of 80% of nominal.

$Z1P := \mathrm{round}(0.8 \cdot |Z1Linesec|, 1)$ $Z1P = 2.2$ Ohms secondary

Existing setting of 2.34 ohms is a little high, and should be reduced especially as the ground distance function will be subject to a little overreach if TL203 is out of service and grounded at both ends. The ground distance reach in the optimho has to be set the same as the phase distance reach; so we need to consider the ground faults too.

The reach of the ground distance element will limit the reach of the zone 1 function. It can be seen from Figure 8 that the apparent impedance presented to the relay for a fault at the remote bus when the parallel line is out of service and grounded at both ends is less than the line impedance.

$Zapp\_ext := 2.44$ ohms $Zapp\_ang := 80.6deg$ This angle is close enough to the line angle to treat it as equal to the line angle.

$\frac{Zapp\_ext}{|Z1Linesec|} = 0.884$ The apparent impedance is reduced by about 12% due to the effect of the parallel line being out of service and grounded at both ends.

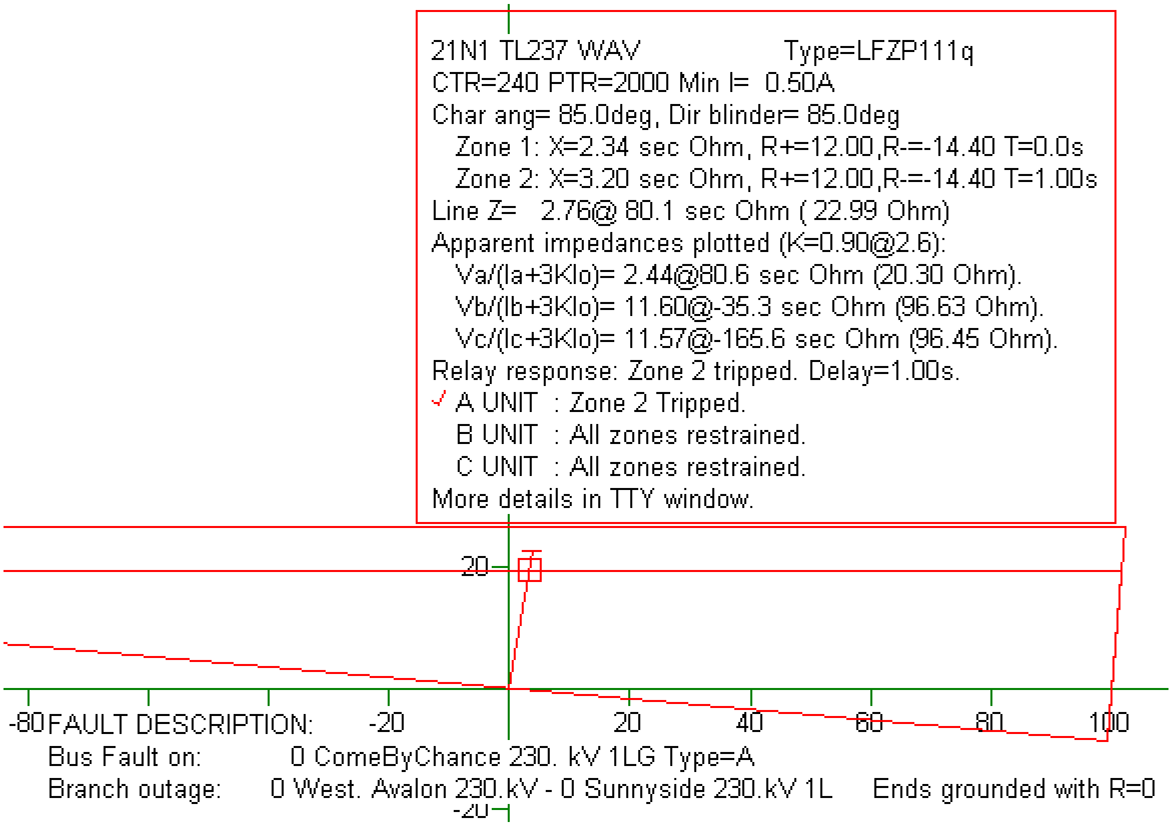


Figure 8 - Apparent impedance to a fault just beyond the remote terminal is reduced by 12% when parallel line is out of service and grounded at both ends.

The normal reach of the zone 1 should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Choose a setting of 75% of the line impedance, which is lower than the setting required to make the zone 1 element more secure for faults beyond the end of this short line. Note that as will be seen later, the reduced reactive reach is required to allow a relatively large resistive reach for sensitivity while retaining security against overreach due to CT and VT errors.

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.75$ per unit

$Z1\_sec := m \cdot |Z1Linesec|$ $Z1\_sec = 2.07$ Ohms secondary

$Z1pri := Z1\_sec \cdot \frac{VTR}{CTR} = 17.246$ Ohms primary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 3.2 ohms secondary (about 117%). However, in order to dependably reach a single line to ground fault at the remote terminal, it will be necessary to set the reach significantly further.

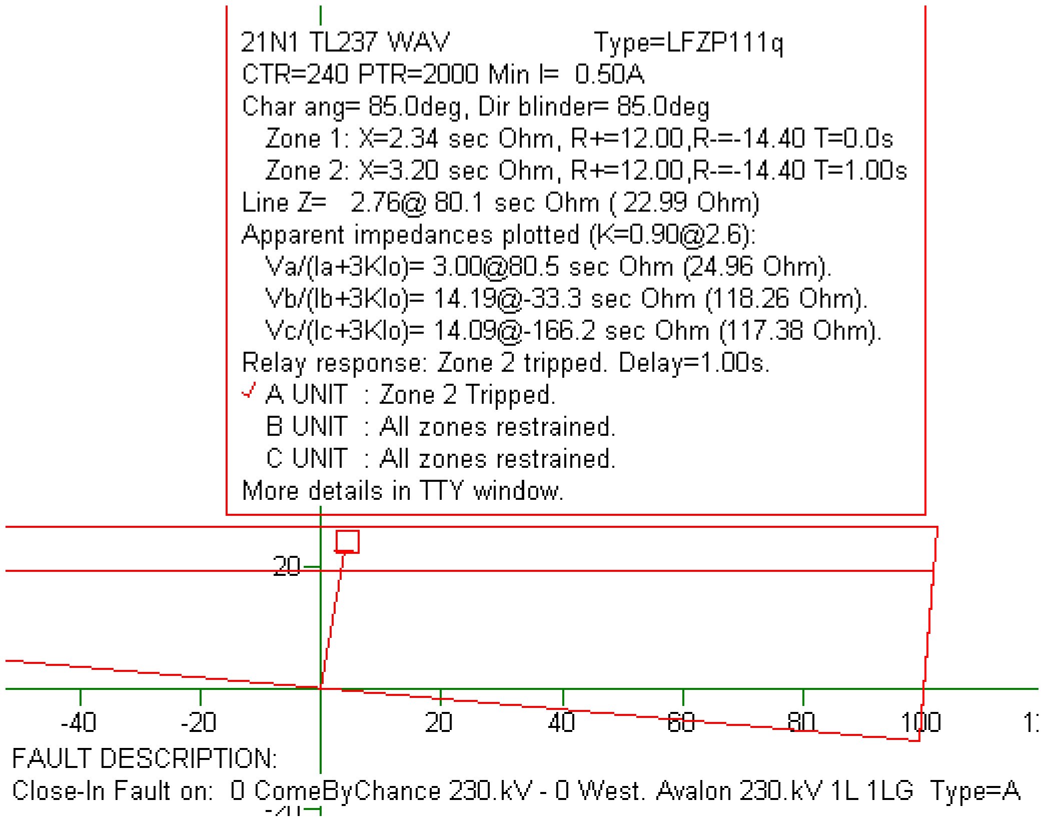


Figure 9 - Apparent impedance to a fault close to the remote terminal is increased by 9% when parallel line is in service. Relay will not operate with existing settings for this fault.

As can be seen from Figure 9, the apparent impedance to a fault close to the remote terminal is increased by 9% when the parallel line is in service.

$Zapp\_int := 3.0$ Ohms secondary

Choose a setting of 143% of the apparent impedance (longer than the normal setting of 125 - 130% of the apparent impedance) in order to keep this zone 2 setting the same as the zone 2 at the remote terminal. The longer reach than normal is of no consequence because the time delay is going to have to be extended anyway, because this element will always overreach the CBC TL207 Zone 1. In fact there is no zone 1 tripping on the P1 system at CBC TL207.

$Z2\_sec := 1.43 \cdot Zapp\_int$ $Z2\_sec = 4.3$ Ohms secondary $\frac{Z2\_sec}{|Z1Linesec|} = 155.47 \cdot \%$

$Z2\_pri := Z2\_sec \cdot \frac{VTR}{CTR} = 35.75$ Ohms primary

The zone 2 timer will be enabled, but with a reduced setting to 0.6 second. This reduced delay is required for coordination for severe single line to ground faults with communications assistance not available. For such faults, faster clearing than is available from the ground time overcurrent protection in the P2 protection is required.

$Z2T := 0.6$ Seconds

Zone 3

The zone 3 function is not used since the POR1 scheme does not include an echo function so there is no need for any reverse blocking function. Since the Zone 2 timer has to be set with the coordination of the ground distance element in mind, it is set at 2 second; so there is no benefit in applying a longer reaching zone 3 function.

Zone 3 element is blocked - same as existing.

Load Encroachment logic

The optimho instruction manual recommends a margin of at least 10% between the impedance of the maximum load and the resistive reach of the quadrilateral distance element.

Check loadability of the Zone 2 phase distance element assuming worst case depressed voltage of a stressed system of 0.9 per unit.

$Zloadmin := \frac{(0.9 kVbase)^2}{Smax}$ $Zloadmin = 176.406$ Ohms primary (assume worst case at 30 degrees)

$Smax = 242.9$

$Zloadmin\_sec := Zloadmin \cdot \frac{CTR}{VTR}$ $Zloadmin\_sec = 21.169$

A 12 ohm secondary resistive reach is less than 90% of the load impedance at anyypower factor and meets the Areva criterion. Anyway there is no difficulty with load encroachment as can be seen in Figure 9.

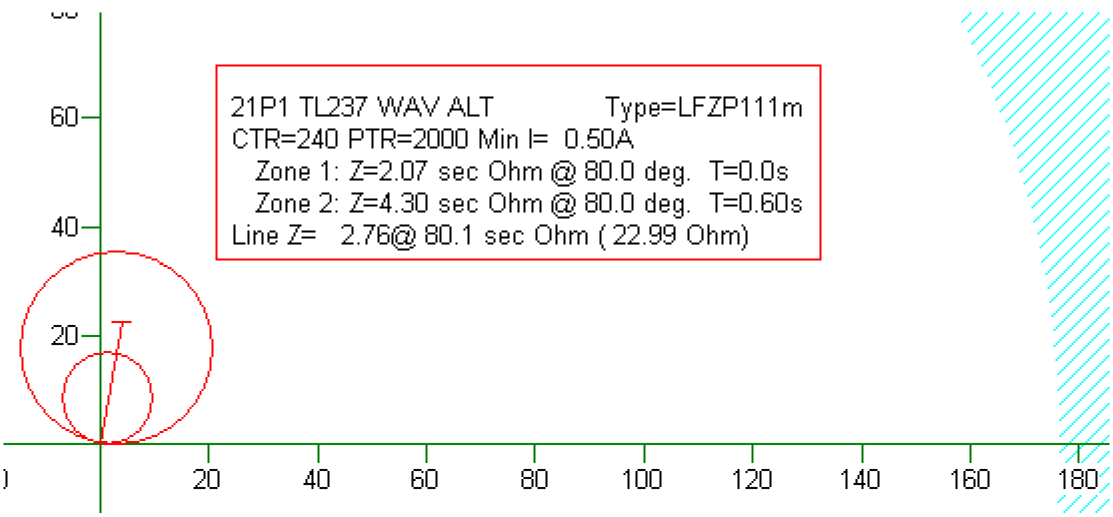


Figure 9 - Apparent impedance of load

Zone 1 Resistance - QUAD

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com. From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$R1Qmax := round[(1 - m) \cdot 20 \cdot Im(Z1Linesec), 2]$ ohm

$R1Qmax = 13.59\,\Omega$ This is the maximum secure setting for the resistive reach and is less than the existing zone 1 resistive reach setting. The existing setting of 12 ohms will be secure enough - but will it be sensitive enough?

With the existing resistive reach setting of 12 ohms, there will be a region of 10% of the line in which neither terminal will see a 100 ohm fault. If the resistive reach is increased to 13 ohms, one or the other terminal will (just) be able to sense a 100 ohm SLG on any portion of the line.

Increase the resistive reach setting from 12 to 13 ohms $\quad$ Rquad := 13 ohms secondary.

Check the maximum fault resistance that can be sensed for a fault at a location where the current contribution from each terminal is roughly the same. From Figure 11, it can be seen that the limit of sensitivity is about 100 ohms, for a fault about 66% of the distance from WAV. This meets the required sensitivity of 100 ohms.

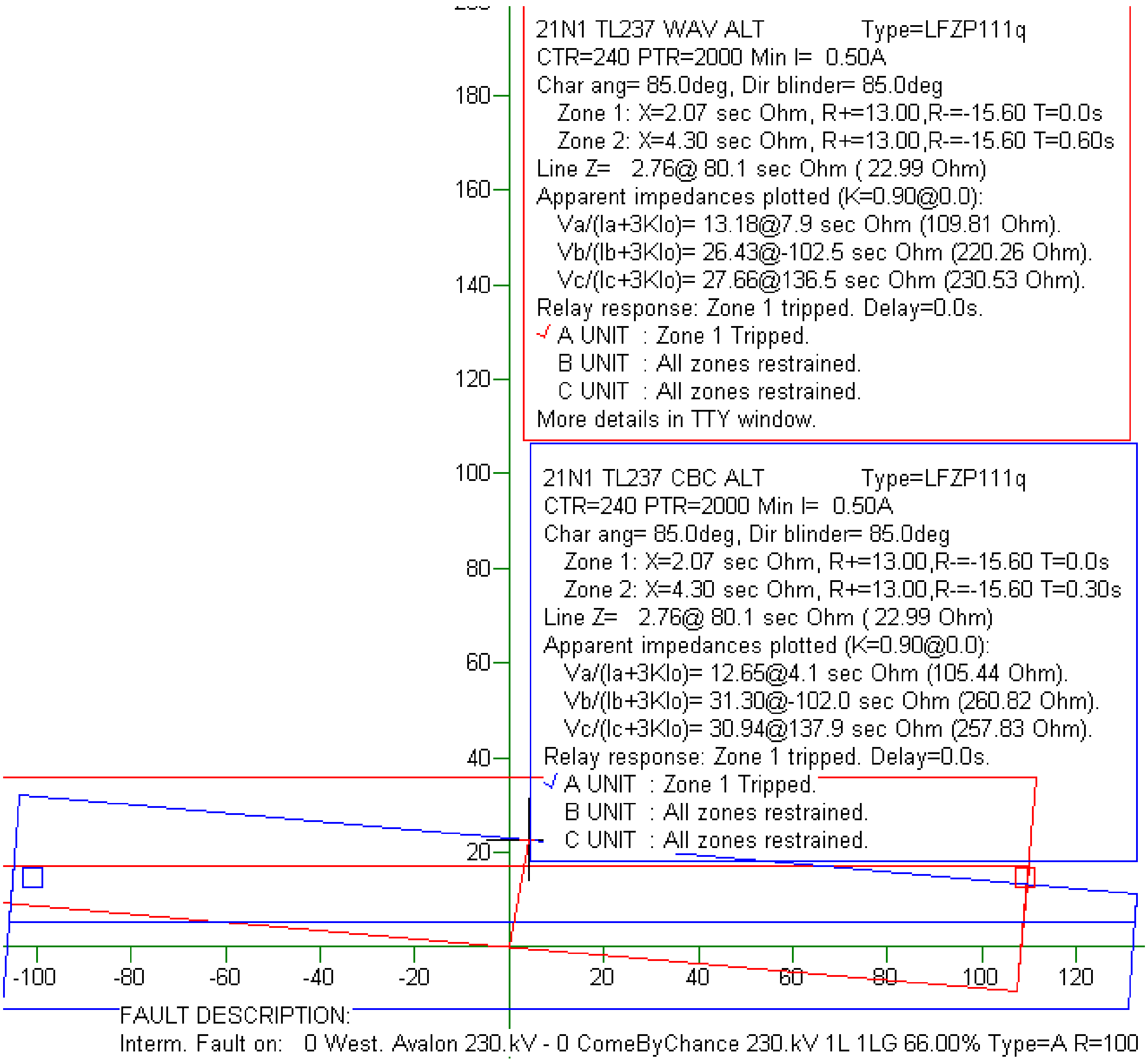


Figure 11 - Apparent impedance of a resistive fault near the mid point of the line.

Settings of K attenuators

KZPh Coarse setting common to all DISTANCE zones should be set as high as possible while below the required Zone 1 reach. The current level detectors vary inversely with KZph. Maximum setting available is 1.0

$KZPh := 1.0$

Zone 1 attenuators and angular selection

$In := 5$ $\quad Z1\_sec = 2.07$ This is the desired secondary reach (previously calculated)

$$KZ1 := \frac{Z1\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ1 = 2.07 \qquad Z1sec\_reach := KZ1 \cdot KZPh \cdot \frac{5}{In} \qquad Z1sec\_reach = 2.07$$

Tripping by the zone 1 function is disabled - same as existing.

$Z\theta PH := (\arg(Z1Linesec)) \qquad Z\theta PH = 80.091 \cdot deg$

Rounded to the nearest 5 degrees $\quad Z\theta PH := 80$ Degrees

$Z\theta N := \arg(Z0Linesec - Z1Linesec) \qquad Z\theta N = 82.7 \cdot deg$

Rounded to the nearest 5 degrees $\quad Z\theta N := 85$ Degrees

Zone 2 attenuators selection

$Z2\_sec = 4.3$ This is the desired secondary reach (previously calculated)

$$KZ2 := \frac{Z2\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ2 = 4.3$$

Zone 3 is not used

QUAD Resistive Reach setting

$Rquad = 13$ ohms secondary. This reach will be required to sense a 100 ohm SLG fault anywhere on the line.

$$KR := \frac{Rquad}{\left(\frac{5}{In}\right)} \qquad KR = 13$$

Residual Compensation attenuators selection

Zero sequence current compensation for ground faults is provided by the KZN factor. Zero sequence mutual compensation is not used in this application (it causes extra complexity for only moderate gain in setting accuracy).

$$KZN := \frac{Z0Linesec - Z1Linesec}{3 \cdot Z1Linesec} \cdot KZPh \qquad KZN = 0.903 + 0.041j$$

$|KZN| = 0.904$ This is very close, but not identical to the existing setting

Switch On To Fault (SOTF) Protection.

If SOTF is enabled, it can be set to 200ms or 110 s after all poles of the line have been de-energized. The 110 s setting is intended to override automatic reclosing dead time. However it makes more sense to enable after the shorter time. Once the SOTF feature has been initiated, it remains in effect for 250ms after the line has been re-energized. The SOTF tripping options are:

a) Any distance comparator.
b) Any current level detector as long as a corresponding voltage level detector has not picked up within 20ms.
c) Either current or distance, as long as a corresponding voltage level detector has not picked up within 20ms.

SOTF := "Enabled"

SOTF_TIME := 0.20 Seconds

Elements_in_SOTF := "BOTH" (Both Comparators and current level detectors).

Power Swing Detector

This element will not be used. It will be left Blocked, and if there is a power swing, the distance elements will trip naturally.

VT Supervision

Set the VT supervision to BLOCK TRIP

Set the VT fail detection to SELF RESET this is as existing .

SELF_RESETTING := "ENABLED"

Start Indication

This function will bring up information on the LCD screen of the relay if a start event occurs. This function will not be used.

START_INDICATION := "BLOCKED"

Communications assisted logic.

The existing communications assisted logic is permissive overreaching transfer trip, scheme **POR 1**. This scheme is familiar to Newfoundland and Labrador Hydro, and even though the POR 2 scheme offers the advantage of weak infeed echo, which would help the sensitivity to resistive faults, it is not recommended to change the existing scheme logic at this stage with years of experience on a product that is nearing the end of its useful life.

The POR 1 logic is a basic permissive overreaching transfer trip scheme but it does include current reversal timers to increase security against misoperation due to current reversal when a fault on the parallel line is cleared sequentially. The current reversal logic is achieved by a timer TP which will block permissive tripping and keying of permissive trip if the local zone 2 element does not pick up within a reasonable time of receiving permissive trip. The block will be maintained for a time delay of TD after the local zone 2 element picks up, or the received permissive trip signal resets.

The application of the current reversal timers is required only if the settings of the zone 2 comparators are greater than 1.5 times the line impedance. Since the reaches of these elements are less than or equal to 1.5 times the line impedance or if current reversals are not possible, the current reversal logic is not theoretically not required. However, given the fact that the WAV terminal of this protection tripped undesirably during the 7 December 2007 fault on TL203, and noting that the current reversal logic could have prevented this misoperation (if indeed an incorrect permissive trip signal was issued from CBC) it is recommended that this logic be enabled on this circuit.

Recommended setting for TP is 30 ms - minimum signalling channel time. It has been found that the minimum signalling channel time is approximately 3 ms. Therefore, unless this time is changed.

$CS\_Min := 3$ $\quad$ $TP := 30 - CS\_Min$ $\quad$ $TP = 27$ ms

Recommended setting for TC is Maximum signalling channel reset time +35 ms. The maximum signalling channel reset time will always be less than 10 ms.

$CR\_Max := 10$ $\quad$ $TD := 35 + CR\_Max$ $\quad$ $TD = 45$ ms

These new times will increase the security of the communications assisted scheme.

Comparison of Existing (red) and Proposed alternative (ALT) settings.

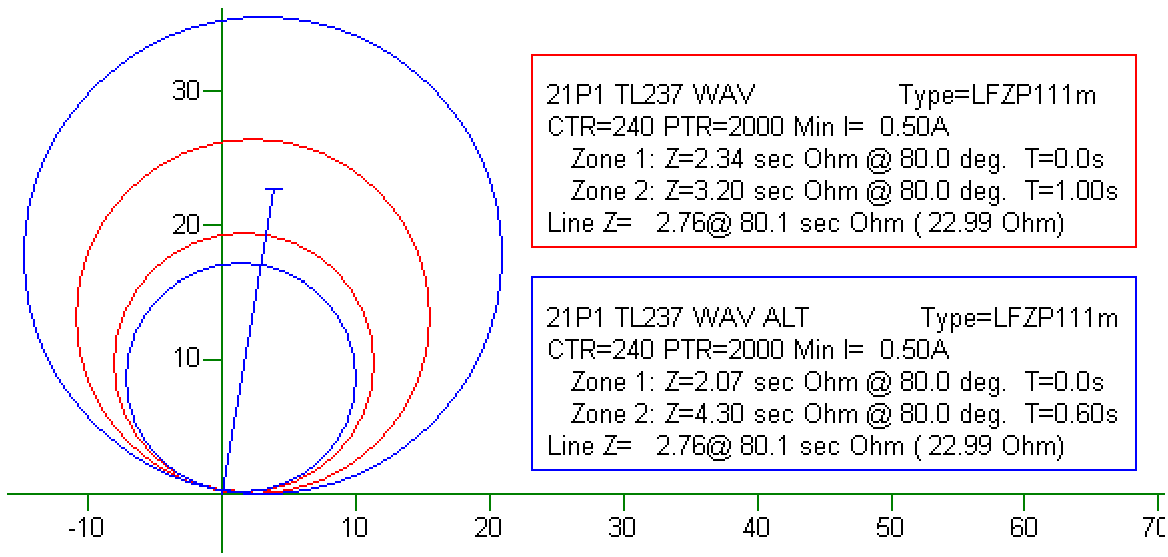


Figure 12 - Comparison of phase distance characteristics

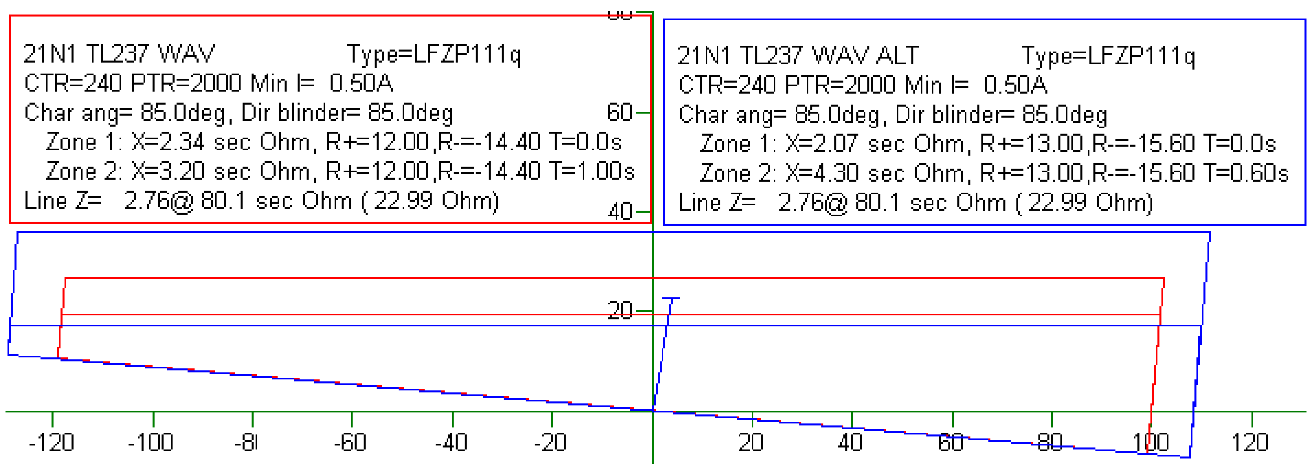


Figure 13 - Comparison of ground distance characteristics

Protection Review for Five 230 kV Transmission Lines

Appendix R
Detailed settings review for WAV TL237 "P2" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P2 protection systems for the Western Avalon (WAV) terminal of circuit TL237 . This 230 kV transmission circuit is from Come By Chance (CBC) to Western Avalon (WAV)
The circuit runs parallel to TL203 for 88% of its length.

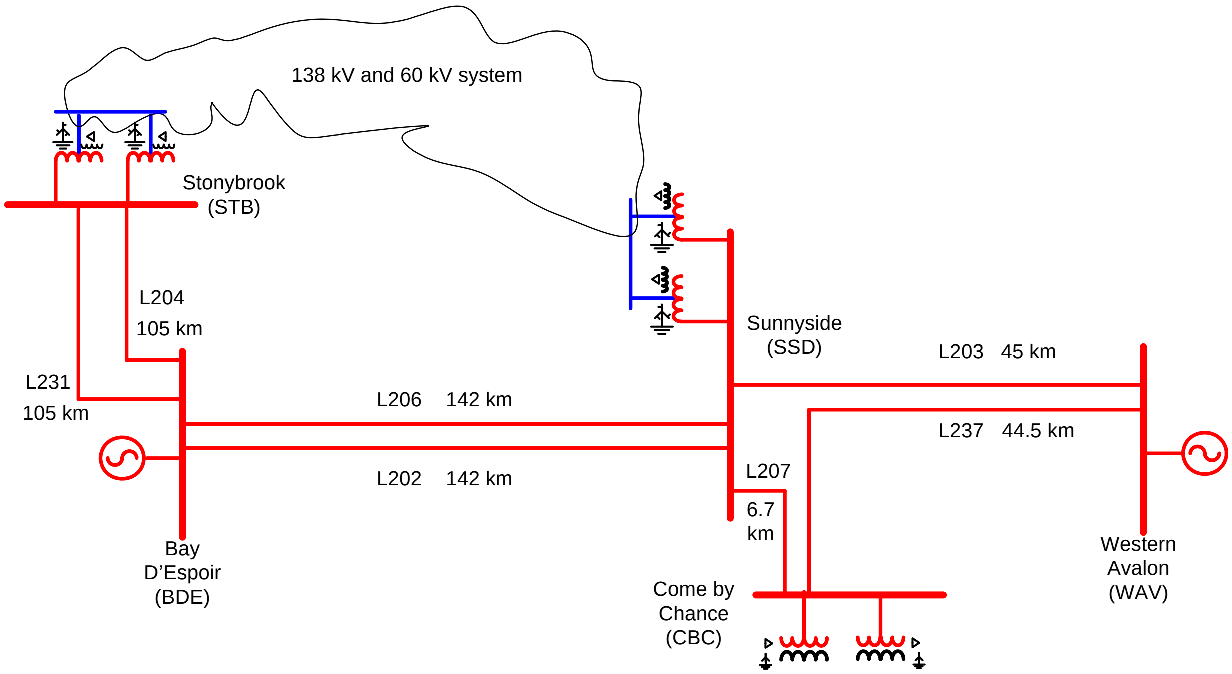


Figure 1 - System Single Line Diagram

Existing P2 protection systems are SEL321 systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $\quad kVbase := 230$ $\quad Ibase := \dfrac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\quad Zbase := \dfrac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $CTR := \dfrac{1200}{5}$ VT ratio is: $VTR := \dfrac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**Hydro Interconnected System (2010-08-13) V10.olr**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with all shunts ignored (unless needed for load flow simulation).

Minimum fault current seen by each terminal (multiphase and SLG with 100 ohm fault resistance).

At WAV with Circuit TL217 out of service, and TL207 and TL203 lines in service, for a fault at the remote terminal.

$I3Pmin := 1069$ $ISLGminPH := 315$ A $ISLGmin0seq := 326$ A

The current for a phase to phase fault would be lower, but the current supervision element of the SEL321 measures phase to phase currents, and the phase to phase current for a phase to phase fault is twice the phase current.

Calculate the minimum negative sequence source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open. **For this calculation only, simulate 50 MVA of generation (i.e., simulating motor load) at CBC to minimize source impedance.**

Minimum source impedance behind WAV $Z2minWAV := 2.64 + j\cdot 25.85$ ohms primary

Minimum um source impedance behind CBC $Z2minCBC := 2.94 + j\cdot 27.18$ ohms primary

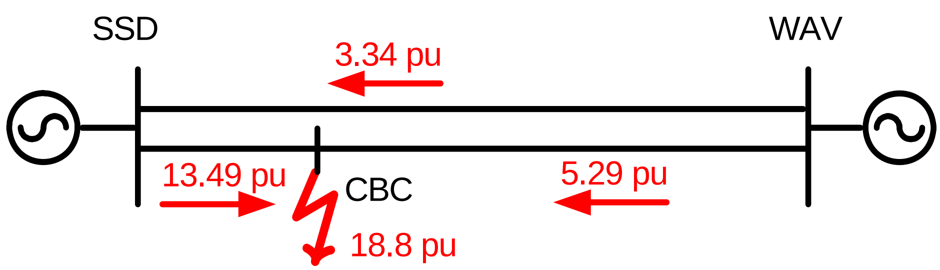


Figure 2 - 3 Phase Fault at CBC

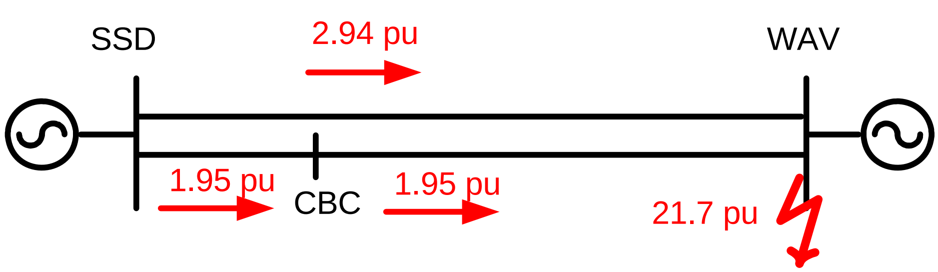


Figure 3 - 3 Phase Fault at WAV

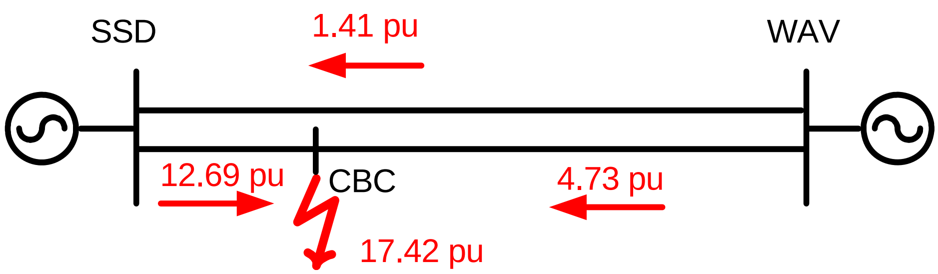


Figure 4 - SLG Fault at CBC (3I0 currents)

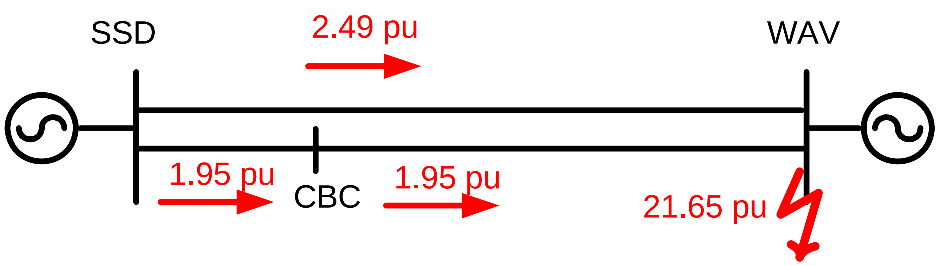


Figure 5 - SLG Fault at WAV (3I0 currents)

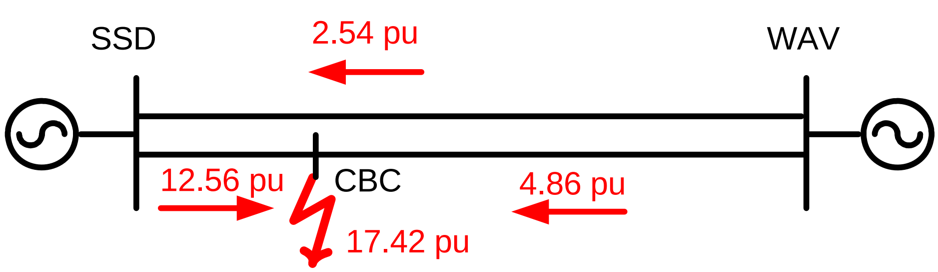


Figure 6 - SLG Fault at CBC (Phase currents)

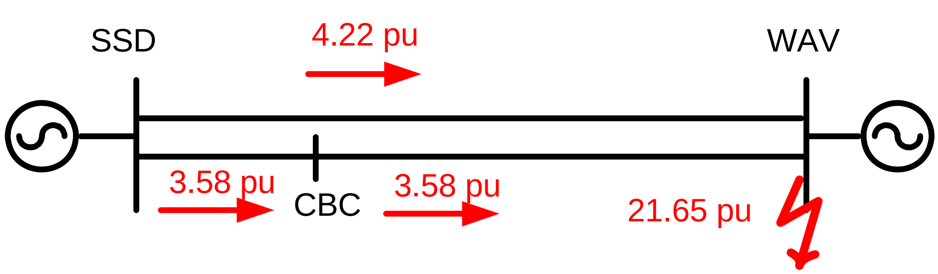


Figure 7 - SLG Fault at WAV (Phase currents)

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L237 := 0.00748 + j\cdot 0.04282$ $\quad Z0L237 := 0.02245 + j\cdot 0.15972$

In primary ohms

$Z1L237pri := Z1L237\cdot Zbase$ $\quad Z0L237pri := Z0L237\cdot Zbase$

In secondary ohms

$$Z1Linesec := Z1L237pri\cdot\frac{CTR}{VTR} \qquad Z0Linesec := Z0L237pri\cdot\frac{CTR}{VTR}$$

$|Z1Linesec| = 2.759$ $\quad \arg(Z1Linesec) = 80.091\cdot deg$

$|Z0Linesec| = 10.239$ $\quad \arg(Z0Linesec) = 81.999\cdot deg$

These impedances match the existing settings in the P2 relay no need for changes.

Zero sequence mutual coupling between TL237 and TL203 is $Z0m := 0.0132 + j\cdot 0.0697$

Load Data

From 2010 System peak load case provided in start up information, the peak load is given as 110.3 MVA (with TL203, TL207 and TL237 in service). The load in TL203 is 132.6 MVA. In the event of sudden loss of TL203. Peak load in TL207 will increase to take up the lost load through TL203. Thus the peak load in TL207 will be slightly more than double until operators can adjust loads.

$Speak\_237 := 110.3$ MVA $\qquad Speak\_203 := 132.6$ MVA

$Smax := Speak\_203 + Speak\_237 = 242.9$ MVA

P2 Relay Settings

The existing line impedance settings are close to the line data book. No need for adjustment

$Z1MAG := |Z1Linesec|$ $\quad Z1MAG = 2.76$ $\quad Z1ANG := \frac{arg(Z1Linesec)}{deg}$ $\quad Z1ANG = 80.09$

$Z0MAG := |Z0Linesec|$ $\quad Z0MAG = 10.24$ $\quad Z0ANG := \frac{arg(Z0Linesec)}{deg}$ $\quad Z0ANG = 82$

$LL237 := 44.95$ km

In order to obtain sensitivity to 100 ohm single line to ground faults, the echo function will be needed. Enable two forward and one reverse zone.

$PMHOZ := 3$ $\quad GMHOZ := 3$ $\quad QUADZ := 3$

$DIR1 := F$ $\quad DIR2 := F$ $\quad DIR3 := R$

Mho phase distance functions

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if the line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the CBC Station bus under weak source conditions with TL217 out of service and all of TL203, TL207 and TL237 lines in service. From ASPEN OneLiner, voltage at WAV for a 3 phase fault at CBC is 0.185 per unit. So there is less than 20% voltage at WAV during a fault at CBC under weak source conditions.

Since the voltage is not higher than 20%, the line is considered short, and a reduced Zone 1 setting is recommended to provide more security. Choose a setting of 80% of nominal.

$Z1P := round(0.8 \cdot |Z1Linesec|, 1)$ $\quad Z1P = 2.2$ Ohms secondary

This is a little lower than the existing setting.

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 3.2 ohms secondary (about 116%) and is too short. It should be increased.

$Z2P := \mathrm{round}(1.3 \cdot |Z1Linesec|, 1)$ $\quad Z2P = 3.6$ Ohms secondary

As can be seen from Figure 8, this element (with the proposed new setting) does overreach the zone 1 element at the CBC terminal of TL207 and there is no infeed.

The existing Zone 2 timer setting of 18 cycles is too short, and needs to be increased to 36 cycles.

$Z2PD := 36$ cycles

Zone 3

Set Zone 3 reverse element to reach further behind this terminal than the remote Zone 2. This function adds security for external faults. The element should always be more sensitive than the forward looking Zone 2 at the remote terminal. Set it the same as the remote Zone 2 overreach plus 20%

$$Z3P := Z1MAG \cdot \left(\frac{Z2P}{Z1MAG} - 1 + .2 \right)$$

$Z3P = 1.4$ Ohms secondary

$\frac{Z3P}{|Z1MAG|} = 50.464 \cdot \%$ of line length

This is a little higher than the existing setting, but provides additional security.

The reverse looking zone 3 element need not be set to trip through a timer. It is needed only for security in the POTT scheme.

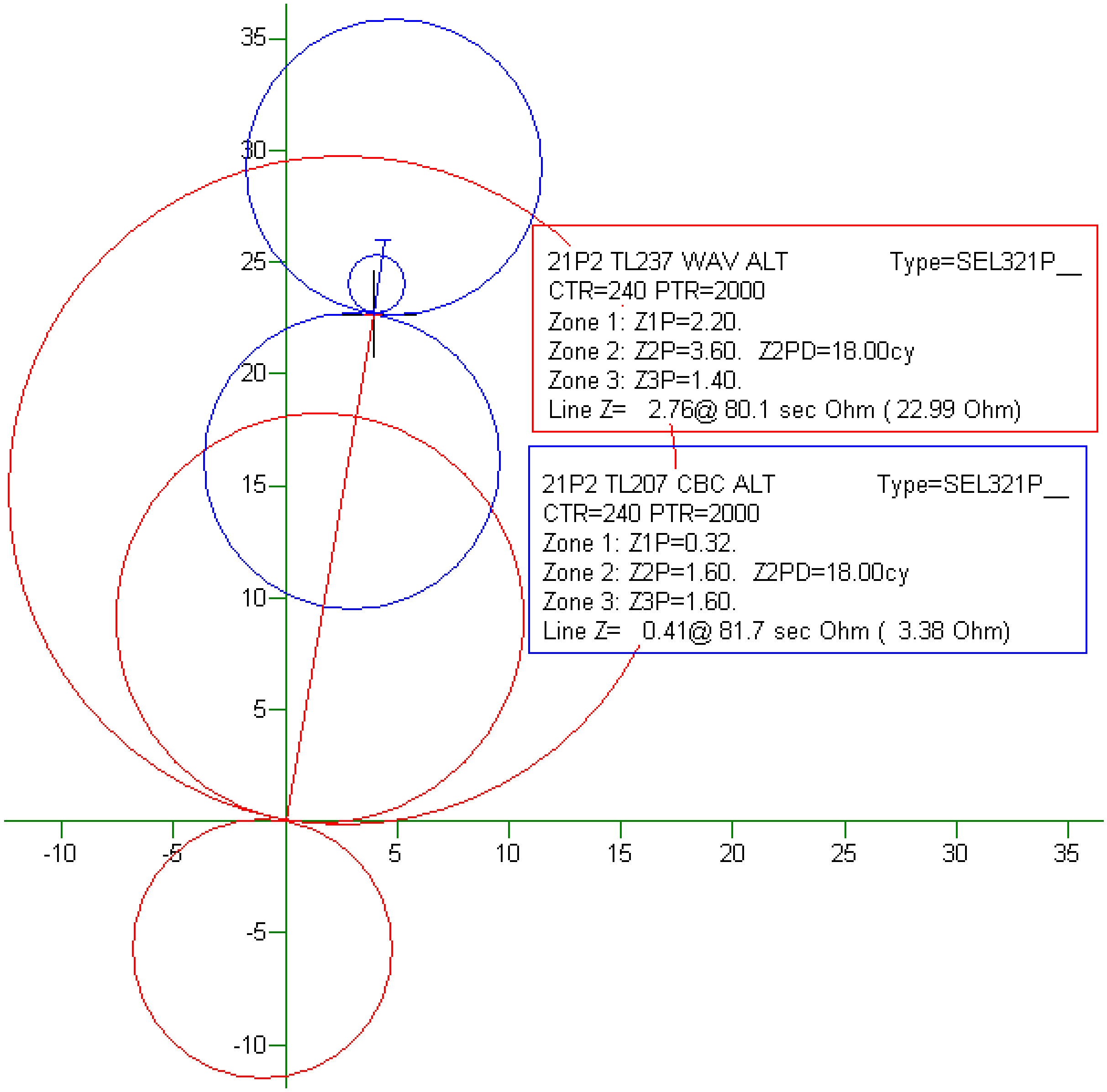


Figure 8 - Proposed new CBC TL237 Zone 2 overreaches CBC TL203 zone 1 and needs longer than standard zone 2 delay

Mho phase distance current supervision

If the current supervision elements can be set above load, they will be secure in the event that potential is lost. However given that loss of potential logic is available, it is recommended that only the zone 1 current supervision function be set above load. If potential is lost, it will be able to block tripping by Zone 2 before it trips on time delay or receives a permissive trip from the remote terminal.

For the point of view of current supervision being above maximum load, there is no need to worry about abnormal conditions. It would be a double contingency for the VT signal to be lost while the parallel line was out of service. Therefore, consider a maximum load of 110 MVA. The current supervision elements for the phase distance functions measure phase to phase currents.

$$IPPmax\_normal := \frac{Speak\_237 \cdot 1000}{kVbase} \qquad IPPmax\_normal = 480 \text{ A primary}$$

The current supervision elements use phase to phase currents for supervision of the phase distance function;. so the minimum phase to phase fault current will be root three times the minim phase fault current. Choose a margin of 50% of the minimum phase to phase fault current for dependability.

$$IPPmin := 0.5 I3Pmin \cdot \sqrt{3} \qquad IPPmin = 926 \text{ A primary}$$

A setting of 528 A primary for 50PP1 will ensure the Zone 1 function operates for any fault even under minimum source conditions but will not be susceptible to trip on load due to loss of potential under normal maximum load conditions. This is higher than the existing setting and will give better security without compromising dependability.

$$'50PP1 := 2.2 \text{ A Sec} \qquad '50PP1 \cdot CTR = 528 \text{ A primary}$$

Since Zone 2 and zone 3 elements will be blocked by LOP function, set them at minimum. This is lower than the existing settings but will not affect the security under loss of potential conditions. The zone 3 current supervision should not be set higher than the zone 2 current supervision element at the remote terminal. In this case the remote zone 2 current supervision element will be set at 1.0 A secondary.

$$'50PP2 := 1 \text{ A Sec} \qquad '50PP3 := 1 \text{ A Sec}$$

Ground Distance Protection

The reach of the ground distance functions will be affected by mutual coupling to the parallel line. These functions will tend to underreach the remote bus while the parallel line is in service, and overreach the remote bus if the parallel line is out of service and grounded at both ends. Figure 9 shows that for a remote bus fault, with the parallel line out of service and grounded, the apparent impedance of the line is reduced to about 2.44 ohms secondary instead of the nominal 2.76 ohms. This is 88% of the actual line impedance.

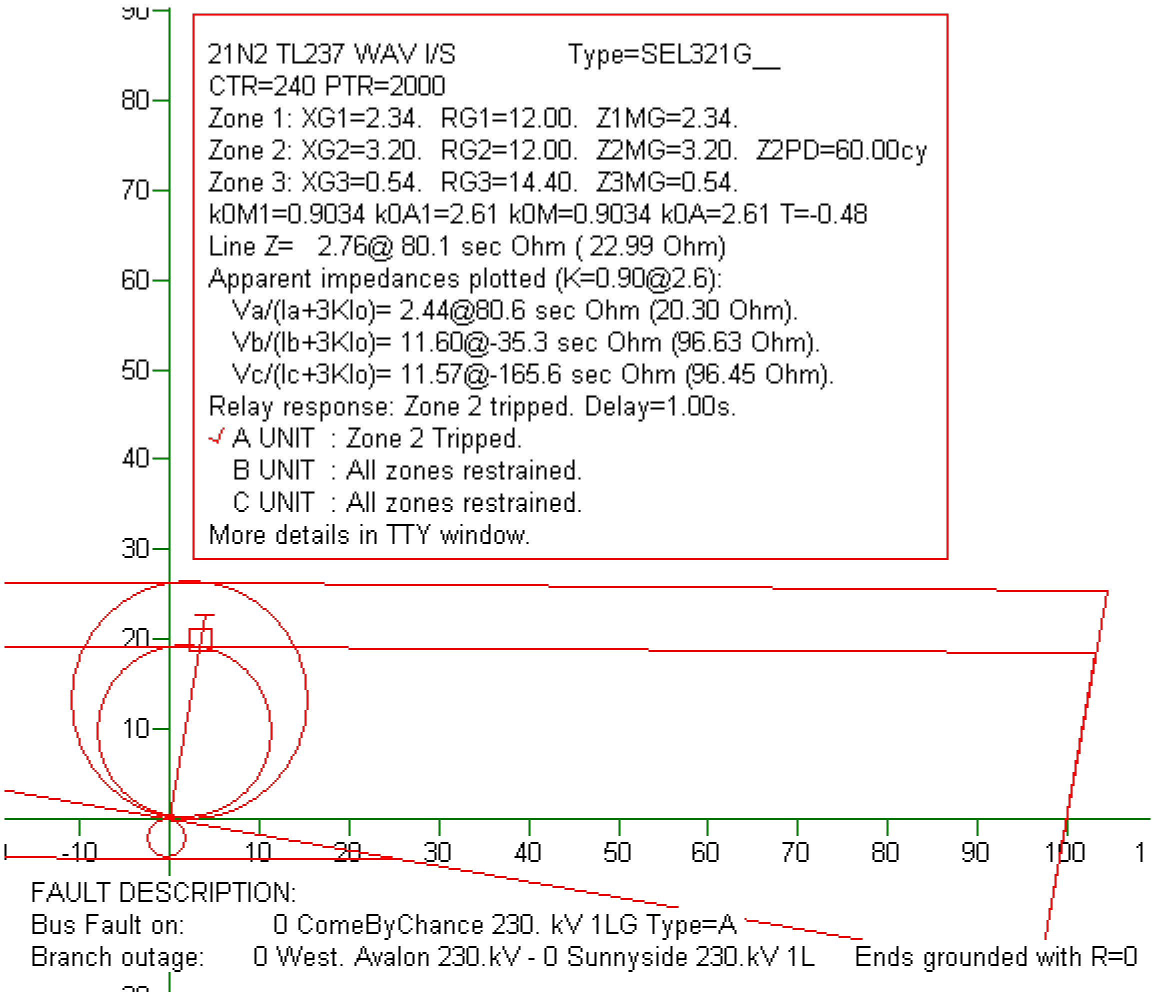


Figure 9 - Apparent impedance to a fault just beyond the remote terminal is reduced by 11% when parallel line is out of service and grounded at both ends. Existing relay settings modeled in this figure.

The normal reach of the zone 1 should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Choose a setting of 75% of the line impedance, which is lower than the setting required to make the zone 1 element more secure for faults beyond the end of this short line. Note that as will be seen later, the reduced reactive reach is required to allow a relatively large resistive reach for sensitivity while retaining security against overreach due to CT and VT errors.

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.75$ per unit

$Z1MG := m \cdot |Z1Linesec|$ $Z1MG = 2.07$

$XG1 := Z1MG$ $XG1 = 2.07$

Zone 1 Resistance

The resistive reach of the Zone 1 quad should provide enough sensitivity to trip the local terminal immediately without waiting for permission from the remote terminal for a severe fault that depresses the voltage significantly. Further, it should not allow the function to reach beyond the remote terminal due to errors in relay measurement or CT or VT. If possible, it should also operate for a 100 ohm SLG 25% of the distance from the local terminal. Operation for a 100 ohm resistive fault at the 25% location will ensure this function can trip for a close in fault without assistance from the remote terminal. The remote terminal zone 1 function will be set to operate sequentially for this fault.

However, with a resistive reach of 12 ohms, the quadrilateral characteristic cannot even sense a 100 ohm SLG close in to the WAV terminal. Therefore the desired sensitivity for the P2 zone 1 function cannot be achieved. With a revised resistive reach setting of 13 ohms, the P2 function will be able to sense a close in SLG fault with a resistance of 90 ohms. This is the best that can be achieved with a secure resistive reach..

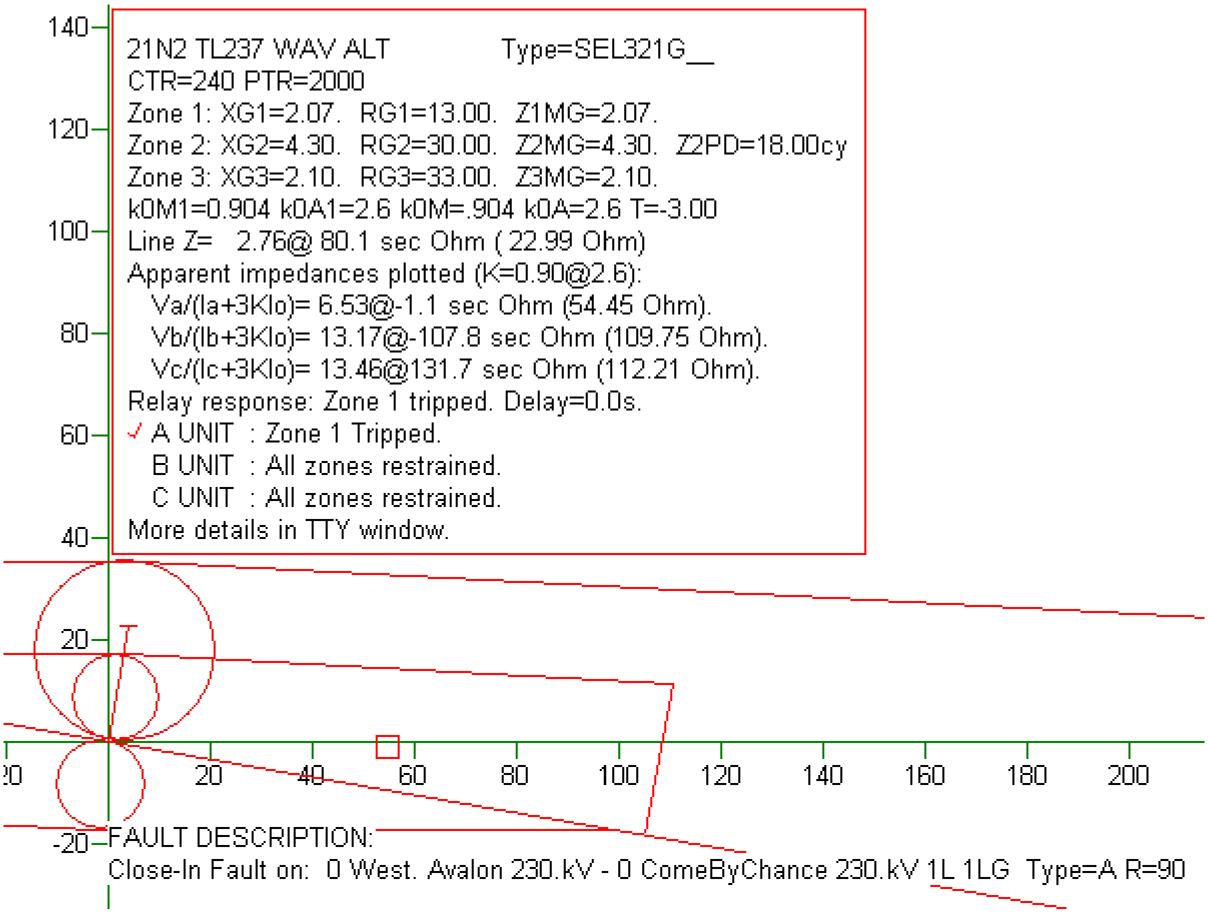


Figure 10 - WAV P2 Zone 1 function limit of sensitivity for resistive faults is for a 90 ohm fault close in to the local terminal.

Check the maximum resistive reach that can be achieved securely.

XG1 is set at m per unit of the transmission line. The imaginary component of this is

$ImXG1sec := Im(Z1Linesec)$ $ImXG1sec = 2.718$ ohms

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$RG1 := round[(1 - m) \cdot 20 \cdot ImXG1sec, 1]$

$RG1 = 13.6$ This is the maximum secure setting for the resistive reach so the desired zone 1 resistive reach setting would not be confirmed as being secure.

Use the maximum secure setting of 13 ohms for RG1 $RG1 := 13$ ohms secondary

With a resistive reach setting of 13 ohms, the WAV Zone 1 quad element will see a 90 ohm resistive SLG fault immediately in front of the SSD terminal and gradually reducing resistance as the fault moves away from the terminal. Zone 2 protection will be depended upon to sense faults with resistance up to 100 ohms.

In spite of this limited sensitivity of the Zone 1 element, it should be noted that the 75 ohm resistive SLG will only depress the faulted phase voltage by about 5%; so this fault is not very severe on the system and communications assisted tripping (slightly slower than zone 1 communications independent tripping) should not have a significant negative impact on the system.

Zone 2 Ground Distance Protection

The Zone 2 ground distance function will need to be set longer than the Zone 2 phase distance protection function because it will tend to underreach the remote terminal while the parallel line is in service. By simulation in ASPEN OneLiner it is found that the apparent impedance to a zero ohm fault close in to the remote terminal is 3.0 ohms secondary, or 9% more than the actual line impedance. Choose a setting of 135% of the apparent impedance (longer than the normal setting of 125 - 130% of the apparent impedance) in order to keep this zone 2 setting the same as the zone 2G at the remote terminal.

$ZSLG\_remote := 3.0$

$Z2MG := round(1.35 \cdot ZSLG\_remote, 1)$ $Z2MG = 4.1$ Ohms secondary

The quad element reactive reach will be set similarly to the mho.

$XG2 := Z2MG$ $XG2 = 4.1$ Ohms secondary

The resistive reach of the quad will be increased to sense a 100 ohm resistive in the middle of the line with a good overlap of zone 2 elements from each end. By trial and error from ASPEN it is found that a resistive reach of 25 ohms secondary will sense a 100 ohm SLG fault from both ends of the line between 61 to 67 percent of the distances from the CBC terminal. However since it will not overlap the Zone 1 element at the remote terminal, the permissive trip echo function will be required to ensure that a fault that is seen by the zone 2 element at only one terminal will still be cleared by the permissive trip logic. Therefore, to avoid extremely large resistive reaches, and to retain sensitivity to 100 ohm resistive SLG faults, it is recommended that the echo function be enabled at both terminals. The zone 2 ground distance time delay trip will need to be reduced from 60 to 36 cycles (0.6 seconds) in order to aid coordination for resistive single line to ground faults "around the loop" of TL203 TL237 and TL207 where otherwise, the ground time overcurrent functions might not have coordinated fully. Check that the Zone 2 ground distance element will not be more sensitive than the Zone 1 ground distance element on the shortest line out of SSD.

The zone 2 element overreaches the CBC TL207 Zone 1 element, so it will be set to trip directly with an extended time delay of 36 cycles.

Z2GD := 36 Cycles

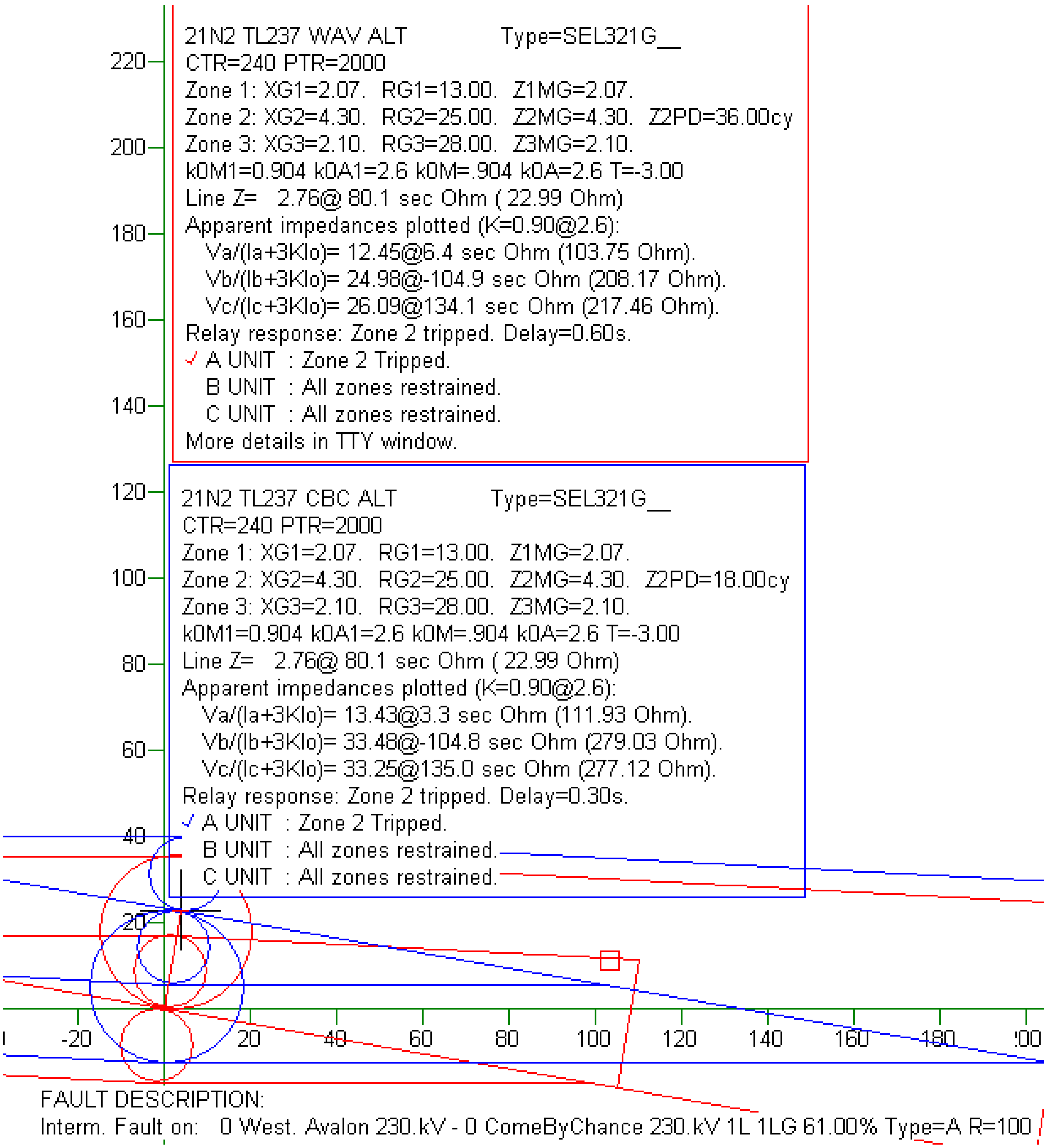


Figure 11 - Local Zone 2 Quad element operates for 100 ohm resistive SLG at 61% of the distance from the local terminal.

Zone 3 Ground Distance Protection

The zone 3 ground mho function will be set using the same principles as the zone 3 phase distance function.

$Z2MGrem := 4.3$ ohms secondary

$$Z3MG := Z1MAG \cdot \left(\frac{Z2MGrem}{Z1MAG} - 1 + .2 \right) \qquad Z3MG = 2.1$$ Ohms secondary

$$\frac{Z3P}{|Z1MAG|} = 50.464 \cdot \%$$ of line length

This is a little higher than the existing setting, but provides additional security.

$XG3 := Z3MG \qquad XG3 = 2.1$ Ohms secondary

Set the Zone 3 quad resistive reach at 10% more than the remote Zone 2

$R2Grem := 25$ Ohms secondary

$R3G := \mathrm{round}(R2Grem \cdot 1.1, 0) \qquad R3G = 28$ Ohms secondary

With very heavy prefault load flow (218 MVA in TL203 and 180 MVA in TL237) if TL203 trips single pole, the ground distance elements with the increased resistive reach on the P2 protection will remain secure. See Figure 14

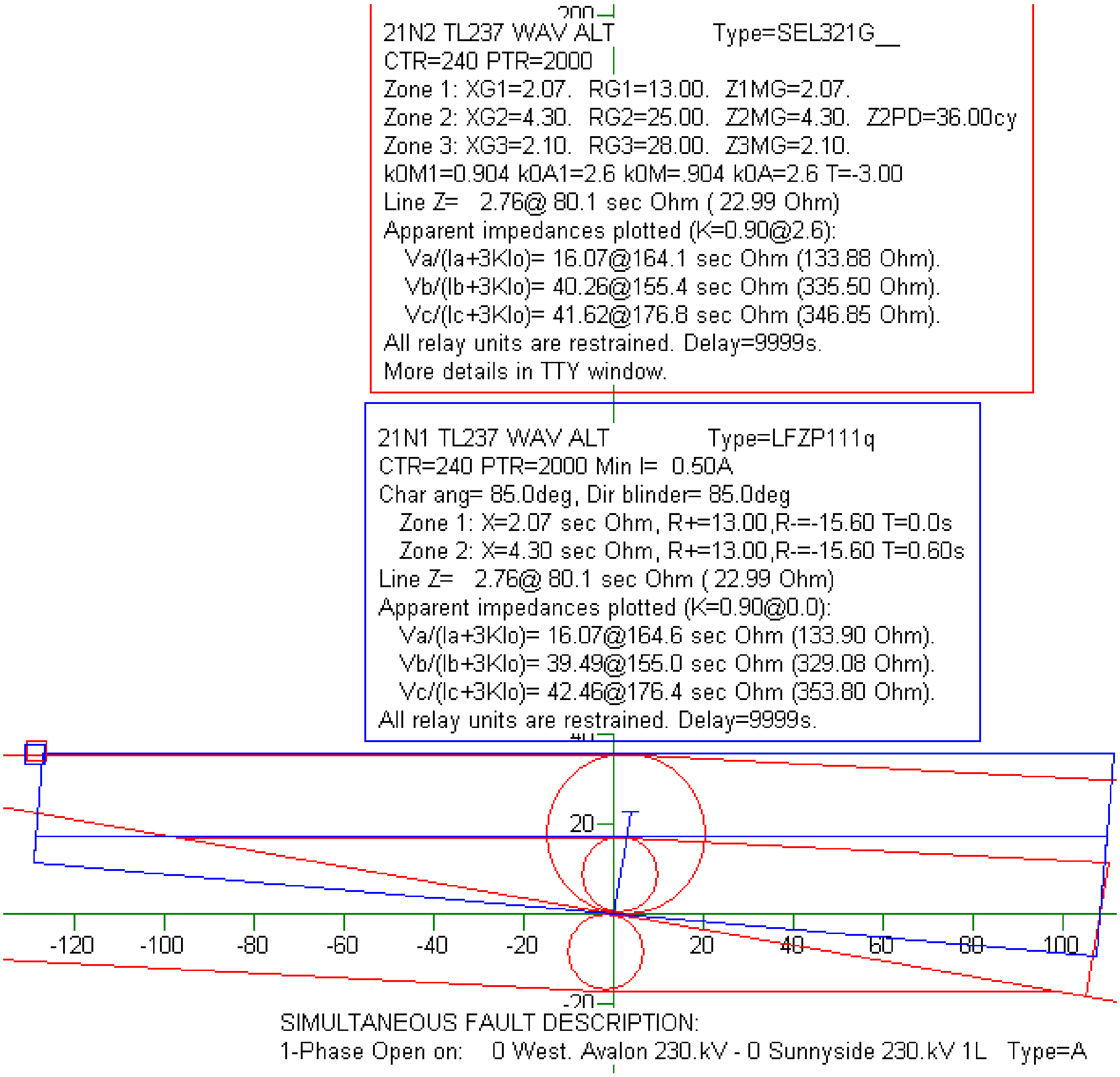


Figure 14 - Ground distance elements remain secure during heavy load flow with one phase open on TL203

The zone 2 ground distance time delay trip will need to be reduced from 60 to 36 cycles (0.6 seconds) in order to aid coordination for resistive single line to ground faults "around the loop" of TL203 TL237 and TL207 where otherwise, the ground time overcurrent functions might not have coordinated fully. A setting of 0.6 seconds is proposed to aid coordination above the CBC TL207 zone 1 ground distance protection since there is no fault current infeed at CBC to aid this coordination.

Z2GD := 36 Cycles

Zone 3 Ground Distance Protection

The zone 3 ground mho function will be set using the same principles as the zone 3 phase distance function.

$Z2MGrem := 4.3$ ohms secondary

$Z3MG := Z1MAG \cdot \left(\frac{Z2MGrem}{Z1MAG} - 1 + .2\right)$ $\quad Z3MG = 2.1$ Ohms secondary

$\frac{Z3P}{|Z1MAG|} = 50.464 \cdot \%$ of line length

This is a little higher than the existing setting, but provides additional security.

$XG3 := Z3MG$ $\quad XG3 = 2.1$ Ohms secondary

Set the Zone 3 quad resistive reach at 10% more than the remote Zone 2

$R2Grem := 30$ Ohms secondary

$R3G := \mathrm{round}(R2Grem \cdot 1.1, 0)$ $\quad R3G = 33$ Ohms secondary

Ground distance current supervision

Since there is no concern about these elements operating on load, even with loss of potential, set all current supervision elements at minimum, for maximum sensitivity of the distance elements.

$'50L1 := 0.5$ A Sec $\quad$ $'50L2 := 0.5$ A Sec $\quad$ $'50L3 := 0.5$ A Sec

$'50G1 := 0.5$ A Sec $\quad$ $'50G2 := 0.5$ A Sec $\quad$ $'50G3 := 0.5$ A Sec

Zero sequence current compensation

Set the zero sequence current compensation as usual.

$k01M := \left(\left|\frac{Z0L237 - Z1L237}{3 \cdot Z1L237}\right|\right)$ $\quad k01M = 0.904$

$k01A := \left(\arg\left(\frac{Z0L237 - Z1L237}{3 \cdot Z1L237}\right)\right)$ $\quad k01A = 2.611 \cdot deg$ $\quad$ Say $\quad k01A := 1deg$

Set the overreaching zones the same as zone 1 $\quad k0M := k01M$ $\quad k0A := k01A$

$k0M = 0.904$ $\quad k0A = 1 \cdot deg$

These settings are only slightly different from the existing settings.

Non Homogenous Angle Setting

Compare the angle of the total zero sequence current at the remote bus with the angle of the zero sequence current contribution from the local terminal to determine this setting. From ASPEN OneLiner, the worst case is normal conditions. For this case, for an SLG at WAV the angle of I0 at the fault is -114 degrees and the angle of I0 out of the CBC terminal is -113 degrees. Therefore, the total fault current lags the current contribution from SSD by 2 degrees and angle T may be set at -1 and ensure no overreach. However, because this is a relatively short line, the angle T should be set at the default angle of -3 degrees for extra security.

$T := -3$ degrees

Out of step blocking and tripping

Not used in this application. There is a danger of out of step conditions arising. Historically no action has been taken to provide special tripping or blocking functions. Natural tripping during swings is accepted.

Load Encroachment logic

Check loadability of the Zone 2 phase distance element assuming worst case power factor of 0.87 simultaneous with worst case depressed voltage of a stressed system of 0.9 per unit. Note that units of kV squared match units of MVA. Note that quadrilateral elements are only used for the ground distance functions that are not sensitive to balanced three phase load. Therefore no need to worry about the reach of the quadrilateral elements.

$Zloadmin := \frac{(0.9kVbase)^2}{Smax}$ $Zloadmin = 176.406$ Ohms primary (assume worst case at 30 degrees)

Maximum reach of the Zone 2 element is at the line angle of 81 degrees. At 30 degrees, the reach will be given by

$Z2load := Z2P \cdot \cos[(Z1ANG - 30)deg]$ $Z2load = 2.31$ ohms secondary

$Z2load \cdot \frac{VTR}{CTR} = 19.247$ ohms primary

Since the reach of the Zone 2 element at 30 degrees is less than the apparent impedance of the maximum load, there is no need to apply load blinding logic. See Figure 15

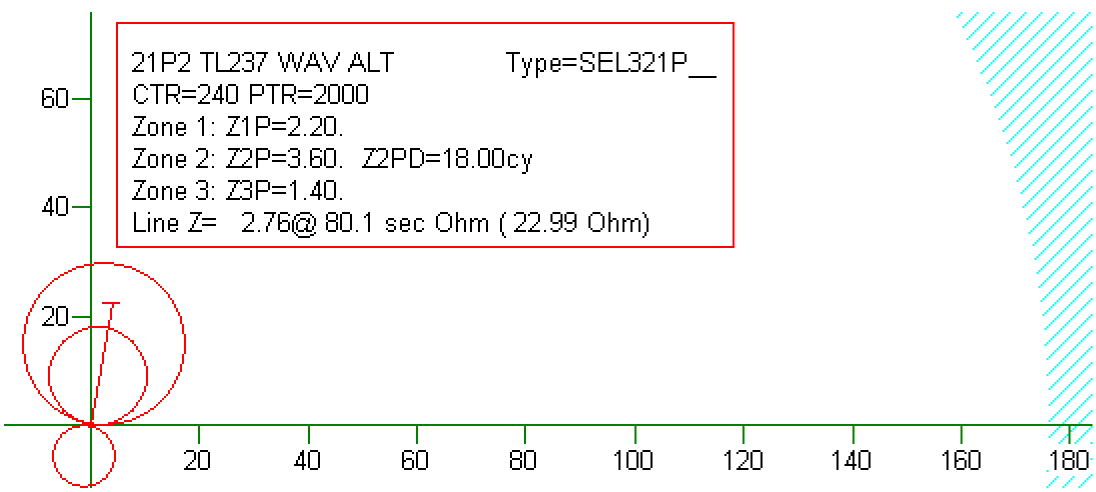


Figure 15 -Load impedance with respect to proposed new Mho function reaches.

Ground directional element

The SEL-321 application example recommends finding the minimum source impedance behind the terminal and setting the reverse and forward boundaries of the negative sequence directional element at the 1/3 and 2/3 points respectively.

In the negative sequence plane, the sum of the two source impedances and the line impedance is:

$Z2total := Z2minWAV + Z1L237pri + Z2minCBC$ $\quad |Z2total| = 76.28$

The 1/3 point is $Z2\_1\_3 := \dfrac{Z2total}{3}$ The 2/3 point is $Z2\_2\_3 := \dfrac{2Z2total}{3}$

$Z2Rpri := Z2\_2\_3 - Z2minWAV$ $\quad |Z2Rpri| = 24.884$ $\quad |Z1L237pri| = 22.995$

$Z2Fpri := Z2\_1\_3 - Z2minWAV$ $\quad |Z2Fpri| = 0.824$ $\quad |Z2minCBC| = 27.339$

$|Z2minWAV| = 25.984$

Converting the primary impedances to secondary ohms

$Z2R := Z2Rpri \cdot \dfrac{CTR}{VTR}$ $\quad |Z2R| = 2.986$ Ohms secondary $\quad arg(Z2R) = 81.407 \cdot deg$

$Z2F := Z2Fpri \cdot \dfrac{CTR}{VTR}$ $\quad |Z2F| = 0.099$ Ohms secondary $\quad arg(Z2F) = -49.124 \cdot deg$

Rounding up Z2F (note that Z2F is negative) and rounding down Z2R gives:

$Z2F := 0$ Ohms secondary $\quad Z2R := 2$ Ohms secondary

The proposed Z2F is close to existing, and Z2R is a little lower than existing.

Set the current level detectors at minimum level that will allow operation of the ground distance elements.

Due to the very small zero sequence current contribution to a single line to ground fault at the remote terminal, the negative sequence current contribution will always be higher than the zero sequence. Therefore there is no point in setting the forward looking negative sequence overcurrent elements any more sensitively than the zero sequence ground overcurrent supervision of the ground distance elements.

$'50QF := '50G2$ $\quad '50QF = 0.5$ A secondary

Set the supervision function for the reverse looking element to be the same as, or a little more sensitive than the forward looking supervision element at the remote terminal.

$'50QR := 0.5$ A secondary

The positive sequence current restraint (a2) factor should be set just smaller than the ratio of the maximum load current (positive sequence) to the most sensitive current supervision element (50QR).

$I1maxpri := \dfrac{Smax \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\quad I1maxsec := \dfrac{I1maxpri}{CTR}$ $\quad I1maxsec = 2.541$

Bearing in mind that the 50QR setting is in units of 3*I2

$\dfrac{'50QR}{3 \cdot I1maxsec} = 0.066$ Choose a value of $a2 := 0.07$

This a2 factor is lower than existing setting because of higher maximum load current used.

Phase time overcurrent element

This element is not used

Residual time overcurrent element

This element is used to provide the most sensitive backup protection. It will be a directional element. Minimum pickup needed to sense a higher resistance than 100 ohm SLG near the CBC terminal. Choose 200 ohm arbitrarily. Choose a desensitization factor of 2 to reflect half the total fault current coming from each end.

$SF := 2$ Desensitization factor due to remote end infeed is $Dfactor := 2$ $Rf := 200$

$$'51NPU := \mathrm{round}\left(\frac{kVbase \cdot 1000}{\sqrt{3} \cdot SF \cdot Dfactor \cdot Rf \cdot CTR}, 1\right) \qquad '51NPU = 0.7$$

The existing setting of 0.5 A is more sensitive than required to sense this fault with arbitrary resistance. It also presents difficulty in coordinating with the CBC TL207 ground protection. It will be increased a little.

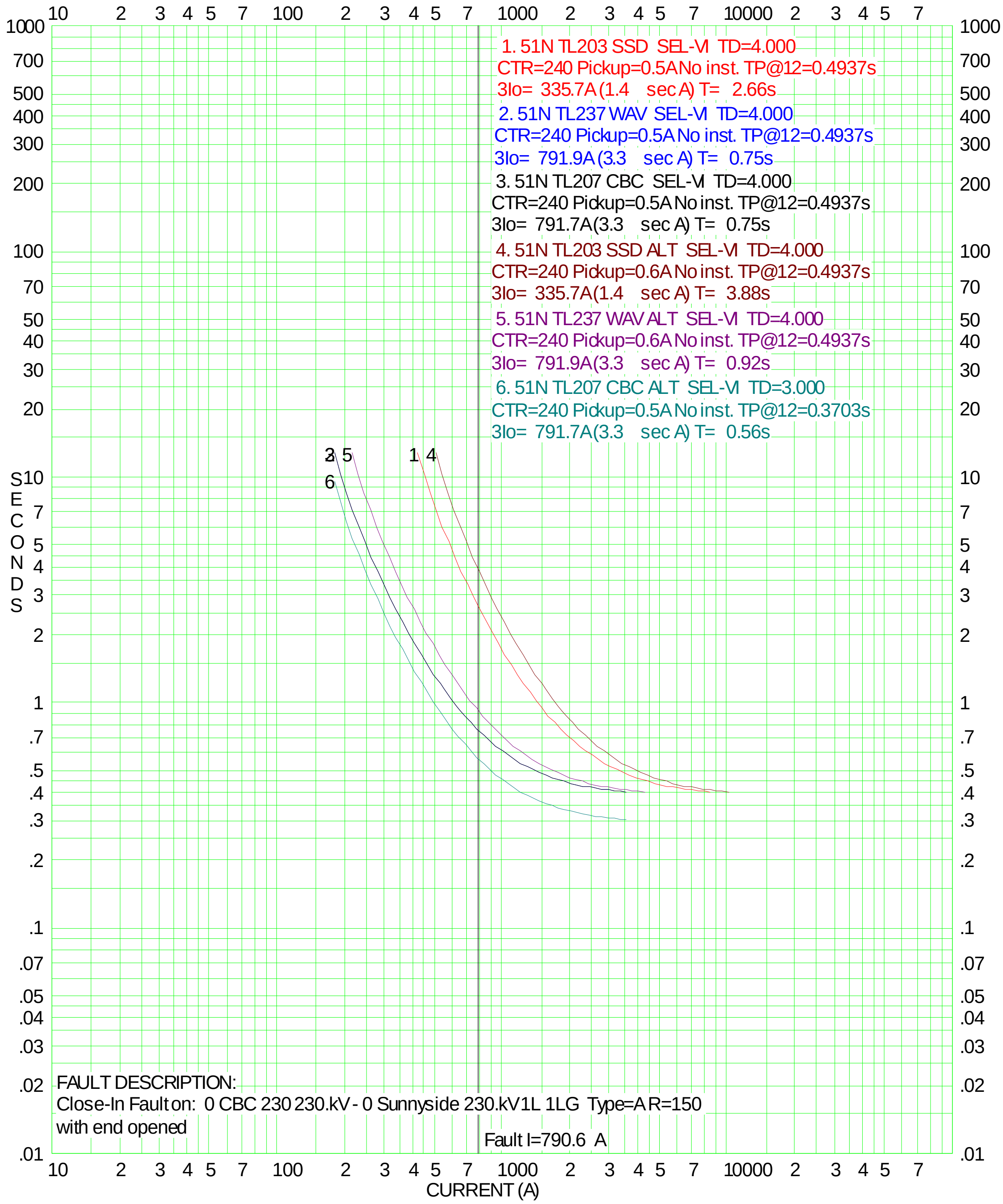
$'51NPU := 0.6$ A secondary

Coordination checks show that existing time dial settings around the loop TL203, TL237 and TL207 (clockwise) will not coordinate, because the CBC TL207 and WAV TL237 relays are set exactly the same. Therefore if there is a fault on TL207 that has to be cleared by the ground time overcurrent relay, the WAV TL237 will trip simultaneously or not coordinate. Therefore the existing settings have to be adjusted. The ground distance elements will speed up tripping for faults with resistance up to 150 ohms fed from one end, where ground relay coordination is challenged), so coordination will be checked for faults with resistance of 150 ohms or more. Trial and error checks show that in order to achieve coordination, the existing time dial setting of CBC TL207 ground time overcurrent relay will have to have its time dial settings reduced from existing 4 to 3 and WAV TL237 pickup increased to 0.6.

Check the coordination with the other relays for three faults (all with 150 ohm resistance). Line end TL203, Close in to CBC on TL207 and 88% from WAV on TL237 (at the end of the mutually coupled section). See Figure 16 to find that existing settings (curves 2&3) do not coordinate, and Figures 16, 17 and 18 to find that revised (Curves 4, 5 and 6) settings will coordinate.

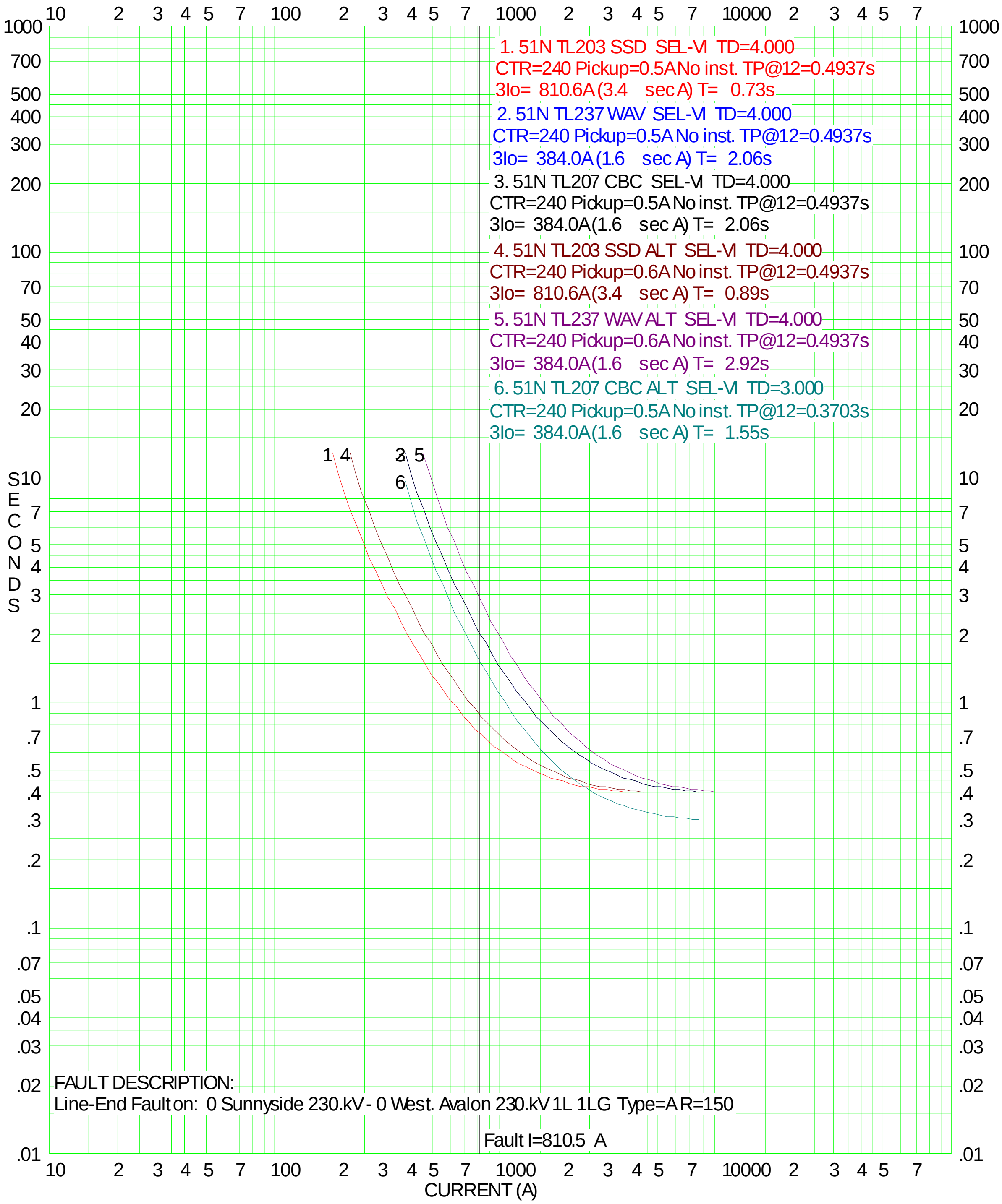
$'51NPU = 0.6$ A secondary $'51NPU \cdot CTR = 144$ A primary

$'51NTD := 4$ $'51NC := "U3"$ $'51NTC := "N"$ $'51NRS := "N"$



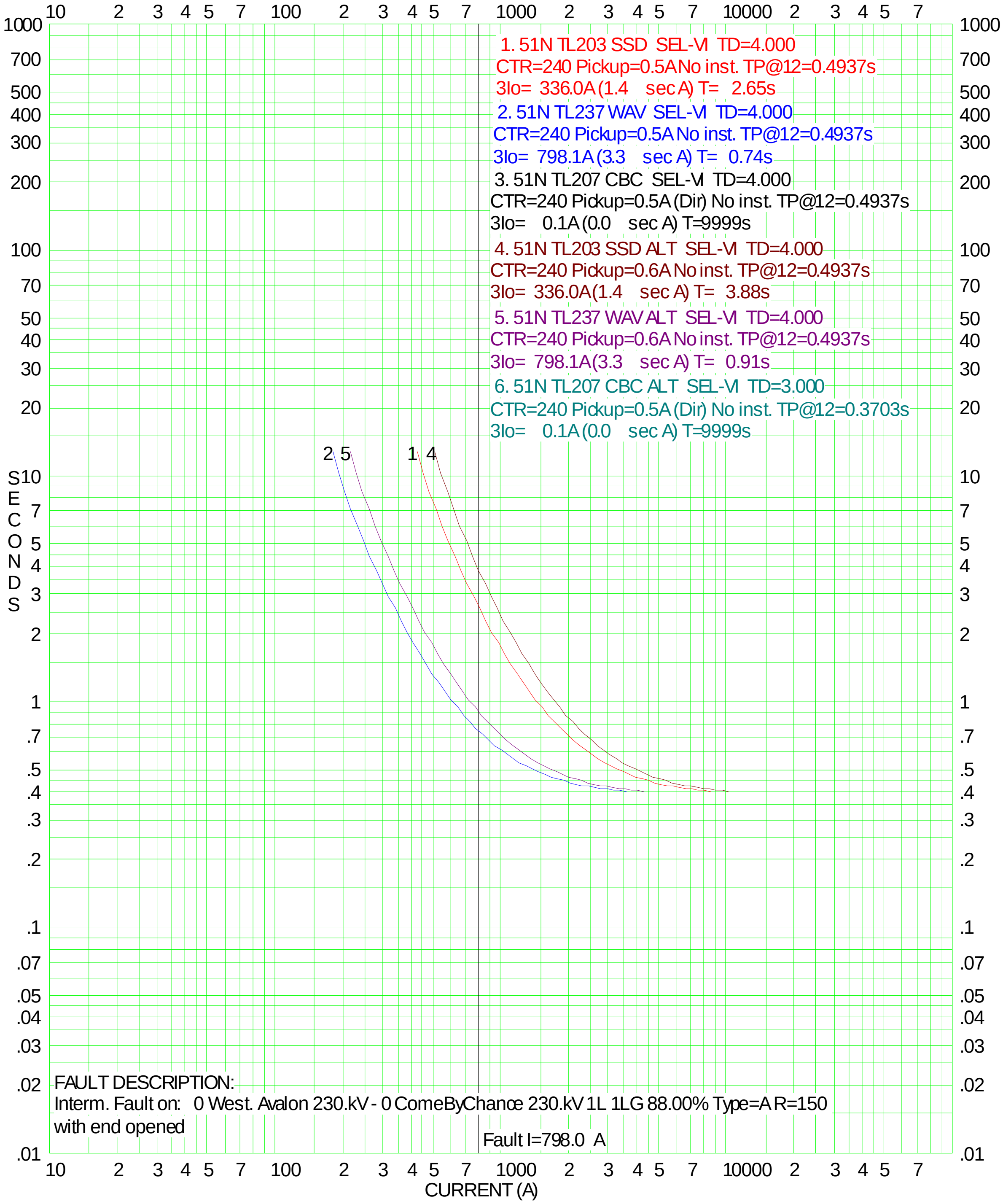
TIME-CURRENT CURVES @ Voltage 230	By CFH
For TL203 TL207 and TL237 CW coordination	No. SSD1
Comment 150 High Resistance SLG	Date 5 Nov. 2010

Figure 16 - coordination of ground time overcurrent elements for close-in fault on TL207 close to CBC



TIME-CURRENT CURVES @ Voltage 230	By CFH
For TL203 TL207 and TL237 CW coordination	No. SSD2
Comment 150 High Resistance SLG	Date 5 Nov. 2010

Figure 17 - coordination of ground time overcurrent elements for line end fault on TL203 close to WAV



SSD3	TIME-CURRENT CURVES @ Voltage 230	By CFH
For	TL203 TL207 and TL237 CW coordination	No. SSD3
Comment	150 High Resistance SLG	Date 5 Nov. 2010

<u>Figure 18</u> - coordination of ground time overcurrent elements for intermediate fault on TL237 88% from WAV with CBC terminal open.

Permissive Overreaching logic settings

EPOTT := "Y"

Z3RBD is set at remote breaker time plus channel reset time plus channel reset time plus zone 2 reset time. From review of fault records it appears that the breaker time is 3 cycles. Channel reset time is not easily determined from existing records but can conservatively be assumed to be 1 cycle, and relay reset time will also be about 1 cycle. Total time for Z3RBD is then 5 cycles.

Z3RBD := 5 cycles

Echo block delay timer blocks the echo after the local elements have picked up. This can be set relatively long since there is no significant need for the echo function shortly after the local terminal has just seen a fault but the remote terminal has not. Set at 10 cycles as per the example in the instruction manual.

EBLKD := 10 cycles

Echo time delay on pickup should be set to override noise on the communications so that it doesn't echo noise. Typical time according to the SEL application guide is 2 cycles. Since this delay only affects clearing time for relatively light (high resistance) faults that are sensed by zone 2 function at one end, the typical setting is acceptable.

ETDPU := 2 cycles

Echo duration should be long enough to ensure the permissive trip is received by the remote terminal and should also be shorter than the Z3RBD time to ensure that the reverse blocking will always be longer than any permissive trip received (including echo time stretching).

EDURD := 4 cycles

No need to enable week feed conversion to trip, since both terminals will be quite sensitive enough to detect high resistance faults after the remote terminal has cleared. Therefore we can accept sequential (or "step") clearing with no need for the added insecurity of weak infeed tripping.

EWFC := "N" **No other communications logic settings are required for this application.**

Switch on to Fault Settings

Switch on to fault logic will ensure the protection will operate when energizing the line onto a close-in three phase fault when there is no polarizing voltage available for the distance elements.

ESOTF := "Y"

The breaker close signal is not available to the relay. The 52A method of enable SOTF will be used. Therefore the Close end delay is not critical. Typical duration for enable SOTF is 10-15 cycles

ENCLO := "N" CLOEND := 0 EN52A := "Y" SOTFD := 15

Set 50H for high magnitude close-in multiphase faults with weakest source at WAV. It should be set less than 50% of the minimum close-in fault magnitude. Minimum close-in magnitude of a three phase fault with TL203 out of service is 2800 A. Therefore desired maximum setting for 50H is 1400 A. This is lower than existing.

Imin3P_close_in := 2800

$$'50H := \frac{Imin3P\_close\_in}{2CTR} \qquad '50H = 5.833 \quad \text{A secondary}$$

Choose a setting of 5. A secondary for this element. '50H := 5 A secondary

Choose a setting for 52AEND less than the shortest reclose time. '52AEND := 30 cycles

Residual overcurrent settings.

Tripping directly by instantaneous ground overcurrent is not applicable because the zone 1 ground distance is more selective. However it would be helpful to monitor steady state unbalance, and issue an alarm for continuous unbalance. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50N := 1$ $\quad$ $'50N1 := 0.25$

Negative Sequence overcurrent settings.

Similar to ground overcurrent, apply a negative sequence overcurrent element to initiate an alarm for steady state unbalances. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50Q := 1$ $\quad$ $'50Q1 := 0.25$

Voltage Element Settings

Similar to unbalance current monitoring, it is helpful to have an unbalance voltage monitor to detect steady state unbalances from the voltage supply.

EVOLT := "Y"

Set the zero sequence overvoltage element at 1% of rated voltage or just at the point necessary to override normal unbalances. The zero sequence voltage element measures 3 times the zero sequence voltage.

$$'59N := 3 \cdot 0.01 \frac{kVbase \cdot 1000}{\sqrt{3} \cdot VTR} \qquad '59N = 1.992 \qquad \text{Say} \quad '59N := 2 \text{ V secondary}$$

Loss of Potential

Enable loss of potential settings. Advanced LOP settings are not available on this model of relay.

ELOP := "Y" $\quad$ Time delay of 1.25 cycles is commonly used. $\quad$ $LOPD := 1.25$

The 50 M element should be set above maximum load and below minimum fault current for a fault at the remote terminal under weak source conditions. The maximum load for this case should be normal maximum, not emergency maximum which only exists for a few minutes before the operator can act to reduce load.

$$Imax\_normal := \frac{Speak\_237 \cdot 1000}{\sqrt{3} \cdot kVbase \cdot CTR} = 1.154 \text{ A secondary}$$

Minimum fault current for a remote three phase fault is $\quad I3Pmin = 1069 \quad$ A primary.

Minimum fault current for a remote phase to phase fault is 87% of the minimum three phase fault current level.

Dependability factor to be sure to operate for a minimum remote fault is chosen to be 1.6. $\quad DF := 1.6$

Maximum setting for 50M should be $\dfrac{0.87 I3Pmin}{DF \cdot CTR} = 2.422$ $\quad$ In this case a setting of 1.5 A secondary will be adequately dependable and secure.

$'50M := 1.5$ A secondary

The 59QL setting should be above normal maximum unbalance and below the level expected for a blown VT fuse. For a blown fuse, one phase voltage will be lost, and the negative sequence voltage will be roughly 33% of the nominal positive sequence voltage. Choose a setting of 15% of the nominal positive sequence voltage. This will be well above any normal unbalance.

$'59QL := \mathrm{round}\left(\frac{0.15 \cdot kVbase \cdot 1000}{\sqrt{3} \cdot VTR}, 0\right)$ $'59QL = 10$ V secondary

The 59PL setting should be less than the minimum voltage to be expected for a remote bus fault under weakest source conditions. There is no minimum setting (above zero) for this function. Choose a setting equal to half the voltage drop along the line impedance at the pickup setting of the 50M element.

$'59PL := \mathrm{round}[0.5 \cdot ('50M \cdot |Z1Linesec|), 0]$ $|'59PL| = 2$

Miscellaneous Scheme Settings

Pole discoordinance logic is not being used. EPOLD := "N" SPPDD := "N/A"

Enable single pole tripping by distance elements only ESPT := "Y"

Enable single pole open ESPO := "Y"

Set single pole open time delay for future SPO conditions SPOD := 0.25

3 Pole open reset delay to override small discrepancies in pole closing '3POD := 0.5

Stub line protection is not required ESTUB := "N" '50MFD := "N/A"

Trip unlatch logic not applied TULO := "N"

Logic variables and Miscellaneous timers

Minimum trip duration timer is set at 9 cycles as per the application example in the SEL-321 instruction manual.

TDURD := 9 Cycles

Trip during open pole time delay should be set longer than the reclose time. Existing setting is OK.

TOPD := 55 Cycles

Retain existing settings except use time ZT to trigger an alarm for sustained unbalance.

LOGIC_Z := "59N+50N1+50Q1" TZPU := 1200 cycles TZDO := 0 cycles

Tripping Logic

Permissive tripping is required only for instantaneous overreaching functions. No need for any functions that trip directly. Existing 51NT word in MTCS is not required.

MTCS := "M2P+Z2G"

Unconditional tripping MTU := "M1P+Z1G+M2PT+Z2GT+51NT"

No need for existing direct tripping zone 1 functions in the switch on to fault logic.

The revised tripping logic includes the timer YT to add a 1 cycle delay to the zone 1 tripping elements.

SOTF Tripping MTO := "M2P+Z2G+50H"

Event records will be triggered automatically by all trip events. Other event record triggers should be by starting of other elements to ensure capture of all relevant events. Events should be triggered by keying or receiving permissive trips to ensure separation of relay and teleprotection issues.

MER := "M2P+Z2G+51N+LOP*52AA1+LOP*52AA2+KEY+PT+EKEY"

Outputs

Retain existing output assignments except add the continuous unbalance alarm to OUT15.

OUT15 := "LOP*50L+ZT"

Input Contact Assignment

Retain existing input assignments.

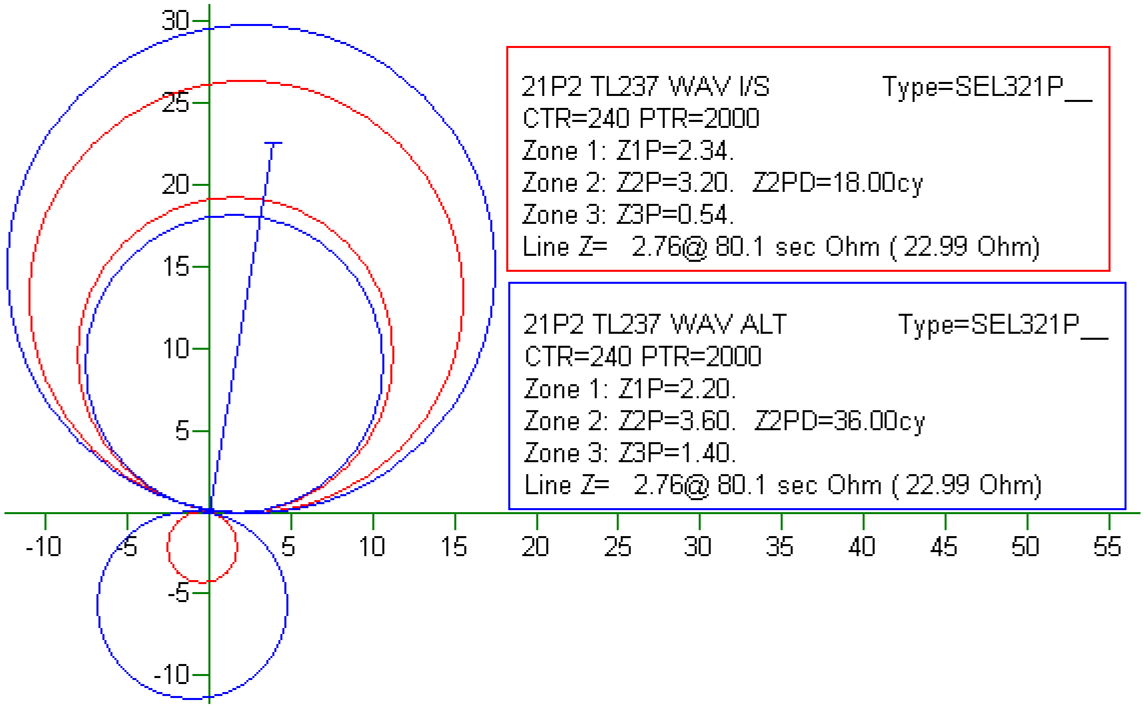


Figure 19 - Comparison of phase distance characteristics. Red is existing, blue is proposed alternative

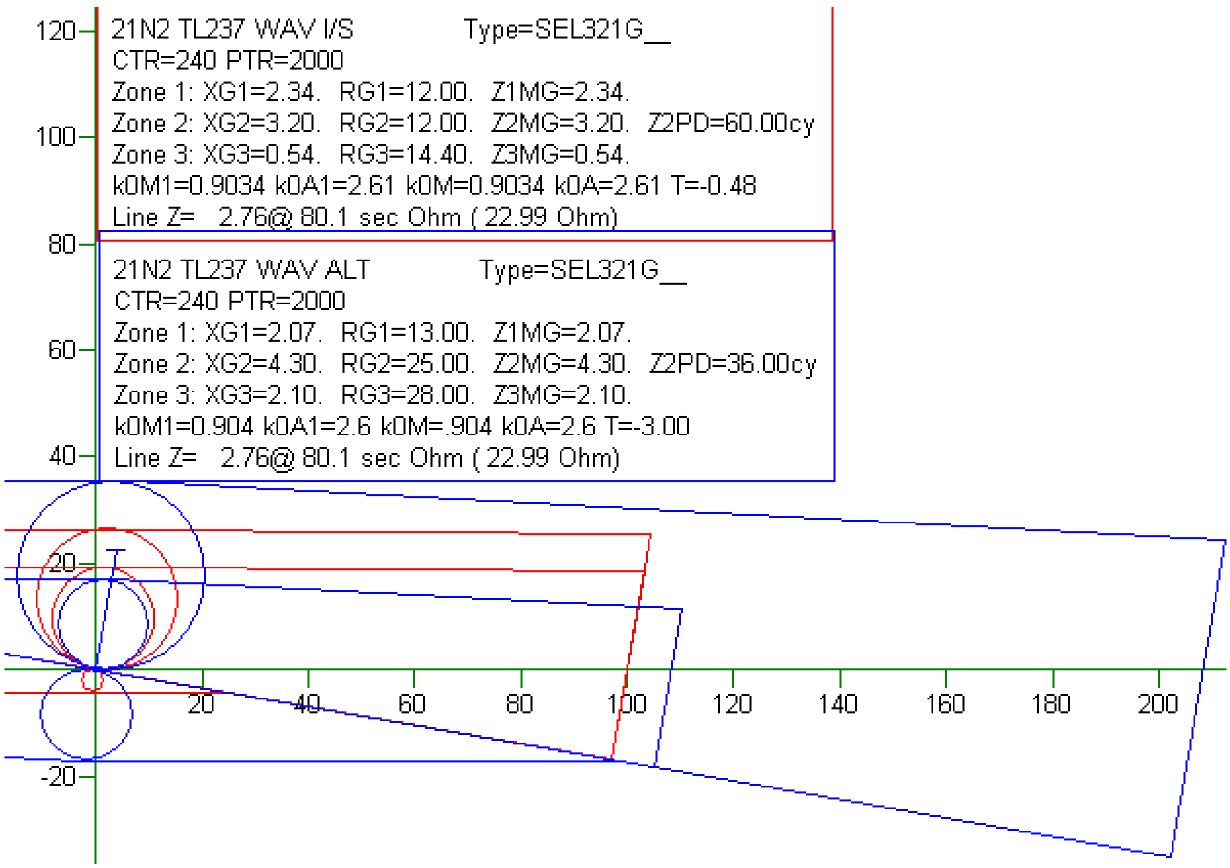
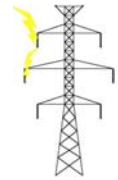


Figure 20 - Comparison of ground distance characteristics. Red is existing, blue is proposed alternative



230 kV Line Protection Review

Report Presentation

Prepared by C. Henville
Henville Consulting Inc. – December 2010

Charles Henville - Introduction

- Background and education
- Career
- Protection projects
- Seminars and training courses
- IEEE activities

Career

- Education in West Indies and England
- Commissioning engineer
  - GEC Gas Turbines 1970-1974
  - BC Hydro 1974-1977
- System protection engineer – BC Hydro 1977-2004
- Consulting protection engineer – Henville Consulting Inc. 2005-date

Protection Projects

- BC Hydro - numerical relay introduction
  - Transmission line protection late ‘80s
  - Generator protection early ‘90s
- Canada
  - Yukon Energy Corporation
  - AltaLink
  - Fortis BC
  - NL Hydro, CF (Labrador) Corporation
- International – USA (legal cases), Malaysia, Indonesia, Saudi Arabia, New Zealand

Training courses and seminars

- Protection – APEGBC, UBC, University of Wisconsin, INP de Grenoble, Gonzaga University, IEEE Vancouver Section
- ASPEN OneLiner - NL Hydro, Iraq Power, ITC, PGE, Fortis BC, Transco Abu Dhabi, Northeast Utilities

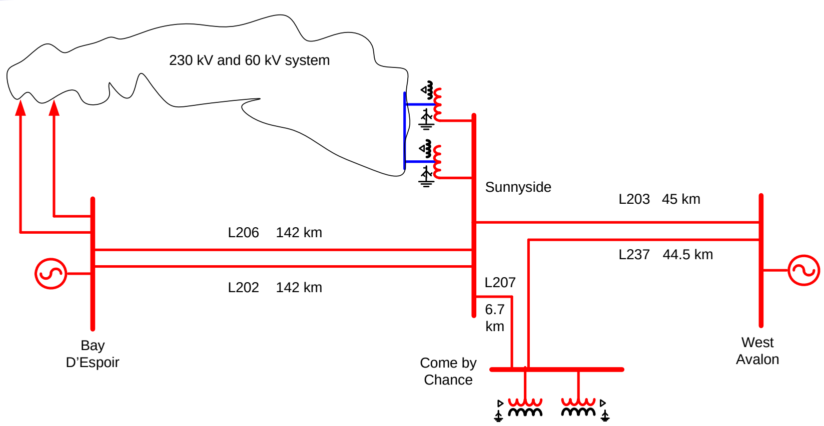
IEEE activities

- Vancouver, PES Chapter Chair, Section Chair
- Transactions and conferences paper reviewer
- PES Power System Relaying Committee, S/c Chair, Committee Chair
- IEEE Fellow, Distinguished lecturer

Line Protection Review Project execution

1. Deliverables
   - settings review report
   - Possible protection and telecomm upgrade report
2. Project start up meeting (August)
3. Setting/coordination study. Draft settings review report (Sept. Oct.)
4. Obtain feedback on settings report (continuous)
5. Finalize settings review report and draft upgrade report (November)
6. Report presentation (December)
7. Finalize reports (by 31 December)

Simplified system diagram



Summary

- Established performance requirements
- Reviewed model of power system
- Reviewed historical disturbances
- Detailed review of existing applications and settings
- Propose revised settings
- Propose modifications

Recommended non capital work

- Revise power system model
- Revise various settings
  - Protection
  - Teleprotection
- Retain more detailed disturbance data

Recommended capital work

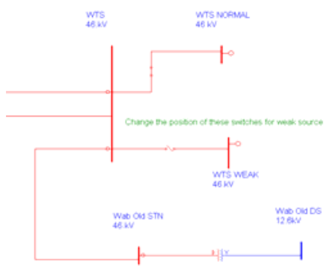
- Replace optimho relays
- Re-wire breaker contacts to SEL321s
- Remove electromechanical 51N relays
- Replace agastat timers
- Modify automatic reclosing schemes
- Modify teleprotection
  - Separate P1 and P2 systems
  - Add independent facilities

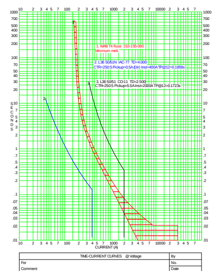
Performance Requirements

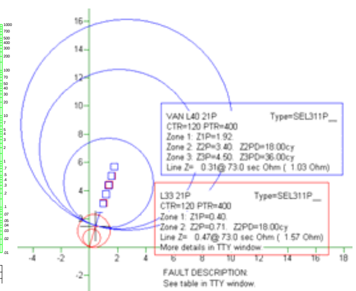
- Redundancy required
- Loadability 2X normal maximum load
- 6 cycle clearing
- 100 ohm SLG fault resistance
- Single phase trip and reclose three lines – three phase trip and reclose two lines (to CBC)

Modeling

- Aspen OneLiner short circuit and relay coordination program.





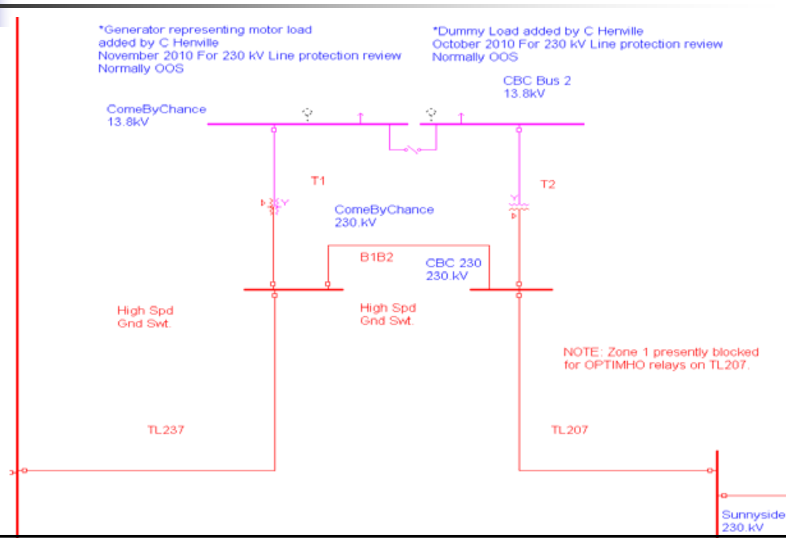


System Model

- Added mutual coupling to lines under review
- Clarified contingencies – lightly loaded system has many BDE generators OOS
- Added simulated load and generation to some busses for protection review purposes
- Modified some generator reference angles and transformer phase shifts to improve pre-fault solution.
- For protections under review, replaced SEL-321 relay settings with more accurate models of relay

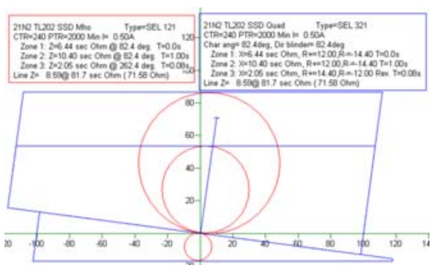
TL201 and TL217 Mutual Coupling

Aspen OneLiner Model

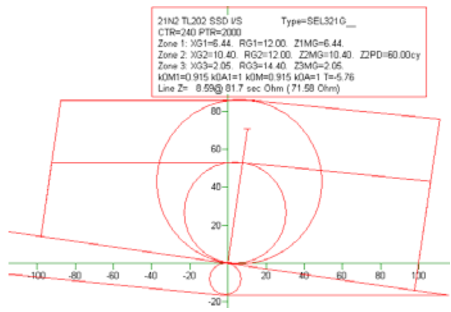


SEL321 Relay Models
Differences in Characteristics...

SSD TL202 P2 21G Older model

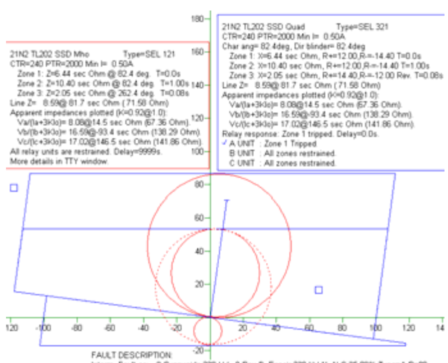


SSD TL202 P2 21G Newer model

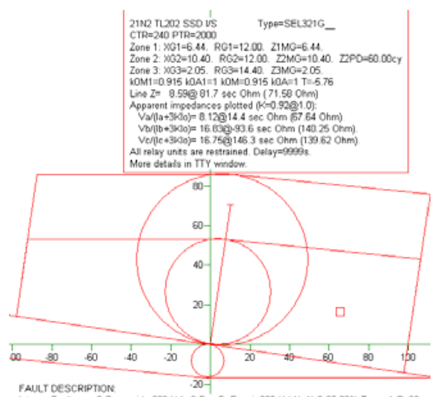


.... and in performance
(80 Ohm SLG at 25% from SSD)

SSD TL202 P2 21G Older model



SSD TL202 P2 21G Newer model

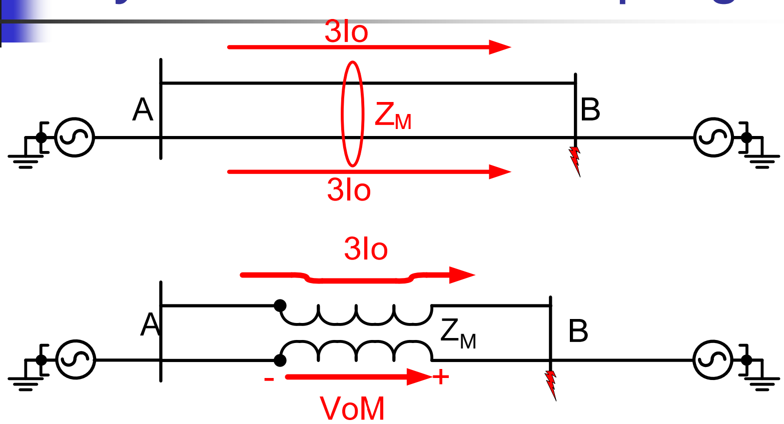


(Zero Sequence) Mutual Coupling

Double circuit lines ✓

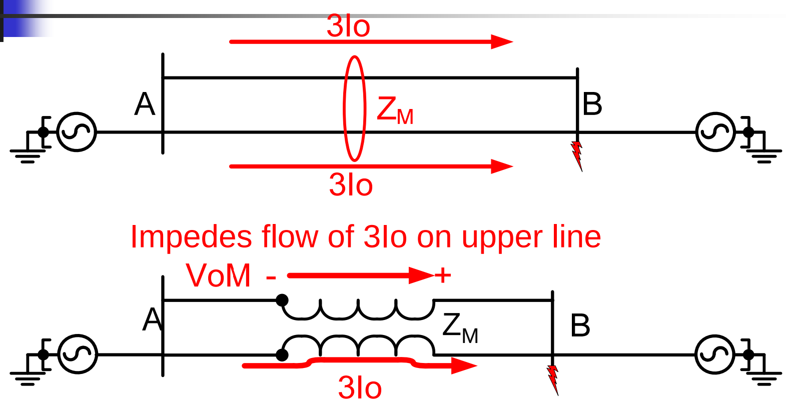
Long lines on same right of way ?

Physics of Mutual Coupling

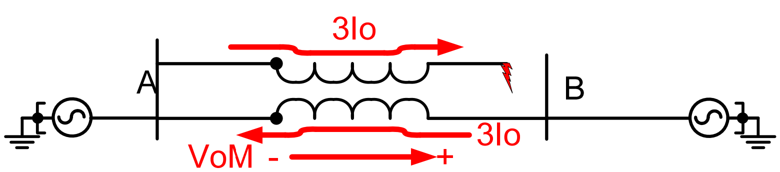


Impedes flow of 3Io on lower line

Physics of Mutual Coupling



Physics of Mutual Coupling



Mutual coupling assists flow of 3Io in both lines when direction is opposite

Previous disturbance analysis

- Most faults cleared OK.
- Some failures to reclose reported

Analysis TL202 SLG 21 July 2010

- Resistive (35Ω) SLG close to BDE
- BDE terminal Zone 1 trips first then SSD Zone 1 trips sequentially
- Analysis shows SSD Zone1 should not have seen this fault
  - CVT transient performance problem?
  - Incorrect assumed fault location?
  - Inaccurate model?

Sequential Zone 1 clearing at SSD

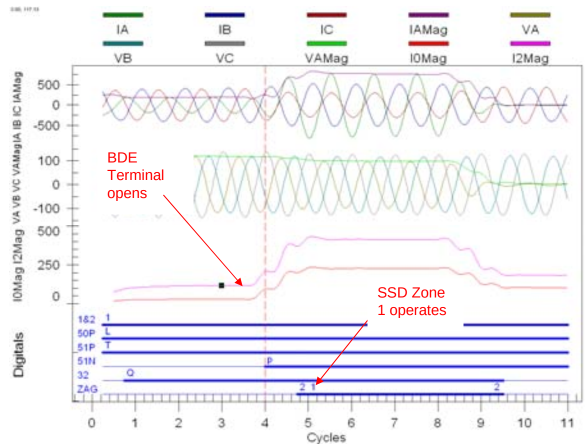
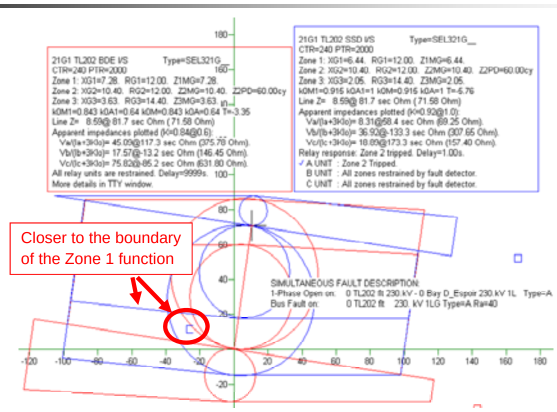


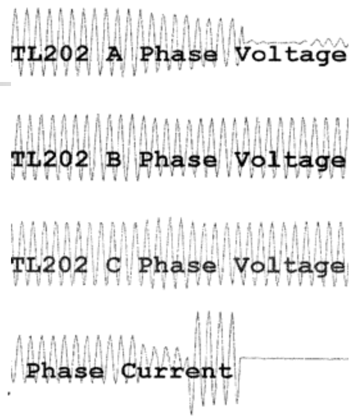
Figure 13 - Sequential operation of the SSD TL202 protection.

Not according to model!



Conclusions regarding TL202 SLG 21 July 2010

- SSD CVT performance could be a problem
- Fault location was further away from BDE than reported.



Fault found between STR 1 and 2. ≃ 600 meters from BDE Station.

Analysis TL203 SLG 2 Dec 2007

- Solid (0Ω) SLG close to SSD
- TL203 trips 1 phase and recloses at SSD
- TL203 trips 3 phase at SSD and WAV
- TL237 trips 3 phase at WAV during second fault at SSD
- Avalon peninsula collapse

Fault at SSD – broken shield wire

Initial trip at SSD

21:11:03.800	Sunnyside	77/TL203		SENT
21:11:03.804	Western Avalon	85-TL203		RECEIVED
21:11:03.805	Sunnyside	21P1/P2-TL203	Simultaneous	TRIP
21:11:03.805	Sunnyside	85-2/TL207		RECEIVED
21:11:03.808	Sunnyside	94C1-TL203		TRIP
21:11:03.808	Sunnyside	94C2-TL203		TRIP
21:11:03.815	Western Avalon	21P1/P2-TL203		FAIL
21:11:03.818	Sunnyside	85-TL203		RECEIVED
21:11:03.819	Western Avalon	94C2-TL203		TRIP
21:11:03.835	Bay d'Espoir TS	77-TL206 PRI	35 ms after SSD saw the fault, and nothing from BDE TL202	SENT
21:11:03.835	Bay d'Espoir TS	77-TL206 SEC		SENT
21:11:03.840	Sunnyside	85-TL206 PRI		RECEIVED
21:11:03.845	Western Avalon	94C1-TL203		TRIP
21:11:03.852	Sunnyside	85-TL206 SEC		RECEIVED

Trip on reclose at SSD

21:11:04.554	Sunnyside	85-2/TL207	PT rec'd from CBC 4 ms before SSD sees fault	RECEIVED
21:11:04.558	Sunnyside	21P1/P2-TL203		TRIP
21:11:04.558	Sunnyside	77/TL203		SENT
21:11:04.560	Sunnyside	94C2-TL203		TRIP
21:11:04.560	Western Avalon	B-L01L03		OPERATED
21:11:04.561	Sunnyside	94B2-TL203		TRIP
21:11:04.561	Sunnyside	94L2-TL203		TRIP
21:11:04.561	Western Avalon	85-TL203		RECEIVED
21:11:04.562	Sunnyside	94A2-TL203		TRIP
21:11:04.562	Sunnyside	94C1-TL203		TRIP
21:11:04.565	Sunnyside	T-B1L03		OPERATED
21:11:04.565	Western Avalon	94L1-TL203		TRIP
21:11:04.580	Western Avalon	T-L03L17	> 34 and 47 ms after CBC saw the fault, and nothing from BDE TL202	OPERATED
21:11:04.583	Sunnyside	T-L03L06		OPERATED
21:11:04.587	Western Avalon	T-L01L03		OPERATED
21:11:04.588	Sunnyside	85-TL206 PRI		RECEIVED
21:11:04.601	Sunnyside	85-TL206 SEC		RECEIVED

Observations from SOE

- Very high speed teleprotection
- Marginal operation of BDE TL206 Zone 2 and no operation of BDE TL202 Zone 2

WAV TL237 just "sees" SSD Reclose onto fault

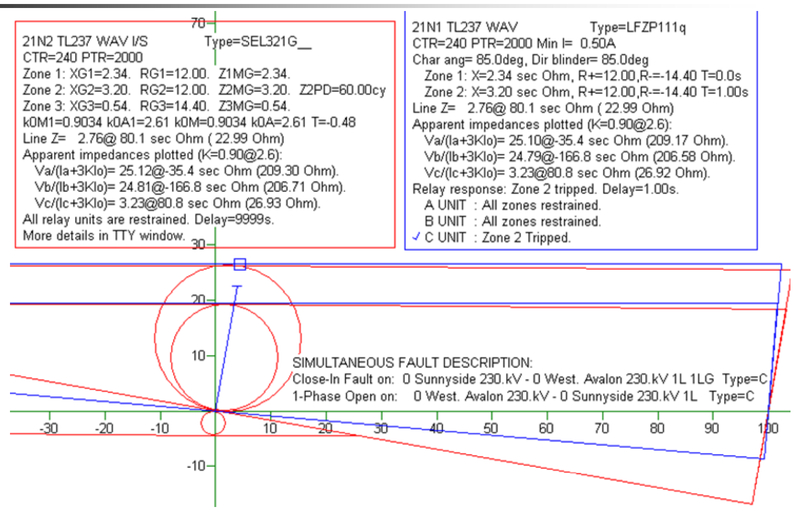


Figure 1 - Simulation of WAV TL237 Protection during SSD Reclose onto fault

WAV TL237 just "sees" SSD Reclose onto fault

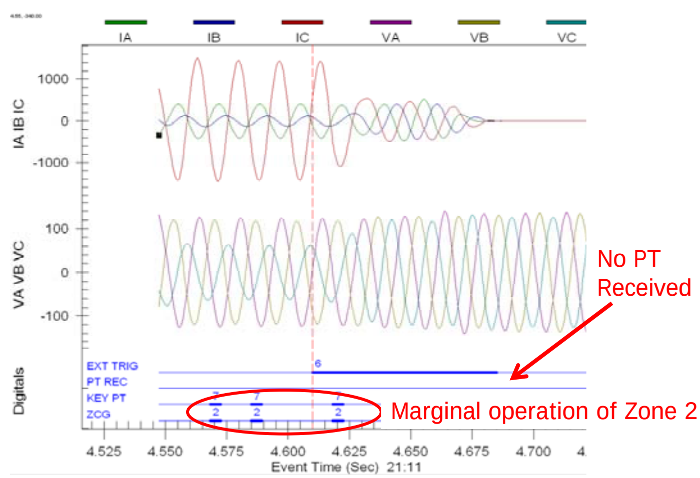
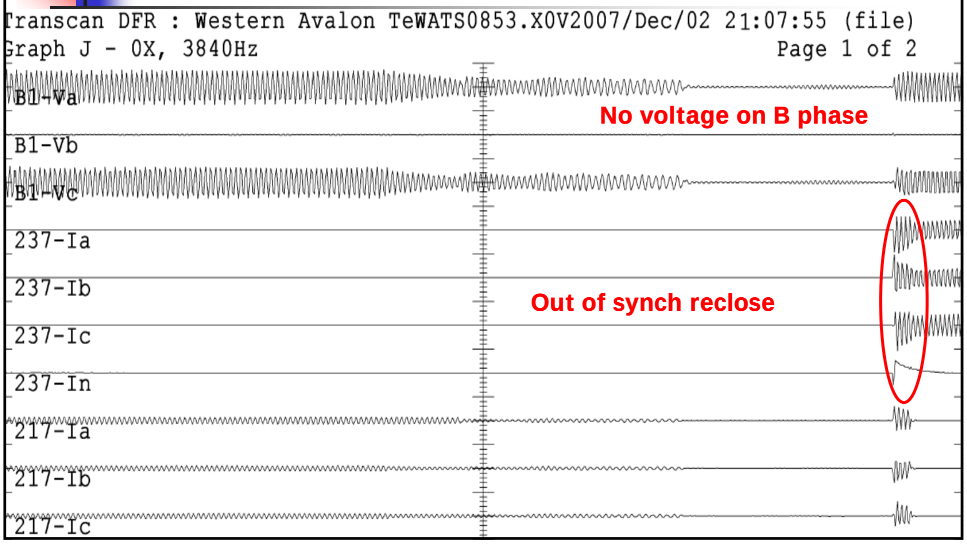


Figure 1 - Event record from WAV TL237 21P2 during fault on reclose

WAV TL237 Out of Synch Reclose



Conclusions regarding 2 December 2007 disturbance

- WAV SEL relay shows no received PT from CBC, but sampling rate is only 4/cycle
- Unlikely that optimho would trip “aided” if teleprotection input was not asserted
- Important to retain records from teleprotection equipment
- Teleprotection interface should be contact, not solid state

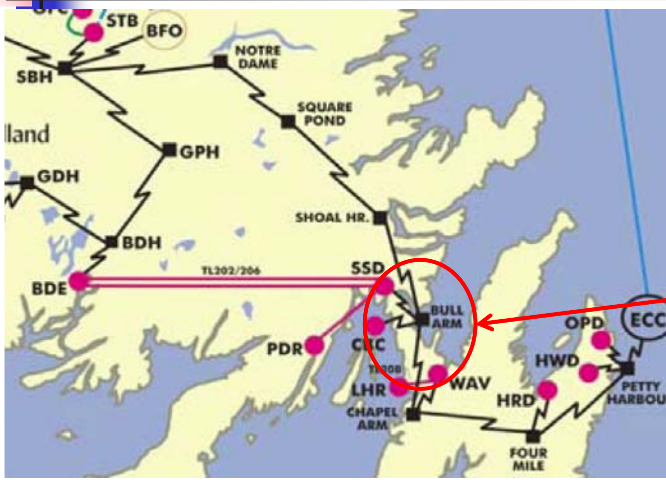
General Issues

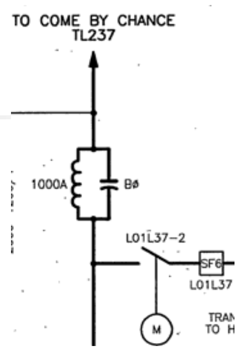
- Teleprotection
- Ground Distance
- Optimho Relays
- Reclosing and auxiliary logic
- Single Pole open status
- Ground time overcurrent protection
- SSD CVT transient response
- Distance element current supervision
- Monitoring of fault records
- Breaker Failure protection

Teleprotection Sharing

- Permissive trip relays coordinate forward and reverse looking elements at each end
  - Different relays (e.g. SEL and optimho) at each end have different responses
  - P1 and P2 channels must not be shared
- TL202 and TL206 have primary and secondary channels
- What about the other three circuits?
  - Secondary microwave?
  - Secondary power line carrier?

Telecommunications





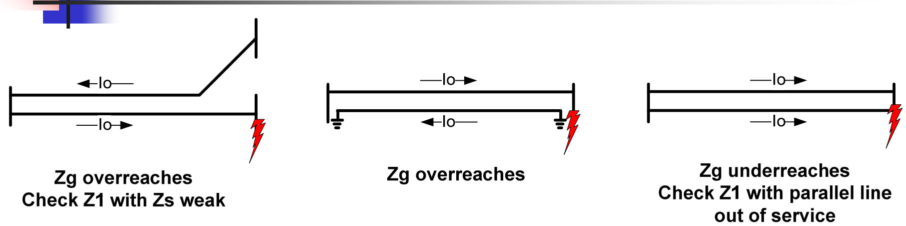
Teleprotection Performance

- Redundancy
  - Independent channels minimize common mode failure
    - Eg. independent microwave
    - Or, microwave and PLC
- Speed – existing is faster than needed
  - Add security delay
  - Use dry contact outputs
- Monitoring – retain event records

Ground distance protection

- Mutual coupling
  - Zone 1 overreach
  - Zone 2 underreach
- Sensitivity to resistive faults
  - Remote infeed reduces sensitivity
  - Use echo function or rely on sequential tripping

Effect of Mutual coupling



May also add parallel line I0 compensation.
More accuracy and extra complexity.
Check polarity of compensation input.

Zone 1 overreaches

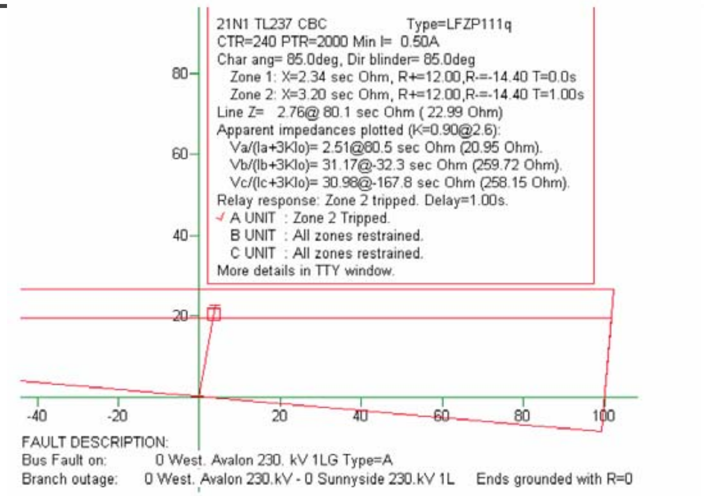


Figure 8 - Apparent impedance to a fault just beyond the remote terminal is reduced by 10% when parallel line is out of service and grounded at both ends.

Zone 2 underreaches

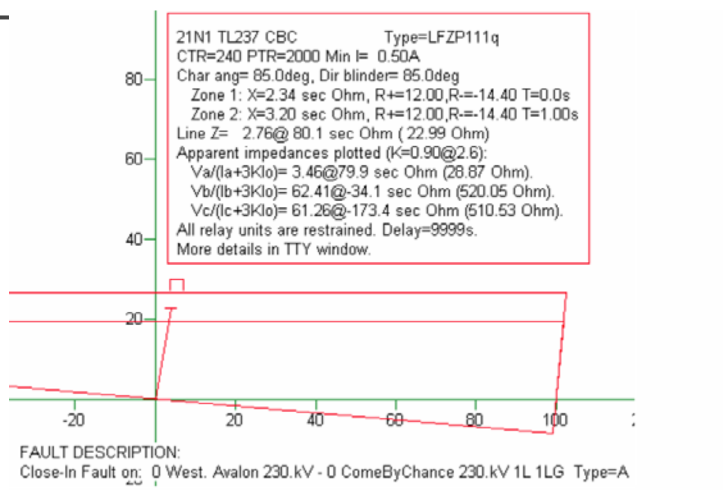
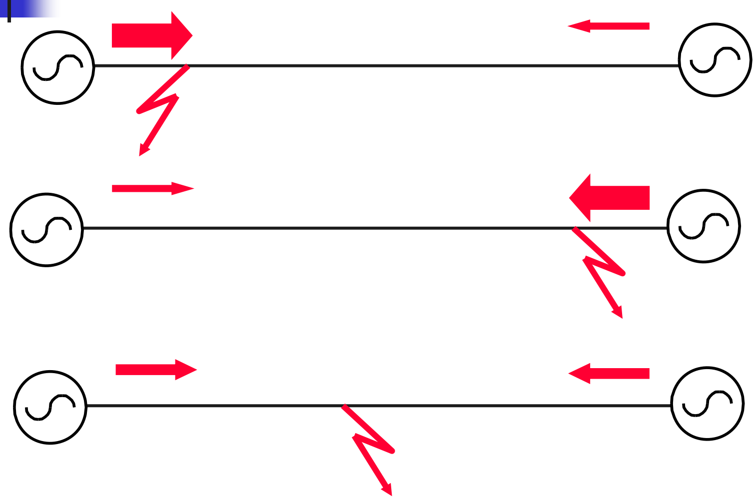
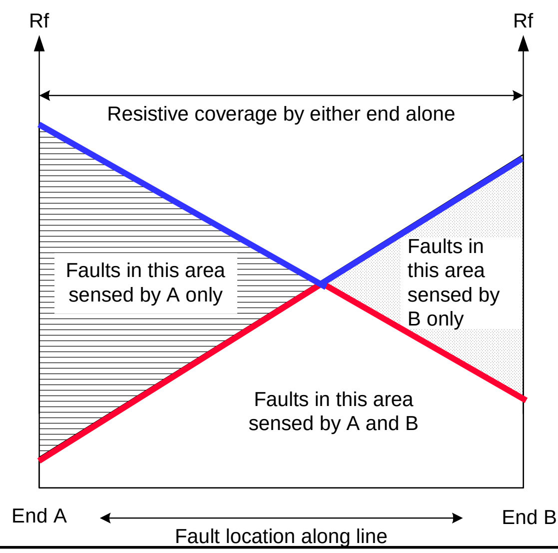


Figure 9 - Apparent impedance to a fault close to the remote terminal is increased by 25% when parallel line is in service. Relay will not operate with existing settings for this fault.

Effect of infeed on sensitivity to resistive SLG faults



Effect of sequential clearing (or sensing)



Echo function will allow permissive tripping even if only one terminal Zone 2 sees the fault

If both ends have to see the fault simultaneously

Increasing sensitivity by use of sequential sensing

- Use communications or time to allow weak source to become strong sequentially.
  - DCB scheme will trip if either end senses a fault and no block received
  - POTT scheme **with echo** will trip if either end senses a fault and no block allows echo from remote terminal
  - Time will allow the communications independent relay at the stronger source to trip first
- Change the mountain to a valley!

Optimho protection systems

- Aging (18-20 years old)
- Lack of analogue recording hampers disturbance analysis
- Phase and ground distance elements cannot be set independently (optimally)
- Resistive reach of Zone 1 and Zone 2 quads have to be the same
  - TL207 Zone 1 disabled
- POR1 scheme has no weak source echo

Reclosing and auxiliary logic

- Most historical problems due to failure to reclose
- Some auxiliaries use agastat timers (unreliable)
- Synch check should check all three phase voltages for dead bus/dead line

Single Pole Open Status

- SEL relays rely on individual pole status to enable/disable appropriate ground distance elements
- Problems in providing this
  - Lack of spare CB aux outputs
  - Lack of spare relay inputs
- Same will apply to P1 systems if Optimhos replaced

Open Pole Mho disabled during SPO All other phases enabled during SPO

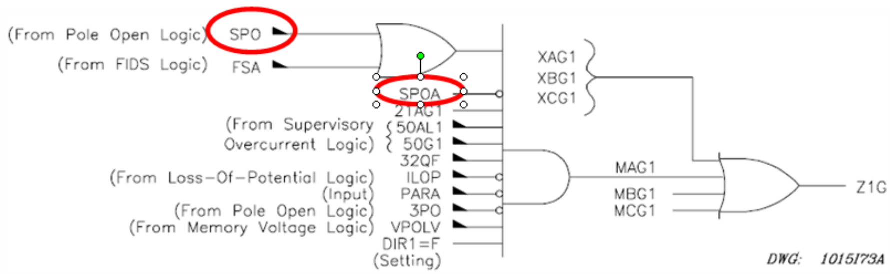


Figure 2.10: Zone 1 Mho Ground Distance Element Logic

All quads disabled during SPO

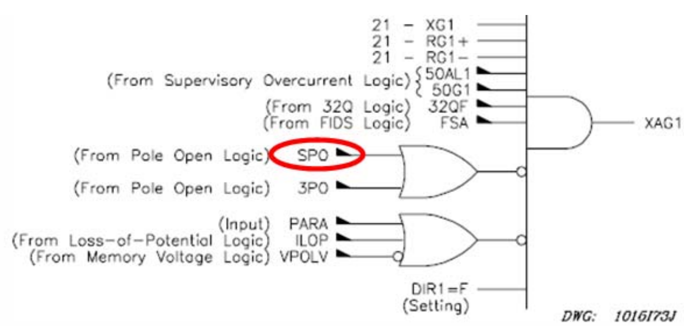
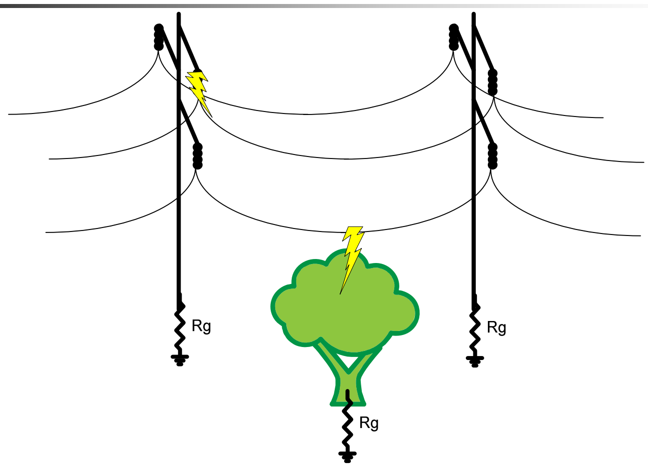


Figure 2.14: Zone 1 Quadrilateral Ground Distance Element Logic

Ground time overcurrent and resistive Faults



Notwithstanding low tower footing resistance, trees don't follow the same rules

Brown Trees – August 2009

A different perspective

No more fault resistance

Ground time overcurrent

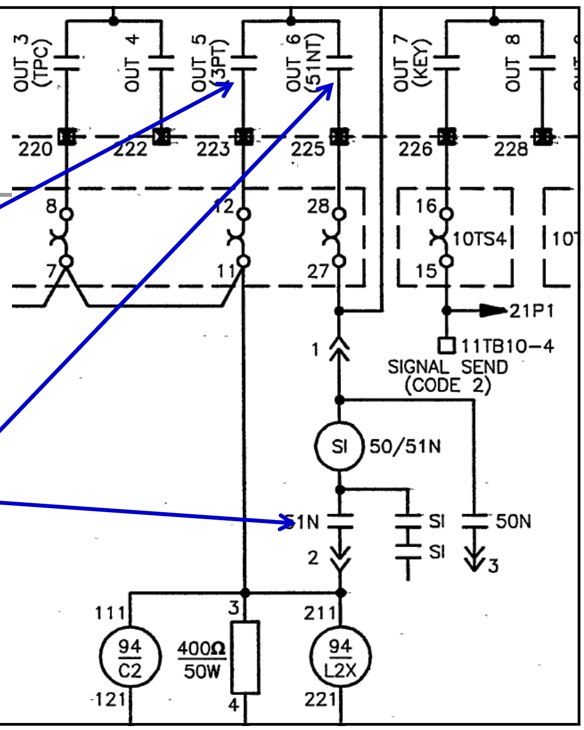
- Existing electromechanical relays add little value
- NL Hydro appears to like to use standard settings for 51N elements
- Not possible to always maintain coordination with standard settings
- Recommend checking coordination for each application

Internal 51NT trips directly

MTU = $\overline{\text{M1P + Z1G + M2PT + Z2GT + 51NT}}$

And supervised by external 51N

OUT6 = $\underline{\text{51NT}}$



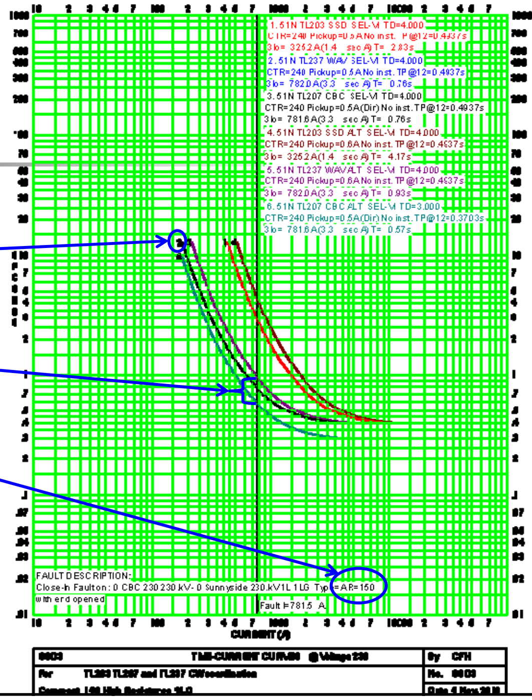
CBC has no infeed to help coordination

Curves 2 and 3 overlaid on each other

Alternative settings coordinate at checked current.

Coordination checked for high resistance fault.

Depend on ZG for lower resistance faults



Sunnyside CVT transient response

- Buchans TL205 CVTs were faulty and replaced in 2003
- SSD TL202 and TL206 are same type?
  - Two Trench Electric
  - Four Haefely>> Trench
- TL202 and TL206 Zone 1 reaches reduced to 75% in August 2003
- Transient performance can be conclusively determined by comparing traces electronically using fault recorder display software

TL206 A phase
(TL202 A Ph. same)

TL206 B phase
(All other phases same)

Distance element current supervision

- Current supervision prevents distance element from operating with no voltage
- Historically, many users set current supervision above load current to prevent misoperation on loss of potential (LOP)
- Modern relays will block distance elements on LOP
- Maybe just set zone 1 supervision above load?

Fault Recording

- Available recorders
  - Sequence Of Events (SOE)
  - Relay records
    - Sequential Events Recorder (SER)
    - Analogue
      - Filtered (default)
      - Unfiltered
  - Teleprotection records
  - DFR records

Sequence Of Events

- Provides system wide correlation of events
- Resolution down to 1 ms
- GPS synchronized
- Includes some auxiliary relay latency
- Workhorse of event analysis

2007-12-02 21:11:03.805	Sunnyside	21P1/P2-TL203	TRIP
2007-12-02 21:11:03.805	Sunnyside	85-2/TL207	RECEIVED
2007-12-02 21:11:03.808	Sunnyside	94C1-TL203	TRIP
2007-12-02 21:11:03.808	Sunnyside	94C2-TL203	TRIP
2007-12-02 21:11:03.815	Western Avalon	21P1/P2-TL203	FAIL
2007-12-02 21:11:03.818	Sunnyside	85-TL203	RECEIVED

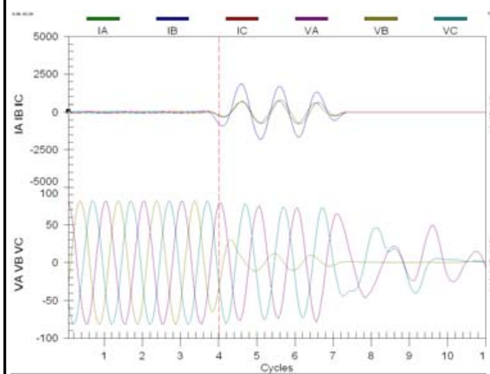
Figure 18 - SOE record during initial fault

Relay records

- SER (not available in early models of SEL-321) – provides correlation of relay I/O and element operations
- Event Record provides analogue information correlated with selected events.
  - Choose sampling rate > 1kHz for resolution at least as good as SOE (960 Hz max for SEL321)

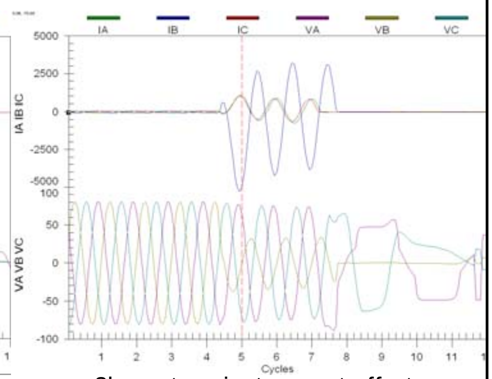
230 kV fault fed by wind farm

Filtered



Shows AC Current decrement
(except for first peak)

Unfiltered



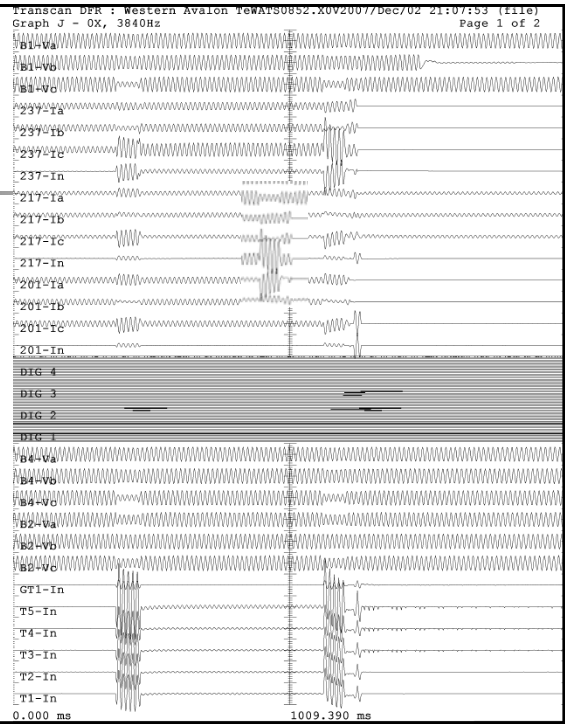
Shows transient current offset
and CVT transients

Teleprotection records

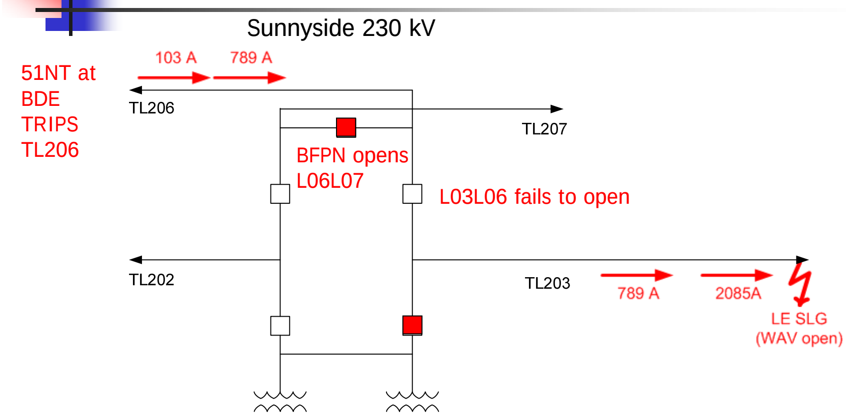
- MTS module of RFL multiplexer includes sequence of events recorder.
  - Provides detailed record of I/O events
  - Retrieve and store routinely after significant disturbances
- NSD50 Power Line carrier does not include event recorder?

DFR Records

- Electronic storage and analysis is good
- But need a widely accessible means of processing
- Comtrade format is best



Breaker failure protection

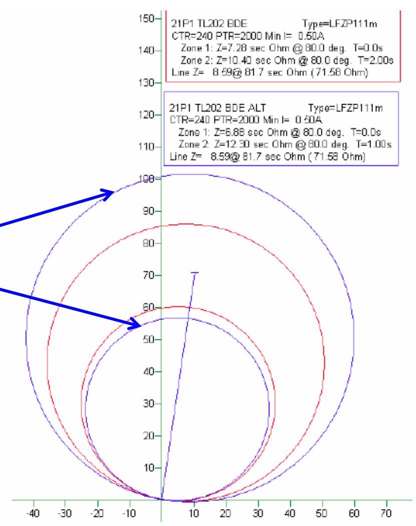


For multiphase faults

- 51NT will not operate for 3 phase or 2 phase (without ground) faults
- Phase distance relays at BDE TL206 will not see multiphase TL203 LE fault near WAV
- Don't expect more than one phase of L03L06 to fail to open
- Fault will convert to SLG or self clear
- CBC B1B2 breaker trips three phase. Is multiphase breaker failure credible?
- Breaker failure criteria should be defined

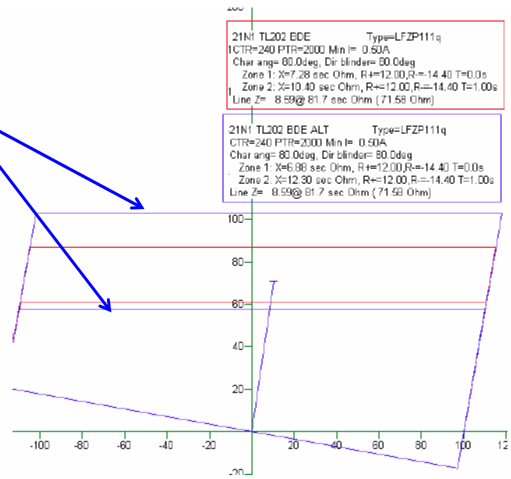
BDE TL202 and TL206 21P1

Zone 1 reduced and Zone 2 increased because of requirements of ground distance protection



BDE TL202 and TL206 21N1

Zone 1 reduced and Zone 2 increased because of impact of mutual coupling

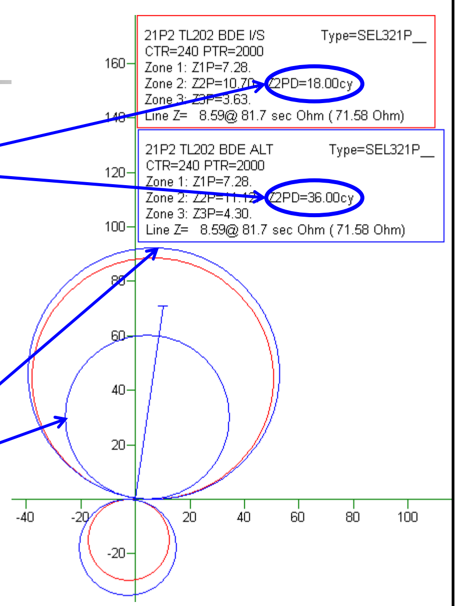


BDE TL202 and TL206 21P2

Zone 2 time delay increased to coordinate with SSD TL207 Zone 2

Zone 2 short delay could be retained and reach reduced, and zone 4 added with longer reach and longer time delay to coordinate with SSD TL207 Zone 2

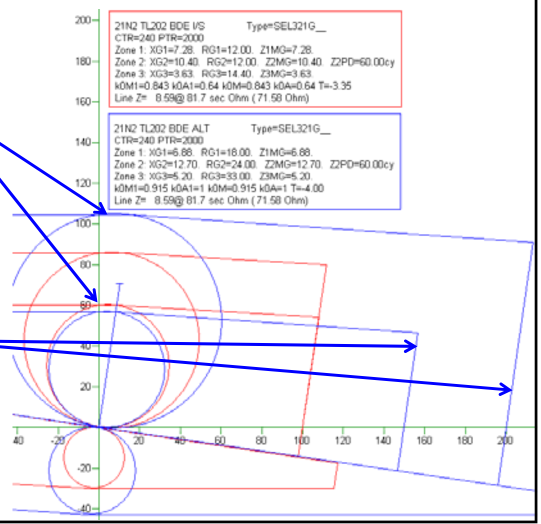
Zone 1 no change and Zone 2 increased slightly for dependability



BDE TL202 and TL206 21N2

Zone 1 reduced for security and Zone 2 increased for dependability

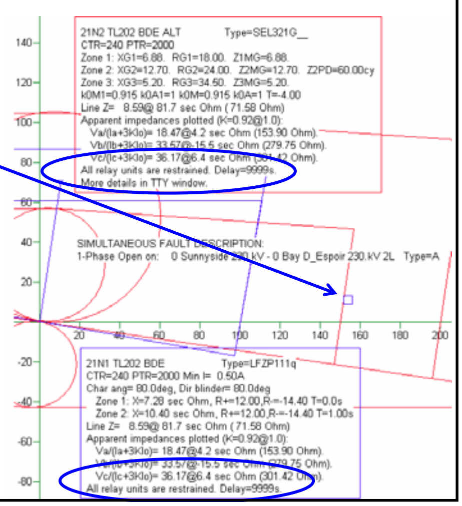
Zone 1 and 2 resistive reach increased for sensitivity to resistive faults



Heavy power flow and SPO threatens security of sensitive quad elements

Impedance appears inside reach of 21N2 quad

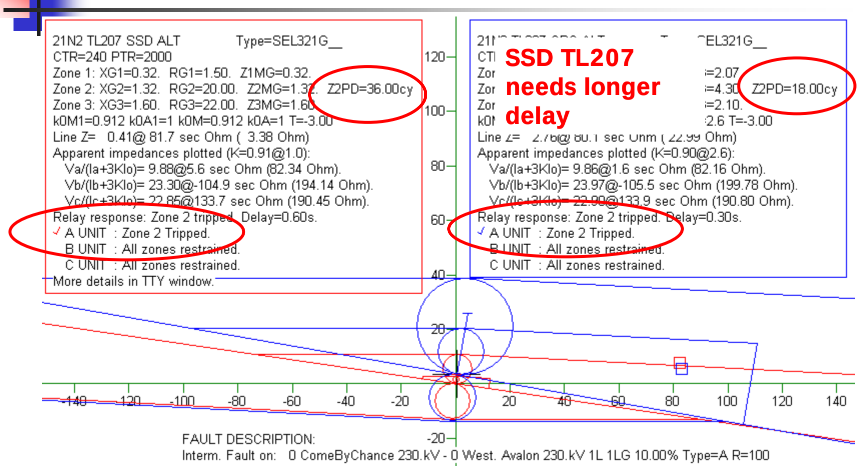
Check security during SPO with power flow modeled and detailed relay model



Note regarding longer zone 2 resistive reach

- Normally OK when there is heavy infeed at remote station (eg BDE, SSD and WAV)
- Needs longer than normal zone 2 timer to with TL237 Zone 2 ground at CBC since there is no infeed at CBC.

CBC TL237 and SSD TL207 Z2G both operate for same fault on TL237

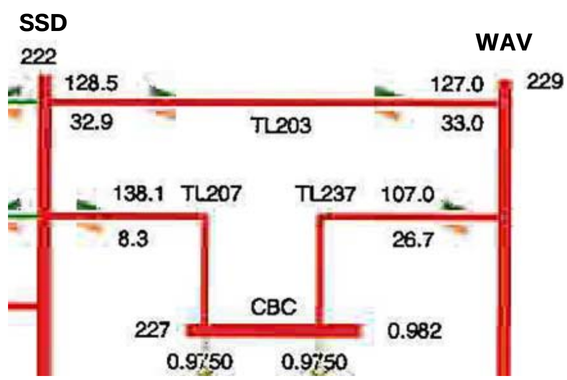


SSD TL203

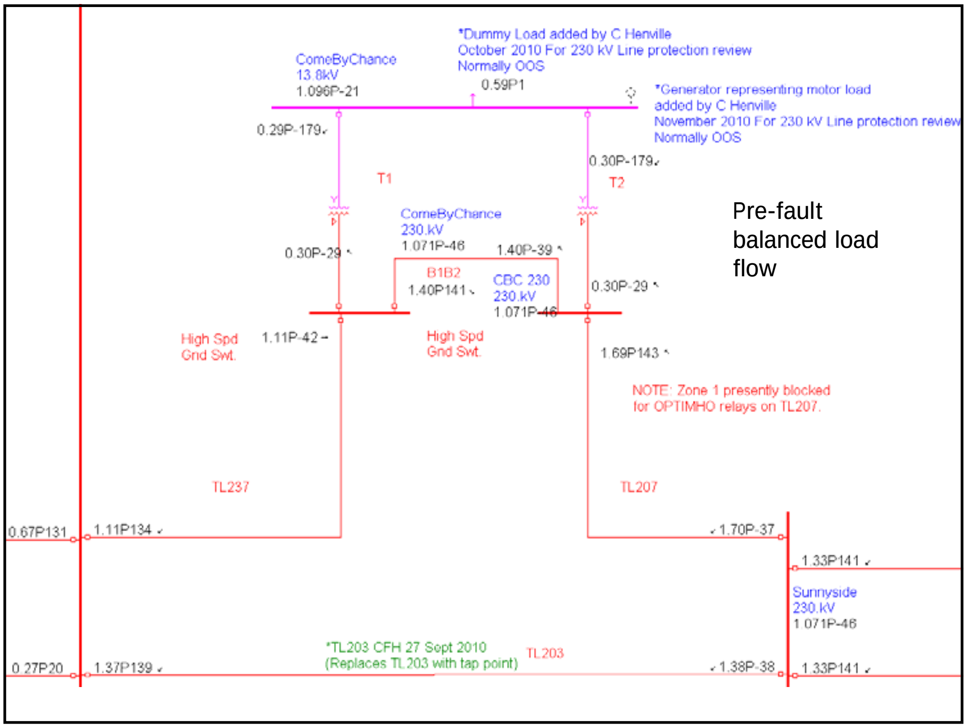
- Many recommended changes similar to TL202 and TL206
- But shorter line results in more zero sequence current during SPO.
- Recommend increasing time dial of 51N element.
- Also more ground time overcurrent coordination difficulties in TL203, TL207 and TL237 loop due to extra station in chain.

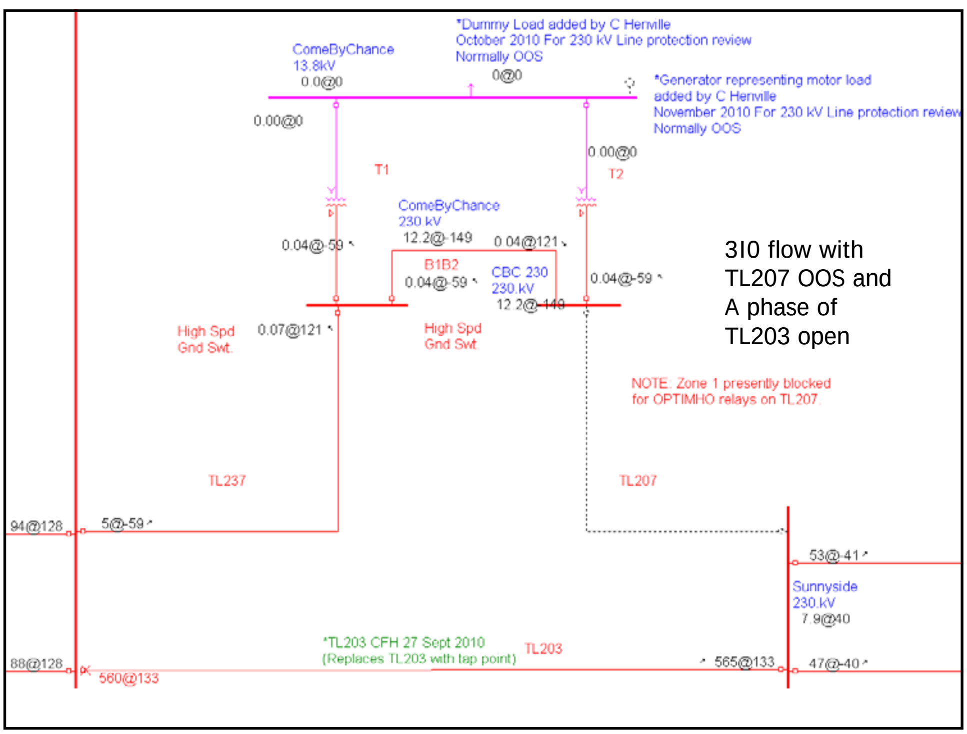
Heavy power flow under contingency

With sudden outage of TL207, TL203 will carry about 270 MVA until operators adjust load/generation



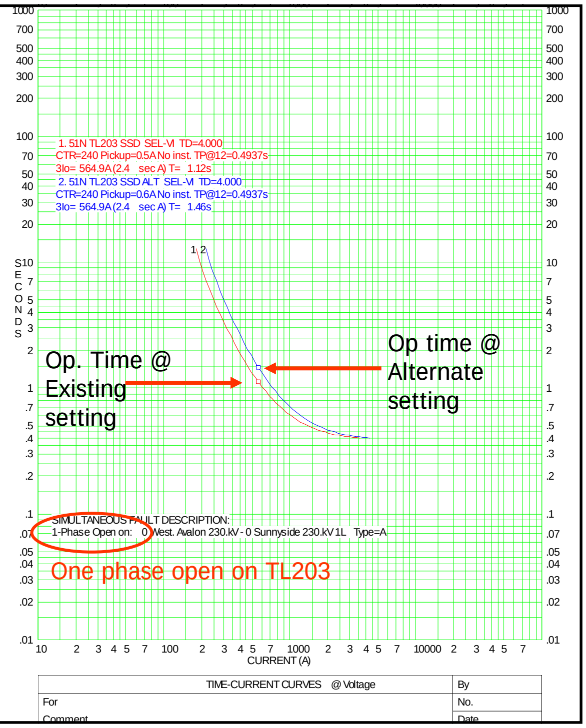
What if TL203 trips single pole while loaded heavily?


*Dummy Load added by C Henville
October 2010 For 230 kV Line protection review
Normally OOS
ComeByChance
13.8kV
1.096P-21
0.59P1
*Generator representing motor load
added by C Henville
November 2010 For 230 kV Line protection review
Normally OOS
0.29P-179
0.30P-179
T1
T2
ComeByChance
230 kV
1.071P-46
1.40P-39
0.30P-29
B1B2
1.40P141
CBC 230
230 kV
1.071P-46
0.30P-29
High Spd
Gnd Swt.
1.11P-42
High Spd
Gnd Swt.
1.69P143
NOTE: Zone 1 presently blocked
for OPTIMHO relays on TL207.
TL237
TL207
0.67P131
1.11P134
1.70P-37
1.33P141
Sunnyside
230 kV
1.071P-46
*TL203 CFH 27 Sept 2010
(Replaces TL203 with tap point)
TL203
0.27P20
1.37P139
1.38P-38
1.33P141
Pre-fault
balanced load
flow


*Dummy Load added by C Henville
October 2010 For 230 kV Line protection review
Normally OOS
ComeByChance
13.8kV
0.0@0
0@0
*Generator representing motor load
added by C Henville
November 2010 For 230 kV Line protection review
Normally OOS
0.00@0
0.00@0
T1
T2
ComeByChance
230 kV
12.2@-149
0.04@-59
0.04@121
B1B2
0.04@-59
CBC 230
230 kV
12.2@-149
0.04@-59
High Spd
Gnd Swt.
0.07@121
High Spd
Gnd Swt
NOTE: Zone 1 presently blocked
for OPTIMHO relays on TL207.
TL237
TL207
94@128
5@-59
53@-41
Sunnyside
230 kV
7.9@40
*TL203 CFH 27 Sept 2010
(Replaces TL203 with tap point)
TL203
88@128
560@133
565@133
47@-40
3I0 flow with
TL207 OOS and
A phase of
TL203 open

Simulated 288 MVA of power flow on TL203 and SPO

3I0 flow would cause 51N to operate after about 1 second



SSD TL207

- This very short line had some additional issues
- Zone 1 phase set at 80% instead of 85%
- Significantly reduce resistive reach of Zone 1 quad in P2
- Zone 2 ground distance delay has to be set longer to coordinate with CBC TL237 Zone 2
- Should a Zone 3 or 4 be applied to cover breaker failure and multiphase fault on TL237?
- For new protection, line current differential is the best application

CBC TL207

- This line is shorter than SSD TL207
- Zone 1 security (in P2 only) is a concern
- Directional ground time overcurrent relay is needed

CBC TL207 21P1 and 21N1

Zone 1 not used and
Zone 2 increased slightly
for consistency with 21P2

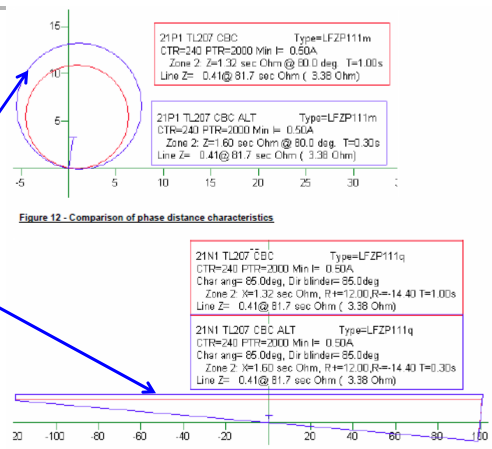
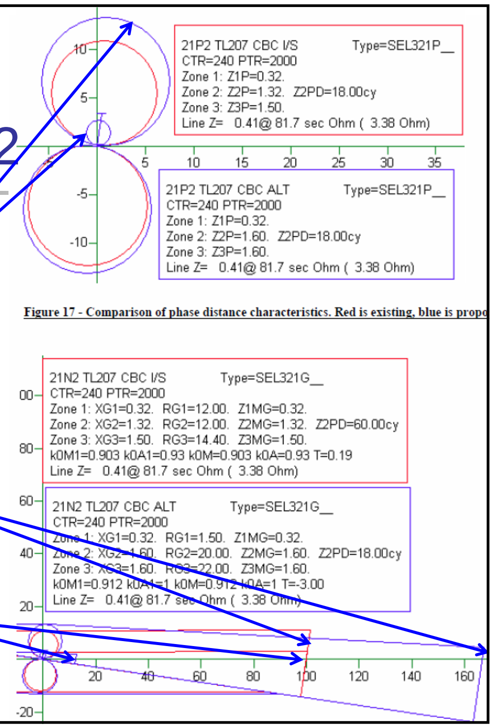


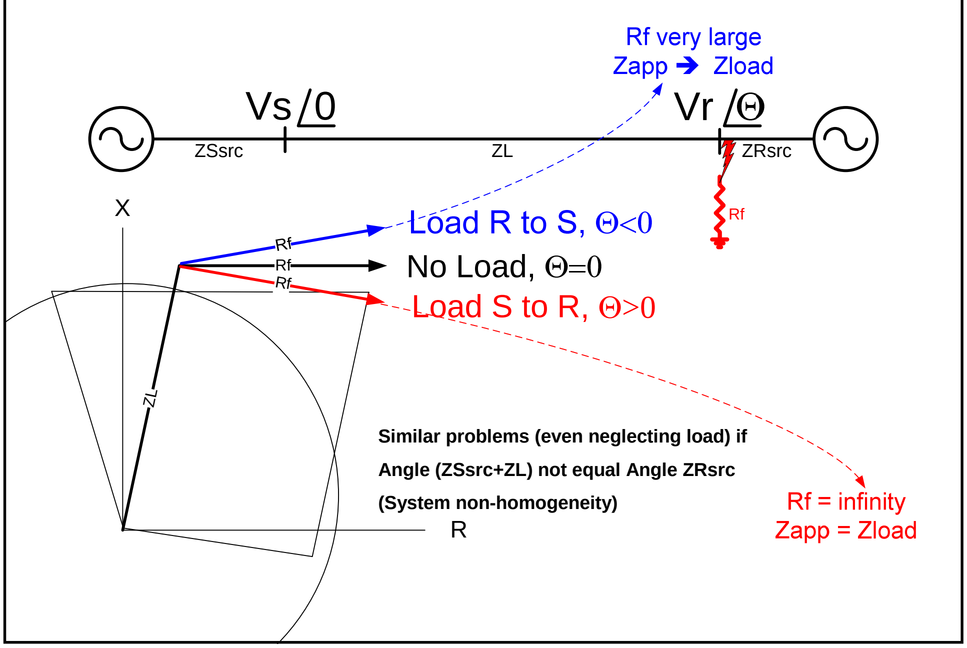
Figure 12 - Comparison of phase distance characteristics

CBC TL207 21P2 and 21N2

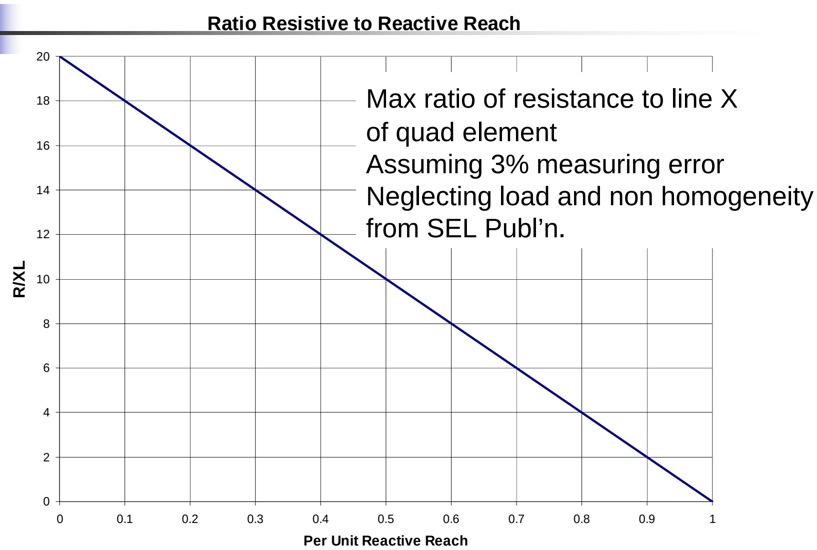
- Zone 1 is used and Zone 2 increased slightly for consistency with 21P1
- 1 cycle time delay added to Zone 1 for security
- Zone 2 resistive reach increased significantly for sensitivity
- Zone 1 reactive slope reduced and resistive reach decreased significantly for security



Fault Resistance Angle



CT, VT and measuring Errors



Setting zones 1 and 2

- Zone 1 set 80%-85% of line Z (less than 80% for short lines)
- Zone 1 ground element can be set with reduced 0 seq. compensation if there is a concern with mutuals
- Zone 2 set at least 125% of line Z and more if not overreaching any remote zone 1 or instantaneous protections.
- If 125% overreaches remote zone 1, use zone 3 time.
- If there is infeed (eg to tap, or third terminal) check overreach of remote terminal with infeed.

Setting a Zone 1 Function

- Must underreach remote bus
- Influencing factors
  - Pre fault load flow and/or non homogeneity of system
  - CT/VT and measuring errors
  - Shape of characteristic
  - Mutual coupling (for ground distance elements)
  - Short line
- May overreach tapped busses
- May overlap remote Zone 1 (for some comm. assisted schemes

Zone 1 characteristic shape

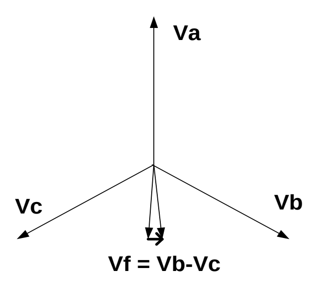
- Mho shape
  - Expands based on source impedance
  - Less sensitivity to fault resistance
- Quad shape
  - More sensitive to fault resistance
  - More likely to overreach
  - May slope reactance line to increase security

Learning from Experience

- Difficulties for application of Zone 1 with Weak Source

Low Voltages and L-L Faults

- Modern digital relays measure phase to neutral voltage phasors and calculate phase to phase voltages
- Small error in VT or relay angle measurement can result in large error in phase to phase voltage

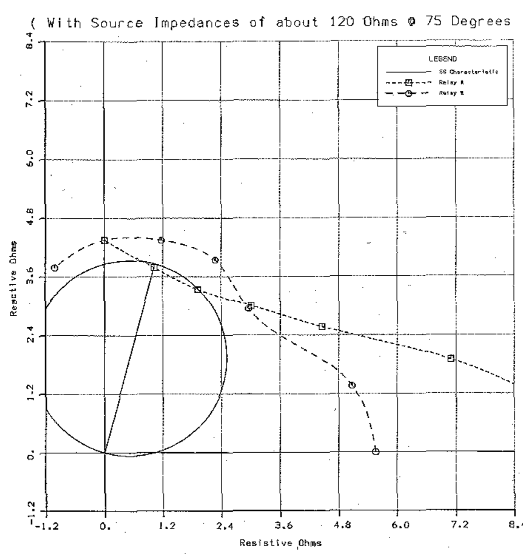


How long is a “long” line?

- Depends on source-to-line impedance ratio “SIR”.
- Ref [3] SIR>4 is “short” SIR <0.5 is “long”
- 500kV stn. with 10,000 MVA fault level
  - 19 km is “short”
  - 150 km is “long”
- 69 kV stn. with 1000 MVA fault level
  - 1.7 km is “short”
  - 14 km is “long”
- SIR affects voltage for fault at line end.

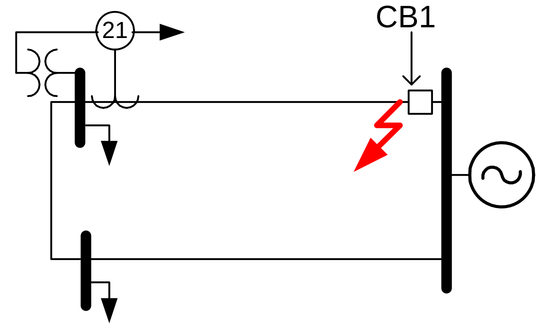
High transient overreach with high SIR

- Earlier dynamic tests revealed difficulties withou any effect from CVTs.

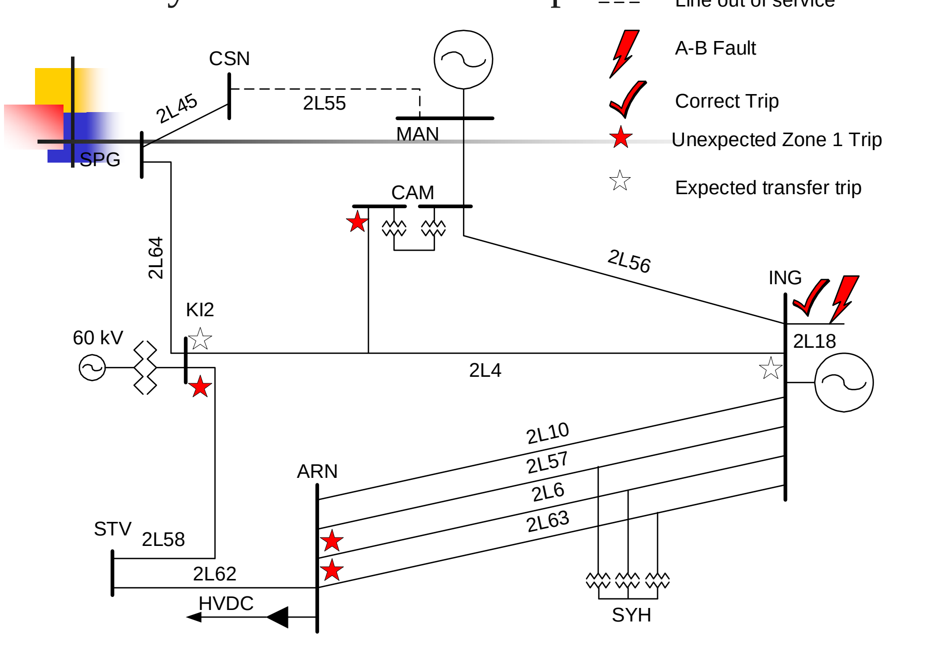


"Dead Loop"

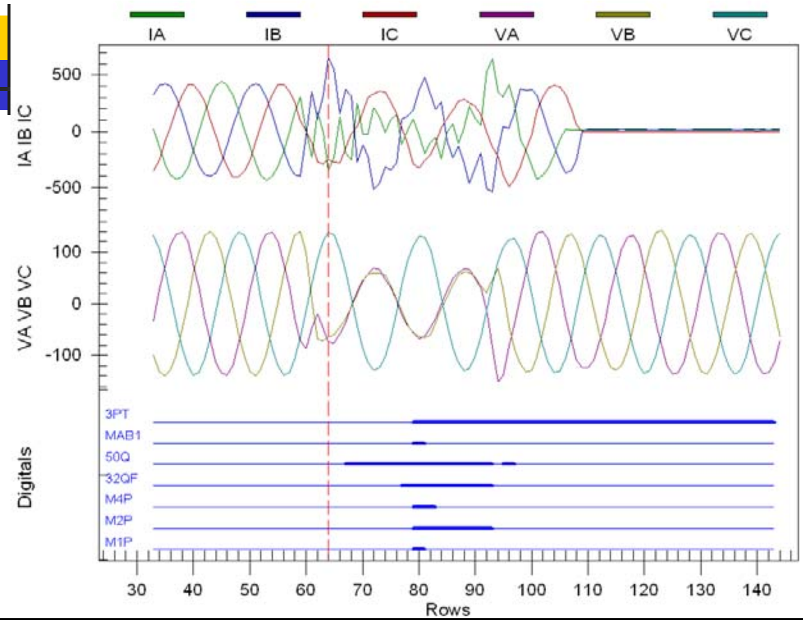
- SIR varies with location
- SIR varies with time (sequentially)



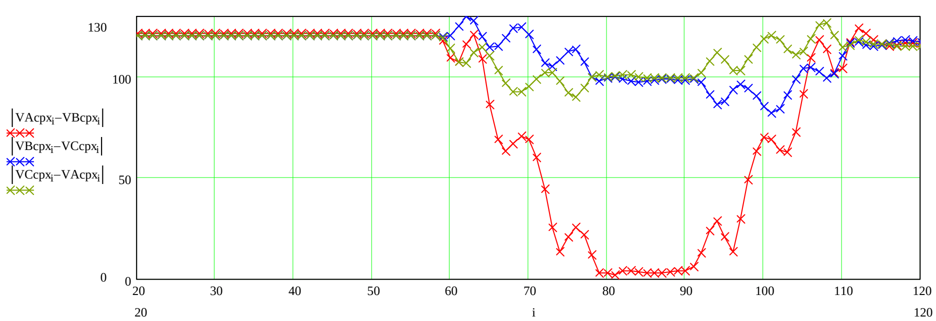
BC Hydro South Metro Loop



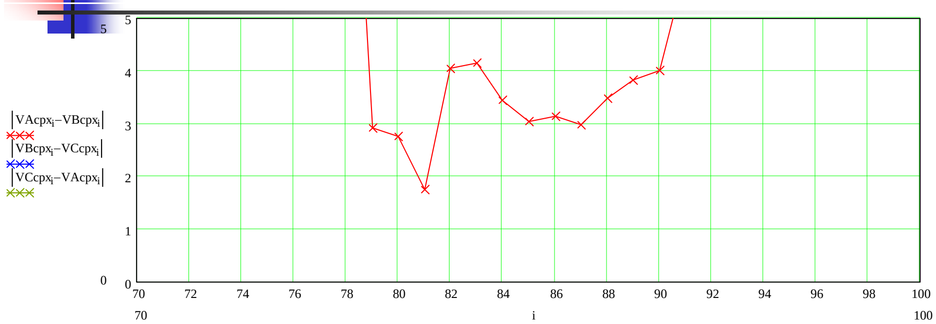
ARN 2L63 Record



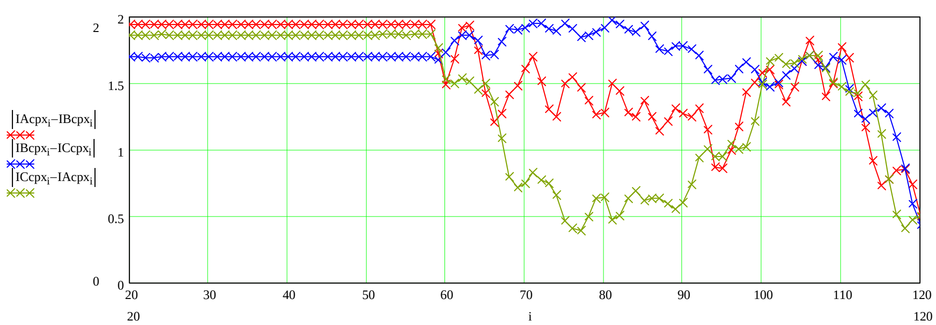
Relay Model Response (courtesy SEL) Ph-Ph Voltages



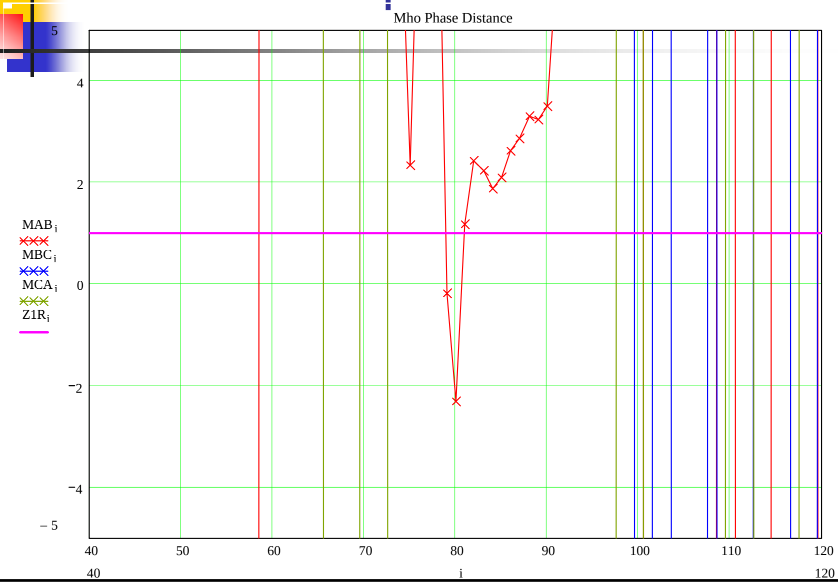
Zoomed A-B Voltages



Phase to phase currents



Measured impedance



WAV TL203 and TL237

- Similar to SSD TL203
- Except that Optimho POR 1 current reversal logic should be applied on TL237 protection
  - To increase security in light of 2 Dec 2007 incident
  - Note, some impact on sequential tripping with aided trip

Conclusion

- No immediate threats to dependability
- But long reaching Zone 1 ground quads on TL207 threaten security
- High resistance faults may be cleared by 51NT with 3 phase tripping instead of by 21N1 or 21N2 with 1 phase trip and reclose
- Several settings modifications proposed
- Several capital modifications proposed
- Additional monitoring recommended

Newfoundland and Labrador Hydro

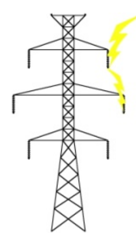
Circuits TL201, TL217, TL218, TL236, and TL242

East Coast Transmission line protection performance and settings Review

Prepared by

Charles F. Henville

Henville Consulting Inc



Prepared for

newfoundland labrador
hydro
a nalcor energy company

Final draft Report

Prepared December 2011

Circuits TL201, TL217, TL218, TL236, and TL242

East Coast Transmission line protection performance and settings Review

Table of Contents

Circuits TL201, TL217, TL218, TL236, and TL242 East Coast Transmission line protection performance and settings Review

1. Summary and recommendations

Summary

The performance and settings of the transmission line protection for five East Coast 230 kV circuits have been reviewed. The review was similar to the review of five Western Avalon circuits completed in 2010 [1]. The following components were reviewed.

a) Establishment of the performance requirements for the existing systems.
b) Review and modification of a model of the power system and the protective relays using ASPEN OneLiner short circuit and coordination program.
c) Review of the historical performance of the existing protection systems.
d) Detailed review of the existing settings using the ASPEN computer model mentioned above.
e) Preparation of proposed revised settings for the existing protection systems.
f) Recommendation of modifications to the existing protection systems including teleprotection equipment.

The performance requirements for some of the lines were increased somewhat in terms of loadability. Two of the lines were considered for loading up to their thermal limits (compared with previous requirements to carry the worst single condition load with the existing system).

It was found that various adjustments could be made to the design and settings of the protection systems to improve the performance. The use of modern computer tools to model power systems and protective relays can result in improved settings compared to those developed earlier with more limited modeling capability.

It was found that the existing sharing of a common teleprotection function by “A” and “B” protection systems could contribute to reduced performance of the systems.

It was concluded that the use of monitoring facilities available with modern protective relays and teleprotection systems can greatly aid disturbance analysis to allow earliest possible identification and mitigation of system disturbances.

Some additional settings or teleprotection revisions may be required to protect against breaker failure in some locations.

Recommendations

As a result of the review, several recommendations are made. Most of these recommendations are identical to those of the previous report [1]. Some of the recommendations of the previous report are not applicable, and there are some new recommendations. All recommendations are listed here with a notation as to whether or not they are **repeat** of the previous report or **new**.

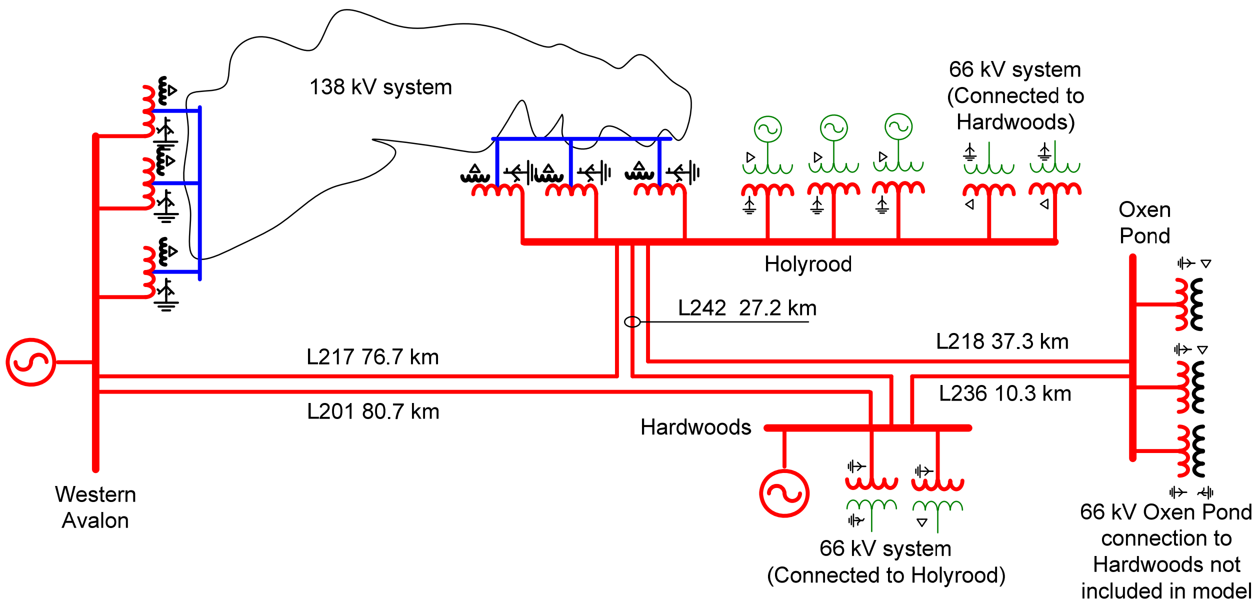
a) Zero sequence mutual coupling impedances between parallel transmission lines sharing a right of way should be modeled during future line protection settings calculations (**repeat**).
b) The 66 kV Newfoundland Power connections to the Oxen Pond 66 kV bus should be added to the ASPEN OneLiner model of the power system (**new**).
c) Separate permissive trip communications facilities should be provided for each of the “A” and “B” protection systems so that coordination is obtained between forward and reverse looking measuring elements. This coordination is important when the permissive trip echo function is used (as is proposed for the SEL321 relays for improved speed and sensitivity) (**repeat**). Some typographical errors are also noted on the teleprotection facilities for these circuits and should be corrected (**new**).
d) The performance of the breaker auxiliary switch on breaker of L01L37 at Western Avalon Terminal station should be monitored or tested.
e) For future applications, where suitable auxiliary contacts are available on circuit breakers, the discrete status of each pole of each breaker should be connected into the SEL 321 relays instead of a single contact that cannot differentiate between a single pole open and all three poles open (**repeat**).
f) During disturbance analysis, “complete” unfiltered event reports from SEL relays should be captured and retained in addition to the filtered event reports. The unfiltered reports are helpful in analyzing transient phenomena and high speed events and also provide more detailed reporting of activities within the device (**repeat**).
g) Several adjustments of the protection settings are proposed, some more important than others. The most significant adjustments to be recommended are as follows:
    i) The permissive trip echo function should be enabled on SEL 321 relays on all lines after implementation of recommendation b) above (**repeat**). The echo function is especially important at Oxen Pond for the TL218 and TL236 protection systems to provide fast clearing of faults near Oxen Pond under the single contingency of one 230 kV line to Oxen Pond being out of service (**new**). The echo function is also important to obtain complete sensitivity for single line to ground faults with resistance of up to 100 ohms on the complete circuit (**repeat**).
    ii) The resistive reach of the zone 1 ground distance elements of the optimho and SEL 321 relays on circuits TL218 and TL242 should be reduced significantly to increase the security of these functions (**new**).

iii) The reactive reaches of the P1 zone 1 ground distance elements on TL218 and TL242 should also be reduced to increase its security with the existing long resisitive reaches (**new**).
iv) The overreaching Zone 2 ground distance functions of all line protections should be increased to provide dependable coverage of single line to ground faults near the remote terminals in the presence of zero sequence mutual coupling from parallel lines (**repeat**).
v) The current supervision elements of all distance protection functions (except perhaps the zone 1 function) should be set at minimum to increase the dependability and to reduce the need to continuously check the relationship between maximum load and minimum fault conditions to determine a setting for these elements (**repeat**).
vi) Setting adjustments should be made to the ground time overcurrent protection systems on circuits TL218 and TL236 (**new**).
vii) The CT ratios on the Oxen Pond terminals of TL218 and TL236 and the Hardwoods terminal of TL236 should be increased when the 230 to 66 kV transformer capacity at Oxen Pond is increased. The existing CT ratio of 600-5 will limit the load carrying capabilities of the 230 kV lines (**new**).

h) Consideration should be given to the following items
   i) Replacing some or all of the existing optimho distance protection systems to improve flexibility of settings and monitoring facilities for disturbance analysis. Maintenance issues due to lack of availability of spare parts for these systems are now becoming a concern (**repeat**). A line current differential protection system is the most appropriate replacement system for circuits TL236 and TL242 since these line are relatively short, and one terminal (OPD for TL242 and HWD for TL242) is very weak under some single contingency conditions (**new**).
   ii) Removal of the electromechanical ground time overcurrent relays in the P2 protection systems since they add little value to the ground time overcurrent function built into the SEL 321 relays. A more independent ground time overcurrent function would be available in the new P1 protection systems if they were replaced (**repeat**).
   iii) Replacing all pneumatic timers used for automatic reclosing or transfer trip auxiliaries with modern digital timers and configurable logic systems (**repeat**).
   iv) Use of the monitoring functions available in the new relays for steady state current and voltage balance checks. These functions could provide an alarm of steady state unbalances that could indicate a problem in the current or voltage sensing to the relays. (**repeat**).
   v) Retrieving event records from relays and teleprotection systems in the highest possible resolution to supplement the sequence of events records, particularly in the case of questionable operations (**repeat**).

2. Introduction and Scope

This report is prepared in response to Newfoundland and Labrador Hydro acceptance of Henville Consulting Inc. proposal no. QNLH006 dated February 20th 2011. The work is to review the performance of protection of five 230 kV transmission lines and make recommendations for changes to settings and/or upgrades to existing protection and teleprotection systems. The transmission circuits involved are TL201, TL217, TL218,



TL236, and TL242 connected as shown in Figure 1.

Figure 1 - Simplified System Diagram of Five 230 kV Transmission Circuits.

This review is similar to a similar review completed for the protection of five other 230 kV transmission lines between Bay D'Espoir and Western Avalon in December 2010. In many cases the findings in this report are similar to those of the report [1] on the previous review. The previous report will be referenced as "The 2010 Report" in this report. These findings will be repeated in this report where necessary, but with reference to the 2010 Report for details. The existing protection systems for the five circuits are similar to each other. Consistent with industry wide practice, they consist of (almost) independent "A" and "B" systems using permissive overreaching transfer trip (POTT) logic.

Protection systems on equipment adjacent to the circuits are not included in the scope of this review except insofar as they may interact with the line protection systems.

3. Performance requirements

- Performance requirements are in all cases similar to the 2010 Report.

- **Reliability and Availability** Redundant "A" and "B" systems are provided to reduce the probability of common mode failure. Where practical, redundant teleprotection facilities are provided.
- **Loadability** Except for the case of circuits TL218 and TL236, protection systems must carry the twice the maximum load (under normal conditions), without tripping, even with one pole open. The rated load is double the peak load under normal conditions in order to allow for the single contingency of the parallel line out of service. In the case of circuits TL218 and TL236, Newfoundland and Labrador Hydro has requested that these short transmission lines be capable of being loaded up to their thermal capacity [2].
- **Speed** Critical clearing time for these circuits has been established as 6 cycles or less With a three cycle breaker clearing time, assume 3 cycle maximum tripping time for all faults including communications time for faults not sensed by instantaneous tripping elements.
- **Sensitivity** Must operate under minimum fault conditions and assuming a maximum fault resistance of 100 ohms for single line to ground faults. Transmission lines are not shielded for most of their length beyond the first 1.5 km from the line terminals. Backup of remote protections is not required.
- **Automatic Reclosing** Single phase tripping and reclosing is required for single line to ground faults for all circuits. Reclosing will be provided by an external controller.

4. Operating procedures.

The following procedures affect minimum fault conditions on the 230 kV network.

- T-022 indicates that during system restoration, the Hardwoods gas turbine may be on line with the Holyrood unit 2 while load is slowly restored. Either of these two units may be operating isolated from each other, but it is expected that they will be synchronized together as soon as possible.
- T-049 states that none of the 230 kV transmission lines interconnecting Bay D’Espoir with the Avalon Peninsula should be taken out of service unless all three units at Holyrood are on line, or the Hardwoods gas turbine is on line as a generator or synchronous condenser.

5. System Modeling

Base ASPEN OneLiner model

The existing Newfoundland and Labrador Hydro ASPEN OneLiner model “**Hydro Interconnected System (2010-08-13) V10.olr**” after modification during the 2010 study was used as a starting point to represent the system. This model was provided as part of the 2010 Report information (Reference [1]). This model does not include the 66 kV Newfoundland Power connections to the Oxen Pond 66 kV bus. Even though these connections will not affect the 230 kV line protection significantly, it is recommended that they be added to the model.

The model was initially modified as follows:

1. Zero sequence mutual couplings between circuits sharing a common right of way were added (for the five lines under study).

2. Detailed and accurate models of the SEL 321 distance relays were used to replace the generic models.

The initially used OneLiner model "**NL Hydro East Coast 230 kV Line PN review 29 Sep 2011.olr**" is provided as an appendix to this report. This model was used to check the settings of the lines TL201 and TL217.

The model was later revised to include the sub-transmission interconnection between the Hardwoods 66 kV bus and the Oxen Pond 66 kV bus. The later model was named "**NL Hydro East Coast 230 kV Line PN review 8 Dec.olr**" and is also provided as an appendix to this report. This later model was used to check the settings of the protections on circuits TL218, TL236 and TL242.

6. Historical performance

Outage records for the last 10 years were reviewed. Significant findings are presented in the following.

Circuit TL201.

This circuit has experienced 36 forced outages since January 2005. For all of those incidents, correct protection operation was reported. Two operations were reviewed in detail.

1. Surge ID 5813 on 6th April 2011 (excavator contact near the HWD terminal)
2. Surge ID 5794 on 7th March 2011 (tree contact assumed. Fault was near Western Avalon)

Detailed event records were available for both of these faults. The performance was reviewed in detail. The detailed analyses are provided in **Appendix A** and **Appendix B**.

In both cases sequential operation was observed, with the terminal nearest the fault opening first, and the second terminal opening after the first had cleared. The detailed analysis concludes that the sequential clearing noted in the 6th April 2011 incident was expected due to the high fault resistance of the excavator contact. For high resistance faults, sequential clearing is often required since it would be rare for the protection at the more remote terminal to be sensitive enough while the near terminal is closed. After the HWD terminal opened, the WAV terminal was able to see the fault, but the operation of the distance elements in the SEL-321 relay was only marginal. Slow operation of the L01L37 auxiliary switch is also observed in this event. The performance of this auxiliary switch should be monitored in future events.

In the case of the 7th March 2011 incident, even though the fault was due to a tree contact, the resistance was very small. For such a low resistance fault, sequential clearing would not have been expected. In this case, the failure of the distant terminal to sense the fault until after the near terminal opened was due to the zero sequence mutual coupling between TL201 and other parallel circuits. The effect of the mutual coupling was to cause the protection at the HWD terminal to reach less than the full length of the line until after the WAV terminal opened. After the WAV terminal opened, the HWD terminal was sensitive enough to sense the fault.

Circuit TL217

This circuit has experienced 11 forced outages since 2005. In three of those incidents incorrect operation of the protection and control equipment reported. The cause of the misoperation for the first incident (on 3 Sept. 2009 Surge ID 5486) is known (reported as "incorrect maintenance" and this was not investigated further. Information on the remaining two incidents (on 21 Sept. 2010 – Surge ID 5708) is still to be collected.

Another outage of TL217 was caused by a bus fault (B1B11 CT fault) between the B1B11 breaker and the CT. The bus protection operated properly, but the WAV line protection was required to operate to clear the infeed from TL217. The fault location was actually in the reverse direction from the HRD terminal of TL217; so the backup time delayed zone 2 protection was required to clear the infeed from WAV. The P1 protection zone 2 did clear the fault, but the P2 protection zone 2 did not operate simultaneously with the P1 even though the settings of the two relays were the same. The failure of the P2 protection to operate is likely due to the marginal sensitivity to single line to ground faults near the remote terminal.

Circuit TL218

This circuit has experienced three forced outages since 2005. No failure of the protection and control equipment has been reported.

Circuit TL236

This circuit has not experienced any forced outages since 2005. No failure of the protection and control equipment has been reported.

Circuit TL242

This circuit has experienced one forced outage since 2005. No failure of the protection and control equipment has been reported.

7. General comments on Line Protection Reviews

Teleprotection issues

Sharing Channels

Similar to the case noted in the 2010 report, the existing teleprotection channels are shared between the P1 and P2 protection systems. This has three significant drawbacks.

1. The security of the protections is threatened because the each protection system uses different logic to retain security during current reversals when a fault on another nearby circuit is cleared sequentially.

2. The dependability of the protections is threatened because of the common mode failure possibility of the single teleprotection channel.

3. The maintenance of the teleprotection system is complicated because it cannot be tested without disabling the teleprotection for the P1 and P2 protections.

Security

As reported previously, the existing teleprotection systems are faster than necessary to meet overall protection performance requirements.

It is not known if the existing teleprotection systems use solid state outputs or contact outputs. If they use solid state outputs it is recommended that they be replaced with contact outputs that are inherently more secure.

It is observed that the existing teleprotection systems have no intentional security delays. It is recommended that a 6-8 ms security delay be added to these systems to provide an overall teleprotection end to end time of 10-12 ms.

Monitoring

Also as previously recommended, the microwave based teleprotection system logs of operations should be retrieved and retained as part of archive information about disturbance analyses.

Drawing errors

Typographical errors on the following drawings should be corrected

- Holyrood A0-310 – E – 224 R0 and B1- 310 – E – 229 R8 show the teleprotection keying inputs signals shorted out.
- Western Avalon B1- 306 – E – 157 shows the transfer trip signal as being code 1 whereas all other drawings and the output of the P2 protection on this drawing show the transfer trip signal as being code 2.
- Western Avalon B1- 306 – E – 159 shows the transfer trip signal as being keyed by 21P1/OUT7 instead of 21P2/OUT7
- Oxen Pond A0- 303 – E – 072 shows the reclose (43R) and teleprotection (43TT) on/off switches as having positions “CLOSE” and “NORMAL” instead of “ON” and “OFF”. This is open to uncertainty with having to guess whether “OFF” or “ON” is “NORMAL” or “CLOSED”. The confusion is compounded by an apparent difference between the 43TT switches for TL218 and TL236. These two switches appear to have the opposite contact senses for the same positions. It is recommended that in addition to clarifying the drawing, that the contact senses of the recloser and transfer trip switches be confirmed and marked on this drawing as being opposite from the switch shown on Oxen Pond A0- 303 – E – 018.

Ground Distance Protection Issues

Zone 1 and Zone 2 Underreaching

As previously reported in [1], the zero sequence mutual coupling between lines sharing the same right of way for a significant distance will affect the performance of the ground distance protection functions. The major impact on the Zone 1 and Zone 2 elements is that they will underreach under normal conditions when both parallel lines between two busses are in service. For ground faults near one end of the line, the zero sequence current flow in both lines will reduce the current in both lines and cause the ground distance function to underreach. This can be demonstrated by considering the response of the Zone 2 element to a fault near the remote bus. Without considering mutual coupling, (i.e. parallel line out of service) the apparent impedance will be equal to the line impedance as expected. However, if the mutual coupling is considered, the apparent impedance will be significantly higher than the actual line impedance, and depending on how much margin is allowed for dependability of the zone 2 element, it may fail to operate for a fault close to the remote terminal until after the remote terminal has opened.

This was the cause of the sequential clearing of the fault on TL201 close to Western Avalon TS on 6th April 2011. Figure 2 shows how the apparent impedance presented to the ground distance relays at Hardwoods was outside the reach of the zone 2 elements while the Western Avalon terminal was closed.

This was also the cause of the sequential clearing of the resistive excavator fault on TL201 close to Hardwoods on 7th March 2011. In this case, detailed analysis of the relay event report by the manufacturer revealed that the reach of the SEL-321 ground distance relays is not dependable even with sequential clearing. This was also probably why the WAV 21P2 protection did not operate as it was expected to for the Holyrood bus fault on 11th June, 2010.

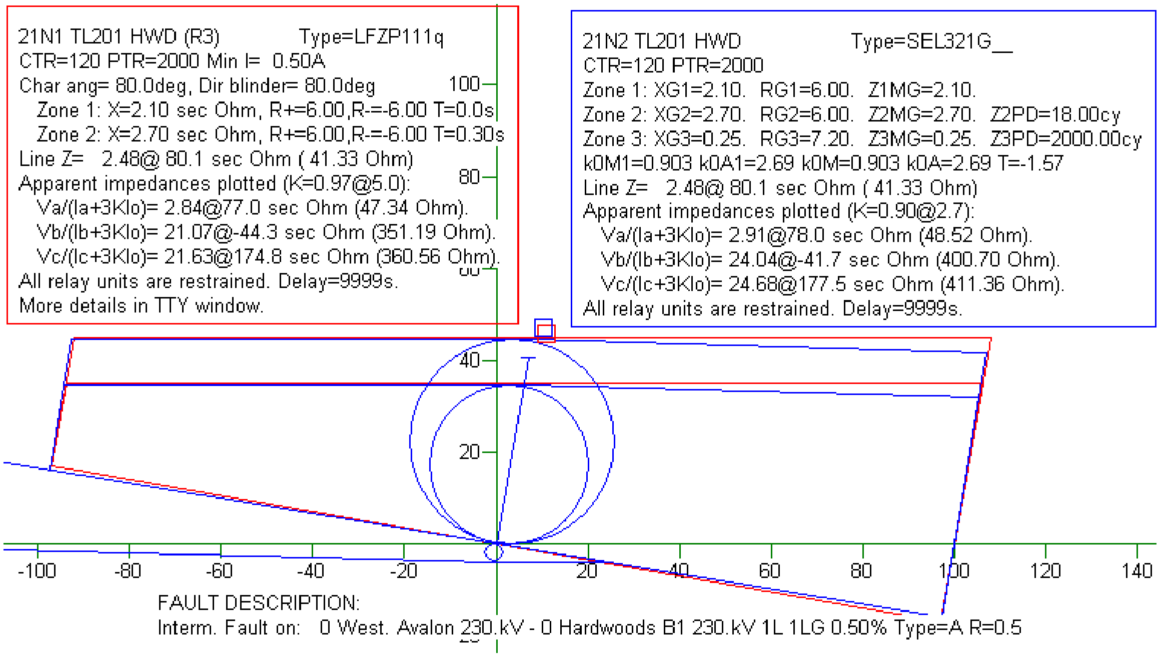


Figure 2 - Apparent impedance to HWD TL201 relays with WAV terminal closed

The underreaching effect caused by the mutual impedance is clearly shown by Figure 2.

Zone 1 Overreaching

As noted in the 2010 report, the mutual coupling effect can cause overreaching in some cases. The worst case is when a parallel line is out of service and grounded at both ends. For instance, when TL217 is out of service and grounded at both ends, the zone 1 elements at the HWD terminal of TL201 have negligible security margin, and are at risk of undesirably tripping for single line to ground faults near WAV. For instance, Figure 3 shows that the P1 protection at HWD TL201 may trip for a close in fault on another circuit out of WAV, and the P2 protection is only marginally secure.

In addition to the findings of the 2010 report, this review has found that the reach of the zone 1 functions on the shorter lines TL218, TL236 and TL242 should be significantly reduced to improve their security against misoperation for resistive faults just beyond the remote terminal. In general, if the reach of a quadrilateral element is set to 80% of a line, the resistive reach should be no more than about four times the reactive reach for good security in the presence of CT and VT errors. In addition, the apparent impedance of a resistive fault can take on a reactive component during heavy load flow that can cause an additional threat to the security of a short reactive reach with a long resistive reach of a quadrilateral element. Figure 4 illustrates the problem for the existing setting on The Holyrood terminal of TL218.

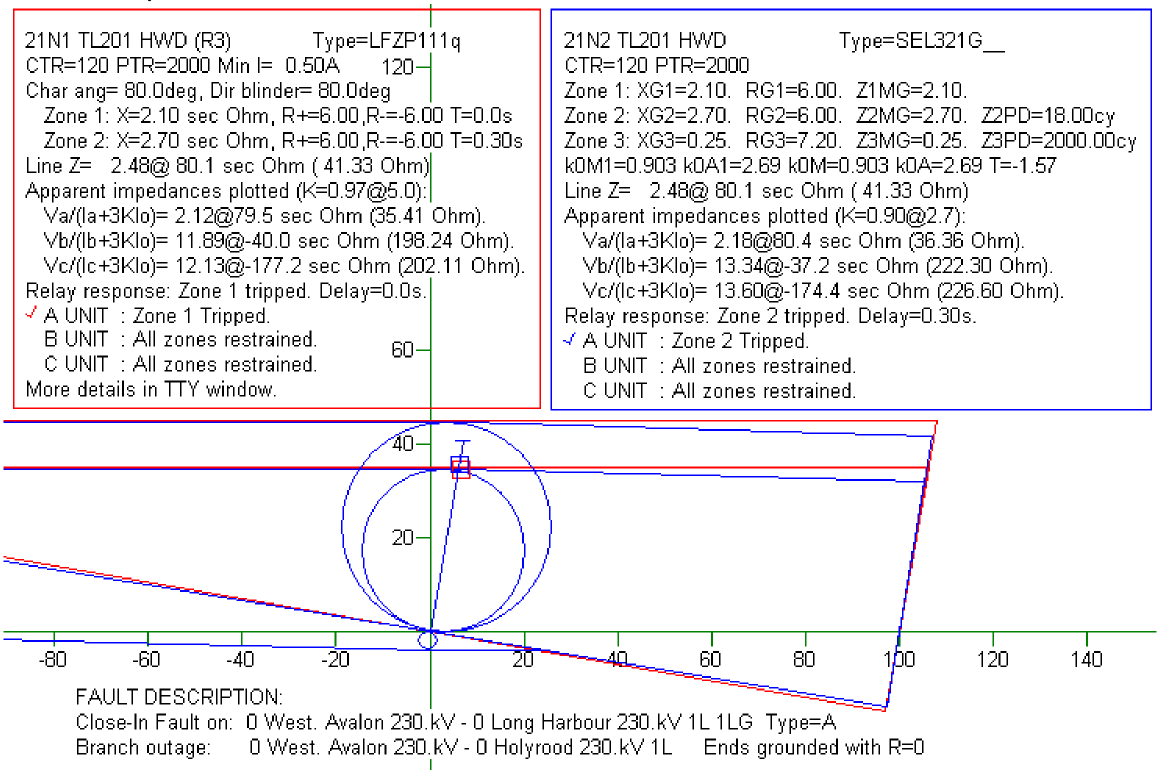


Figure 3 - HWD TL201 protection is not secure when TL217 is out of service and grounded at both ends

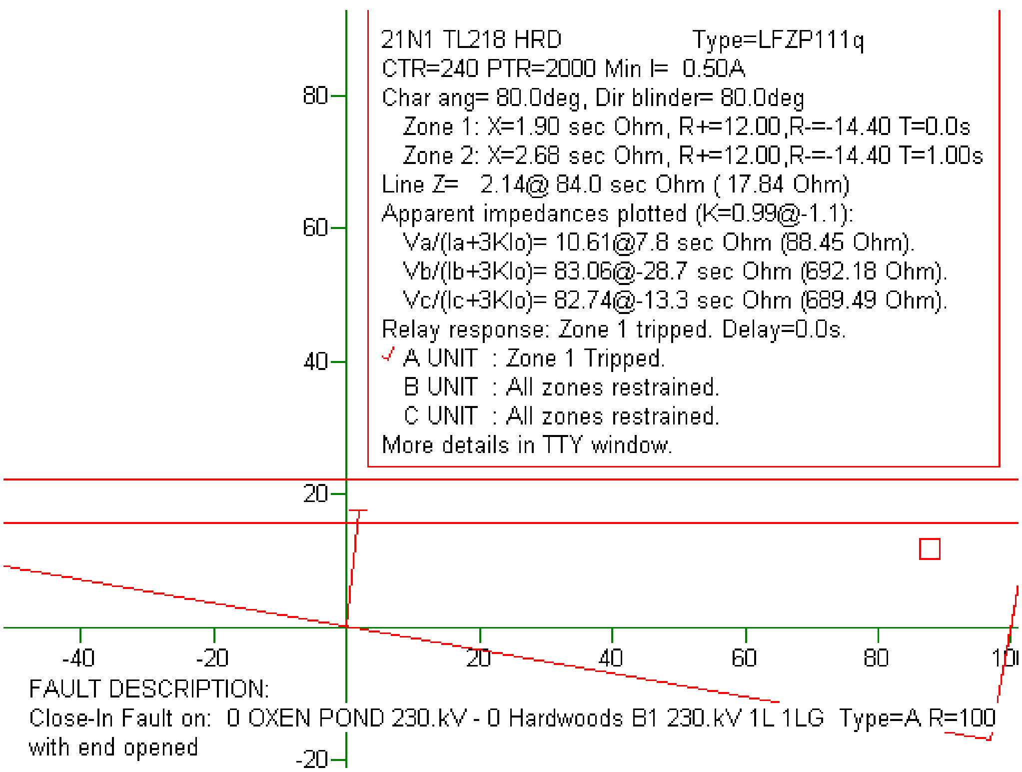


Figure 4 - Zone 1 element set at 85% with 12 ohms resistive reach operates for resistive out of zone fault.

Sensitivity to resistive SLG Faults and use of the Echo function.

As recommended in the 2010 report, the permissive trip echo function should be enabled in the SEL-321 relays after the teleprotection systems of the P1 and P2 protections are separated.

Performance of the Optimho Line Protection Systems

As noted in the 2010 report the existing optimho P1 protection systems are aging and provided inadequate functionality. The limitations of the optimho relay are detailed in the 2010 report, but noted here for convenience.

a) Analogue and event recording functionality is not available for this device. Such functionality is key for successful disturbance analysis to identify actions required to avoid or minimize future reoccurrence of undesirable behaviour.
b) The reactive reaches of the phase and ground distance elements have to be set the same as each other. This limitation affects the ability to optimize the reaches of these elements in the presence of zero sequence mutual coupling.
c) The resistive reaches of the distance elements on all zones have to be set the same as each other. This means that on the short line TL236, the zone 1 trip function has to be blocked.
d) The weak source echo function is not available in the permissive overreaching transfer trip logic scheme POR1 that is used by Newfoundland and Labrador Hydro.

Given the age and limitations of the optimho relays, their replacement may be considered. Greatest value would likely be realized by replacing the relays on Circuit TL236 first since this short line would benefit most from a line current differential protection application.

Reclosing and auxiliary logic

Similar to the case reported in [1], some transmission lines use pneumatic (Agastat) timers for automatic reclosing and auxiliary transfer trip functions. These timers suffer from lack of repeatability due to dust and temperature changes that affect their performance. They need to be tested and maintained regularly to ensure their performance is retained. Consideration should be given to replacing these timers with modern alternatives that provide better performance with improved monitoring and require significantly less maintenance.

Single Pole Open Status to SEL 321 relays

On most breakers, the existing breaker status inputs to SEL321 relays consists of a single input per breaker which is set in each relay to show the status of all three poles of the breaker. The ground distance measuring elements in this relay are each controlled by the status of its pole. All quadrilateral elements are disabled during SPO conditions and the mho distance element on the open phase is also disabled.

The ideal breaker status connections cannot be achieved due to limitations on the number of auxiliary switches available on the breakers. On the air blast breakers “52b” auxiliary switches are available, and assuming that these contacts close when any single pole is open, it is probable that these switches will provide adequate information to the relays.

Detailed event records from the relays during TL201 open pole conditions have been reviewed to confirm that the existing status connections are adequate for this circuit.

Ground time overcurrent protection.

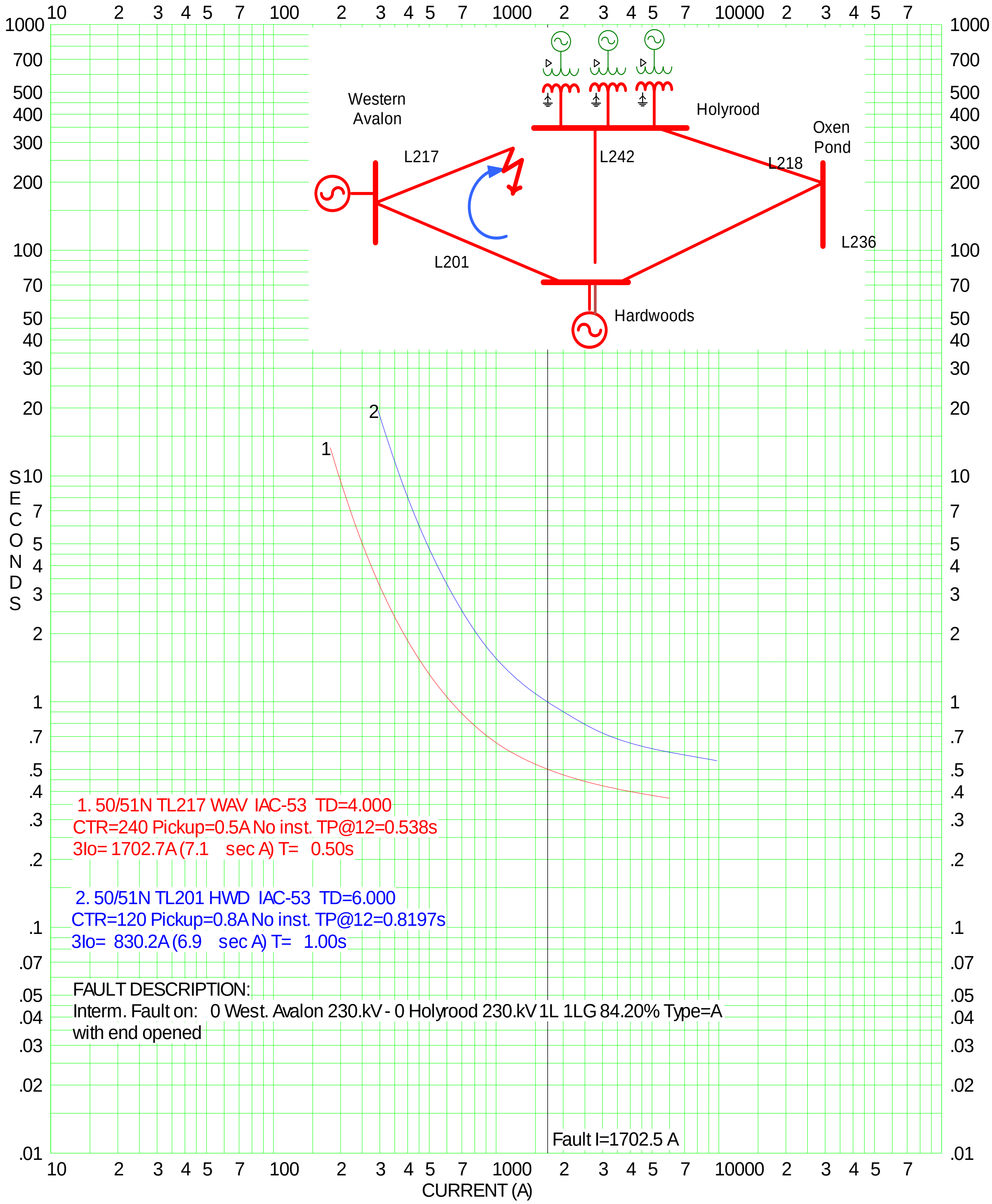
Need for ground time overcurrent protection

The ground time overcurrent function is applied to ensure communications independent protection is available in the event of failure of the communications assistance for the protection systems. It may also be required in some cases for unusually high fault resistance as might be caused by a tree contact. As noted in [1] the ground time overcurrent protection function is presently provided in the P2 protection and should be retained. Also as noted in [1] the existing ground time overcurrent electromechanical relay has little value since its operation is supervised by the ground time overcurrent function in the P2 protection system (unless the P2 relay failure alarm is asserted). It is recommended that consideration be given to removing the discrete electromechanical time ground overcurrent relay from the P2 protection. It can be added to the P1 protection if the P1 protection is not to be replaced.

Coordination of ground time overcurrent protection functions

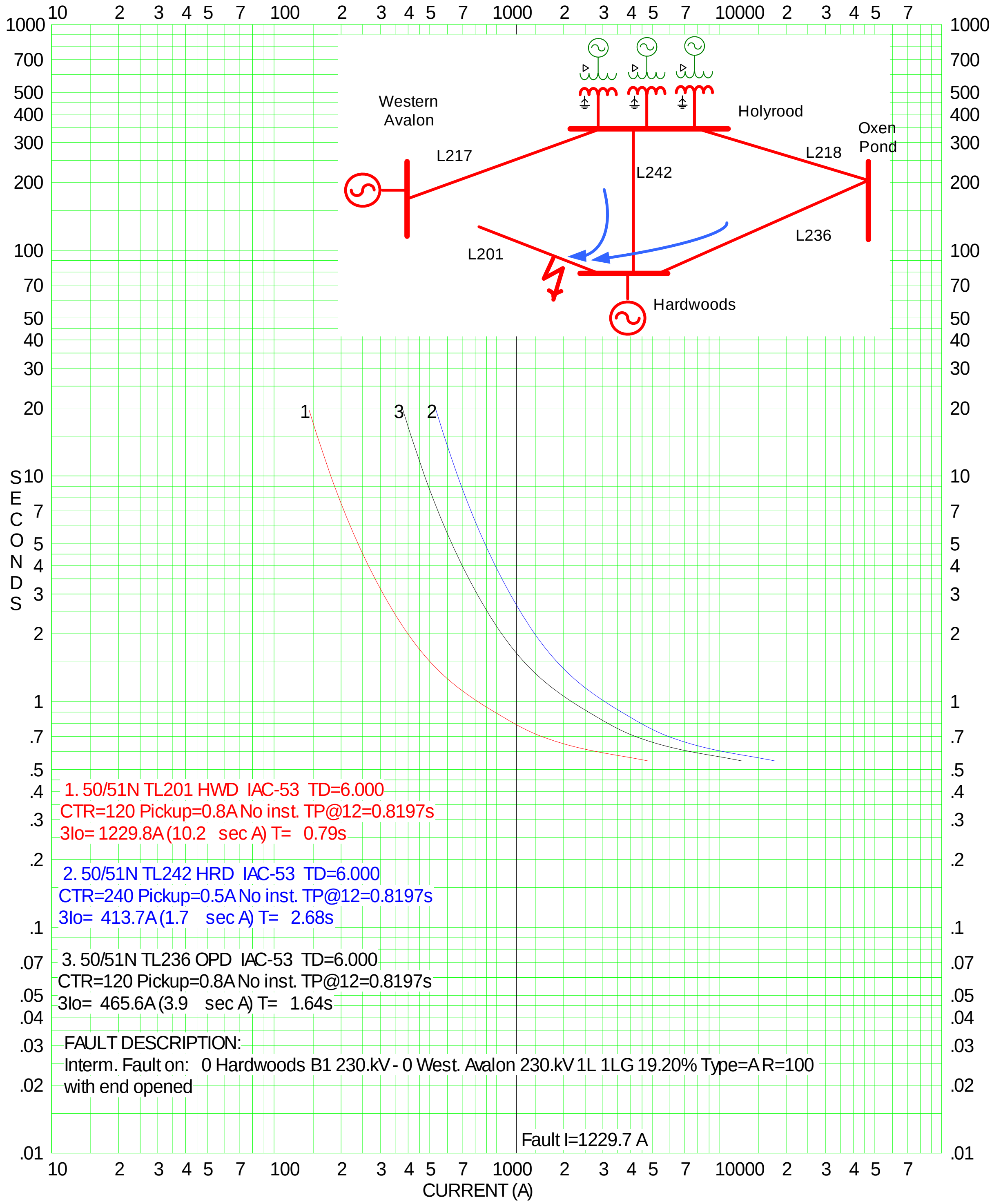
The coordination of ground time overcurrent protection in the various loops were checked as shown in the Figure 5 to Figure 14 following. In some cases (as shown on the system diagram for the coordination chart) two generators and their step up transformers were simulated as being out of service at HRD. In some cases coordination is shown as being achieved for a resistive fault. This is because coordination of the ground time overcurrent functions cannot be achieved for low fault resistances at certain locations. For low fault resistances Zone 2 or zone 1 ground distance elements are needed to operate to clear the fault promptly. The required settings changes will be indicated in the individual comments for each line.

In the case of circuits TL218 and TL236, Newfoundland and Labrador Hydro have indicated a desire to be able to load these circuits up to their thermal ratings of approximately 370 MVA [2]. With such heavy load, the unbalance neutral current will be quite large during the period when one pole is open in a single phase tripping and reclosing sequence. With the existing settings, there is a danger that the ground time overcurrent protection might undesirably operate on the unbalanced load current and trip the circuit three phase. It has been recommended that the time dial settings of the ground time overcurrent protections on these circuits be increased. The increased settings are shown as "ALT" settings in Figure 11 to Figure 14. It can be seen from these figures that the revised settings will still coordinate satisfactorily with each other and with other protections. Note that since the proposed new settings are slower than the existing settings, the relays on these lines will still coordinate satisfactorily with the ground time overcurrent protections on the other circuits. Figure 5 to Figure 10 do not show the proposed new settings on circuits TL218 and TL236, but instead show the existing settings.



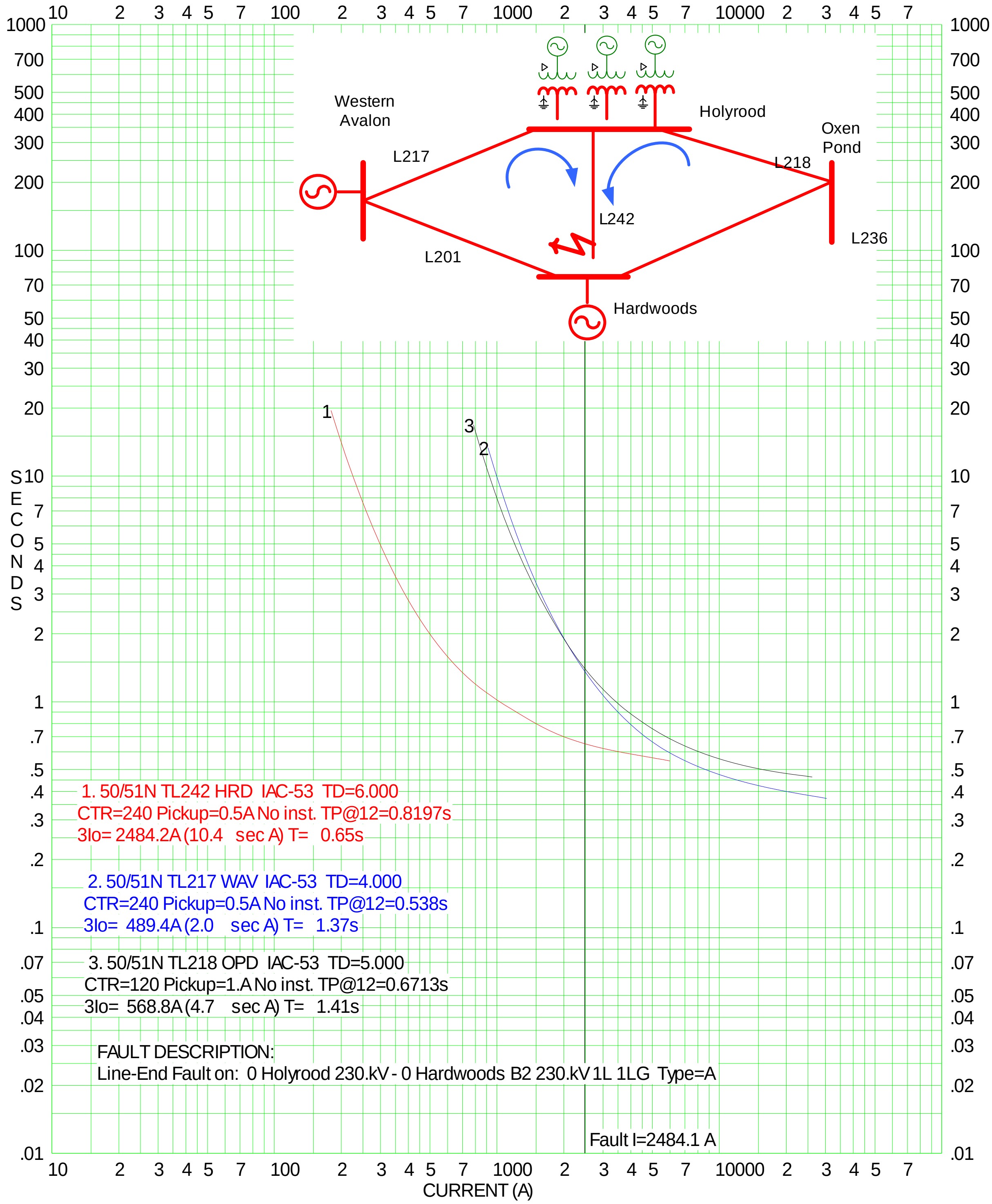
	TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For	Coordination of WAV TL217 Ground PN below HWD TL201	No. EC 230-1
Comment		Date 29 Sept 2011

Figure 5 - HWD TL201 coordinates above WAV TL217



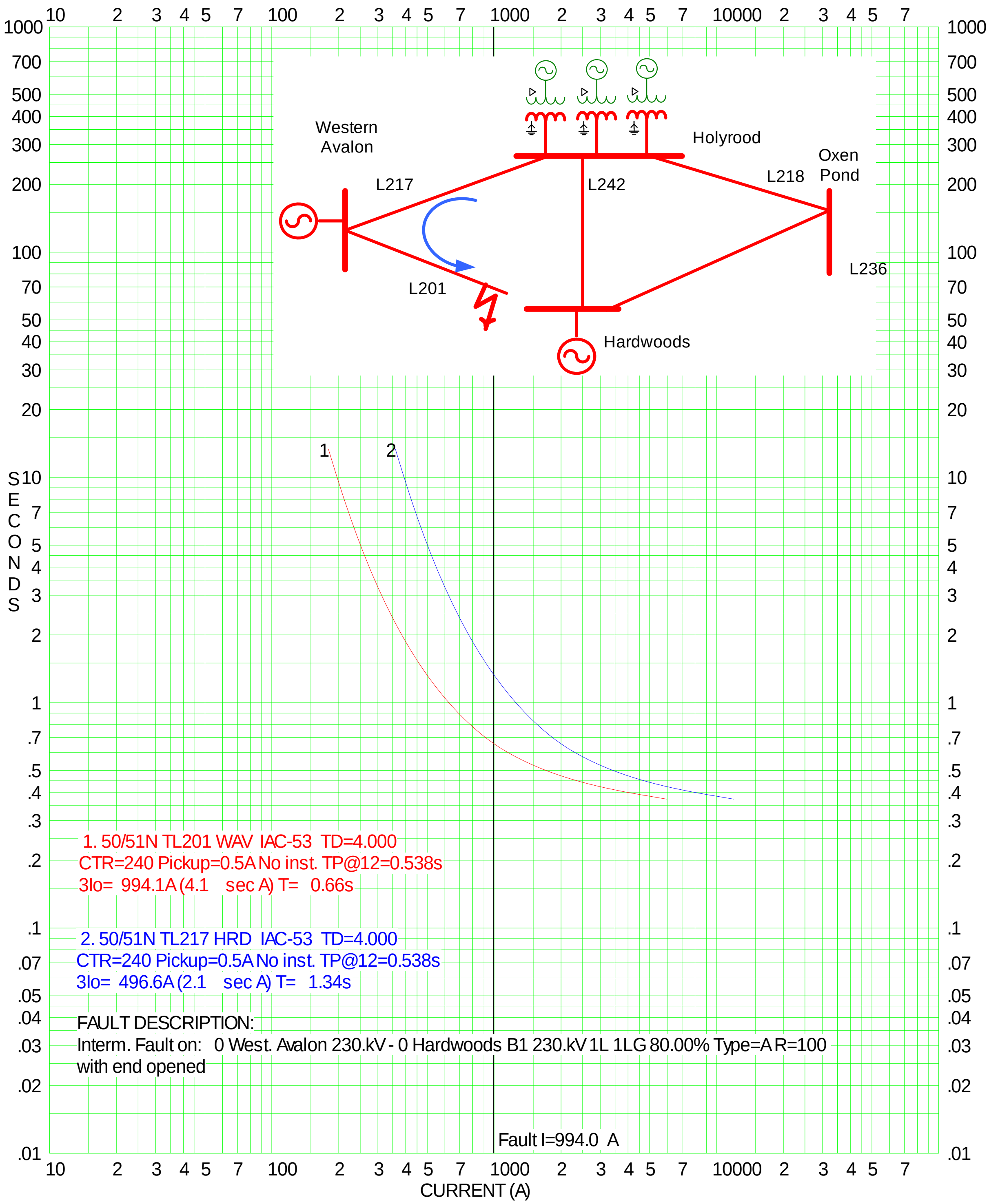
TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For Coordination of HWD L201 Ground PN below HRD L242 & OPD L236	No. EC 230-2
Comment Z1G needed for coordination with RF<100 phms	Date 29 Sept 2011

Figure 6 - HWD TL201 coordinates below HRD TL242 and OPD TL236



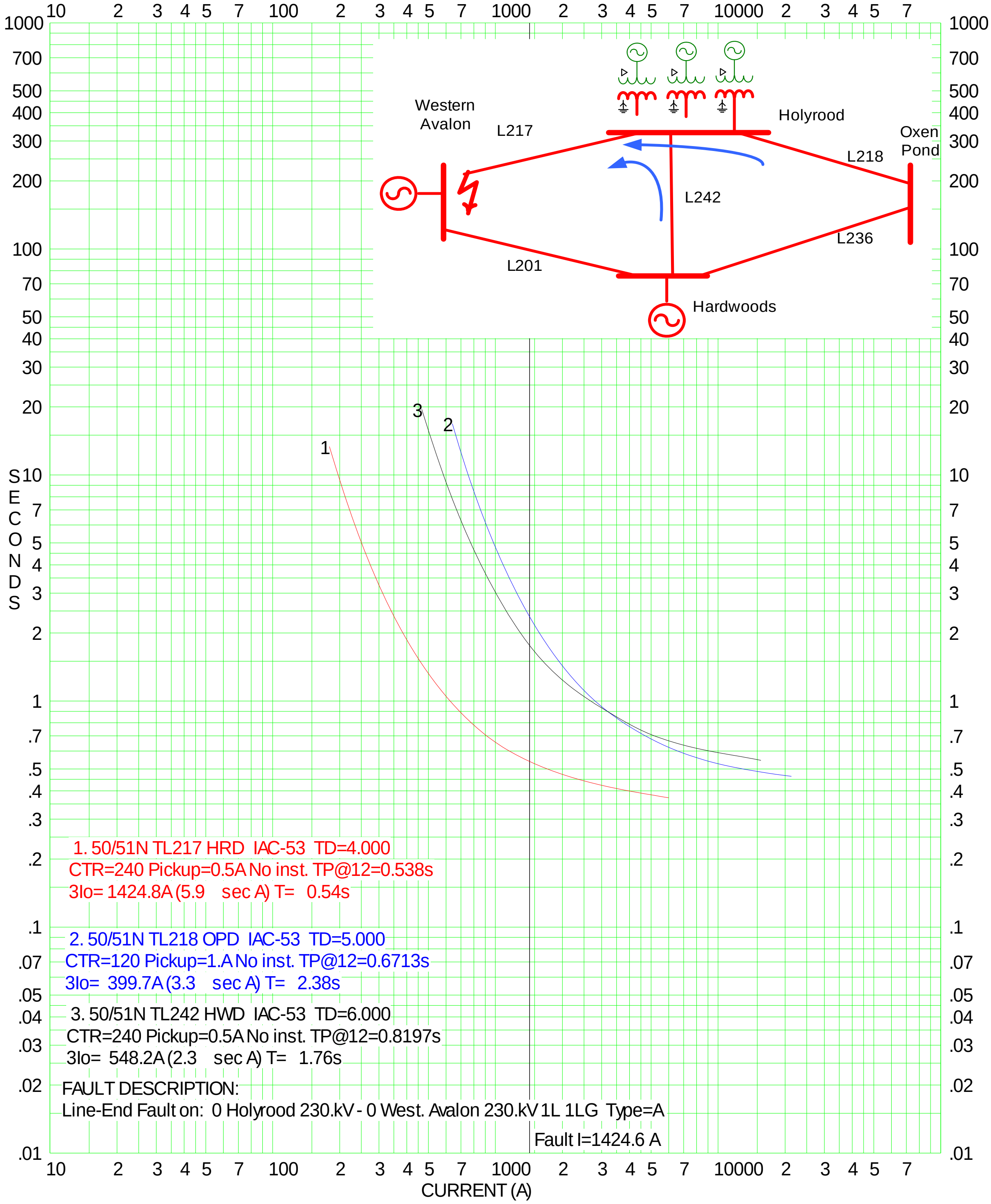
TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For HRD L242 coordinates below WAV L217 and OPD L218	No. EC 230-3
Comment Two units at HRD off line (summer)	Date 29 Sept 2011

Figure 7 - HRD TL242 coordinates below WAV TL217 and OPD TL218



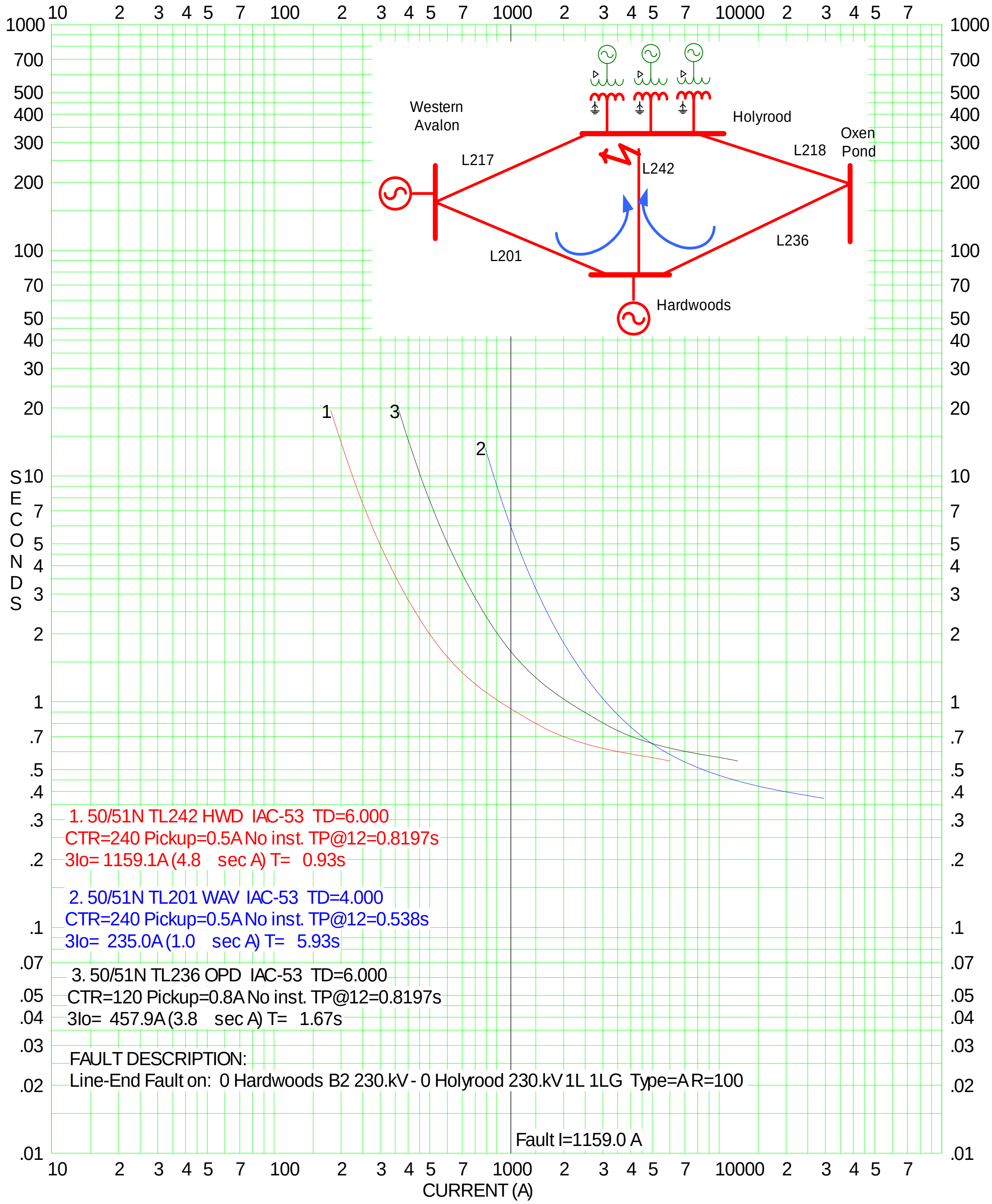
EC 230-4	TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For Coordination of WAV TL201 below HRD TL 217		No. EC 230-4
Comment Requires Z1G and Z3G for coordination with RF <100 ohms		Date 29 Sep 2011

Figure 8 - WAV TL201 Coordinates below HRD TL217



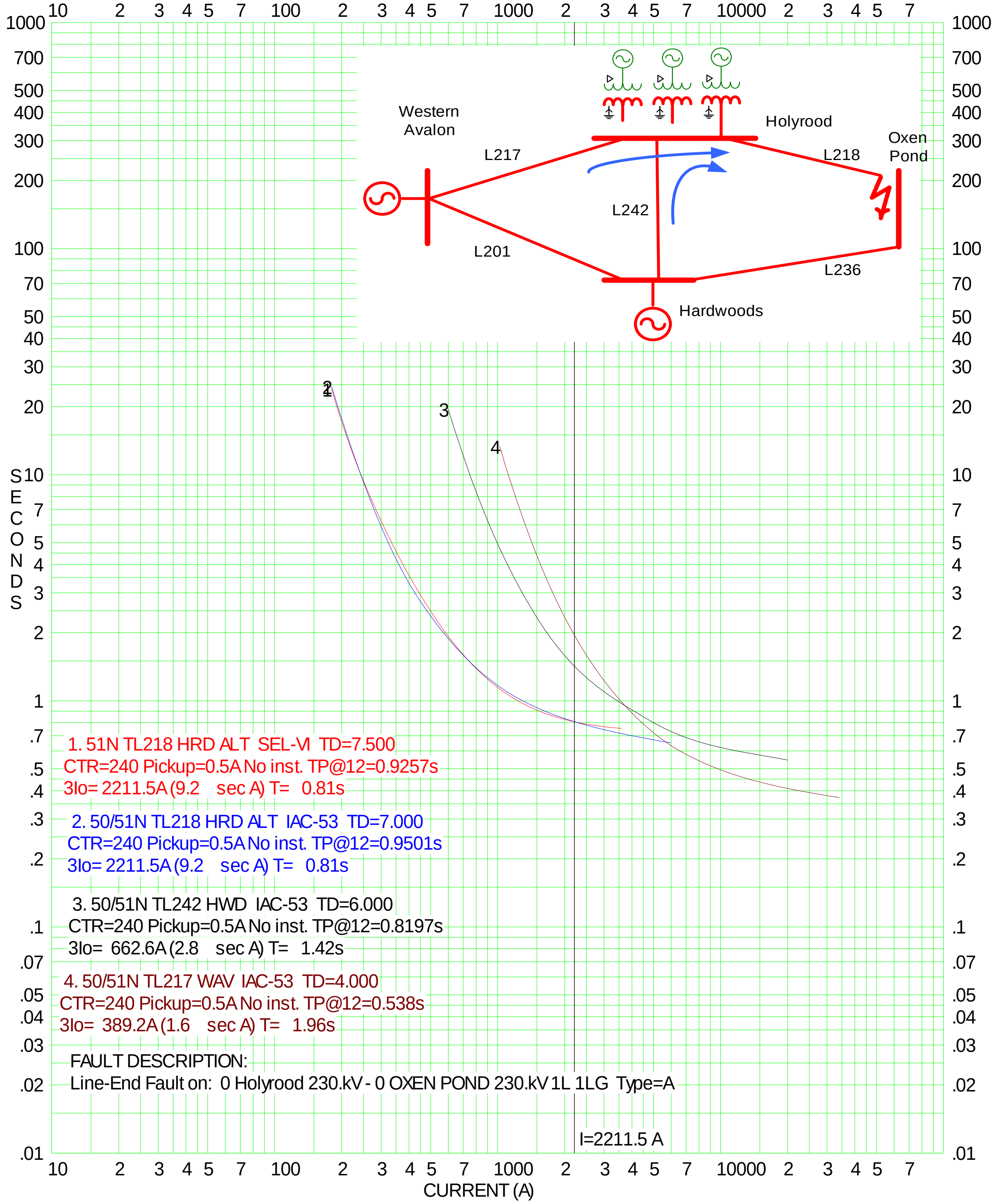
TIME-CURRENT CURVES @ Voltage 230 kV		By C Henville
For	Coordination of HRD TL217 below OPD L218 and HWD L242	No. EC 230-6
Comment	Two units out of service at HRD.	Date 29 Sep 2011

Figure 9 - HRD TL217 coordinates below HWD TL242 and OPD TL218



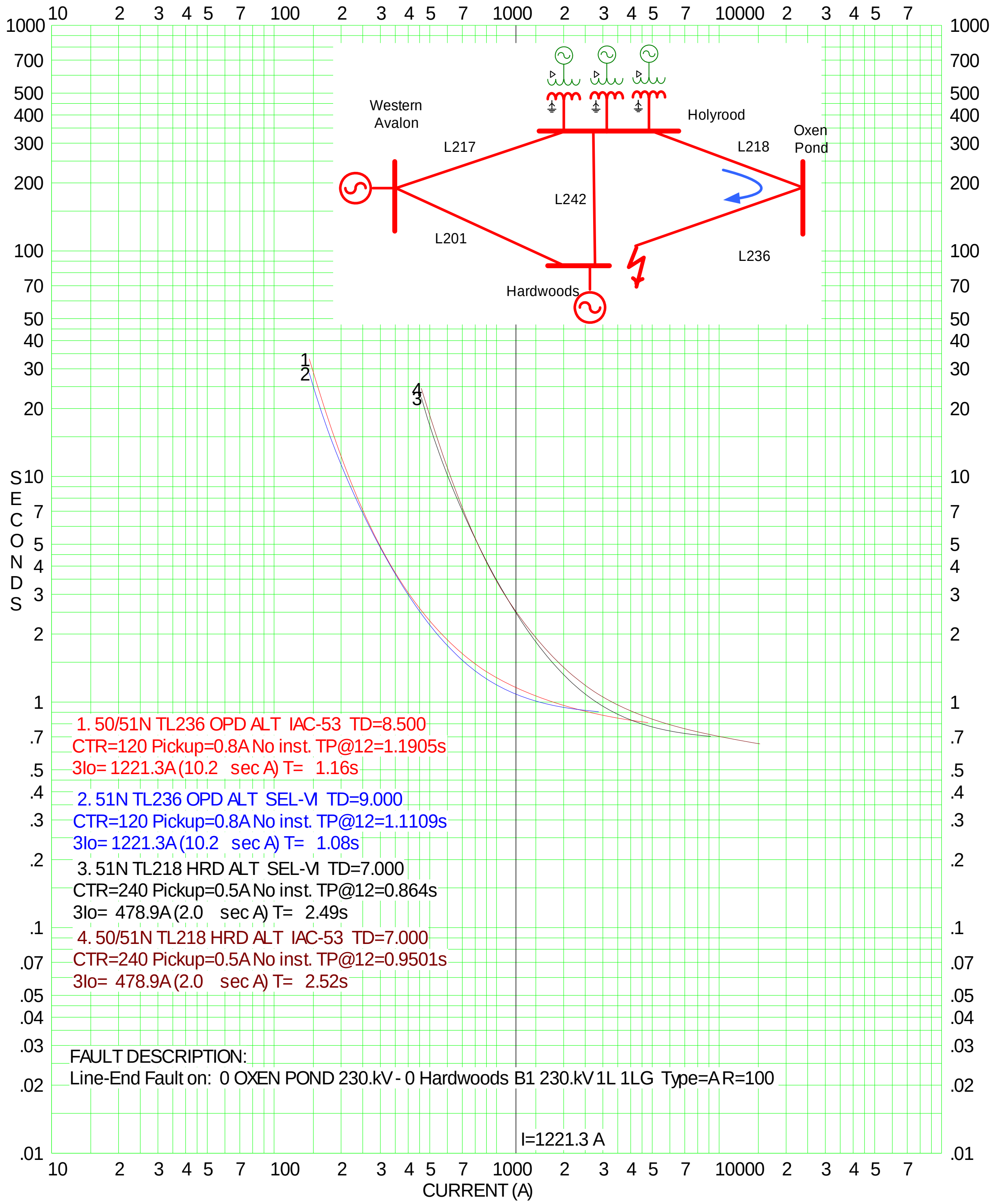
	TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For	Coordination of HWD TL242 below WAV L201 and OPD L236	No. EC 230-5
Comment	Z1G and Z2G needed for coordination with RF<100 ohms	Date 29 Sep 2011

Figure 10 - HWD TL242 coordinates below WAV TL201 and OPD TL236



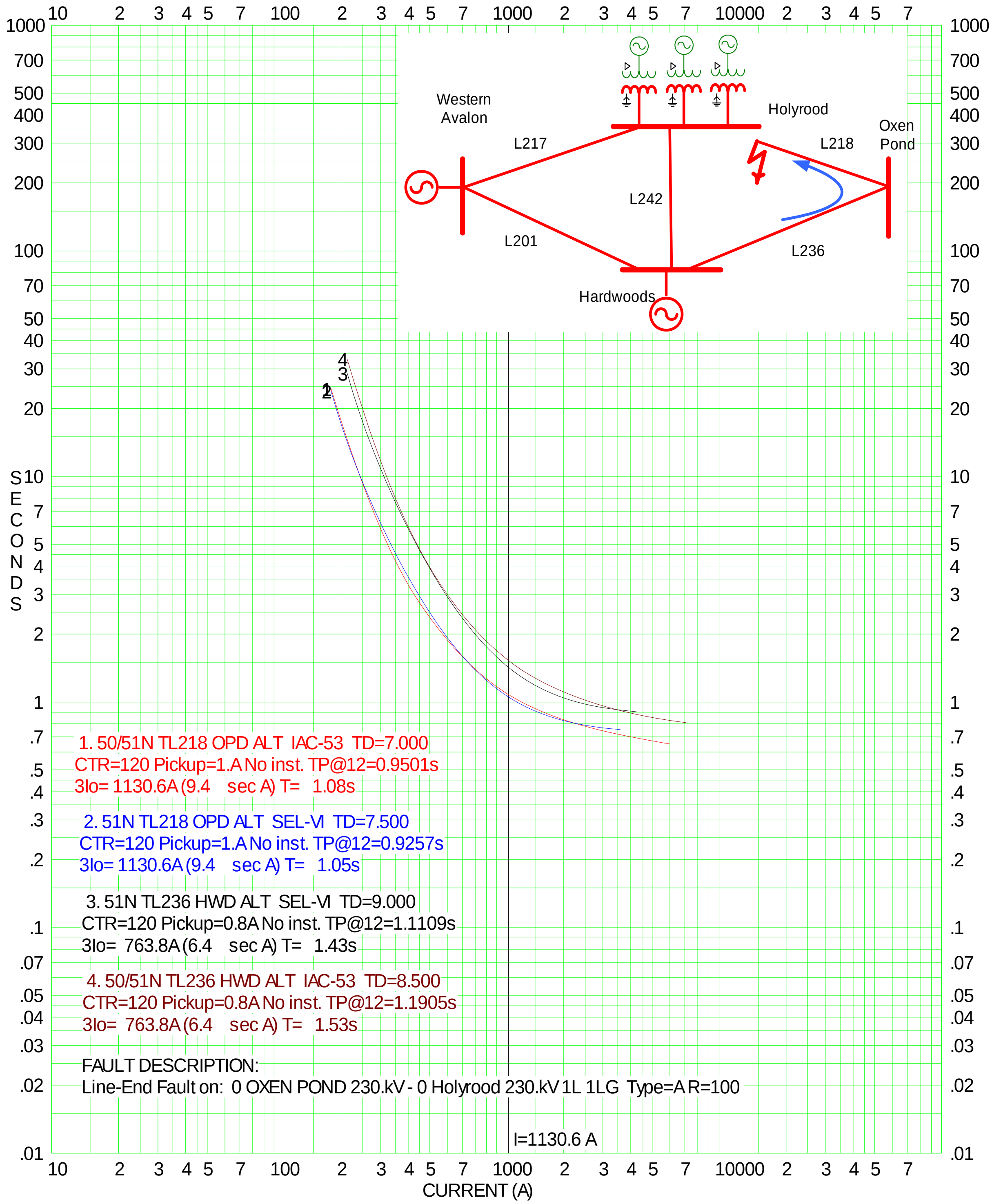
EC 230-7	TIME-CURRENT CURVES @ Voltage 230 kV	By	C Henville
For	Coordination of HRD TL218 below WAV L217 and HWD L242	No.	EC 230-7
Comment	Two units OOS at HRD	Date	13 Dec 2011

Figure 11- HRD TL218 coordinates below WAV TL217 and HWD TL242



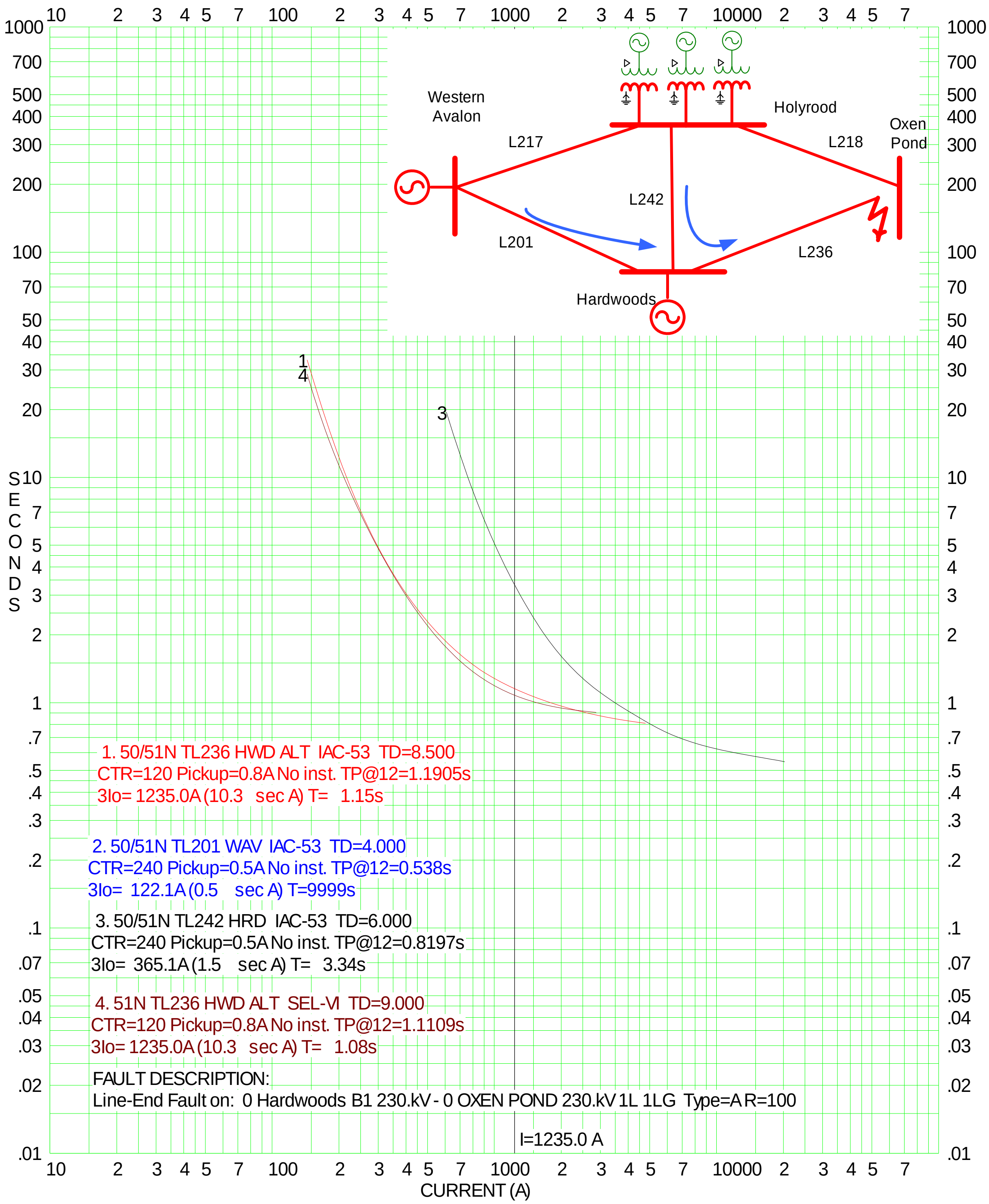
EC 230-8	TIME-CURRENT CURVES @ Voltage 230 kV	By	C Henville
For	Coordination of OPD TL236 below HRD TL218	No.	EC 230-8
Comment	Z2G needed for coordination with RF <100 ohms	Date	13 Dec 2011

Figure 12- OPD TL236 coordinates below HWD TL218



	TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For	Coordination of new OPD TL218 settings below new HWD TL236	No. ECS230-9
Comment	Z2G needed for faults with Rf<100 ohms	Date 13 Dec 2011

Figure 13 - OPD TL218 coordinates below HWD TL236



TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For Coordination of HWD L236 below HRD TL242 and WAV TL201	No. ECS230-10
Comment Coordination requires Z2G for RF<100 ohms	Date 13 Dec 2011

Figure 14- HWD TL236 coordinates below HRD TL242 and WAV TL201

Distance element current supervision

In [1] it was noted that Newfoundland and Labrador Hydro practice is to set distance current supervision elements (where such elements are adjustable) above load if it is possible to do so. It is recommended also in this report that at least for all zones higher than zone 1, that the current supervision elements be set at minimum, and the loss of potential function be depended upon to block the distance elements from operating on load currents if the potential source should be lost.

Monitoring of fault Records

It was recommended in [1] that in future disturbances both filtered and unfiltered (8 samples per cycle) reports be retrieved from SEL relays to assist in disturbance analysis. Some detailed event reports from TL201 protections were reviewed and are discussed in Appendices A and B. The reports confirmed that the single pole open status is being correctly measured by the SEL-321 relays on this line. Questionable operation of the SEL-321 relay at the WAV terminal of TL201 was also observed as a result of availability of the detailed report.

The detailed report of the 7th march 2011 fault on TL201 also revealed a need for attention to be paid to the performance of the breaker auxiliary switch on breaker of L01L37 at WAV.

The recommendation to retrieve and store detailed event reports from all SEL relays is repeated in this report.

Breaker Failure

Breaker failure protection at WAV and HRD is only initiated for multiphase faults. It is assumed that for the more common single line to ground faults, it is expected that ground time overcurrent protection on adjacent zones will operate to clear single line to ground faults. This means that a large region will be tripped in the event of breaker failure.

8. TL201 review comments

Detailed calculations and comments are provided in Appendices D, E, F and G. Several minor changes are proposed. Apart from the general items noted in Section 7, the specific major changes to this line terminal include the following:

1. Increase the reach of the zone 2 distance elements in the P1 and P2 protections (both terminals). Since this increased reach will overreach zone 1 elements on

TL236 at HWD, increase the delay on the P1 and P2 zone 2 tripping at WAV to 1 second.

2. To provide faster communications independent protection at the WAV terminal for faults near the HWD terminal, add an extra overreaching zone to each of the P1 and P2 protections. The extra zone will be Zone 3 on the P1 and Zone 4 on the P2. This zone should be set at 115% of the line impedance (to underreach HWD TL236 Zone 1) and at normal zone 2 time. This shorter reaching distance element will cover the whole line sequentially (with the remote terminal open), and almost the whole line with the remote terminal closed.
3. Decrease the reach of the zone 1 distance elements in the P1 protection and the ground distance elements in the P2 protection (Both terminals)
4. Increase the resistive reach of the zone 1, zone 2 and zone 3 ground distance elements in the P2 protection (both terminals).
5. Add the echo function to the P2 protection at both terminals to increase the sensitivity to resistive faults near one end or the other. This should only be done after the P1 teleprotection is separated from the P2 protection.
6. Add unbalance monitoring functions to the P2 protection and connect them to the existing loss of potential alarm output.
7. Since the permissive trip echo logic will be enabled on the P2 protection, the HWD SEL 321 Zone 2 current supervision elements will need to be set at twice the pickup setting of the WAV Zone 3 current supervision elements. This is because the CT ratio at HWD is half the ratio at WAV, and it is important that the zone 2 elements at HWD not be more sensitive than the reverse looking zone 3 elements at WAV.
8. Implement miscellaneous small settings adjustments as shown in Appendices D, E, F and G.

9. TL217 review comments

Detailed calculations and comments are provided in Appendices H, I, J and K. Several minor changes are proposed. Apart from the general items noted in Section 7, the specific major changes to this line terminal include the following:

1. Increase the reach of the zone 2 distance elements in the P1 and P2 protections (both terminals)
2. Decrease the reach of the zone 1 distance elements in the P1 protection and the ground distance elements in the P2 protection (Both terminals)
3. Increase the resistive reach of the zone 1, zone 2 and zone 3 ground distance elements in the P2 protection (both terminals).
4. Add the echo function to the P2 protection at both terminals to increase the sensitivity to resistive faults near one end or the other. This should only be done after the P1 teleprotection is separated from the P2 protection.

5. Add unbalance monitoring functions to the P2 protection and connect them to the existing loss of potential alarm output.
6. Implement miscellaneous small settings adjustments as shown in Appendices H, I, J and K.

10. TL218 review comments

Detailed calculations and comments are provided in Appendices L, M, N and O. Several minor changes are proposed. Apart from the general items noted in Section 7, the specific major changes to this line terminal include the following:

1. The OPD terminal of this line is very weak under the contingency of TL236 being out of service. This means that the echo function is very important to ensure fast clearing of faults near OPD when TL236 is out of service. It also means the loss of potential function cannot be set at OPD to ensure blocking of the distance protections under normal load conditions.
2. Increase the reach of the zone 2 distance elements in the P1 and P2 protections (both terminals)
3. Decrease the reach of the zone 1 distance elements in the P1 protection and the ground distance elements in the P2 protection (Both terminals)
4. Increase the resistive reach of the zone 2 and zone 3 ground distance elements in the P2 protection (both terminals).
5. Decrease the resistive reach of the Zone 1 P2 ground distance elements (both terminals).
6. Add the echo function to the P2 protection at both terminals to increase the sensitivity to resistive faults near one end or the other. This should only be done after the P1 teleprotection is separated from the P2 protection.
7. Add unbalance monitoring functions to the P2 protection and connect them to the existing loss of potential alarm output.
8. Implement miscellaneous small settings adjustments as shown in Appendices L, M, N and O.
9. When the transformation capacity at Oxen Pond is increased, the CT ratios of the P1 and P2 protections at this terminal of the line should be increased so as to not limit the loadability of this circuit.
10. Increase the time dial settings of the inverse time ground overcurrent protections to ensure this protection does not operate due to unbalance current with heavy load flow and one phase open (before reclose)

11. TL236 review comments

Detailed calculations and comments are provided in Appendices P, Q, R, and S. Several minor changes are proposed. Apart from the general items noted in Section 7, the specific major changes to this line terminal include the following:

1. The OPD terminal of this line is very weak under the contingency of TL218 being out of service. This means that the echo function is very important to ensure fast clearing of faults near OPD when TL218 is out of service. It also means the loss of potential function cannot be set at OPD to ensure blocking of the distance protections under normal load conditions.
2. Increase the P1 KZPH setting to be as high as possible while still obtaining the required zone 2 reach so that sensitivity of the protection is maximized.
3. Decrease the reactive and resistive reaches of the P2 zone 1 quadrilateral elements significantly to increase their security (both terminals).
4. Decrease the setting of the zone 2 time delays from 1 second to 0.3 seconds on the P1 protection and on the P2 ground protection. The zone 2 phase distance protection is already 0.3 seconds.
5. Add the echo function to the P2 protection at both terminals to increase the sensitivity to resistive faults near one end or the other. This should only be done after the P1 teleprotection is separated from the P2 protection.
6. Add unbalance monitoring functions to the P2 protection and connect them to the existing loss of potential alarm output.
7. Implement miscellaneous small settings adjustments as shown in Appendices P, Q, R, and S.
8. The settings for the P1 protections will not be secure for the full rated thermal load of this line. The settings will be secure for the rated load of TL218 (370 MVA).
9. When the transformation capacity at Oxen Pond is increased, the CT ratios of the P1 and P2 protections at both terminals of the line should be increased so as to not limit the loadability of this circuit.
10. Increase the time dial settings of the inverse time ground overcurrent protections to ensure this protection does not operate due to unbalance current with heavy load flow and one phase open (before reclose)

12. TL242 review comments

Detailed calculations and comments are provided in Appendices T, U, V, and W. Several minor changes are proposed. Apart from the general items noted in Section 7, the specific major changes to this line terminal include the following:

1. The HWD terminal of this line is very weak for faults near HRD under the contingency of TL201 being out of service. This means that the echo function is very important to ensure fast clearing of faults near HRD when TL201 is out of service. It also means the loss of potential function at HWD cannot be set to ensure blocking of the distance protections under normal load conditions.
2. Decrease the reach of the zone 1 distance elements in the P1 protection and the ground distance elements in the P2 protection (Both terminals)

3. Add a zone 4 function (at the Holyrood terminal only) with less reach than the zone 2 function and shorter operating time to increase the speed of the time delayed overreaching protection with reduced dependability.
4. Increase the resistive reach of the zone 2 and zone 3 ground distance elements in the P2 protection (both terminals).
5. Decrease the resistive reach of the P2 zone 1 ground distance elements (both terminals).
6. Add the echo function to the P2 protection at both terminals to increase the sensitivity to resistive faults near one end or the other. This should only be done after the P1 teleprotection is separated from the P2 protection.
7. Add unbalance monitoring functions to the P2 protection and connect them to the existing loss of potential alarm output.
8. Implement miscellaneous small settings adjustments as shown in Appendices T, U, V, and W.
9. Increase the time dial settings of the inverse time ground overcurrent protections to ensure this protection does not operate due to unbalance current with heavy load flow and one phase open (before reclose)

13. Conclusions

The review of the line protection settings has found opportunities to improve the reliability of the protections by setting adjustments. It has also revealed the functional limitations of the existing P1 (optimho) protection systems, and recommended consideration of replacing these first generation static line protection systems.

The ASPEN OneLiner Short Circuit Model of the Eastern Avalon system has been improved significantly by the addition of zero sequence mutual coupling impedances between the 230 kV transmission lines, and also by the addition of the 66 kV subtransmission circuits between Hardwoods and Oxen Pond.

14. References

1. C. Henville, "Circuits TL202, TL203, TL206, TL207 and TL237 Transmission line protection performance and settings Review" Report to Newfoundland and Labrador Hydro dated 30th December, 2010
2. P. Thomas email to C. Henville "Fw: Re: PSSE Files" dated 9 December 2011.

15. Appendices

Appendix A – Detailed Analysis of TL201 Fault 7 March 2011

On 7th March 2011 a single line to ground fault occurred on this circuit. The fault was caused by an excavator contact. The fault location was 3.4 km from Hardwoods, or about 4.2% of the distance of the line from Hardwoods to Western Avalon.

A single line to ground fault with 27 ohms of resistance was simulated at the reported location and found to have a reasonable match with the measured currents at each end of the line.

The response of the relay at the WAV end of the line initially (before the HWD terminal opened) is shown in Figure 15. In Figure 15 it can be seen that the WAV distance element does not sense the fault. The fault current infeed from HWD increases the apparent fault resistance presented to the WAV relays so they are not responsive. Also, the apparent reactance is 5.727 ohms secondary that is greater than the set reactance reach of 5.26 ohms. This matches the observation of the actual relay performance.

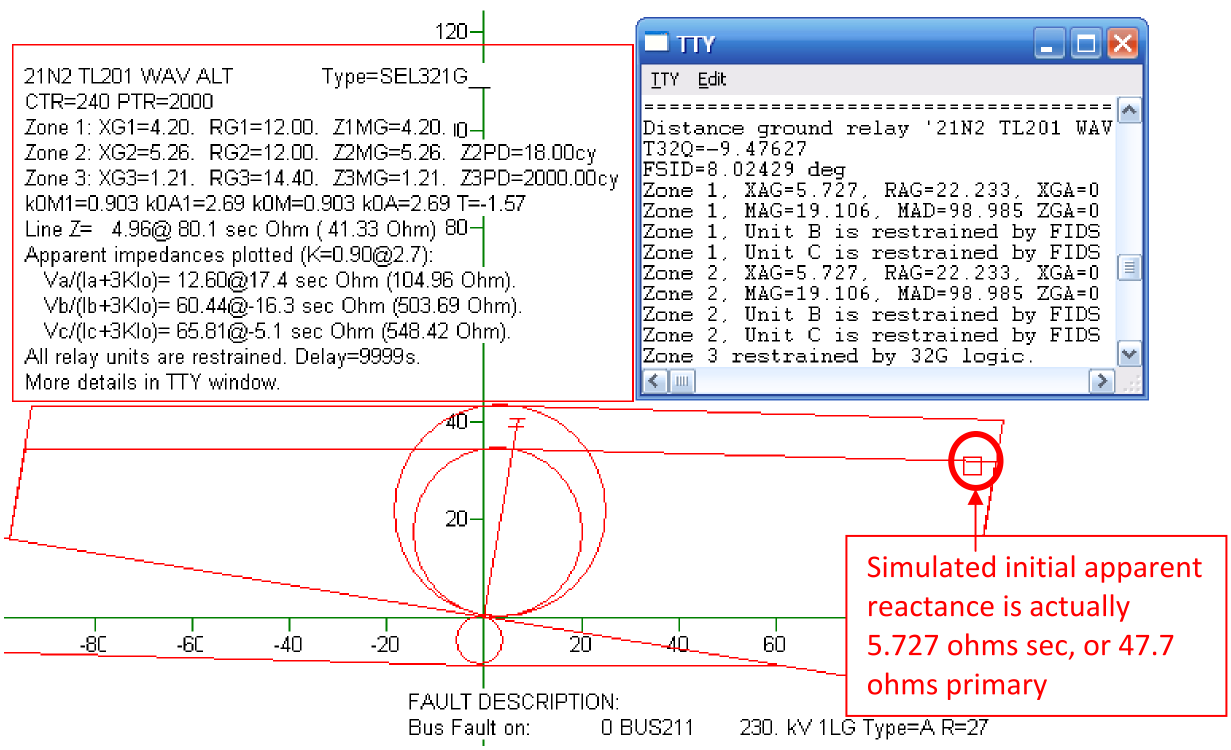


Figure 15 - Initial response WAV SEL-321 relay to 7 March 2011 fault

Note that the apparent impedance plot is not correctly shown on the RX diagram of OneLiner due to limitations in the display capability. However, the OneLiner TTY window is also shown in Figure 15 and the simulated apparent reactance is shown as 5.727 ohms secondary.

The relay event record was played through a model of the relay by SEL and the plotted apparent reactance of the actual fault is shown in Figure 16. It can be seen that the initial apparent reactance presented to the relay is significantly higher than 5.7 ohms, at about 6.7 ohms.

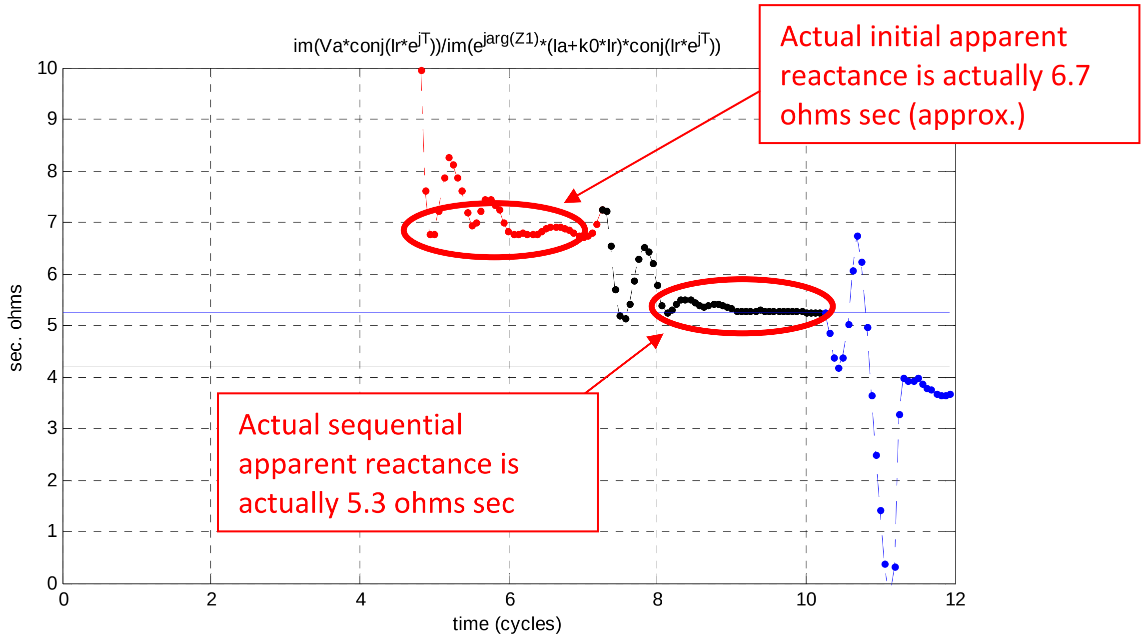


Figure 16 - Apparent reactances of real initial sequentially cleared fault as seen by relay model

After the HWD terminal opens, the WAV the simulated apparent impedance is now within the reach of the zone 2 element of the WAV relay as shown in Figure 17. The ground distance elements on this line will tend to reach further when the remote terminal is open because of the zero sequence mutual coupling with other lines on the same right of way. However, the remote terminal being open single phase and faulted on that phase presents a higher reactance than if the remote terminal was open on three phases and faulted on one phase.

However, sequentially, after the HWD terminal opens, the measured reactance of the line is 5.3 ohms secondary (as shown Figure 16) which is higher than the modeled line reactance and marginally higher than the set zone 2 reactance of 5.26 ohms secondary. Thus the response of the zone 2 element to this fault is marginal.

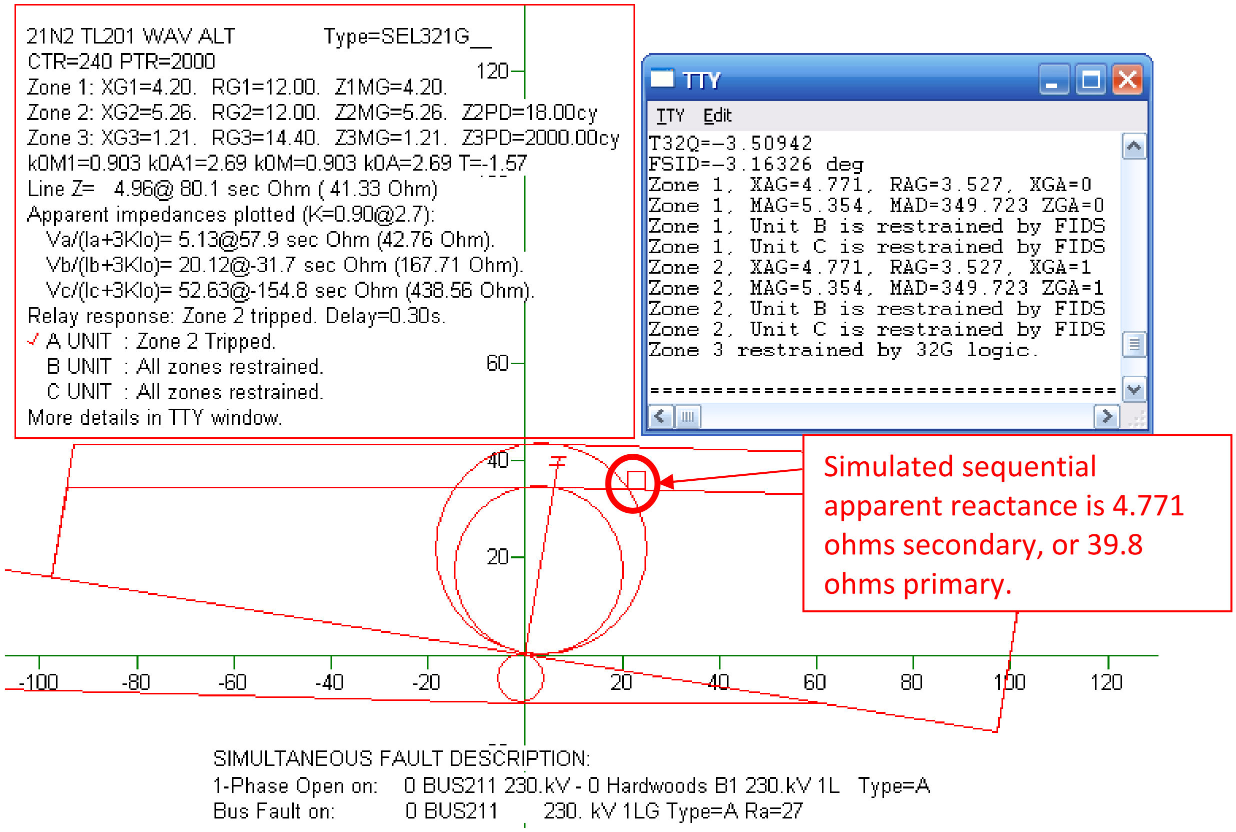


Figure 17 - Sequential response of WAV SEL-321 relay to 7 March 2011 fault

The simulated response of the WAV SEL relay in ASPEN OneLiner can be compared to the actual response which is shown in Figure 18. In Figure 18 it can be seen that the SEL zone 1 and 2 distance elements do operate after the HWD terminal opens, but relatively slowly (compared to the optimho relay) and do not pick up solidly when they eventually operate. The slow pickup is due to the marginal sensitivity of the set reach.

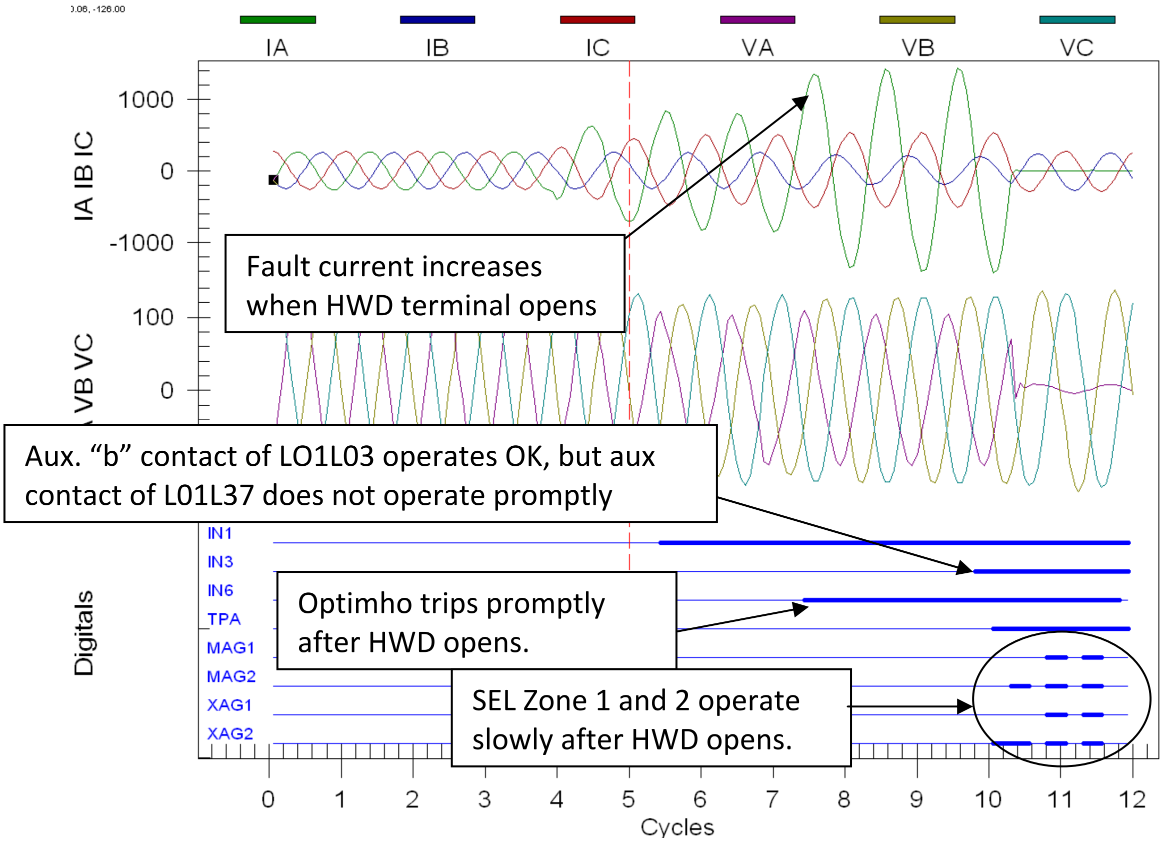


Figure 18 - Response of the WAV SEL-321 to the 7 March 2011 fault

During the automatic reclose, the fault resistance was somewhat higher than initially, but apart from an initial transient, the response of the zone 2 reactance element was still slow. Figure 19 shows that the apparent reactance presented to the relay is changing during the fault, becoming less and less with time. This effect is surprizing considering that the fault location is not changing. However the conclusion is still that the apparent reactance is very close to the set reach of the zone 2 quadrilateral element.

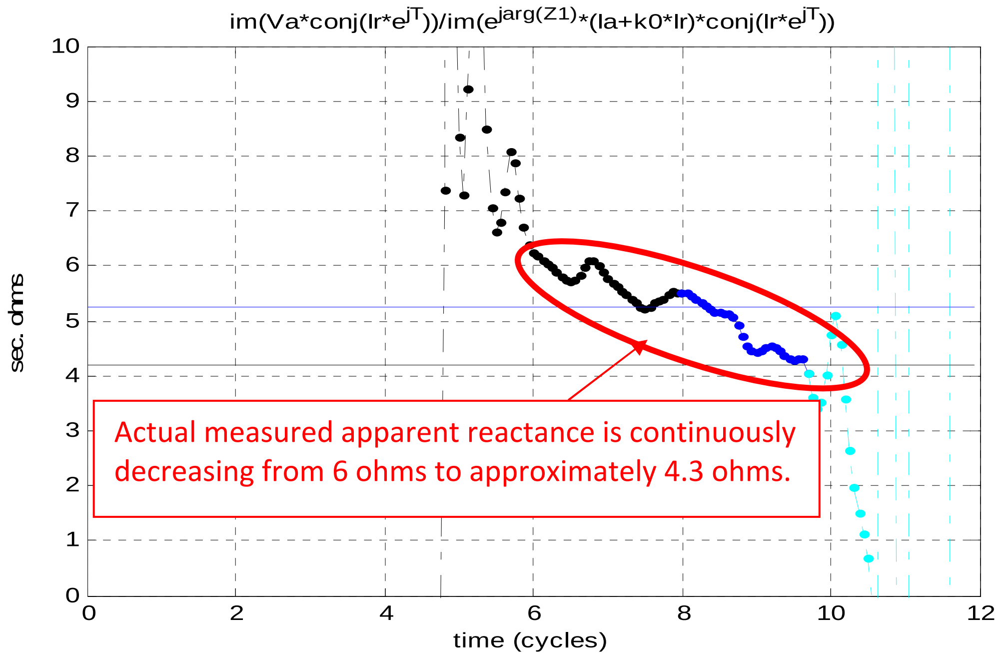


Figure 19 - Apparent reactance of real fault on reclose as seen by relay model

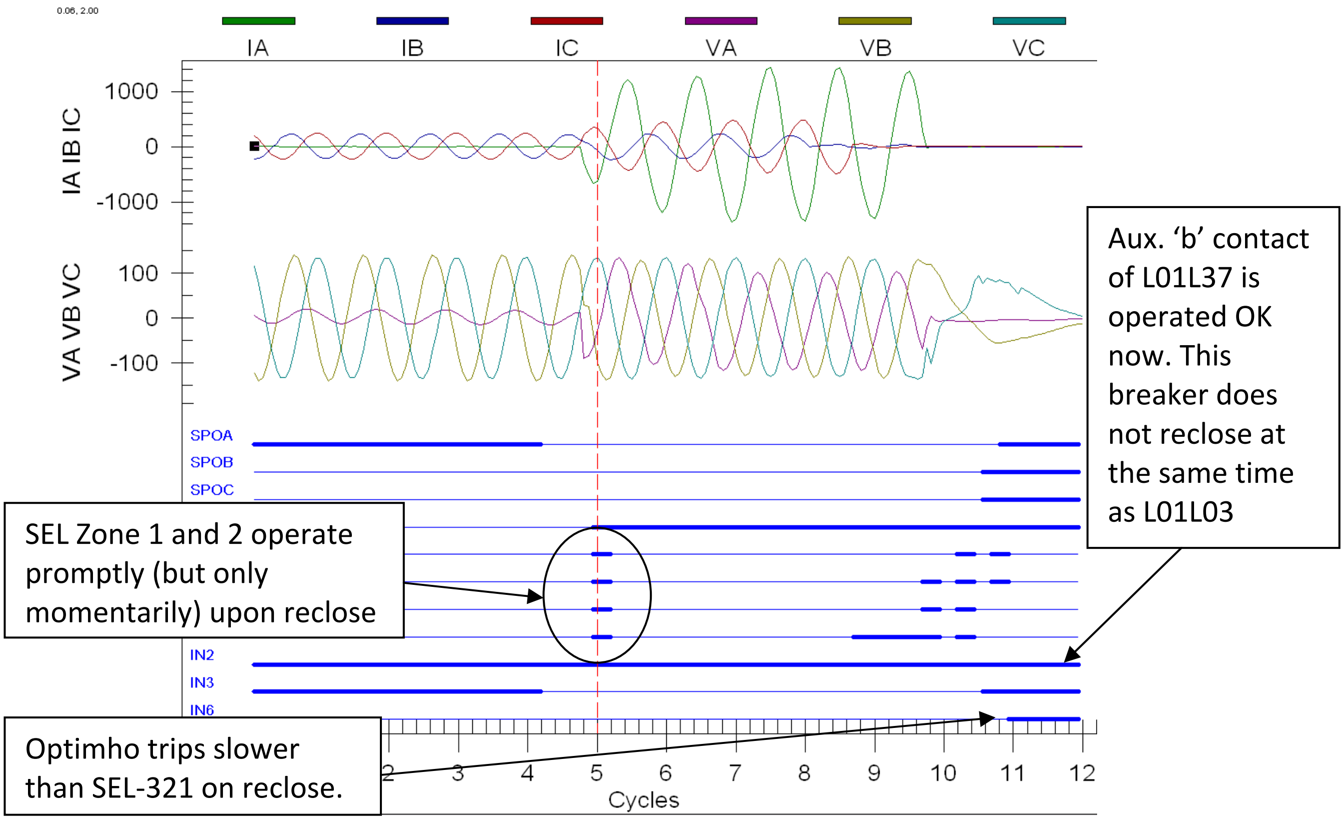


Figure 20 - - Response of the WAV SEL-321 to the reclose onto the 7 March 2011 fault

The event report from the WAV SEL-321 relay during the reclose (which was not successful because the excavator was still in contact with the line) is shown in Figure 20. This figure shows that the distance elements in the SEL-321 operate promptly (even faster than the optimho relay) upon reclose, but only stay operated for ¼ cycle. It would have been expected that at least the zone 2 distance functions would have remained solidly picked up for the duration of the fault. This reinforces a concern that there is something unexplained happening with this relay. The event reports were sent to Schweitzer Engineering Laboratories (SEL) for further analysis.

Figure 18 also shows that the auxiliary contact of the L01L37 breaker operates slowly compared to the auxiliary contact of breaker L01L03. The record persists for more than 2 cycles after the auxiliary contact of L01L03 operates, but the L01L37 auxiliary contact does not operate within that time.

Figure 20 also shows that the auxiliary 'b' contact of breaker L01L37 has operated by the time the reclose occurs, but the gap between the initial fault and the reclose prevents observation of how long the auxiliary switch takes to operate.

SEL modeled the relay response to the measured quantities during the fault. They provided plots of the modeled response to the initial fault in Figure 21 and Figure 22.

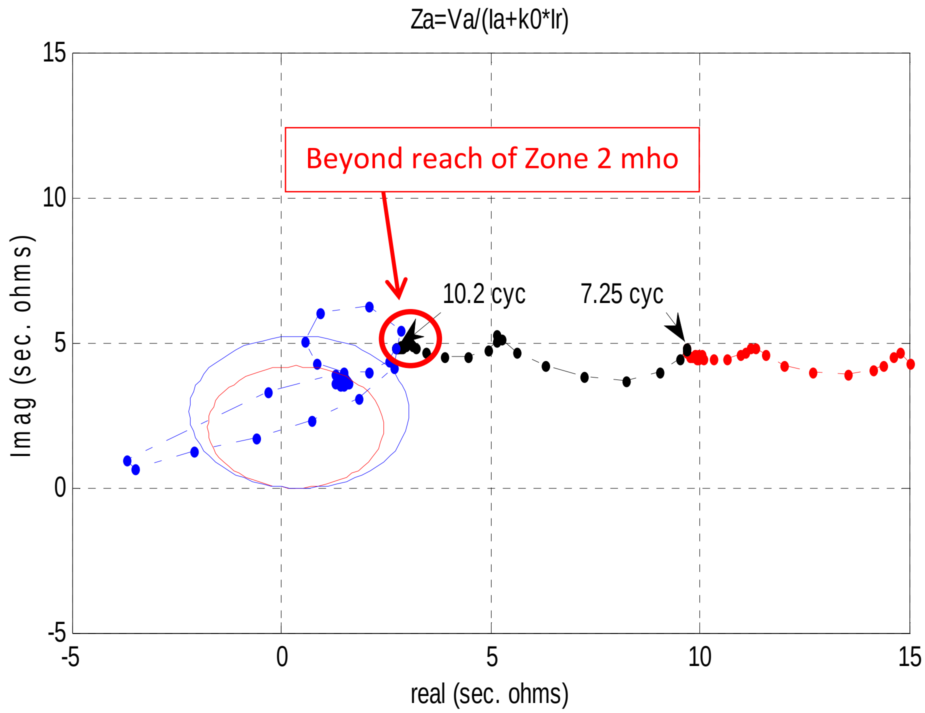


Figure 21 - Response of mho AG element during initial fault.

It can be seen that the apparent impedance presented to the relay remained outside the reaches of the mho and quadrilateral elements until 10.2 cycles, when the fault was being cleared by the optimho relay. Figure 22 shows that the apparent reactance of the fault was just beyond the reach of the quadrilateral element. The quadrilateral element reactive reach slopes downwards at an angle of -1.5 degrees, whereas the reactive reach of the quadrilateral element of the optimho relay does not slope downwards at all. This explains why the optimho relay operated promptly to clear the initial fault, while the SEL relay was slow.

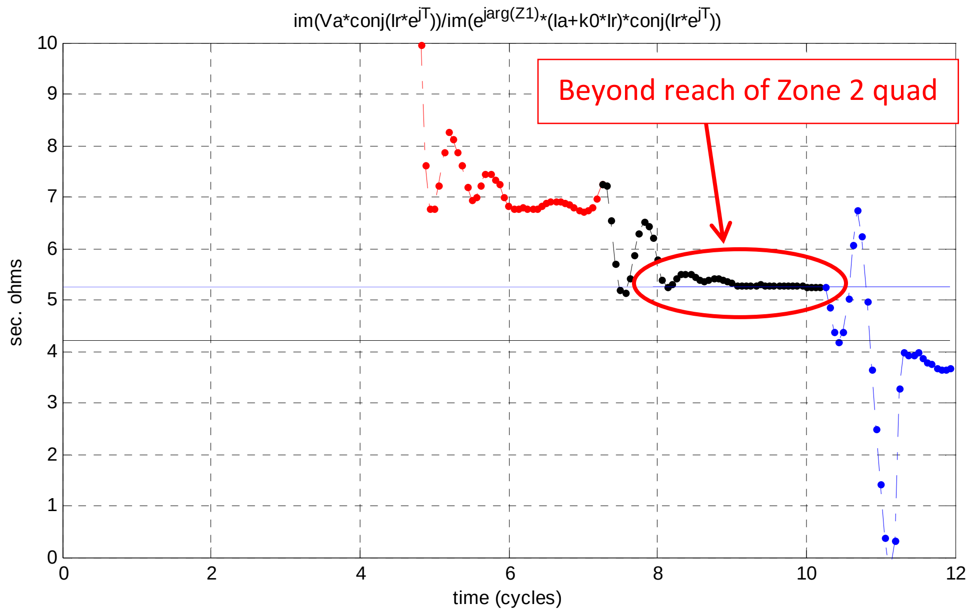


Figure 22 - Response of XAG element to initial fault

This analysis confirms that the reach of the SEL zone 2 elements is presently set too short to dependably cover the complete line, and the optimho zone 2 element setting is marginal.

Appendix B – Detailed Analysis of TL201 Fault 6 April 2011

On 6th April 2011 TL201 tripped C phase and reclosed successfully. There were high winds at the time of the fault, but the line patrol did not find any evidence of where the fault had been. This fault was very close to the WAV terminal of the line, with the relay estimated location being only 0.4 km from WAV. The fault was very low resistance, and reduced the WAV C phase voltage to about 3% of nominal. A low resistance (0.5 ohm) fault was simulated on ASPEN OneLiner at 0.5% of the line from WAV, and a reasonable match between the currents and voltages was observed.

The simulated response of the HWD SEL321 relay showed that even though the fault resistance was low, the effect of the zero sequence mutual impedance with other parallel lines was to make the apparent impedance presented to the relay lie outside the reach of the HWD relay (see Figure 23). After the WAV terminal opens, the apparent impedance presented to the HWD terminal decreases so much that the zone 2 element can easily “see” the fault (see Figure 24). This simulated response is the same as was observed on the actual relay performance (see Figure 25). Note that in this case the zone 1 element picks up on the transient at fault clearing similar to the 7th March excavator fault.

In order to avoid the need for sequential clearing of one terminal or the other for a fault near the remote terminal, the zone 2 ground distance functions need to be set with increased reach to accommodate the underreaching effect of the zero sequence mutual coupling.

Figure 25 also shows that the optimho relay is about 1 cycle slower than the SEL 321 relay for this incident. It is expected that the transient response of the SEL-321 and optimho relays will be different.

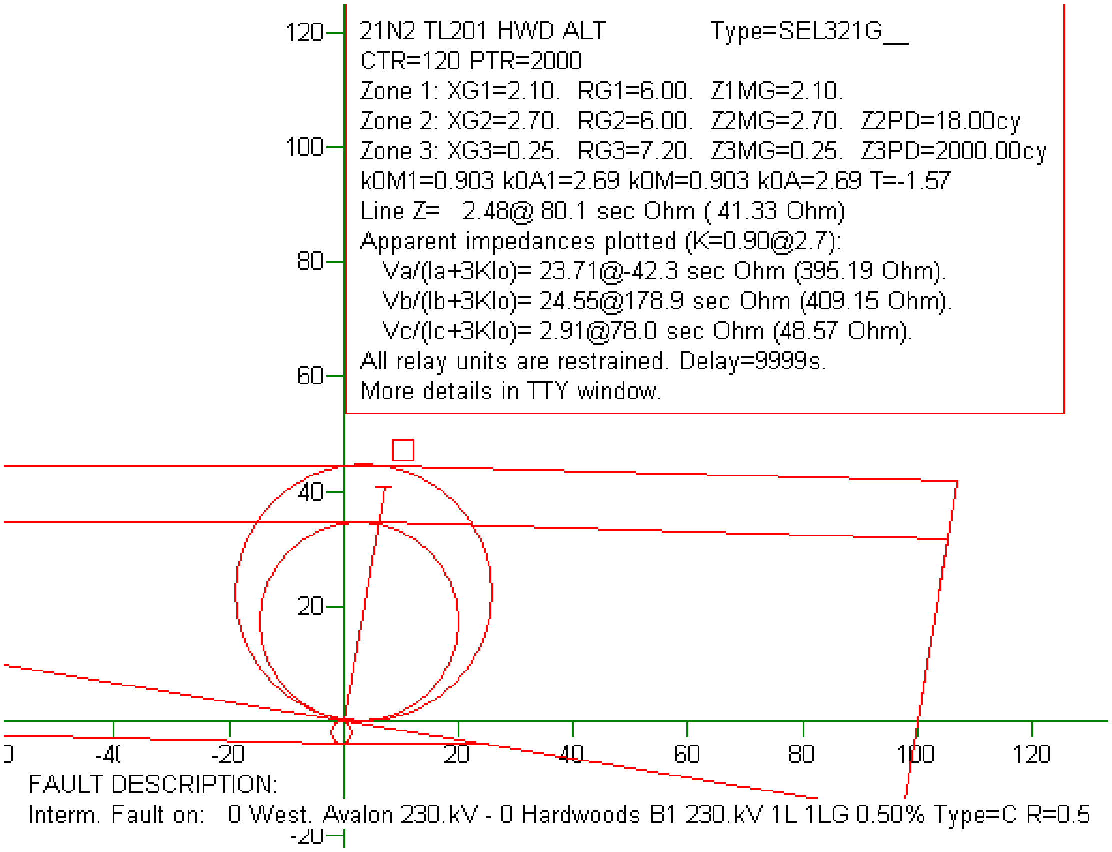


Figure 23 - Initially HWD terminal cannot see the fault close to WAV

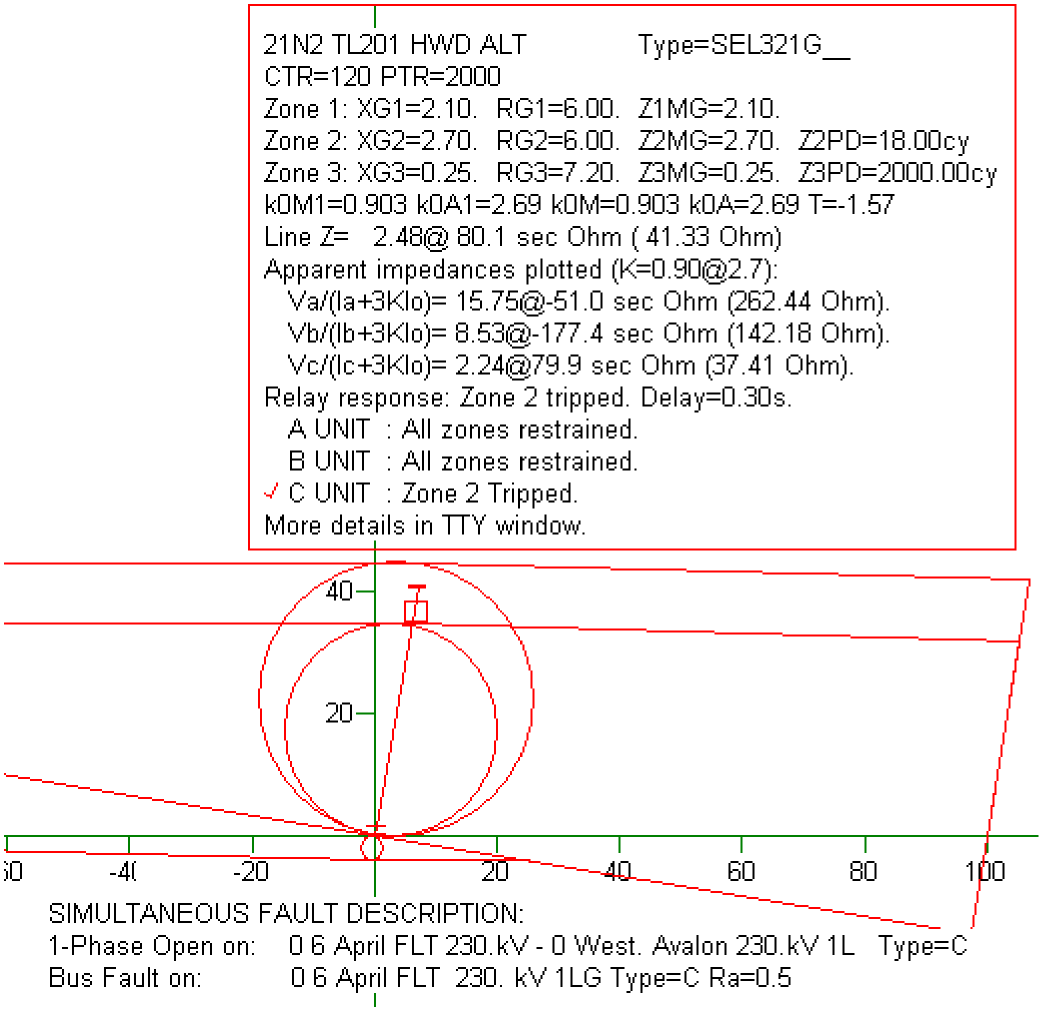


Figure 24 - After WAV opens HWD Zone 1 can see the fault

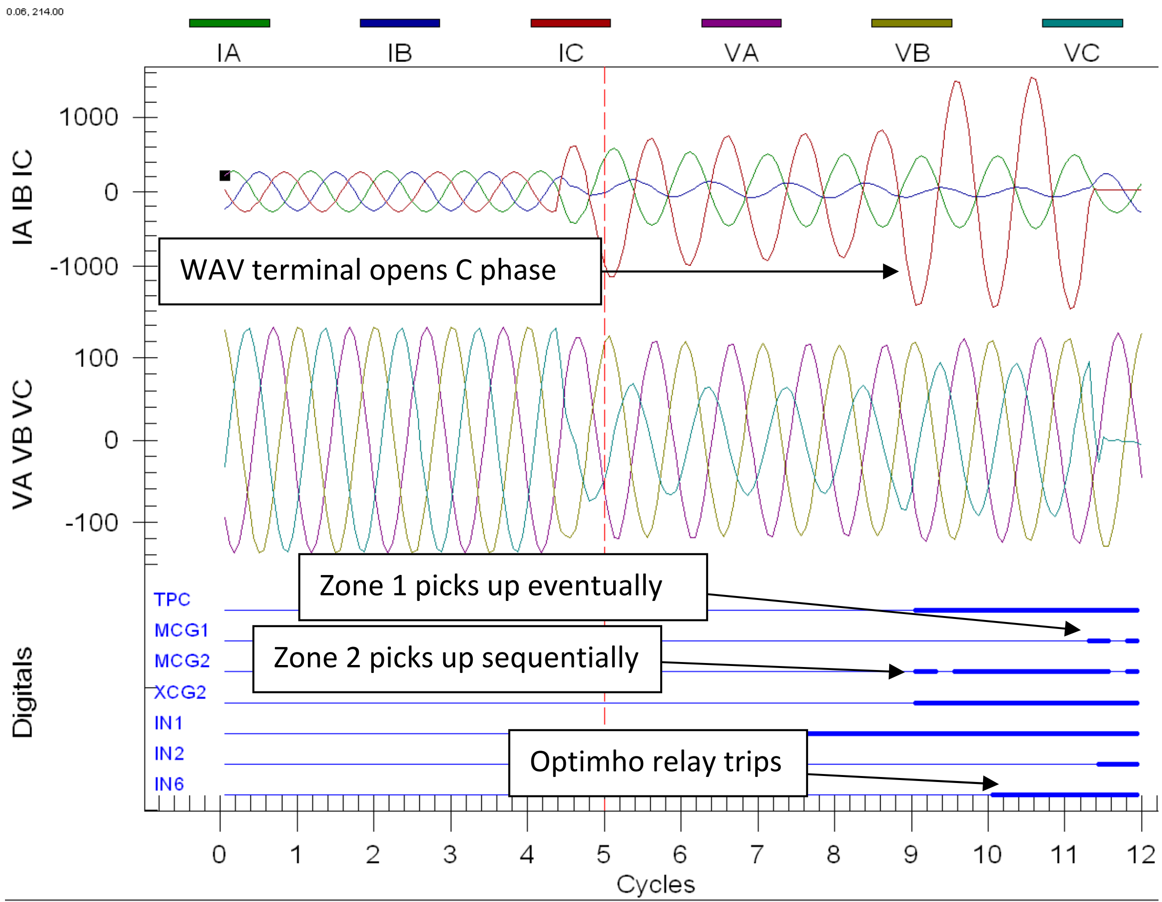


Figure 25 - Response of HWD TL201 SEL 321 to 6 April 2011 Fault

Appendix C – Detailed Analysis of Holyrood B1B11 Fault on 11th June 2010

In this incident, the communications independent zone 2 protection at the Western Avalon terminal of TL217 was required to clear a fault on the Holyrood 230 kV bus. Only the P1 protection system operated at WAV to clear this fault. It would have been expected that the zone 2 elements of both the P1 and the P2 protections would have cleared this fault since both elements are set the same. The fault was simulated in ASPEN OneLiner as shown in Figure 26 shows that the apparent impedance presented to these relays is very close to the limit of zone 2 operation. The intended dependability margin for these zone 2 elements was 18% overreach. That is, the setting was 118% of the line impedance to ensure they would dependably operate for a fault close to the remote bus. However because if mutual coupling of TL217 to adjacent circuits, the apparent impedance presented to the relays was only 1% less than the setting. This 1% dependability margin is not normally adequate to ensure dependable operation. In this case the P1 protection operated satisfactorily, but not the P2 element.

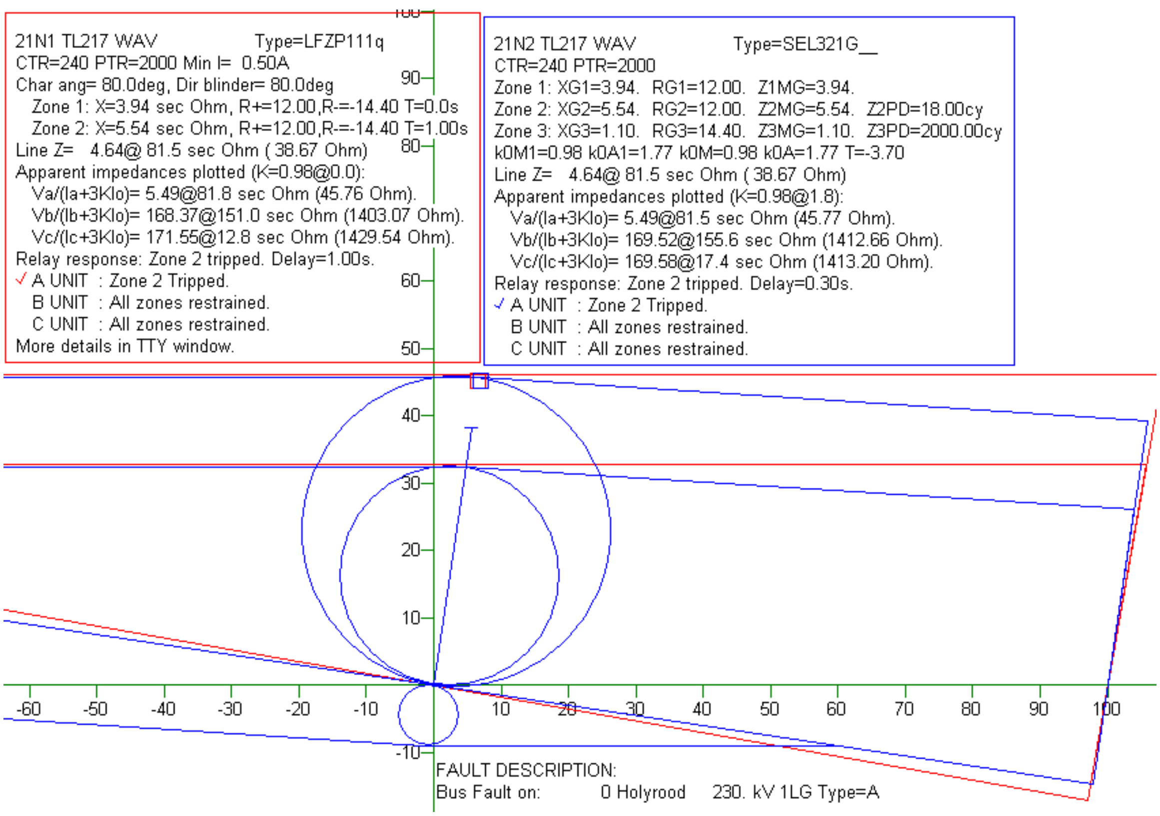


Figure 26 - Apparent impedances of a Holyrood bus fault to WAV TL217 protections

Figure 26 and Figure 27 show that the P2 zone 2 element is not solidly asserted during the Holyrood bus fault, thereby confirming that this element does not dependably cover the whole line.

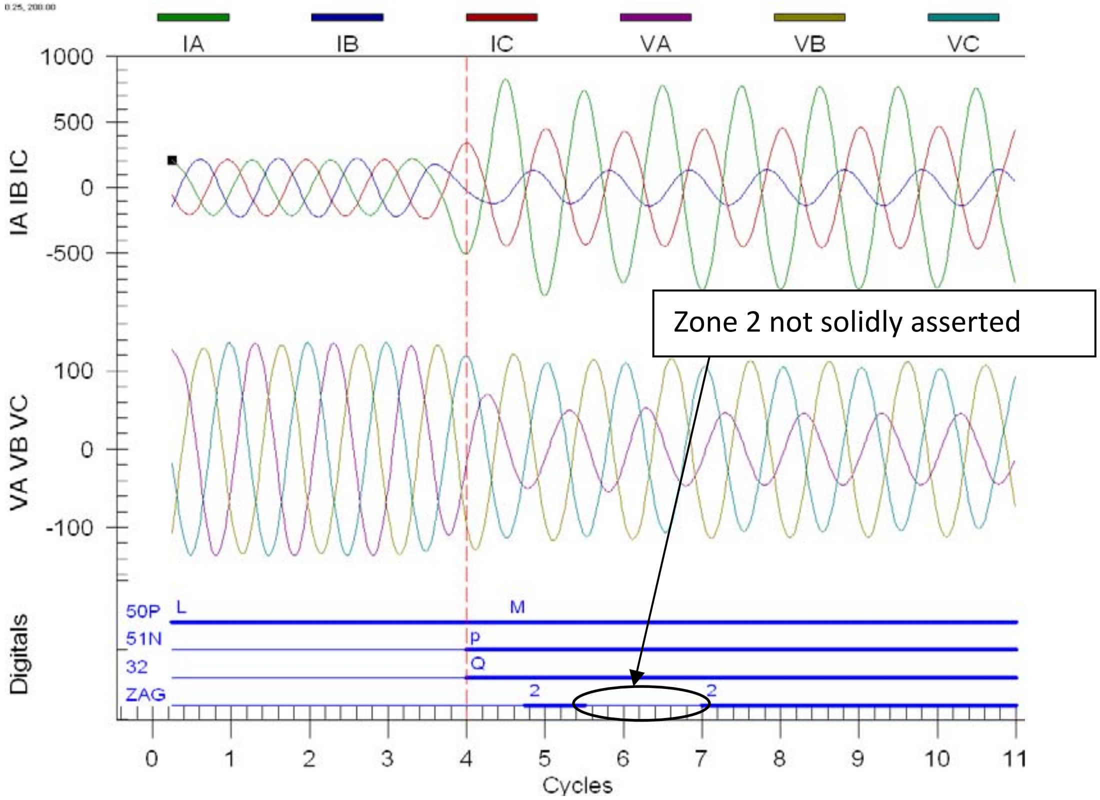


Figure 27 - Event report from WAV TL217 P2 relay at start of Holyrood fault

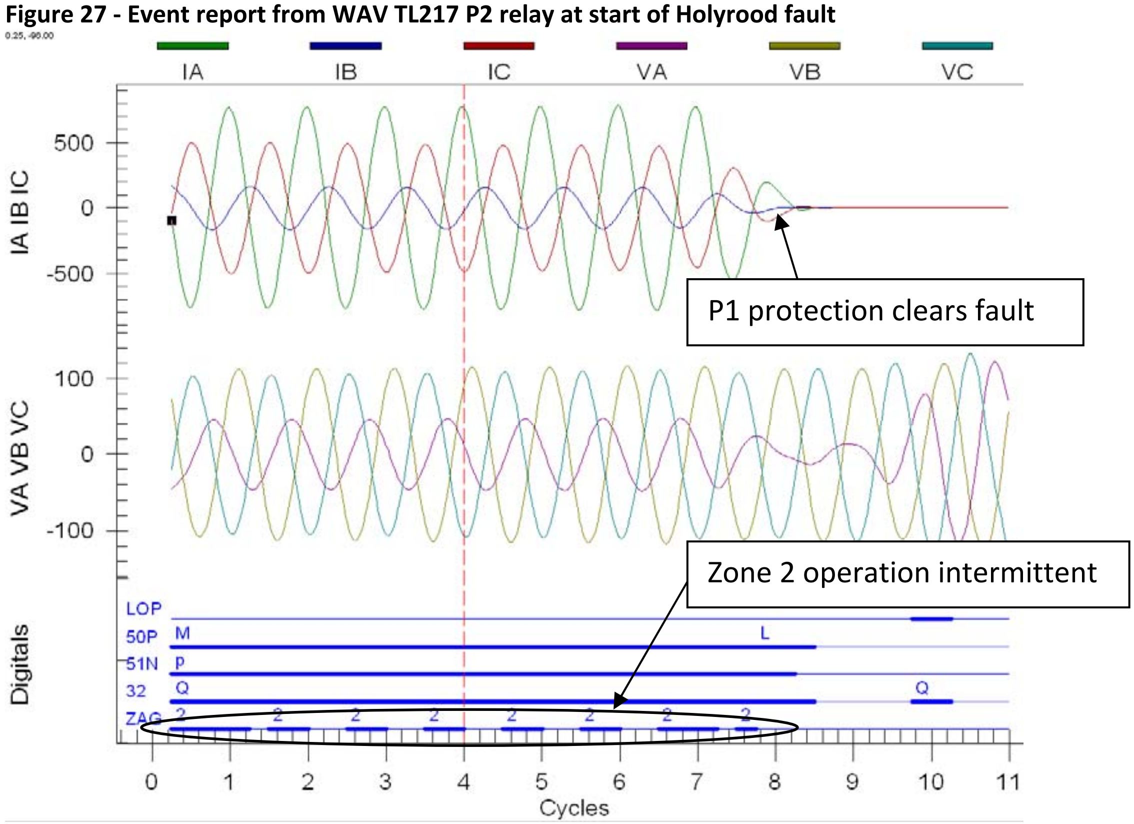


Figure 28 - Event report from WAV TL217 relay during clearing of Holyrood fault

Protection Review for Five 230 kV Transmission Lines

Appendix D
Detailed settings review for WAV TL201 "P1" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador Hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Western Avalon Terminal (WAV) terminal of circuits TL201. This 230 kV transmission circuit is from WAV to Hardwoods (HWD).
The circuit runs parallel to Circuit TL217 for most of its length.

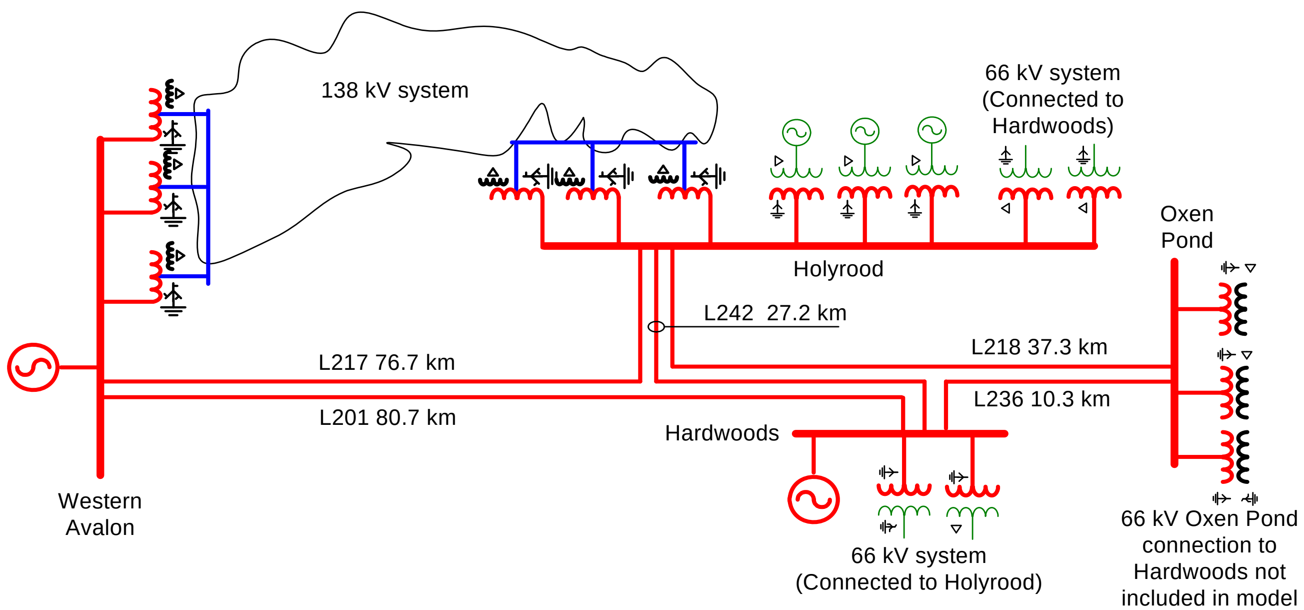


Figure 1 - System Single Line Diagram

Existing P1 protection systems are Areva LZFP111 (Optimho) systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $kVbase := 230$ $Ibase := \frac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $Zbase := \frac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at the line terminal.

CT ratio is: $CTR := \frac{1200}{5}$ VT ratio is: $VTR := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "N**L HYDRO WITH MUTUALS FOR EAST COAST 230 kV LINE PN REVIEW.OLR**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with loads and shunts ignored.

Minimum fault current seen by each terminal (phase to phase, and SLG with 0 ohm fault resistance).

At WAV, with TL203 out of service, and both TL201 and TL217 in service, for a fault at the remote terminal.

$ILLmin := 832$ A $ISLGminPH := 856$ A $ISLGmin0seq := 241$ A

The optimho current level detectors that block the distance comparators in the event of line opening are fixed at 5% of the rated current, or 0.25 A secondary, or 60 A primary. They will have no difficulty in operating for minimum bolted fault levels. However, the ground distance elements are also supervised by a low set neutral current level detector (LDLSN that requires the neutral current to be greater than 10% of the maximum amplitude of phase difference current. This prevents the ground comparators from operating during close-in multiphase faults with CT errors. ASPEN OneLiner shows that for a bolted fault at the remote bus even under heavy load, there is sufficient neutral current (17% of maximum phase to phase fault current) that means this LDLSN function does not inhibit the ground distance comparator.

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind WAV $Z2minWAV := 3.2 + j \cdot 29.3$ ohms primary

Minimum source impedance behind HWD $Z2minHWD := 1.8 + j \cdot 27.7$ ohms primary

<u>Line impedances</u>.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L201 := 0.01346 + j \cdot 0.07696$ $Z0L201 := 0.04011 + j \cdot 0.28691$

$Z1Line := Z1L201 = 0.013 + 0.077j$ pu $Z0Line := Z0L201 = 0.04 + 0.287j$ pu

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line \cdot Zbase$ $Z0Linephys := Z0Line \cdot Zbase$

$Z1Linephys = 7.1 + 40.7i$ ohms primary $Z0Linephys = 21.2 + 151.8i$ ohms primary

Converting primary ohms to secondary ohms gives:

$Z1Linesec := Z1Linephys \cdot \frac{CTR}{VTR}$ $Z0Linesec := Z0Linephys \cdot \frac{CTR}{VTR}$

$|Z1Linesec| = 4.96$ ohms sec $arg(Z1Linesec) = 80.1 \cdot deg$

$|Z0Linesec| = 18.39$ ohms sec $arg(Z0Linesec) = 82.04 \cdot deg$

Load Data

From 2011 System summer load case provided in start up information, the peak load (sum of TL201 and TL217) is given as 205 MVA (split between TL201 and TL217). In the event of sudden loss of one line, peak load will be the sum of both line loads until operators can adjust loads. Therefore it is assumed that peak load for a short duration is 205 MVA

$Speak := 205$ MVA $Smax := Speak = 205$ MVA

P1 Relay Settings

Distance element reach settings

Note that resistive reaches are forced to be the same for all zones. Reactive reaches for phase and ground distance elements must be the same as each other.

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the HWD Station bus under light load conditions with one line from SSD to WAV out of service and both TL201 and TL217 lines in service. From ASPEN OneLiner, voltage at WAV for a 3 phase fault at HWD is 0.3 per unit. So there is plenty of voltage at WAV during a fault at HWD, even under weak source conditions.

Since the voltage is higher than 20%, the line is not considered short, and a conventional Zone 1 setting is acceptable.

$Z1P := 0.85 \cdot |Z1Linesec|$ $Z1P = 4.2$ Ohms secondary

Existing setting of 4.22 ohms is OK, and could be retained if only the phase distance functions had to be considered. However, the ground distance reach in the optimho has to be set the same as the phase distance reach; so we need to consider the ground faults too.

$Z1P := 4.2$ For phase faults only.

The worst case from the point of view of overreach of the zone 1 ground distance element is with TL242 out of service and grounded at both ends, and a close-in fault on TL236 with the Oxen Pond end open. For this case, the apparent impedance presented to the relay is only 4.6 ohms secondary (see Figure 2). This is 93% of the line impedance. So the reach of the zone 1 element should be reduced somewhat.

$Zapp\_ext := 4.43$ ohms $Zapp\_ang := 80.3deg$ This angle is close enough to the line angle to treat it as equal to the line angle.

$\frac{Zapp\_ext}{|Z1Linesec|} = 0.893$ The apparent impedance is reduced by about 11% mostly due to the effect of the parallel line being out of service and grounded at both ends but also partly due to the zero sequence current compensation factor being set slightly too high on this protection.

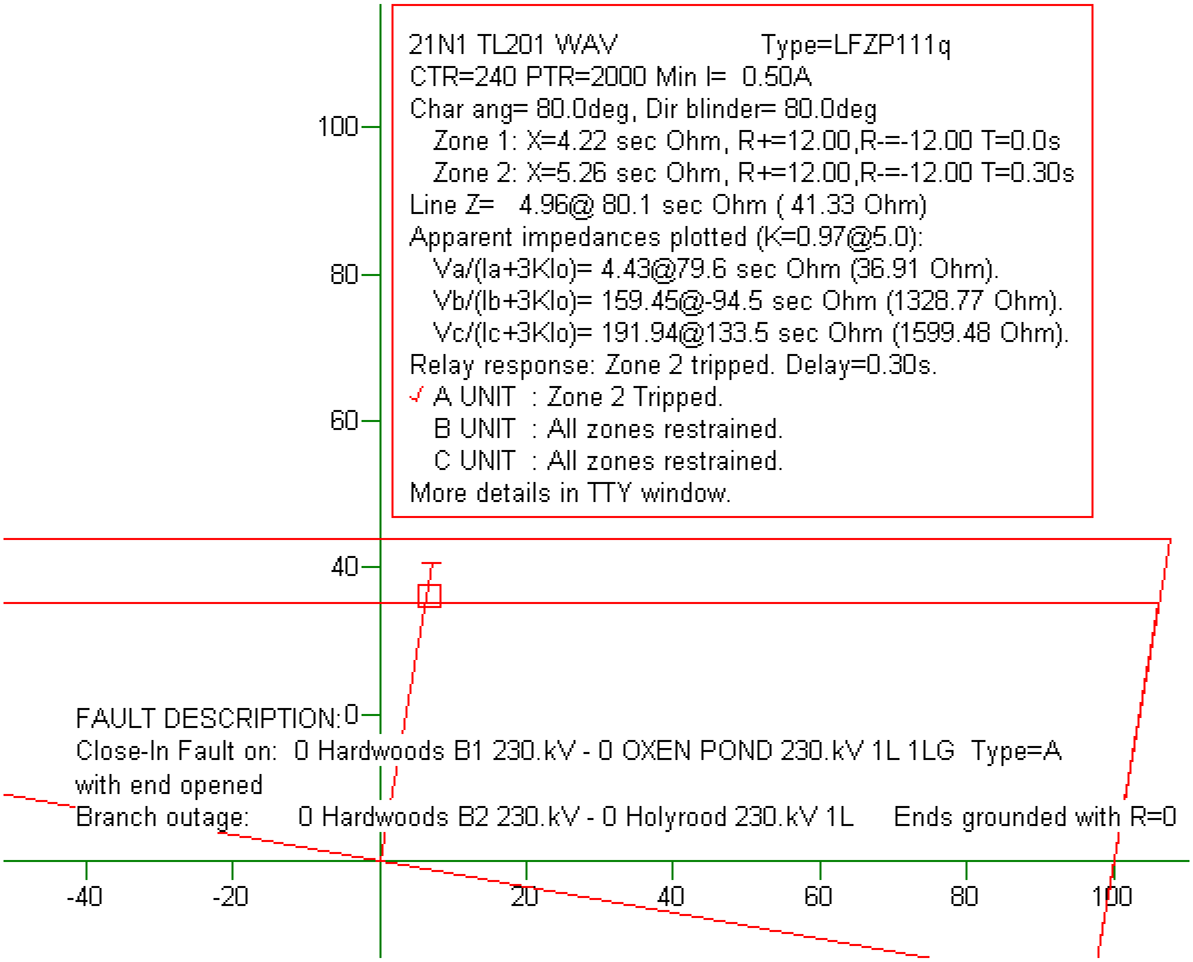


Figure 2 - Apparent impedance to a fault just beyond the remote terminal is reduced by 7.% when parallel line is out of service and grounded at both ends. Existing relay settings modeled in this figure.

The reach of the zone 1 ground distance element should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Choose a setting of 80% of line which will underreach the remote bus by 10% when the parallel line is out of service and grounded at both ends and when the zero sequence current compensation factor is reduced slightly.

Let the per unit reach of the Zone 1 function be m per unit of the line. $m := 0.8$ per unit

$Z1\_sec := \mathrm{round}(m \cdot |Z1Linesec|, 1)$ $Z1\_sec = 4$ Ohms secondary

$Z1pri := Z1\_sec \cdot \frac{VTR}{CTR} = 33.333$ Ohms primary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is just less than 5.26 ohms secondary (about 106%). However, in order to reach a single line to ground fault at the remote terminal, it will be necessary to set the reach significantly further.

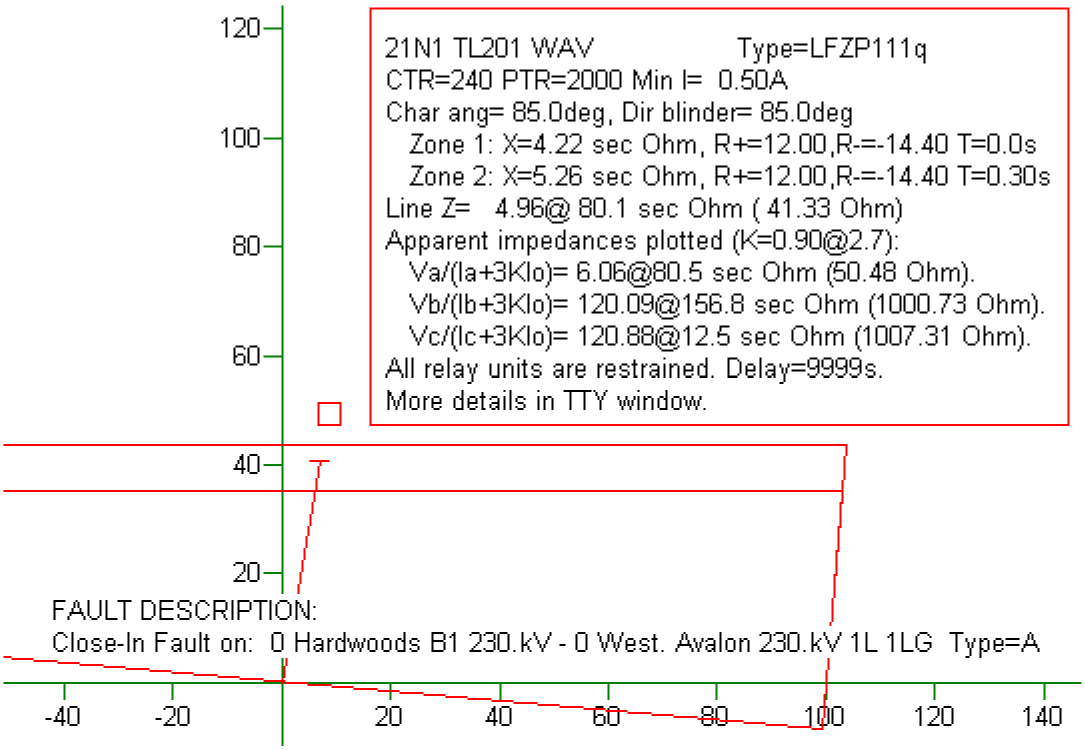


Figure 3 - Apparent impedance to a fault close to the remote terminal is increased by 22% when parallel line is in service.

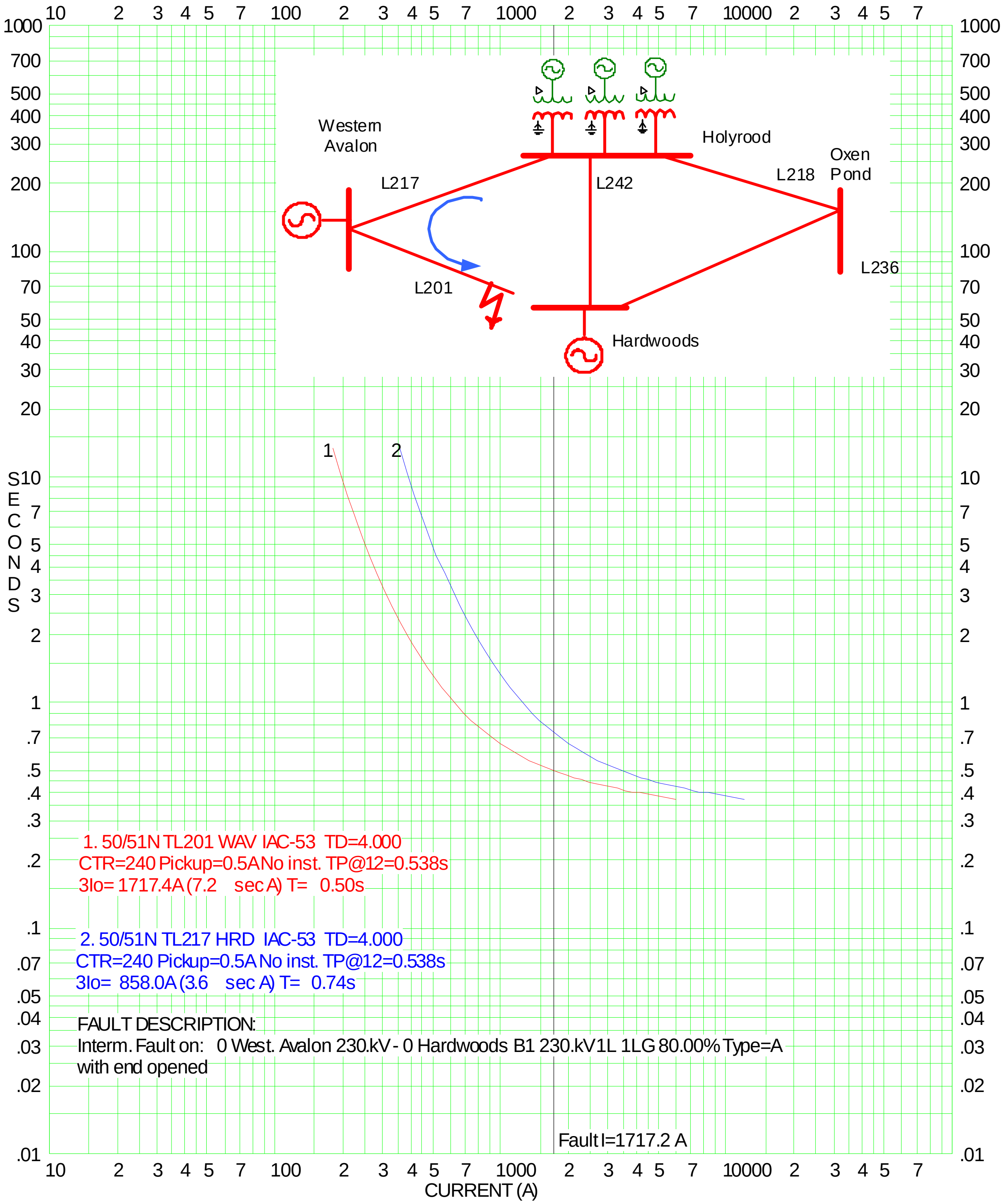
As can be seen from Figure 3, the apparent impedance to a fault close to the remote terminal is increased when the parallel line is in service.

$Zapp\_int := 6.06$ Ohms secondary

$Z2\_sec := 1.25 \cdot Zapp\_int$ $\quad Z2\_sec = 7.6$ Ohms secondary $\quad \frac{Z2\_sec}{|Z1Linesec|} = 152.735 \cdot \%$

$Z2\_pri := Z2\_sec \cdot \frac{VTR}{CTR} = 63.125$ Ohms primary

The zone 2 timer will be enabled, and set at 1 second (to coordinate with remote ground time overcurrent functions). This long delay will have no difficulty in coordinating with the zone 2 element on the short line TL236 beyond HWD. However, this long time will not help coordination below the HWD TL217 ground overcurrent protection for the case when the communications fail and a fault such as shown on Figure 4 is faced. For this case, we have to set the Zone 3 element to trip also. The zone 3 element will be set shorter and faster than the zone 2.



EC 230-4	TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For	Coordination of WAV TL201 below HRD TL 217	No. EC 230-4A
Comment	Requires Z1G and Z3G for coordination with RF <100 ohms	Date 6 Oct 2011

Figure 4 - small coordination margin for 0 ohm fault at 80% of line with remote terminal open

Due to the small coordination margin, a shorter reaching (than Zone 2) but faster zone 3 element will be applied.

This element will be set about 10% more than the existing zone 2 ground distance function that has proven to be marginal for a resistive fault near the end of the line (as in 7 march 2011 excavator fault), but operates dependably when the fault resistance decreases. Therefore the desired reach for the zone 3 element is 115% of the line.

Zone 3

Enable zone 3 time delayed tripping to improve coordination underneath remote ground overcurrent protection and bearing in mind that the new zone 2 reach will be increased but with longer time delay.

$Z3\_sec := \mathrm{round}(1.15 \cdot |Z1Linesec|, 1) = 5.7$ Ohms secondary

Z3 timer will be set at 0.3 seconds. This will coordinate above all communications assisted protection (instantaneous) and it is not expected that communications assisted protection will be unavailable during contingency conditions such as a parallel line out of service and grounded) at the same time that the communications assistance fails.

$Z3\_TD := 0.3$ Seconds

Load Encroachment logic

The optimho instruction manual recommends a margin of at least 10% between the impedance of the maximum load and the resistive reach of the quadrilateral distance element.

Check loadability of the Zone 2 phase distance element assuming worst case depressed voltage of a stressed system of 0.9 per unit.

$Zloadmin := \frac{(0.9kVbase)^2}{Smax}$ $Zloadmin = 209.02$ Ohms primary (assume worst case at 30 degrees)

$Zloadmin\_sec := Zloadmin \cdot \frac{CTR}{VTR}$ $Zloadmin\_sec = 25.082$

A 12 ohm secondary resistive reach is less than 90% of the load impedance at unity power factor and meets the Areva criterion as shown in Figure 5.

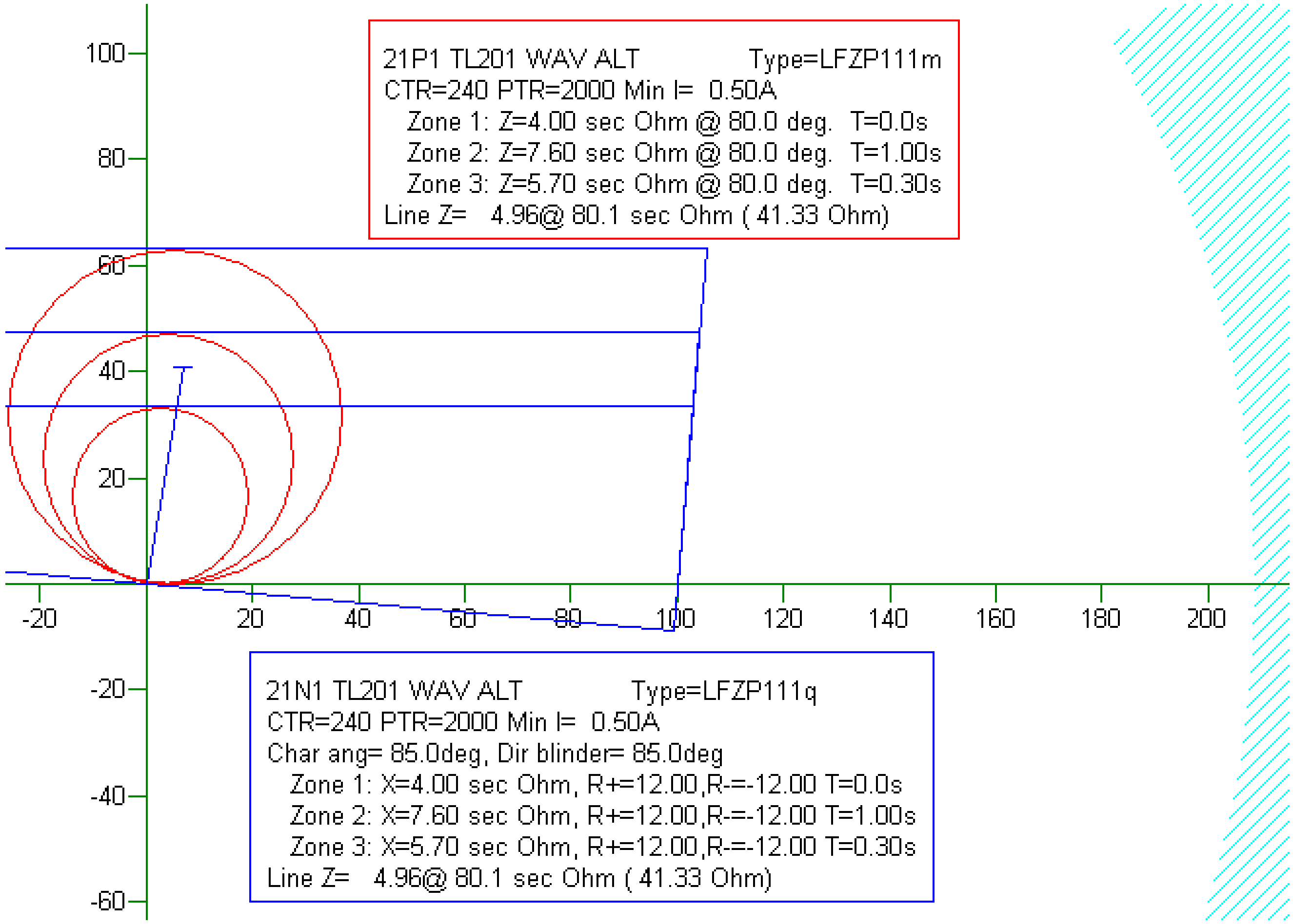


Figure 5 - Apparent impedance of load

Resistive reach of quadrilateral elements

Check the maximum fault resistance that can be sensed for a fault at a location where the current contribution from each terminal is roughly the same. From Figure 6, it can be seen that the limit of sensitivity (where quadrilateral elements at both ends can see a fault) is about 93 ohms, for a fault about 45% of the distance from WAV. This is close enough to the required sensitivity of 100 ohms. Note that the point of overlap of quadrilateral elements may move along the line depending on the strength of the source at either end, but they will always overlap somewhere. For resistive faults outside the overlapping zone, sequential clearing will have to be accepted.

Rquad := 12 Ohms secondary

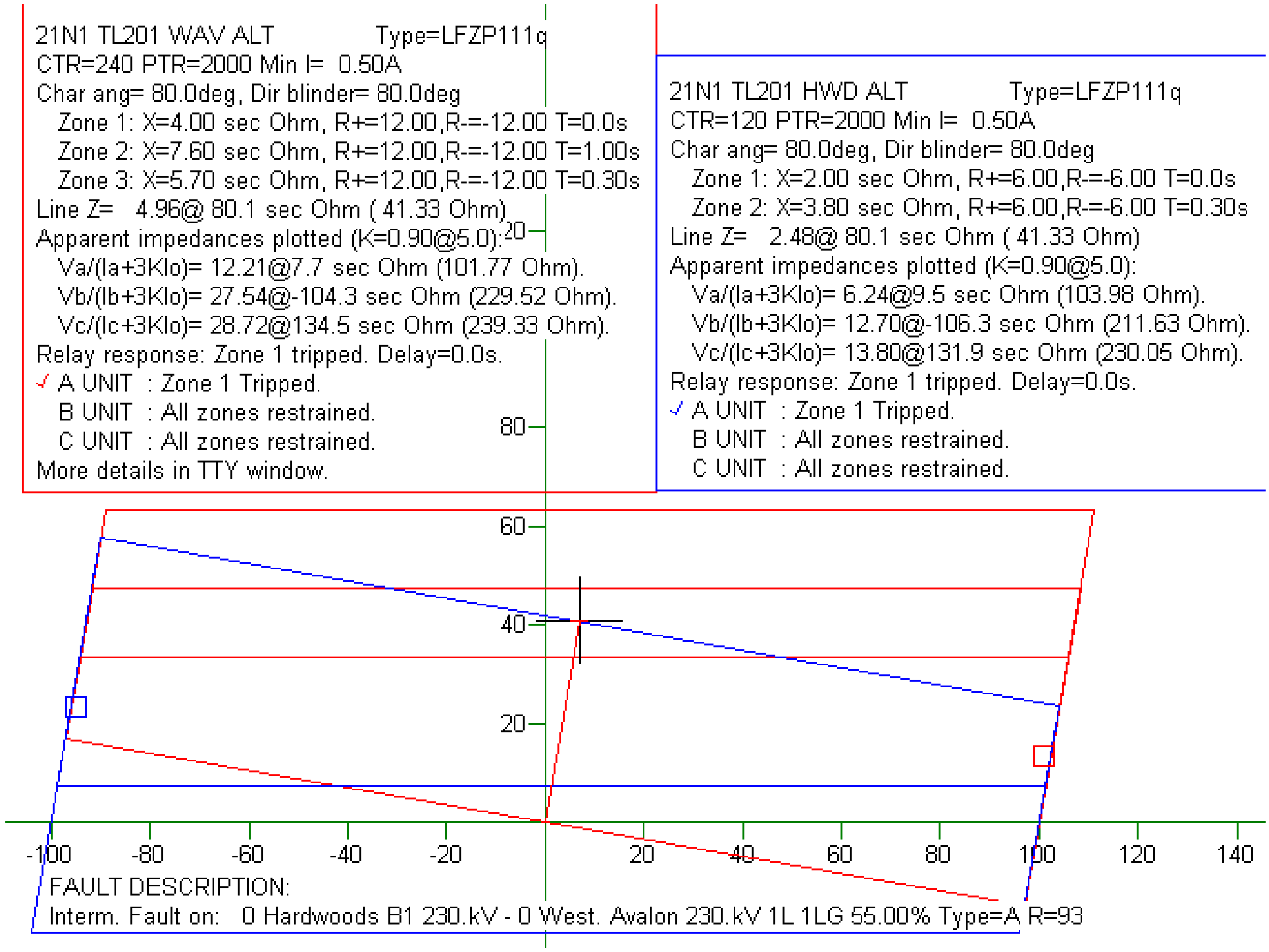


Figure 6 - Apparent impedance of a resistive fault near the mid point of the line.

Settings of K attenuators

KZPh Coarse setting common to all DISTANCE zones should be set as high as possible while below the required Zone 1 reach. The current level detectors vary inversely with KZph. Maximum setting available is 1.0

$KZPh := 1.0$

Zone 1 attenuators and angular selection

$In := 5$ $\quad Z1\_sec = 4$ This is the desired secondary reach (previously calculated)

$$KZ1 := \frac{Z1\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ1 = 4 \qquad Z1sec\_reach := KZ1 \cdot KZPh \cdot \frac{5}{In} \qquad Z1sec\_reach = 4$$

$Z\theta PH := (\arg(Z1Linesec))$ $\quad Z\theta PH = 80.08 \cdot deg$

Rounded to the nearest 5 degrees $\quad Z\theta PH := 80$ Degrees

$Z\theta N := \arg(Z0Linesec - Z1Linesec)$ $\quad Z\theta N = 82.766 \cdot deg$

Rounded to the nearest 5 degrees $\quad Z\theta N := 80$ Degrees

Zone 2 attenuators selection

$Z2\_sec = 7.6$ This is the desired secondary reach (previously calculated)

$$KZ2 := \frac{Z2\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ2 = 7.6$$

Zone 3 attenuators selection

$Z3\_sec = 5.7$ This is the desired secondary reach (previously calculated)

$$KZ3 := \frac{Z3\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ3 = 5.7$$

QUAD Resistive Reach setting

$Rquad = 12$ This is the desired secondary reach (previously calculated)

$$KR := \frac{Rquad}{\left(\frac{5}{In}\right)} \qquad KR = 12$$

Residual Compensation attenuators selection

Zero sequence current compensation for ground faults is provided by the KZN factor. Zero sequence mutual compensation is not used in this application (it causes extra complexity for only moderate gain in setting accuracy).

$$KZN := \frac{Z0Linesec - Z1Linesec}{3 \cdot Z1Linesec} \cdot KZPh \qquad KZN = 0.902 + 0.042j$$

$|KZN| = 0.903$ This is a reduction from the existing setting of 0.967

Switch On To Fault (SOTF) Protection.

If SOTF is enabled, it can be set to 200ms or 110 s after all poles of the line have been de-energized. The 110 s setting is intended to override automatic reclosing dead time. However it makes more sense to enable after the shorter time. Once the SOTF feature has been initiated, it remains in effect for 250ms after the line has been re-energized. The SOTF tripping options are:

a) Any distance comparator.
b) Any current level detector as long as a corresponding voltage level detector has not picked up within 20ms.
c) Either current or distance, as long as a corresponding voltage level detector has not picked up within 20ms.

SOTF := "Enabled"

SOTF_TIME := 0.20 Seconds

Elements_in_SOTF := "BOTH" (Both Comparators and current level detectors).

Power Swing Detector

This element will not be used. It will be left Blocked, and if there is a power swing, the distance elements will trip naturally.

VT Supervision

Set the VT supervision to BLOCK TRIP

Set the VT fail detection to SELF RESET.

Start Indication

This function will bring up information on the LCD screen of the relay if a start event occurs. This function will not be used.

START_INDICATION := "BLOCKED"

Communications assisted logic.

The existing communications assisted logic is permissive overreaching transfer trip, scheme **POR 1**. This scheme is familiar to Newfoundland and Labrador Hydro, and even though the POR 2 scheme offers the advantage of weak infeed echo, which would help the sensitivity to resistive faults, it is not recommended to change the existing scheme logic at this stage with years of experience on a product that is nearing the end of its useful life.

The POR 1 logic is a basic permissive overreaching transfer trip scheme but it does include current reversal timers to increase security against misoperation due to current reversal when a fault on the parallel line is cleared sequentially. The current reversal logic is achieved by a timer TP which will block permissive tripping and keying of permissive trip if the local zone 2 element does not pick up within a reasonable time of receiving permissive trip. The block will be maintained for a time delay of TD after the local zone 2 element picks up, or the received permissive trip signal resets.

The application of the current reversal timers is required only if the settings of the zone 2 comparators are greater than 1.5 times the line impedance .Although the reaches of these elements slightly more than 1.5 times the line impedance, there is no parallel line and there is infeed at each terminal that will minimize overreach. Therefore, the current reversal logic is not required, and the recommended default settings are as existing

$TP := 98$ ms

$TD := 0$ ms

Comparison of Existing (I/S) and Proposed alternative (ALT) settings.

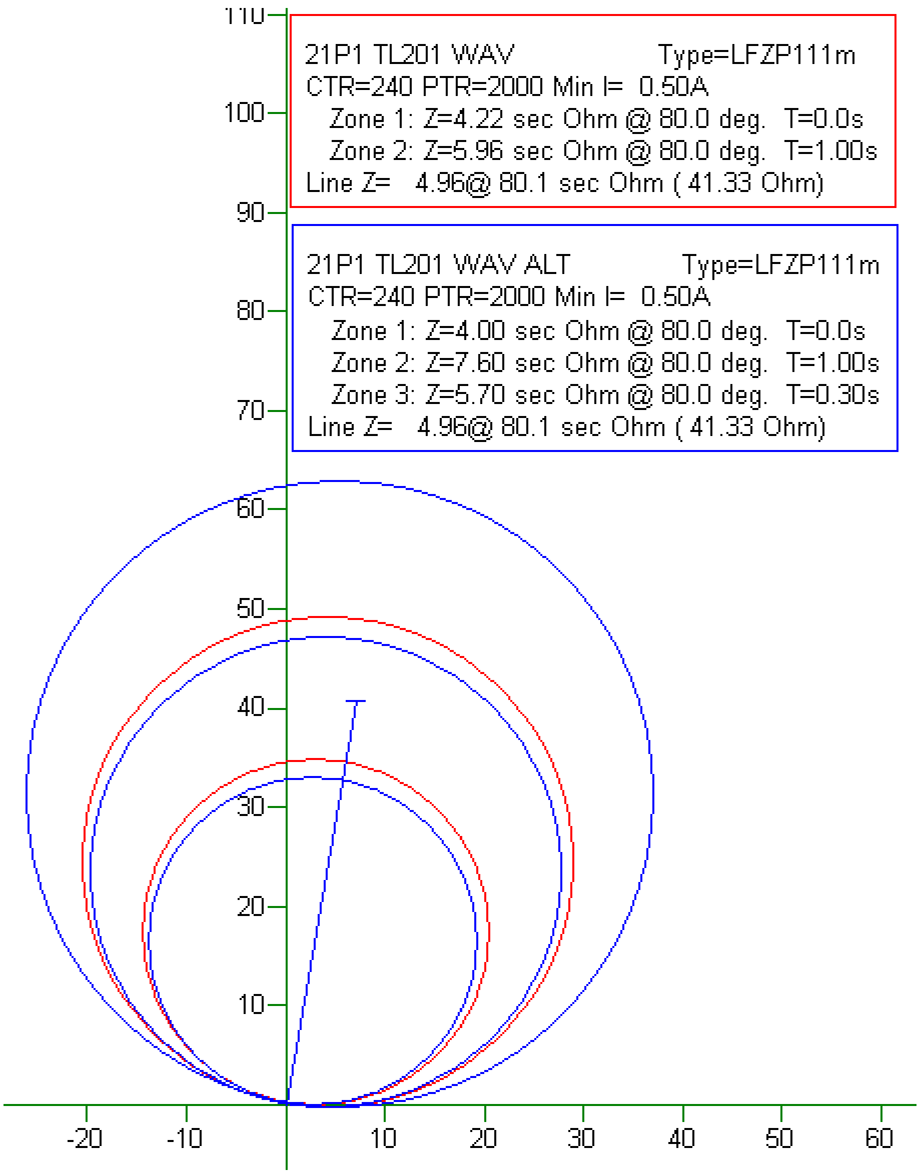


Figure 7 - Comparison of phase distance characteristics

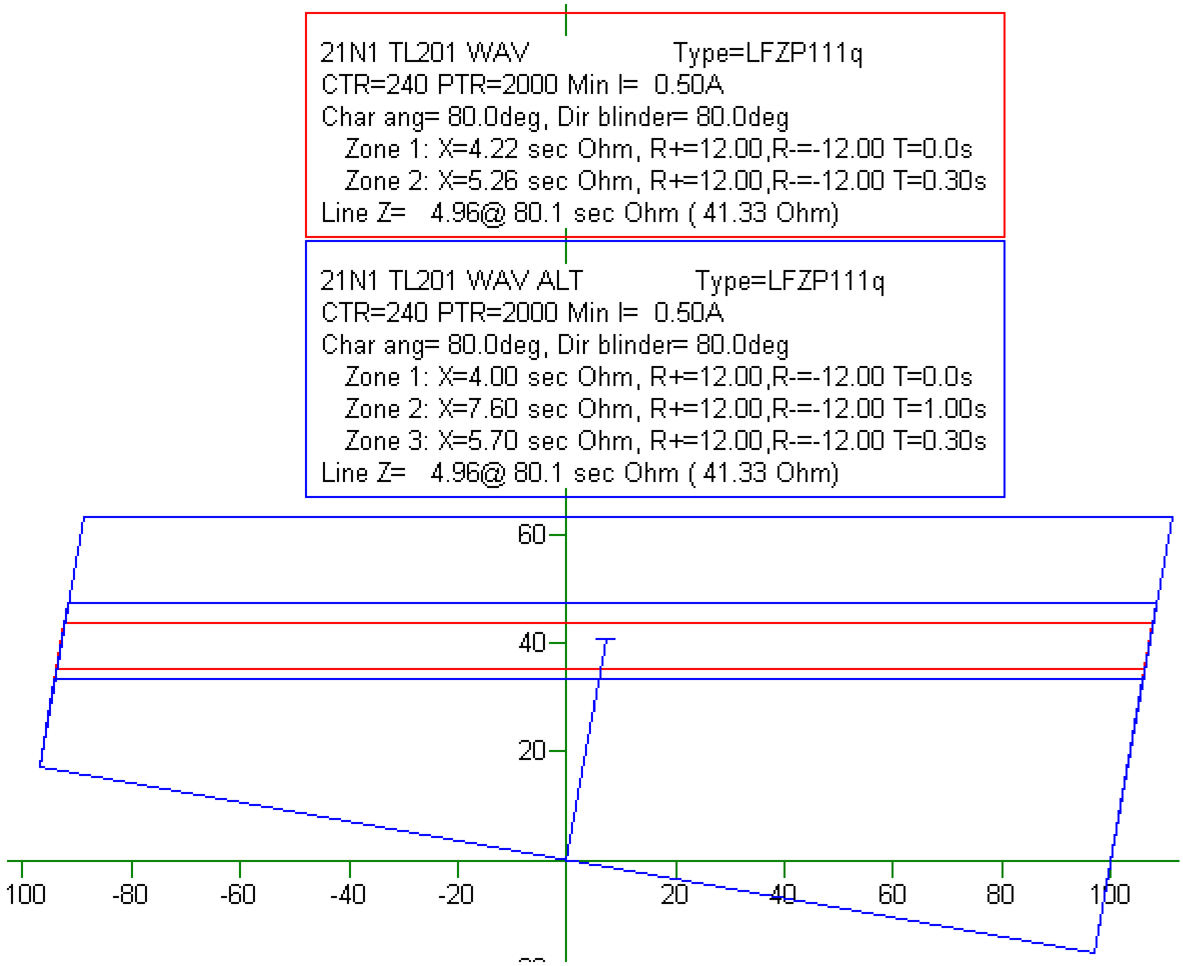


Figure 8 - Comparison of ground distance characteristics

Protection Review for Five 230 kV Transmission Lines

Appendix E
Detailed settings review for WAV TL201 "P2" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Western Avalon Terminal (WAV) terminal of circuits TL201. This 230 kV transmission circuit is from WAV to Hardwoods (HWD).
The circuit runs parallel to Circuit TL217 for most of its length.

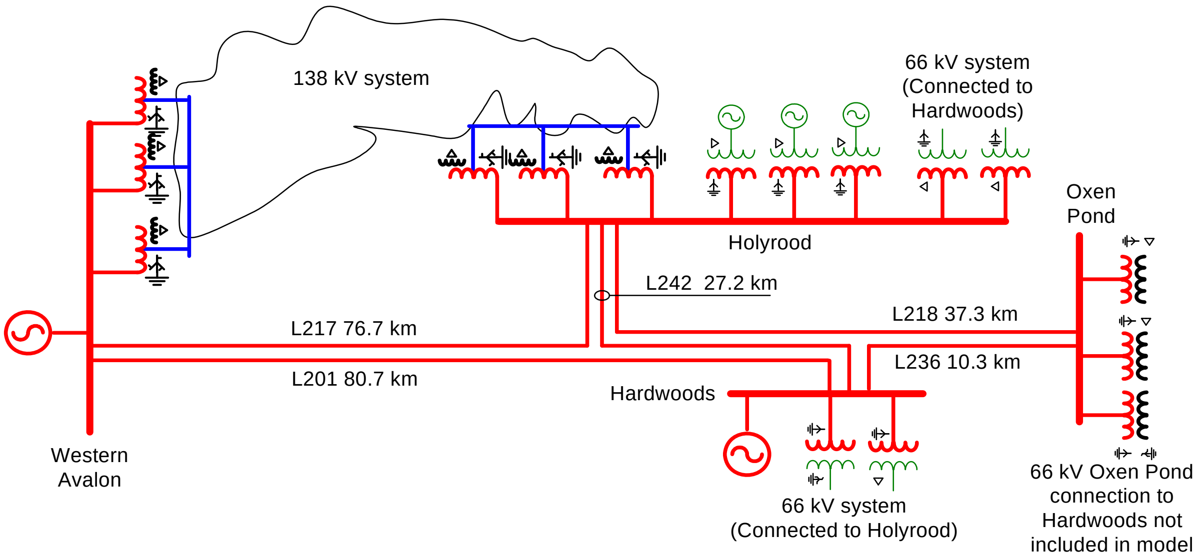


Figure 1 - System Single Line Diagram

Existing P2 protection systems are SEL321 systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $kVbase := 230$ $Ibase := \frac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $Zbase := \frac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $CTR := \frac{1200}{5}$ VT ratio is: $VTR := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "N**L HYDRO WITH MUTUALS FOR EAST COAST 230 kV LINE PN REVIEW.OLR**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with loads and shunts ignored.

Minimum fault current seen by each terminal (phase to phase, and SLG with 0 ohm fault resistance).

At WAV, with TL203 out of service, and both TL201 and TL217 in service, for a fault at the remote terminal.

$I3Pmin := 954$ A $\quad ISLGminPH := 856$ A $\quad ISLGmin0seq := 241$ A

The current for a phase to phase fault would be lower, but the current supervision element of the SEL321 measures phase to phase currents, and the phase to phase current for a phase to phase fault is twice the phase current.

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind WAV $\quad Z2minWAV := 3.2 + j \cdot 29.3$ ohms primary

$Z0minWAV := 1.81 + j \cdot 24.4$ ohms primary

Minimum source impedance behind HWD $\quad Z2minHWD := 1.8 + j \cdot 27.7$ ohms primary

$Z0minHWD := 0.85 + j \cdot 12.6$ ohms primary

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L201 := 0.01346 + j \cdot 0.07696 \quad Z0L201 := 0.04011 + j \cdot 0.28691$

$Z1Line := Z1L201 = 0.013 + 0.077j$ pu $\quad Z0Line := Z0L201 = 0.04 + 0.287j$ pu

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line \cdot Zbase \quad Z0Linephys := Z0Line \cdot Zbase$

$Z1Linephys = 7.1 + 40.7i$ ohms primary $\quad Z0Linephys = 21.2 + 151.8i$ ohms primary

Converting primary ohms to secondary ohms gives:

$$Z1Linesec := Z1Linephys \cdot \frac{CTR}{VTR} \qquad Z0Linesec := Z0Linephys \cdot \frac{CTR}{VTR}$$

$|Z1Linesec| = 4.96$ ohms sec $\quad arg(Z1Linesec) = 80.1 \cdot deg$

$|Z0Linesec| = 18.39$ ohms sec $\quad arg(Z0Linesec) = 82.04 \cdot deg$

Load Data

From 2011 System summer load case provided in start up information, the peak load (sum of TL201 and TL217) is given as 205 MVA (split between TL201 and TL217). In the event of sudden loss of one line, peak load will be the sum of both line loads until operators can adjust loads. Therefore it is assumed that peak load for a short duration is 205 MVA

$Speak := 205$ MVA $\quad Smax := Speak = 205$ MVA

Max load in this line with TL217 in service is $Smax\_L201 := 115$ MVA

P2 Relay Settings

Minor changes to the set line impedances are recommended to assist fault locations.

$Z1MAG := |Z1Linesec|$ $\quad Z1MAG = 4.96$ $\quad Z1ANG := \frac{arg(Z1Linesec)}{deg}$ $\quad Z1ANG = 80.1$

$Z0MAG := |Z0Linesec|$ $\quad Z0MAG = 18.4$ $\quad Z0ANG := \frac{arg(Z0Linesec)}{deg}$ $\quad Z0ANG = 82$

$LL := 80.69$

In order to obtain sensitivity to 100 ohm single line to ground faults, the echo function will be needed. Enable three forward and one reverse zone.

$PMHOZ := 4 \quad GMHOZ := 4 \quad QUADZ := 4$

$DIR1 := F \quad DIR2 := F \quad DIR3 := R \quad DIR4 := F$

(Note, given the fact that conventional zone 2 distance settings need a zone 3 time delay, a reduced reach zone 4 function with zone 2 time delay is recommended to be used in addition to the extended zone 2 with longer time delay. This is to be discussed with Newfoundland and Labrador Hydro.

Mho phase distance functions

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the HWD Station bus under light load conditions with one line from SSD to WAV out of service and both TL201 and TL217 lines in service. From ASPEN OneLiner, voltage at WAV for a 3 phase fault at HWD is 0.3 per unit. So there is plenty of voltage at WAV during a fault at HWD, even under weak source conditions.

Since the voltage is higher than 20%, the line is not considered short, and a conventional Zone 1 setting is acceptable.

$Z1P := 0.85 \cdot |Z1Linesec|$ $\quad Z1P = 4.2$ Ohms secondary

Existing setting of 4.2 ohms is OK, and will be retained. $\quad Z1P := 4.2$

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 5.26 ohms secondary (about 106%) and should be increased to 125%. This will give a more comfortable dependability margin.

$Z2P := 1.25 \cdot |Z1Linesec|$ $\quad Z2P = 6.2$ Ohms secondary

As can be seen from Figure 2, this element only marginally overreaches the zone 1 element at the HWD terminal of TL236 even with strong infeed. So we need to use a delayed zone 2 timer in order to coordinate with the HWD TL236 Zone 2 function. There is no benefit in retaining the existing setting since it is too short. Therefore, the timer setting will be increased beyond the normal zone 2. An additional zone 4 with a shorter setting will be used for faster acting zone 2 protection with less dependability.

It is recommended to apply another (shorter reaching) distance element to provide the time delayed tripping, so there is no need for any special optimizing of delay times for this longer reaching zone 2 function. A shorter reaching zone 2 (actually the zone 4 element) will be applied and set at 115% of the line impedance to give faster communications independent clearing of faults near the remote terminal. This Zone 4 function will securely underreach the remote zone 1.

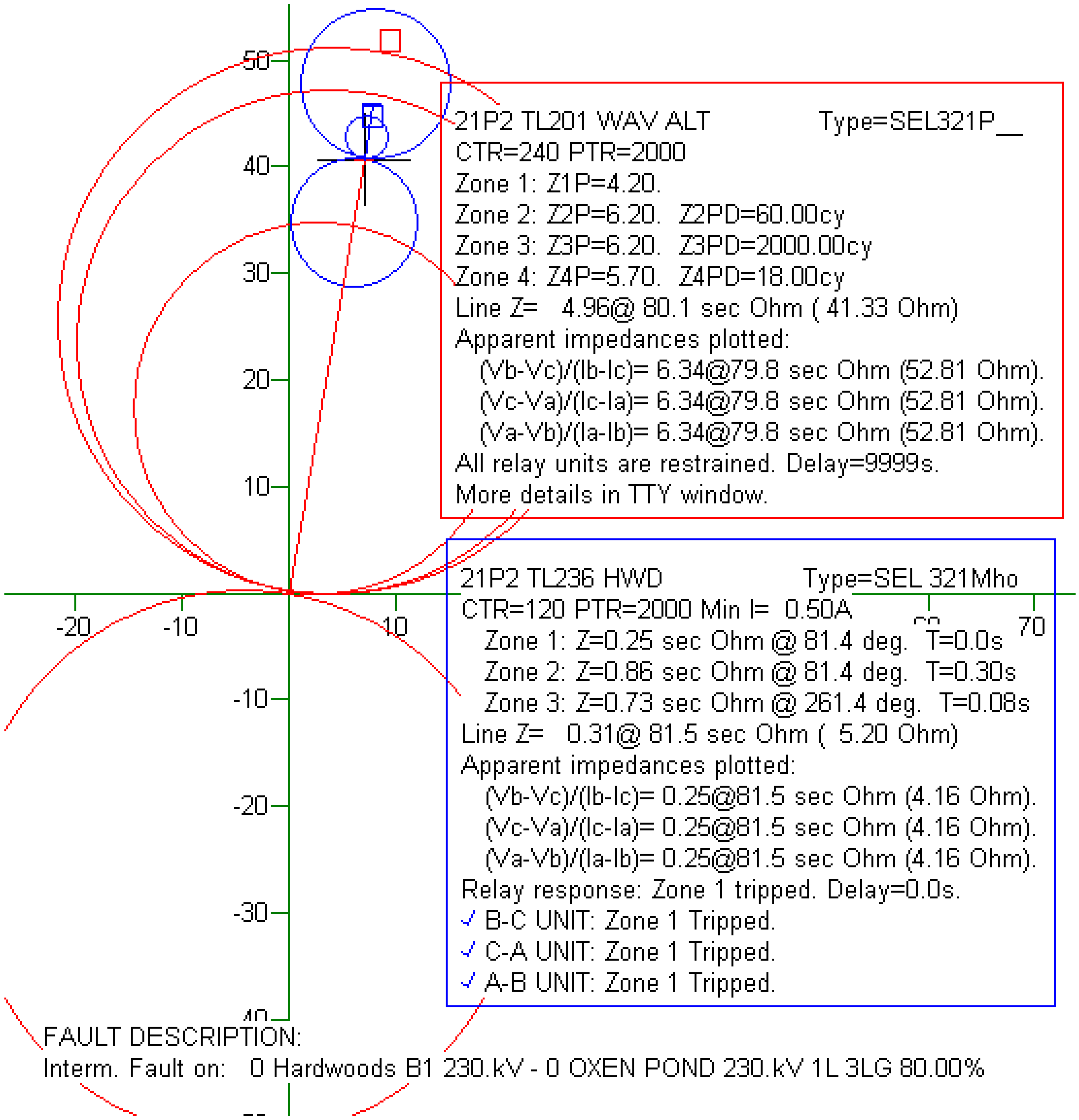


Figure 2 - Proposed new WAV TL201 Zone 2 only marginally underreaches HWD TL236 Zone 1 even with infeed. Zone 3 timing is needed for the Zone 2 function at WAV.

Because of marginal coordination with the remote zone 1, the time delay on this element will be set to 1 second.

$Z2PD := 60$ Cycles

Zone 3

Set Zone 3 reverse element to reach further behind this terminal than the remote Zone 2. This function adds security for external faults. The element should always be more sensitive than the forward looking Zone 2 at the remote terminal. Due to the long overreach of the remote zone 2 ground distance element under some circumstances, set it the same as the remote Zone 2 using the line impedance as margin.

$Z3P := Z2P$ $\qquad$ $Z3P = 6.2$ Ohms secondary

$\frac{Z3P}{|Z1MAG|} = 125 \cdot \%$ of line length $\qquad$ This is a much higher than the existing setting, but provides additional security.

Zone 4

Similar to the P1 protection (that uses a shorter reaching forward zone 3), a forward looking zone 4 element element is recommended to be used with a shorter, less dependable reach and with a shorter time delay. This zone 4 element will only provide communications independent tripping. The setting will be similar to the existing zone 2 setting (115% of the line) and will not overreach any remote zone 1. It will trip in normal zone 2 time.

$Z4P := \mathrm{round}(1.15 \cdot |Z1Linesec|, 1)$ $\qquad$ $Z4P = 5.7$ Ohms secondary

$\frac{Z4P}{|Z1MAG|} = 114.929 \cdot \%$ of line length $\qquad$ This is similar to the existing zone 2 setting.

$Z4PD := 18$ Cycles

Mho phase distance current supervision

If the current supervision elements can be set above load, they will be secure in the event that potential is lost. However given that loss of potential logic is available, it is recommended that only the zone 1 current supervision function be set above load. If potential is lost, it will be able to block tripping by Zone 2 before it trips on time delay or receives a permissive trip from the remote terminal.

For the point of view of current supervision being above maximum load, there is no need to worry about abnormal conditions. It would be a double contingency for the VT signal to be lost while the parallel line was out of service. Therefore, consider a maximum load of 115 MVA (with TL217 in service). The current supervision elements for the phase distance functions measure phase to phase currents.

$IPPmax\_normal := \frac{Smax\_L201 \cdot 1000}{kVbase}$ $IPPmax\_normal = 500$ A primary

The current supervision elements use phase to phase currents for supervision of the phase distance functions; so the minimum phase to phase fault current will be root three times the minim phase fault current. Choose a margin of 50% of the minimum phase to phase fault current for dependability.

$IPPmin := 0.5I3Pmin \cdot \sqrt{3}$ $IPPmin = 826$ A primary

A setting of 500 A primary for 50PP1 will ensure the Zone 1 function operates for any fault even under minimum source conditions while remaining unable to trip on load due to loss of potential under any normal maximum load conditions. This is a little higher than the existing setting, but is quite dependable.

$'50PP1 := 2.1$ A Sec $'50PP1 \cdot CTR = 504$ A primary

Since Zone 2 and zone 3 elements will be blocked by LOP function, set them at minimum. This is a little lower than the existing setting, but will be made secure by the use of LOP blocking..

$'50PP2 := 1$ A Sec $'50PP3 := 1$ A Sec $'50PP4 := 1$ A Sec

Ground Distance Protection

The reach of the ground distance functions will be affected by mutual coupling to the parallel line. These functions will tend to underreach the remote bus while the parallel line is in service, and overreach the remote bus if a parallel line is out of service and grounded at both ends. Figure 3 shows that for a remote close in fault on TL236, with 2L242 out of service and grounded, the apparent impedance of the line is reduced to about 4.51 ohms secondary instead of the nominal 4.96 ohms. This is 91% of the actual line impedance.

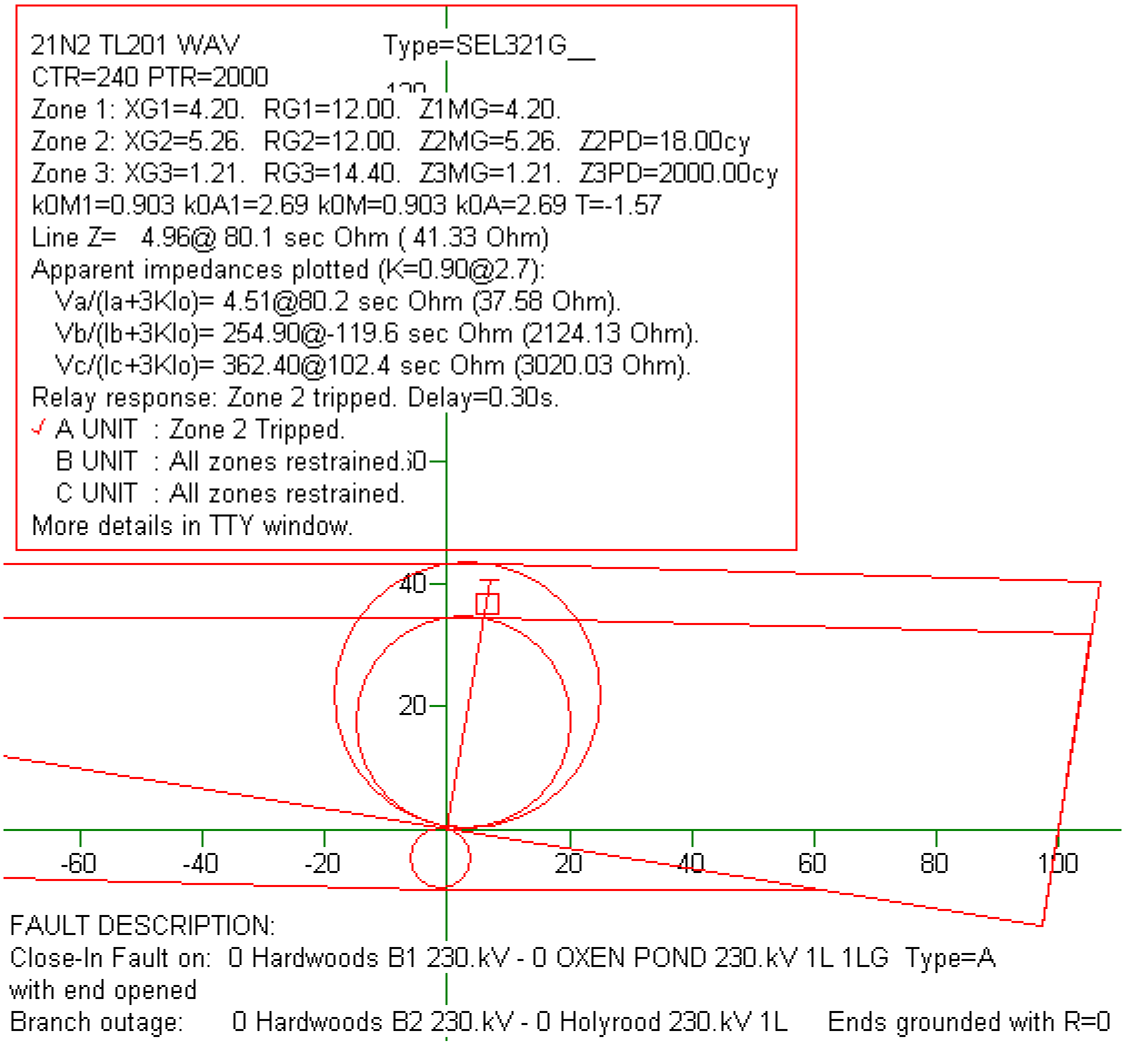


Figure 3 - Apparent impedance to a fault just beyond the remote terminal is reduced by 9% when parallel line is out of service and grounded at both ends.

The reach of the zone 1 should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Choose a setting of 80% of line which will underreach the remote bus by 11% when the parallel line is out of service and grounded at both ends.

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.8$ per unit

$Z1MG := \mathrm{round}(m \cdot |Z1Linesec|, 1)$ $Z1MG = 4$ Ohms secondary

$XG1 := Z1MG$ $XG1 = 4$ Ohms secondary

Zone 1 Resistance

The resistive reach of the Zone 1 quad should provide enough sensitivity to trip the local terminal immediately without waiting for permission from the remote terminal for a severe fault that depresses the voltage significantly. Further, it should not allow the function to reach beyond the remote terminal due to errors in relay measurement or CT or VT. In general, a reasonable limit for resistive reach of a zone 1 function is 4 times the reactive reach. If possible, it should operate for a 100 ohm SLG within 10% of the distance from the local terminal. Operation for a 100 ohm resistive fault at the 10% location will ensure this function can trip for a close in fault without assistance from the remote terminal. The remote terminal zone 2 function will be set to operate sequentially for this fault.

By simulating a fault with 100 ohms fault resistance at 10% of the distance from WAV, with the WAV terminal weak (TL203 out of service) it is found that a reach of 18 ohms secondary is required to sense this fault. See Figure 4

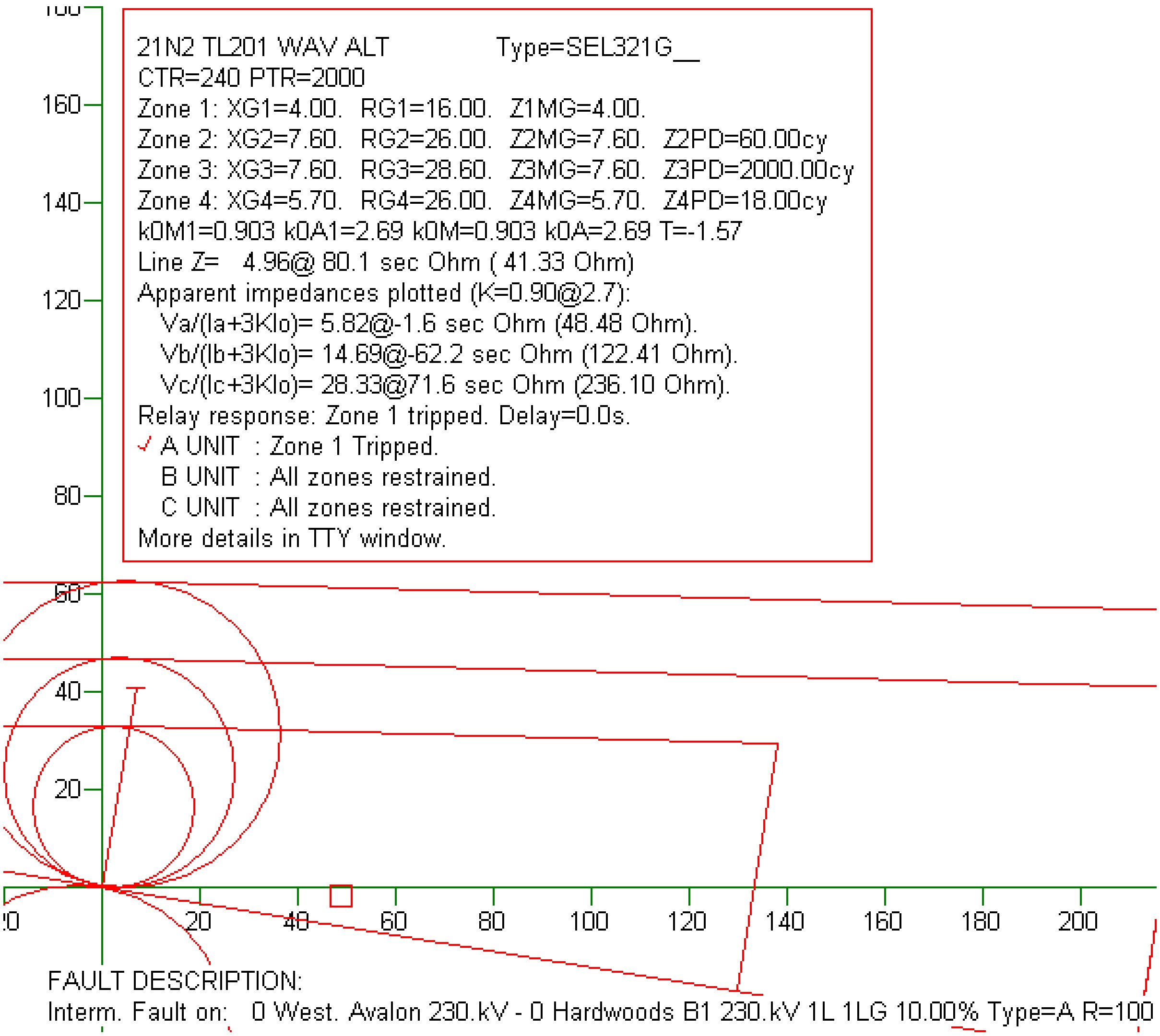


Figure 4 - WAV Zone 1 function if set with 16 ohm resistive reach, operates for a 100 ohm SLG fault at 10% from the local terminal.

The existing 12 ohm secondary resistive reach of the zone 1 element will not sense this fault, and should be increased to 16 ohms secondary. Check whether this reach will be secure, considering possible CT and VT errors.

XG1 is set at m per unit of the transmission line. The imaginary component of the line is

$ImXG1sec := Im(Z1Linesec)$ $\quad$ $ImXG1sec = 4.885$ ohms

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$RG1 := round[(1 - m) \cdot 20 \cdot ImXG1sec, 2]$

$RG1 = 19.54$ This is the maximum secure setting for the resistive reach and is above the proposed zone 1 resistive reach setting..

Use the proposed setting of 16 ohms for RG1 $\quad$ $RG1 := 16$ ohms secondary

With a resistive reach setting of 16 ohms, the WAV Zone 1 quad element will see an 60 ohm resistive SLG fault at 50% of the distance from WAV. Zone 2 protection will be depended upon to sense faults with resistance up to 100 ohms.

Zone 2 Ground Distance Protection

The Zone 2 ground distance function will need to be set longer than the Zone 2 phase distance protection function because it will tend to underreach the remote terminal while the parallel line is in service. By simulation in ASPEN OneLiner it is found that the apparent impedance to a zero ohm fault close in to the remote terminal is 6.06 ohms secondary, or 22% more than the actual line impedance. The reach of the Zone 2 ground distance element should be set at least to 1.25 times the apparent impedance.

$ZSLG\_remote := 6.06$

$Z2MG := round(1.25 \cdot ZSLG\_remote, 1)$ $\quad$ $Z2MG = 7.6$ Ohms secondary

The quad element reactive reach will be set similarly to the mho.

$XG2 := Z2MG$ $\quad$ $XG2 = 7.6$ Ohms secondary

It would be desirable to set the resistive reach of the quad element to sense a 100 ohm SLG fault at 75% of the line with the local terminal weak. This would ensure overlap with the zone 1element at the remote terminal. However, that would require too much resistive reach. Therefore choose a setting to sense a 100 ohm SLG fault just past the mid point of the line, and depend on the echo function to provide coverage for high resistance faults in the region where the remote zone 1 won't operate.

By trial and error from ASPEN it is found that a resistive reach of 26 ohms secondary will sense a 100 ohm SLG fault with an overlap with a similarly set remote zone 2 of 10% of the line length. See Figure 5. This will give positive overlap with the zone 2 element at the remote terminal. However since it will not overlap the Zone 1 element at the remote terminal, the permissive trip echo function will be required to ensure that a fault that is seen by the zone 2 element at only one terminal will still be cleared by the permissive trip logic.

Therefore, to avoid extremely large resistive reaches, and to retain sensitivity to 100 ohm resistive SLG faults, it is recommended that the echo function be enabled at both terminals.

$RG2 := 26$ Ohms secondary

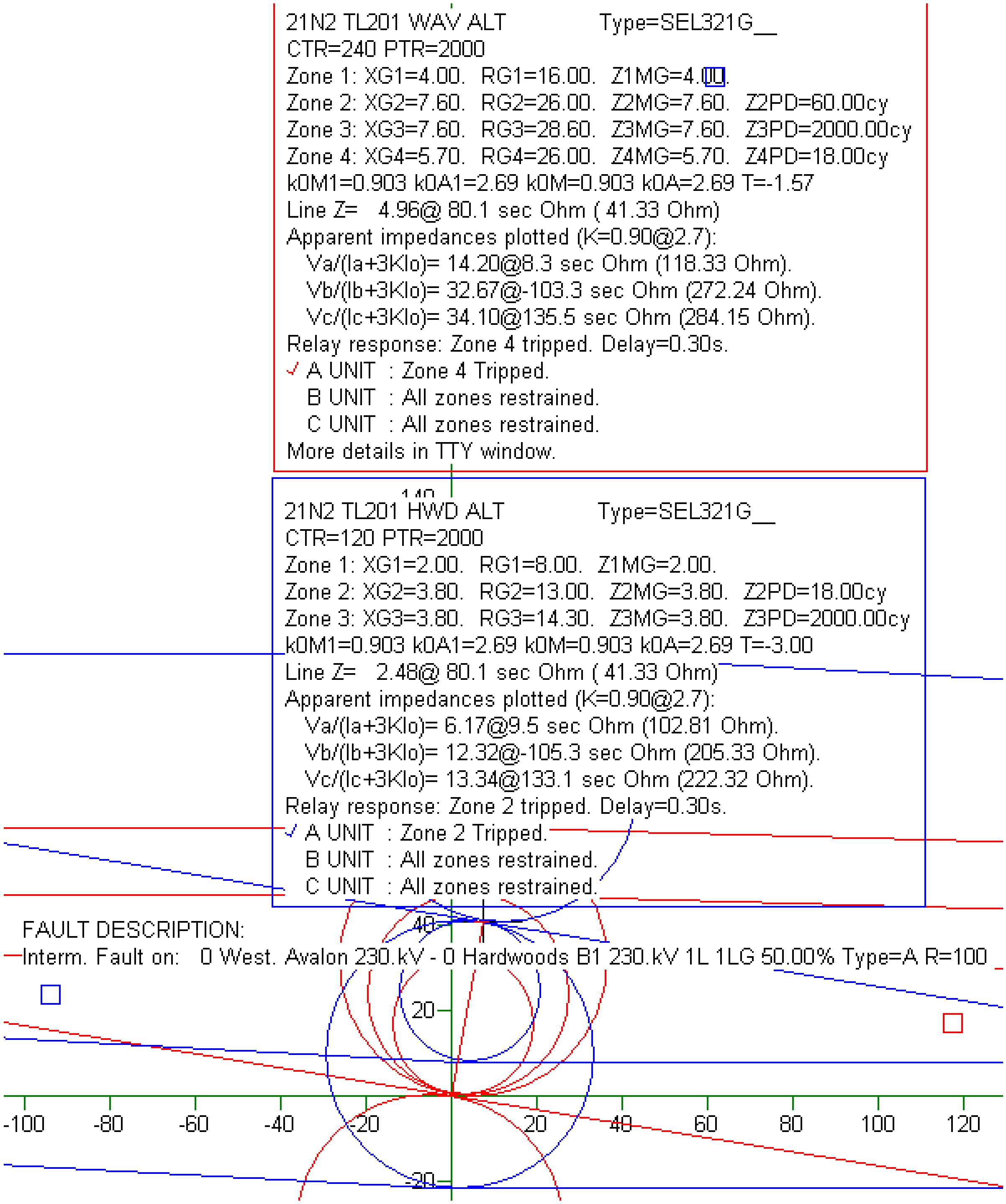


Figure 5 - Quad elements overlap with remote quad elements and operate for 100 ohm resistive SLG at the mid line location (only) WAV Zones 2 and 4 have same resistive reach.

Check that this resistive reach won't cause the zone 2 function to trip while a parallel line is open single phase, with heavy power flow. See Figure 6. Unusually heavy power flow has been simulated to challenge security.

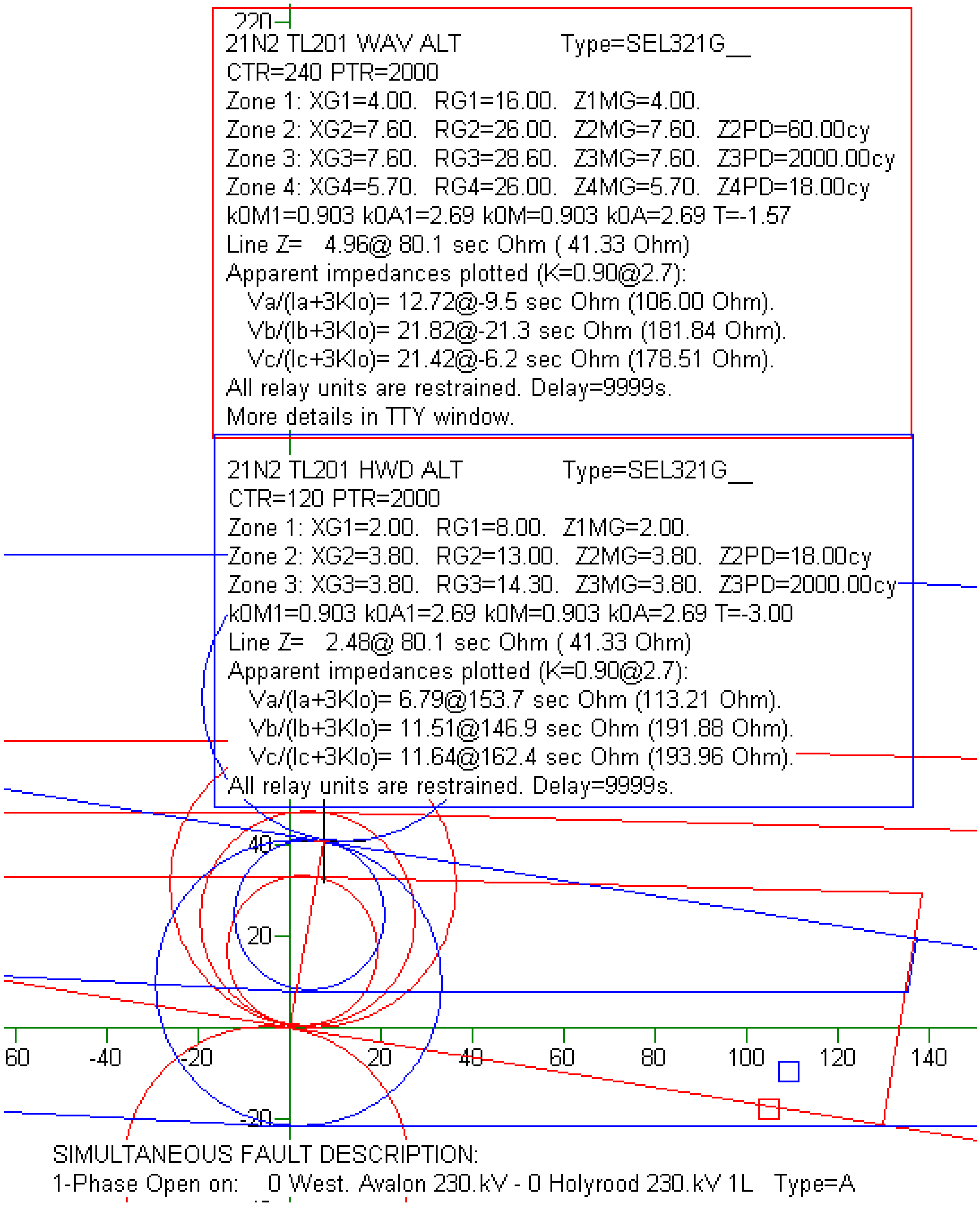


Figure 6 - Quad elements are secure with extremely heavy load flow (190 MVA in TL217 and 300 MVA in TL201) while TL217 is open single pole.

Zone 3

The zone 3 ground mho function will be set using the same principles as the zone 3 phase distance function. Although the remote zone 2 has a different CT ratio, the setting is the same as the local zone 2 in primary ohms. Therefore use the setting for local zone 2 in secondary ohms as the remote zone 2.

$Z2MGrem := Z2MG$ ohms secondary

$Z3MG := Z2MGrem$ $Z3MG = 7.6$ Ohms secondary

$\frac{Z3MG}{|Z1MAG|} = 153.2\cdot\%$ of line length

This is much higher than the existing setting, but provides additional security.

$XG3 := Z3MG$ $XG3 = 7.6$ Ohms secondary

Set the Zone 3 quad resistive reach at 10% more than the remote Zone 2. Although the remote zone 2 has a different CT ratio, the setting is the same as the local zone 2 in primary ohms. Therefore use the setting for local zone 2 in secondary ohms as the remote zone 2.

$RG2rem := RG2$ Ohms secondary $RG3 := RG2rem\cdot 1.1$ $RG3 = 28.6$ Ohms secondary

Zone 4

The zone 4 ground mho function will be set using the same principles as the zone 4 phase distance function.

$Z4MG := Z4P$ $Z4MG = 5.7$ Ohms secondary

$\frac{Z4MG}{|Z1MAG|} = 114.9\cdot\%$ of line length

$XG4 := Z4MG$ $XG4 = 5.7$ Ohms secondary

Set the Zone 4 quad resistive reach the same as the zone 2 quad resistive reach. This will provide good sensitivity to 100 ohm faults on the whole line on a sequential basis. Studies for the Zone 2 ground quad element have shown it to be secure under heavy load with one phase open on a parallel line.

$RG4 := RG2$ $RG4 = 26$ Ohms secondary

Since the zone 4 ground distance element reach is so short, the delay can be conventional zone 2 delay.

$Z4GD := 18$ cycles

Ground distance current supervision

Since there is no concern about these elements operating on load, even with loss of potential, set all current supervision elements at minimum, for maximum sensitivity of the distance elements.

$'50L1 := 0.5$ A Sec $\quad$ $'50L2 := 0.5$ A Sec $\quad$ $'50L3 := 0.5$ A Sec

$'50G1 := 0.5$ A Sec $\quad$ $'50G2 := 0.5$ A Sec $\quad$ $'50G3 := 0.5$ A Sec

Note that due to heavy infeed of zero sequence currents from the local terminal for close-in faults, the ground overcurrent detectors will not operate for faults with more than a small amount of resistance close to the remote terminal. Therefore, we will have to rely on sequential clearing for that type of fault. However setting the current supervision at minimum allows maximum sensitivity.

Zero sequence current compensation

The zero sequence current compensation could be adjusted to compensate for the significant amount of mutual coupling. However as discussed in the settings of reaches of the ground distance elements we will accept underreach of the Zone 2 function for the normal case by setting it at 125% of the apparent impedance for a remote fault. Set the zero sequence current compensation as usual.

$$k01M := \left(\left|\frac{Z0Line - Z1Line}{3 \cdot Z1Line}\right|\right) \qquad k01M = 0.903$$

$$k01A := \left(\arg\left(\frac{Z0Line - Z1Line}{3 \cdot Z1Line}\right)\right) \qquad k01A = 2.69 \cdot deg$$

Set the overreaching zones the same as zone 1 $\quad$ $k0M := k01M \quad k0A := k01A$

$k0M = 0.903 \quad k0A = 2.69 \cdot deg$

Non Homogenous Angle Setting

Compare the angle of the remote zero sequence source impedance with the total zero sequence source impedance to the fault to determine this setting.

$$T := \arg\left(\frac{Z0minHWD + Z0Linephys + Z0minWAV}{Z0minHWD}\right) = -3.3 \cdot deg \qquad T = -3 \cdot deg$$

Out of step blocking and tripping

Not used in this application. There is a danger of out of step conditions arising. Historically no action has been taken to provide special tripping or blocking functions. Natural tripping during swings is accepted.

Load Encroachment logic

Check loadability of the Zone 2 phase distance element assuming worst case power factor of 0.87 simultaneous with worst case depressed voltage of a stressed system of 0.85 per unit. Note that units of kV squared match units of MVA. Note that quadrilateral elements are only used for the ground distance functions that are not sensitive to balanced three phase load. Therefore no need to worry about the reach of the quadrilateral elements.

$Zloadmin := \frac{(0.85kVbase)^2}{Smax}$ $\quad Zloadmin = 186.44$ $\quad$ Ohms primary (assume worst case at 30 degrees)

Maximum reach of the Zone 2 element is at the line angle of 81 degrees. At 30 degrees, the reach will be given by

$Z2load := Z2P \cdot \cos[(Z1ANG - 30)deg]$ $\quad Z2load = 3.978$ $\quad$ ohms secondary

$Z2load \cdot \frac{VTR}{CTR} = 33.153$ $\quad$ ohms primary

Since the reach of the Zone 2 element at 30 degrees is less than the apparent impedance of the maximum load, there is no need to apply load blinding logic. See Figure 7

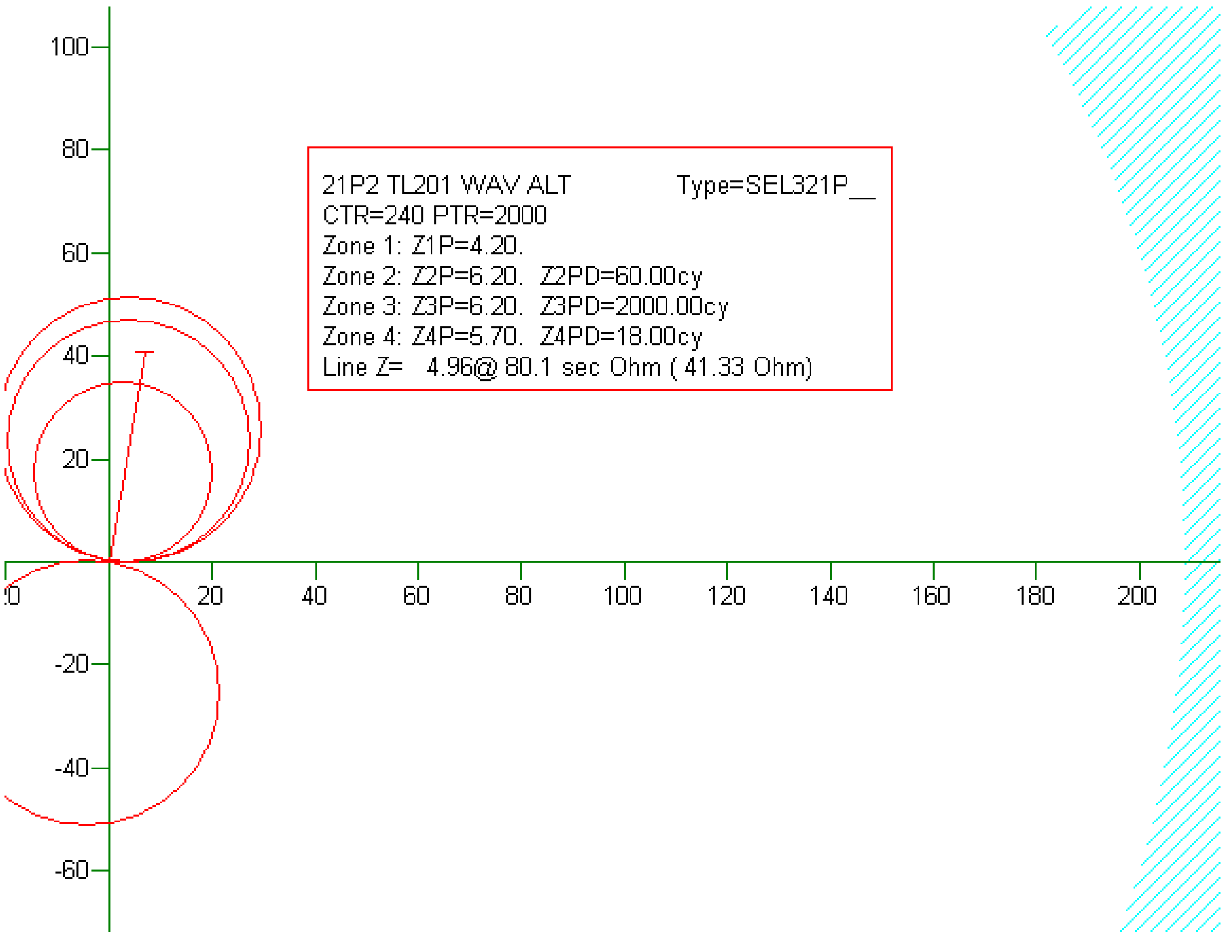


Figure 7 -Load impedance with respect to proposed new Mho function reaches.

Ground directional element

The SEL-321 application example recommends finding the minimum source impedance behind the terminal and setting the reverse and forward boundaries of the negative sequence directional element at the 1/3 and 2/3 points respectively.

In the negative sequence plane, the sum of the two source impedances and the line impedance is:

$$Z2total := Z2minWAV + Z1Linephys + Z2minHWD$$

The 1/3 point is $Z2\_1\_3 := \frac{Z2total}{3}$ The 2/3 point is $Z2\_2\_3 := \frac{2Z2total}{3}$

$Z2Rpri := Z2\_2\_3 - Z2minWAV$ $|Z2Rpri| = 36.172$

$Z2Fpri := Z2\_1\_3 - Z2minWAV$ $|Z2Fpri| = 3.377$

Converting the primary impedances to secondary ohms

$Z2R := Z2Rpri \cdot \frac{CTR}{VTR}$ $|Z2R| = 4.341$ Ohms secondary $arg(Z2R) = 82.246 \cdot deg$

$Z2F := Z2Fpri \cdot \frac{CTR}{VTR}$ $|Z2F| = 0.405$ Ohms secondary $arg(Z2F) = 75.594 \cdot deg$

Rounding up Z2F and rounding down Z2R gives:

$Z2F := 0.4$ Ohms secondary $Z2R := 4.3$ Ohms secondary

These are quite different from the existing settings.

Set the current level detectors at minimum level that will allow operation of the ground distance elements.

Due to the very small zero sequence current contribution to a single line to ground fault at the remote terminal, the negative sequence current contribution will always be higher than the zero sequence. Therefore there is no point in setting the forward looking negative sequence overcurrent elements any more sensitively than the zero sequence ground overcurrent supervision of the ground distance elements.

$'50QF := '50G2$ $'50QF = 0.5$ A secondary

Set the supervision function for the reverse looking element to be the same as, or a little more sensitive than the forward looking supervision element at the remote terminal.

$'50QR := 0.5$ A secondary

The positive sequence current restraint (a2) factor should be set just smaller than the ratio of the maximum load current (positive sequence) to the most sensitive current supervision element (50QR).

$I1maxpri := \frac{Smax \cdot 1000}{kVbase \cdot \sqrt{3}}$ $I1maxsec := \frac{I1maxpri}{CTR}$ $I1maxsec = 2.144$

Bearing in mind that the 50QR setting is in units of 3*I2

$\frac{'50QR}{3 \cdot I1maxsec} = 0.078$ Choose a value of $a2 := 0.08$

The proposed new setting of a2 is a little lower than the existing setting (0.09).

Phase time overcurrent element

This element is not used

Residual time overcurrent element

This element is used to provide the most sensitive backup protection. It will be a non directional element.

Set pickup to sense a higher resistance than 100 ohm SLG in the middle of the line with equal zero sequence current infeed from both ends. Choose a resistance of 200 ohms arbitrarily. Use a safety factor of 2 so that operating time is not infinity at this fault level.

$SF := 2$ Desensitization factor due to remote end infeed is $Dfactor := 2$ $Rf := 200$

$$'51NPU := round\left(\frac{kVbase \cdot 1000}{\sqrt{3} \cdot SF \cdot Dfactor \cdot Rf \cdot CTR}, 1\right) \qquad '51NPU = 0.7$$

The existing setting of 0.5 A is more sensitive than required to sense this mid line fault with arbitrary resistance. Since TL206 experience with the high resistance tree fault on 28th August 2009 has shown value in the existing setting, it will be retained.

$'51NPU := 0.5$ A secondary

Coordination checks show that existing time dial settings will coordinate with each other. See Figures 8 and 9

$'51NPU = 0.5$ A secondary $'51NPU \cdot CTR = 120$ A primary

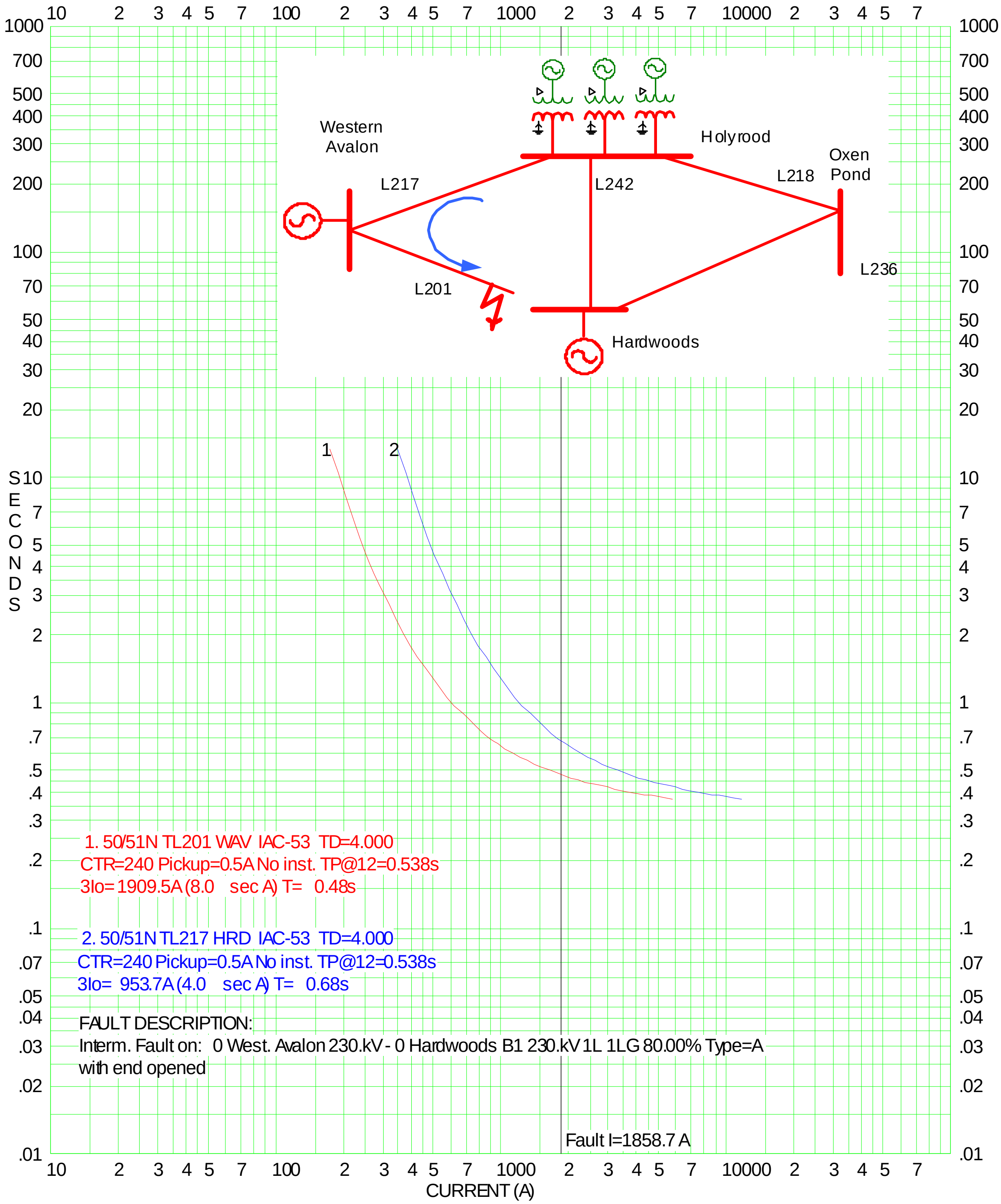
$'51NTD := 6$ $'51NC := "U3"$ $'51NTC := "N"$ $'51NRS := "N"$

Checks for close-in fault show that this element will not operate in less than 0.4 seconds so there is no danger of it tripping 3 pole before the zone 1 element trips the faulted phase selectively.

Check the coordination below the HRD TL217 51N fault at 80% of TL201 (at the end of the mutually coupled section with TL217). This is the type of fault that will produce the most sensitivity (least desensitization) with respect to the backup protection on TL217. see Figure 8. coordination margin is not big enough. Instead of adjusting the time overcurrent protection, make sure the definite time Zone 4 ground distance element will operate for this fault. According to ASPEN OneLiner, the zone 1 ground distance element will operate easily for this fault even with fault resistance up to 100 ohms.

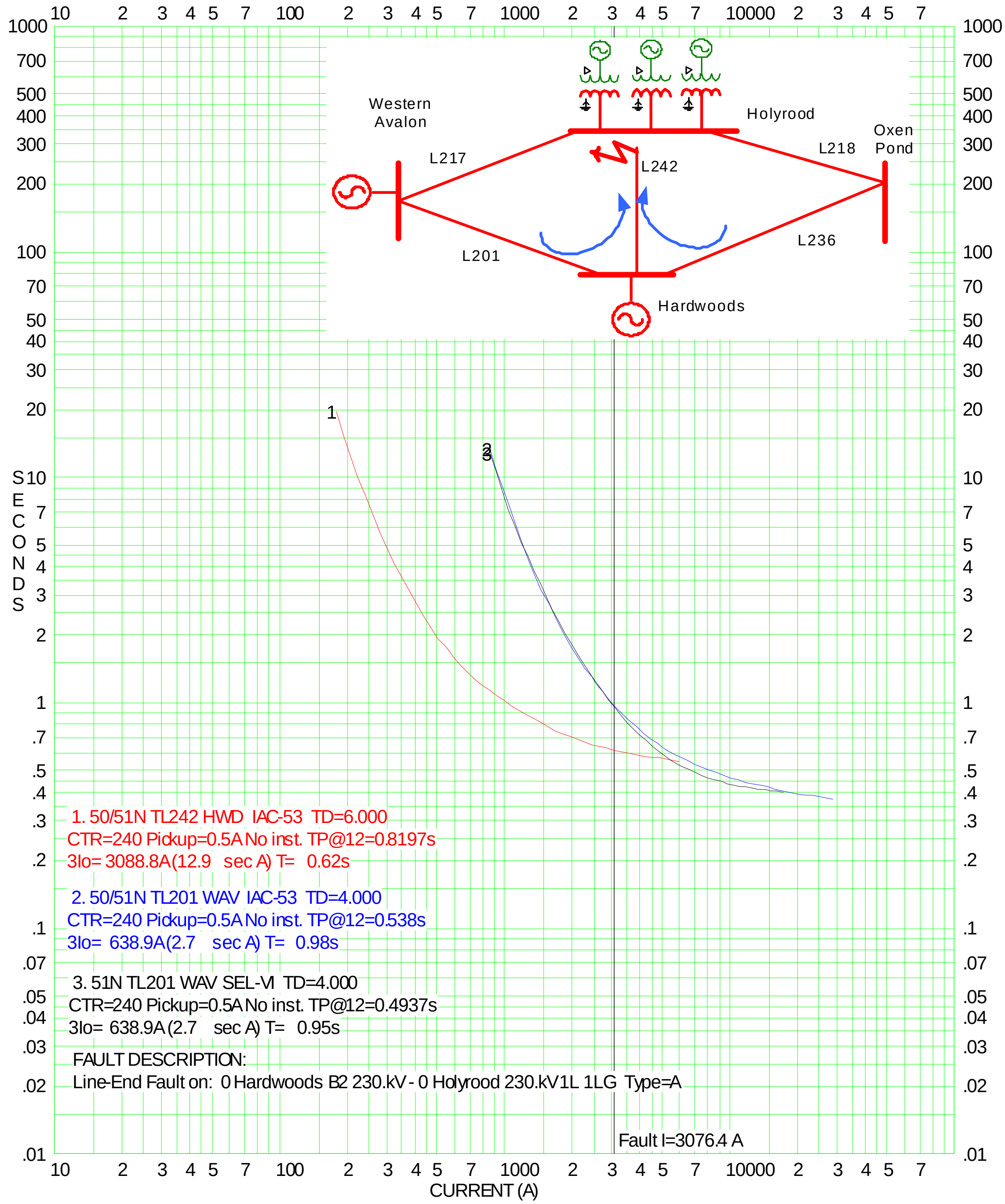
Check the coordination above the HWD TL242 protection for a line end fault near HRD. See Figure 9. It can be seen that the existing setting coordinates well above the HWD TL242 protection. However it would not be wise to reduce the time dial of the existing setting because coordination is just OK.

Worst case load unbalance with single pole open will be in the future if single pole tripping is enabled with parallel line out of service. ASPEN OneLiner shows that with 280 MVA of load on this line (considerably more than existing maximum possible load), and with one phase open, the 3I0 current is approximately 480 A. The 51N relay with existing settings will take approximately 1.4 seconds to operate on 480 A primary. No danger of tripping on load unbalance during SPO time.



EC 230-4	TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For Coordination of WAV TL201 below HRD TL 217		No. EC 230-4
Comment Requires Z1G and Z2G for coordination with RF <100 ohms		Date 29 Sep 2011

Figure 8 - coordination of ground time overcurrent elements for fault at 80% TL201



EC 230-5	TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For Coordination of HWD TL242 below WAV L201		No. EC 230-5a
Comment		Date 7 Oct 2011

Figure 9 - coordination of ground time overcurrent elements for line end fault on TL242 close to HRD

Permissive Overreaching logic settings

EPOTT := "Y"

Z3RBD is set at remote breaker time plus channel reset time plus channel reset time plus zone 2 reset time. From review of fault records it appears that the breaker time is 3 cycles. Channel reset time is not easily determined from existing records but can conservatively be assumed to be 1 cycle, and relay reset time will also be about 1 cycle. Total time for Z3RBD is then 5 cycles.

Z3RBD := 5 cycles

Echo block delay timer blocks the echo after the local elements have picked up. This can be set relatively long since there is no significant need for the echo function shortly after the local terminal has just seen a fault but the remote terminal has not. Set at 10 cycles as per the example in the instruction manual.

EBLKD := 10 cycles

Echo time delay on pickup should be set to override noise on the communications so that it doesn't echo noise. Typical time according to the SEL application guide is 2 cycles. Since this delay only affects clearing time for relatively light (high resistance) faults that are sensed by zone 2 function at one end, the typical setting is acceptable.

ETDPU := 2 cycles

Echo duration should be long enough to ensure the permissive trip is received by the remote terminal and should also be shorter than the Z3RBD time to ensure that the reverse blocking will always be longer than any permissive trip received (including echo time stretching).

EDURD := 4 cycles

No need to enable week feed conversion to trip, since both terminals will be quite sensitive enough to detect high resistance faults after the remote terminal has cleared. Therefore we can accept sequential (or "step") clearing with no need for the added insecurity of weak infeed tripping.

EWFC := "N" **No other communications logic settings are required for this application.**

Switch on to Fault Settings

Switch on to fault logic will ensure the protection will operate when energizing the line onto a close-in three phase fault when there is no polarizing voltage available for the distance elements.

ESOTF := "Y"

The breaker close signal is not available to the relay. The 52A method of enable SOTF will be used. Therefore the Close end delay is not critical. Typical duration for enable SOTF is 10-15 cycles

ENCLO := "N" CLOEND := 0 EN52A := "Y" SOTFD := 15

Set 50H for high magnitude close-in multiphase faults with weakest source at WAV. It should be set less than 50% of the minimum close-in fault magnitude. Minimum close-in magnitude of a three phase fault with TL217 out of service is 3100 A. Therefore desired maximum setting for 50H is 1500 A.

Imin3P_close_in := 3100

$$'50H := \frac{Imin3P\_close\_in}{2CTR} \qquad '50H = 6.458 \quad \text{A secondary}$$

Choose a setting of 6 A secondary for this element. '50H := 6 A secondary

Choose a setting for 52AEND less than the shortest reclose time. '52AEND := 30 cycles

Residual overcurrent settings.

Tripping directly by instantaneous ground overcurrent is not applicable because it is not phase selective. However it would be helpful to monitor steady state unbalance, and issue an alarm for continuous unbalance. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50N := 1$ $\quad$ $'50N1 := 0.25$

Negative Sequence overcurrent settings.

Similar to ground overcurrent, apply a negative sequence overcurrent element to initiate an alarm for steady state unbalances. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50Q := 1$ $\quad$ $'50Q1 := 0.25$

Voltage Element Settings

Similar to unbalance current monitoring, it is helpful to have an unbalance voltage monitor to detect steady state unbalances from the voltage supply.

EVOLT := "Y"

Set the zero sequence overvoltage element at 1% of rated voltage or just at the point necessary to override normal unbalances. The zero sequence voltage element measures 3 times the zero sequence voltage.

$$'59N := 3 \cdot 0.01 \frac{kVbase \cdot 1000}{\sqrt{3} \cdot VTR} \qquad '59N = 1.992 \qquad \text{Say} \quad '59N := 2 \text{ V secondary}$$

Loss of Potential

Enable loss of potential settings. Advanced LOP settings are not available on this model of relay.

ELOP := "Y" $\quad$ Time delay of 1.25 cycles is commonly used. $\quad$ $LOPD := 1.25$

The 50 M element should be set above maximum load and below minimum fault current for a fault at the remote terminal under weak source conditions. The maximum load for this case should be normal maximum, not emergency maximum which only exists for a few minutes before the operator can act to reduce load.

$$Imax\_normal := \frac{Smax\_L201 \cdot 1000}{\sqrt{3} \cdot kVbase \cdot CTR} = 1.203 \text{ A secondary}$$

Minimum fault current for a remote three phase fault is $\quad I3Pmin = 954 \quad$ A primary.

Minimum fault current for a remote phase to phase fault is 87% of the minimum three phase fault current level.

Dependability factor to be sure to operate for a minimum remote fault is chosen to be 1.6. $\quad DF := 1.6$

Maximum setting for 50M should be $\dfrac{0.87 I3Pmin}{DF \cdot CTR} = 2.161$ $\quad$ In this case a setting of 2.0 A secondary will be adequately dependable and secure.

$'50M := 2.0$ A secondary

The 59QL setting should be above normal maximum unbalance and below the level expected for a blown VT fuse. For a blown fuse, one phase voltage will be lost, and the negative sequence voltage will be roughly 33% of the nominal positive sequence voltage. Choose a setting of 15% of the nominal positive sequence voltage. This will be well above any normal unbalance.

$'59QL := \mathrm{round}\left(\frac{0.15 \cdot kVbase \cdot 1000}{\sqrt{3} \cdot VTR}, 0\right)$ $'59QL = 10$ V secondary

The 59PL setting should be less than the minimum voltage to be expected for a remote bus fault under weakest source conditions. There is no minimum setting (above zero) for this function. Choose a setting equal to half the voltage drop along the line impedance at the pickup setting of the 50M element.

$'59PL := \mathrm{round}[0.5 \cdot ('50M \cdot |Z1Linesec|), 0]$ $|'59PL| = 5$

Miscellaneous Scheme Settings

Pole discoordinance logic is not being used. EPOLD := "N" SPPDD := "N/A"

Enable single pole tripping by distance elements only ESPT := "Y"

Enable single pole open ESPO := "Y"

Set single pole open time delay for future SPO conditions SPOD := 0.25
Note that SPOD was short enough to allow a transient operation when the line was reclosed with a fault on it during the fault of 7 March 2011. This transient operation was helpful to clear the fault more quickly than it otherwise would have cleared. SEL have been asked whether the SPOD setting of 0.5 would be better to increase the security.

3 Pole open reset delay to override small discrepancies in pole closing '3POD := 0.5

Stub line protection is not required ESTUB := "N" '50MFD := "N/A"

Trip unlatch logic not applied TULO := "N"

Logic variables and Miscellaneous timers

Minimum trip duration timer is set at 9 cycles as per the application example in the SEL-321 instruction manual.

TDURD := 9 Cycles

Trip during open pole time delay should be set longer than the reclose time. Existing reclose time is 45 cycles. Existing setting is too marginal. This setting should be increased to 55 cycles.

TOPD := 55 Cycles

Existing logic variables are not used.

Add the use of ZT to trigger an alarm for sustained unbalance.

LOGIC_Z := "59N+50N1+50Q1" TZPU := 1200 cycles TZDO := 0 cycles

Tripping Logic

Permissive tripping is required only for instantaneous overreaching functions. No need for any functions that trip directly. Existing 51NT word in MTCS is not required.

MTCS := "M2P+Z2G"

Unconditional tripping must add the newly used zone 4 elements.

MTU := "M1P+Z1G+M2PT+Z2GT+M4PT+Z4GT+51NT"

No need for existing direct tripping zone 1 functions in the switch on to fault logic.

SOTF Tripping MTO := "M2P+Z2G+50H"

Event records will be triggered automatically by all trip events. Other event record triggers should be by starting of other elements to ensure capture of all relevant events. Events should be triggered by keying or receiving permissive trips to ensure separation of relay and teleprotection issues.

MER := "M2P+Z2G+51NP+LOP*52AA1+LOP*52AA2+KEY+PT+EKEY"

Outputs

Retain existing output assignments except add the continuous unbalance alarm to OUT15.

OUT15 := "LOP*50L+ZT"

Input Contact Assignment

It would be desirable to provide phase segregated inputs to the relay so that the quadrilateral functions could be disabled during single pole open conditions. it is not known if phase segregated auxiliary switches are available on the breakers.

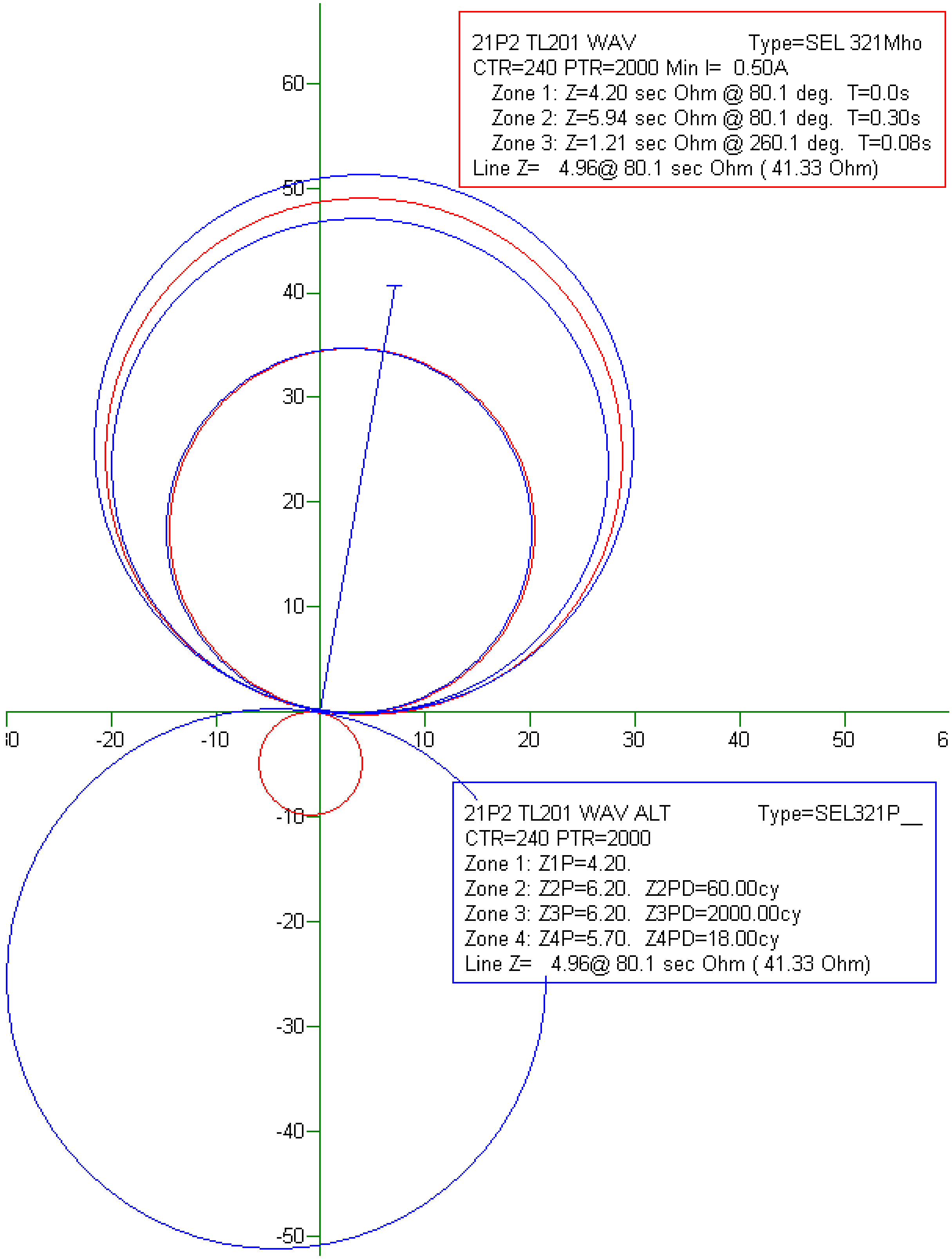


Figure 10 - Comparison between existing (red) and proposed new (blue) phase distance characteristics.

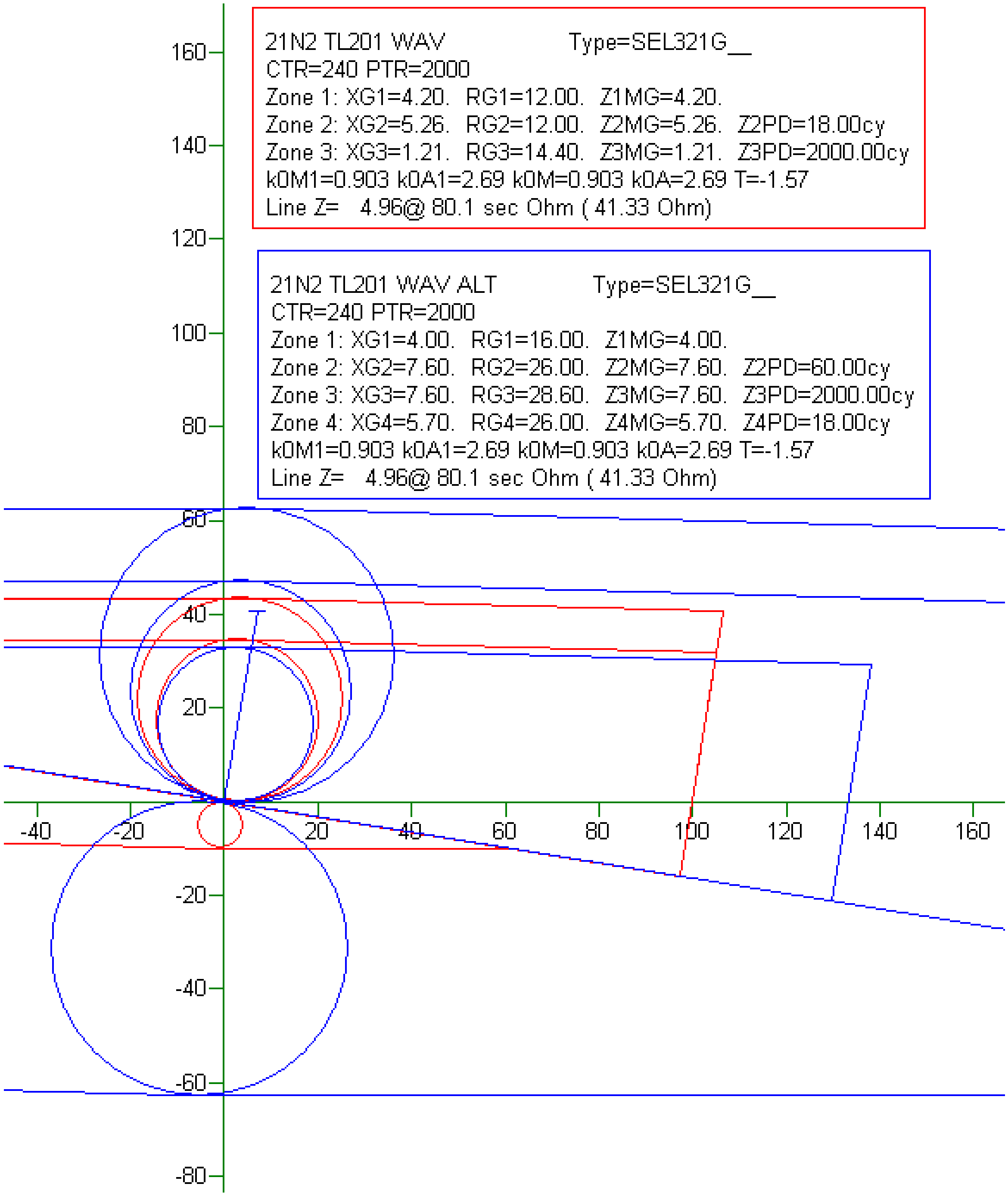


Figure 11 - Comparison between existing (red) and proposed new (blue) ground distance characteristics.

Protection Review for Five 230 kV Transmission Lines

Appendix F
Detailed settings review for HWD TL201 "P1" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador Hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Hardwoods (HWD) terminal of circuits TL201. This 230 kV transmission circuit is from HWD to Western Avalon Terminal (WAV).
The circuit runs parallel to Circuit TL217 for most of its length.

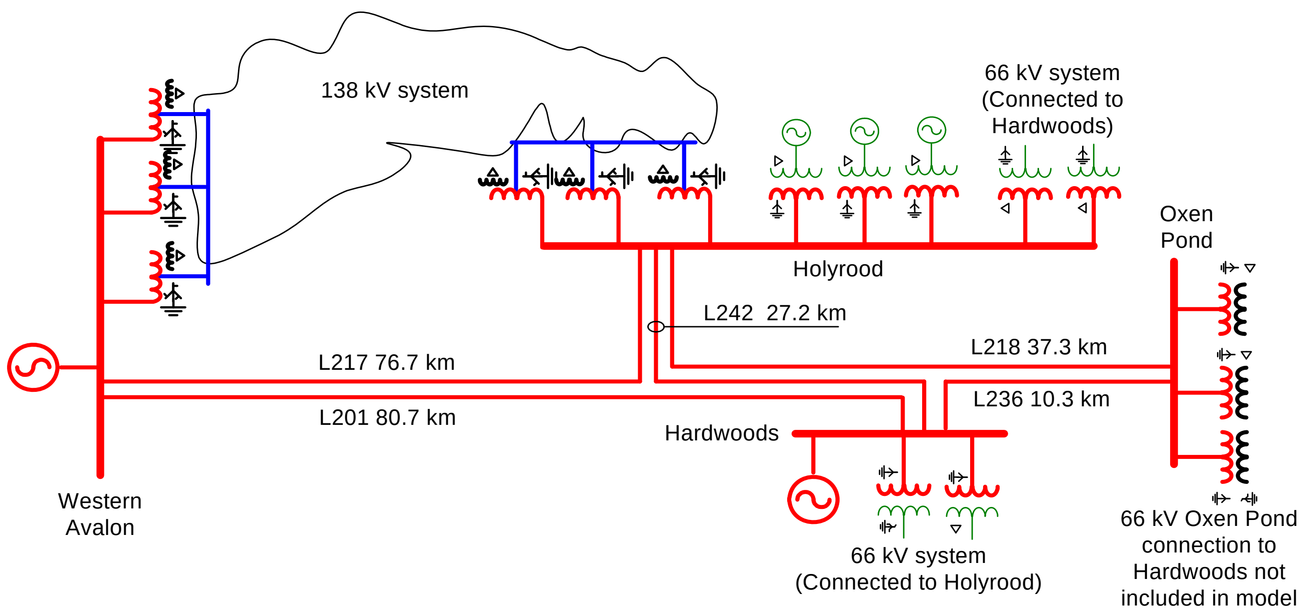


Figure 1 - System Single Line Diagram

Existing P1 protection systems are Areva LZFP111 (Optimho) systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$\text{MVAbase} := 100$ $\text{kVbase} := 230$ $\text{Ibase} := \dfrac{\text{MVAbase}\cdot 1000}{\text{kVbase}\cdot\sqrt{3}}$ $\text{Zbase} := \dfrac{\text{kVbase}^2}{\text{MVAbase}}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at the line terminal.

CT ratio is: $\text{CTR} := \dfrac{600}{5}$ VT ratio is: $\text{VTR} := \dfrac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**NL HYDRO WITH MUTUALS FOR EAST COAST 230 kV LINE PN REVIEW.OLR**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with loads and shunts ignored.

Minimum fault current seen by each terminal (phase to phase, and SLG with 0 ohm fault resistance).

At HWD, with TL203 out of service, and both TL201 and TL217 in service, for a fault at the remote terminal.

$ILLmin := 582$ A $ISLGminPH := 711$ A $ISLGmin0seq := 437$ A

The optimho current level detectors that block the distance comparators in the event of line opening are fixed at 5% of the rated current, or 0.25 A secondary, or 30 A primary. They will have no difficulty in operating for minimum bolted fault levels. However, the ground distance elements are also supervised by a low set neutral current level detector (LDLSN that requires the neutral current to be greater than 10% of the maximum amplitude of phase difference current. This prevents the ground comparators from operating during close-in multiphase faults with CT errors. ASPEN OneLiner shows that for a bolted fault at the remote bus even under heavy load, there is sufficient neutral current (90% of maximum phase to phase fault current) that means this LDLSN function does not inhibit the ground distance comparator.

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind HWD $Z2minHWD := 1.8 + j \cdot 27.7$ ohms primary

Minimum source impedance behind WAV $Z2minWAV := 3.2 + j \cdot 29.3$ ohms primary

<u>Line impedances</u>.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L201 := 0.01346 + j \cdot 0.07696$ $Z0L201 := 0.04011 + j \cdot 0.28691$

$Z1Line := Z1L201 = 0.013 + 0.077j$ pu $Z0Line := Z0L201 = 0.04 + 0.287j$ pu

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line \cdot Zbase$ $Z0Linephys := Z0Line \cdot Zbase$

$Z1Linephys = 7.1 + 40.7i$ ohms primary $Z0Linephys = 21.2 + 151.8i$ ohms primary

Converting primary ohms to secondary ohms gives:

$Z1Linesec := Z1Linephys \cdot \frac{CTR}{VTR}$ $Z0Linesec := Z0Linephys \cdot \frac{CTR}{VTR}$

$|Z1Linesec| = 2.48$ ohms sec $\arg(Z1Linesec) = 80.1 \cdot deg$

$|Z0Linesec| = 9.195$ ohms sec $\arg(Z0Linesec) = 82.04 \cdot deg$

Load Data

From 2011 System summer load case provided in start up information, the peak load (sum of TL201 and TL217) is given as 205 MVA (split between TL201 and TL217). In the event of sudden loss of one line, peak load will be the sum of both line loads until operators can adjust loads. Therefore it is assumed that peak load for a short duration is 205 MVA

$Speak := 205$ MVA $Smax := Speak = 205$ MVA

P1 Relay Settings

Distance element reach settings

Note that resistive reaches are forced to be the same for all zones. Reactive reaches for phase and ground distance elements must be the same as each other.

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the HWD Station bus under light load conditions with TL236 out of service and two units at Holyrood out of service, and both TL201 and TL217 lines in service. From ASPEN OneLiner, voltage at HWD for a 3 phase fault at HWD is 0.2 per unit. So there is plenty of voltage at HWD during a fault at HWD, even under weak source conditions.

Since the voltage is 20%, the line is not considered short, and a conventional Zone 1 setting is acceptable.

$Z1P := 0.85 \cdot |Z1Linesec|$ $Z1P = 2.1$ Ohms secondary

Existing setting of 2.1 ohms is OK, and could be retained if only the phase distance functions had to be considered. However, the ground distance reach in the optimho has to be set the same as the phase distance reach; so we need to consider the ground faults too.

$Z1P := 2.1$ For phase faults only.

The worst case from the point of view of overreach of the zone 1 ground distance element is for a remote close in fault on TL237, with 2L217 out of service and grounded, the apparent impedance of the line is reduced to about 2.13 ohms secondary instead of the nominal 2.48 ohms. This is 86% of the actual line impedance.

$Zapp\_ext := 2.13$ ohms $Zapp\_ang := 79.4deg$ This angle is close enough to the line angle to treat it as equal to the line angle.

$\frac{Zapp\_ext}{|Z1Linesec|} = 0.859$ The apparent impedance is reduced by about 14% mostly due to the effect of the parallel line being out of service and grounded at both ends but also partly due to the zero sequence current compensation factor being set slightly too high on this protection.

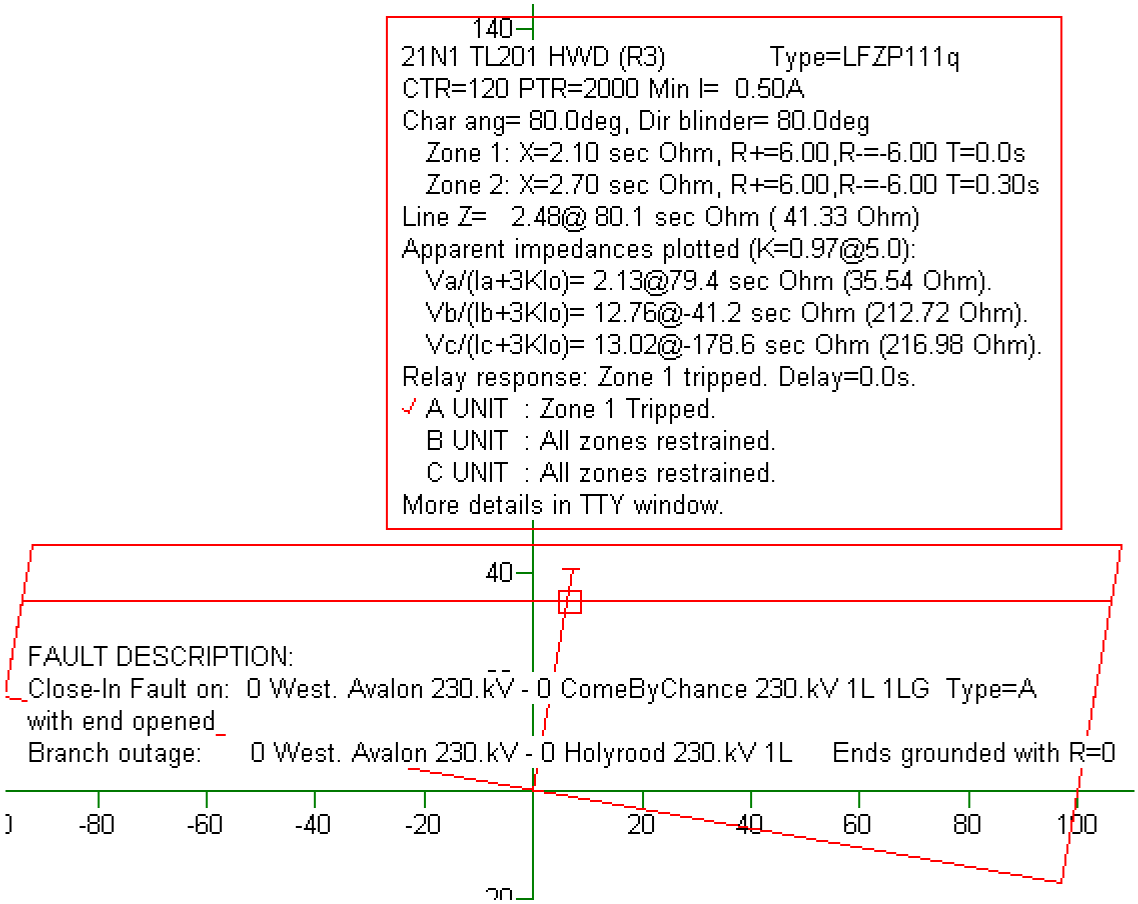


Figure 2 - Apparent impedance to a fault just beyond the remote terminal is reduced by 14% when parallel line is out of service and grounded at both ends. Existing relay settings modeled in this figure.

The reach of the zone 1 ground distance element should be reduced to less than 85% of the line impedance to make it more secure against misoperation for an external fault with the parallel line out of service and grounded. Choose a setting of 80% of line which will underreach the remote bus by 9% when the parallel line is out of service and grounded at both ends and when the zero sequence current compensation factor is reduced slightly.

Let the per unit reach of the Zone 1 function be m per unit of the line. $m := 0.8$ per unit

$Z1\_sec := \mathrm{round}(m \cdot |Z1Linesec|, 1)$ $Z1\_sec = 2$ Ohms secondary

$Z1pri := Z1\_sec \cdot \frac{VTR}{CTR} = 33.333$ Ohms primary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 2.7 ohms secondary (about 106%). However, in order to reach a single line to ground fault at the remote terminal, it will be necessary to set the reach significantly further.

By simulation in ASPEN OneLiner it is found that the apparent impedance to a zero ohm fault close in to the remote terminal is 3 ohms secondary (in summer, with two HRD units off line), or 20% more than the actual line impedance. The reach of the Zone 2 ground distance element should be set at least to 1.25 times the apparent impedance.

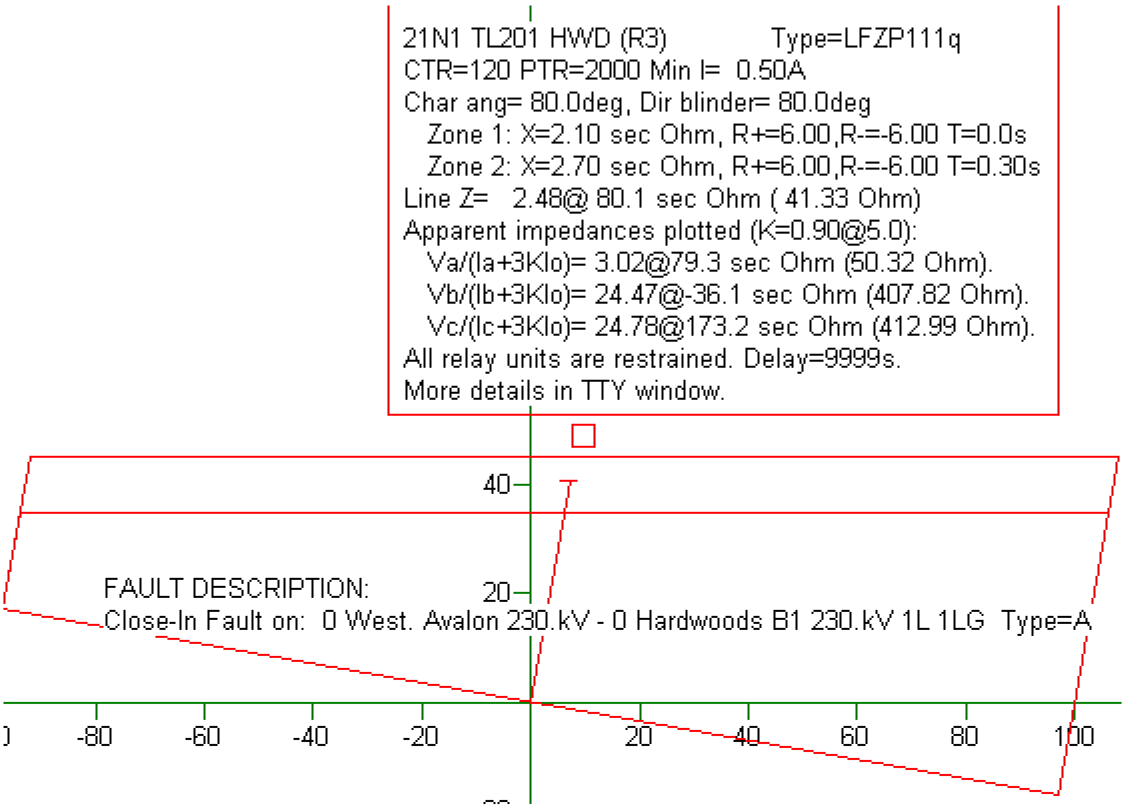


Figure 3 - Apparent impedance to a fault close to the remote terminal is increased by 20% when parallel line is in service.

As can be seen from Figure 3, the apparent impedance to a fault close to the remote terminal is increased when the parallel line is in service.

$Zapp\_int := 3$ Ohms secondary

$Z2\_sec := 1.25 \cdot Zapp\_int$ $\quad Z2\_sec = 3.8$ Ohms secondary $\quad \frac{Z2\_sec}{|Z1Linesec|} = 151.223 \cdot \%$

$Z2\_pri := Z2\_sec \cdot \frac{VTR}{CTR} = 62.5$ Ohms primary

The zone 2 element will securely underreach the zone 1 protection on the shortest line out of WAV even without infeed. Therefore a conventional zone 2 timer setting of 0.3 seconds (same as existing) is appropriate.

$Z2\_TD := 0.3$ Seconds

Zone 3

Zone 3 will be disabled as per the existing settings.

Load Encroachment logic

The optimho instruction manual recommends a margin of at least 10% between the impedance of the maximum load and the resistive reach of the quadrilateral distance element.

Check loadability of the Zone 2 phase distance element assuming worst case depressed voltage of a stressed system of 0.9 per unit.

$$Zloadmin := \frac{(0.9kVbase)^2}{Smax} \qquad Zloadmin = 209.02$$ Ohms primary (assume worst case at 30 degrees)

$$Zloadmin\_sec := Zloadmin \cdot \frac{CTR}{VTR} \qquad Zloadmin\_sec = 12.541$$

A 6 ohm secondary resistive reach is less than 90% of the load impedance at unity power factor and meets the Areva criterion as shown in Figure 4.

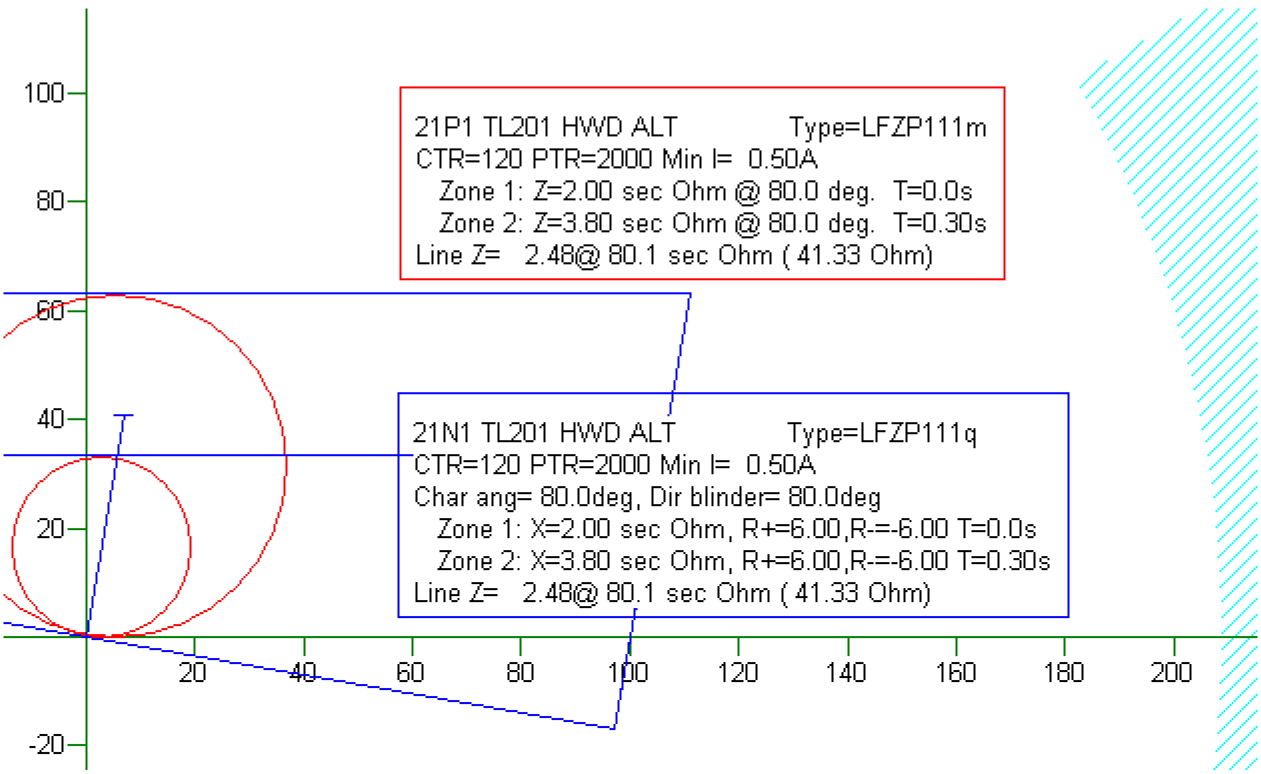


Figure 4 - Apparent impedance of load

Resistive reach of quadrilateral elements

Check the maximum fault resistance that can be sensed for a fault at a location where the current contribution from each terminal is roughly the same. From Figure 5, it can be seen that the limit of sensitivity (where quadrilateral elements at both ends can see a fault) is about 93 ohms, for a fault about 55% of the distance from HWD. This is close enough to the required sensitivity of 100 ohms. Note that the point of overlap of quadrilateral elements may move along the line depending on the strength of the source at either end, but they will always overlap somewhere. For resistive faults outside the overlapping zone, sequential clearing will have to be accepted.

Rquad := 6 Ohms secondary

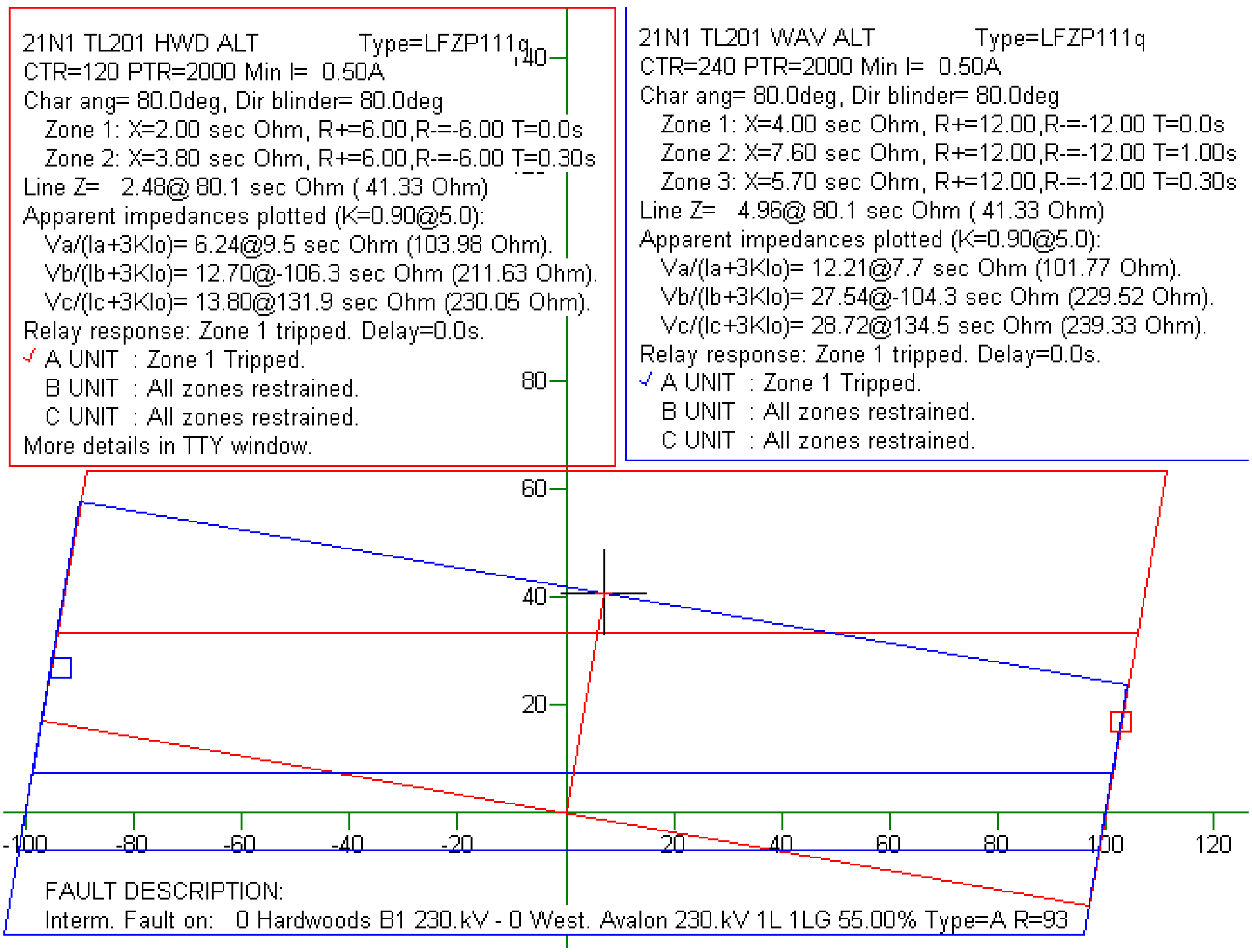


Figure 5 - Apparent impedance of a resistive fault near the mid point of the line.

Settings of K attenuators

KZPh Coarse setting common to all DISTANCE zones should be set as high as possible while below the required Zone 1 reach. The current level detectors vary inversely with KZph. Maximum setting available is 1.0

$KZPh := 1.0$

Zone 1 attenuators and angular selection

$In := 5$ $\quad Z1\_sec = 2$ This is the desired secondary reach (previously calculated)

$$KZ1 := \frac{Z1\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ1 = 2 \qquad Z1sec\_reach := KZ1 \cdot KZPh \cdot \frac{5}{In} \qquad Z1sec\_reach = 2$$

$Z\theta PH := (\arg(Z1Linesec)) \qquad Z\theta PH = 80.08 \cdot deg$

Rounded to the nearest 5 degrees $\quad Z\theta PH := 80$ Degrees

$Z\theta N := \arg(Z0Linesec - Z1Linesec) \qquad Z\theta N = 82.766 \cdot deg$

Rounded to the nearest 5 degrees $\quad Z\theta N := 80$ Degrees

Zone 2 attenuators selection

$Z2\_sec = 3.8$ This is the desired secondary reach (previously calculated)

$$KZ2 := \frac{Z2\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ2 = 3.8$$

QUAD Resistive Reach setting

$Rquad = 6$ This is the desired secondary reach (previously calculated)

$$KR := \frac{Rquad}{\left(\frac{5}{In}\right)} \qquad KR = 6$$

Residual Compensation attenuators selection

Zero sequence current compensation for ground faults is provided by the KZN factor. Zero sequence mutual compensation is not used in this application (it causes extra complexity for only moderate gain in setting accuracy).

$$KZN := \frac{Z0Linesec - Z1Linesec}{3 \cdot Z1Linesec} \cdot KZPh \qquad KZN = 0.902 + 0.042j$$

$|KZN| = 0.903$ This is a reduction from the existing setting of 0.967

Switch On To Fault (SOTF) Protection.

If SOTF is enabled, it can be set to 200ms or 110 s after all poles of the line have been de-energized. The 110 s setting is intended to override automatic reclosing dead time. However it makes more sense to enable after the shorter time. Once the SOTF feature has been initiated, it remains in effect for 250ms after the line has been re-energized. The SOTF tripping options are:

a) Any distance comparator.
b) Any current level detector as long as a corresponding voltage level detector has not picked up within 20ms.
c) Either current or distance, as long as a corresponding voltage level detector has not picked up within 20ms.

SOTF := "Enabled"

SOTF_TIME := 0.20 Seconds

Elements_in_SOTF := "BOTH" (Both Comparators and current level detectors).

Power Swing Detector

This element will not be used. It will be left Blocked, and if there is a power swing, the distance elements will trip naturally.

VT Supervision

Set the VT supervision to BLOCK TRIP

Set the VT fail detection to SELF RESET.

Start Indication

This function will bring up information on the LCD screen of the relay if a start event occurs. This function will not be used.

START_INDICATION := "BLOCKED"

Communications assisted logic.

The existing communications assisted logic is permissive overreaching transfer trip, scheme **POR 1**. This scheme is familiar to Newfoundland and Labrador Hydro, and even though the POR 2 scheme offers the advantage of weak infeed echo, which would help the sensitivity to resistive faults, it is not recommended to change the existing scheme logic at this stage with years of experience on a product that is nearing the end of its useful life.

The POR 1 logic is a basic permissive overreaching transfer trip scheme but it does include current reversal timers to increase security against misoperation due to current reversal when a fault on the parallel line is cleared sequentially. The current reversal logic is achieved by a timer TP which will block permissive tripping and keying of permissive trip if the local zone 2 element does not pick up within a reasonable time of receiving permissive trip. The block will be maintained for a time delay of TD after the local zone 2 element picks up, or the received permissive trip signal resets.

The application of the current reversal timers is required only if the settings of the zone 2 comparators are greater than 1.5 times the line impedance .Although the reaches of these elements slightly more than 1.5 times the line impedance, there is no parallel line and there is infeed at each terminal that will minimize overreach. Therefore, the current reversal logic is not required, and the recommended default settings are as existing

TP := 98 ms TD := 0 ms

Comparison of Existing (R3) and proposed alternative (ALT) settings.

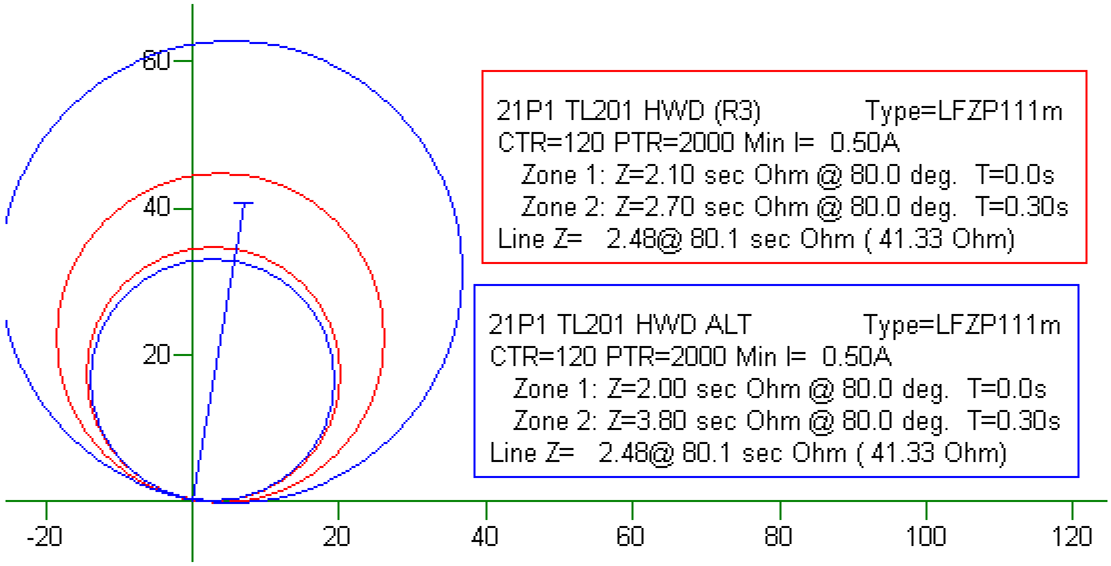


Figure 6 - Comparison of phase distance characteristics

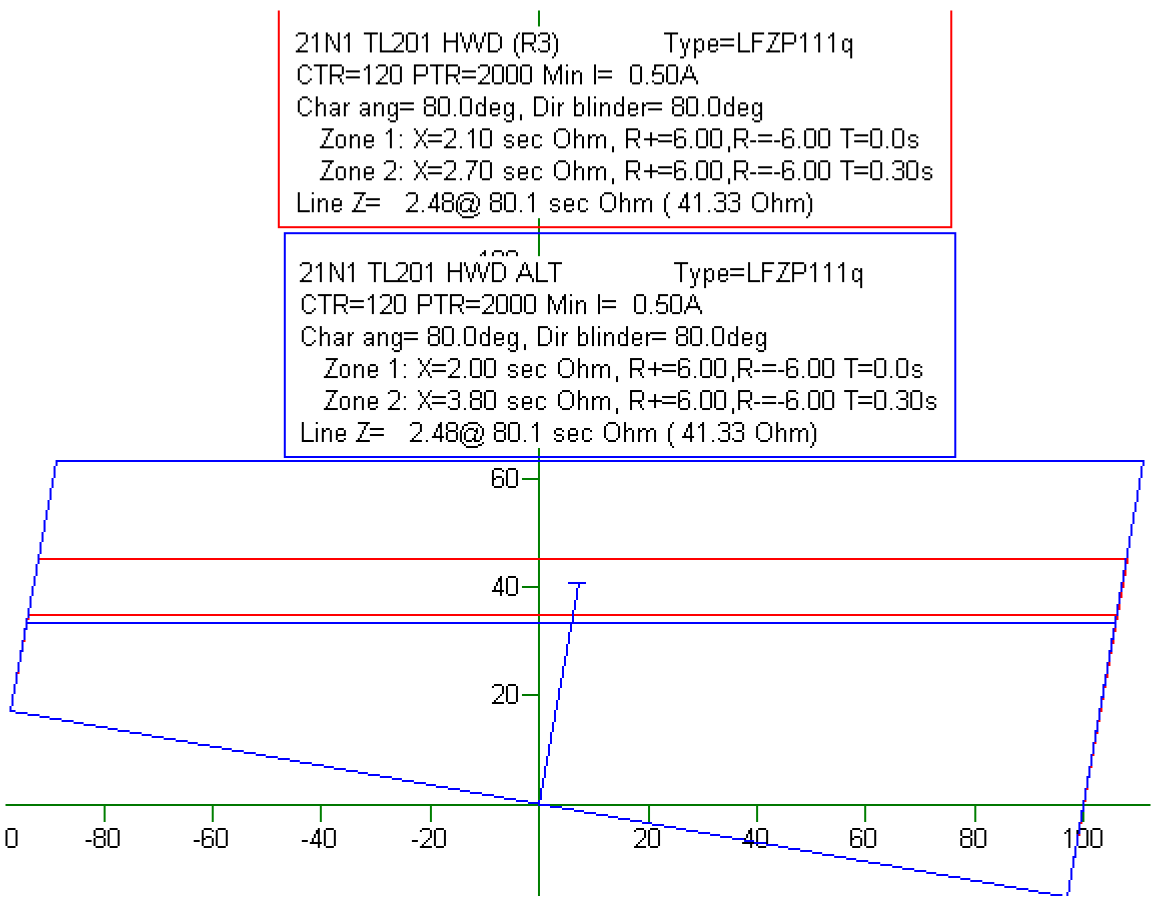


Figure 7 - Comparison of ground distance characteristics

Protection Review for Five 230 kV Transmission Lines

Appendix G
Detailed settings review for HWD TL201 "P2" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Hardwoods (HWD) terminal of circuit TL201. This 230 kV transmission circuit is from HWD to Western Avalon (WAV).
The circuit runs parallel to Circuit TL217 for most of its length.

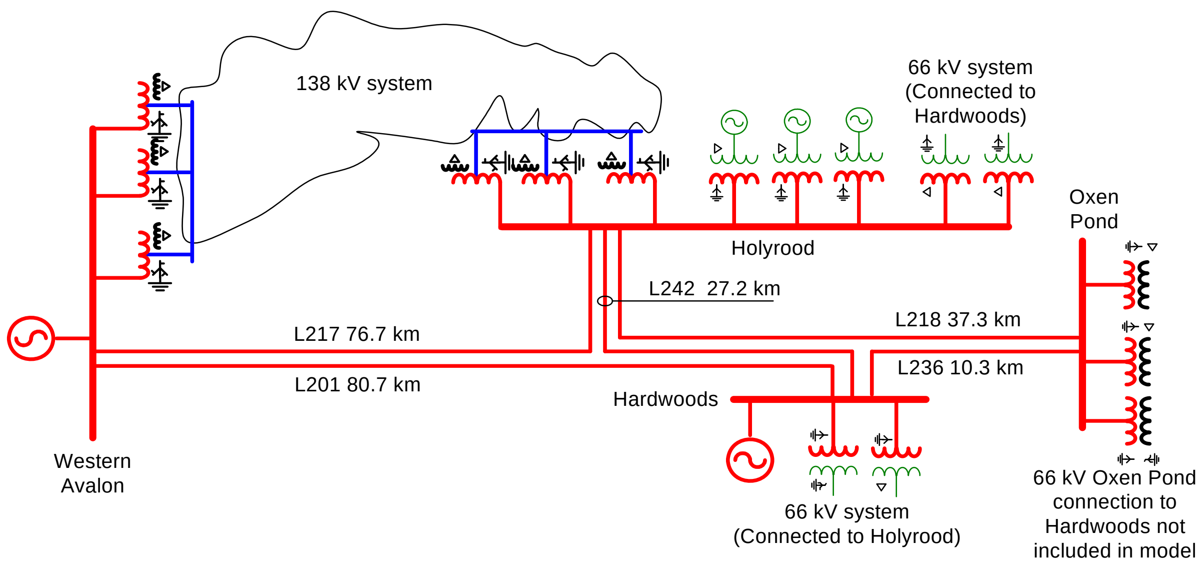


Figure 1 - System Single Line Diagram

Existing P2 protection systems are SEL321 systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $kVbase := 230$ $Ibase := \frac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $Zbase := \frac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $CTR := \frac{600}{5}$ VT ratio is: $VTR := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "N**L HYDRO WITH MUTUALS FOR EAST COAST 230 kV LINE PN REVIEW.OLR**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with loads and shunts ignored.

Minimum fault current seen by each terminal (phase to phase, and SLG with 0 ohm fault resistance).

At HWD, with TL236 out of service, and all of TL242 and TL201 and TL217 in service, and two units at HRD off line, for a fault at the remote terminal.

$I3Pmin := 672$ A $ISLGminPH := 711$ A $ISLGmin0seq := 437$ A

The current for a phase to phase fault would be lower, but the current supervision element of the SEL321 measures phase to phase currents, and the phase to phase current for a phase to phase fault is twice the phase current.

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind HWD $Z2minHWD := 1.8 + j \cdot 27.7$ ohms primary

$Z0minHWD := 0.85 + j \cdot 12.6$ ohms primary

Minimum source impedance behind WAV $Z2minWAV := 3.3 + j \cdot 29.4$ ohms primary

$Z0minWAV := 1.81 + j \cdot 24.4$ ohms primary

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L201 := 0.01346 + j \cdot 0.07696$ $Z0L201 := 0.04011 + j \cdot 0.28691$

$Z1Line := Z1L201 = 0.013 + 0.077j$ pu $Z0Line := Z0L201 = 0.04 + 0.287j$ pu

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line \cdot Zbase$ $Z0Linephys := Z0Line \cdot Zbase$

$Z1Linephys = 7.1 + 40.7i$ ohms primary $Z0Linephys = 21.2 + 151.8i$ ohms primary

Converting primary ohms to secondary ohms gives:

$Z1Linesec := Z1Linephys \cdot \frac{CTR}{VTR}$ $Z0Linesec := Z0Linephys \cdot \frac{CTR}{VTR}$

$|Z1Linesec| = 2.48$ ohms sec $\arg(Z1Linesec) = 80.1 \cdot deg$

$|Z0Linesec| = 9.195$ ohms sec $\arg(Z0Linesec) = 82.04 \cdot deg$

Load Data

From 2011 System summer load case provided in start up information, the peak load (sum of TL201 and TL217) is given as 205 MVA (split between TL201 and TL217). In the event of sudden loss of one line, peak load will be the sum of both line loads until operators can adjust loads. Therefore it is assumed that peak load for a short duration is 205 MVA

$Speak := 205$ MVA $Smax := Speak = 205$ MVA

Max load in this line with TL217 in service is $Smax\_L201 := 115$ MVA

P2 Relay Settings

Minor changes to the set line impedances are recommended to assist fault locations.

$Z1MAG := |Z1Linesec|$ $Z1MAG = 2.48$ $Z1ANG := \frac{arg(Z1Linesec)}{deg}$ $Z1ANG = 80.1$

$Z0MAG := |Z0Linesec|$ $Z0MAG = 9.2$ $Z0ANG := \frac{arg(Z0Linesec)}{deg}$ $Z0ANG = 82$

$LL := 80.69$

In order to obtain sensitivity to 100 ohm single line to ground faults, the echo function will be needed. Enable two forward and one reverse zone.

$PMHOZ := 3$ $GMHOZ := 3$ $QUADZ := 3$

$DIR1 := F$ $DIR2 := F$ $DIR3 := R$

<u>Mho phase distance functions</u>

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the HWD Station bus under light load conditions with TL236 out of service and two units at Holyrood out of service, and both TL201 and TL217 lines in service. From ASPEN OneLiner, voltage at HWD for a 3 phase fault at HWD is 0.2 per unit. So there is plenty of voltage at HWD during a fault at HWD, even under weak source conditions.

Since the voltage is 20%, the line is not considered short, and a conventional Zone 1 setting is acceptable.

$Z1P := 0.85 \cdot |Z1Linesec|$ $Z1P = 2.1$ Ohms secondary

Existing setting of 2.1 ohms is OK, and will be retained. $Z1P := 2.1$

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 2.7 ohms secondary (about 109%) and should be increased to 125%. This will give a more comfortable dependability margin.

$Z2P := 1.25 \cdot |Z1Linesec|$ $Z2P = 3.1$ Ohms secondary

As can be seen from Figure 2, this element significantly underreaches the zone 1 on TL237 (the shortest line out of WAV). Therefore there is no problem with increasing the setting and retaining normal zone 2 time.

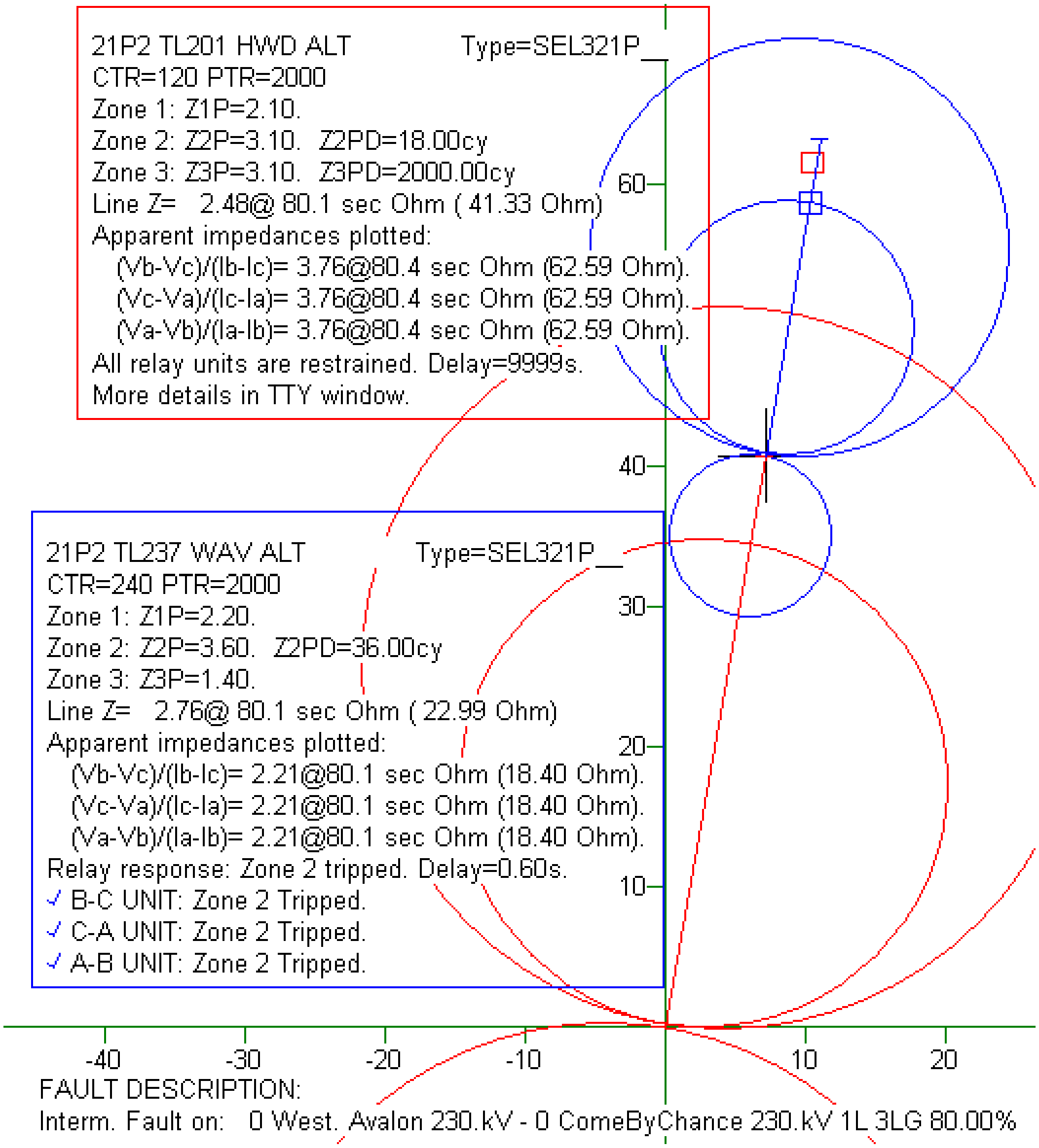


Figure 2 - Proposed new HWD TL201 Zone 2 only securely underreaches WAV TL237 Zone 1 even with infeed. Zone 3 timing is needed for the Zone 2 function at HWD.

Normal zone 2 delay for 230 kV lines will be appropriate

$Z2PD := 18$ Cycles

Zone 3

Set Zone 3 reverse element to reach further behind this terminal than the remote Zone 2. This function adds security for external faults. The element should always be more sensitive than the forward looking Zone 2 at the remote terminal. Due to the long overreach of the remote zone 2 ground distance element under some circumstances, set it the same as the remote Zone 2 using the line impedance as margin.

$Z3P := Z2P$ $\qquad Z3P = 3.1$ Ohms secondary

$$\frac{Z3P}{|Z1MAG|} = 125\cdot\%$$ of line length

This is a much higher than the existing setting, but provides additional security.

Mho phase distance current supervision

If the current supervision elements can be set above load, they will be secure in the event that potential is lost. However given that loss of potential logic is available, it is recommended that only the zone 1 current supervision function be set above load. If potential is lost, it will be able to block tripping by Zone 2 before it trips on time delay or receives a permissive trip from the remote terminal.

For the point of view of current supervision being above maximum load, there is no need to worry about abnormal conditions. It would be a double contingency for the VT signal to be lost while the parallel line was out of service. Therefore, consider a maximum load of 115 MVA (with TL217 in service). The current supervision elements for the phase distance functions measure phase to phase currents.

$$IPPmax\_normal := \frac{Smax\_L201\cdot 1000}{kVbase} \qquad IPPmax\_normal = 500$$ A primary

The current supervision elements use phase to phase currents for supervision of the phase distance functions; so the minimum phase to phase fault current will be root three times the minim phase fault current. Choose a margin of 50% of the minimum phase to phase fault current for dependability.

$$IPPmin := 0.5I3Pmin\cdot\sqrt{3} \qquad IPPmin = 582$$ A primary

A setting of 500 A primary for 50PP1 will ensure the Zone 1 function operates for any fault even under minimum source conditions while remaining unable to trip on load due to loss of potential under any normal maximum load conditions. This is a little higher than the existing setting, but is quite dependable.

$'50PP1 := 2.1$ A Sec $\qquad '50PP1\cdot CTR = 252$ A primary

The Zone 2 and zone 3 elements will be blocked by LOP function, therefore they could be set at minimum from the point of view of security during loss of potential. However, because of using the echo function, we have to be sure that the zone 3 at the remote terminal is no less sensitive than the zone 2 at this terminal. The remote terminal uses CT with double the ratio of the CTs at this terminal. The zone 2 function must be set at 2 A secondary (same as existing) in order to be no more sensitive than the zone 3 element at the remote terminal. The zone 3 can be set at minimum since it will be twice as sensitive at the remote zone 2.

$'50PP2 := 2$ A Sec $\qquad '50PP3 := 1$ A Sec

Ground Distance Protection

The reach of the ground distance functions will be affected by mutual coupling to the parallel line. These functions will tend to underreach the remote bus while the parallel line is in service, and overreach the remote bus if a parallel line is out of service and grounded at both ends. Figure 3 shows that for a remote close in fault on TL237, with 2L217 out of service and grounded, the apparent impedance of the line is reduced to about 2.18 ohms secondary instead of the nominal 2.48 ohms. This is 89% of the actual line impedance.

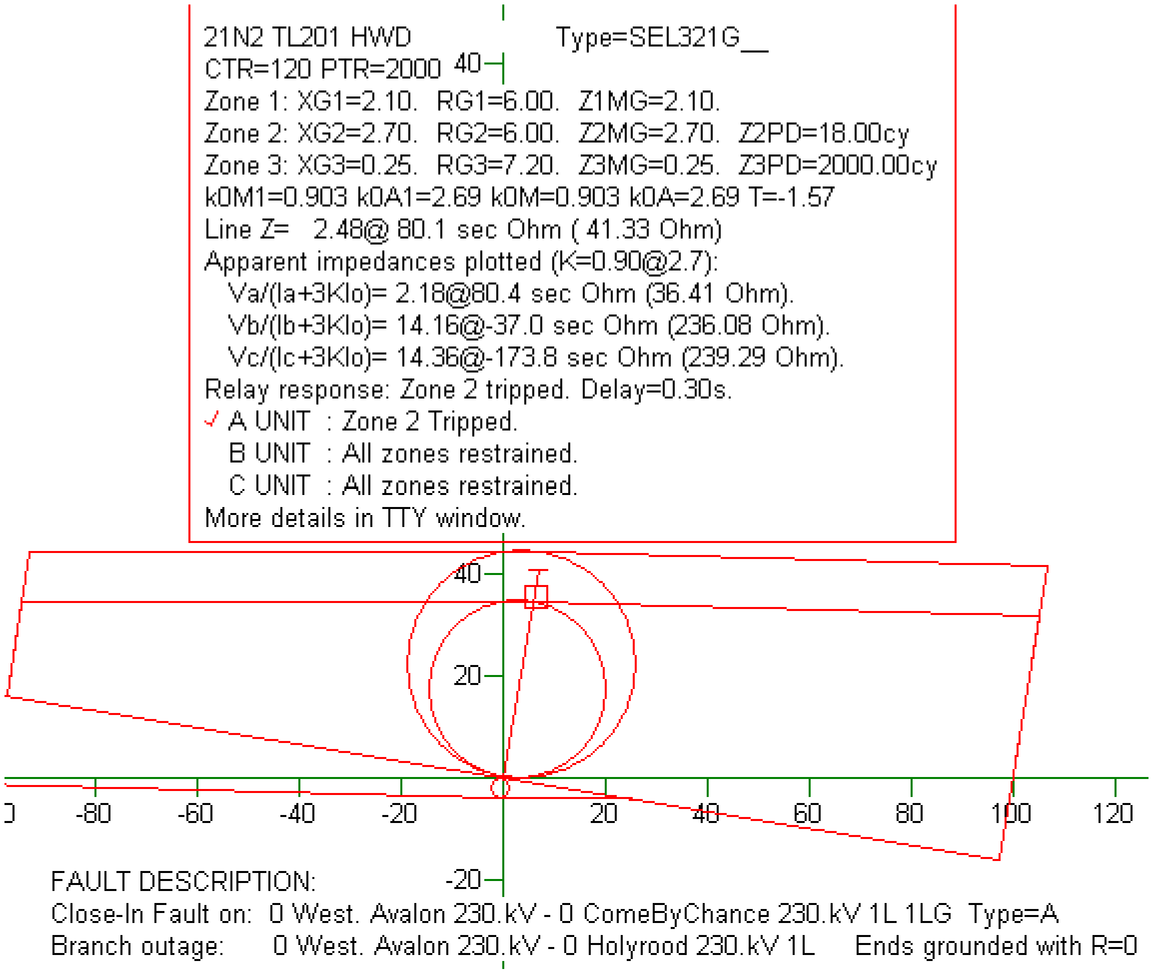


Figure 3 - Apparent impedance to a fault just beyond the remote terminal is reduced by 11% when parallel line is out of service and grounded at both ends.

The reach of the zone 1 should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Choose a setting of 80% of line which will underreach the remote bus by 9% when the parallel line is out of service and grounded at both ends.

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.8$ per unit

$Z1MG := \mathrm{round}(m \cdot |Z1Linesec|, 1)$ $Z1MG = 2$ Ohms secondary

$XG1 := Z1MG$ $XG1 = 2$ Ohms secondary

Zone 1 Resistance

The resistive reach of the Zone 1 quad should provide enough sensitivity to trip the local terminal immediately without waiting for permission from the remote terminal for a severe fault that depresses the voltage significantly. Further, it should not allow the function to reach beyond the remote terminal due to errors in relay measurement or CT or VT. In general, a reasonable limit for resistive reach of a zone 1 function is 4 times the reactive reach. If possible, it should operate for a 100 ohm SLG within 10% of the distance from the local terminal. Operation for a 100 ohm resistive fault at the 10% location will ensure this function can trip for a close in fault without assistance from the remote terminal. The remote terminal zone 2 function will be set to operate sequentially for this fault.

By simulating a fault with 100 ohms fault resistance at 10% of the distance from HWD, with the HWD terminal normal it is found that a reach of 8 ohms secondary is required to sense this fault. See Figure 4. Note that with HWD weak, the 8 ohm resistance setting will not be sensitive enough. However it not desirable to set the resistive reach of the zone 1 element too far with respect to the reactive reach.

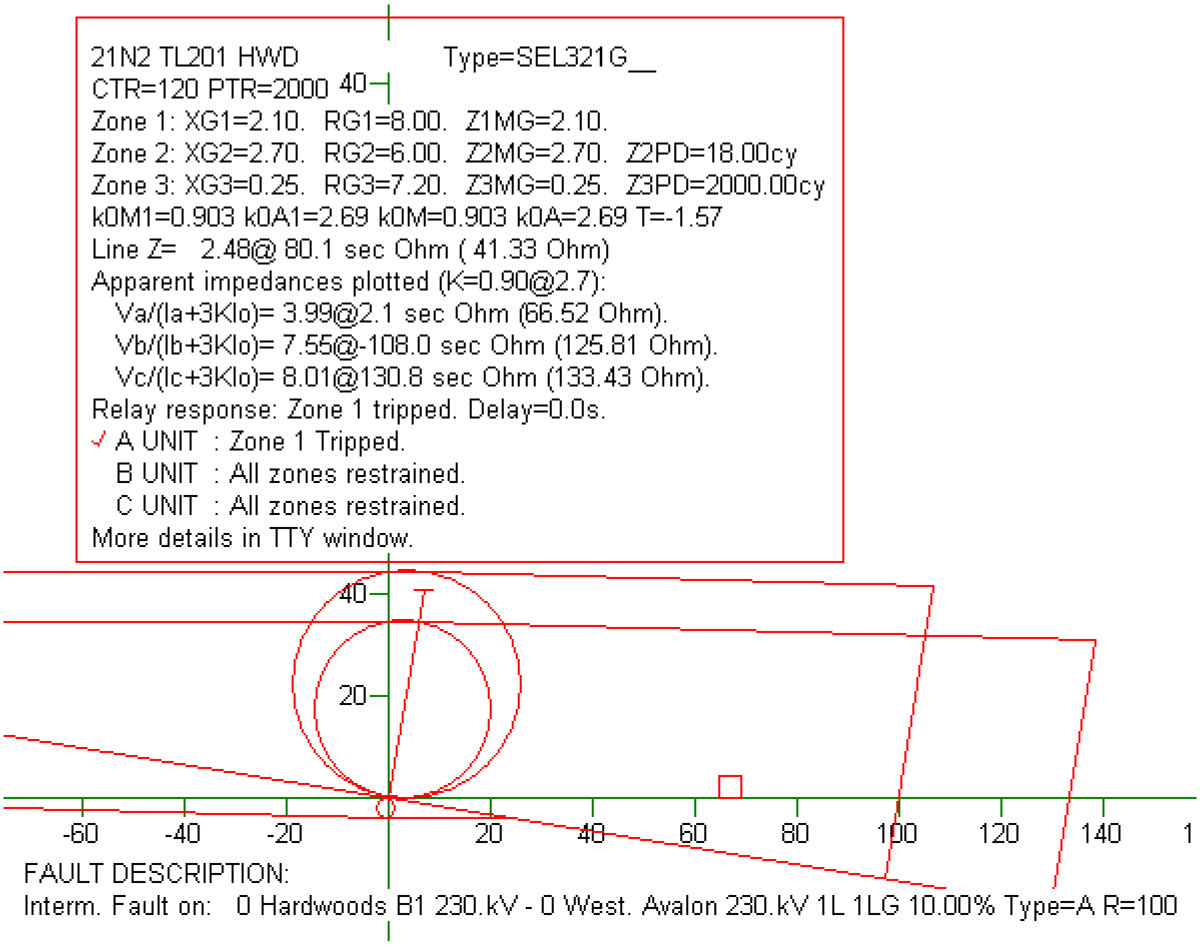


Figure 4 - HWD Zone 1 function if set with 8 ohm resistive reach, operates for a 100 ohm SLG fault at 10% from the local terminal.

The existing 6 ohm secondary resistive reach of the zone 1 element will not sense this fault, and should be increased to 8 ohms secondary. Check whether this reach will be secure, considering possible CT and VT errors.

XG1 is set at m per unit of the transmission line. The imaginary component of the line is

$ImXG1sec := Im(Z1Linesec)$ $\quad ImXG1sec = 2.443$ ohms

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$RG1 := round[(1 - m)\cdot 20\cdot ImXG1sec, 2]$

$RG1 = 9.77$ This is the maximum secure setting for the resistive reach and is above the proposed zone 1 resistive reach setting..

Use the proposed setting of 8 ohms for RG1 $\quad RG1 := 8$ ohms secondary

With a resistive reach setting of 18 ohms, the HWD Zone 1 quad element will see an 60 ohm resistive SLG fault at 50% of the distance from HWD. Zone 2 protection will be depended upon to sense faults with resistance up to 100 ohms.

Zone 2 Ground Distance Protection

The Zone 2 ground distance function will need to be set longer than the Zone 2 phase distance protection function because it will tend to underreach the remote terminal while the parallel line is in service. By simulation in ASPEN OneLiner it is found that the apparent impedance to a zero ohm fault close in to the remote terminal is 3 ohms secondary (in summer, with two HRD units off line), or 20% more than the actual line impedance. The reach of the Zone 2 ground distance element should be set at least to 1.25 times the apparent impedance.

$ZSLG\_remote := 3$

$Z2MG := round(1.25\cdot ZSLG\_remote, 1)$ $\quad Z2MG = 3.8$ Ohms secondary

The quad element reactive reach will be set similarly to the mho.

$XG2 := Z2MG$ $\quad XG2 = 3.8$ Ohms secondary

It would be desirable to set the resistive reach of the quad element to sense a 100 ohm SLG fault at 75% of the line with the local terminal weak. This would ensure overlap with the zone 1element at the remote terminal. However, that would require too much resistive reach. Therefore choose a setting to sense a 100 ohm SLG fault just past the mid point of the line, and depend on the echo function to provide coverage for high resistance faults in the region where the remote zone 1 won't operate.

By trial and error from ASPEN it is found that a resistive reach of 13 ohms secondary will sense a 100 ohm SLG fault with an overlap with a similarly set remote zone 2 of 10% of the line length. See Figure 5. This will give positive overlap with the zone 2 element at the remote terminal. However since it will not overlap the Zone 1 element at the remote terminal, the permissive trip echo function will be required to ensure that a fault that is seen by the zone 2 element at only one terminal will still be cleared by the permissive trip logic.

Therefore, to avoid extremely large resistive reaches, and to retain sensitivity to 100 ohm resistive SLG faults, it is recommended that the echo function be enabled at both terminals.

$RG2 := 13$ Ohms secondary

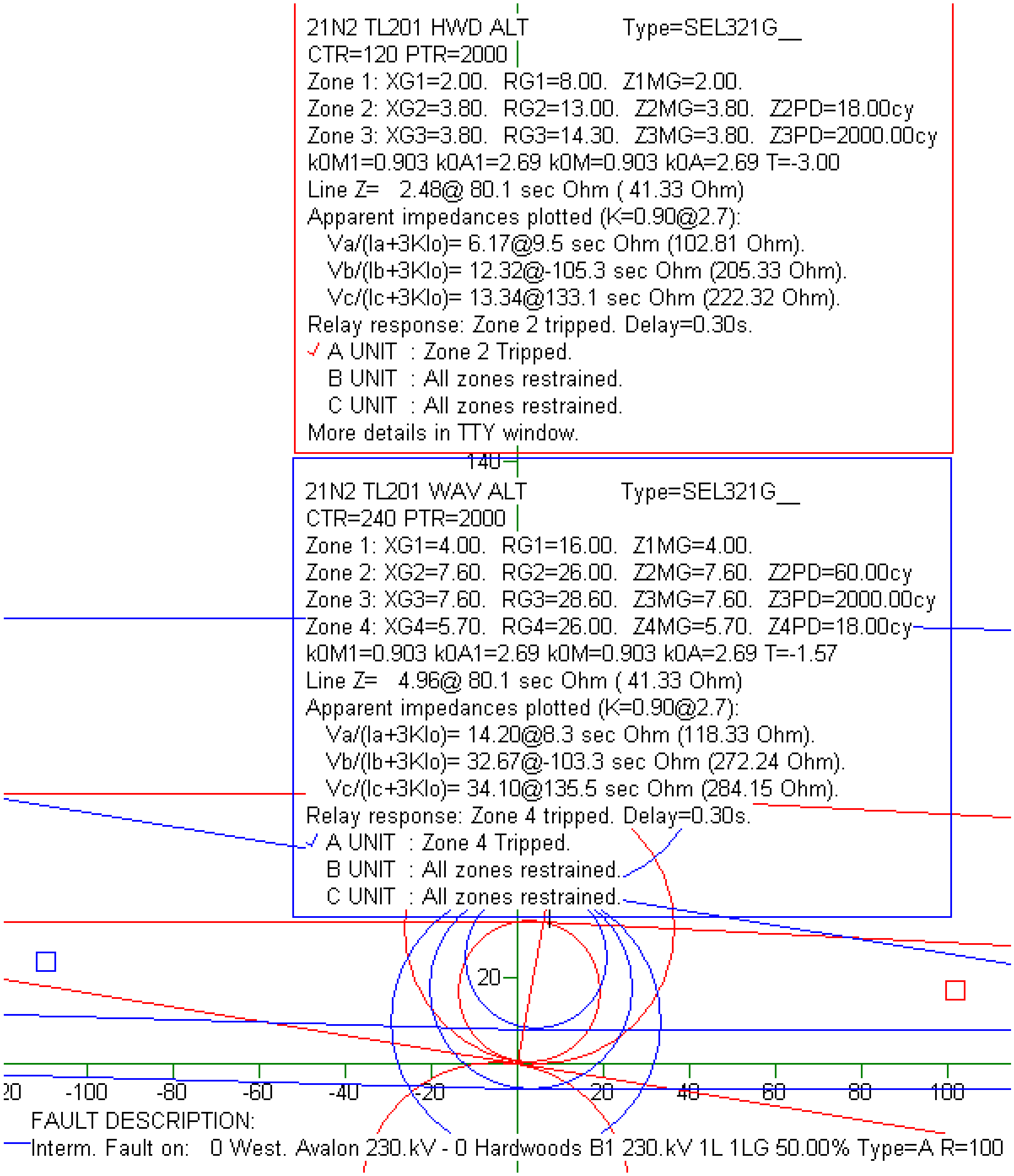


Figure 5 - Quad elements overlap with remote quad elements and operate for 100 ohm resistive SLG at the mid line location (only) HWD Zones 2 and 4 have same resistive reach.

Check that this resistive reach won't cause the zone 2 function to trip while a parallel line is open single phase, with heavy power flow. See Figure 6. Unusually heavy power flow has been simulated to challenge security.

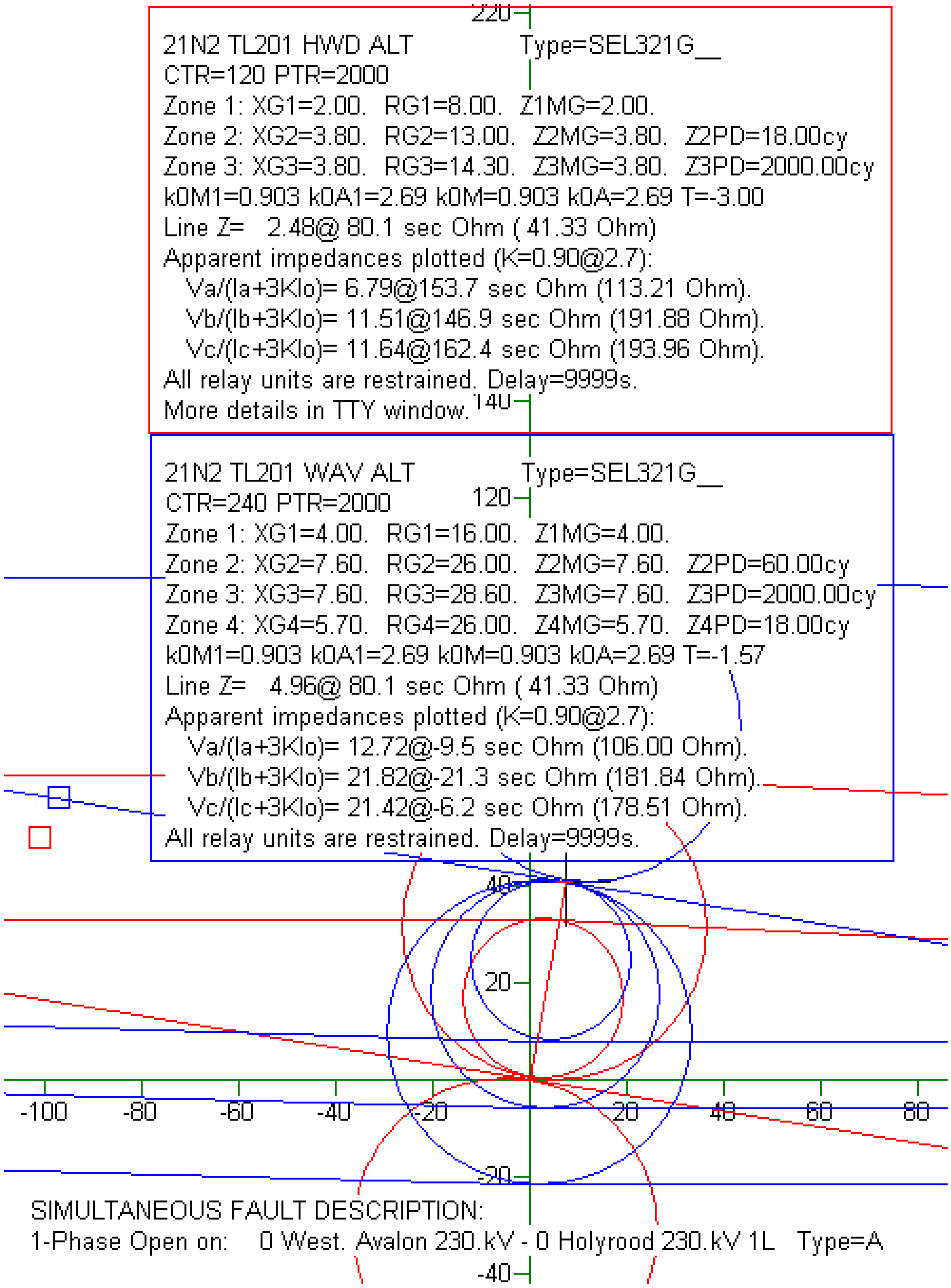


Figure 6 - Quad elements are secure with extremely heavy load flow (190 MVA in TL217 and 300 MVA in TL201) while TL217 is open single pole.

Zone 3

The zone 3 ground mho function will be set using the same principles as the zone 3 phase distance function. Although the remote zone 2 has a different CT ratio, the setting is the same as the local zone 2 in primary ohms. Therefore use the setting for local zone 2 in secondary ohms as the remote zone 2.

$Z2MGrem := Z2MG$ ohms secondary

$Z3MG := Z2MGrem$ $Z3MG = 3.8$ Ohms secondary

$\frac{Z3MG}{|Z1MAG|} = 153.2 \cdot \%$ of line length This is much higher than the existing setting, but provides additional security.

$XG3 := Z3MG$ $XG3 = 3.8$ Ohms secondary

Set the Zone 3 quad resistive reach at 10% more than the remote Zone 2. Although the remote zone 2 has a different CT ratio, the setting is the same as the local zone 2 in primary ohms. Therefore use the setting for local zone 2 in secondary ohms as the remote zone 2.

$RG2rem := RG2$ Ohms secondary $RG3 := RG2rem \cdot 1.1$ $RG3 = 14.3$ Ohms secondary

Ground distance current supervision

Since there is no concern about these elements operating on load, even with loss of potential, set all current supervision except zone 2 elements at minimum, for maximum sensitivity of the distance elements. The zone 2 elements should be set at 1.0 A secondary to ensure they are not more sensitive than the reverse looking zone 3 element at the WAV terminal which uses 240:1 CTs.

$'50L1 := 0.5$ A Sec $'50L2 := 1.0$ A Sec $'50L3 := 0.5$ A Sec

$'50G1 := 0.5$ A Sec $'50G2 := 1.0$ A Sec $'50G3 := 0.5$ A Sec

Note that due to heavy infeed of zero sequence currents from the local terminal for close-in faults, the ground overcurrent detectors will not operate for faults with more than a small amount of resistance close to the remote terminal. Therefore, we will have to rely on sequential clearing for that type of fault. However setting the current supervision at minimum allows maximum sensitivity.

Zero sequence current compensation

The zero sequence current compensation could be adjusted to compensate for the significant amount of mutual coupling. However as discussed in the settings of reaches of the ground distance elements we will accept underreach of the Zone 2 function for the normal case by setting it at 125% of the apparent impedance for a remote fault. Set the zero sequence current compensation as usual.

$$k01M := \left(\left|\frac{Z0Line - Z1Line}{3 \cdot Z1Line}\right|\right) \qquad k01M = 0.903$$

$$k01A := \left(\arg\left(\frac{Z0Line - Z1Line}{3 \cdot Z1Line}\right)\right) \qquad k01A = 2.69 \cdot deg$$

Set the overreaching zones the same as zone 1 $k0M := k01M$ $k0A := k01A$

$k0M = 0.903$ $k0A = 2.69 \cdot deg$

Non Homogenous Angle Setting

Compare the angle of the remote zero sequence source impedance with the total zero sequence source impedance to the fault to determine this setting.

$$T := \arg\left(\frac{Z0minHWD + Z0Linephys + Z0minWAV}{Z0minWAV}\right) = -3\cdot deg \qquad T = -3\cdot deg$$

Out of step blocking and tripping

Not used in this application. There is a danger of out of step conditions arising. Historically no action has been taken to provide special tripping or blocking functions. Natural tripping during swings is accepted.

Load Encroachment logic

Check loadability of the Zone 2 phase distance element assuming worst case power factor of 0.87 simultaneous with worst case depressed voltage of a stressed system of 0.85 per unit. Note that units of kV squared match units of MVA. Note that quadrilateral elements are only used for the ground distance functions that are not sensitive to balanced three phase load. Therefore no need to worry about the reach of the quadrilateral elements.

$Zloadmin := \frac{(0.85kVbase)^2}{Smax}$ $Zloadmin = 186.44$ Ohms primary (assume worst case at 30 degrees)

Maximum reach of the Zone 2 element is at the line angle of 81 degrees. At 30 degrees, the reach will be given by

$Z2load := Z2P \cdot \cos[(Z1ANG - 30)deg]$ $Z2load = 1.989$ ohms secondary

$Z2load \cdot \frac{VTR}{CTR} = 33.153$ ohms primary

Since the reach of the Zone 2 element at 30 degrees is less than the apparent impedance of the maximum load, there is no need to apply load blinding logic. See Figure 7

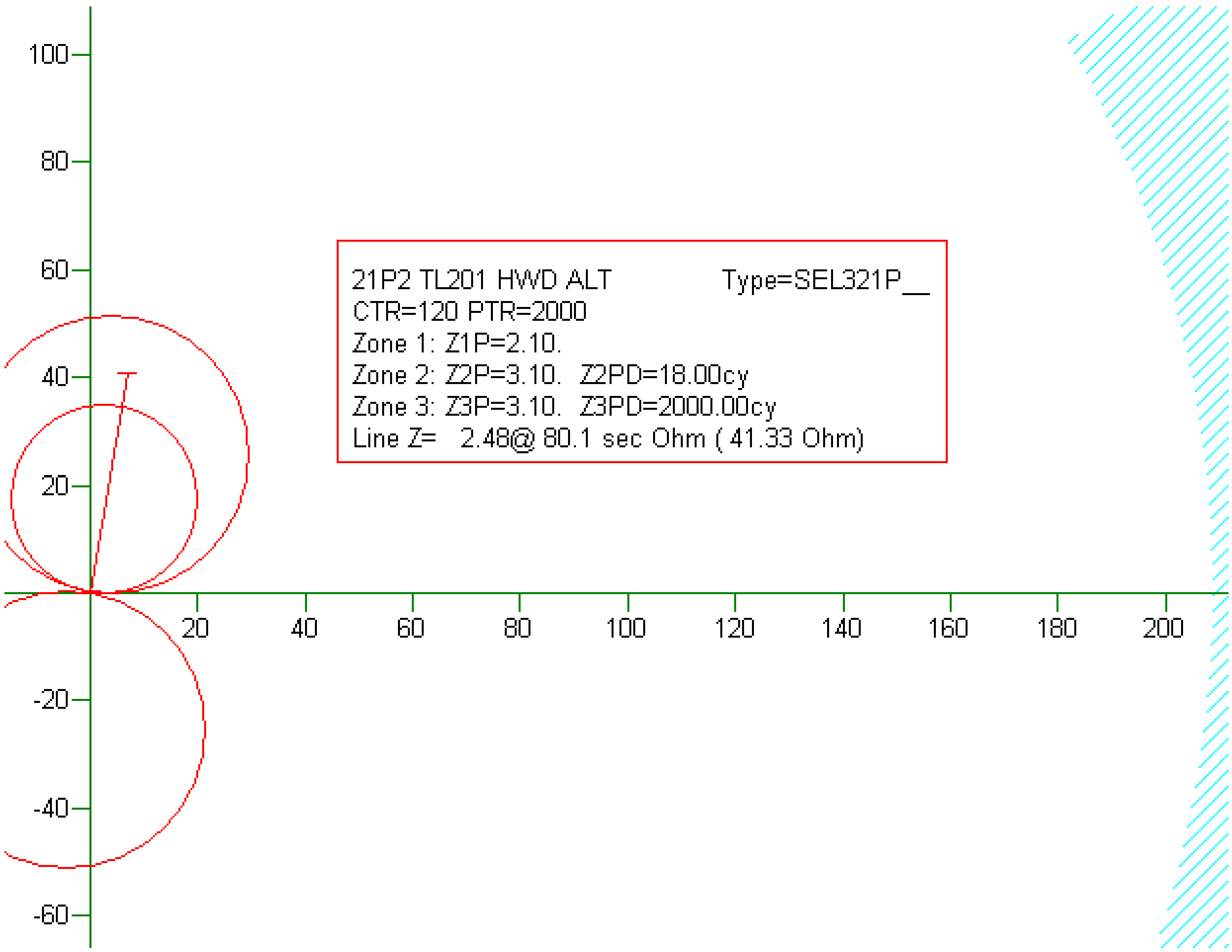


Figure 7 -Load impedance with respect to proposed new Mho function reaches.

Ground directional element

The SEL-321 application example recommends finding the minimum source impedance behind the terminal and setting the reverse and forward boundaries of the negative sequence directional element at the 1/3 and 2/3 points respectively.

In the negative sequence plane, the sum of the two source impedances and the line impedance is:

$$Z2total := Z2minHWD + Z1Linephys + Z2minWAV$$

The 1/3 point is $Z2\_1\_3 := \frac{Z2total}{3}$ The 2/3 point is $Z2\_2\_3 := \frac{2Z2total}{3}$

$Z2Rpri := Z2\_2\_3 - Z2minHWD$ $|Z2Rpri| = 38.041$

$Z2Fpri := Z2\_1\_3 - Z2minHWD$ $|Z2Fpri| = 5.405$

Converting the primary impedances to secondary ohms

$Z2R := Z2Rpri \cdot \frac{CTR}{VTR}$ $|Z2R| = 2.282$ Ohms secondary $\arg(Z2R) = 80.396 \cdot deg$

$Z2F := Z2Fpri \cdot \frac{CTR}{VTR}$ $|Z2F| = 0.324$ Ohms secondary $\arg(Z2F) = 65.128 \cdot deg$

Rounding up Z2F and rounding down Z2R gives:

$Z2F := 0.4$ Ohms secondary $Z2R := 2.2$ Ohms secondary

These are quite different from the existing settings.

Set the current level detectors at minimum level that will allow operation of the ground distance elements.

Due to the very small zero sequence current contribution to a single line to ground fault at the remote terminal, the negative sequence current contribution will always be higher than the zero sequence. Therefore there is no point in setting the forward looking negative sequence overcurrent elements any more sensitively than the zero sequence ground overcurrent supervision of the ground distance elements.

$'50QF := '50G2$ $'50QF = 1$ A secondary

Set the supervision function for the reverse looking element to be the same as, or a little more sensitive than the forward looking supervision element at the remote terminal.

$'50QR := 0.5$ A secondary

The positive sequence current restraint (a2) factor should be set just smaller than the ratio of the maximum load current (positive sequence) to the most sensitive current supervision element (50QR).

$I1maxpri := \frac{Smax \cdot 1000}{kVbase \cdot \sqrt{3}}$ $I1maxsec := \frac{I1maxpri}{CTR}$ $I1maxsec = 4.288$

Bearing in mind that the 50QR setting is in units of 3*I2

$\frac{'50QR}{3 \cdot I1maxsec} = 0.039$ Choose a value of $a2 := 0.08$

The proposed new setting of a2 is higher than the existing setting (0.04).

Phase time overcurrent element

This element is not used

Residual time overcurrent element

This element is used to provide the most sensitive backup protection. It will be a non directional element.

Set pickup to sense a higher resistance than 100 ohm SLG in the middle of the line with equal zero sequence current infeed from both ends. Choose a resistance of 200 ohms arbitrarily. Use a safety factor of 2 so that operating time is not infinity at this fault level.

$SF := 2$ Desensitization factor due to remote end infeed is $Dfactor := 2$ $Rf := 200$

$$'51NPU := \mathrm{round}\left(\frac{kVbase \cdot 1000}{\sqrt{3} \cdot SF \cdot Dfactor \cdot Rf \cdot CTR}, 1\right) \qquad '51NPU = 1.4$$

The existing setting of 0.8 A is more sensitive than required to sense this mid line fault with arbitrary resistance. Since TL206 experience with the high resistance tree fault on 28th August 2009 has shown value in the existing setting, it will be retained.

$'51NPU := 0.8$ A secondary

Coordination checks show that existing time dial settings will coordinate with each other. See Figures 8 and 9

$'51NPU = 0.8$ A secondary $'51NPU \cdot CTR = 96$ A primary

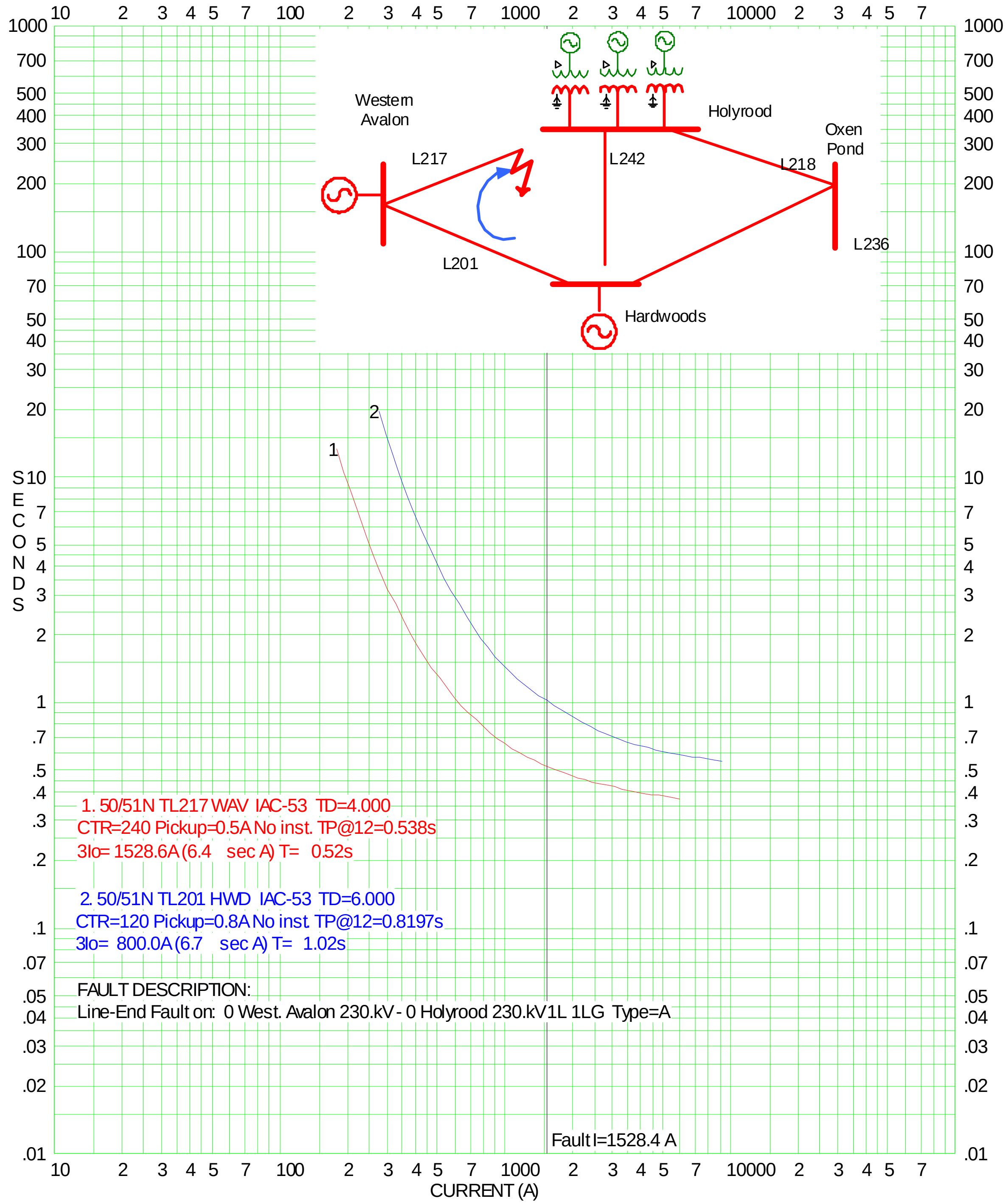
$'51NTD := 6$ $'51NC := "U3"$ $'51NTC := "N"$ $'51NRS := "N"$

Checks for close-in fault show that this element will not operate in less than 0.4 seconds so there is no danger of it tripping 3 pole before the zone 1 element trips the faulted phase selectively.

Check the coordination above the WAV TL217 51N line end fault on TL217. This is the type of fault that will produce the most sensitivity (least desensitization) with respect to the primary protection on TL217. see Figure 8. coordination margin is satisfactory.

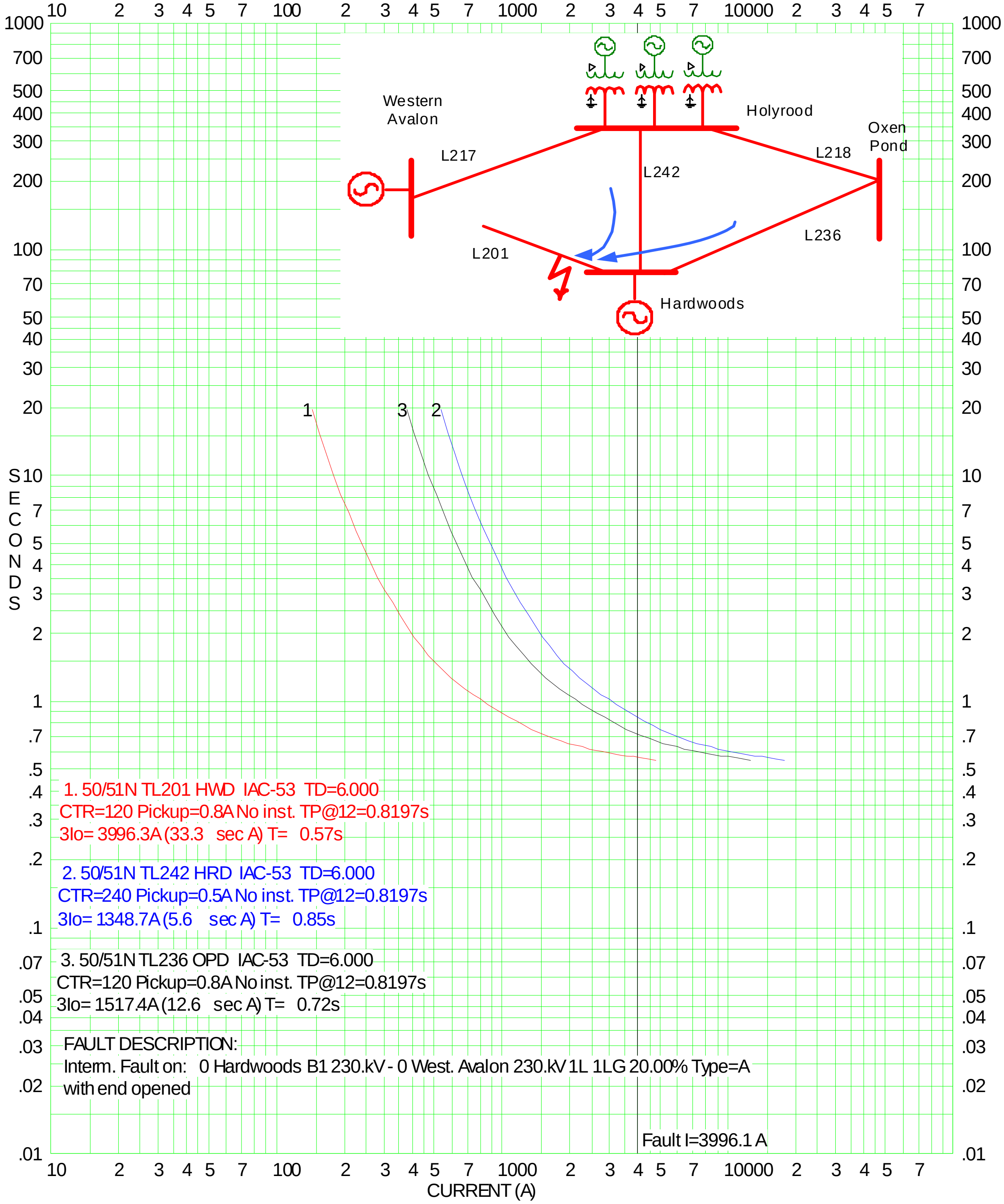
Check the coordination below the HRD TL242 and OPD TL236 protections for a TL201 fault at 20% of the distance to WAV. See Figure 9. It can be seen that the existing setting is not fast enough to coordinate satisfactorily below these two relays. It will be necessary to depend on the definite time ground distance protection functions to trip instantaneously or in zone 2 time to ensure the TL201 trips before backup protections can operate. The zone 1 and 2 ground distance functions at this terminal will be instantaneous and 0.3 seconds respectively; so will provide satisfactory coordination for low resistance faults.

Worst case load unbalance with single pole open will be in the future if single pole tripping is enabled with parallel line out of service. ASPEN OneLiner shows that with 280 MVA of load on this line (considerably more than existing maximum possible load), and with one phase open, the 3I0 current is approximately 480 A. The 51N relay with existing settings will take approximately 1.6 seconds to operate on 480 A primary. No danger of tripping on load unbalance during SPO time.



EC 230-1	TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For	Coordination of WAV TL217 Ground PN below HWD TL201	No. EC 230-1
Comment		Date 29 Sept 2011

Figure 8 - coordination of ground time overcurrent elements for Line end fault TL217



EC 230-2	TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For Coordination of HWD L201 Ground PN below HRD L242 & OPD L236		No. EC 230-2A
Comment		Date 7 Oct 2011

Figure 9 - coordination of ground time overcurrent elements for line end fault on TL242 close to HRD

Permissive Overreaching logic settings

EPOTT := "Y"

Z3RBD is set at remote breaker time plus channel reset time plus channel reset time plus zone 2 reset time. From review of fault records it appears that the breaker time is 3 cycles. Channel reset time is not easily determined from existing records but can conservatively be assumed to be 1 cycle, and relay reset time will also be about 1 cycle. Total time for Z3RBD is then 5 cycles.

Z3RBD := 5 cycles

Echo block delay timer blocks the echo after the local elements have picked up. This can be set relatively long since there is no significant need for the echo function shortly after the local terminal has just seen a fault but the remote terminal has not. Set at 10 cycles as per the example in the instruction manual.

EBLKD := 10 cycles

Echo time delay on pickup should be set to override noise on the communications so that it doesn't echo noise. Typical time according to the SEL application guide is 2 cycles. Since this delay only affects clearing time for relatively light (high resistance) faults that are sensed by zone 2 function at one end, the typical setting is acceptable.

ETDPU := 2 cycles

Echo duration should be long enough to ensure the permissive trip is received by the remote terminal and should also be shorter than the Z3RBD time to ensure that the reverse blocking will always be longer than any permissive trip received (including echo time stretching).

EDURD := 4 cycles

No need to enable week feed conversion to trip, since both terminals will be quite sensitive enough to detect high resistance faults after the remote terminal has cleared. Therefore we can accept sequential (or "step") clearing with no need for the added insecurity of weak infeed tripping.

EWFC := "N" **No other communications logic settings are required for this application.**

Switch on to Fault Settings

Switch on to fault logic will ensure the protection will operate when energizing the line onto a close-in three phase fault when there is no polarizing voltage available for the distance elements.

ESOTF := "Y"

The breaker close signal is not available to the relay. The 52A method of enable SOTF will be used. Therefore the Close end delay is not critical. Typical duration for enable SOTF is 10-15 cycles

ENCLO := "N" CLOEND := 0 EN52A := "Y" SOTFD := 15

Set 50H for high magnitude close-in multiphase faults with weakest source at HWD. It should be set less than 50% of the minimum close-in fault magnitude. Minimum close-in magnitude of a three phase fault with TL242 out of service is 2560 A. Therefore desired maximum setting for 50H is 1300 A.

Imin3P_close_in := 2560

$$'50H := \frac{Imin3P\_close\_in}{2CTR} \qquad '50H = 10.667 \quad \text{A secondary}$$

Choose a setting of 10 A secondary for this element. '50H := 10 A secondary

Choose a setting for 52AEND less than the shortest reclose time. '52AEND := 30 cycles

Existing setting is 55 cycles, which is longer than the reclose time. It is assumed this was to prevent operation on inrush. However 52AEND will not assert during the single pole open period only during three pole open. Therefore, no need to override the single pole open dead time.

Residual overcurrent settings.

Tripping directly by instantaneous ground overcurrent is not applicable because it is not phase selective. However it would be helpful to monitor steady state unbalance, and issue an alarm for continuous unbalance. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50N := 1$ $\quad$ $'50N1 := 0.25$

Negative Sequence overcurrent settings.

Similar to ground overcurrent, apply a negative sequence overcurrent element to initiate an alarm for steady state unbalances. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50Q := 1$ $\quad$ $'50Q1 := 0.25$

Voltage Element Settings

Similar to unbalance current monitoring, it is helpful to have an unbalance voltage monitor to detect steady state unbalances from the voltage supply.

$EVOLT := "Y"$

Set the zero sequence overvoltage element at 1% of rated voltage or just at the point necessary to override normal unbalances. The zero sequence voltage element measures 3 times the zero sequence voltage.

$$'59N := 3 \cdot 0.01 \frac{kVbase \cdot 1000}{\sqrt{3} \cdot VTR} \qquad '59N = 1.992 \qquad \text{Say} \quad '59N := 2 \quad \text{V secondary}$$

Loss of Potential

Enable loss of potential settings. Advanced LOP settings are not available on this model of relay.

$ELOP := "Y"$ $\quad$ Time delay of 1.25 cycles is commonly used. $\quad$ $LOPD := 1.25$

The 50 M element should be set above maximum load and below minimum fault current for a fault at the remote terminal under weak source conditions. The maximum load for this case should be normal maximum, not emergency maximum which only exists for a few minutes before the operator can act to reduce load.

$$Imax\_normal := \frac{Smax\_L201 \cdot 1000}{\sqrt{3} \cdot kVbase \cdot CTR} = 2.406 \text{ A secondary}$$

Minimum fault current for a remote three phase fault is $\quad I3Pmin = 672 \quad$ A primary.

Minimum fault current for a remote phase to phase fault is 87% of the minimum three phase fault current level.

Dependability factor to be sure to operate for a minimum remote fault is chosen to be 1.6. $\quad DF := 1.6$

Maximum setting for 50M should be $\dfrac{0.87I3Pmin}{DF \cdot CTR} = 3.045$ $\quad$ In this case a setting of 3.0 A secondary will be adequately dependable and secure.

$'50M := 3.0$ A secondary

The 59QL setting should be above normal maximum unbalance and below the level expected for a blown VT fuse. For a blown fuse, one phase voltage will be lost, and the negative sequence voltage will be roughly 33% of the nominal positive sequence voltage. Choose a setting of 15% of the nominal positive sequence voltage. This will be well above any normal unbalance.

$$'59QL := \mathrm{round}\left(\frac{0.15 \cdot kVbase \cdot 1000}{\sqrt{3} \cdot VTR}, 0\right)$$ $'59QL = 10$ V secondary

The 59PL setting should be less than the minimum voltage to be expected for a remote bus fault under weakest source conditions. There is no minimum setting (above zero) for this function. Choose a setting equal to half the voltage drop along the line impedance at the pickup setting of the 50M element.

$$'59PL := \mathrm{round}[0.5 \cdot ('50M \cdot |Z1Linesec|), 0]$$ $|'59PL| = 4$

Miscellaneous Scheme Settings

Pole discoordinance logic is not being used. EPOLD := "N" SPPDD := "N/A"

Enable single pole tripping by distance elements only ESPT := "Y"

Enable single pole open ESPO := "Y"

Set single pole open time delay for future SPO conditions SPOD := 0.25

Note that SPOD was short enough to allow a transient operation when the line was reclosed with a fault on it during the fault of 7 March 2011. This transient operation was helpful to clear the fault more quickly than it otherwise would have cleared. SEL have been asked whether the SPOD setting of 0.5 would be better to increase the security.

3 Pole open reset delay to override small discrepancies in pole closing '3POD := 0.5

Stub line protection is not required ESTUB := "N" '50MFD := "N/A"

Trip unlatch logic not applied TULO := "N"

Logic variables and Miscellaneous timers

Minimum trip duration timer is set at 9 cycles as per the application example in the SEL-321 instruction manual.

TDURD := 9 Cycles

Trip during open pole time delay should be set longer than the reclose time. Existing reclose time is 45 cycles. Existing setting is too marginal. This setting should be increased to 55 cycles.

TOPD := 55 Cycles

Existing logic variables are not used.

Add the use of ZT to trigger an alarm for sustained unbalance.

LOGIC_Z := "59N+50N1+50Q1" TZPU := 1200 cycles TZDO := 0 cycles

Tripping Logic

Permissive tripping is required only for instantaneous overreaching functions. No need for any functions that trip directly. Existing 51NT word in MTCS is not required.

MTCS := "M2P+Z2G"

Existing settings for unconditional tripping are good.

MTU := "M1P+Z1G+M2PT+Z2GT+51NT"

No need for existing direct tripping zone 1 functions in the switch on to fault logic.

SOTF Tripping MTO := "M2P+Z2G+50H"

Event records will be triggered automatically by all trip events. Other event record triggers should be by starting of other elements to ensure capture of all relevant events. Events should be triggered by keying or receiving permissive trips to ensure separation of relay and teleprotection issues.

MER := "M2P+Z2G+51NP+LOP*52AA1+LOP*52AA2+KEY+PT+EKEY"

Outputs

Retain existing output assignments except add the continuous unbalance alarm to OUT15.

OUT15 := "LOP*50L+ZT"

Input Contact Assignment

It would be desirable to provide phase segregated inputs to the relay so that the quadrilateral functions could be disabled during single pole open conditions. it is not known if phase segregated auxiliary switches are available on the breakers.

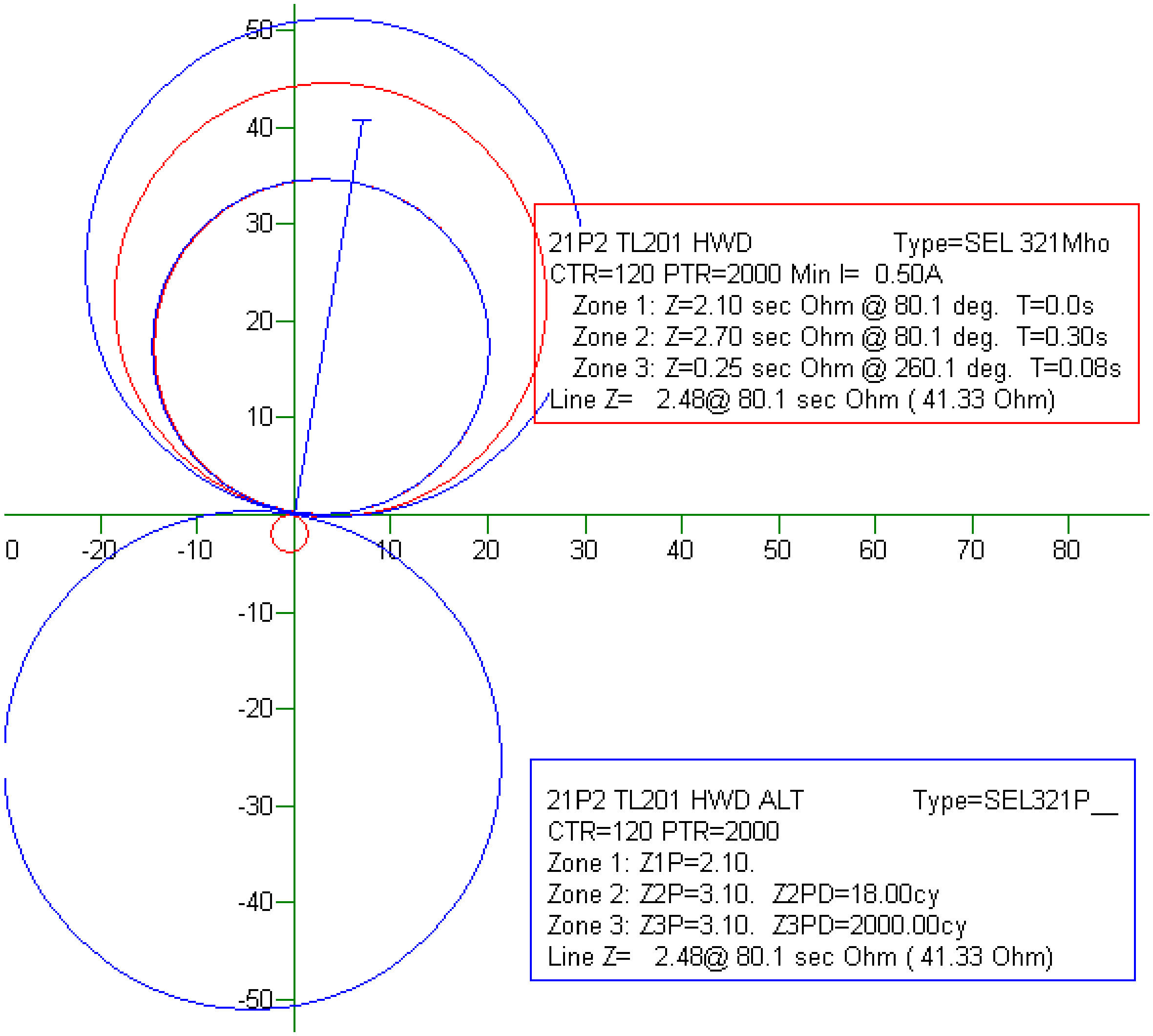


Figure 10 - Comparison between existing (red) and proposed new (blue) phase distance characteristics.

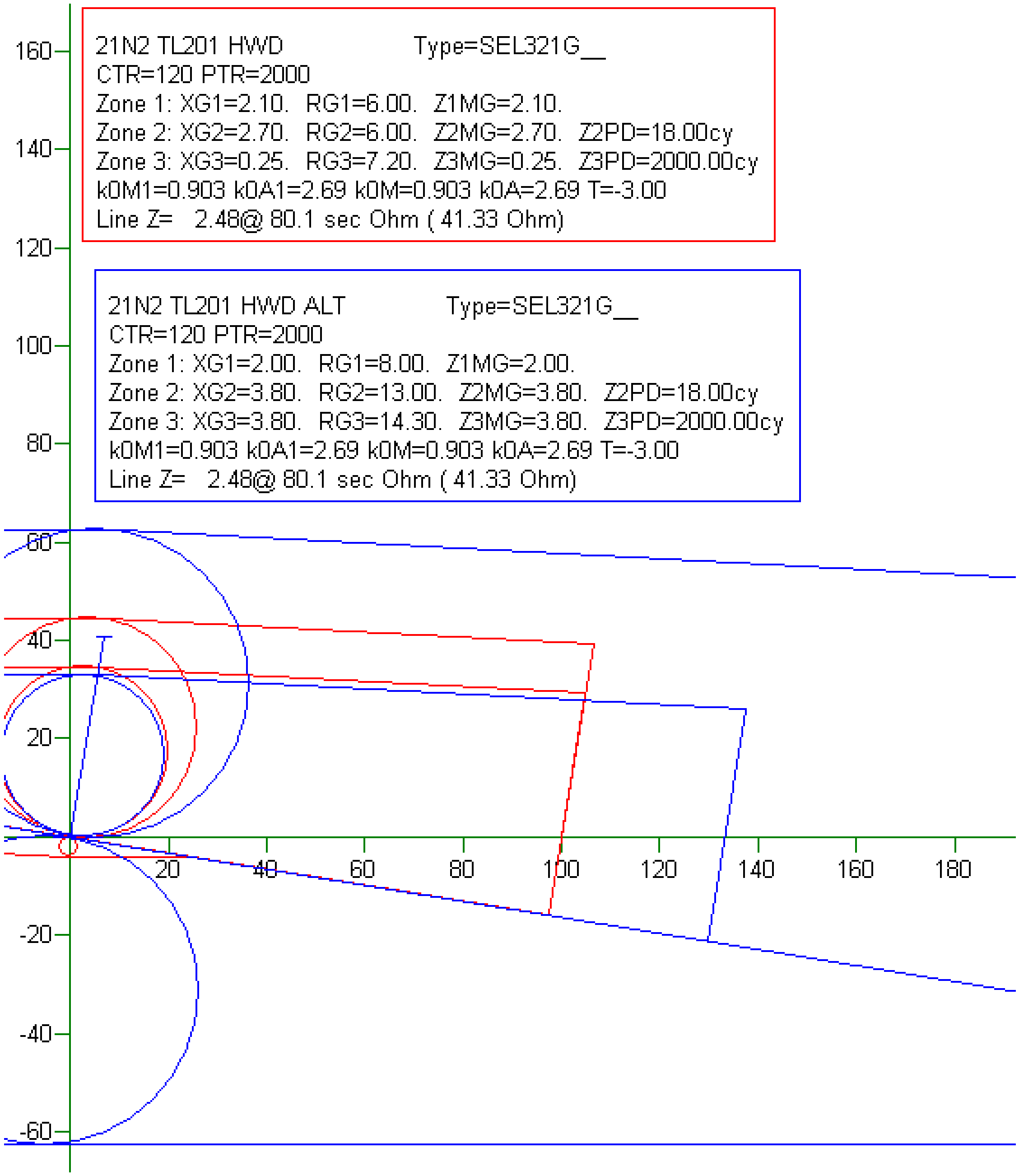


Figure 11 - Comparison between existing (red) and proposed new (blue) ground distance characteristics.

Protection Review for Five 230 kV Transmission Lines

Appendix H
Detailed settings review for WAV TL217 "P1" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador Hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Western Avalon Terminal (WAV) terminal of circuit TL217. This 230 kV transmission circuit is from WAV to Holyrood (HRD).
The circuit runs parallel to Circuit TL201 for most of its length.

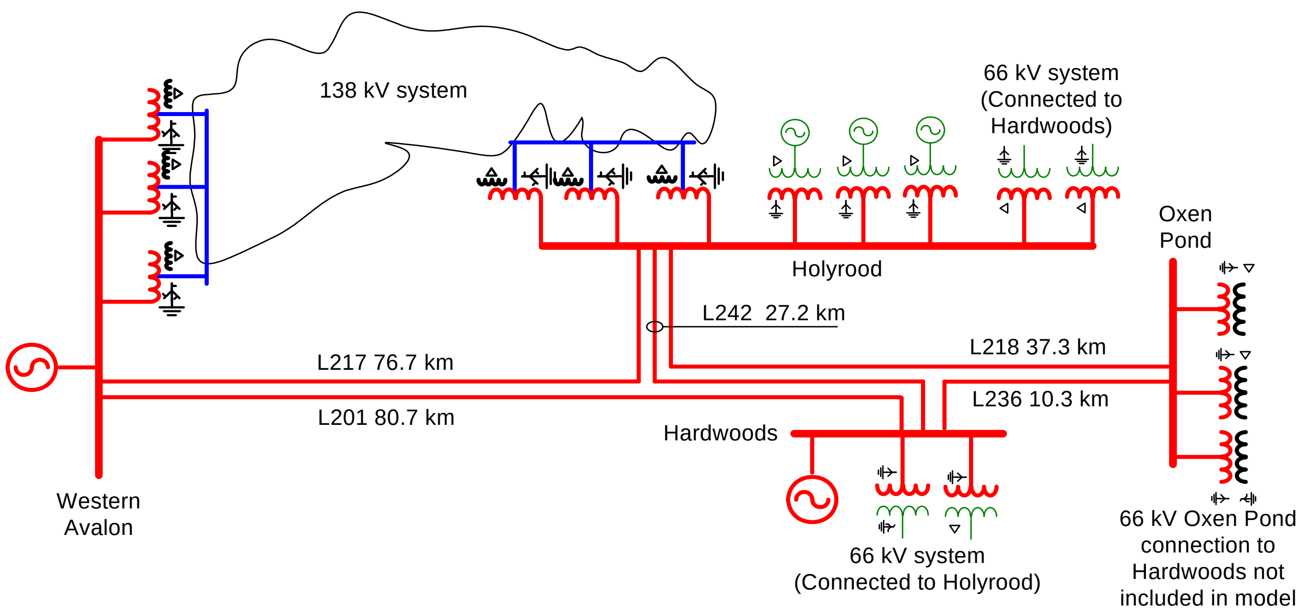


Figure 1 - System Single Line Diagram

Existing P1 protection systems are Areva LZFP111 (Optimho) systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $\quad$ $kVbase := 230$ $\quad$ $Ibase := \dfrac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\quad$ $Zbase := \dfrac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at the line terminal.

CT ratio is: $CTR := \dfrac{1200}{5}$ $\quad$ VT ratio is: $VTR := \dfrac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**NL HYDRO WITH MUTUALS FOR EAST COAST 230 kV LINE PN REVIEW.OLR**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with loads and shunts ignored.

Minimum fault current seen by each terminal (phase to phase, and SLG with 0 ohm fault resistance).

At WAV, with TL203 out of service, and both TL201 and TL217 in service, for a fault at the remote terminal.

$ILLmin := 650$ A $ISLGminPH := 745$ A $ISLGmin0seq := 211$ A

The optimho current level detectors that block the distance comparators in the event of line opening are fixed at 5% of the rated current, or 0.25 A secondary, or 60 A primary. They will have no difficulty in operating for minimum bolted fault levels. However, the ground distance elements are also supervised by a low set neutral current level detector (LDLSN that requires the neutral current to be greater than 10% of the maximum amplitude of phase difference current. This prevents the ground comparators from operating during close-in multiphase faults with CT errors. ASPEN OneLiner shows that for a bolted fault at the remote bus even under heavy load, there is sufficient neutral current (23% of maximum phase to phase fault current) that means this LDLSN function does not inhibit the ground distance comparator.

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind WAV $Z2minWAV := 3.6 + j \cdot 30.4$ ohms primary

Minimum source impedance behind HRD $Z2minHRD := 1.0 + j \cdot 22$ ohms primary

<u>Line impedances</u>.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L217 := 0.01077 + j \cdot 0.07231$ $Z0L217 := 0.03629 + j \cdot 0.2719$

$Z1Line := Z1L217 = 0.011 + 0.072j$ pu $Z0Line := Z0L217 = 0.036 + 0.272j$ pu

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line \cdot Zbase$ $Z0Linephys := Z0Line \cdot Zbase$

$Z1Linephys = 5.7 + 38.3i$ ohms primary $Z0Linephys = 19.2 + 143.8i$ ohms primary

Converting primary ohms to secondary ohms gives:

$Z1Linesec := Z1Linephys \cdot \frac{CTR}{VTR}$ $Z0Linesec := Z0Linephys \cdot \frac{CTR}{VTR}$

$|Z1Linesec| = 4.64$ ohms sec $\arg(Z1Linesec) = 81.5 \cdot deg$

$|Z0Linesec| = 17.413$ ohms sec $\arg(Z0Linesec) = 82.4 \cdot deg$

Load Data

From 2011 System summer load case provided in start up information, the peak load (sum of TL217 and TL217) is given as 205 MVA (split between TL217 and TL217). In the event of sudden loss of one line, peak load will be the sum of both line loads until operators can adjust loads. Therefore it is assumed that peak load for a short duration is 205 MVA

$Speak := 205$ MVA $Smax := Speak = 205$ MVA

P1 Relay Settings

Distance element reach settings

Note that resistive reaches are forced to be the same for all zones. Reactive reaches for phase and ground distance elements must be the same as each other.

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the HRD Station bus under light load conditions with one line from SSD to WAV out of service and both TL217 and TL217 lines in service. From ASPEN OneLiner, voltage at WAV for a 3 phase fault at HRD is 0.22 per unit. So there is plenty of voltage at WAV during a fault at HRD, even under weak source conditions.

Since the voltage is higher than 20%, the line is not considered short, and a conventional Zone 1 setting is acceptable.

$Z1P := 0.85 \cdot |Z1Linesec|$ $Z1P = 3.94$ Ohms secondary

Existing setting of 3.94 ohms is OK, and could be retained if only the phase distance functions had to be considered. However, the ground distance reach in the optimho has to be set the same as the phase distance reach; so we need to consider the ground faults too.

$Z1P = 3.94$ For phase faults only.

The worst case from the point of view of overreach of the zone 1 ground distance element is with TL242 out of service and grounded at both ends, and a close-in fault on TL218 with the Oxen Pond end open. For this case, the apparent impedance presented to the relay is only 4.11 ohms secondary (see Figure 2). This is 89% of the line impedance. So the reach of the zone 1 element should be reduced somewhat.

$Zapp\_ext := 4.11$ ohms $Zapp\_ang := 82.4deg$ This angle is close enough to the line angle to treat it as equal to the line angle.

$$\frac{Zapp\_ext}{|Z1Linesec|} = 0.886$$

The apparent impedance is reduced by about 11% mostly due to the effect of the parallel line being out of service and grounded at both ends but also partly due to the zero sequence current compensation factor being set slightly too high on this protection.

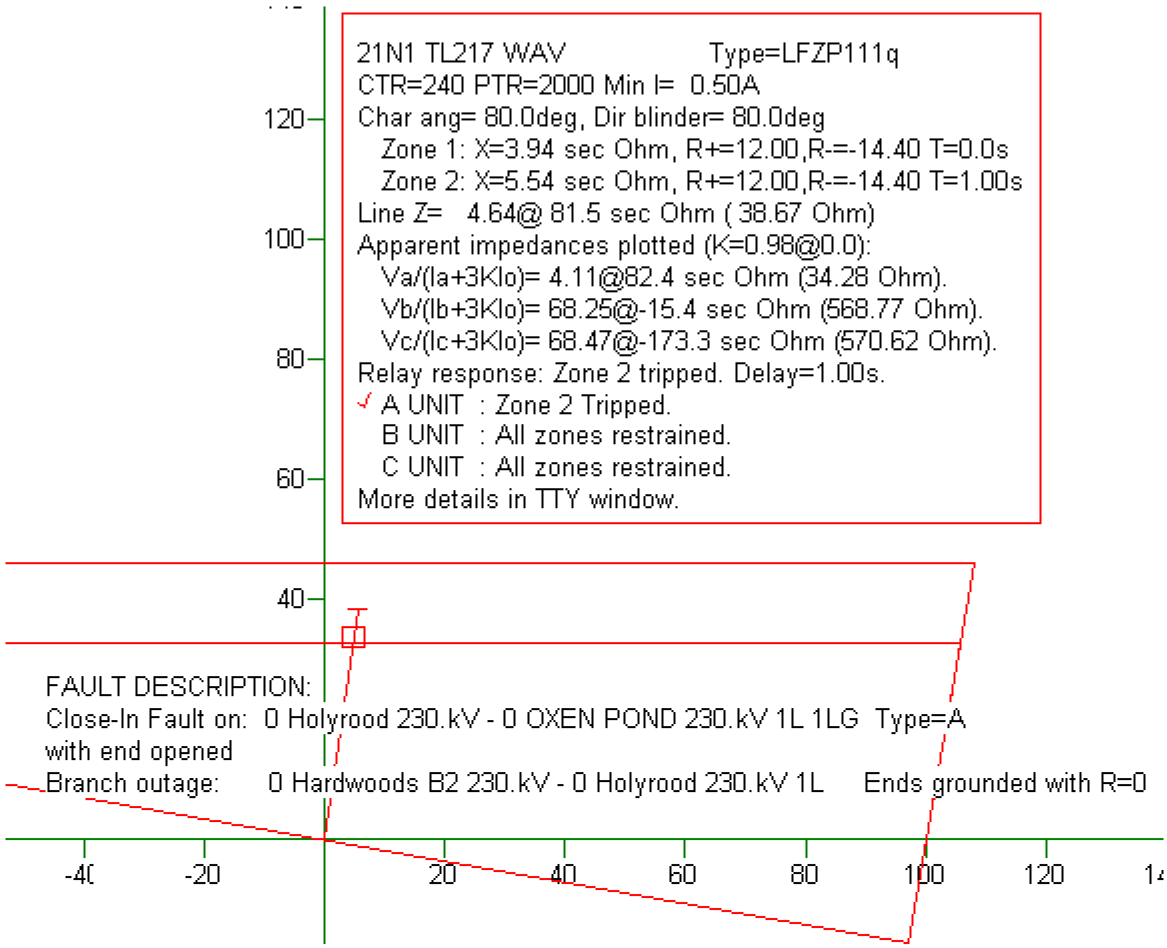


Figure 2 - Apparent impedance to a fault just beyond the remote terminal is reduced by 11% when TL242 line is out of service and grounded at both ends. Existing relay settings modeled in this figure.

The reach of the zone 1 ground distance element should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Choose a setting of 80% of line which will underreach the remote bus by 10% when the parallel line is out of service and grounded at both ends and when the zero sequence current compensation factor is reduced slightly.

Let the per unit reach of the Zone 1 function be m per unit of the line. $m := 0.8$ per unit

$Z1\_sec := \mathrm{round}(m \cdot |Z1Linesec|, 1)$ $Z1\_sec = 3.7$ Ohms secondary

$Z1pri := Z1\_sec \cdot \frac{VTR}{CTR} = 30.833$ Ohms primary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 5.54 ohms secondary (about 119%). However, in order to dependably reach a single line to ground fault at the remote terminal, it will be necessary to set the reach significantly further.

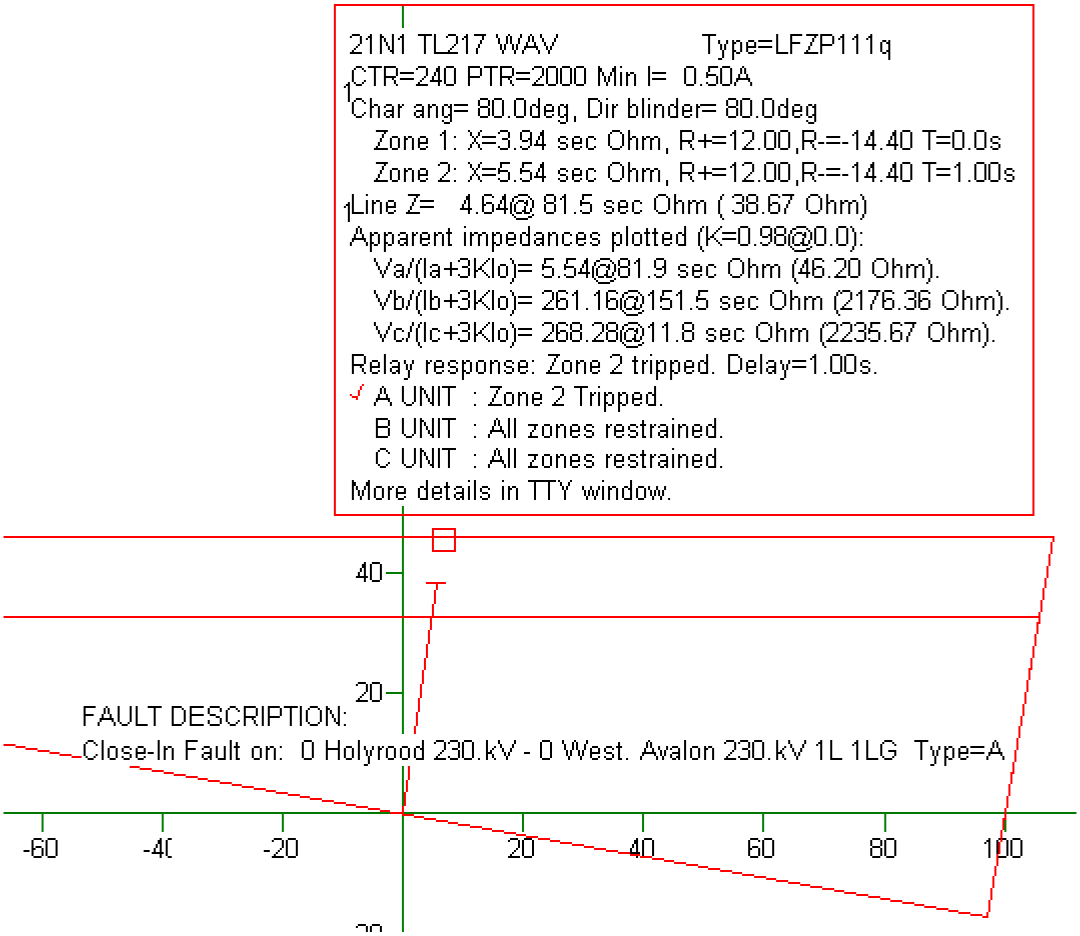


Figure 3 - Apparent impedance to a fault close to the remote terminal is increased by 20% when parallel line is in service.

As can be seen from Figure 3, the apparent impedance to a fault close to the remote terminal is increased when the parallel line is in service. Note that the zero sequence current compensation of the existing settings (shown in Figure 3) is higher than it should be. If the compensation was reduced, the apparent impedance would be outside the reach of the Zone 2 element instead of marginally within the reach.

$Zapp\_int := 5.54$ Ohms secondary

$Z2\_sec := 1.25 \cdot Zapp\_int$ $Z2\_sec = 6.9$ Ohms secondary $\frac{Z2\_sec}{|Z1Linesec|} = 149.218 \cdot \%$

$Z2\_pri := Z2\_sec \cdot \frac{VTR}{CTR} = 57.708$ Ohms primary

Even with this long reach setting, the zone 2 element will not overreach the shortest reaching zone 1 (TL242) out of Holyrood, even in the summer case when two units might be out of service at Holyrood.

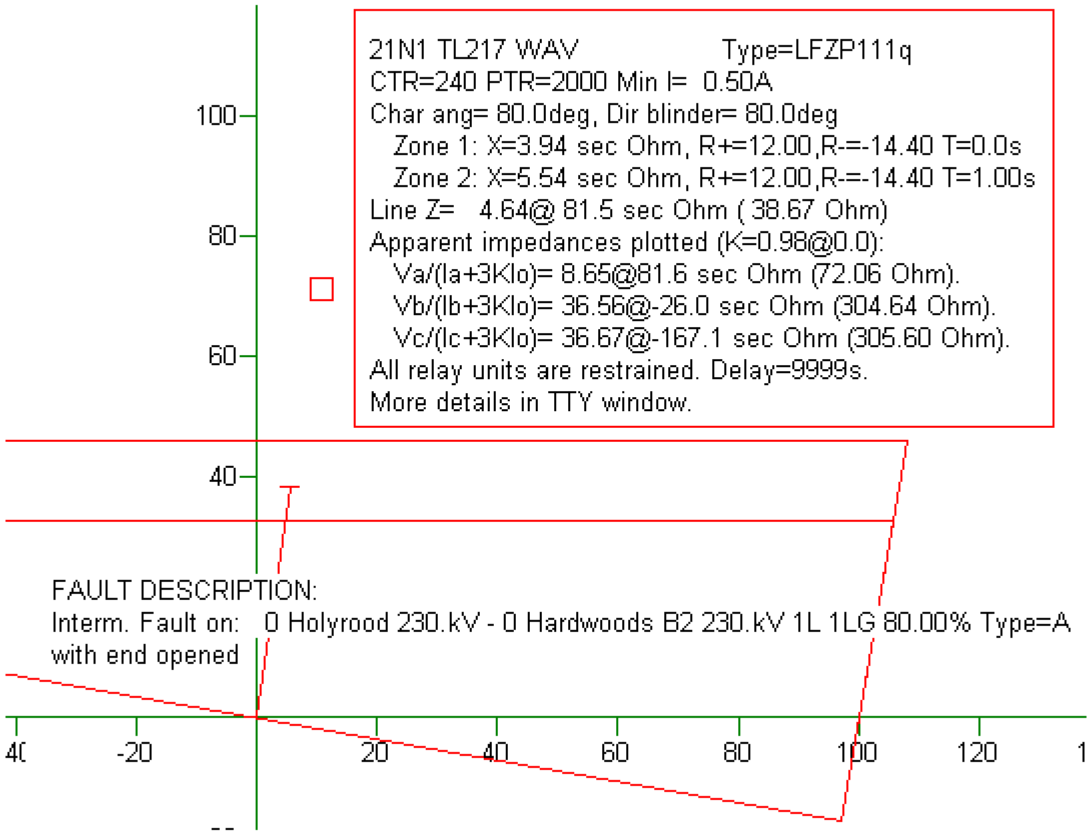


Figure 4 -High apparent impedance for 0 ohm SLG fault at 80% ofTL242 with remote terminal open and with two units at Holyrood out of service.

Due to the secure underreach of the shortest line out of Holyrood, conventional Zone 2 time (same as existing) will be applied even with this new, longer setting.

$Z2\_TD := 0.3$ Seconds

Load Encroachment logic

The optimho instruction manual recommends a margin of at least 10% between the impedance of the maximum load and the resistive reach of the quadrilateral distance element.

Check loadability of the Zone 2 phase distance element assuming worst case depressed voltage of a stressed system of 0.9 per unit.

$$Zloadmin := \frac{(0.9kVbase)^2}{Smax} \qquad Zloadmin = 209.02$$ Ohms primary (assume worst case at 30 degrees)

$$Zloadmin\_sec := Zloadmin \cdot \frac{CTR}{VTR} \qquad Zloadmin\_sec = 25.082$$

A 12 ohm secondary resistive reach is less than 90% of the load impedance at unity power factor and meets the Areva criterion as shown in Figure 5.

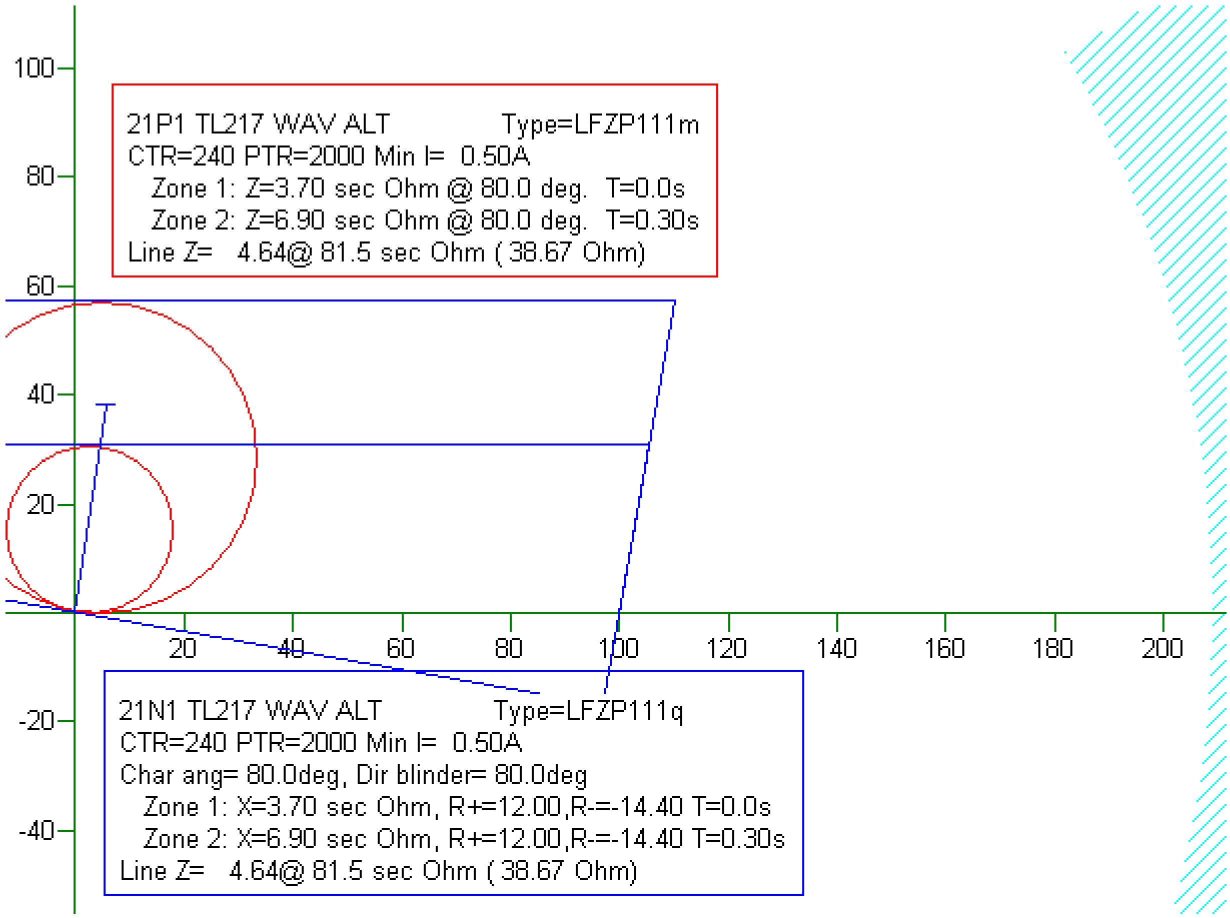


Figure 5 - Apparent impedance of load

Resistive reach of quadrilateral elements

Check the maximum fault resistance that can be sensed for a fault at a location where the current contribution from each terminal is roughly the same. From Figure 6, it can be seen that the limit of sensitivity (where quadrilateral elements at both ends can see a fault) is about 95 ohms, for a fault about 42% of the distance from WAV. This is close enough to the required sensitivity of 100 ohms. Note that the point of overlap of quadrilateral elements may move along the line depending on the strength of the source at either end, but they will always overlap somewhere. For resistive faults outside the overlapping zone, sequential clearing will have to be accepted.

Rquad := 12 Ohms secondary

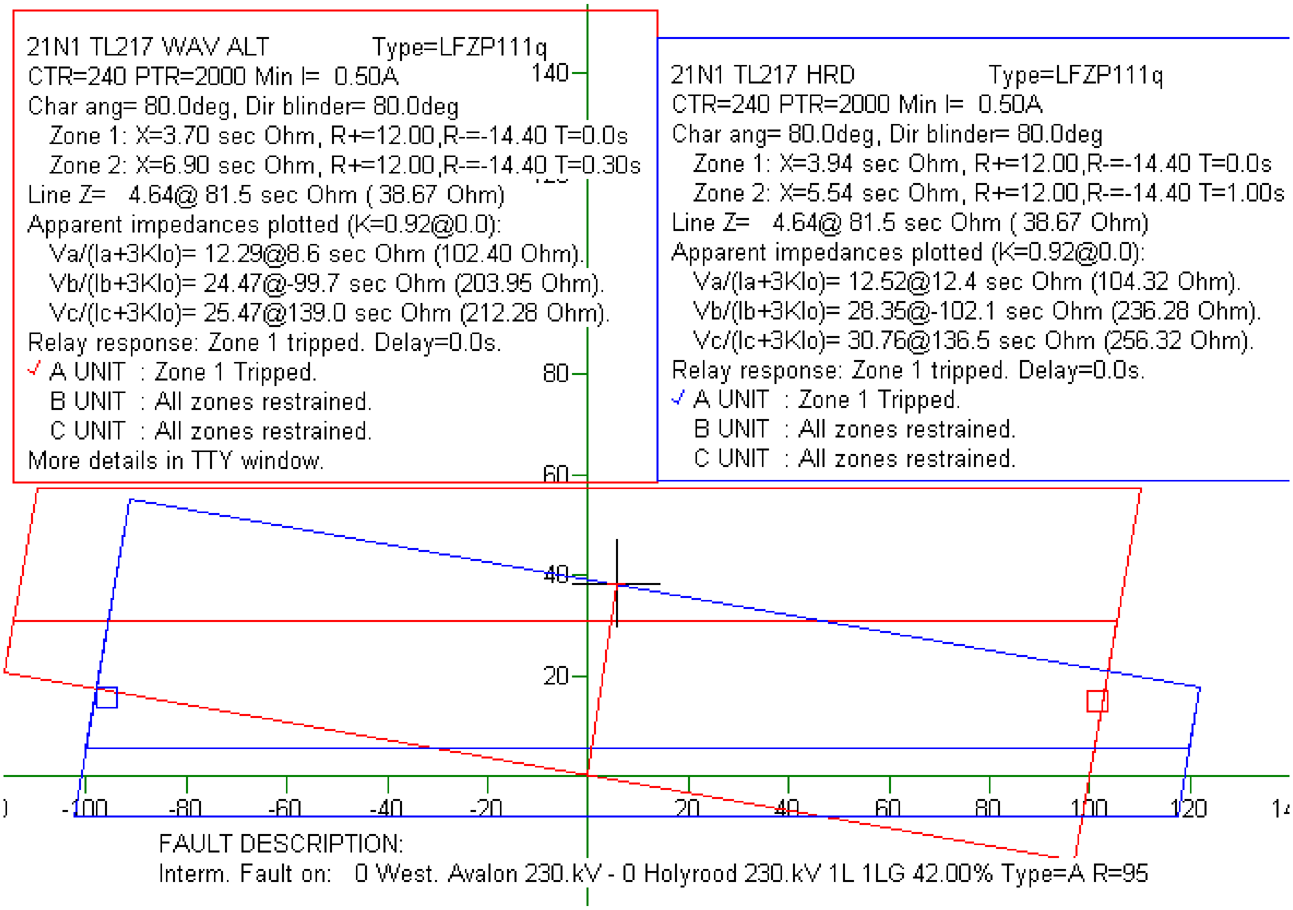


Figure 6 - Apparent impedance of a resistive fault near the mid point of the line.

Settings of K attenuators

KZPh Coarse setting common to all DISTANCE zones should be set as high as possible while below the required Zone 1 reach. The current level detectors vary inversely with KZph. Maximum setting available is 1.0

$KZPh := 1.0$

Zone 1 attenuators and angular selection

$In := 5$ $\quad Z1\_sec = 3.7$ This is the desired secondary reach (previously calculated)

$$KZ1 := \frac{Z1\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ1 = 3.7 \qquad Z1sec\_reach := KZ1 \cdot KZPh \cdot \frac{5}{In} \qquad Z1sec\_reach = 3.7$$

$Z\theta PH := (\arg(Z1Linesec))$ $\qquad Z\theta PH = 81.529 \cdot deg$

Rounded to the nearest 5 degrees $\qquad Z\theta PH := 80$ Degrees

$Z\theta N := \arg(Z0Linesec - Z1Linesec)$ $\qquad Z\theta N = 82.714 \cdot deg$

Rounded to the nearest 5 degrees $\qquad Z\theta N := 80$ Degrees

Zone 2 attenuators selection

$Z2\_sec = 6.9$ This is the desired secondary reach (previously calculated)

$$KZ2 := \frac{Z2\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ2 = 6.9$$

QUAD Resistive Reach setting

$Rquad = 12$ This is the desired secondary reach (previously calculated)

$$KR := \frac{Rquad}{\left(\frac{5}{In}\right)} \qquad KR = 12$$

Residual Compensation attenuators selection

Zero sequence current compensation for ground faults is provided by the KZN factor. Zero sequence mutual compensation is not used in this application (it causes extra complexity for only moderate gain in setting accuracy).

$$KZN := \frac{Z0Linesec - Z1Linesec}{3 \cdot Z1Linesec} \cdot KZPh \qquad KZN = 0.917 + 0.019j$$

$|KZN| = 0.917$ This is a reduction from the existing setting of 0.98

Switch On To Fault (SOTF) Protection.

If SOTF is enabled, it can be set to 200ms or 110 s after all poles of the line have been de-energized. The 110 s setting is intended to override automatic reclosing dead time. However it makes more sense to enable after the shorter time. Once the SOTF feature has been initiated, it remains in effect for 250ms after the line has been re-energized. The SOTF tripping options are:

a) Any distance comparator.
b) Any current level detector as long as a corresponding voltage level detector has not picked up within 20ms.
c) Either current or distance, as long as a corresponding voltage level detector has not picked up within 20ms.

SOTF := "Enabled"

SOTF_TIME := 0.20 Seconds

Elements_in_SOTF := "BOTH" (Both Comparators and current level detectors).

Power Swing Detector

This element will not be used. It will be left Blocked, and if there is a power swing, the distance elements will trip naturally.

VT Supervision

Set the VT supervision to BLOCK TRIP

Set the VT fail detection to SELF RESET.

Start Indication

This function will bring up information on the LCD screen of the relay if a start event occurs. This function will not be used.

START_INDICATION := "BLOCKED"

Communications assisted logic.

The existing communications assisted logic is permissive overreaching transfer trip, scheme **POR 1**. This scheme is familiar to Newfoundland and Labrador Hydro, and even though the POR 2 scheme offers the advantage of weak infeed echo, which would help the sensitivity to resistive faults, it is not recommended to change the existing scheme logic at this stage with years of experience on a product that is nearing the end of its useful life.

The POR 1 logic is a basic permissive overreaching transfer trip scheme but it does include current reversal timers to increase security against misoperation due to current reversal when a fault on the parallel line is cleared sequentially. The current reversal logic is achieved by a timer TP which will block permissive tripping and keying of permissive trip if the local zone 2 element does not pick up within a reasonable time of receiving permissive trip. The block will be maintained for a time delay of TD after the local zone 2 element picks up, or the received permissive trip signal resets.

The application of the current reversal timers is required only if the settings of the zone 2 comparators are greater than 1.5 times the line impedance .Although the reaches of these elements are only marginally less than 1.5 times the line impedance, there is no parallel line and there is infeed at each terminal that will minimize overreach. Therefore, the current reversal logic is not required, and the recommended default settings are as existing

$TP := 98$ ms

$TD := 0$ ms

Comparison of Existing (red) and Proposed alternative (ALT) settings.

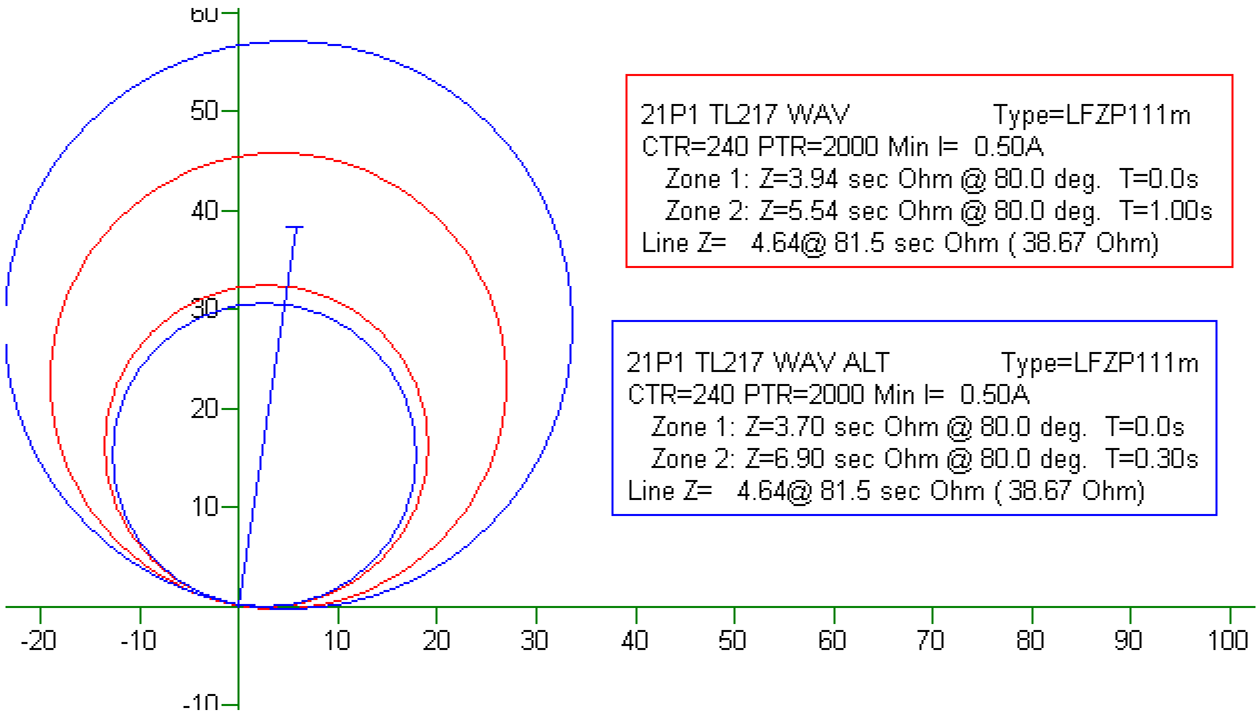


Figure 7 - Comparison of phase distance characteristics

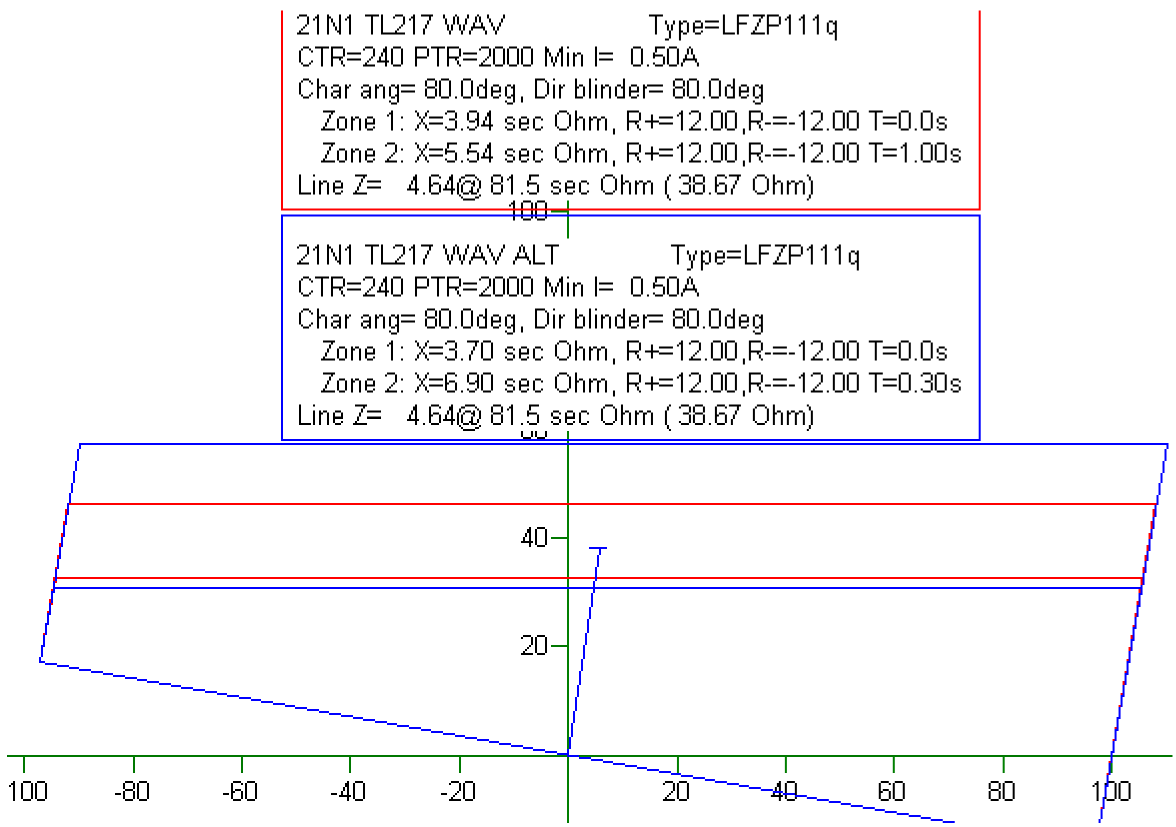


Figure 8 - Comparison of ground distance characteristics

Protection Review for Five 230 kV Transmission Lines

Appendix I
Detailed settings review for WAV TL217 "P2" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Western Avalon Terminal (WAV) terminal of circuit TL217. This 230 kV transmission circuit is from WAV to Holyrood (HRD).
The circuit runs parallel to Circuit TL201 for most of its length.

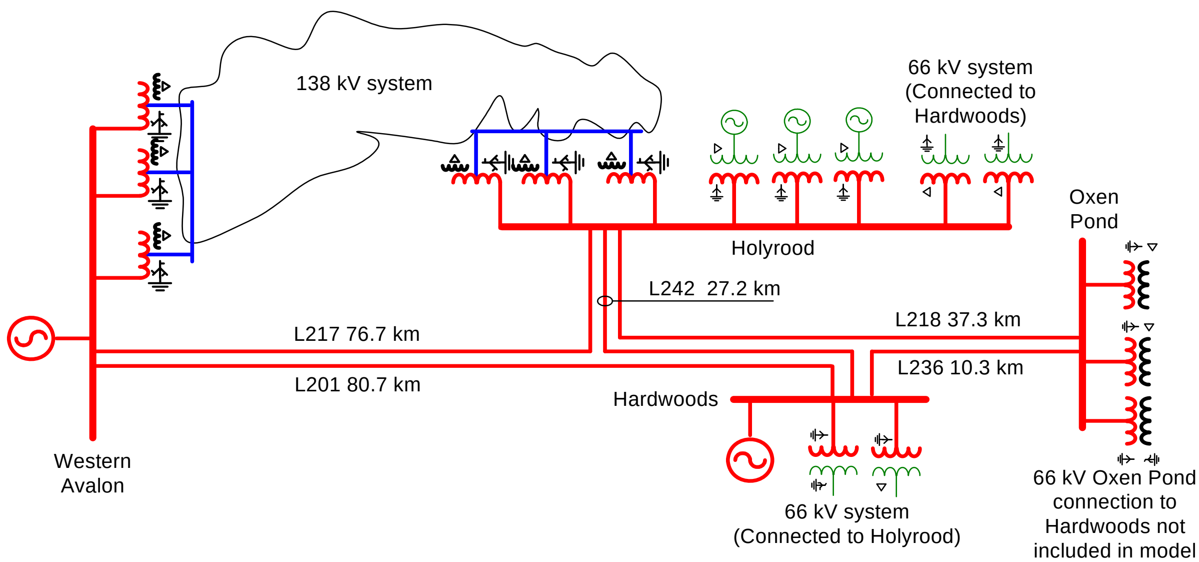


Figure 1 - System Single Line Diagram

Existing P2 protection systems are SEL321 systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$$\mathrm{MVAbase} := 100 \qquad \mathrm{kVbase} := 230 \qquad \mathrm{Ibase} := \frac{\mathrm{MVAbase}\cdot 1000}{\mathrm{kVbase}\cdot\sqrt{3}} \qquad \mathrm{Zbase} := \frac{\mathrm{kVbase}^2}{\mathrm{MVAbase}}$$

$$j := \sqrt{-1}$$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $\mathrm{CTR} := \frac{1200}{5}$ VT ratio is: $\mathrm{VTR} := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**NL HYDRO WITH MUTUALS FOR EAST COAST 230 kV LINE PN REVIEW.OLR**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with loads and shunts ignored.

Minimum fault current seen by each terminal (phase to phase, and SLG with 0 ohm fault resistance).

At WAV, with TL203 out of service, and both TL217 and TL201 in service, for a fault at the remote terminal.

$I3Pmin := 750$ A $ISLGminPH := 745$ A $ISLGmin0seq := 211$ A

The current for a phase to phase fault would be lower, but the current supervision element of the SEL321 measures phase to phase currents, and the phase to phase current for a phase to phase fault is twice the phase current.

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind WAV $Z2minWAV := 3.2 + j\cdot 29.3$ ohms primary

$Z0minWAV := 1.84 + j\cdot 24.5$ ohms primary

Minimum source impedance behind HRD $Z2minHRD := 1.0 + j\cdot 22$ ohms primary

$Z0minHRD := 0.38 + j\cdot 8.21$ ohms primary

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L217 := 0.01077 + j\cdot 0.07231$ $Z0L217 := 0.03629 + j\cdot 0.2719$

$Z1Line := Z1L217 = 0.011 + 0.072j$ pu $Z0Line := Z0L217 = 0.036 + 0.272j$ pu

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line\cdot Zbase$ $Z0Linephys := Z0Line\cdot Zbase$

$Z1Linephys = 5.7 + 38.3i$ ohms primary $Z0Linephys = 19.2 + 143.8i$ ohms primary

Converting primary ohms to secondary ohms gives:

$Z1Linesec := Z1Linephys\cdot \frac{CTR}{VTR}$ $Z0Linesec := Z0Linephys\cdot \frac{CTR}{VTR}$

$|Z1Linesec| = 4.64$ ohms sec $arg(Z1Linesec) = 81.5\cdot deg$

$|Z0Linesec| = 17.413$ ohms sec $arg(Z0Linesec) = 82.4\cdot deg$

Load Data

From 2011 System summer load case provided in start up information, the peak load (sum of TL217 and TL217) is given as 205 MVA (split between TL217 and TL217). In the event of sudden loss of one line, peak load will be the sum of both line loads until operators can adjust loads. Therefore it is assumed that peak load for a short duration is 205 MVA

$Speak := 205$ MVA $\quad$ $Smax := Speak = 205$ MVA

Max load in this line with TL201 in service is $\quad Smax\_L217 := 100$ MVA

P2 Relay Settings

Minor changes to the set line impedances are recommended to assist fault locations.

$Z1MAG := |Z1Linesec|$ $\quad$ $Z1MAG = 4.64$ $\quad$ $Z1ANG := \frac{arg(Z1Linesec)}{deg}$ $\quad$ $Z1ANG = 81.5$

$Z0MAG := |Z0Linesec|$ $\quad$ $Z0MAG = 17.4$ $\quad$ $Z0ANG := \frac{arg(Z0Linesec)}{deg}$ $\quad$ $Z0ANG = 82.4$

$LL := 76.63$

In order to obtain sensitivity to 100 ohm single line to ground faults, the echo function will be needed. Enable two forward and one reverse zone.

$PMHOZ := 3$ $\quad$ $GMHOZ := 3$ $\quad$ $QUADZ := 3$

$DIR1 := F$ $\quad$ $DIR2 := F$ $\quad$ $DIR3 := R$

Mho phase distance functions

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the HRD Station bus under light load conditions with one line from SSD to WAV out of service and both TL217 and TL217 lines in service. From ASPEN OneLiner, voltage at WAV for a 3 phase fault at HRD is 0.22 per unit. So there is plenty of voltage at WAV during a fault at HRD, even under weak source conditions.

Since the voltage is higher than 20%, the line is not considered short, and a conventional Zone 1 setting is acceptable.

$Z1P := 0.85 \cdot |Z1Linesec|$ $\quad$ $Z1P = 3.94$ Ohms secondary

Existing setting of 3.94 ohms is OK, and will be retained. $\quad Z1P = 3.94$ Ohms secondary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 5.54 ohms secondary (about 119%) and should be increased to 125%. This will give a more comfortable dependability margin.

$Z2P := 1.25 \cdot |Z1Linesec|$ $\quad$ $Z2P = 5.8$ Ohms secondary

As can be seen from Figure 2, this element significantly underreaches the zone 1 on TL242 (the shortest line out of HRD). Therefore there is no problem with increasing the setting and retaining normal zone 2 time.

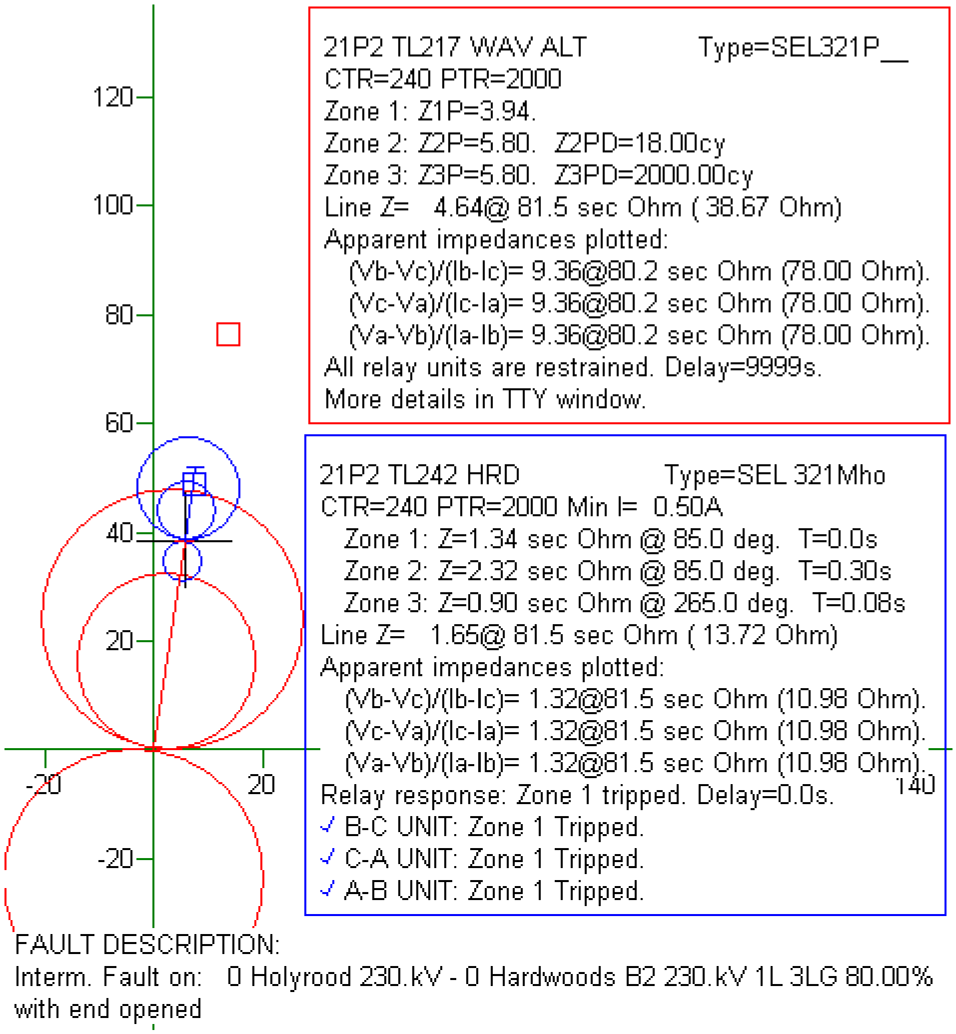


Figure 2 - Proposed new WAV TL217 Zone 2 securely underreaches HRD TL242 Zone 1 even without infeed. Normal zone 2 timing is secure for the Zone 2 function at WAV.

Because of secure coordination with the remote zone 1, the time delay on this element will be set to 0.3 second (as existing).

$Z2PD := 18$ Cycles

Zone 3

Set Zone 3 reverse element to reach further behind this terminal than the remote Zone 2. This function adds security for external faults. The element should always be more sensitive than the forward looking Zone 2 at the remote terminal. Due to the long overreach of the remote zone 2 ground distance element under some circumstances, set it the same as the remote Zone 2 using the line impedance as margin.

$Z3P := Z2P$ $\qquad$ $Z3P = 5.8$ Ohms secondary

$\frac{Z3P}{|Z1MAG|} = 125 \cdot \%$ of line length $\qquad$ This is a much higher than the existing setting, but provides additional security.

Mho phase distance current supervision

If the current supervision elements can be set above load, they will be secure in the event that potential is lost. However given that loss of potential logic is available, it is recommended that only the zone 1 current supervision function be set above load. If potential is lost, it will be able to block tripping by Zone 2 before it trips on time delay or receives a permissive trip from the remote terminal.

For the point of view of current supervision being above maximum load, there is no need to worry about abnormal conditions. It would be a double contingency for the VT signal to be lost while the parallel line was out of service. Therefore, consider a maximum load of 100 MVA (with TL201 in service). The current supervision elements for the phase distance functions measure phase to phase currents.

$$IPPmax\_normal := \frac{Smax\_L217 \cdot 1000}{kVbase} \qquad IPPmax\_normal = 435 \text{ A primary}$$

The current supervision elements use phase to phase currents for supervision of the phase distance functions; so the minimum phase to phase fault current will be root three times the minim phase fault current. Choose a margin of 50% of the minimum phase to phase fault current for dependability.

$$IPPmin := 0.5I3Pmin \cdot \sqrt{3} \qquad IPPmin = 650 \text{ A primary}$$

A setting of 480 A primary for 50PP1 will ensure the Zone 1 function operates for any fault even under minimum source conditions while remaining unable to trip on load due to loss of potential under any normal maximum load conditions. This is a little higher than the existing setting, but is quite dependable.

$'50PP1 := 2.0$ A Sec $\qquad '50PP1 \cdot CTR = 480$ A primary

Since Zone 2 and zone 3 elements will be blocked by LOP function, set them at minimum. For the zone 3, this is a little lower than the existing setting, but will enhance security of the echo function.

$'50PP2 := 1$ A Sec $\qquad '50PP3 := 1$ A Sec

Ground Distance Protection

The reach of the ground distance functions will be affected by mutual coupling to the parallel line. These functions will tend to underreach the remote bus while the parallel line is in service, and overreach the remote bus if a parallel line is out of service and grounded at both ends. Figure 3 shows that for a remote close in fault on TL236, with 2L242 out of service and grounded, the apparent impedance of the line is reduced to about 4.11 ohms secondary instead of the nominal 4.64 ohms. This is 88% of the actual line impedance.

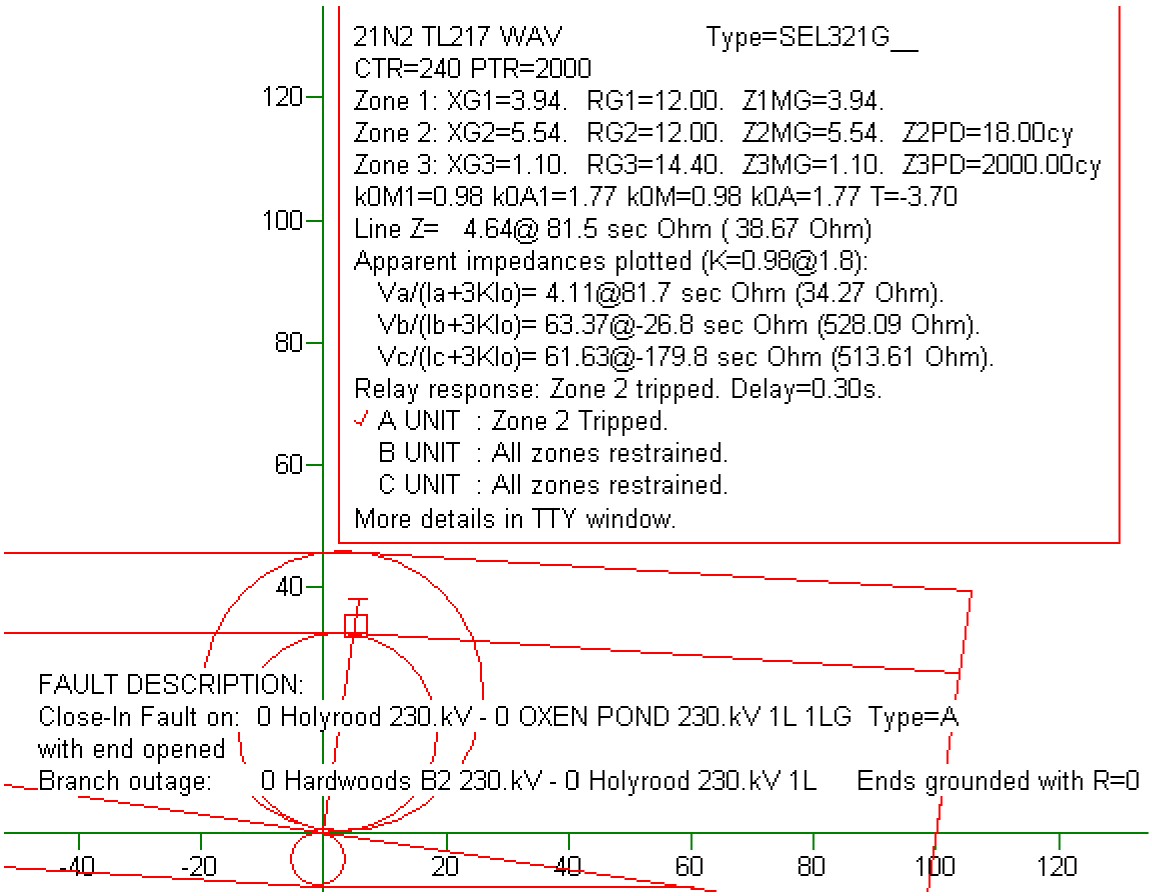


Figure 3 - Apparent impedance to a fault just beyond the remote terminal is reduced by 9% when parallel line is out of service and grounded at both ends.

The reach of the zone 1 should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Choose a setting of 80% of line which will underreach the remote bus by 11% when the parallel line is out of service and grounded at both ends.

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.8$ per unit

$Z1MG := \mathrm{round}(m \cdot |Z1Linesec|, 1)$ $Z1MG = 3.7$ Ohms secondary

$XG1 := Z1MG$ $XG1 = 3.7$ Ohms secondary

Zone 1 Resistance

The resistive reach of the Zone 1 quad should provide enough sensitivity to trip the local terminal immediately without waiting for permission from the remote terminal for a severe fault that depresses the voltage significantly. Further, it should not allow the function to reach beyond the remote terminal due to errors in relay measurement or CT or VT. In general, a reasonable limit for resistive reach of a zone 1 function is 4 times the reactive reach. If possible, it should operate for a 100 ohm SLG within 10% of the distance from the local terminal. Operation for a 100 ohm resistive fault at the 10% location will ensure this function can trip for a close in fault without assistance from the remote terminal. The remote terminal zone 2 function will be set to operate sequentially for this fault.

By simulating a fault with 100 ohms fault resistance at 10% of the distance from WAV, with the WAV terminal weak (TL203 out of service) it is found that a reach of 17 ohms secondary is required to sense this fault. See Figure 4

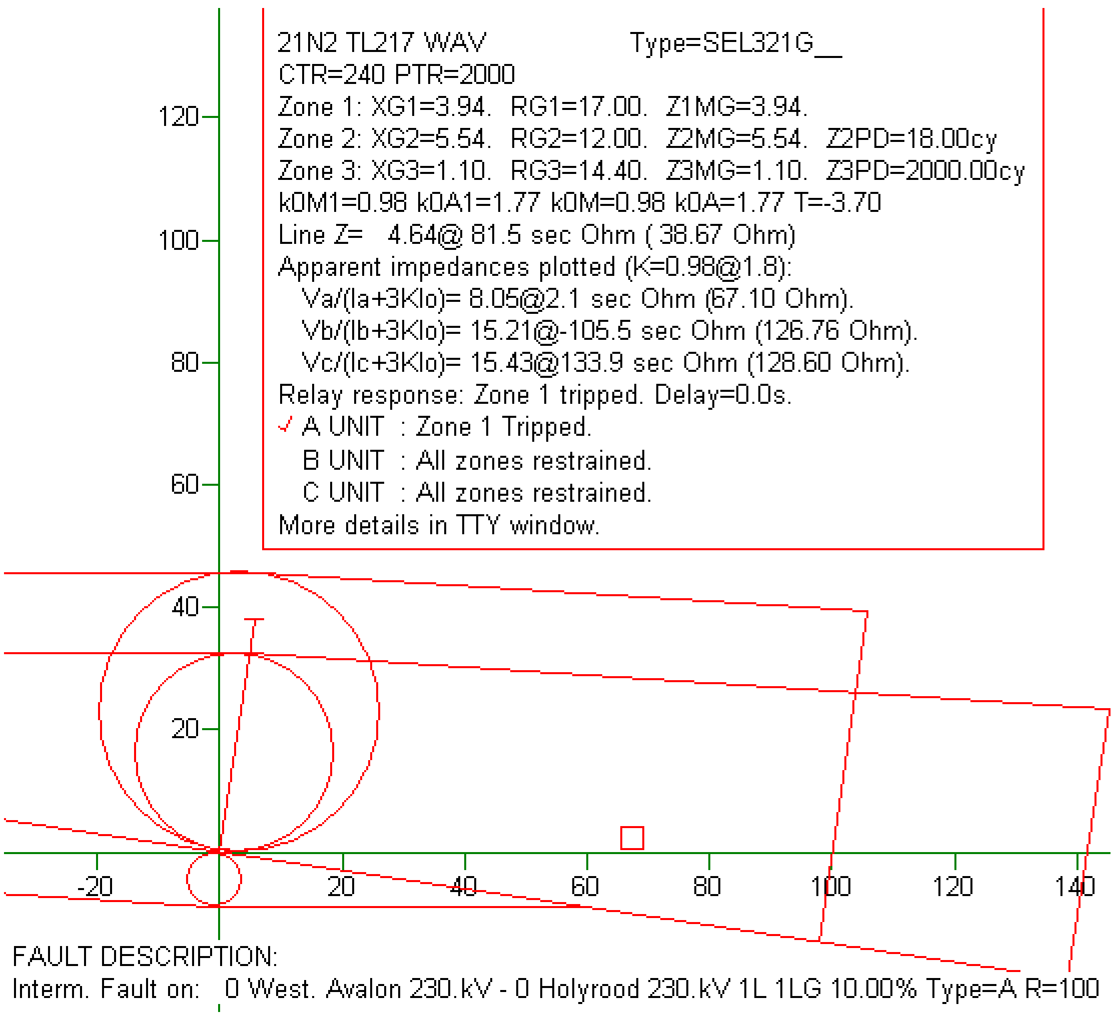


Figure 4 - WAV Zone 1 function if set with 17 ohm resistive reach, operates for a 100 ohm SLG fault at 10% from the local terminal.

The existing 12 ohm secondary resistive reach of the zone 1 element will not sense this fault, and should be increased to 17 ohms secondary. Check whether this reach will be secure, considering possible CT and VT errors.

XG1 is set at m per unit of the transmission line. The imaginary component of the line is

$ImXG1sec := Im(Z1Linesec)$ $ImXG1sec = 4.59$ ohms

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$RG1 := round[(1 - m) \cdot 20 \cdot ImXG1sec, 2]$

$RG1 = 18.36$ This is the maximum secure setting for the resistive reach and is above the proposed zone 1 resistive reach setting..

Use the proposed setting of 17 ohms for RG1 $RG1 := 17$ ohms secondary

With a resistive reach setting of 17 ohms, the WAV Zone 1 quad element will see an 60 ohm resistive SLG fault at 50% of the distance from WAV. Zone 2 protection will be depended upon to sense faults with resistance up to 100 ohms.

Zone 2 Ground Distance Protection

The Zone 2 ground distance function will need to be set longer than the Zone 2 phase distance protection function because it will tend to underreach the remote terminal while the parallel line is in service. By simulation in ASPEN OneLiner it is found that the apparent impedance to a zero ohm fault close in to the remote terminal is 5.48 ohms secondary, or 18% more than the actual line impedance. The reach of the Zone 2 ground distance element should be set at least to 1.25 times the apparent impedance.

$ZSLG\_remote := 5.48$

$Z2MG := round(1.25 \cdot ZSLG\_remote, 1)$ $Z2MG = 6.9$ Ohms secondary

The quad element reactive reach will be set similarly to the mho.

$XG2 := Z2MG$ $XG2 = 6.9$ Ohms secondary

It would be desirable to set the resistive reach of the quad element to sense a 100 ohm SLG fault at 75% of the line with the local terminal weak. This would ensure overlap with the zone 1element at the remote terminal. However, that would require too much resistive reach. Therefore choose a setting to sense a 100 ohm SLG fault just past the mid point of the line, and depend on the echo function to provide coverage for high resistance faults in the region where the remote zone 1 won't operate.

By trial and error from ASPEN it is found that a resistive reach of 25 ohms secondary will sense a 100 ohm SLG fault with an overlap with a similarly set remote zone 2 of 10% of the line length. See Figure 5. This will give positive overlap with the zone 2 element at the remote terminal. However since it will not overlap the Zone 1 element at the remote terminal, the permissive trip echo function will be required to ensure that a fault that is seen by the zone 2 element at only one terminal will still be cleared by the permissive trip logic.

Therefore, to avoid extremely large resistive reaches, and to retain sensitivity to 100 ohm resistive SLG faults, it is recommended that the echo function be enabled at both terminals.

$RG2 := 26$ Ohms secondary

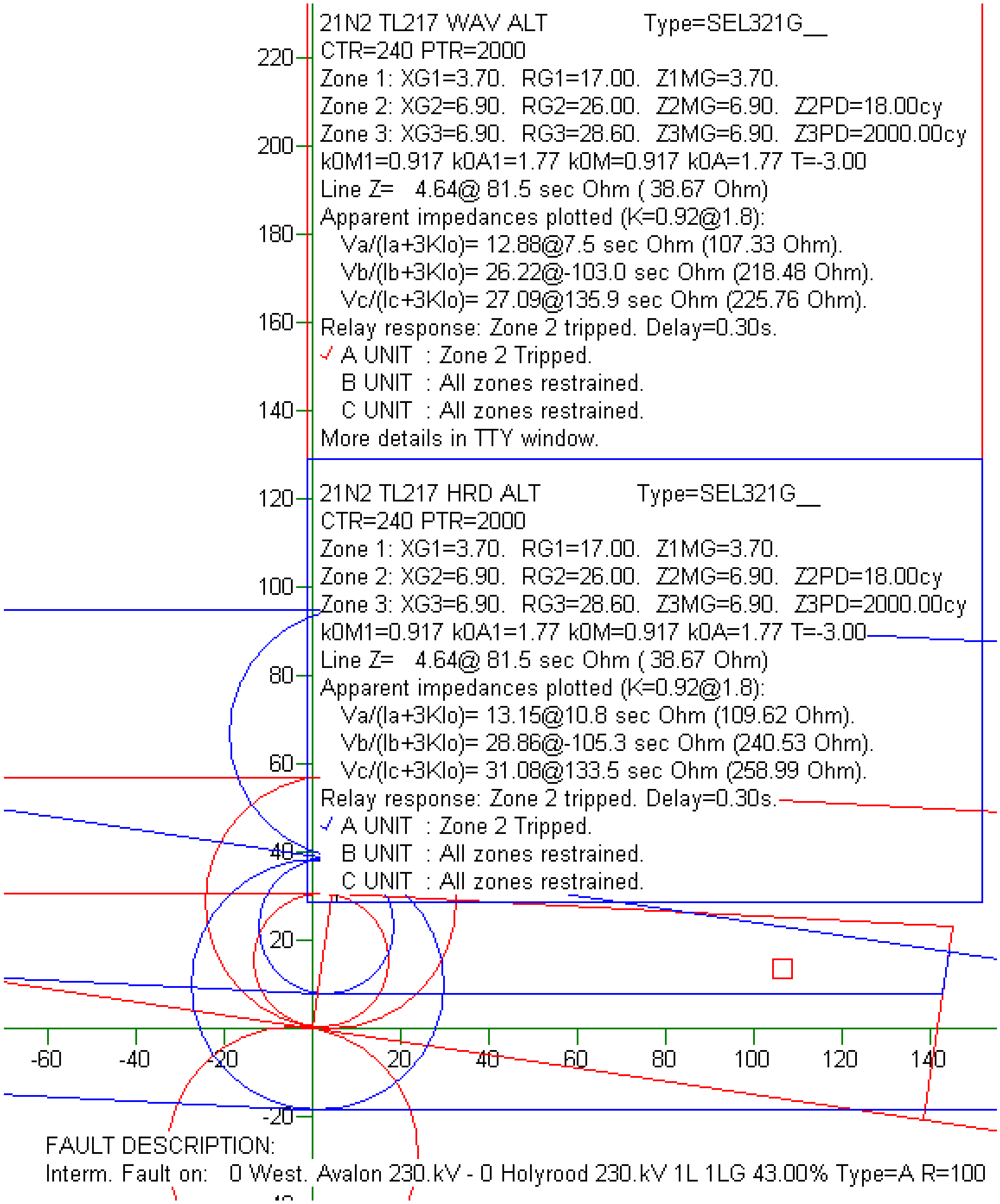


Figure 5 - Quad elements overlap with remote quad elements and operate for 100 ohm resistive SLG near the mid line location.

Check that this resistive reach won't cause the zone 2 function to trip while a parallel line is open single phase, with heavy power flow. See Figure 6. Unusually heavy power flow has been simulated to challenge security.

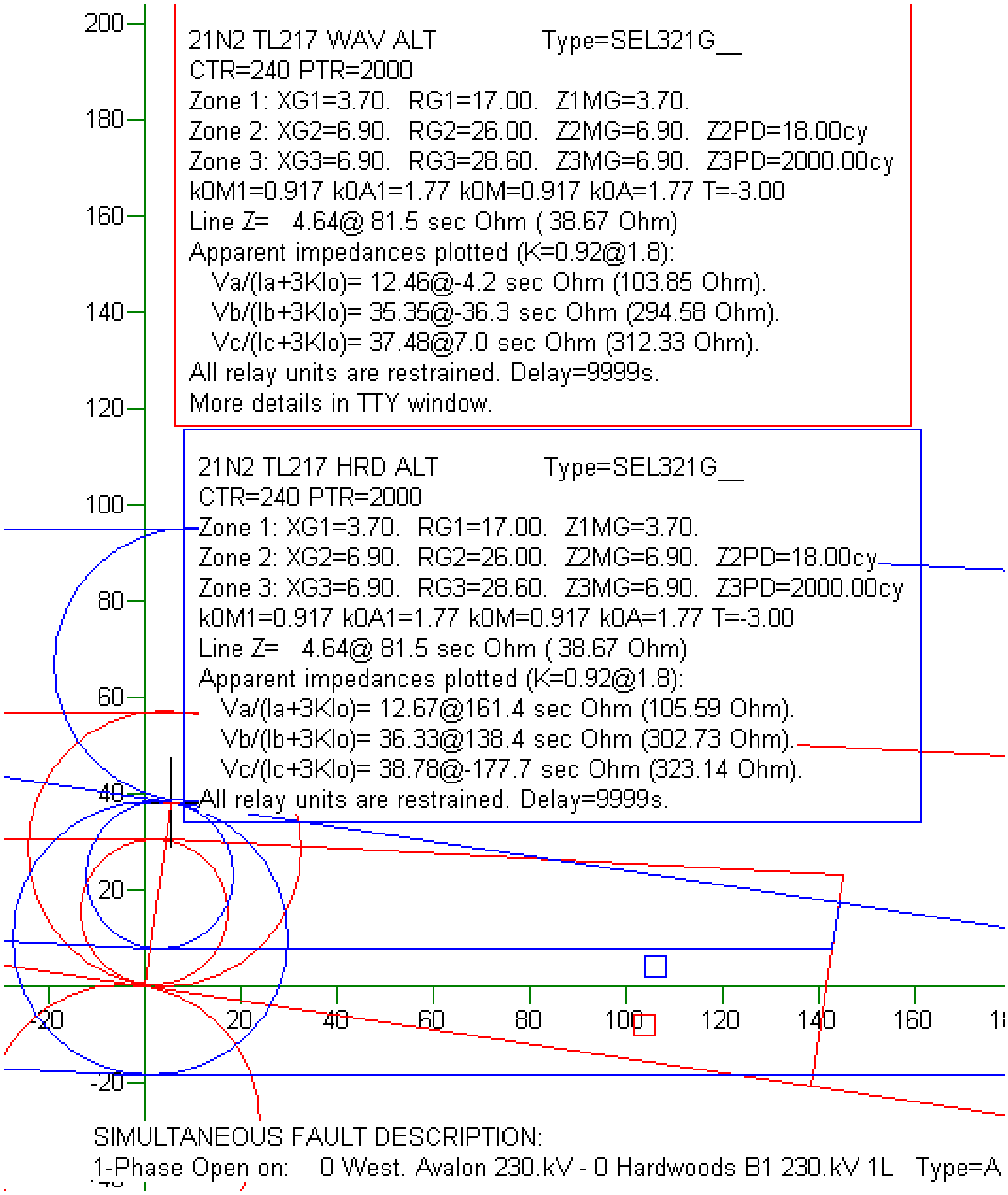


Figure 6 - Quad elements are secure with extremely heavy load flow (190 MVA in TL217 and 300 MVA in TL201) while TL201 is open single pole.

Zone 3

The zone 3 ground mho function will be set using the same principles as the zone 3 phase distance function. Use the setting for local zone 2 in secondary ohms as the remote zone 2.

$Z2MGrem := Z2MG$ ohms secondary

$Z3MG := Z2MGrem$ $Z3MG = 6.9$ Ohms secondary

$\frac{Z3MG}{|Z1MAG|} = 148.7 \cdot \%$ of line length This is much higher than the existing setting, but provides additional security.

$XG3 := Z3MG$ $XG3 = 6.9$ Ohms secondary

Set the Zone 3 quad resistive reach at 10% more than the remote Zone 2. Although the remote zone 2 has a different CT ratio, the setting is the same as the local zone 2 in primary ohms. Therefore use the setting for local zone 2 in secondary ohms as the remote zone 2.

$RG2rem := RG2$ Ohms secondary $RG3 := RG2rem \cdot 1.1$ $RG3 = 28.6$ Ohms secondary

Ground distance current supervision

Since there is no concern about these elements operating on load, even with loss of potential, set all current supervision elements at minimum, for maximum sensitivity of the distance elements.

$'50L1 := 0.5$ A Sec $'50L2 := 0.5$ A Sec $'50L3 := 0.5$ A Sec

$'50G1 := 0.5$ A Sec $'50G2 := 0.5$ A Sec $'50G3 := 0.5$ A Sec

Note that due to heavy infeed of zero sequence currents from the local terminal for close-in faults, the ground overcurrent detectors will not operate for faults with more than a small amount of resistance close to the remote terminal. Therefore, we will have to rely on sequential clearing for that type of fault. However setting the current supervision at minimum allows maximum sensitivity.

Zero sequence current compensation

The zero sequence current compensation could be adjusted to compensate for the significant amount of mutual coupling. However as discussed in the settings of reaches of the ground distance elements we will accept underreach of the Zone 2 function for the normal case by setting it at 125% of the apparent impedance for a remote fault. Set the zero sequence current compensation as usual.

$$k01M := \left(\left| \frac{Z0Line - Z1Line}{3 \cdot Z1Line} \right| \right) \qquad k01M = 0.917$$

$$k01A := \left(\arg\left(\frac{Z0Line - Z1Line}{3 \cdot Z1Line} \right) \right) \qquad k01A = 1.19 \cdot deg$$

Set the overreaching zones the same as zone 1 $k0M := k01M$ $k0A := k01A$

$k0M = 0.917$ $k0A = 1.19 \cdot deg$

Non Homogenous Angle Setting

Compare the angle of the remote zero sequence source impedance with the total zero sequence source impedance to the fault to determine this setting.

$$T := \arg\left(\frac{Z0minHRD + Z0Linephys + Z0minWAV}{Z0minHRD}\right) = -4.3\cdot deg \qquad T = -4\cdot deg$$

Out of step blocking and tripping

Not used in this application. There is a danger of out of step conditions arising. Historically no action has been taken to provide special tripping or blocking functions. Natural tripping during swings is accepted.

Load Encroachment logic

Check loadability of the Zone 2 phase distance element assuming worst case power factor of 0.87 simultaneous with worst case depressed voltage of a stressed system of 0.85 per unit. Note that units of kV squared match units of MVA. Note that quadrilateral elements are only used for the ground distance functions that are not sensitive to balanced three phase load. Therefore no need to worry about the reach of the quadrilateral elements.

$$Zloadmin := \frac{(0.85kVbase)^2}{Smax} \qquad Zloadmin = 186.44$$ Ohms primary (assume worst case at 30 degrees)

Maximum reach of the Zone 2 element is at the line angle of 81 degrees. At 30 degrees, the reach will be given by

$$Z2load := Z2P \cdot \cos[(Z1ANG - 30)deg] \qquad Z2load = 3.609$$ ohms secondary

$$Z2load \cdot \frac{VTR}{CTR} = 30.075$$ ohms primary

Since the reach of the Zone 2 element at 30 degrees is less than the apparent impedance of the maximum load, there is no need to apply load blinding logic. See Figure 7

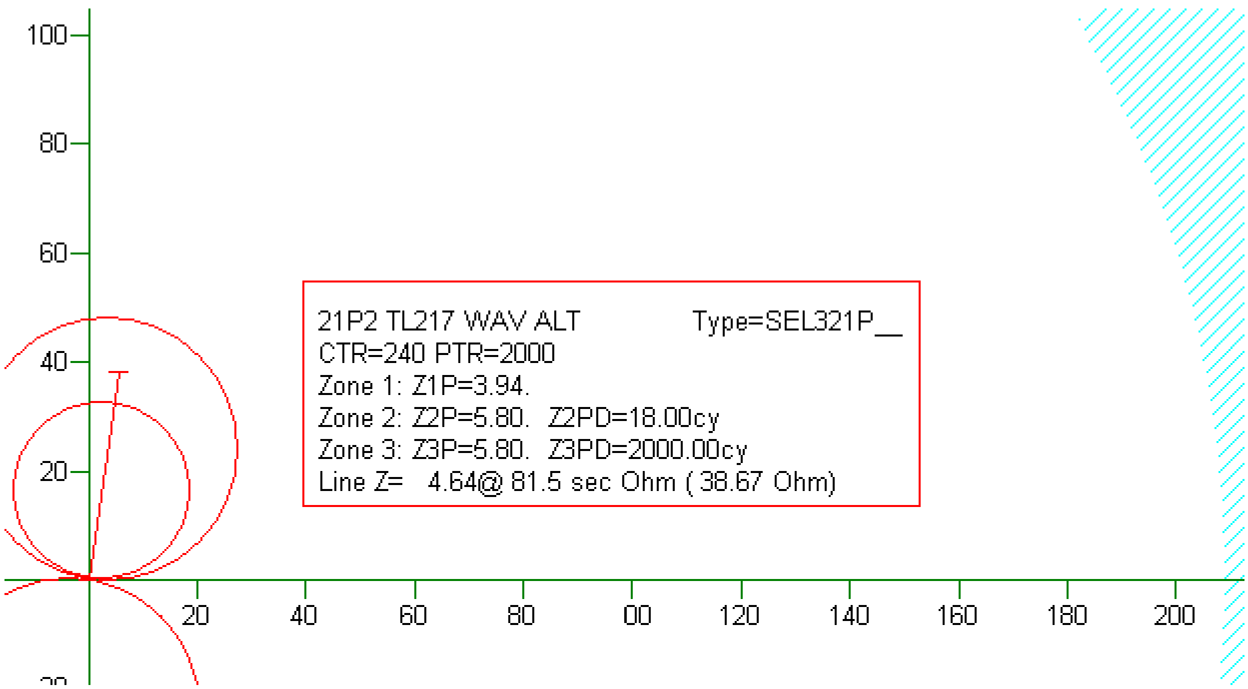


Figure 7 -Load impedance with respect to proposed new Mho function reaches.

Ground directional element

The SEL-321 application example recommends finding the minimum source impedance behind the terminal and setting the reverse and forward boundaries of the negative sequence directional element at the 1/3 and 2/3 points respectively.

In the negative sequence plane, the sum of the two source impedances and the line impedance is:

$$Z2total := Z2minWAV + Z1Linephys + Z2minHRD$$

The 1/3 point is $Z2\_1\_3 := \frac{Z2total}{3}$ The 2/3 point is $Z2\_2\_3 := \frac{2Z2total}{3}$

$Z2Rpri := Z2\_2\_3 - Z2minWAV$ $|Z2Rpri| = 30.591$

$Z2Fpri := Z2\_1\_3 - Z2minWAV$ $|Z2Fpri| = 0.56$

Converting the primary impedances to secondary ohms

$Z2R := Z2Rpri \cdot \frac{CTR}{VTR}$ $|Z2R| = 3.671$ Ohms secondary $arg(Z2R) = 83.622 \cdot deg$

$Z2F := Z2Fpri \cdot \frac{CTR}{VTR}$ $|Z2F| = 0.067$ Ohms secondary $arg(Z2F) = 79.797 \cdot deg$

Rounding up Z2F and rounding down Z2R gives:

$Z2F := 0.4$ Ohms secondary $Z2R := 4.3$ Ohms secondary

These are similar to the existing settings.

Set the current level detectors at minimum level that will allow operation of the ground distance elements.

Due to the very small zero sequence current contribution to a single line to ground fault at the remote terminal, the negative sequence current contribution will always be higher than the zero sequence. Therefore there is no point in setting the forward looking negative sequence overcurrent elements any more sensitively than the zero sequence ground overcurrent supervision of the ground distance elements.

$'50QF := '50G2$ $'50QF = 0.5$ A secondary

Set the supervision function for the reverse looking element to be the same as, or a little more sensitive than the forward looking supervision element at the remote terminal.

$'50QR := 0.5$ A secondary

The positive sequence current restraint (a2) factor should be set just smaller than the ratio of the maximum load current (positive sequence) to the most sensitive current supervision element (50QR).

$I1maxpri := \frac{Smax \cdot 1000}{kVbase \cdot \sqrt{3}}$ $I1maxsec := \frac{I1maxpri}{CTR}$ $I1maxsec = 2.144$

Bearing in mind that the 50QR setting is in units of 3*I2

$\frac{'50QR}{3 \cdot I1maxsec} = 0.078$ Choose a value of $a2 := 0.08$

The proposed new setting of a2 is a little higher than the existing setting (0.07).

Phase time overcurrent element

This element is not used

Residual time overcurrent element

This element is used to provide the most sensitive backup protection. It will be a non directional element.

Set pickup to sense a higher resistance than 100 ohm SLG in the middle of the line with equal zero sequence current infeed from both ends. Choose a resistance of 200 ohms arbitrarily. Use a safety factor of 2 so that operating time is not infinity at this fault level.

$SF := 2$ Desensitization factor due to remote end infeed is $Dfactor := 2$ $Rf := 200$

$$'51NPU := \mathrm{round}\left(\frac{kVbase \cdot 1000}{\sqrt{3} \cdot SF \cdot Dfactor \cdot Rf \cdot CTR}, 1\right) \qquad '51NPU = 0.7$$

The existing setting of 0.5 A is more sensitive than required to sense this mid line fault with arbitrary resistance. Since TL206 experience with the high resistance tree fault on 28th August 2009 has shown value in the existing setting, it will be retained.

$'51NPU := 0.5$ A secondary

Coordination checks show that existing time dial settings will coordinate with each other. See Figures 8 and 9

$'51NPU = 0.5$ A secondary $'51NPU \cdot CTR = 120$ A primary

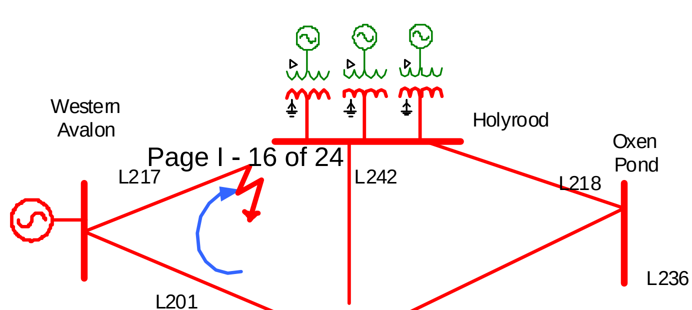
$'51NTD := 4$ $'51NC := "U3"$ $'51NTC := "N"$ $'51NRS := "N"$

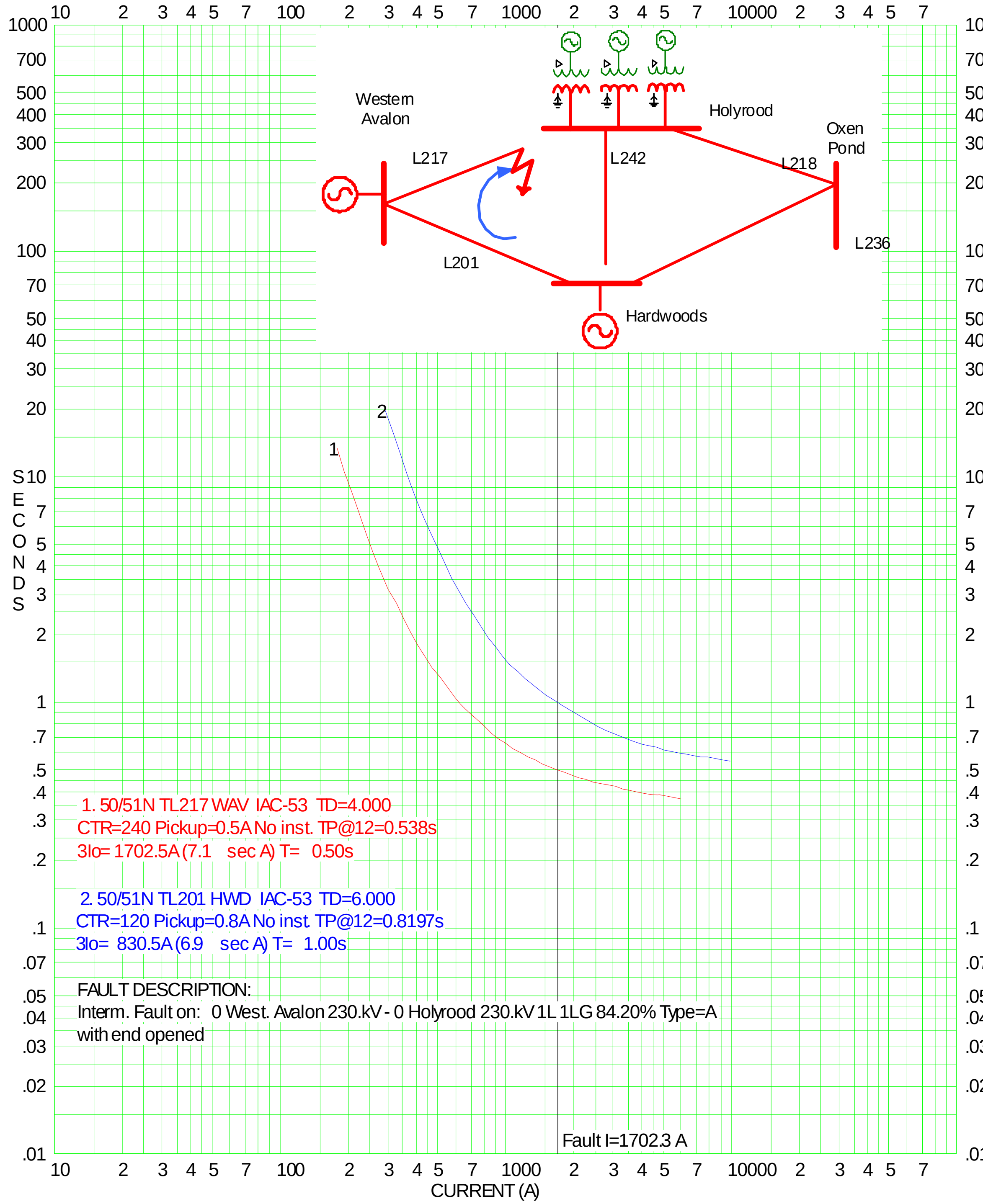
Checks for close-in fault show that this element will not operate in less than 0.39 seconds so there is no danger of it tripping 3 pole before the zone 1 element trips the faulted phase selectively.

Check the coordination below the HWD TL201 51N fault for a fault at 84% of TL217 (at the end of the mutually coupled section with TL201). This is the type of fault that will produce the most sensitivity (least desensitization) with respect to the backup protection on TL201. see Figure 8. Coordination margin is satisfactory.

Check the coordination above the HRD TL242 protection for a line end fault near HRD. See Figure 9. It can be seen that the existing setting coordinates well above the HRD TL242 protection.

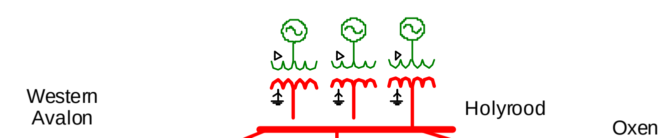
Worst case load unbalance with single pole open will be in the future if single pole tripping is enabled with parallel line out of service. ASPEN OneLiner shows that with 250 MVA of load on this line (considerably more than existing maximum possible load), and with one phase open, the 3I0 current is approximately 430 A. The 51N relay with existing settings will take approximately 1.6 seconds to operate on 430 A primary. No danger of tripping on load unbalance during SPO time.

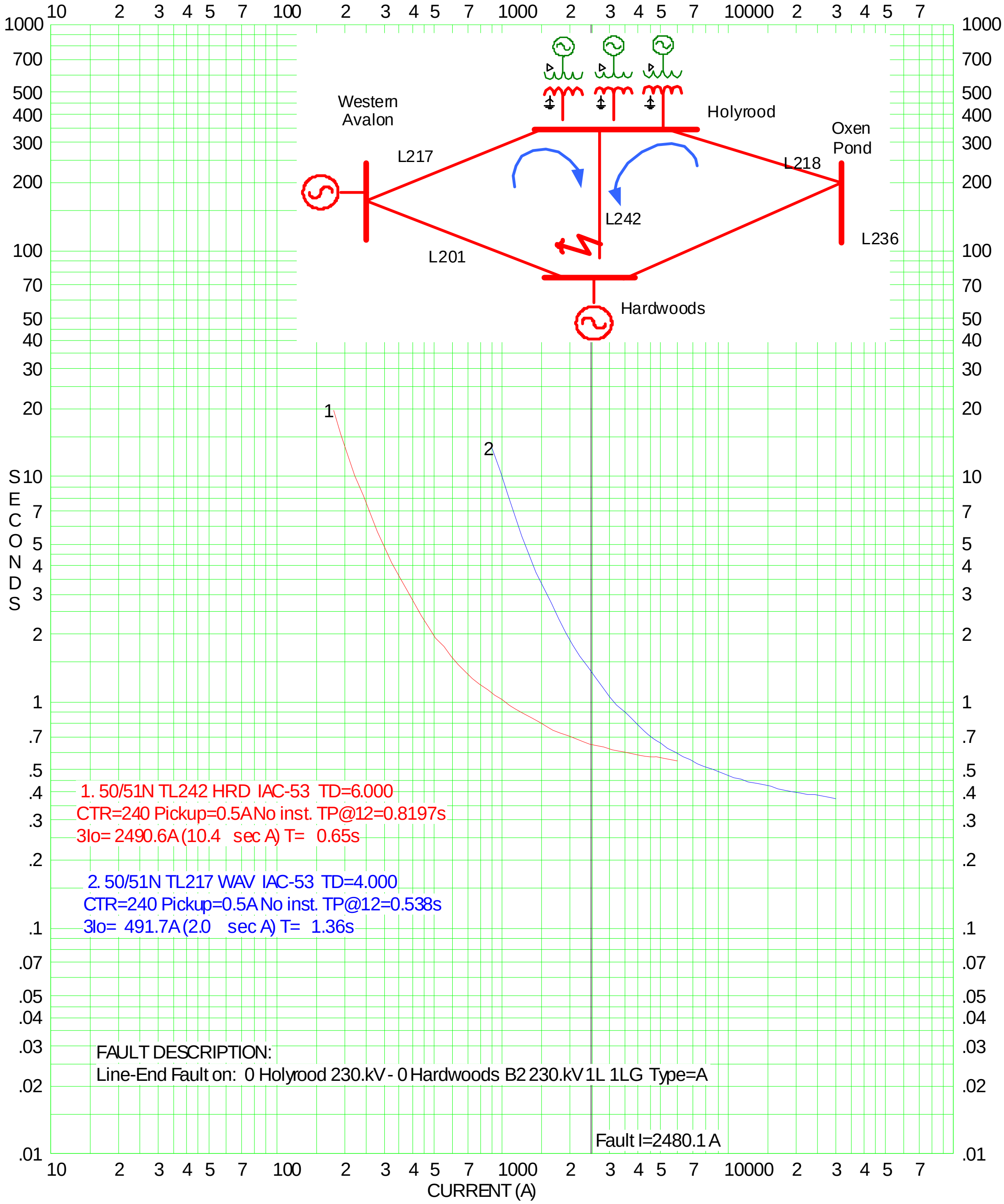




EC 230-1	TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For	Coordination of WAV TL217 Ground PN below HWD TL201	No. EC 230-1
Comment		Date 29 Sept 2011

Figure 8 - coordination of ground time overcurrent elements for fault at 84% TL217





EC 230-3	TIME-CURRENT CURVES @ Voltage 230 kV	By	C Henville
For	HRD L242 coordinates below WAV L217 and OPD L218	No.	EC 230-3
Comment	Two units at HRD offline (summer)	Date	29 Sept 2011

Figure 9 - coordination of ground time overcurrent elements for line end fault on TL242 close to HRD

Permissive Overreaching logic settings

EPOTT := "Y"

Z3RBD is set at remote breaker time plus channel reset time plus channel reset time plus zone 2 reset time. From review of fault records it appears that the breaker time is 3 cycles. Channel reset time is not easily determined from existing records but can conservatively be assumed to be 1 cycle, and relay reset time will also be about 1 cycle. Total time for Z3RBD is then 5 cycles.

Z3RBD := 5 cycles

Echo block delay timer blocks the echo after the local elements have picked up. This can be set relatively long since there is no significant need for the echo function shortly after the local terminal has just seen a fault but the remote terminal has not. Set at 10 cycles as per the example in the instruction manual.

EBLKD := 10 cycles

Echo time delay on pickup should be set to override noise on the communications so that it doesn't echo noise. Typical time according to the SEL application guide is 2 cycles. Since this delay only affects clearing time for relatively light (high resistance) faults that are sensed by zone 2 function at one end, the typical setting is acceptable.

ETDPU := 2 cycles

Echo duration should be long enough to ensure the permissive trip is received by the remote terminal and should also be shorter than the Z3RBD time to ensure that the reverse blocking will always be longer than any permissive trip received (including echo time stretching).

EDURD := 4 cycles

No need to enable week feed conversion to trip, since both terminals will be quite sensitive enough to detect high resistance faults after the remote terminal has cleared. Therefore we can accept sequential (or "step") clearing with no need for the added insecurity of weak infeed tripping.

EWFC := "N" **No other communications logic settings are required for this application.**

Switch on to Fault Settings

Switch on to fault logic will ensure the protection will operate when energizing the line onto a close-in three phase fault when there is no polarizing voltage available for the distance elements.

ESOTF := "Y"

The breaker close signal is not available to the relay. The 52A method of enable SOTF will be used. Therefore the Close end delay is not critical. Typical duration for enable SOTF is 10-15 cycles

ENCLO := "N" CLOEND := 0 EN52A := "Y" SOTFD := 15

Set 50H for high magnitude close-in multiphase faults with weakest source at WAV. It should be set less than 50% of the minimum close-in fault magnitude. Minimum close-in magnitude of a three phase fault with TL203 out of service is 3100 A. Therefore desired maximum setting for 50H is 1500 A.

Imin3P_close_in := 3100

$$'50H := \frac{Imin3P\_close\_in}{2CTR} \qquad '50H = 6.458 \quad \text{A secondary}$$

Choose a setting of 6 A secondary for this element. '50H := 6 A secondary

Choose a setting for 52AEND less than the shortest reclose time. '52AEND := 30 cycles

The existing setting of 52AEND is 60 cycles. it is not known why the setting is set longer than the reclosing time.

Residual overcurrent settings.

Tripping directly by instantaneous ground overcurrent is not applicable because it is not phase selective. However it would be helpful to monitor steady state unbalance, and issue an alarm for continuous unbalance. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50N := 1$ $\quad$ $'50N1 := 0.25$

Negative Sequence overcurrent settings.

Similar to ground overcurrent, apply a negative sequence overcurrent element to initiate an alarm for steady state unbalances. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50Q := 1$ $\quad$ $'50Q1 := 0.25$

Voltage Element Settings

Similar to unbalance current monitoring, it is helpful to have an unbalance voltage monitor to detect steady state unbalances from the voltage supply.

EVOLT := "Y"

Set the zero sequence overvoltage element at 1% of rated voltage or just at the point necessary to override normal unbalances. The zero sequence voltage element measures 3 times the zero sequence voltage.

$$'59N := 3 \cdot 0.01 \frac{kVbase \cdot 1000}{\sqrt{3} \cdot VTR} \qquad '59N = 1.992 \qquad \text{Say} \quad '59N := 2 \ \text{V secondary}$$

Loss of Potential

Enable loss of potential settings. Advanced LOP settings are not available on this model of relay.

ELOP := "Y" $\quad$ Time delay of 1.25 cycles is commonly used. $\quad$ $LOPD := 1.25$

The 50 M element should be set above maximum load and below minimum fault current for a fault at the remote terminal under weak source conditions. The maximum load for this case should be normal maximum, not emergency maximum which only exists for a few minutes before the operator can act to reduce load.

$$Imax\_normal := \frac{Smax\_L217 \cdot 1000}{\sqrt{3} \cdot kVbase \cdot CTR} = 1.046 \ \text{A secondary}$$

Minimum fault current for a remote three phase fault is $I3Pmin = 750$ A primary.

Minimum fault current for a remote phase to phase fault is 87% of the minimum three phase fault current level.

Dependability factor to be sure to operate for a minimum remote fault is chosen to be 1.6. $\quad DF := 1.6$

Maximum setting for 50M should be $\frac{0.87 I3Pmin}{DF \cdot CTR} = 1.699$ $\quad$ In this case a setting of 1.7 A secondary will be adequately dependable and secure.

$'50M := 1.7$ A secondary

The 59QL setting should be above normal maximum unbalance and below the level expected for a blown VT fuse. For a blown fuse, one phase voltage will be lost, and the negative sequence voltage will be roughly 33% of the nominal positive sequence voltage. Choose a setting of 15% of the nominal positive sequence voltage. This will be well above any normal unbalance.

$$'59QL := \mathrm{round}\left(\frac{0.15\cdot kVbase\cdot 1000}{\sqrt{3}\cdot VTR},0\right)$$ $'59QL = 10$ V secondary

The 59PL setting should be less than the minimum voltage to be expected for a remote bus fault under weakest source conditions. There is no minimum setting (above zero) for this function. Choose a setting equal to half the voltage drop along the line impedance at the pickup setting of the 50M element.

$$'59PL := \mathrm{round}[0.5\cdot('50M\cdot|Z1Linesec|),0]$$ $|'59PL| = 4$

Miscellaneous Scheme Settings

Pole discoordinance logic is not being used. EPOLD := "N" SPPDD := "N/A"

Enable single pole tripping by distance elements only ESPT := "Y"

Enable single pole open ESPO := "Y"

Set single pole open time delay for future SPO conditions SPOD := 0.25

Note that SPOD was short enough to allow a transient operation when TL201 was reclosed with a fault on it during the fault of 7 March 2011. This transient operation was helpful to clear the fault more quickly than it otherwise would have cleared. SEL have been asked whether the SPOD setting of 0.5 would be better to increase the security.

3 Pole open reset delay to override small discrepancies in pole closing '3POD := 0.5

Stub line protection is not required ESTUB := "N" '50MFD := "N/A"

Trip unlatch logic not applied TULO := "N"

Logic variables and Miscellaneous timers

Minimum trip duration timer is set at 9 cycles as per the application example in the SEL-321 instruction manual.

TDURD := 9 Cycles

Trip during open pole time delay should be set longer than the reclose time. Existing reclose time is 55 cycles. This is acceptable.

TOPD := 55 Cycles

Existing logic variables are not used.

Add the use of ZT to trigger an alarm for sustained unbalance.

LOGIC_Z := "59N+50N1+50Q1" TZPU := 1200 cycles TZDO := 0 cycles

Tripping Logic

Permissive tripping is required only for instantaneous overreaching functions. No need for any functions that trip directly. Existing 51NT word in MTCS is not required.

MTCS := "M2P+Z2G"

Existing settings for unconditional tripping are suitable

MTU := "M1P+Z1G+M2PT+Z2GT+51NT"

No need for existing direct tripping zone 1 functions in the switch on to fault logic.

SOTF Tripping MTO := "M2P+Z2G+50H"

Event records will be triggered automatically by all trip events. Other event record triggers should be by starting of other elements to ensure capture of all relevant events. Events should be triggered by keying or receiving permissive trips to ensure separation of relay and teleprotection issues.

MER := "M2P+Z2G+51NP+LOP*52AA1+LOP*52AA2+KEY+PT+EKEY"

Outputs

Retain existing output assignments except add the continuous unbalance alarm to OUT15.

OUT15 := "LOP*50L+ZT"

Input Contact Assignment

It would be desirable to provide phase segregated inputs to the relay so that the quadrilateral functions could be disabled during single pole open conditions. it is not known if phase segregated auxiliary switches are available on the breakers.

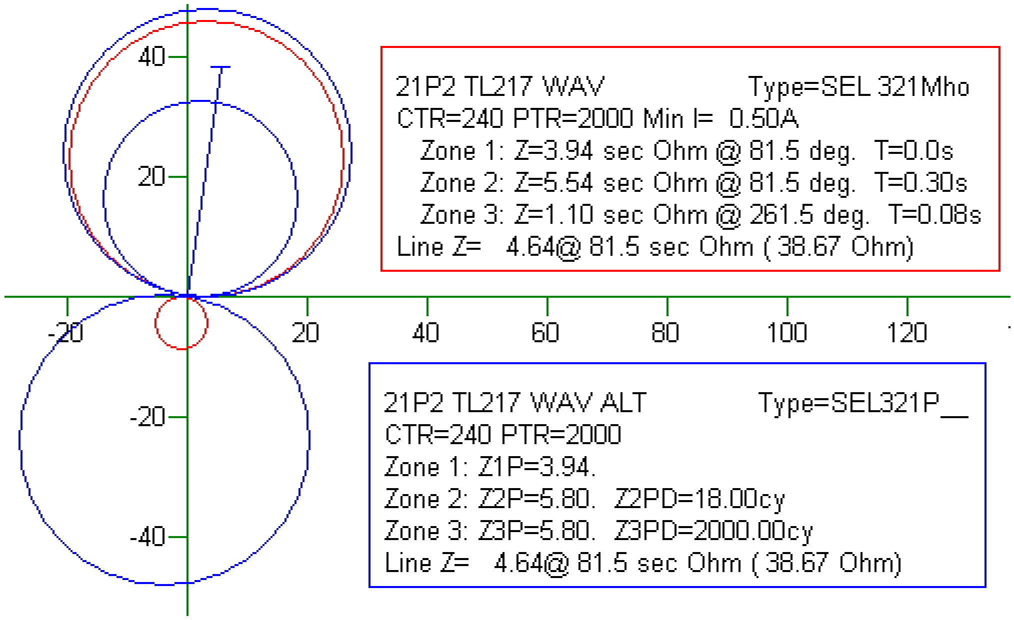


Figure 10 - Comparison between existing (red) and proposed new (blue) phase distance characteristics.

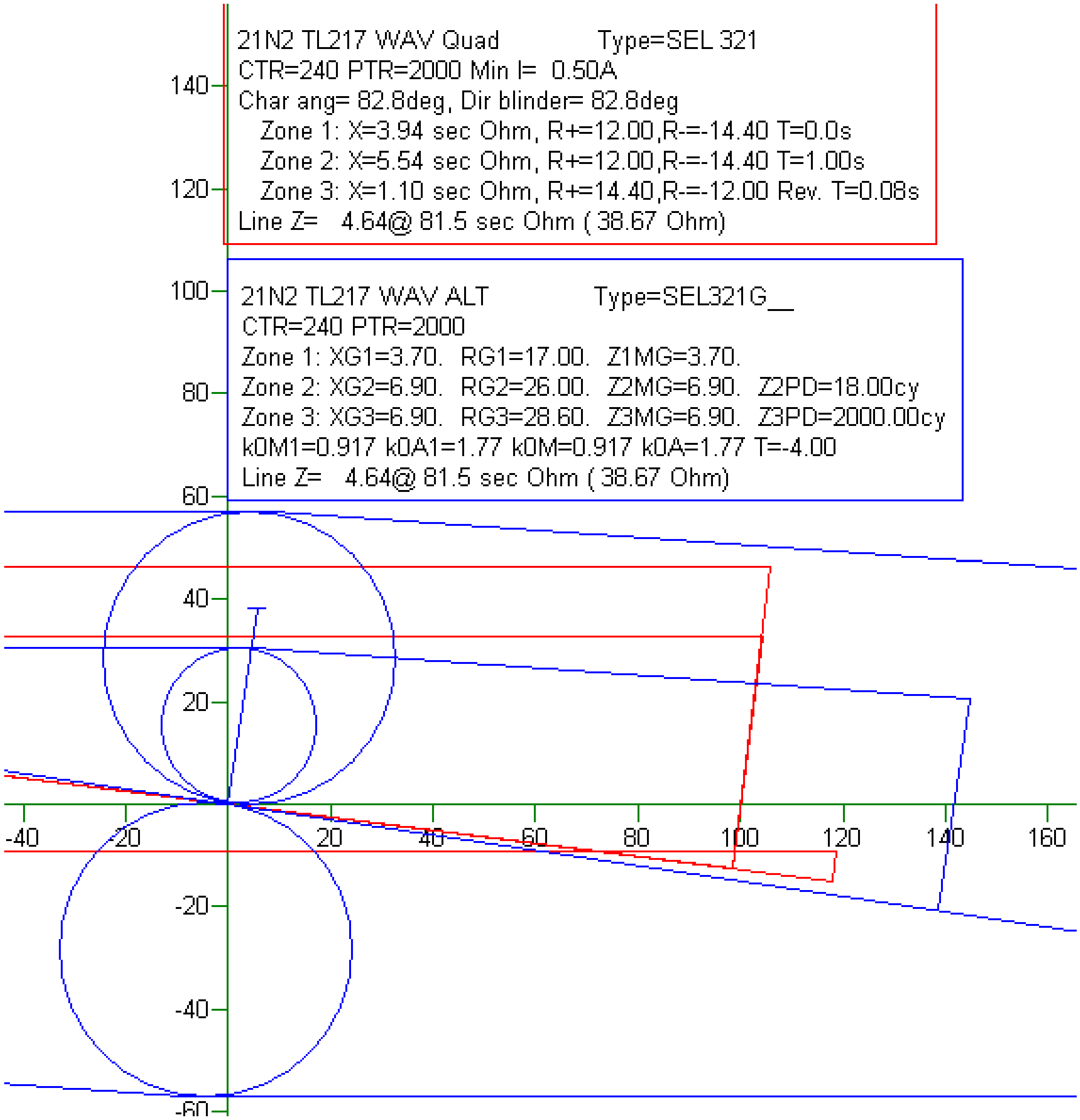


Figure 11 - Comparison between existing (red) and proposed new (blue) ground distance characteristics.

Protection Review for Five 230 kV Transmission Lines

Appendix J
Detailed settings review for HRD TL217 "P1" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador Hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Holyrood Terminal (HRD) terminal of circuit TL217. This 230 kV transmission circuit is from HRD to Western Avalon (WAV).
The circuit runs parallel to Circuit TL201 for most of its length.

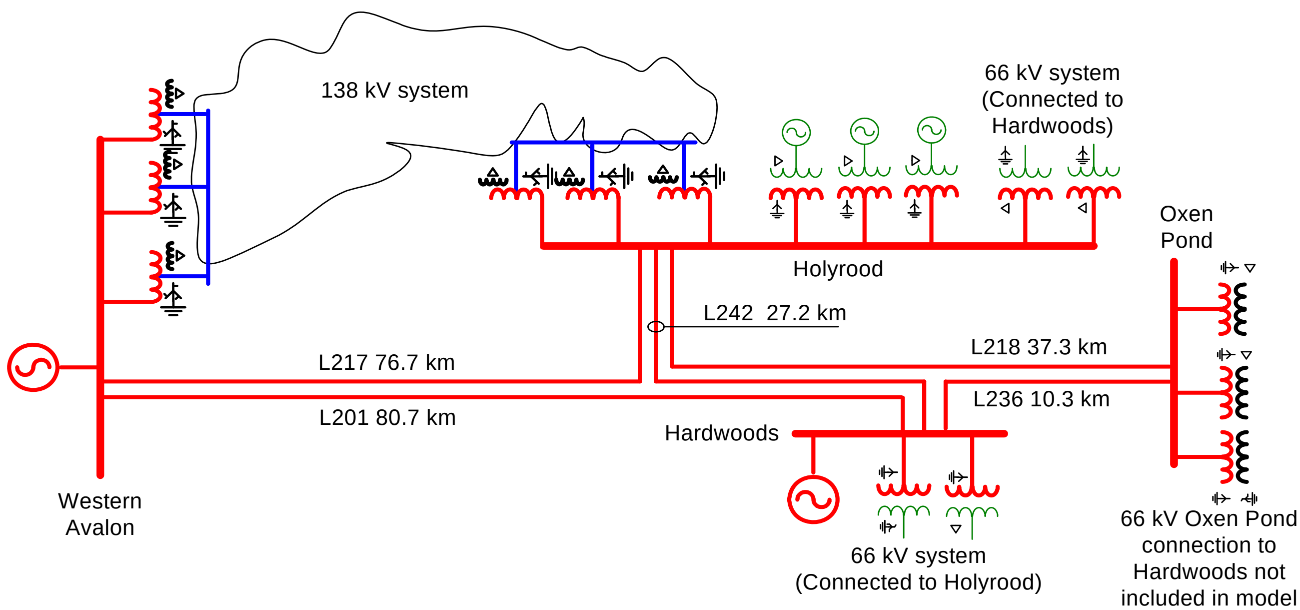


Figure 1 - System Single Line Diagram

Existing P1 protection systems are Areva LZFP111 (Optimho) systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $\quad$ $kVbase := 230$ $\quad$ $Ibase := \dfrac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\quad$ $Zbase := \dfrac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at the line terminal.

CT ratio is: $CTR := \dfrac{1200}{5}$ $\quad$ VT ratio is: $VTR := \dfrac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**NL HYDRO WITH MUTUALS FOR EAST COAST 230 kV LINE PN REVIEW.OLR**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with loads and shunts ignored.

Minimum fault current seen by each terminal (phase to phase, and SLG with 0 ohm fault resistance).

At HRD, with two units off line, and both parallel lines in service, for a fault at the remote terminal.

$ILLmin := 636$ A $ISLGminPH := 697$ A $ISLGmin0seq := 451$ A

The optimho current level detectors that block the distance comparators in the event of line opening are fixed at 5% of the rated current, or 0.25 A secondary, or 60 A primary. They will have no difficulty in operating for minimum bolted fault levels. However, the ground distance elements are also supervised by a low set neutral current level detector (LDLSN that requires the neutral current to be greater than 10% of the maximum amplitude of phase difference current. This prevents the ground comparators from operating during close-in multiphase faults with CT errors. ASPEN OneLiner shows that for a bolted fault at the remote bus even under heavy load, there is sufficient neutral current (50% of maximum phase to phase fault current) that means this LDLSN function does not inhibit the ground distance comparator.

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind HRD $Z2minHRD := 1.0 + j\cdot 22$ ohms primary

Minimum source impedance behind WAV $Z2minWAV := 3.6 + j\cdot 30.4$ ohms primary

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L217 := 0.01077 + j\cdot 0.07231$ $Z0L217 := 0.03629 + j\cdot 0.2719$

$Z1Line := Z1L217 = 0.011 + 0.072j$ pu $Z0Line := Z0L217 = 0.036 + 0.272j$ pu

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line\cdot Zbase$ $Z0Linephys := Z0Line\cdot Zbase$

$Z1Linephys = 5.7 + 38.3i$ ohms primary $Z0Linephys = 19.2 + 143.8i$ ohms primary

Converting primary ohms to secondary ohms gives:

$Z1Linesec := Z1Linephys\cdot\frac{CTR}{VTR}$ $Z0Linesec := Z0Linephys\cdot\frac{CTR}{VTR}$

$|Z1Linesec| = 4.64$ ohms sec $arg(Z1Linesec) = 81.5\cdot deg$

$|Z0Linesec| = 17.413$ ohms sec $arg(Z0Linesec) = 82.4\cdot deg$

Load Data

From 2011 System summer load case provided in start up information, the peak load (sum of TL217 and TL201) is given as 205 MVA (split between TL217 and TL201). In the event of sudden loss of one line, peak load will be the sum of both line loads until operators can adjust loads. Therefore it is assumed that peak load for a short duration is 205 MVA

$Speak := 205$ MVA $Smax := Speak = 205$ MVA

P1 Relay Settings

Distance element reach settings

Note that resistive reaches are forced to be the same for all zones. Reactive reaches for phase and ground distance elements must be the same as each other.

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the HRD Station bus under light load conditions with one line from SSD to HRD out of service and both TL217 and TL201 lines in service. From ASPEN OneLiner, voltage at HRD for a 3 phase fault at HRD is 0.21 per unit. So there is plenty of voltage at HRD during a fault at HRD, even under weak source conditions.

Since the voltage is higher than 20%, the line is not considered short, and a conventional Zone 1 setting is acceptable.

$Z1P := 0.85 \cdot |Z1Linesec|$ $Z1P = 3.94$ Ohms secondary

Existing setting of 3.94 ohms is OK, and could be retained if only the phase distance functions had to be considered. However, the ground distance reach in the optimho has to be set the same as the phase distance reach; so we need to consider the ground faults too.

$Z1P = 3.94$ For phase faults only.

The worst case from the point of view of overreach of the zone 1 ground distance element is with TL242 out of service and grounded at both ends, and a close-in fault on TL218 with the Oxen Pond end open. For this case, the apparent impedance presented to the relay is only 4.11 ohms secondary (see Figure 2). This is 89% of the line impedance. So the reach of the zone 1 element should be reduced somewhat.

$Zapp\_ext := 4.05$ ohms $Zapp\_ang := 82.3deg$ This angle is close enough to the line angle to treat it as equal to the line angle.

$\frac{Zapp\_ext}{|Z1Linesec|} = 0.873$ The apparent impedance is reduced by about 12% mostly due to the effect of the parallel line being out of service and grounded at both ends but also partly due to the zero sequence current compensation factor being set slightly too high on this protection.

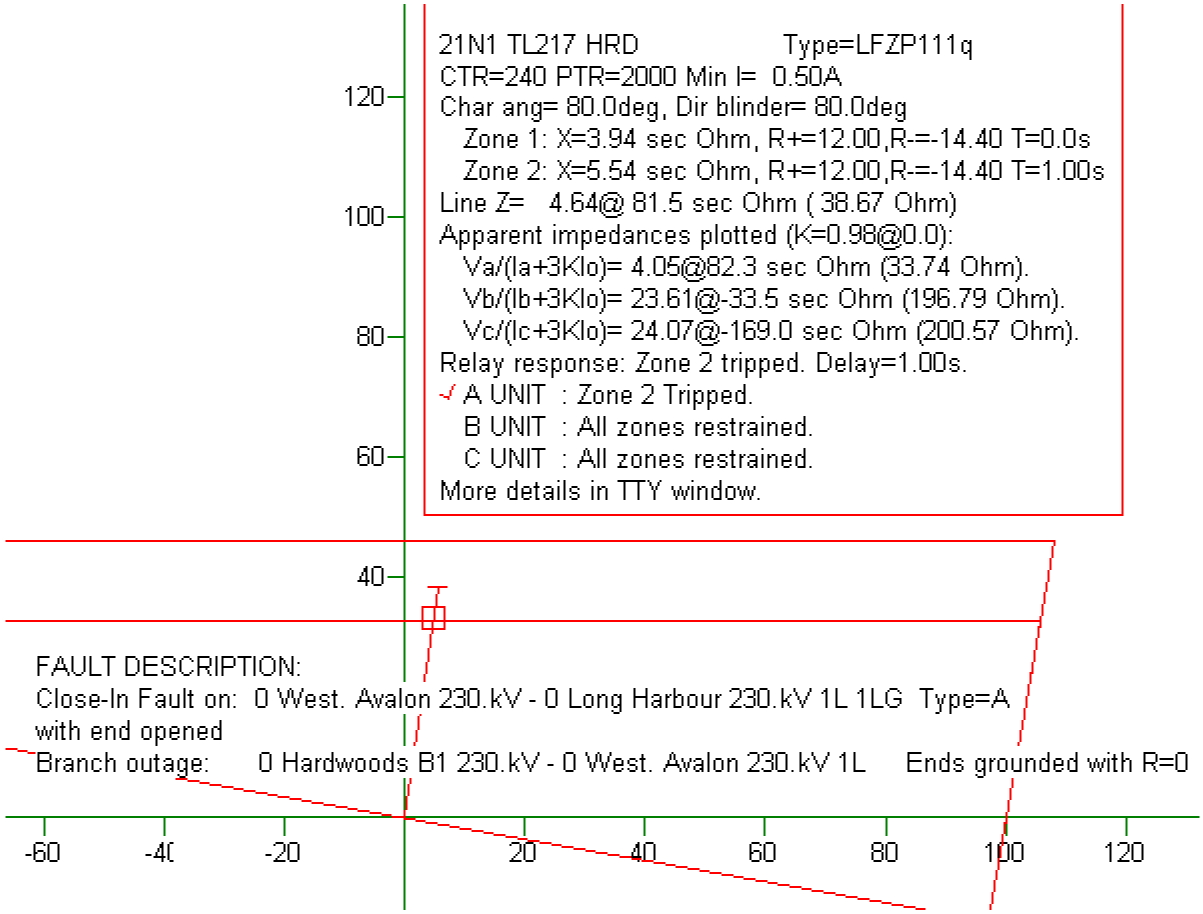


Figure 2 - Apparent impedance to a fault just beyond the remote terminal is reduced by 11% when TL201 line is out of service and grounded at both ends. Existing relay settings modeled in this figure.

The reach of the zone 1 ground distance element should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Choose a setting of 80% of line which will underreach the remote bus by 7% when the parallel line is out of service and grounded at both ends and when the zero sequence current compensation factor is reduced slightly.

Let the per unit reach of the Zone 1 function be m per unit of the line. $m := 0.8$ per unit

$Z1\_sec := \mathrm{round}(m \cdot |Z1Linesec|, 1)$ $Z1\_sec = 3.7$ Ohms secondary

$Z1pri := Z1\_sec \cdot \frac{VTR}{CTR} = 30.833$ Ohms primary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 5.54 ohms secondary (about 119%). However, in order to dependably reach a single line to ground fault at the remote terminal, it will be necessary to set the reach significantly further.

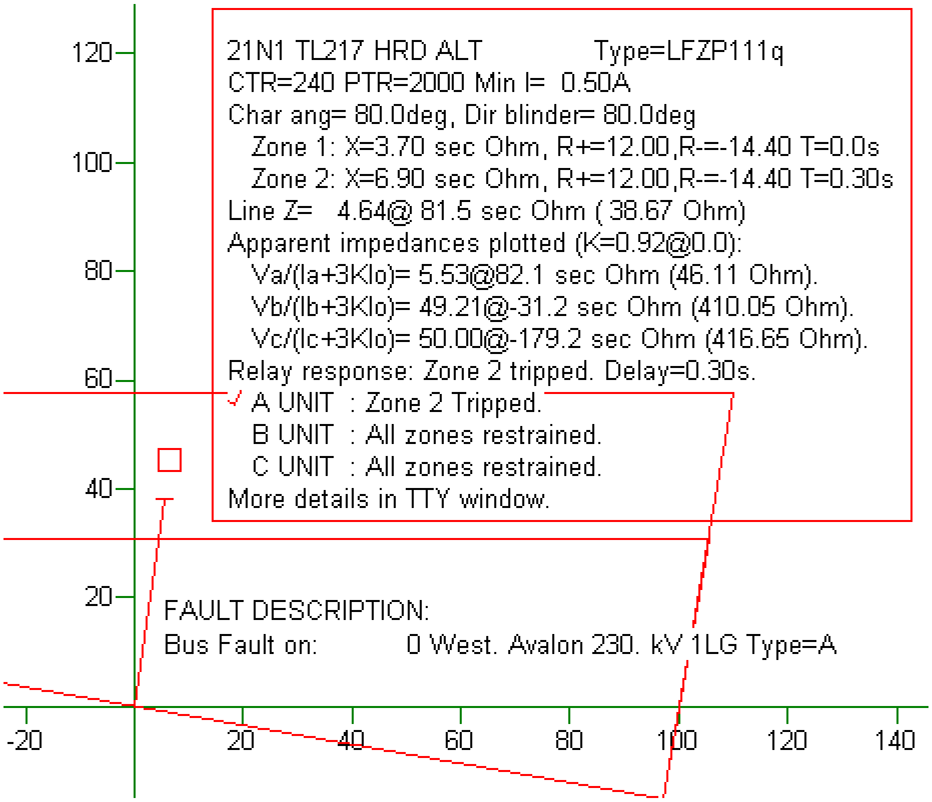


Figure 3 - Apparent impedance to a fault close to the remote terminal is increased by 20% when parallel line is in service (and two units off line at HRD).

As can be seen from Figure 3, the apparent impedance to a fault close to the remote terminal is increased when the parallel line is in service.

$Zapp\_int := 5.53$ Ohms secondary

$Z2\_sec := 1.25 \cdot Zapp\_int$ $Z2\_sec = 6.9$ Ohms secondary $\dfrac{Z2\_sec}{|Z1Linesec|} = 148.948 \cdot \%$

$Z2\_pri := Z2\_sec \cdot \dfrac{VTR}{CTR} = 57.604$ Ohms primary

Even with this long reach setting, the zone 2 element will not overreach the shortest reaching zone 1 (TL237) out of WAV.

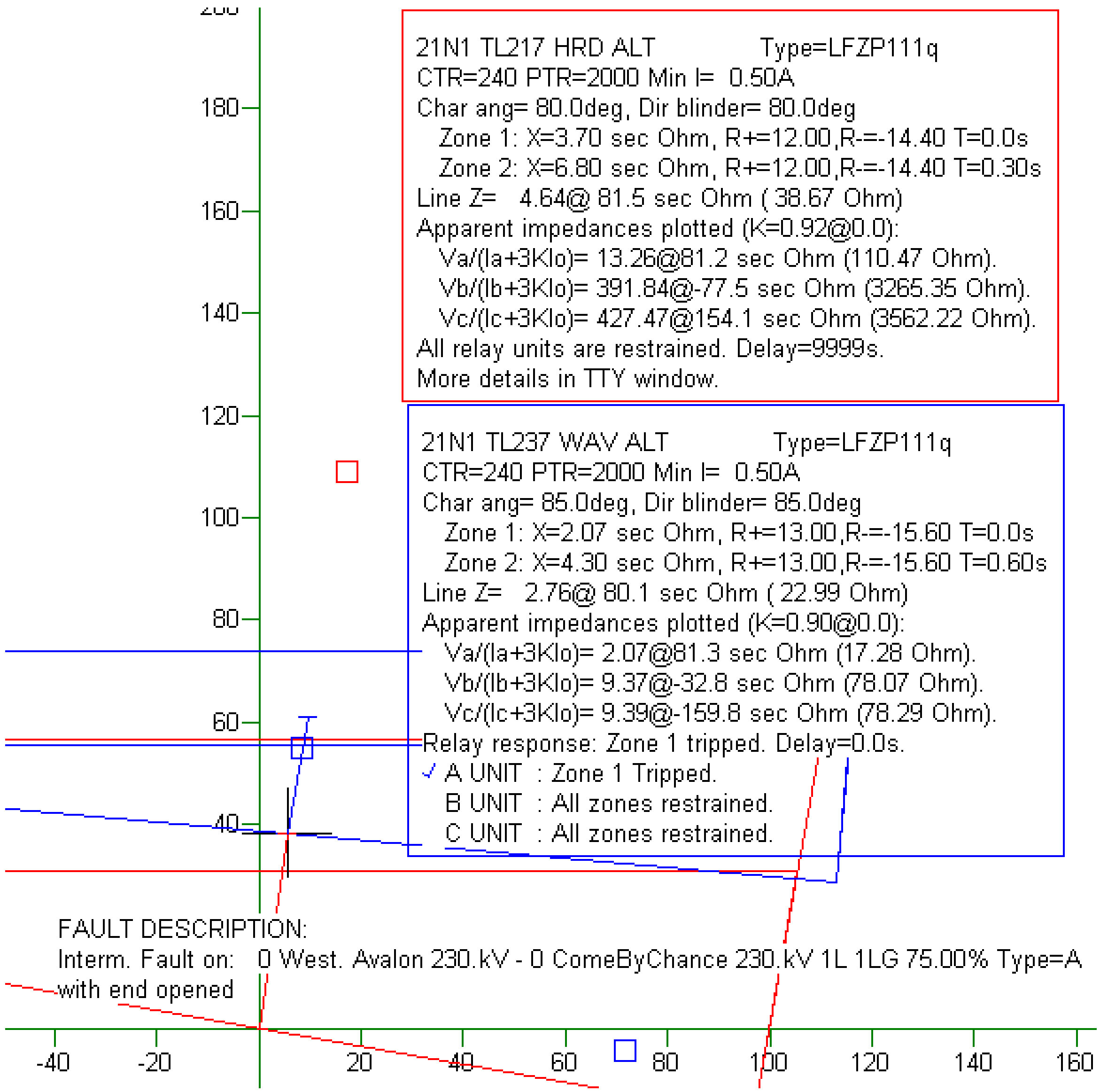


Figure 4 -High apparent impedance for 0 ohm SLG fault at 80% ofTL237 with remote terminal open and with two units at Holyrood out of service and TL203 out of service.

Due to the secure underreach of the shortest line out of Holyrood, conventional Zone 2 time (same as existing) will be applied even with this new, longer setting.

Z2_TD := 0.3 Seconds

Load Encroachment logic

The optimho instruction manual recommends a margin of at least 10% between the impedance of the maximum load and the resistive reach of the quadrilateral distance element.

Check loadability of the Zone 2 phase distance element assuming worst case depressed voltage of a stressed system of 0.9 per unit.

$$Zloadmin := \frac{(0.9kVbase)^2}{Smax} \qquad Zloadmin = 209.02$$ Ohms primary (assume worst case at 30 degrees)

$$Zloadmin\_sec := Zloadmin \cdot \frac{CTR}{VTR} \qquad Zloadmin\_sec = 25.082$$

A 12 ohm secondary resistive reach is less than 90% of the load impedance at unity power factor and meets the Areva criterion as shown in Figure 5.

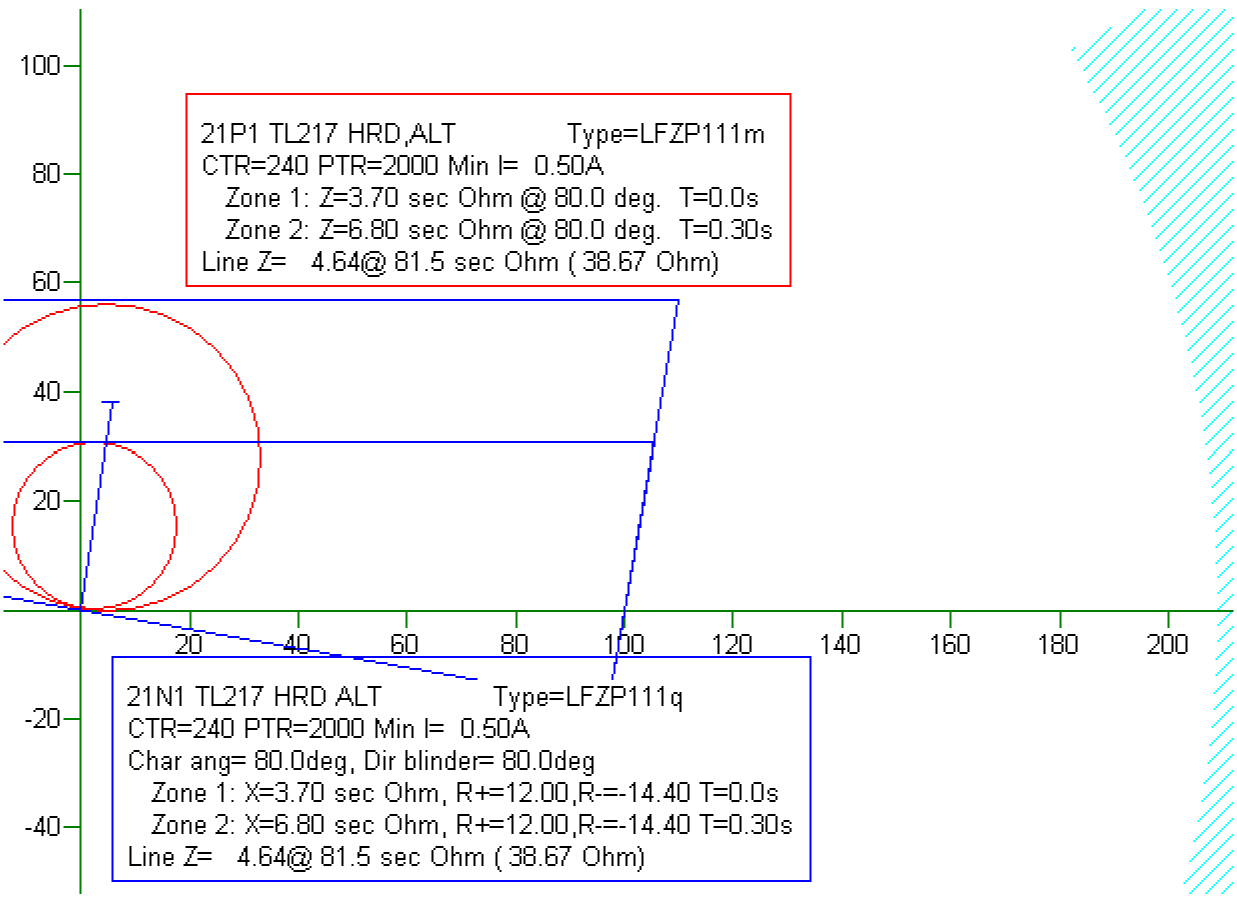


Figure 5 - Apparent impedance of load

Resistive reach of quadrilateral elements

Check the maximum fault resistance that can be sensed for a fault at a location where the current contribution from each terminal is roughly the same. From Figure 6, it can be seen that the limit of sensitivity (where quadrilateral elements at both ends can see a fault) is about 95 ohms, for a fault about 58% of the distance from HRD. This is close enough to the required sensitivity of 100 ohms. Note that the point of overlap of quadrilateral elements may move along the line depending on the strength of the source at either end, but they will always overlap somewhere. For resistive faults outside the overlapping zone, sequential clearing will have to be accepted.

Rquad := 12 Ohms secondary

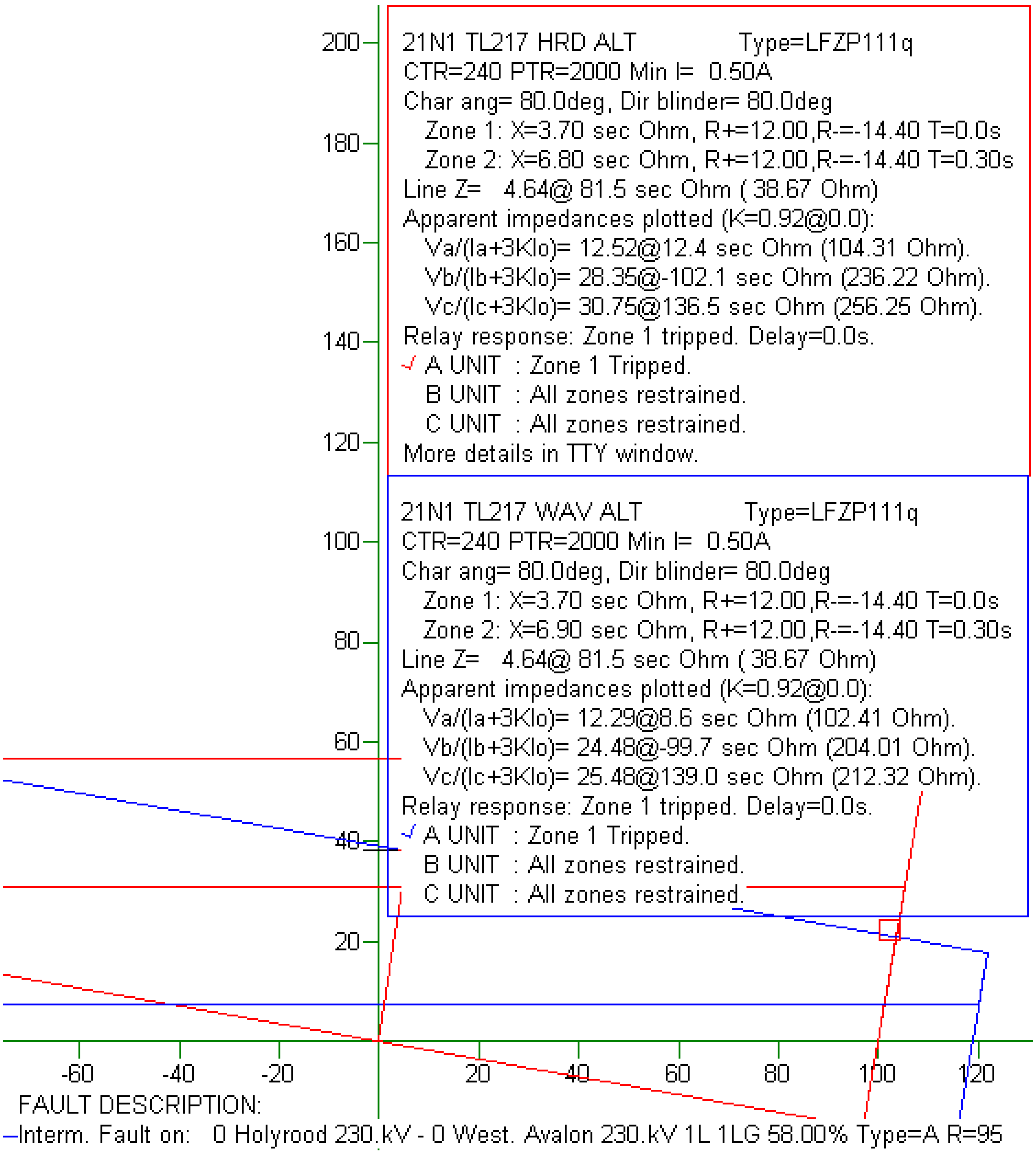


Figure 6 - Apparent impedance of a resistive fault near the mid point of the line.

Settings of K attenuators

KZPh Coarse setting common to all DISTANCE zones should be set as high as possible while below the required Zone 1 reach. The current level detectors vary inversely with KZph. Maximum setting available is 1.0

$KZPh := 1.0$

Zone 1 attenuators and angular selection

$In := 5$ $\quad Z1\_sec = 3.7$ This is the desired secondary reach (previously calculated)

$$KZ1 := \frac{Z1\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ1 = 3.7 \qquad Z1sec\_reach := KZ1 \cdot KZPh \cdot \frac{5}{In} \qquad Z1sec\_reach = 3.7$$

$Z\theta PH := (\arg(Z1Linesec))$ $\qquad Z\theta PH = 81.529 \cdot deg$

Rounded to the nearest 5 degrees $\qquad Z\theta PH := 80$ Degrees

$Z\theta N := \arg(Z0Linesec - Z1Linesec)$ $\qquad Z\theta N = 82.714 \cdot deg$

Rounded to the nearest 5 degrees $\qquad Z\theta N := 80$ Degrees

Zone 2 attenuators selection

$Z2\_sec = 6.9$ This is the desired secondary reach (previously calculated)

$$KZ2 := \frac{Z2\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ2 = 6.9$$

QUAD Resistive Reach setting

$Rquad = 12$ This is the desired secondary reach (previously calculated)

$$KR := \frac{Rquad}{\left(\frac{5}{In}\right)} \qquad KR = 12$$

Residual Compensation attenuators selection

Zero sequence current compensation for ground faults is provided by the KZN factor. Zero sequence mutual compensation is not used in this application (it causes extra complexity for only moderate gain in setting accuracy).

$$KZN := \frac{Z0Linesec - Z1Linesec}{3 \cdot Z1Linesec} \cdot KZPh \qquad KZN = 0.917 + 0.019j$$

$|KZN| = 0.917$ $\qquad$ This is a reduction from the existing setting of 0.98

Switch On To Fault (SOTF) Protection.

If SOTF is enabled, it can be set to 200ms or 110 s after all poles of the line have been de-energized. The 110 s setting is intended to override automatic reclosing dead time. However it makes more sense to enable after the shorter time. Once the SOTF feature has been initiated, it remains in effect for 250ms after the line has been re-energized. The SOTF tripping options are:

a) Any distance comparator.
b) Any current level detector as long as a corresponding voltage level detector has not picked up within 20ms.
c) Either current or distance, as long as a corresponding voltage level detector has not picked up within 20ms.

SOTF := "Enabled"

SOTF_TIME := 0.20 Seconds

Elements_in_SOTF := "BOTH" (Both Comparators and current level detectors).

Power Swing Detector

This element will not be used. It will be left Blocked, and if there is a power swing, the distance elements will trip naturally.

VT Supervision

Set the VT supervision to BLOCK TRIP

Set the VT fail detection to SELF RESET.

Start Indication

This function will bring up information on the LCD screen of the relay if a start event occurs. This function will not be used.

START_INDICATION := "BLOCKED"

Communications assisted logic.

The existing communications assisted logic is permissive overreaching transfer trip, scheme **POR 1**. This scheme is familiar to Newfoundland and Labrador Hydro, and even though the POR 2 scheme offers the advantage of weak infeed echo, which would help the sensitivity to resistive faults, it is not recommended to change the existing scheme logic at this stage with years of experience on a product that is nearing the end of its useful life.

The POR 1 logic is a basic permissive overreaching transfer trip scheme but it does include current reversal timers to increase security against misoperation due to current reversal when a fault on the parallel line is cleared sequentially. The current reversal logic is achieved by a timer TP which will block permissive tripping and keying of permissive trip if the local zone 2 element does not pick up within a reasonable time of receiving permissive trip. The block will be maintained for a time delay of TD after the local zone 2 element picks up, or the received permissive trip signal resets.

The application of the current reversal timers is required only if the settings of the zone 2 comparators are greater than 1.5 times the line impedance .Although the reaches of these elements are only marginally less than 1.5 times the line impedance, there is no parallel line and there is infeed at each terminal that will minimize overreach. Therefore, the current reversal logic is not required, and the recommended default settings are as existing

$TP := 98$ ms

$TD := 0$ ms

Comparison of Existing (red) and Proposed alternative (ALT) settings.

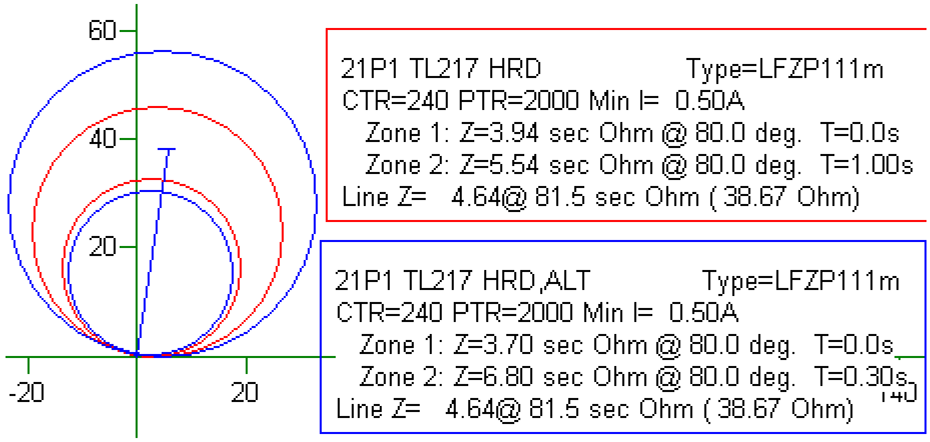


Figure 7 - Comparison of phase distance characteristics

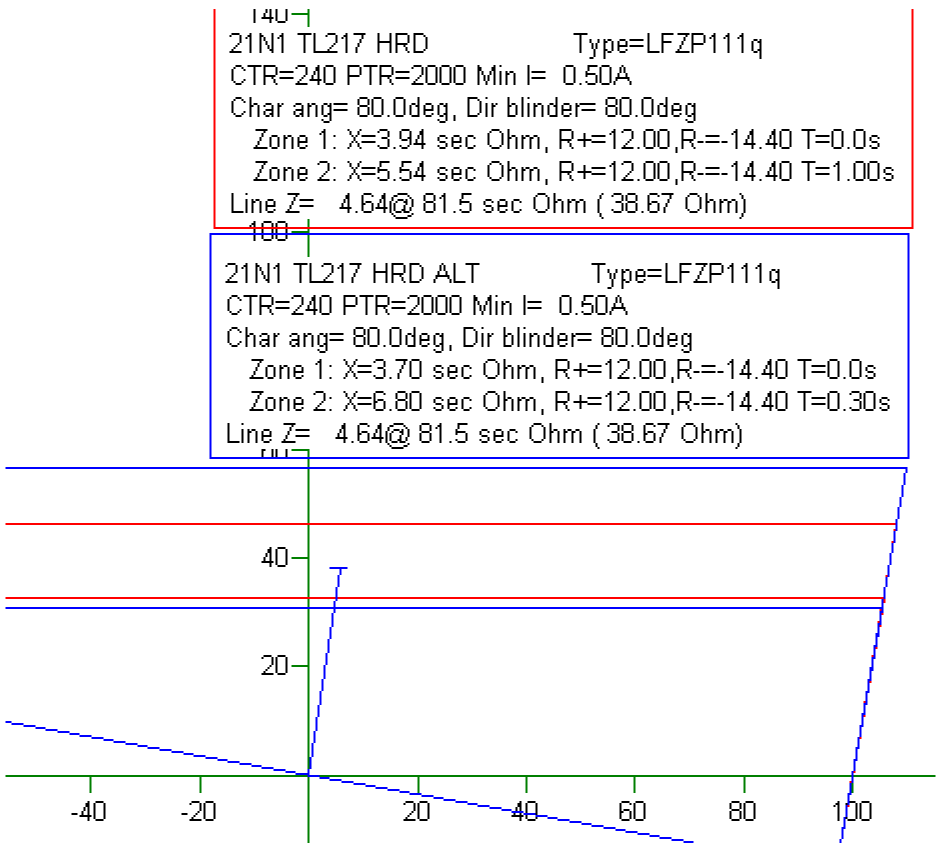


Figure 8 - Comparison of ground distance characteristics

Protection Review for Five 230 kV Transmission Lines

Appendix J
Detailed settings review for HRD TL217 "P1" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador Hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Holyrood Terminal (HRD) terminal of circuit TL217. This 230 kV transmission circuit is from HRD to Western Avalon (WAV).
The circuit runs parallel to Circuit TL201 for most of its length.

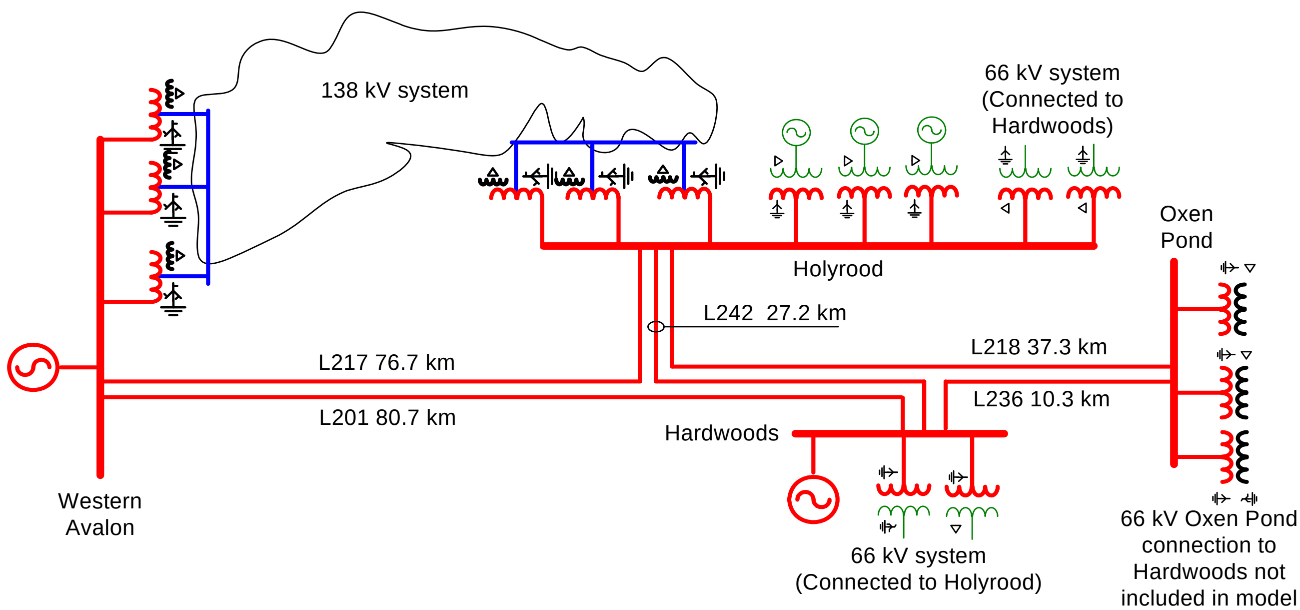


Figure 1 - System Single Line Diagram

Existing P1 protection systems are Areva LZFP111 (Optimho) systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $kVbase := 230$ $Ibase := \frac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $Zbase := \frac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at the line terminal.

CT ratio is: $CTR := \frac{1200}{5}$ VT ratio is: $VTR := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case “**NL HYDRO WITH MUTUALS FOR EAST COAST 230 kV LINE PN REVIEW.OLR**” with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with loads and shunts ignored.

Minimum fault current seen by each terminal (phase to phase, and SLG with 0 ohm fault resistance).

At HRD, with two units off line, and both parallel lines in service, for a fault at the remote terminal.

$ILLmin := 636$ A $ISLGminPH := 697$ A $ISLGmin0seq := 451$ A

The optimho current level detectors that block the distance comparators in the event of line opening are fixed at 5% of the rated current, or 0.25 A secondary, or 60 A primary. They will have no difficulty in operating for minimum bolted fault levels. However, the ground distance elements are also supervised by a low set neutral current level detector (LDLSN that requires the neutral current to be greater than 10% of the maximum amplitude of phase difference current. This prevents the ground comparators from operating during close-in multiphase faults with CT errors. ASPEN OneLiner shows that for a bolted fault at the remote bus even under heavy load, there is sufficient neutral current (50% of maximum phase to phase fault current) that means this LDLSN function does not inhibit the ground distance comparator.

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind HRD $Z2minHRD := 1.0 + j \cdot 22$ ohms primary

Minimum source impedance behind WAV $Z2minWAV := 3.6 + j \cdot 30.4$ ohms primary

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L217 := 0.01077 + j \cdot 0.07231$ $Z0L217 := 0.03629 + j \cdot 0.2719$

$Z1Line := Z1L217 = 0.011 + 0.072j$ pu $Z0Line := Z0L217 = 0.036 + 0.272j$ pu

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line \cdot Zbase$ $Z0Linephys := Z0Line \cdot Zbase$

$Z1Linephys = 5.7 + 38.3i$ ohms primary $Z0Linephys = 19.2 + 143.8i$ ohms primary

Converting primary ohms to secondary ohms gives:

$Z1Linesec := Z1Linephys \cdot \frac{CTR}{VTR}$ $Z0Linesec := Z0Linephys \cdot \frac{CTR}{VTR}$

$|Z1Linesec| = 4.64$ ohms sec $arg(Z1Linesec) = 81.5 \cdot deg$

$|Z0Linesec| = 17.413$ ohms sec $arg(Z0Linesec) = 82.4 \cdot deg$

Load Data

From 2011 System summer load case provided in start up information, the peak load (sum of TL217 and TL201) is given as 205 MVA (split between TL217 and TL201). In the event of sudden loss of one line, peak load will be the sum of both line loads until operators can adjust loads. Therefore it is assumed that peak load for a short duration is 205 MVA

$Speak := 205$ MVA $\quad$ $Smax := Speak = 205$ MVA

P1 Relay Settings

Distance element reach settings

Note that resistive reaches are forced to be the same for all zones. Reactive reaches for phase and ground distance elements must be the same as each other.

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the HRD Station bus under light load conditions with one line from SSD to HRD out of service and both TL217 and TL201 lines in service. From ASPEN OneLiner, voltage at HRD for a 3 phase fault at HRD is 0.21 per unit. So there is plenty of voltage at HRD during a fault at HRD, even under weak source conditions.

Since the voltage is higher than 20%, the line is not considered short, and a conventional Zone 1 setting is acceptable.

$Z1P := 0.85 \cdot |Z1Linesec|$ $\quad$ $Z1P = 3.94$ Ohms secondary

Existing setting of 3.94 ohms is OK, and could be retained if only the phase distance functions had to be considered. However, the ground distance reach in the optimho has to be set the same as the phase distance reach; so we need to consider the ground faults too.

$Z1P = 3.94$ For phase faults only.

The worst case from the point of view of overreach of the zone 1 ground distance element is with TL242 out of service and grounded at both ends, and a close-in fault on TL218 with the Oxen Pond end open. For this case, the apparent impedance presented to the relay is only 4.11 ohms secondary (see Figure 2). This is 89% of the line impedance. So the reach of the zone 1 element should be reduced somewhat.

$Zapp\_ext := 4.05$ ohms $\quad$ $Zapp\_ang := 82.3deg$ $\quad$ This angle is close enough to the line angle to treat it as equal to the line angle.

$$\frac{Zapp\_ext}{|Z1Linesec|} = 0.873$$

The apparent impedance is reduced by about 12% mostly due to the effect of the parallel line being out of service and grounded at both ends but also partly due to the zero sequence current compensation factor being set slightly too high on this protection.

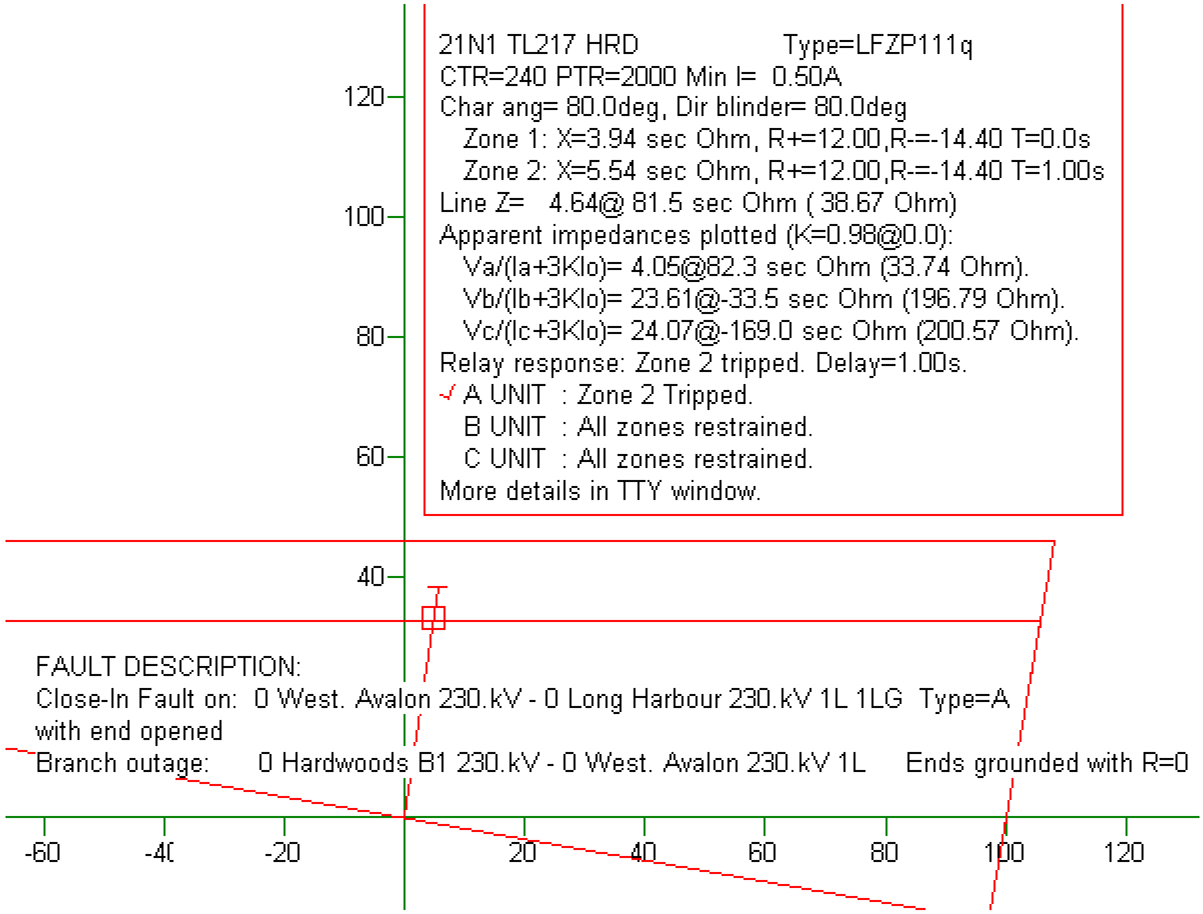


Figure 2 - Apparent impedance to a fault just beyond the remote terminal is reduced by 11% when TL201 line is out of service and grounded at both ends. Existing relay settings modeled in this figure.

The reach of the zone 1 ground distance element should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Choose a setting of 80% of line which will underreach the remote bus by 7% when the parallel line is out of service and grounded at both ends and when the zero sequence current compensation factor is reduced slightly.

Let the per unit reach of the Zone 1 function be m per unit of the line. $m := 0.8$ per unit

$Z1\_sec := \mathrm{round}(m \cdot |Z1Linesec|, 1)$ $Z1\_sec = 3.7$ Ohms secondary

$Z1pri := Z1\_sec \cdot \frac{VTR}{CTR} = 30.833$ Ohms primary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 5.54 ohms secondary (about 119%). However, in order to dependably reach a single line to ground fault at the remote terminal, it will be necessary to set the reach significantly further.

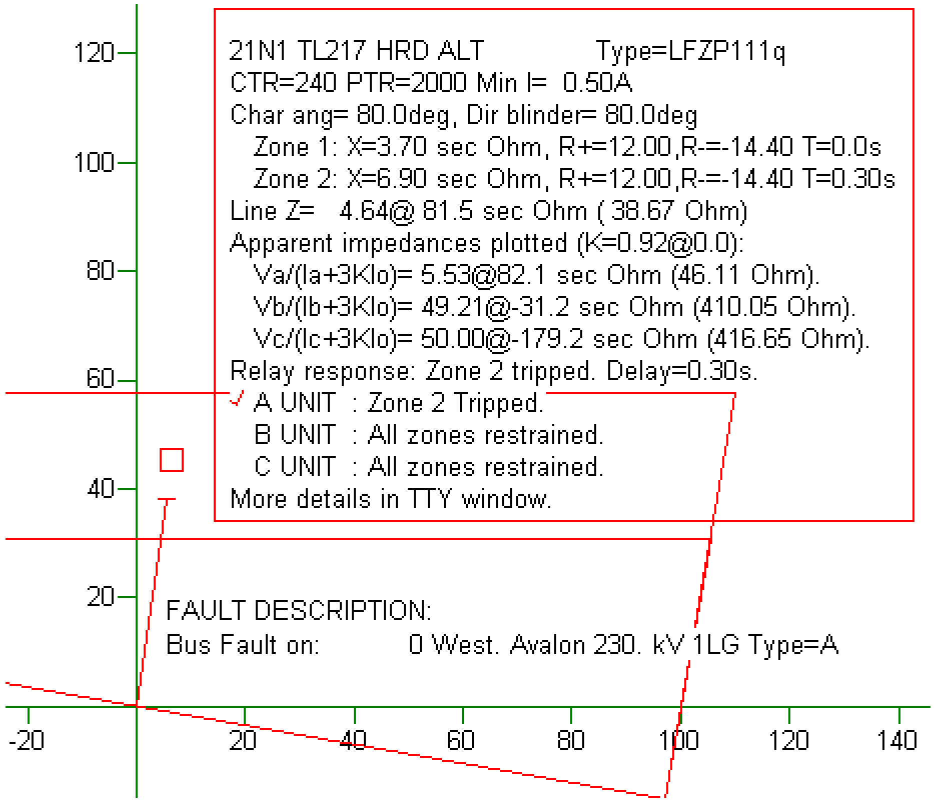


Figure 3 - Apparent impedance to a fault close to the remote terminal is increased by 20% when parallel line is in service (and two units off line at HRD).

As can be seen from Figure 3, the apparent impedance to a fault close to the remote terminal is increased when the parallel line is in service.

$Zapp\_int := 5.53$ Ohms secondary

$Z2\_sec := 1.25 \cdot Zapp\_int$ $Z2\_sec = 6.9$ Ohms secondary $\dfrac{Z2\_sec}{|Z1Linesec|} = 148.948 \cdot \%$

$Z2\_pri := Z2\_sec \cdot \dfrac{VTR}{CTR} = 57.604$ Ohms primary

Even with this long reach setting, the zone 2 element will not overreach the shortest reaching zone 1 (TL237) out of WAV.

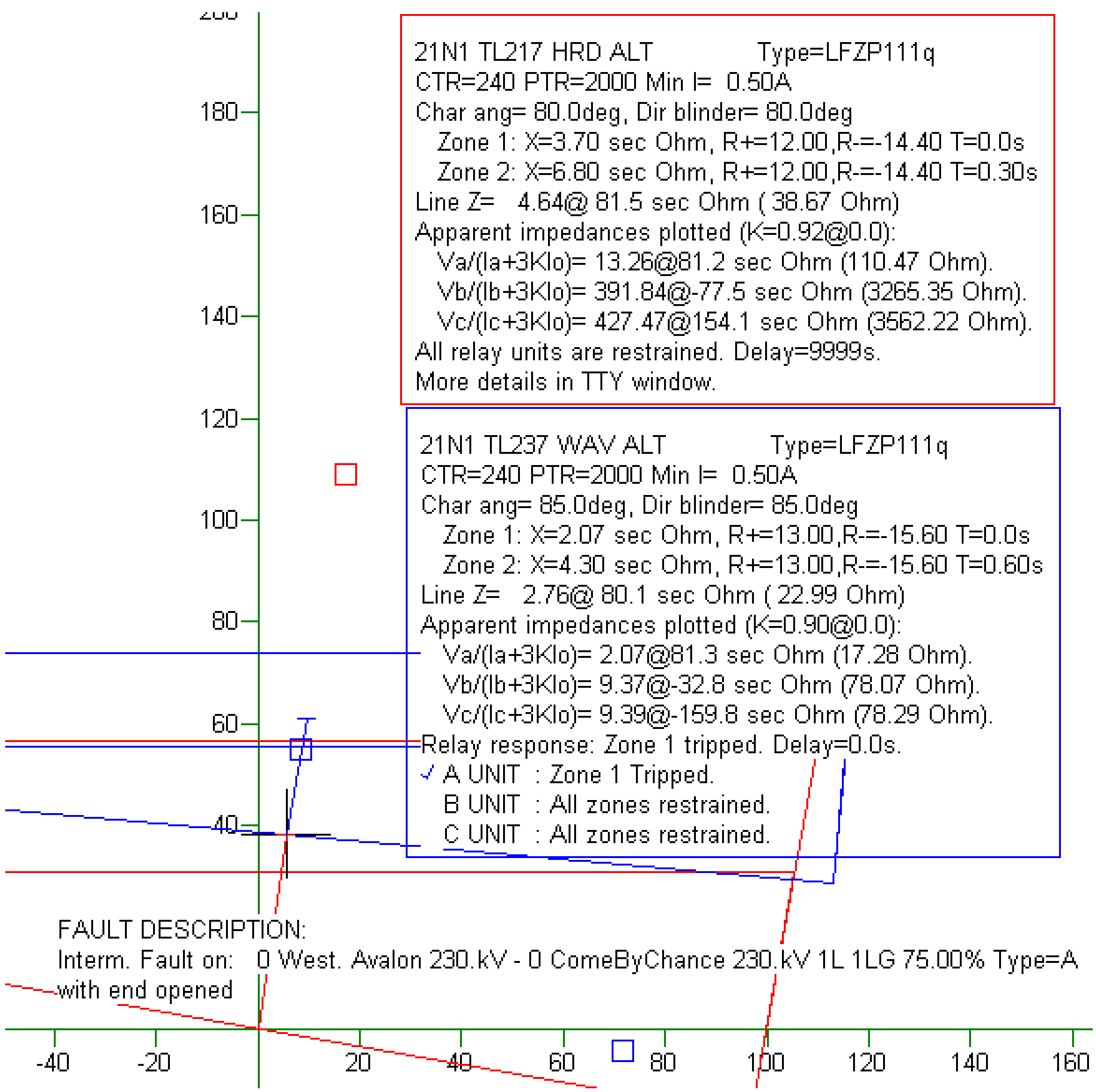


Figure 4 -High apparent impedance for 0 ohm SLG fault at 80% ofTL237 with remote terminal open and with two units at Holyrood out of service and TL203 out of service.

Due to the secure underreach of the shortest line out of Holyrood, conventional Zone 2 time (same as existing) will be applied even with this new, longer setting.

Z2_TD := 0.3 Seconds

Load Encroachment logic

The optimho instruction manual recommends a margin of at least 10% between the impedance of the maximum load and the resistive reach of the quadrilateral distance element.

Check loadability of the Zone 2 phase distance element assuming worst case depressed voltage of a stressed system of 0.9 per unit.

$$Zloadmin := \frac{(0.9kVbase)^2}{Smax} \qquad Zloadmin = 209.02$$ Ohms primary (assume worst case at 30 degrees)

$$Zloadmin\_sec := Zloadmin \cdot \frac{CTR}{VTR} \qquad Zloadmin\_sec = 25.082$$

A 12 ohm secondary resistive reach is less than 90% of the load impedance at unity power factor and meets the Areva criterion as shown in Figure 5.

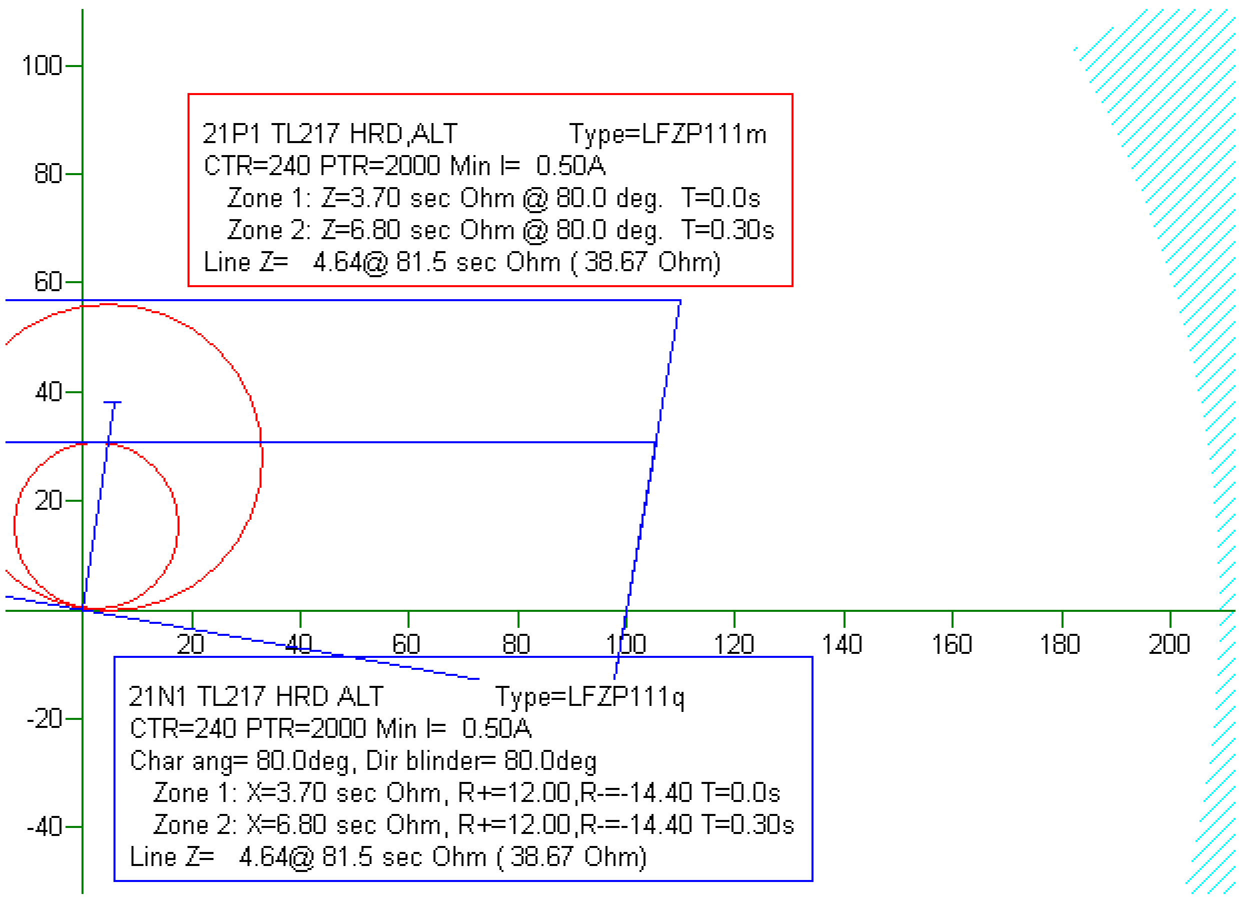


Figure 5 - Apparent impedance of load

Resistive reach of quadrilateral elements

Check the maximum fault resistance that can be sensed for a fault at a location where the current contribution from each terminal is roughly the same. From Figure 6, it can be seen that the limit of sensitivity (where quadrilateral elements at both ends can see a fault) is about 95 ohms, for a fault about 58% of the distance from HRD. This is close enough to the required sensitivity of 100 ohms. Note that the point of overlap of quadrilateral elements may move along the line depending on the strength of the source at either end, but they will always overlap somewhere. For resistive faults outside the overlapping zone, sequential clearing will have to be accepted.

Rquad := 12 Ohms secondary

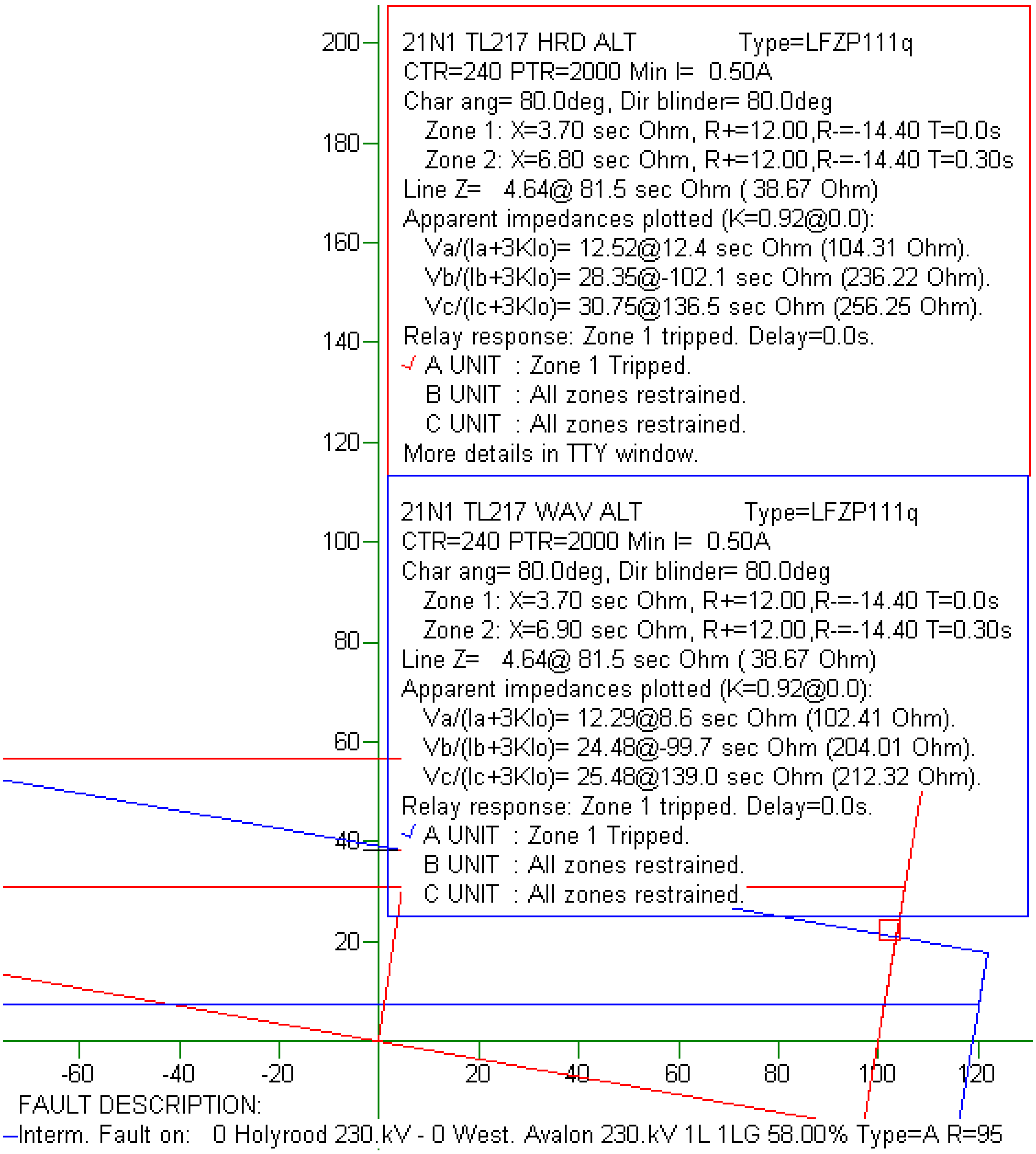


Figure 6 - Apparent impedance of a resistive fault near the mid point of the line.

Settings of K attenuators

KZPh Coarse setting common to all DISTANCE zones should be set as high as possible while below the required Zone 1 reach. The current level detectors vary inversely with KZph. Maximum setting available is 1.0

$KZPh := 1.0$

Zone 1 attenuators and angular selection

$In := 5$ $\quad Z1\_sec = 3.7$ This is the desired secondary reach (previously calculated)

$$KZ1 := \frac{Z1\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ1 = 3.7 \qquad Z1sec\_reach := KZ1 \cdot KZPh \cdot \frac{5}{In} \qquad Z1sec\_reach = 3.7$$

$Z\theta PH := (\arg(Z1Linesec))$ $\quad Z\theta PH = 81.529 \cdot deg$

Rounded to the nearest 5 degrees $\quad Z\theta PH := 80$ Degrees

$Z\theta N := \arg(Z0Linesec - Z1Linesec)$ $\quad Z\theta N = 82.714 \cdot deg$

Rounded to the nearest 5 degrees $\quad Z\theta N := 80$ Degrees

Zone 2 attenuators selection

$Z2\_sec = 6.9$ This is the desired secondary reach (previously calculated)

$$KZ2 := \frac{Z2\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ2 = 6.9$$

QUAD Resistive Reach setting

$Rquad = 12$ This is the desired secondary reach (previously calculated)

$$KR := \frac{Rquad}{\left(\frac{5}{In}\right)} \qquad KR = 12$$

Residual Compensation attenuators selection

Zero sequence current compensation for ground faults is provided by the KZN factor. Zero sequence mutual compensation is not used in this application (it causes extra complexity for only moderate gain in setting accuracy).

$$KZN := \frac{Z0Linesec - Z1Linesec}{3 \cdot Z1Linesec} \cdot KZPh \qquad KZN = 0.917 + 0.019j$$

$|KZN| = 0.917$ This is a reduction from the existing setting of 0.98

Switch On To Fault (SOTF) Protection.

If SOTF is enabled, it can be set to 200ms or 110 s after all poles of the line have been de-energized. The 110 s setting is intended to override automatic reclosing dead time. However it makes more sense to enable after the shorter time. Once the SOTF feature has been initiated, it remains in effect for 250ms after the line has been re-energized. The SOTF tripping options are:

a) Any distance comparator.
b) Any current level detector as long as a corresponding voltage level detector has not picked up within 20ms.
c) Either current or distance, as long as a corresponding voltage level detector has not picked up within 20ms.

SOTF := "Enabled"

SOTF_TIME := 0.20 Seconds

Elements_in_SOTF := "BOTH" (Both Comparators and current level detectors).

Power Swing Detector

This element will not be used. It will be left Blocked, and if there is a power swing, the distance elements will trip naturally.

VT Supervision

Set the VT supervision to BLOCK TRIP

Set the VT fail detection to SELF RESET.

Start Indication

This function will bring up information on the LCD screen of the relay if a start event occurs. This function will not be used.

START_INDICATION := "BLOCKED"

Communications assisted logic.

The existing communications assisted logic is permissive overreaching transfer trip, scheme **POR 1**. This scheme is familiar to Newfoundland and Labrador Hydro, and even though the POR 2 scheme offers the advantage of weak infeed echo, which would help the sensitivity to resistive faults, it is not recommended to change the existing scheme logic at this stage with years of experience on a product that is nearing the end of its useful life.

The POR 1 logic is a basic permissive overreaching transfer trip scheme but it does include current reversal timers to increase security against misoperation due to current reversal when a fault on the parallel line is cleared sequentially. The current reversal logic is achieved by a timer TP which will block permissive tripping and keying of permissive trip if the local zone 2 element does not pick up within a reasonable time of receiving permissive trip. The block will be maintained for a time delay of TD after the local zone 2 element picks up, or the received permissive trip signal resets.

The application of the current reversal timers is required only if the settings of the zone 2 comparators are greater than 1.5 times the line impedance .Although the reaches of these elements are only marginally less than 1.5 times the line impedance, there is no parallel line and there is infeed at each terminal that will minimize overreach. Therefore, the current reversal logic is not required, and the recommended default settings are as existing

$TP := 98$ ms

$TD := 0$ ms

Comparison of Existing (red) and Proposed alternative (ALT) settings.

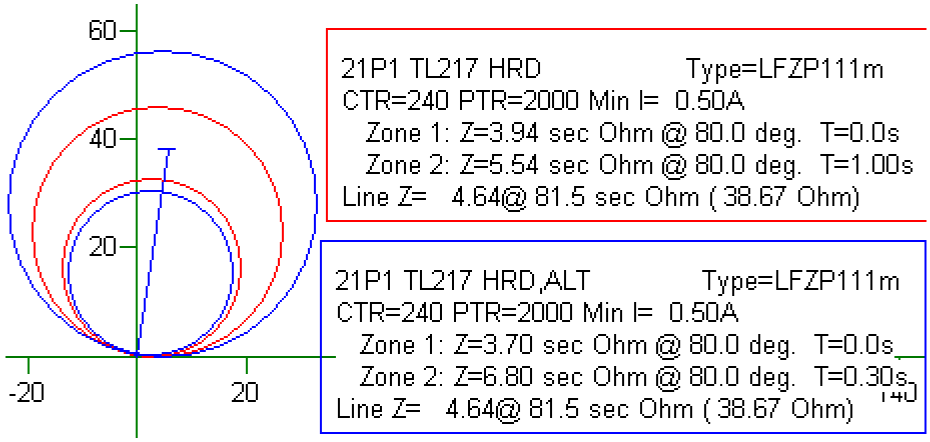


Figure 7 - Comparison of phase distance characteristics

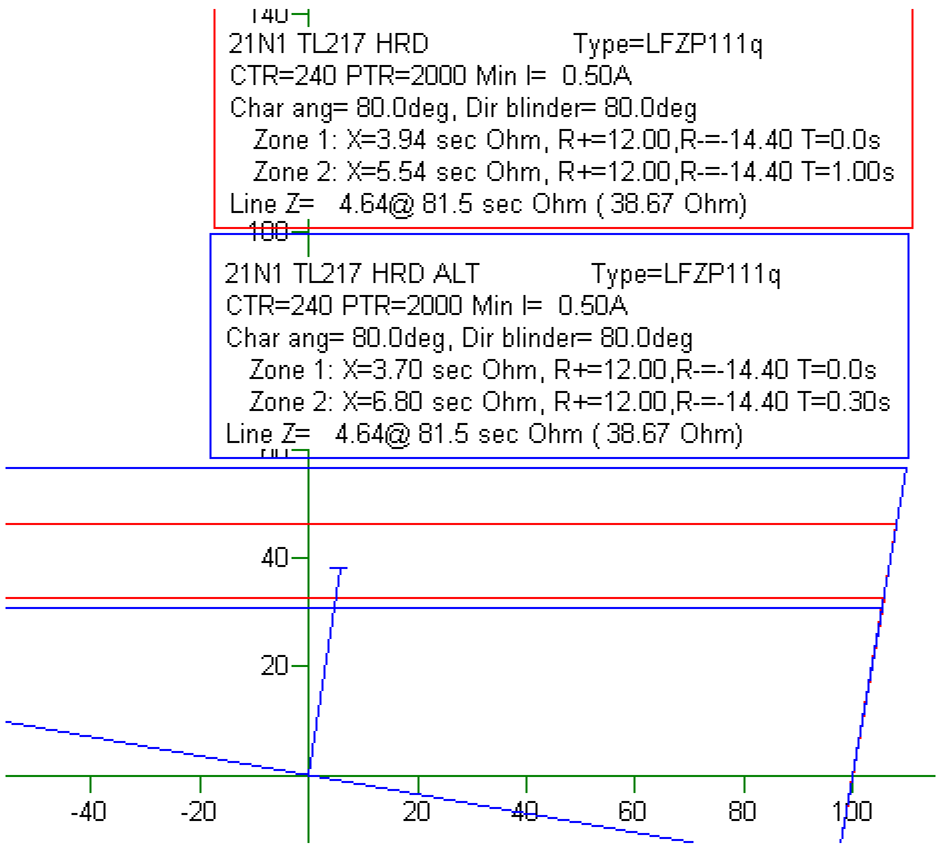


Figure 8 - Comparison of ground distance characteristics

Protection Review for Five 230 kV Transmission Lines

Appendix K
Detailed settings review for HRD TL217 "P2" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Holyrood Terminal (HRD) terminal of circuit TL217. This 230 kV transmission circuit is from HRD to Western Avalon (WAV).
The circuit runs parallel to Circuit TL201 for most of its length.

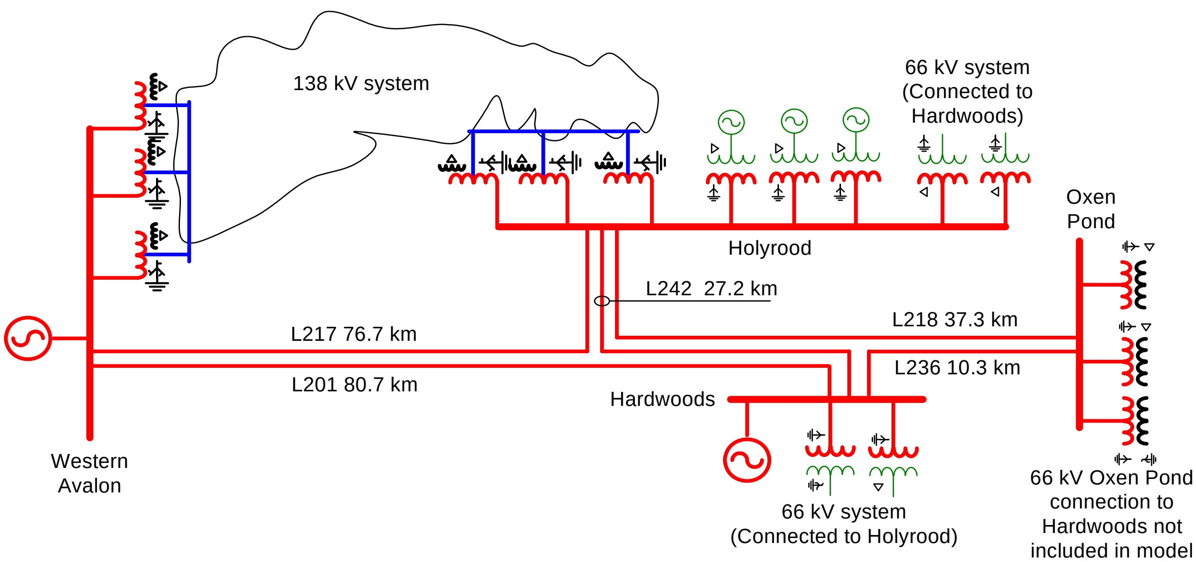


Figure 1 - System Single Line Diagram

Existing P2 protection systems are SEL321 systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $\quad kVbase := 230$ $\quad Ibase := \frac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\quad Zbase := \frac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $CTR := \frac{1200}{5}$ VT ratio is: $VTR := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**NL HYDRO WITH MUTUALS FOR EAST COAST 230 kV LINE PN REVIEW.OLR**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with loads and shunts ignored.

Minimum fault current seen by each terminal (phase to phase, and SLG with 0 ohm fault resistance).

At HRD, with two units off line, and both TL242 and TL218 in service, for a fault at the remote terminal.

$I3Pmin := 721$ A $\qquad ISLGminPH := 697$ A $\qquad ISLGmin0seq := 451$ A

The current for a phase to phase fault would be lower, but the current supervision element of the SEL321 measures phase to phase currents, and the phase to phase current for a phase to phase fault is twice the phase current.

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind HRD $\quad Z2minHRD := 1.0 + j\cdot 22$ ohms primary

$Z0minHRD := 0.38 + j\cdot 8.21$ ohms primary

Minimum source impedance behind WAV $\quad Z2minWAV := 3.2 + j\cdot 29.3$ ohms primary

$Z0minWAV := 1.84 + j\cdot 24.5$ ohms primary

<u>Line impedances</u>.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L217 := 0.01077 + j\cdot 0.07231 \qquad Z0L217 := 0.03629 + j\cdot 0.2719$

$Z1Line := Z1L217 = 0.011 + 0.072j$ pu $\qquad Z0Line := Z0L217 = 0.036 + 0.272j$ pu

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line\cdot Zbase \qquad Z0Linephys := Z0Line\cdot Zbase$

$Z1Linephys = 5.7 + 38.3i$ ohms primary $\qquad Z0Linephys = 19.2 + 143.8i$ ohms primary

Converting primary ohms to secondary ohms gives:

$$Z1Linesec := Z1Linephys\cdot\frac{CTR}{VTR} \qquad Z0Linesec := Z0Linephys\cdot\frac{CTR}{VTR}$$

$|Z1Linesec| = 4.64$ ohms sec $\qquad arg(Z1Linesec) = 81.5\cdot deg$

$|Z0Linesec| = 17.413$ ohms sec $\qquad arg(Z0Linesec) = 82.4\cdot deg$

Load Data

From 2011 System summer load case provided in start up information, the peak load (sum of TL217 and TL217) is given as 205 MVA (split between TL217 and TL217). In the event of sudden loss of one line, peak load will be the sum of both line loads until operators can adjust loads. Therefore it is assumed that peak load for a short duration is 205 MVA

$Speak := 205$ MVA $\qquad Smax := Speak = 205$ MVA

Max load in this line with TL201 in service is $\quad Smax\_L217 := 100$ MVA

P2 Relay Settings

Minor changes to the set line impedances are recommended to assist fault locations.

$Z1MAG := |Z1Linesec| \qquad Z1MAG = 4.64 \qquad Z1ANG := \frac{arg(Z1Linesec)}{deg} \qquad Z1ANG = 81.5$

$Z0MAG := |Z0Linesec| \qquad Z0MAG = 17.4 \qquad Z0ANG := \frac{arg(Z0Linesec)}{deg} \qquad Z0ANG = 82.4$

$LL := 76.63$

In order to obtain sensitivity to 100 ohm single line to ground faults, the echo function will be needed. Enable two forward and one reverse zone.

$PMHOZ := 3 \qquad GMHOZ := 3 \qquad QUADZ := 3$

$DIR1 := F \qquad DIR2 := F \qquad DIR3 := R$

Mho phase distance functions

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the HRD Station bus under light load conditions with two units at HRD out of service and both TL217 and TL217 lines in service. From ASPEN OneLiner, voltage at HRD for a 3 phase fault at HRD is 0.21 per unit. So there is plenty of voltage at HRD during a fault at HRD, even under weak source conditions.

Since the voltage is higher than 20%, the line is not considered short, and a conventional Zone 1 setting is acceptable.

$Z1P := 0.85 \cdot |Z1Linesec| \qquad Z1P = 3.94$ Ohms secondary

Existing setting of 3.94 ohms is OK, and will be retained. $\quad Z1P = 3.94$ Ohms secondary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 5.06 ohms secondary (about 109%) and should be increased to 125%. This will give a more comfortable dependability margin.

$Z2P := 1.25 \cdot |Z1Linesec| \qquad Z2P = 5.8$ Ohms secondary

As can be seen from Figure 2, this element significantly underreaches the zone 1 on TL237 (the shortest line out of WAV- not counting line TL208 to Long Harbour that has an overreaching zone 1 function) even without infeed. Therefore there is no problem with increasing the setting and retaining normal zone 2 time.

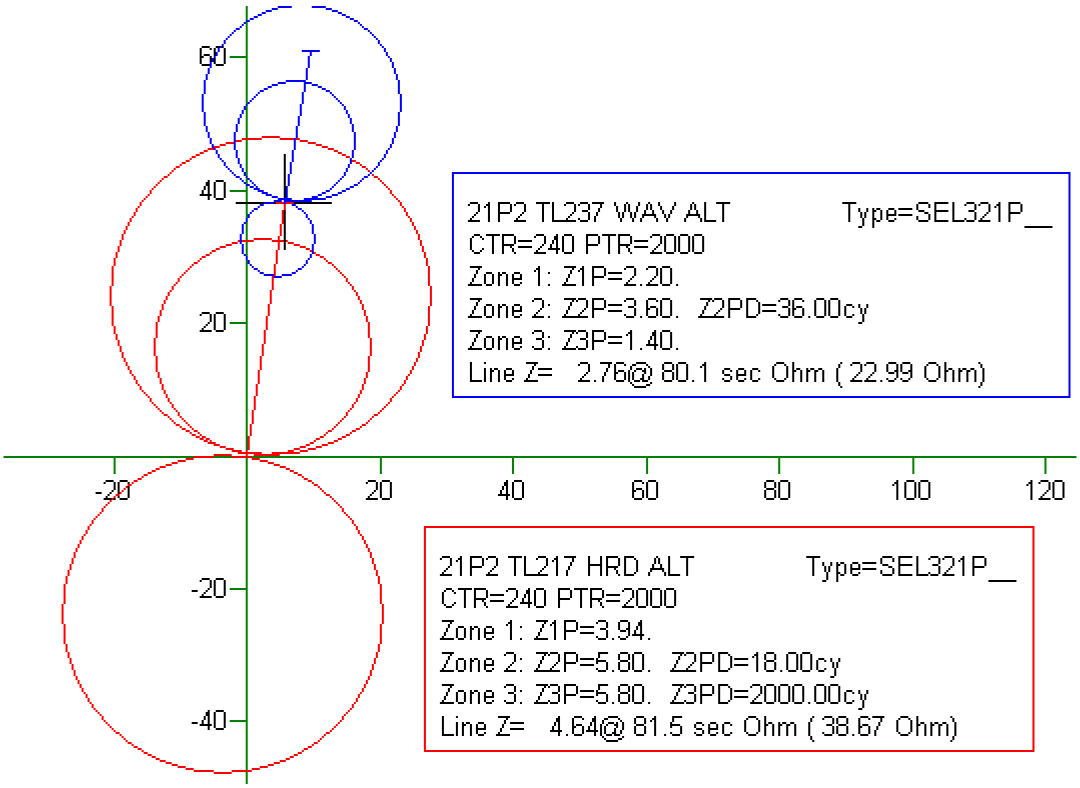


Figure 2 - Proposed new HRD TL217 Zone 2 securely underreaches WAV TL237 Zone 1 even without infeed. Normal zone 2 timing is secure for the Zone 2 function at HRD.

Because of secure coordination with the remote zone 1, the time delay on this element will be set to 0.3 second (as existing).

$Z2PD := 18$ Cycles

Zone 3

Set Zone 3 reverse element to reach further behind this terminal than the remote Zone 2. This function adds security for external faults. The element should always be more sensitive than the forward looking Zone 2 at the remote terminal. Due to the long overreach of the remote zone 2 ground distance element under some circumstances, set it the same as the remote Zone 2 using the line impedance as margin.

$Z3P := Z2P$ $Z3P = 5.8$ Ohms secondary

$\frac{Z3P}{|Z1MAG|} = 125 \cdot \%$ of line length

This is a much higher than the existing setting, but provides additional security.

Mho phase distance current supervision

If the current supervision elements can be set above load, they will be secure in the event that potential is lost. However given that loss of potential logic is available, it is recommended that only the zone 1 current supervision function be set above load. If potential is lost, it will be able to block tripping by Zone 2 before it trips on time delay or receives a permissive trip from the remote terminal.

For the point of view of current supervision being above maximum load, there is no need to worry about abnormal conditions. It would be a double contingency for the VT signal to be lost while the parallel line was out of service. Therefore, consider a maximum load of 100 MVA (with TL201 in service). The current supervision elements for the phase distance functions measure phase to phase currents.

$$IPPmax\_normal := \frac{Smax\_L217 \cdot 1000}{kVbase} \qquad IPPmax\_normal = 435 \text{ A primary}$$

The current supervision elements use phase to phase currents for supervision of the phase distance functions; so the minimum phase to phase fault current will be root three times the minim phase fault current. Choose a margin of 50% of the minimum phase to phase fault current for dependability.

$$IPPmin := 0.5I3Pmin \cdot \sqrt{3} \qquad IPPmin = 624 \qquad \text{A primary}$$

A setting of 480 A primary for 50PP1 will ensure the Zone 1 function operates for any fault even under minimum source conditions while remaining unable to trip on load due to loss of potential under any normal maximum load conditions. This is a little higher than the existing setting, but is quite dependable.

$'50PP1 := 2.0$ A Sec $\quad '50PP1 \cdot CTR = 480$ A primary

Since Zone 2 and zone 3 elements will be blocked by LOP function, set them at minimum. For zones 2 and 3, this is a little lower than the existing setting, but will be secure and dependable.

$'50PP2 := 1$ A Sec $\quad '50PP3 := 1$ A Sec

Ground Distance Protection

The reach of the ground distance functions will be affected by mutual coupling to the parallel line. These functions will tend to underreach the remote bus while the parallel line is in service, and overreach the remote bus if a parallel line is out of service and grounded at both ends. Figure 3 shows that for a remote close in fault on TL237, with 2L201 out of service and grounded, the apparent impedance of the line is reduced to about 4.06 ohms secondary instead of the nominal 4.64 ohms. This is 88% of the actual line impedance.

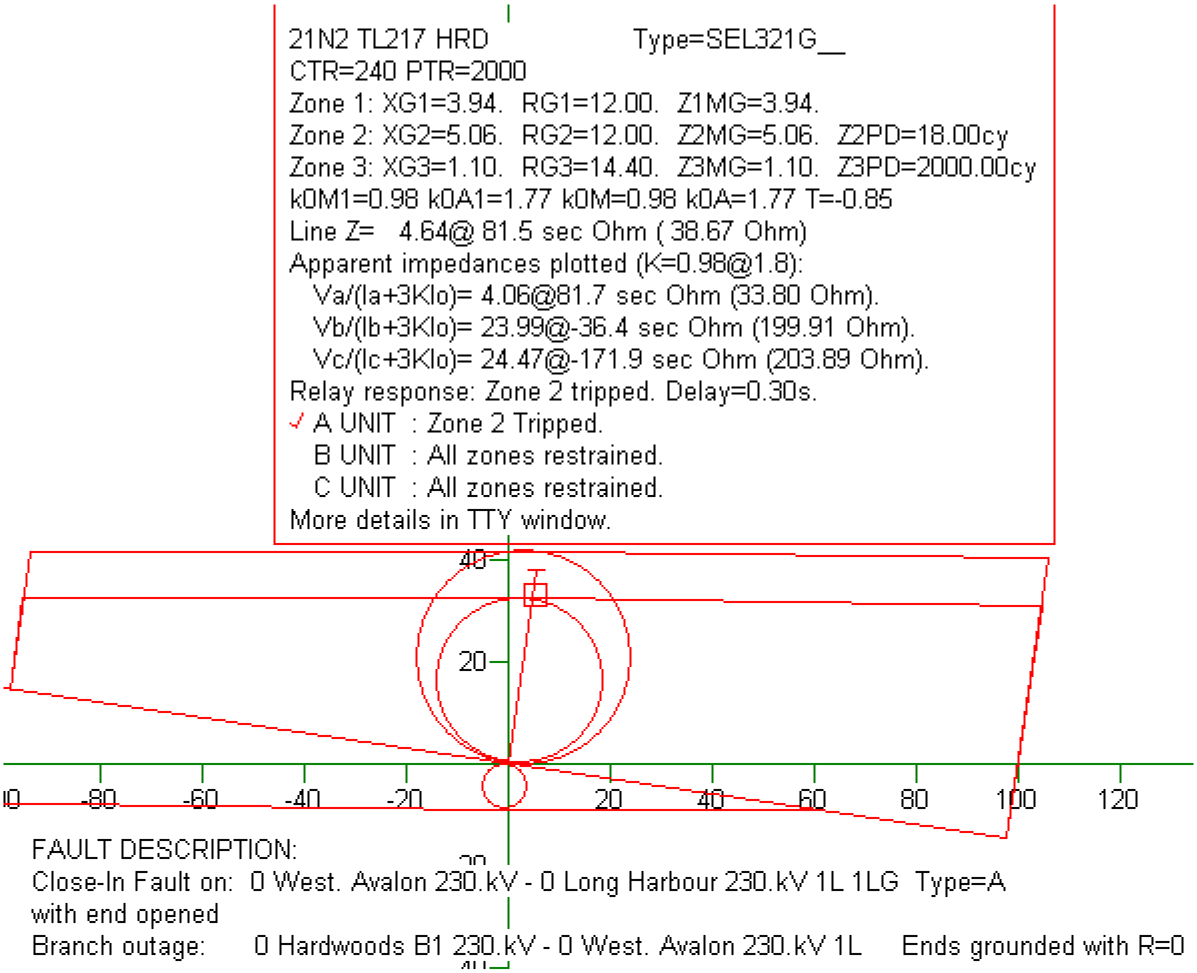


Figure 3 - Apparent impedance to a fault just beyond the remote terminal is reduced by 9% when TL201is out of service and grounded at both ends.

The reach of the zone 1 should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Choose a setting of 80% of line which will underreach the remote bus by 11% when the parallel line is out of service and grounded at both ends.

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.8$ per unit

$Z1MG := \text{round}(m \cdot |Z1Linesec|, 1)$ $Z1MG = 3.7$ Ohms secondary

$XG1 := Z1MG$ $XG1 = 3.7$ Ohms secondary

Zone 1 Resistance

The resistive reach of the Zone 1 quad should provide enough sensitivity to trip the local terminal immediately without waiting for permission from the remote terminal for a severe fault that depresses the voltage significantly. Further, it should not allow the function to reach beyond the remote terminal due to errors in relay measurement or CT or VT. In general, a reasonable limit for resistive reach of a zone 1 function is 4 times the reactive reach. If possible, it should operate for a 100 ohm SLG within 10% of the distance from the local terminal. Operation for a 100 ohm resistive fault at the 10% location will ensure this function can trip for a close in fault without assistance from the remote terminal. The remote terminal zone 2 function will be set to operate sequentially for this fault.

By simulating a fault with 100 ohms fault resistance at 10% of the distance from HRD, with the HRD terminal weak (two units off line) it is found that a reach of 16 ohms secondary is required to sense this fault. See Figure 4

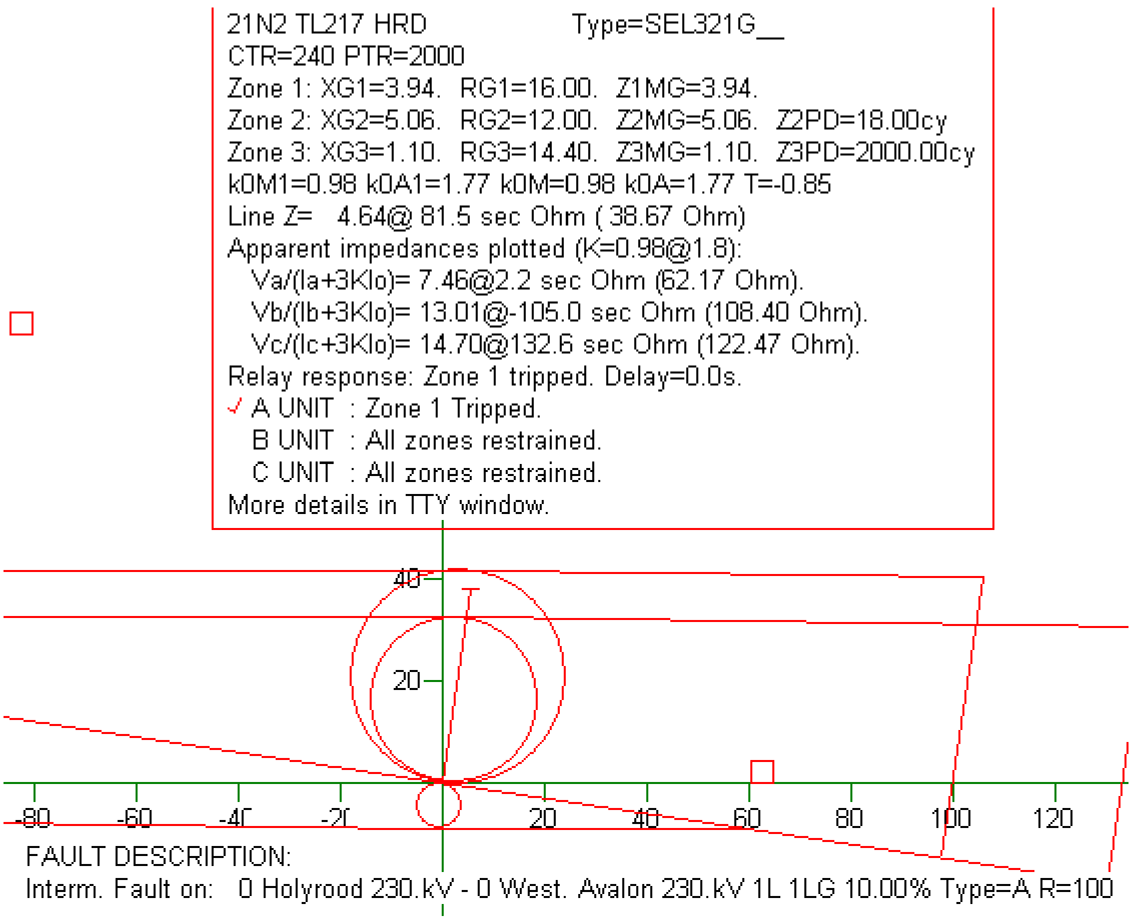


Figure 4 - HRD Zone 1 function if set with 16 ohm resistive reach, operates for a 100 ohm SLG fault at 10% from the local terminal.

The existing 12 ohm secondary resistive reach of the zone 1 element will not sense this fault, and should be increased to 16 ohms secondary. Check whether this reach will be secure, considering possible CT and VT errors.

XG1 is set at m per unit of the transmission line. The imaginary component of the line is

$ImXG1sec := Im(Z1Linesec)$ $\qquad ImXG1sec = 4.59$ ohms

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$RG1 := \mathrm{round}[(1 - m)\cdot 20\cdot ImXG1sec, 2]$

$RG1 = 18.36$ This is the maximum secure setting for the resistive reach and is above the proposed zone 1 resistive reach setting..

Use the proposed setting of 16 ohms for RG1 $RG1 := 16$ ohms secondary

With a resistive reach setting of 17 ohms, the HRD Zone 1 quad element will see an 60 ohm resistive SLG fault at 50% of the distance from HRD. Zone 2 protection will be depended upon to sense faults with resistance up to 100 ohms.

Zone 2 Ground Distance Protection

The Zone 2 ground distance function will need to be set longer than the Zone 2 phase distance protection function because it will tend to underreach the remote terminal while the parallel line is in service. By simulation in ASPEN OneLiner it is found that the apparent impedance to a zero ohm fault close in to the remote terminal is 5.54 ohms secondary, or 19% more than the actual line impedance. The reach of the Zone 2 ground distance element should be set at least to 1.25 times the apparent impedance.

$ZSLG\_remote := 5.54$

$Z2MG := \mathrm{round}(1.25\cdot ZSLG\_remote, 1)$ $Z2MG = 6.9$ Ohms secondary

The quad element reactive reach will be set similarly to the mho.

$XG2 := Z2MG$ $XG2 = 6.9$ Ohms secondary

It would be desirable to set the resistive reach of the quad element to sense a 100 ohm SLG fault at 75% of the line with the local terminal weak. This would ensure overlap with the zone 1element at the remote terminal. However, that would require too much resistive reach. Therefore choose a setting to sense a 100 ohm SLG fault just past the mid point of the line, and depend on the echo function to provide coverage for high resistance faults in the region where the remote zone 1 won't operate.

By trial and error from ASPEN it is found that a resistive reach of 25 ohms secondary will sense a 100 ohm SLG fault with an overlap with a similarly set remote zone 2 of 10% of the line length. See Figure 5. This will give positive overlap with the zone 2 element at the remote terminal. However since it will not overlap the Zone 1 element at the remote terminal, the permissive trip echo function will be required to ensure that a fault that is seen by the zone 2 element at only one terminal will still be cleared by the permissive trip logic.

Therefore, to avoid extremely large resistive reaches, and to retain sensitivity to 100 ohm resistive SLG faults, it is recommended that the echo function be enabled at both terminals.

$RG2 := 26$ Ohms secondary

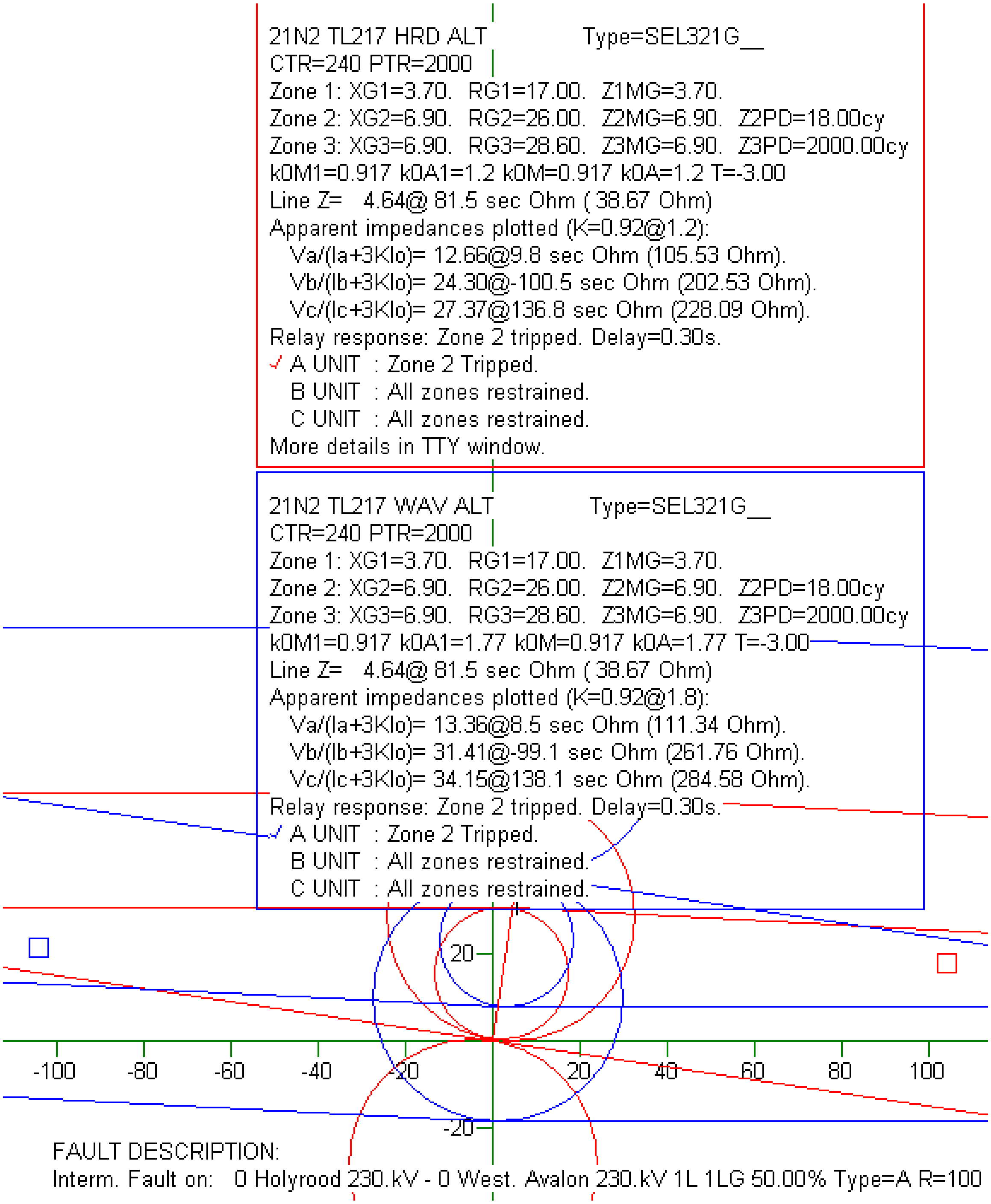
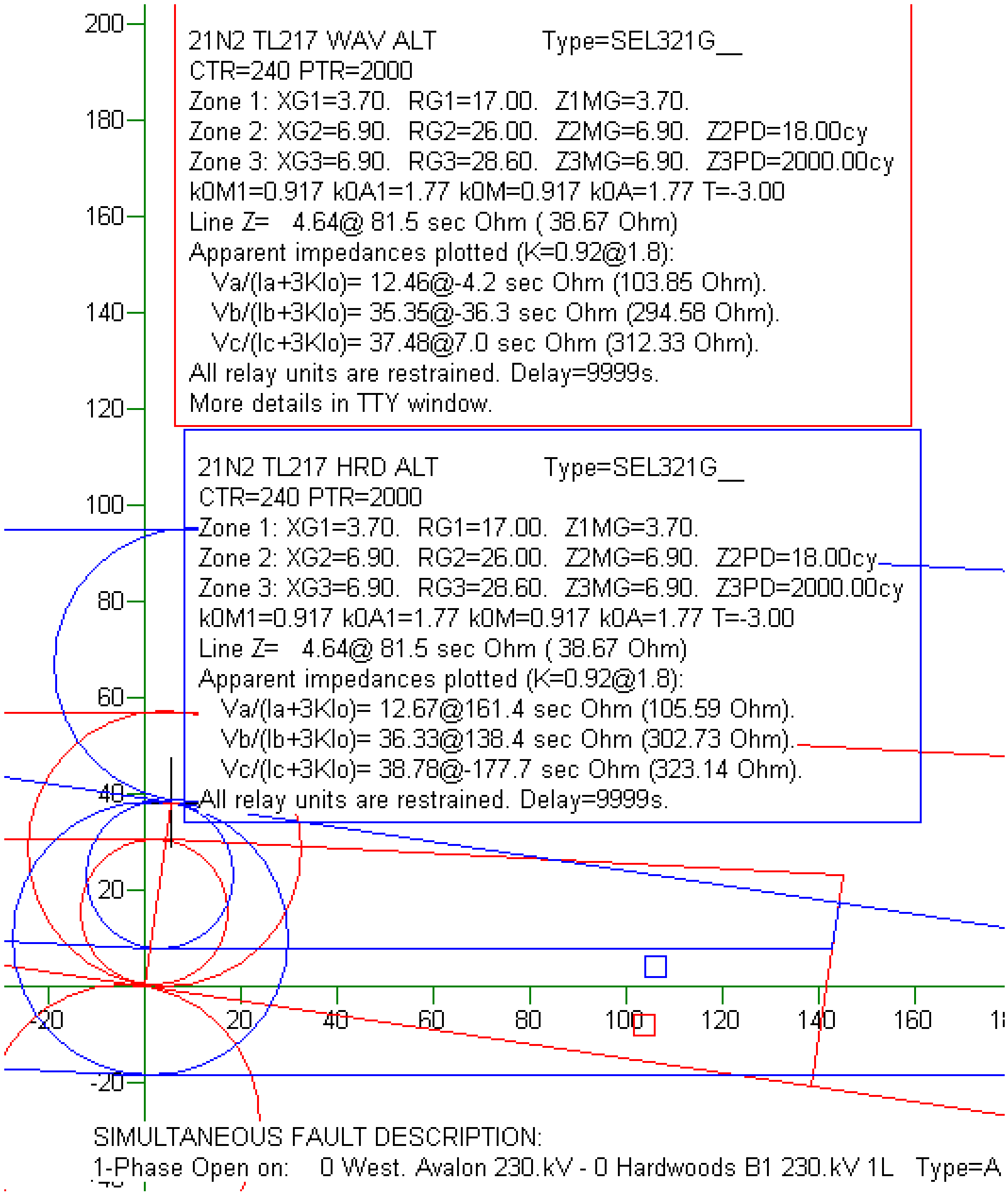


Figure 5 - Quad elements overlap with remote quad elements and operate for 100 ohm resistive SLG near the mid line location.

Check that this resistive reach won't cause the zone 2 function to trip while a parallel line is open single phase, with heavy power flow. See Figure 6. Unusually heavy power flow has been simulated to challenge security.



<ins>**Figure 6 - Quad elements are secure with extremely heavy load flow (190 MVA in TL217 and 300 MVA in TL201) while TL201 is open single pole.**</ins>

Zone 3

The zone 3 ground mho function will be set using the same principles as the zone 3 phase distance function. Use the setting for local zone 2 in secondary ohms as the remote zone 2.

$Z2MGrem := Z2MG$ ohms secondary

$Z3MG := Z2MGrem$ $Z3MG = 6.9$ Ohms secondary

$\frac{Z3MG}{|Z1MAG|} = 148.7 \cdot \%$ of line length This is much higher than the existing setting, but provides additional security.

$XG3 := Z3MG$ $XG3 = 6.9$ Ohms secondary

Set the Zone 3 quad resistive reach at 10% more than the remote Zone 2. Although the remote zone 2 has a different CT ratio, the setting is the same as the local zone 2 in primary ohms. Therefore use the setting for local zone 2 in secondary ohms as the remote zone 2.

$RG2rem := RG2$ Ohms secondary $RG3 := RG2rem \cdot 1.1$ $RG3 = 28.6$ Ohms secondary

Ground distance current supervision

Since there is no concern about these elements operating on load, even with loss of potential, set all current supervision elements at minimum, for maximum sensitivity of the distance elements.

$'50L1 := 0.5$ A Sec $'50L2 := 0.5$ A Sec $'50L3 := 0.5$ A Sec

$'50G1 := 0.5$ A Sec $'50G2 := 0.5$ A Sec $'50G3 := 0.5$ A Sec

Note that due to heavy infeed of zero sequence currents from the local terminal for close-in faults, the ground overcurrent detectors will not operate for faults with more than a small amount of resistance close to the remote terminal. Therefore, we will have to rely on sequential clearing for that type of fault. However setting the current supervision at minimum allows maximum sensitivity.

Zero sequence current compensation

The zero sequence current compensation could be adjusted to compensate for the significant amount of mutual coupling. However as discussed in the settings of reaches of the ground distance elements we will accept underreach of the Zone 2 function for the normal case by setting it at 125% of the apparent impedance for a remote fault. Set the zero sequence current compensation as usual.

$$k01M := \left(\left|\frac{Z0Line - Z1Line}{3 \cdot Z1Line}\right|\right) \qquad k01M = 0.917$$

$$k01A := \left(\arg\left(\frac{Z0Line - Z1Line}{3 \cdot Z1Line}\right)\right) \qquad k01A = 1.19 \cdot deg$$

Set the overreaching zones the same as zone 1 $k0M := k01M$ $k0A := k01A$

$k0M = 0.917$ $k0A = 1.19 \cdot deg$

Non Homogenous Angle Setting

Compare the angle of the remote zero sequence source impedance with the total zero sequence source impedance to the fault to determine this setting.

$$T := \arg\left(\frac{Z0minHRD + Z0Linephys + Z0minWAV}{Z0minWAV}\right) = -2.6 \cdot deg \qquad T = -3 \cdot deg$$

Out of step blocking and tripping

Not used in this application. There is a danger of out of step conditions arising. Historically no action has been taken to provide special tripping or blocking functions. Natural tripping during swings is accepted.

Load Encroachment logic

Check loadability of the Zone 2 phase distance element assuming worst case power factor of 0.87 simultaneous with worst case depressed voltage of a stressed system of 0.85 per unit. Note that units of kV squared match units of MVA. Note that quadrilateral elements are only used for the ground distance functions that are not sensitive to balanced three phase load. Therefore no need to worry about the reach of the quadrilateral elements.

$$\text{Zloadmin} := \frac{(0.85\text{kVbase})^2}{\text{Smax}} \qquad \text{Zloadmin} = 186.44$$ Ohms primary (assume worst case at 30 degrees)

Maximum reach of the Zone 2 element is at the line angle of 81 degrees. At 30 degrees, the reach will be given by

$$\text{Z2load} := \text{Z2P}\cdot\cos[(\text{Z1ANG} - 30)\text{deg}] \qquad \text{Z2load} = 3.609$$ ohms secondary

$$\text{Z2load}\cdot\frac{\text{VTR}}{\text{CTR}} = 30.075$$ ohms primary

Since the reach of the Zone 2 element at 30 degrees is less than the apparent impedance of the maximum load, there is no need to apply load blinding logic. See Figure 7

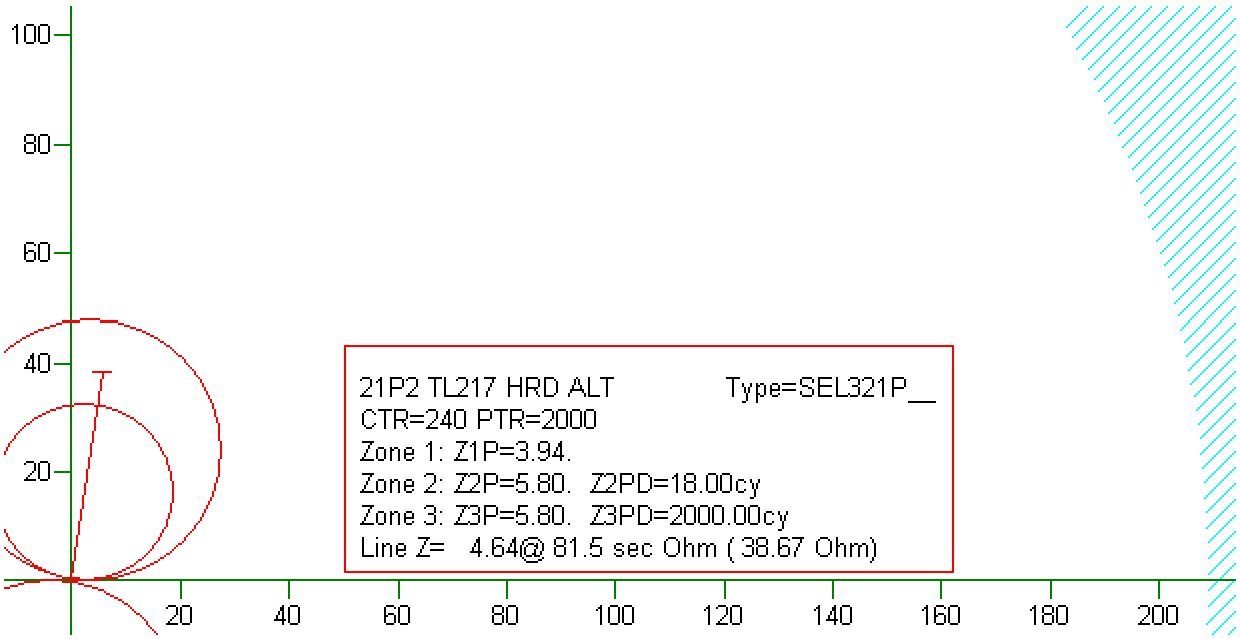


Figure 7 -Load impedance with respect to proposed new Mho function reaches.

Ground directional element

The SEL-321 application example recommends finding the minimum source impedance behind the terminal and setting the reverse and forward boundaries of the negative sequence directional element at the 1/3 and 2/3 points respectively.
In the negative sequence plane, the sum of the two source impedances and the line impedance is:

$$Z2total := Z2minHRD + Z1Linephys + Z2minWAV$$

The 1/3 point is $Z2\_1\_3 := \frac{Z2total}{3}$ The 2/3 point is $Z2\_2\_3 := \frac{2Z2total}{3}$

$Z2Rpri := Z2\_2\_3 - Z2minHRD$ $|Z2Rpri| = 38.115$

$Z2Fpri := Z2\_1\_3 - Z2minHRD$ $|Z2Fpri| = 8.18$

Converting the primary impedances to secondary ohms

$Z2R := Z2Rpri \cdot \frac{CTR}{VTR}$ $|Z2R| = 4.574$ Ohms secondary $\arg(Z2R) = 81.554 \cdot deg$

$Z2F := Z2Fpri \cdot \frac{CTR}{VTR}$ $|Z2F| = 0.982$ Ohms secondary $\arg(Z2F) = 73.677 \cdot deg$

Rounding up Z2F and rounding down Z2R gives:

$Z2F := 0.4$ Ohms secondary $Z2R := 4.3$ Ohms secondary

These are significantly lower than to the existing settings.

Set the current level detectors at minimum level that will allow operation of the ground distance elements.

Due to the very small zero sequence current contribution to a single line to ground fault at the remote terminal, the negative sequence current contribution will always be higher than the zero sequence. Therefore there is no point in setting the forward looking negative sequence overcurrent elements any more sensitively than the zero sequence ground overcurrent supervision of the ground distance elements.

$'50QF := '50G2$ $'50QF = 0.5$ A secondary

Set the supervision function for the reverse looking element to be the same as, or a little more sensitive than the forward looking supervision element at the remote terminal.

$'50QR := 0.5$ A secondary

The positive sequence current restraint (a2) factor should be set just smaller than the ratio of the maximum load current (positive sequence) to the most sensitive current supervision element (50QR).

$I1maxpri := \frac{Smax \cdot 1000}{kVbase \cdot \sqrt{3}}$ $I1maxsec := \frac{I1maxpri}{CTR}$ $I1maxsec = 2.144$

Bearing in mind that the 50QR setting is in units of 3*I2

$\frac{'50QR}{3 \cdot I1maxsec} = 0.078$ Choose a value of $a2 := 0.08$

The proposed new setting of a2 is a little higher than the existing setting (0.07).

Phase time overcurrent element

This element is not used

Residual time overcurrent element

This element is used to provide the most sensitive backup protection. It will be a non directional element.

Set pickup to sense a higher resistance than 100 ohm SLG in the middle of the line with equal zero sequence current infeed from both ends. Choose a resistance of 200 ohms arbitrarily. Use a safety factor of 2 so that operating time is not infinity at this fault level.

$SF := 2$ Desensitization factor due to remote end infeed is $Dfactor := 2$ $Rf := 200$

$$'51NPU := round\left(\frac{kVbase \cdot 1000}{\sqrt{3} \cdot SF \cdot Dfactor \cdot Rf \cdot CTR}, 1\right) \qquad '51NPU = 0.7$$

The existing setting of 0.5 A is more sensitive than required to sense this mid line fault with arbitrary resistance. Since TL206 experience with the high resistance tree fault on 28th August 2009 has shown value in the existing setting, it will be retained.

$'51NPU := 0.5$ A secondary

Coordination checks show that existing time dial settings will coordinate with each other. See Figures 8 and 9

$'51NPU = 0.5$ A secondary $'51NPU \cdot CTR = 120$ A primary

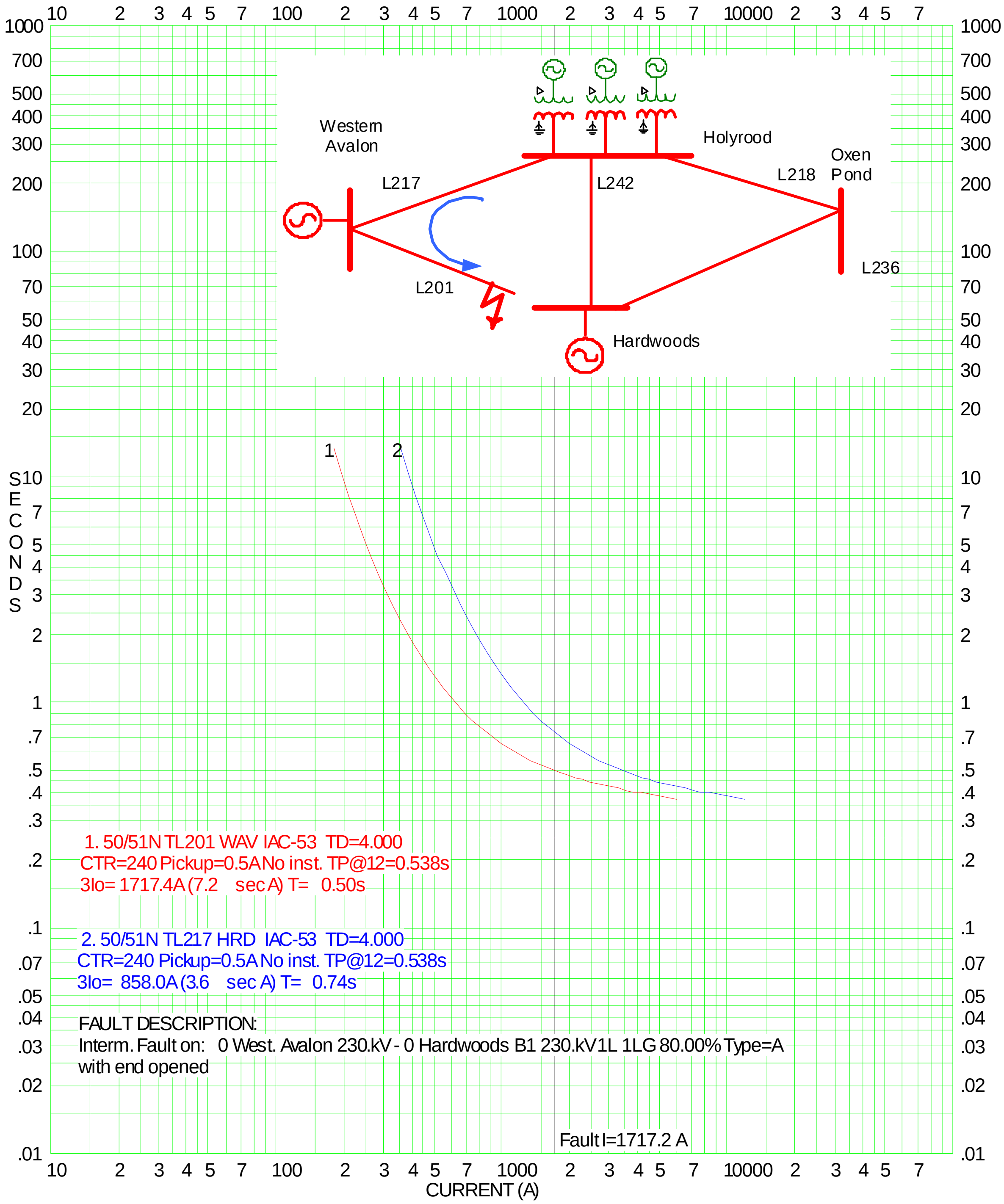
$'51NTD := 4$ $'51NC := "U3"$ $'51NTC := "N"$ $'51NRS := "N"$

Checks for close-in fault show that this element will not operate in less than 0.39 seconds so there is no danger of it tripping 3 pole before the zone 1 element trips the faulted phase selectively.

Check the coordination above the WAV TL201 protection for a fault at 80% of the distance to HRD. See Figure 8. It can be seen that the existing setting is only marginally slower than the WAV TL201 protection for a 0 ohm fault. For this type of fault we can rely on the 0.3 second time of the zone 4 ground distance function at WAV. For resistive faults the current will be much lower and the ground time overcurrent functions will coordinate satisfactorily.

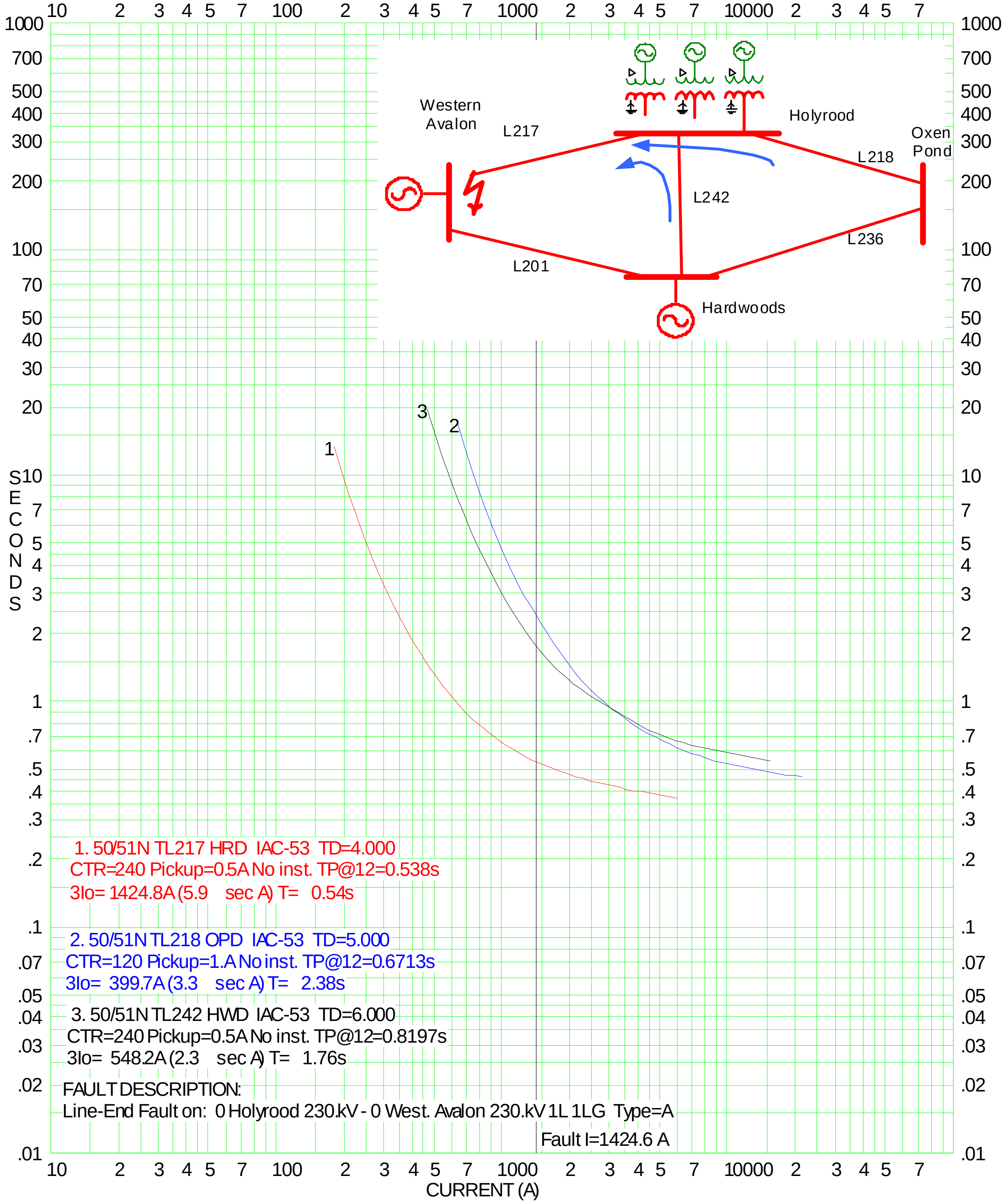
Check the coordination below the HWD TL242 51N and below the OPD TL218 51N for a line end fault on TL217 with two HRD units off line. This is the type of fault that will produce the most sensitivity (least desensitization) with respect to the backup protection on TL242 and TL218. see Figure 9. Coordination margin is satisfactory.

Worst case load unbalance with single pole open will be in the future if single pole tripping is enabled with parallel line out of service. ASPEN OneLiner shows that with 250 MVA of load on this line (considerably more than existing maximum possible load), and with one phase open, the 3I0 current is approximately 430 A. The 51N relay with existing settings will take approximately 1.6 seconds to operate on 430 A primary. No danger of tripping on load unbalance during SPO time.



EC 230-4	TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For Coordination of WAV TL201 below HRD TL 217		No. EC 230-4a
Comment Requires Z1G and Z2G for coordination with RF <100 ohms		Date 13 Oct 2011

Figure 8 - coordination of ground time overcurrent elements for fault at 80% TL201



EC 230-6	TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For Coordination of HRD TL217 below OPD L218 and HWD L242		No. EC 230-6
Comment Two units out of service at HRD.		Date 29 Sep 2011

Figure 9 - coordination of ground time overcurrent elements for line end fault on TL217 close to WAV

Permissive Overreaching logic settings

EPOTT := "Y"

Z3RBD is set at remote breaker time plus channel reset time plus channel reset time plus zone 2 reset time. From review of fault records it appears that the breaker time is 3 cycles. Channel reset time is not easily determined from existing records but can conservatively be assumed to be 1 cycle, and relay reset time will also be about 1 cycle. Total time for Z3RBD is then 5 cycles.

Z3RBD := 5 cycles

Echo block delay timer blocks the echo after the local elements have picked up. This can be set relatively long since there is no significant need for the echo function shortly after the local terminal has just seen a fault but the remote terminal has not. Set at 10 cycles as per the example in the instruction manual.

EBLKD := 10 cycles

Echo time delay on pickup should be set to override noise on the communications so that it doesn't echo noise. Typical time according to the SEL application guide is 2 cycles. Since this delay only affects clearing time for relatively light (high resistance) faults that are sensed by zone 2 function at one end, the typical setting is acceptable.

ETDPU := 2 cycles

Echo duration should be long enough to ensure the permissive trip is received by the remote terminal and should also be shorter than the Z3RBD time to ensure that the reverse blocking will always be longer than any permissive trip received (including echo time stretching).

EDURD := 4 cycles

No need to enable week feed conversion to trip, since both terminals will be quite sensitive enough to detect high resistance faults after the remote terminal has cleared. Therefore we can accept sequential (or "step") clearing with no need for the added insecurity of weak infeed tripping.

EWFC := "N" **No other communications logic settings are required for this application.**

Switch on to Fault Settings

Switch on to fault logic will ensure the protection will operate when energizing the line onto a close-in three phase fault when there is no polarizing voltage available for the distance elements.

ESOTF := "Y"

The breaker close signal is not available to the relay. The 52A method of enable SOTF will be used. Therefore the Close end delay is not critical. Typical duration for enable SOTF is 10-15 cycles

ENCLO := "N" CLOEND := 0 EN52A := "Y" SOTFD := 15

Set 50H for high magnitude close-in multiphase faults with weakest source at HRD. It should be set less than 50% of the minimum close-in fault magnitude. Minimum close-in magnitude of a three phase fault with two units off line and TL242 out of service is 3000 A. Therefore desired maximum setting for 50H is 1500 A.

Imin3P_close_in := 3000

$$'50H := \frac{\text{Imin3P\_close\_in}}{2\text{CTR}} \qquad '50H = 6.25 \quad \text{A secondary}$$

Choose a setting of 6 A secondary for this element. '50H := 6 A secondary

Choose a setting for 52AEND less than the shortest reclose time. '52AEND := 30 cycles

The existing setting of 52AEND is 60 cycles. It is not known why the setting is set longer than the reclosing time.

Residual overcurrent settings.

Tripping directly by instantaneous ground overcurrent is not applicable because it is not phase selective. However it would be helpful to monitor steady state unbalance, and issue an alarm for continuous unbalance. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50N := 1$ $\quad$ $'50N1 := 0.25$

Negative Sequence overcurrent settings.

Similar to ground overcurrent, apply a negative sequence overcurrent element to initiate an alarm for steady state unbalances. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50Q := 1$ $\quad$ $'50Q1 := 0.25$

Voltage Element Settings

Similar to unbalance current monitoring, it is helpful to have an unbalance voltage monitor to detect steady state unbalances from the voltage supply.

$EVOLT := "Y"$

Set the zero sequence overvoltage element at 1% of rated voltage or just at the point necessary to override normal unbalances. The zero sequence voltage element measures 3 times the zero sequence voltage.

$$'59N := 3 \cdot 0.01 \frac{kVbase \cdot 1000}{\sqrt{3} \cdot VTR} \qquad '59N = 1.992$$

Say $'59N := 2$ V secondary

Loss of Potential

Enable loss of potential settings. Advanced LOP settings are not available on this model of relay.

$ELOP := "Y"$ $\quad$ Time delay of 1.25 cycles is commonly used. $\quad$ $LOPD := 1.25$

The 50 M element should be set above maximum load and below minimum fault current for a fault at the remote terminal under weak source conditions. The maximum load for this case should be normal maximum, not emergency maximum which only exists for a few minutes before the operator can act to reduce load.

$$Imax\_normal := \frac{Smax\_L217 \cdot 1000}{\sqrt{3} \cdot kVbase \cdot CTR} = 1.046$$ A secondary

Minimum fault current for a remote three phase fault is $\quad I3Pmin = 721 \quad$ A primary.

Minimum fault current for a remote phase to phase fault is 87% of the minimum three phase fault current level.

Dependability factor to be sure to operate for a minimum remote fault is chosen to be 1.6. $\quad DF := 1.6$

Maximum setting for 50M should be $\dfrac{0.87 I3Pmin}{DF \cdot CTR} = 1.634$ $\quad$ In this case a setting of 1.7 A secondary will be adequately dependable and secure.

$'50M := 1.6$ A secondary

The 59QL setting should be above normal maximum unbalance and below the level expected for a blown VT fuse. For a blown fuse, one phase voltage will be lost, and the negative sequence voltage will be roughly 33% of the nominal positive sequence voltage. Choose a setting of 15% of the nominal positive sequence voltage. This will be well above any normal unbalance.

$$'59QL := \mathrm{round}\left(\frac{0.15 \cdot kVbase \cdot 1000}{\sqrt{3} \cdot VTR}, 0\right)$$ $'59QL = 10$ V secondary

The 59PL setting should be less than the minimum voltage to be expected for a remote bus fault under weakest source conditions. There is no minimum setting (above zero) for this function. Choose a setting equal to half the voltage drop along the line impedance at the pickup setting of the 50M element.

$$'59PL := \mathrm{round}[0.5 \cdot ('50M \cdot |Z1Linesec|), 0]$$ $|'59PL| = 4$

Miscellaneous Scheme Settings

Pole discoordinance logic is not being used. EPOLD := "N" SPPDD := "N/A"

Enable single pole tripping by distance elements only ESPT := "Y"

Enable single pole open ESPO := "Y"

Set single pole open time delay for future SPO conditions SPOD := 0.25

Note that SPOD was short enough to allow a transient operation when TL201 was reclosed with a fault on it during the fault of 7 March 2011. This transient operation was helpful to clear the fault more quickly than it otherwise would have cleared. SEL have been asked whether the SPOD setting of 0.5 would be better to increase the security.

3 Pole open reset delay to override small discrepancies in pole closing '3POD := 0.5

Stub line protection is not required ESTUB := "N" '50MFD := "N/A"

Trip unlatch logic not applied TULO := "N"

Logic variables and Miscellaneous timers

Minimum trip duration timer is set at 9 cycles as per the application example in the SEL-321 instruction manual.

TDURD := 9 Cycles

Trip during open pole time delay should be set longer than the reclose time. Existing reclose time is 55 cycles. This is acceptable.

TOPD := 55 Cycles

Existing logic variables are not used.

Add the use of ZT to trigger an alarm for sustained unbalance.

LOGIC_Z := "59N+50N1+50Q1" TZPU := 1200 cycles TZDO := 0 cycles

Tripping Logic

Permissive tripping is required only for instantaneous overreaching functions. No need for any functions that trip directly. Existing 51NT word in MTCS is not required.

MTCS := "M2P+Z2G"

Existing settings for unconditional tripping are suitable

MTU := "M1P+Z1G+M2PT+Z2GT+51NT"

No need for existing direct tripping zone 1 functions in the switch on to fault logic.

SOTF Tripping MTO := "M2P+Z2G+50H"

Event records will be triggered automatically by all trip events. Other event record triggers should be by starting of other elements to ensure capture of all relevant events. Events should be triggered by keying or receiving permissive trips to ensure separation of relay and teleprotection issues.

MER := "M2P+Z2G+51NP+LOP*52AA1+LOP*52AA2+KEY+PT+EKEY"

Outputs

Retain existing output assignments except add the continuous unbalance alarm to OUT15.

OUT15 := "LOP*50L+ZT"

Input Contact Assignment

It would be desirable to provide phase segregated inputs to the relay so that the quadrilateral functions could be disabled during single pole open conditions. it is not known if phase segregated auxiliary switches are available on the breakers.

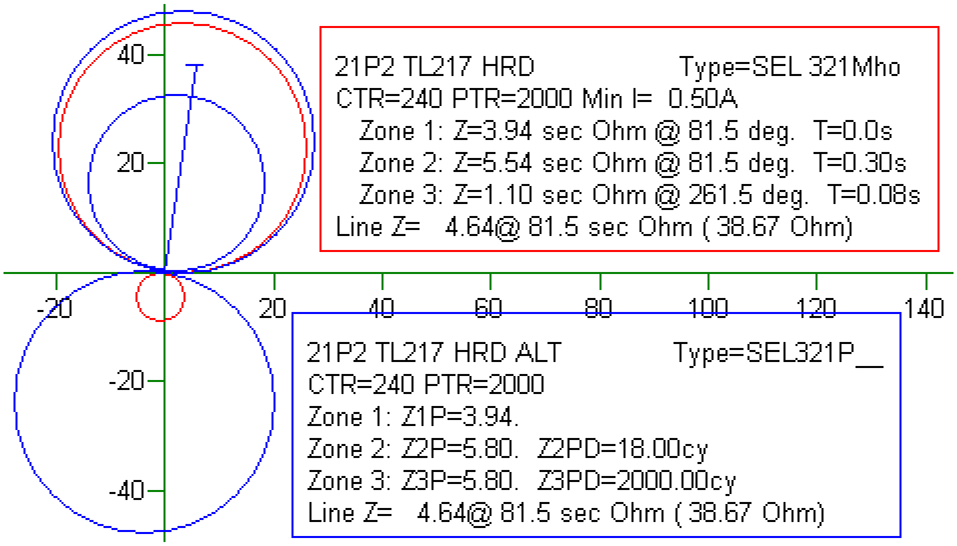


Figure 10 - Comparison between existing (red) and proposed new (blue) phase distance characteristics.

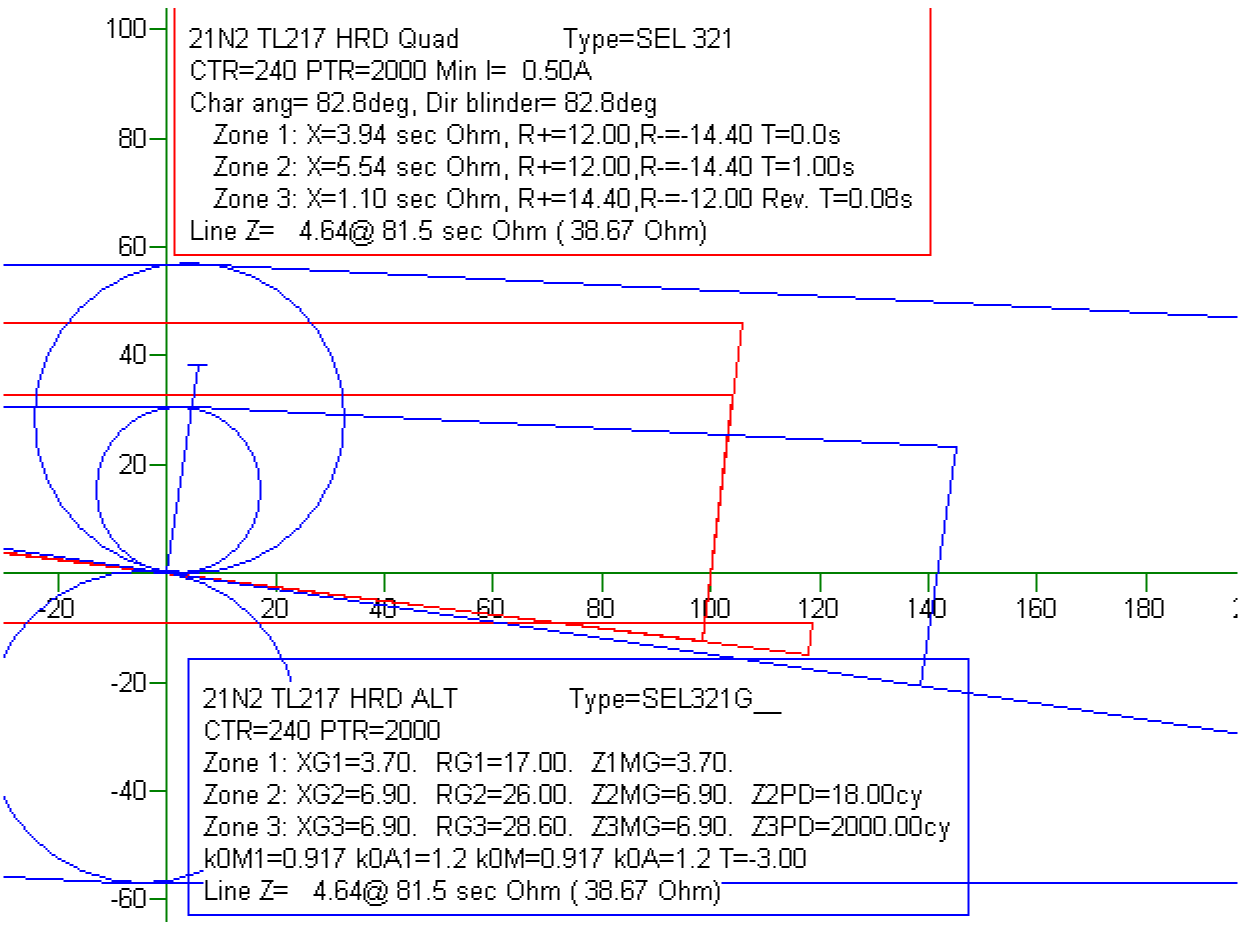


Figure 11 - Comparison between existing (red) and proposed new (blue) ground distance characteristics.

Protection Review for Five 230 kV Transmission Lines

Appendix K
Detailed settings review for HRD TL217 "P2" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Holyrood Terminal (HRD) terminal of circuit TL217. This 230 kV transmission circuit is from HRD to Western Avalon (WAV).
The circuit runs parallel to Circuit TL201 for most of its length.

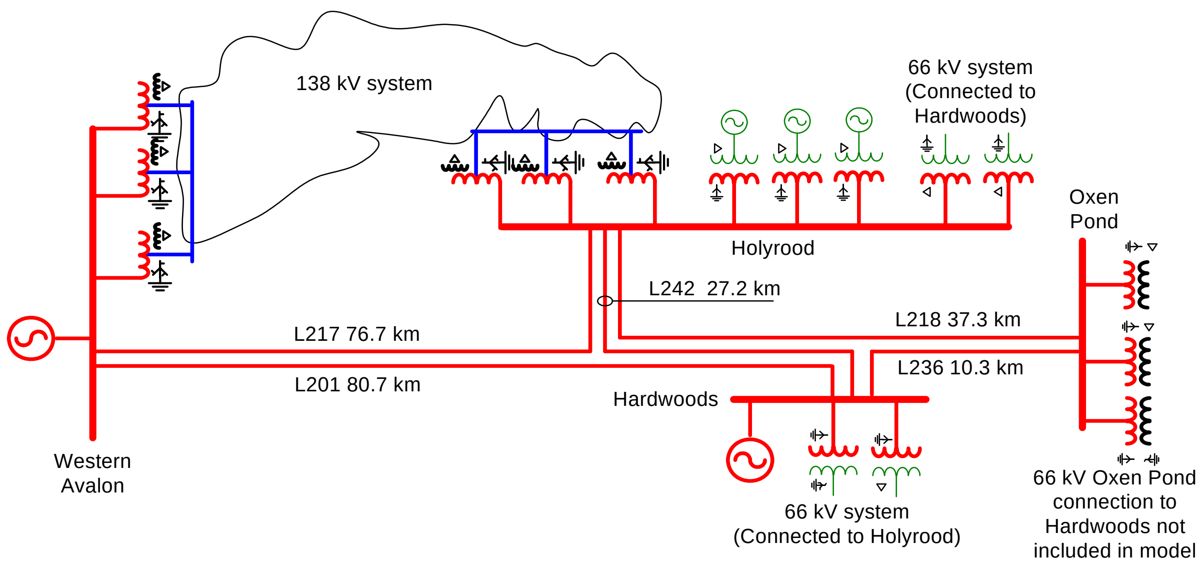


Figure 1 - System Single Line Diagram

Existing P2 protection systems are SEL321 systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $kVbase := 230$ $Ibase := \frac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $Zbase := \frac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $CTR := \frac{1200}{5}$ VT ratio is: $VTR := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**NL HYDRO WITH MUTUALS FOR EAST COAST 230 kV LINE PN REVIEW.OLR**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with loads and shunts ignored.

Minimum fault current seen by each terminal (phase to phase, and SLG with 0 ohm fault resistance).

At HRD, with two units off line, and both TL242 and TL218 in service, for a fault at the remote terminal.

$I3Pmin := 721$ A $\qquad ISLGminPH := 697$ A $\qquad ISLGmin0seq := 451$ A

The current for a phase to phase fault would be lower, but the current supervision element of the SEL321 measures phase to phase currents, and the phase to phase current for a phase to phase fault is twice the phase current.

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind HRD $\qquad Z2minHRD := 1.0 + j\cdot 22$ ohms primary

$Z0minHRD := 0.38 + j\cdot 8.21$ ohms primary

Minimum source impedance behind WAV $\qquad Z2minWAV := 3.2 + j\cdot 29.3$ ohms primary

$Z0minWAV := 1.84 + j\cdot 24.5$ ohms primary

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L217 := 0.01077 + j\cdot 0.07231 \qquad Z0L217 := 0.03629 + j\cdot 0.2719$

$Z1Line := Z1L217 = 0.011 + 0.072j$ pu $\qquad Z0Line := Z0L217 = 0.036 + 0.272j$ pu

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line\cdot Zbase \qquad Z0Linephys := Z0Line\cdot Zbase$

$Z1Linephys = 5.7 + 38.3i$ ohms primary $\qquad Z0Linephys = 19.2 + 143.8i$ ohms primary

Converting primary ohms to secondary ohms gives:

$$Z1Linesec := Z1Linephys\cdot\frac{CTR}{VTR} \qquad Z0Linesec := Z0Linephys\cdot\frac{CTR}{VTR}$$

$|Z1Linesec| = 4.64$ ohms sec $\qquad arg(Z1Linesec) = 81.5\cdot deg$

$|Z0Linesec| = 17.413$ ohms sec $\qquad arg(Z0Linesec) = 82.4\cdot deg$

Load Data

From 2011 System summer load case provided in start up information, the peak load (sum of TL217 and TL217) is given as 205 MVA (split between TL217 and TL217). In the event of sudden loss of one line, peak load will be the sum of both line loads until operators can adjust loads. Therefore it is assumed that peak load for a short duration is 205 MVA

$Speak := 205$ MVA $\quad Smax := Speak = 205$ MVA

Max load in this line with TL201 in service is $Smax\_L217 := 100$ MVA

P2 Relay Settings

Minor changes to the set line impedances are recommended to assist fault locations.

$Z1MAG := |Z1Linesec|$ $\quad Z1MAG = 4.64$ $\quad Z1ANG := \dfrac{arg(Z1Linesec)}{deg}$ $\quad Z1ANG = 81.5$

$Z0MAG := |Z0Linesec|$ $\quad Z0MAG = 17.4$ $\quad Z0ANG := \dfrac{arg(Z0Linesec)}{deg}$ $\quad Z0ANG = 82.4$

$LL := 76.63$

In order to obtain sensitivity to 100 ohm single line to ground faults, the echo function will be needed. Enable two forward and one reverse zone.

$PMHOZ := 3$ $\quad GMHOZ := 3$ $\quad QUADZ := 3$

$DIR1 := F$ $\quad DIR2 := F$ $\quad DIR3 := R$

Mho phase distance functions

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the HRD Station bus under light load conditions with two units at HRD out of service and both TL217 and TL217 lines in service. From ASPEN OneLiner, voltage at HRD for a 3 phase fault at HRD is 0.21 per unit. So there is plenty of voltage at HRD during a fault at HRD, even under weak source conditions.

Since the voltage is higher than 20%, the line is not considered short, and a conventional Zone 1 setting is acceptable.

$Z1P := 0.85 \cdot |Z1Linesec|$ $\quad Z1P = 3.94$ Ohms secondary

Existing setting of 3.94 ohms is OK, and will be retained. $\quad Z1P = 3.94$ Ohms secondary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 5.06 ohms secondary (about 109%) and should be increased to 125%. This will give a more comfortable dependability margin.

$Z2P := 1.25 \cdot |Z1Linesec|$ $\quad Z2P = 5.8$ Ohms secondary

As can be seen from Figure 2, this element significantly underreaches the zone 1 on TL237 (the shortest line out of WAV- not counting line TL208 to Long Harbour that has an overreaching zone 1 function) even without infeed. Therefore there is no problem with increasing the setting and retaining normal zone 2 time.

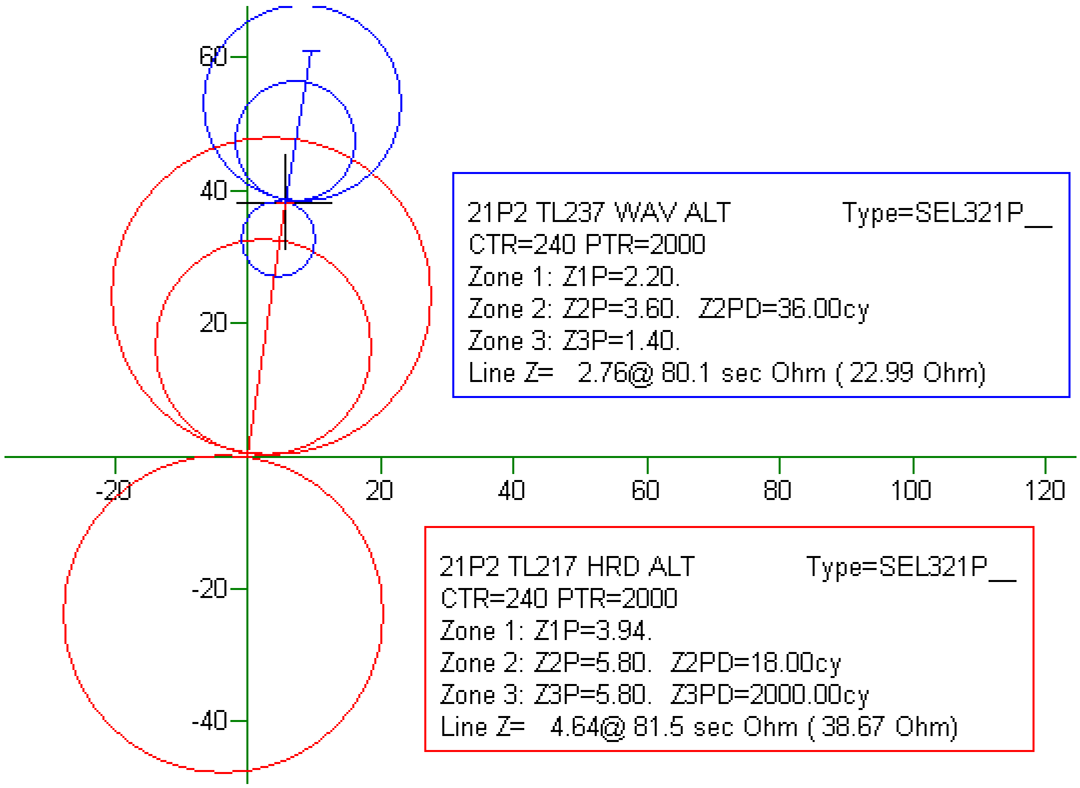


Figure 2 - Proposed new HRD TL217 Zone 2 securely underreaches WAV TL237 Zone 1 even without infeed. Normal zone 2 timing is secure for the Zone 2 function at HRD.

Because of secure coordination with the remote zone 1, the time delay on this element will be set to 0.3 second (as existing).

$Z2PD := 18$ Cycles

Zone 3

Set Zone 3 reverse element to reach further behind this terminal than the remote Zone 2. This function adds security for external faults. The element should always be more sensitive than the forward looking Zone 2 at the remote terminal. Due to the long overreach of the remote zone 2 ground distance element under some circumstances, set it the same as the remote Zone 2 using the line impedance as margin.

$Z3P := Z2P$ $\quad Z3P = 5.8$ Ohms secondary

$\frac{Z3P}{|Z1MAG|} = 125\cdot\%$ of line length $\quad$ This is a much higher than the existing setting, but provides additional security.

Mho phase distance current supervision

If the current supervision elements can be set above load, they will be secure in the event that potential is lost. However given that loss of potential logic is available, it is recommended that only the zone 1 current supervision function be set above load. If potential is lost, it will be able to block tripping by Zone 2 before it trips on time delay or receives a permissive trip from the remote terminal.

For the point of view of current supervision being above maximum load, there is no need to worry about abnormal conditions. It would be a double contingency for the VT signal to be lost while the parallel line was out of service. Therefore, consider a maximum load of 100 MVA (with TL201 in service). The current supervision elements for the phase distance functions measure phase to phase currents.

$$IPPmax\_normal := \frac{Smax\_L217 \cdot 1000}{kVbase} \quad IPPmax\_normal = 435 \text{ A primary}$$

The current supervision elements use phase to phase currents for supervision of the phase distance functions; so the minimum phase to phase fault current will be root three times the minim phase fault current. Choose a margin of 50% of the minimum phase to phase fault current for dependability.

$$IPPmin := 0.5I3Pmin \cdot \sqrt{3} \qquad IPPmin = 624 \qquad \text{A primary}$$

A setting of 480 A primary for 50PP1 will ensure the Zone 1 function operates for any fault even under minimum source conditions while remaining unable to trip on load due to loss of potential under any normal maximum load conditions. This is a little higher than the existing setting, but is quite dependable.

$$'50PP1 := 2.0 \quad \text{A Sec} \qquad '50PP1 \cdot CTR = 480 \qquad \text{A primary}$$

Since Zone 2 and zone 3 elements will be blocked by LOP function, set them at minimum. For zones 2 and 3, this is a little lower than the existing setting, but will be secure and dependable.

$$'50PP2 := 1 \quad \text{A Sec} \qquad '50PP3 := 1 \quad \text{A Sec}$$

Ground Distance Protection

The reach of the ground distance functions will be affected by mutual coupling to the parallel line. These functions will tend to underreach the remote bus while the parallel line is in service, and overreach the remote bus if a parallel line is out of service and grounded at both ends. Figure 3 shows that for a remote close in fault on TL237, with 2L201 out of service and grounded, the apparent impedance of the line is reduced to about 4.06 ohms secondary instead of the nominal 4.64 ohms. This is 88% of the actual line impedance.

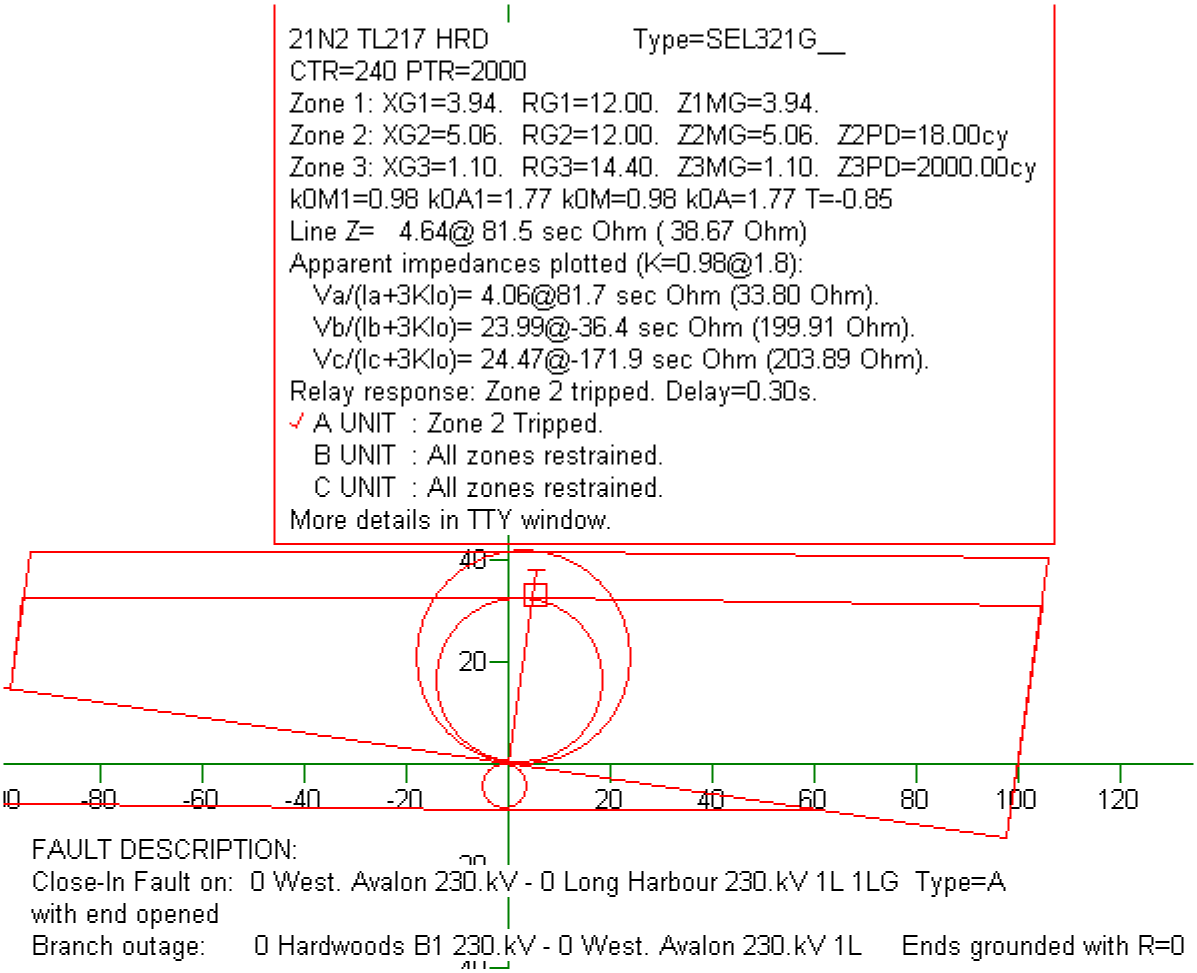


Figure 3 - Apparent impedance to a fault just beyond the remote terminal is reduced by 9% when TL201is out of service and grounded at both ends.

The reach of the zone 1 should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Choose a setting of 80% of line which will underreach the remote bus by 11% when the parallel line is out of service and grounded at both ends.

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.8$ per unit

$Z1MG := \text{round}(m \cdot |Z1Linesec|, 1)$ $Z1MG = 3.7$ Ohms secondary

$XG1 := Z1MG$ $XG1 = 3.7$ Ohms secondary

Zone 1 Resistance

The resistive reach of the Zone 1 quad should provide enough sensitivity to trip the local terminal immediately without waiting for permission from the remote terminal for a severe fault that depresses the voltage significantly. Further, it should not allow the function to reach beyond the remote terminal due to errors in relay measurement or CT or VT. In general, a reasonable limit for resistive reach of a zone 1 function is 4 times the reactive reach. If possible, it should operate for a 100 ohm SLG within 10% of the distance from the local terminal. Operation for a 100 ohm resistive fault at the 10% location will ensure this function can trip for a close in fault without assistance from the remote terminal. The remote terminal zone 2 function will be set to operate sequentially for this fault.

By simulating a fault with 100 ohms fault resistance at 10% of the distance from HRD, with the HRD terminal weak (two units off line) it is found that a reach of 16 ohms secondary is required to sense this fault. See Figure 4

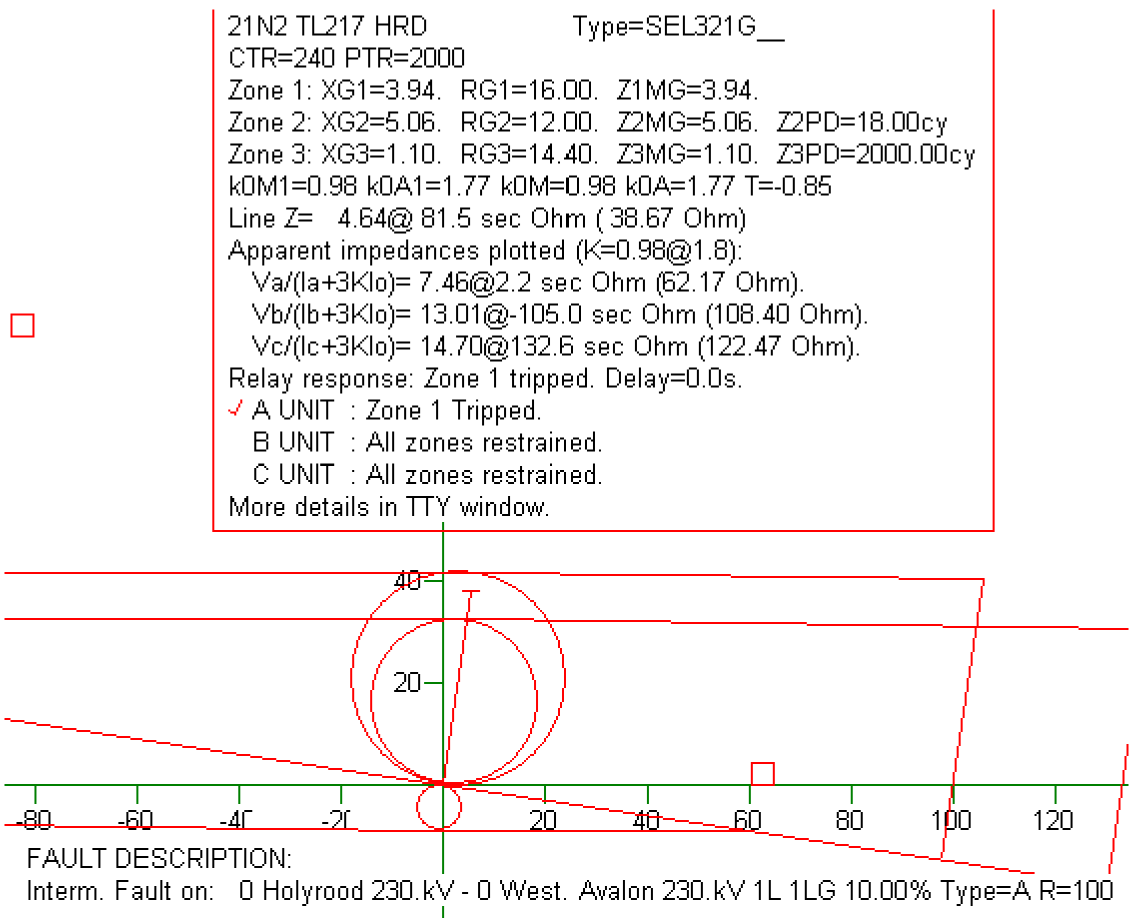


Figure 4 - HRD Zone 1 function if set with 16 ohm resistive reach, operates for a 100 ohm SLG fault at 10% from the local terminal.

The existing 12 ohm secondary resistive reach of the zone 1 element will not sense this fault, and should be increased to 16 ohms secondary. Check whether this reach will be secure, considering possible CT and VT errors.

XG1 is set at m per unit of the transmission line. The imaginary component of the line is

$ImXG1sec := Im(Z1Linesec)$ $\quad ImXG1sec = 4.59$ ohms

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$RG1 := \text{round}[(1 - m)\cdot 20\cdot \text{ImXG1sec}, 2]$

$RG1 = 18.36$ This is the maximum secure setting for the resistive reach and is above the proposed zone 1 resistive reach setting..

Use the proposed setting of 16 ohms for RG1 $RG1 := 16$ ohms secondary

With a resistive reach setting of 17 ohms, the HRD Zone 1 quad element will see an 60 ohm resistive SLG fault at 50% of the distance from HRD. Zone 2 protection will be depended upon to sense faults with resistance up to 100 ohms.

Zone 2 Ground Distance Protection

The Zone 2 ground distance function will need to be set longer than the Zone 2 phase distance protection function because it will tend to underreach the remote terminal while the parallel line is in service. By simulation in ASPEN OneLiner it is found that the apparent impedance to a zero ohm fault close in to the remote terminal is 5.54 ohms secondary, or 19% more than the actual line impedance. The reach of the Zone 2 ground distance element should be set at least to 1.25 times the apparent impedance.

$ZSLG\_remote := 5.54$

$Z2MG := \text{round}(1.25\cdot ZSLG\_remote, 1)$ $Z2MG = 6.9$ Ohms secondary

The quad element reactive reach will be set similarly to the mho.

$XG2 := Z2MG$ $XG2 = 6.9$ Ohms secondary

It would be desirable to set the resistive reach of the quad element to sense a 100 ohm SLG fault at 75% of the line with the local terminal weak. This would ensure overlap with the zone 1element at the remote terminal. However, that would require too much resistive reach. Therefore choose a setting to sense a 100 ohm SLG fault just past the mid point of the line, and depend on the echo function to provide coverage for high resistance faults in the region where the remote zone 1 won't operate.

By trial and error from ASPEN it is found that a resistive reach of 25 ohms secondary will sense a 100 ohm SLG fault with an overlap with a similarly set remote zone 2 of 10% of the line length. See Figure 5. This will give positive overlap with the zone 2 element at the remote terminal. However since it will not overlap the Zone 1 element at the remote terminal, the permissive trip echo function will be required to ensure that a fault that is seen by the zone 2 element at only one terminal will still be cleared by the permissive trip logic.

Therefore, to avoid extremely large resistive reaches, and to retain sensitivity to 100 ohm resistive SLG faults, it is recommended that the echo function be enabled at both terminals.

$RG2 := 26$ Ohms secondary

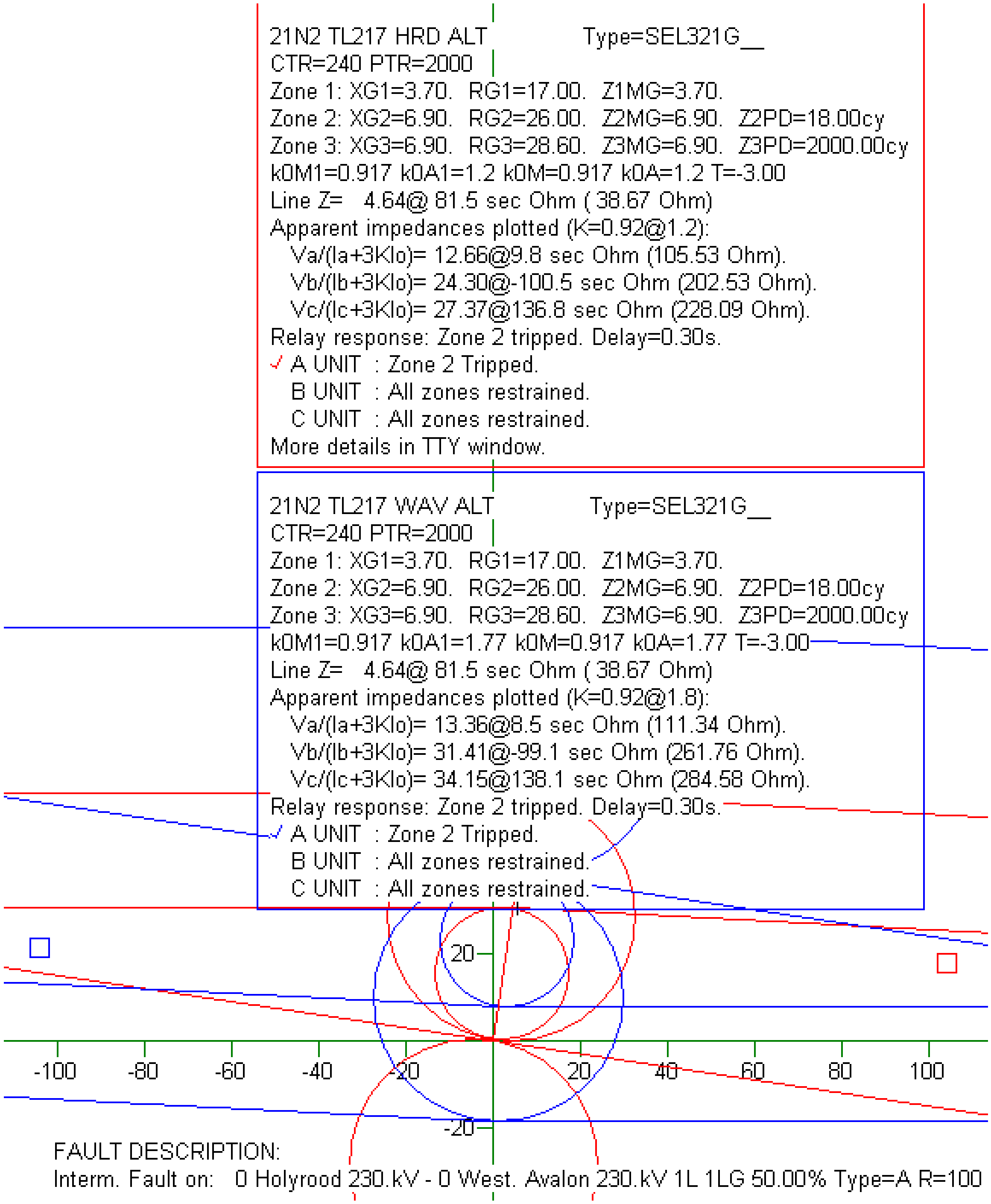


Figure 5 - Quad elements overlap with remote quad elements and operate for 100 ohm resistive SLG near the mid line location.

Check that this resistive reach won't cause the zone 2 function to trip while a parallel line is open single phase, with heavy power flow. See Figure 6. Unusually heavy power flow has been simulated to challenge security.

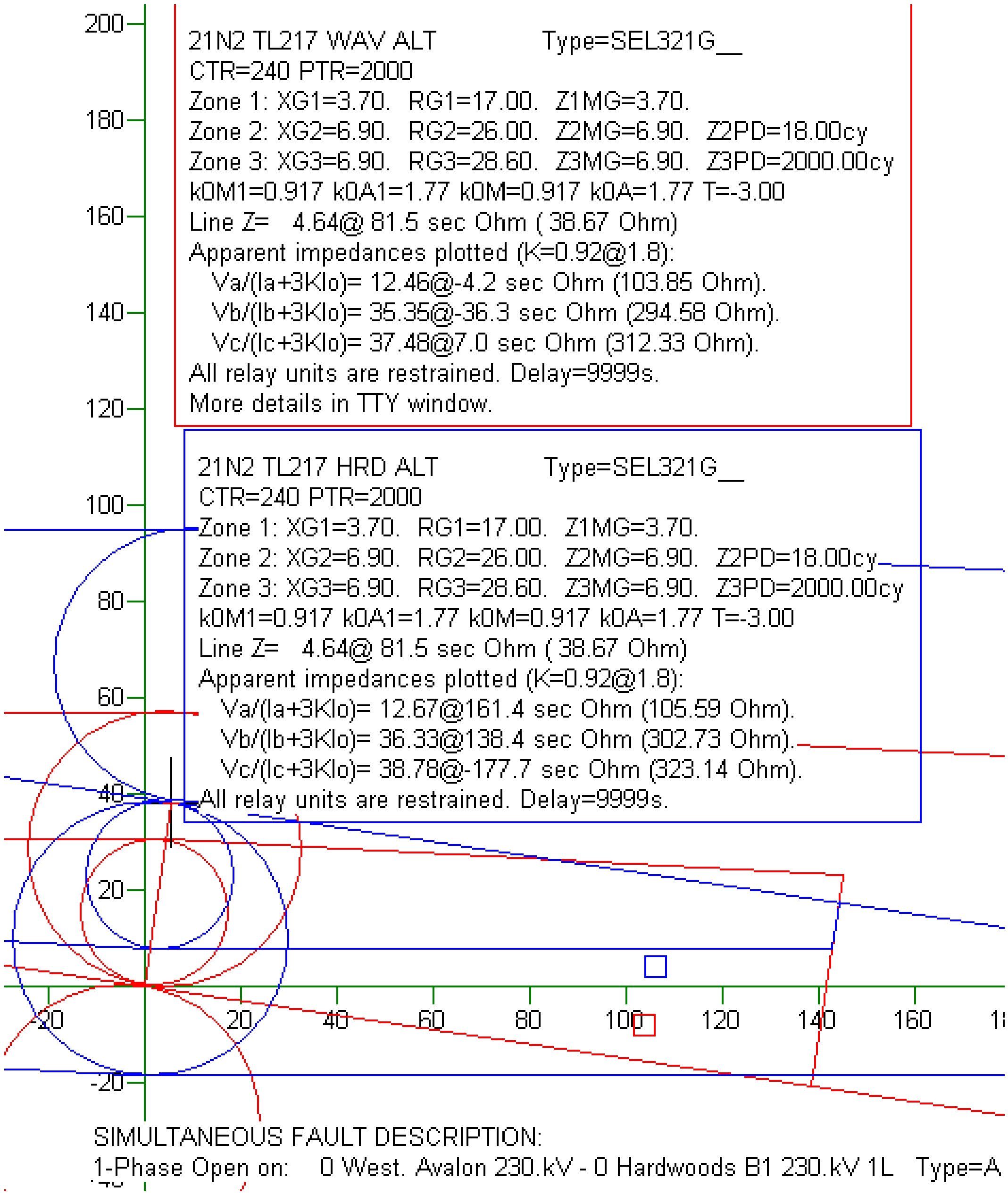


Figure 6 - Quad elements are secure with extremely heavy load flow (190 MVA in TL217 and 300 MVA in TL201) while TL201 is open single pole.

Zone 3

The zone 3 ground mho function will be set using the same principles as the zone 3 phase distance function. Use the setting for local zone 2 in secondary ohms as the remote zone 2.

$Z2MGrem := Z2MG$ ohms secondary

$Z3MG := Z2MGrem$ $Z3MG = 6.9$ Ohms secondary

$\frac{Z3MG}{|Z1MAG|} = 148.7 \cdot \%$ of line length This is much higher than the existing setting, but provides additional security.

$XG3 := Z3MG$ $XG3 = 6.9$ Ohms secondary

Set the Zone 3 quad resistive reach at 10% more than the remote Zone 2. Although the remote zone 2 has a different CT ratio, the setting is the same as the local zone 2 in primary ohms. Therefore use the setting for local zone 2 in secondary ohms as the remote zone 2.

$RG2rem := RG2$ Ohms secondary $RG3 := RG2rem \cdot 1.1$ $RG3 = 28.6$ Ohms secondary

Ground distance current supervision

Since there is no concern about these elements operating on load, even with loss of potential, set all current supervision elements at minimum, for maximum sensitivity of the distance elements.

$'50L1 := 0.5$ A Sec $'50L2 := 0.5$ A Sec $'50L3 := 0.5$ A Sec

$'50G1 := 0.5$ A Sec $'50G2 := 0.5$ A Sec $'50G3 := 0.5$ A Sec

Note that due to heavy infeed of zero sequence currents from the local terminal for close-in faults, the ground overcurrent detectors will not operate for faults with more than a small amount of resistance close to the remote terminal. Therefore, we will have to rely on sequential clearing for that type of fault. However setting the current supervision at minimum allows maximum sensitivity.

Zero sequence current compensation

The zero sequence current compensation could be adjusted to compensate for the significant amount of mutual coupling. However as discussed in the settings of reaches of the ground distance elements we will accept underreach of the Zone 2 function for the normal case by setting it at 125% of the apparent impedance for a remote fault. Set the zero sequence current compensation as usual.

$$k01M := \left(\left| \frac{Z0Line - Z1Line}{3 \cdot Z1Line} \right| \right) \qquad k01M = 0.917$$

$$k01A := \left(\arg\left(\frac{Z0Line - Z1Line}{3 \cdot Z1Line} \right) \right) \qquad k01A = 1.19 \cdot deg$$

Set the overreaching zones the same as zone 1 $k0M := k01M$ $k0A := k01A$

$k0M = 0.917$ $k0A = 1.19 \cdot deg$

Non Homogenous Angle Setting

Compare the angle of the remote zero sequence source impedance with the total zero sequence source impedance to the fault to determine this setting.

$$T := \arg\left(\frac{Z0minHRD + Z0Linephys + Z0minWAV}{Z0minWAV}\right) = -2.6 \cdot deg \qquad T = -3 \cdot deg$$

Out of step blocking and tripping

Not used in this application. There is a danger of out of step conditions arising. Historically no action has been taken to provide special tripping or blocking functions. Natural tripping during swings is accepted.

Load Encroachment logic

Check loadability of the Zone 2 phase distance element assuming worst case power factor of 0.87 simultaneous with worst case depressed voltage of a stressed system of 0.85 per unit. Note that units of kV squared match units of MVA. Note that quadrilateral elements are only used for the ground distance functions that are not sensitive to balanced three phase load. Therefore no need to worry about the reach of the quadrilateral elements.

$$Zloadmin := \frac{(0.85kVbase)^2}{Smax} \qquad Zloadmin = 186.44$$ Ohms primary (assume worst case at 30 degrees)

Maximum reach of the Zone 2 element is at the line angle of 81 degrees. At 30 degrees, the reach will be given by

$$Z2load := Z2P \cdot \cos[(Z1ANG - 30)deg] \qquad Z2load = 3.609$$ ohms secondary

$$Z2load \cdot \frac{VTR}{CTR} = 30.075$$ ohms primary

Since the reach of the Zone 2 element at 30 degrees is less than the apparent impedance of the maximum load, there is no need to apply load blinding logic. See Figure 7

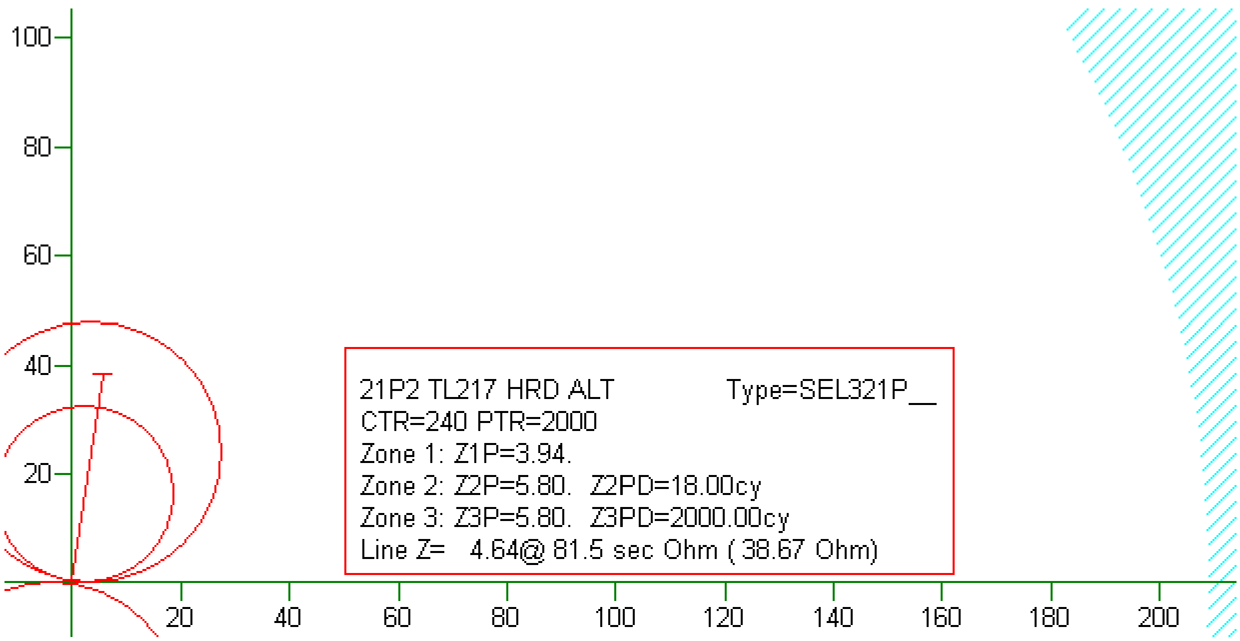


Figure 7 -Load impedance with respect to proposed new Mho function reaches.

Ground directional element

The SEL-321 application example recommends finding the minimum source impedance behind the terminal and setting the reverse and forward boundaries of the negative sequence directional element at the 1/3 and 2/3 points respectively.

In the negative sequence plane, the sum of the two source impedances and the line impedance is:

$$Z2total := Z2minHRD + Z1Linephys + Z2minWAV$$

The 1/3 point is $Z2\_1\_3 := \frac{Z2total}{3}$ The 2/3 point is $Z2\_2\_3 := \frac{2Z2total}{3}$

$Z2Rpri := Z2\_2\_3 - Z2minHRD$ $|Z2Rpri| = 38.115$

$Z2Fpri := Z2\_1\_3 - Z2minHRD$ $|Z2Fpri| = 8.18$

Converting the primary impedances to secondary ohms

$Z2R := Z2Rpri \cdot \frac{CTR}{VTR}$ $|Z2R| = 4.574$ Ohms secondary $arg(Z2R) = 81.554 \cdot deg$

$Z2F := Z2Fpri \cdot \frac{CTR}{VTR}$ $|Z2F| = 0.982$ Ohms secondary $arg(Z2F) = 73.677 \cdot deg$

Rounding up Z2F and rounding down Z2R gives:

$Z2F := 0.4$ Ohms secondary $Z2R := 4.3$ Ohms secondary

These are significantly lower than to the existing settings.

Set the current level detectors at minimum level that will allow operation of the ground distance elements.

Due to the very small zero sequence current contribution to a single line to ground fault at the remote terminal, the negative sequence current contribution will always be higher than the zero sequence. Therefore there is no point in setting the forward looking negative sequence overcurrent elements any more sensitively than the zero sequence ground overcurrent supervision of the ground distance elements.

$'50QF := '50G2$ $'50QF = 0.5$ A secondary

Set the supervision function for the reverse looking element to be the same as, or a little more sensitive than the forward looking supervision element at the remote terminal.

$'50QR := 0.5$ A secondary

The positive sequence current restraint (a2) factor should be set just smaller than the ratio of the maximum load current (positive sequence) to the most sensitive current supervision element (50QR).

$I1maxpri := \frac{Smax \cdot 1000}{kVbase \cdot \sqrt{3}}$ $I1maxsec := \frac{I1maxpri}{CTR}$ $I1maxsec = 2.144$

Bearing in mind that the 50QR setting is in units of 3*I2

$\frac{'50QR}{3 \cdot I1maxsec} = 0.078$ Choose a value of $a2 := 0.08$

The proposed new setting of a2 is a little higher than the existing setting (0.07).

Phase time overcurrent element

This element is not used

Residual time overcurrent element

This element is used to provide the most sensitive backup protection. It will be a non directional element.

Set pickup to sense a higher resistance than 100 ohm SLG in the middle of the line with equal zero sequence current infeed from both ends. Choose a resistance of 200 ohms arbitrarily. Use a safety factor of 2 so that operating time is not infinity at this fault level.

$SF := 2$ Desensitization factor due to remote end infeed is $Dfactor := 2$ $Rf := 200$

$$'51NPU := \text{round}\left(\frac{kVbase \cdot 1000}{\sqrt{3} \cdot SF \cdot Dfactor \cdot Rf \cdot CTR}, 1\right) \qquad '51NPU = 0.7$$

The existing setting of 0.5 A is more sensitive than required to sense this mid line fault with arbitrary resistance. Since TL206 experience with the high resistance tree fault on 28th August 2009 has shown value in the existing setting, it will be retained.

$'51NPU := 0.5$ A secondary

Coordination checks show that existing time dial settings will coordinate with each other. See Figures 8 and 9

$'51NPU = 0.5$ A secondary $'51NPU \cdot CTR = 120$ A primary

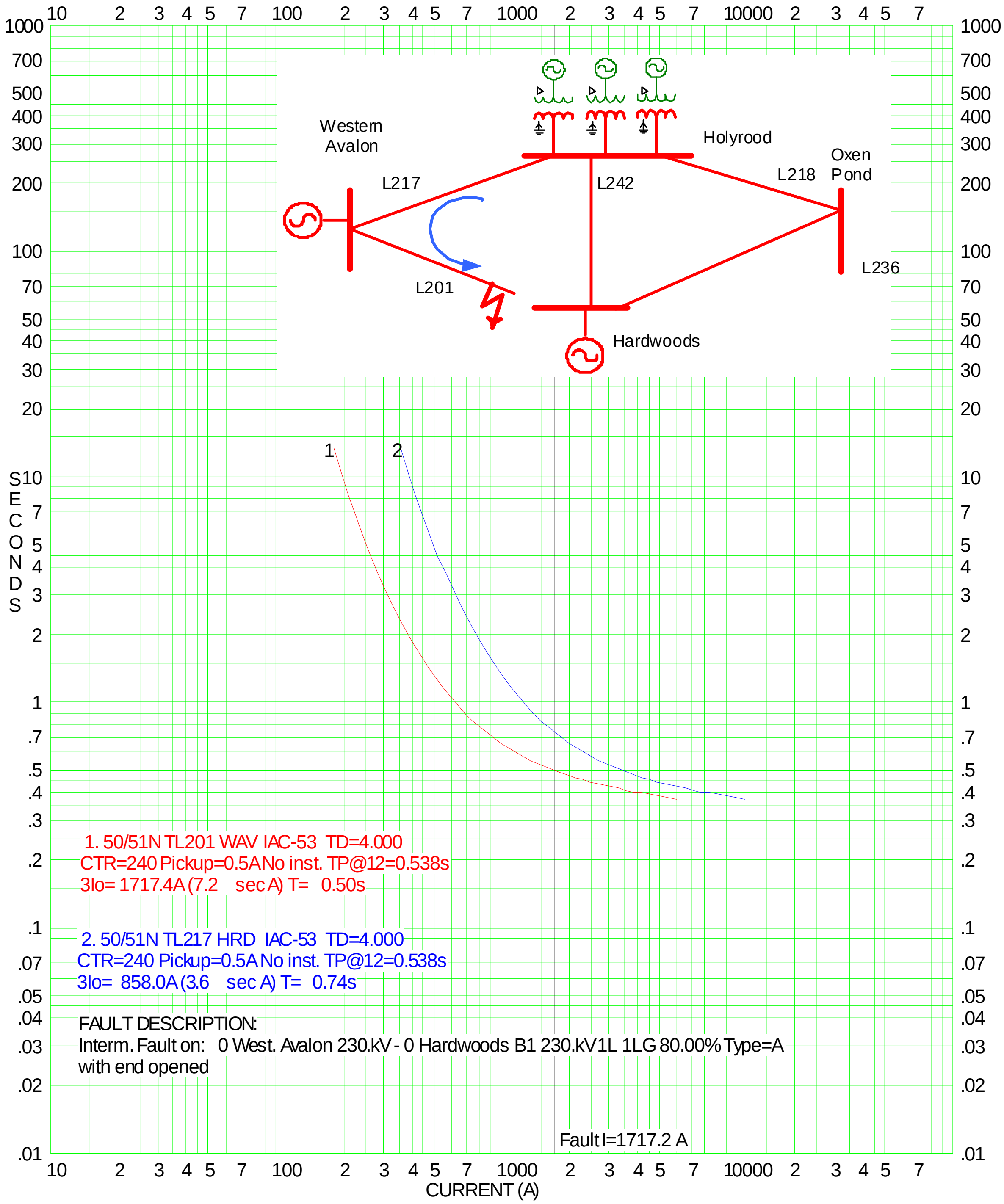
$'51NTD := 4$ $'51NC := "U3"$ $'51NTC := "N"$ $'51NRS := "N"$

Checks for close-in fault show that this element will not operate in less than 0.39 seconds so there is no danger of it tripping 3 pole before the zone 1 element trips the faulted phase selectively.

Check the coordination above the WAV TL201 protection for a fault at 80% of the distance to HRD. See Figure 8. It can be seen that the existing setting is only marginally slower than the WAV TL201 protection for a 0 ohm fault. For this type of fault we can rely on the 0.3 second time of the zone 4 ground distance function at WAV. For resistive faults the current will be much lower and the ground time overcurrent functions will coordinate satisfactorily.

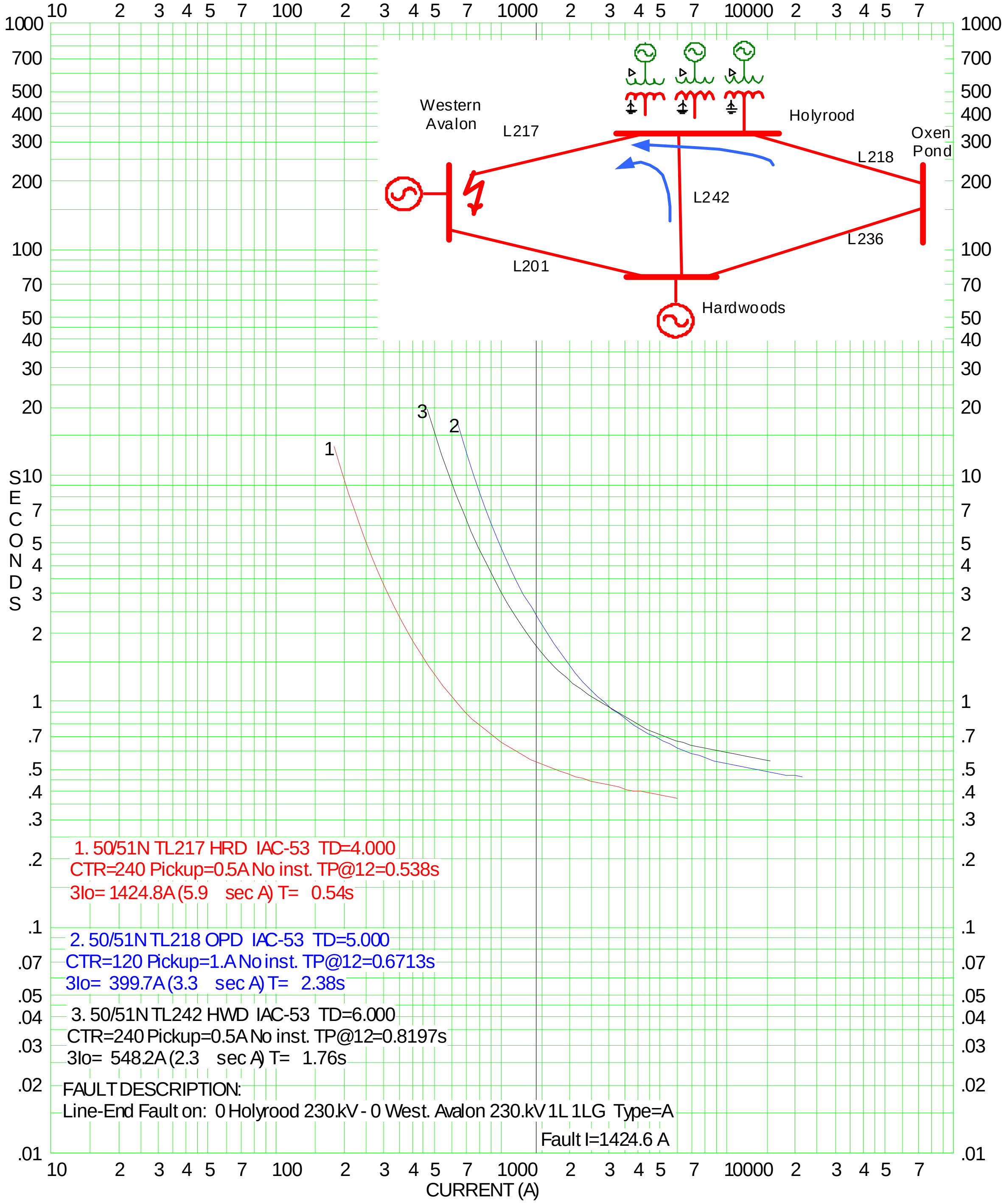
Check the coordination below the HWD TL242 51N and below the OPD TL218 51N for a line end fault on TL217 with two HRD units off line. This is the type of fault that will produce the most sensitivity (least desensitization) with respect to the backup protection on TL242 and TL218. see Figure 9. Coordination margin is satisfactory.

Worst case load unbalance with single pole open will be in the future if single pole tripping is enabled with parallel line out of service. ASPEN OneLiner shows that with 250 MVA of load on this line (considerably more than existing maximum possible load), and with one phase open, the 3I0 current is approximately 430 A. The 51N relay with existing settings will take approximately 1.6 seconds to operate on 430 A primary. No danger of tripping on load unbalance during SPO time.



EC 230-4	TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For Coordination of WAV TL201 below HRD TL 217		No. EC 230-4a
Comment Requires Z1G and Z2G for coordination with RF <100 ohms		Date 13 Oct 2011

Figure 8 - coordination of ground time overcurrent elements for fault at 80% TL201



EC 230-6	TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For Coordination of HRD TL217 below OPD L218 and HWD L242		No. EC 230-6
Comment Two units out of service at HRD.		Date 29 Sep 2011

Figure 9 - coordination of ground time overcurrent elements for line end fault on TL217 close to WAV

Permissive Overreaching logic settings

EPOTT := "Y"

Z3RBD is set at remote breaker time plus channel reset time plus channel reset time plus zone 2 reset time. From review of fault records it appears that the breaker time is 3 cycles. Channel reset time is not easily determined from existing records but can conservatively be assumed to be 1 cycle, and relay reset time will also be about 1 cycle. Total time for Z3RBD is then 5 cycles.

Z3RBD := 5 cycles

Echo block delay timer blocks the echo after the local elements have picked up. This can be set relatively long since there is no significant need for the echo function shortly after the local terminal has just seen a fault but the remote terminal has not. Set at 10 cycles as per the example in the instruction manual.

EBLKD := 10 cycles

Echo time delay on pickup should be set to override noise on the communications so that it doesn't echo noise. Typical time according to the SEL application guide is 2 cycles. Since this delay only affects clearing time for relatively light (high resistance) faults that are sensed by zone 2 function at one end, the typical setting is acceptable.

ETDPU := 2 cycles

Echo duration should be long enough to ensure the permissive trip is received by the remote terminal and should also be shorter than the Z3RBD time to ensure that the reverse blocking will always be longer than any permissive trip received (including echo time stretching).

EDURD := 4 cycles

No need to enable week feed conversion to trip, since both terminals will be quite sensitive enough to detect high resistance faults after the remote terminal has cleared. Therefore we can accept sequential (or "step") clearing with no need for the added insecurity of weak infeed tripping.

EWFC := "N" **No other communications logic settings are required for this application.**

Switch on to Fault Settings

Switch on to fault logic will ensure the protection will operate when energizing the line onto a close-in three phase fault when there is no polarizing voltage available for the distance elements.

ESOTF := "Y"

The breaker close signal is not available to the relay. The 52A method of enable SOTF will be used. Therefore the Close end delay is not critical. Typical duration for enable SOTF is 10-15 cycles

ENCLO := "N" CLOEND := 0 EN52A := "Y" SOTFD := 15

Set 50H for high magnitude close-in multiphase faults with weakest source at HRD. It should be set less than 50% of the minimum close-in fault magnitude. Minimum close-in magnitude of a three phase fault with two units off line and TL242 out of service is 3000 A. Therefore desired maximum setting for 50H is 1500 A.

Imin3P_close_in := 3000

$$'50H := \frac{Imin3P\_close\_in}{2CTR} \qquad '50H = 6.25 \quad \text{A secondary}$$

Choose a setting of 6 A secondary for this element. '50H := 6 A secondary

Choose a setting for 52AEND less than the shortest reclose time. '52AEND := 30 cycles

The existing setting of 52AEND is 60 cycles. It is not known why the setting is set longer than the reclosing time.

Residual overcurrent settings.

Tripping directly by instantaneous ground overcurrent is not applicable because it is not phase selective. However it would be helpful to monitor steady state unbalance, and issue an alarm for continuous unbalance. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50N := 1$ $\quad$ $'50N1 := 0.25$

Negative Sequence overcurrent settings.

Similar to ground overcurrent, apply a negative sequence overcurrent element to initiate an alarm for steady state unbalances. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50Q := 1$ $\quad$ $'50Q1 := 0.25$

Voltage Element Settings

Similar to unbalance current monitoring, it is helpful to have an unbalance voltage monitor to detect steady state unbalances from the voltage supply.

EVOLT := "Y"

Set the zero sequence overvoltage element at 1% of rated voltage or just at the point necessary to override normal unbalances. The zero sequence voltage element measures 3 times the zero sequence voltage.

$$'59N := 3 \cdot 0.01 \frac{kVbase \cdot 1000}{\sqrt{3} \cdot VTR} \qquad '59N = 1.992 \qquad \text{Say} \quad '59N := 2 \quad \text{V secondary}$$

Loss of Potential

Enable loss of potential settings. Advanced LOP settings are not available on this model of relay.

ELOP := "Y" $\quad$ Time delay of 1.25 cycles is commonly used. $\quad$ $LOPD := 1.25$

The 50 M element should be set above maximum load and below minimum fault current for a fault at the remote terminal under weak source conditions. The maximum load for this case should be normal maximum, not emergency maximum which only exists for a few minutes before the operator can act to reduce load.

$$Imax\_normal := \frac{Smax\_L217 \cdot 1000}{\sqrt{3} \cdot kVbase \cdot CTR} = 1.046 \text{ A secondary}$$

Minimum fault current for a remote three phase fault is $I3Pmin = 721$ A primary.

Minimum fault current for a remote phase to phase fault is 87% of the minimum three phase fault current level.

Dependability factor to be sure to operate for a minimum remote fault is chosen to be 1.6. $\quad$ $DF := 1.6$

Maximum setting for 50M should be $\dfrac{0.87 I3Pmin}{DF \cdot CTR} = 1.634$ $\quad$ In this case a setting of 1.7 A secondary will be adequately dependable and secure.

$'50M := 1.6$ A secondary

The 59QL setting should be above normal maximum unbalance and below the level expected for a blown VT fuse. For a blown fuse, one phase voltage will be lost, and the negative sequence voltage will be roughly 33% of the nominal positive sequence voltage. Choose a setting of 15% of the nominal positive sequence voltage. This will be well above any normal unbalance.

$'59QL := \mathrm{round}\left(\frac{0.15 \cdot kVbase \cdot 1000}{\sqrt{3} \cdot VTR}, 0\right)$ $'59QL = 10$ V secondary

The 59PL setting should be less than the minimum voltage to be expected for a remote bus fault under weakest source conditions. There is no minimum setting (above zero) for this function. Choose a setting equal to half the voltage drop along the line impedance at the pickup setting of the 50M element.

$'59PL := \mathrm{round}[0.5 \cdot ('50M \cdot |Z1Linesec|), 0]$ $|'59PL| = 4$

Miscellaneous Scheme Settings

Pole discoordinance logic is not being used. EPOLD := "N" SPPDD := "N/A"

Enable single pole tripping by distance elements only ESPT := "Y"

Enable single pole open ESPO := "Y"

Set single pole open time delay for future SPO conditions SPOD := 0.25

Note that SPOD was short enough to allow a transient operation when TL201 was reclosed with a fault on it during the fault of 7 March 2011. This transient operation was helpful to clear the fault more quickly than it otherwise would have cleared. SEL have been asked whether the SPOD setting of 0.5 would be better to increase the security.

3 Pole open reset delay to override small discrepancies in pole closing '3POD := 0.5

Stub line protection is not required ESTUB := "N" '50MFD := "N/A"

Trip unlatch logic not applied TULO := "N"

Logic variables and Miscellaneous timers

Minimum trip duration timer is set at 9 cycles as per the application example in the SEL-321 instruction manual.

TDURD := 9 Cycles

Trip during open pole time delay should be set longer than the reclose time. Existing reclose time is 55 cycles. This is acceptable.

TOPD := 55 Cycles

Existing logic variables are not used.

Add the use of ZT to trigger an alarm for sustained unbalance.

LOGIC_Z := "59N+50N1+50Q1" TZPU := 1200 cycles TZDO := 0 cycles

Tripping Logic

Permissive tripping is required only for instantaneous overreaching functions. No need for any functions that trip directly. Existing 51NT word in MTCS is not required.

MTCS := "M2P+Z2G"

Existing settings for unconditional tripping are suitable

MTU := "M1P+Z1G+M2PT+Z2GT+51NT"

No need for existing direct tripping zone 1 functions in the switch on to fault logic.

SOTF Tripping MTO := "M2P+Z2G+50H"

Event records will be triggered automatically by all trip events. Other event record triggers should be by starting of other elements to ensure capture of all relevant events. Events should be triggered by keying or receiving permissive trips to ensure separation of relay and teleprotection issues.

MER := "M2P+Z2G+51NP+LOP*52AA1+LOP*52AA2+KEY+PT+EKEY"

Outputs

Retain existing output assignments except add the continuous unbalance alarm to OUT15.

OUT15 := "LOP*50L+ZT"

Input Contact Assignment

It would be desirable to provide phase segregated inputs to the relay so that the quadrilateral functions could be disabled during single pole open conditions. it is not known if phase segregated auxiliary switches are available on the breakers.

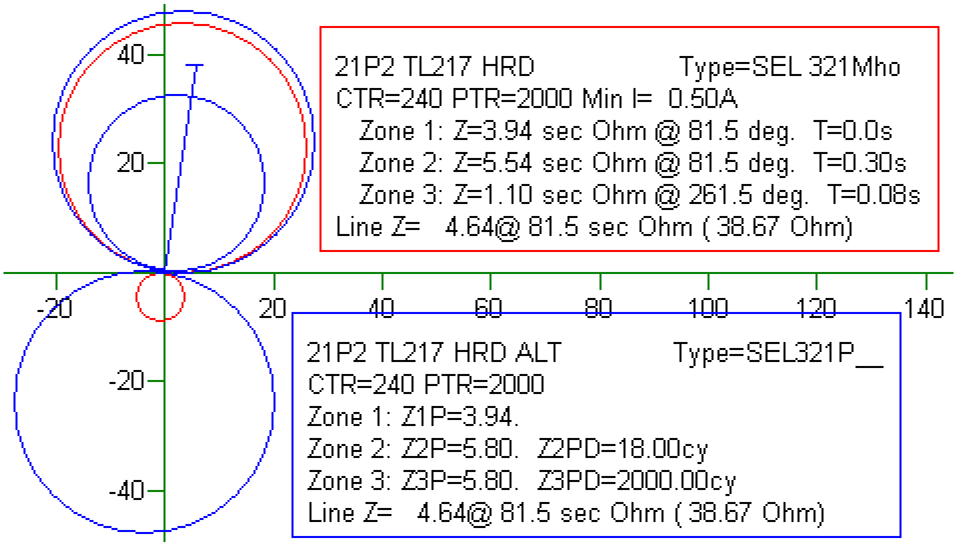


Figure 10 - Comparison between existing (red) and proposed new (blue) phase distance characteristics.

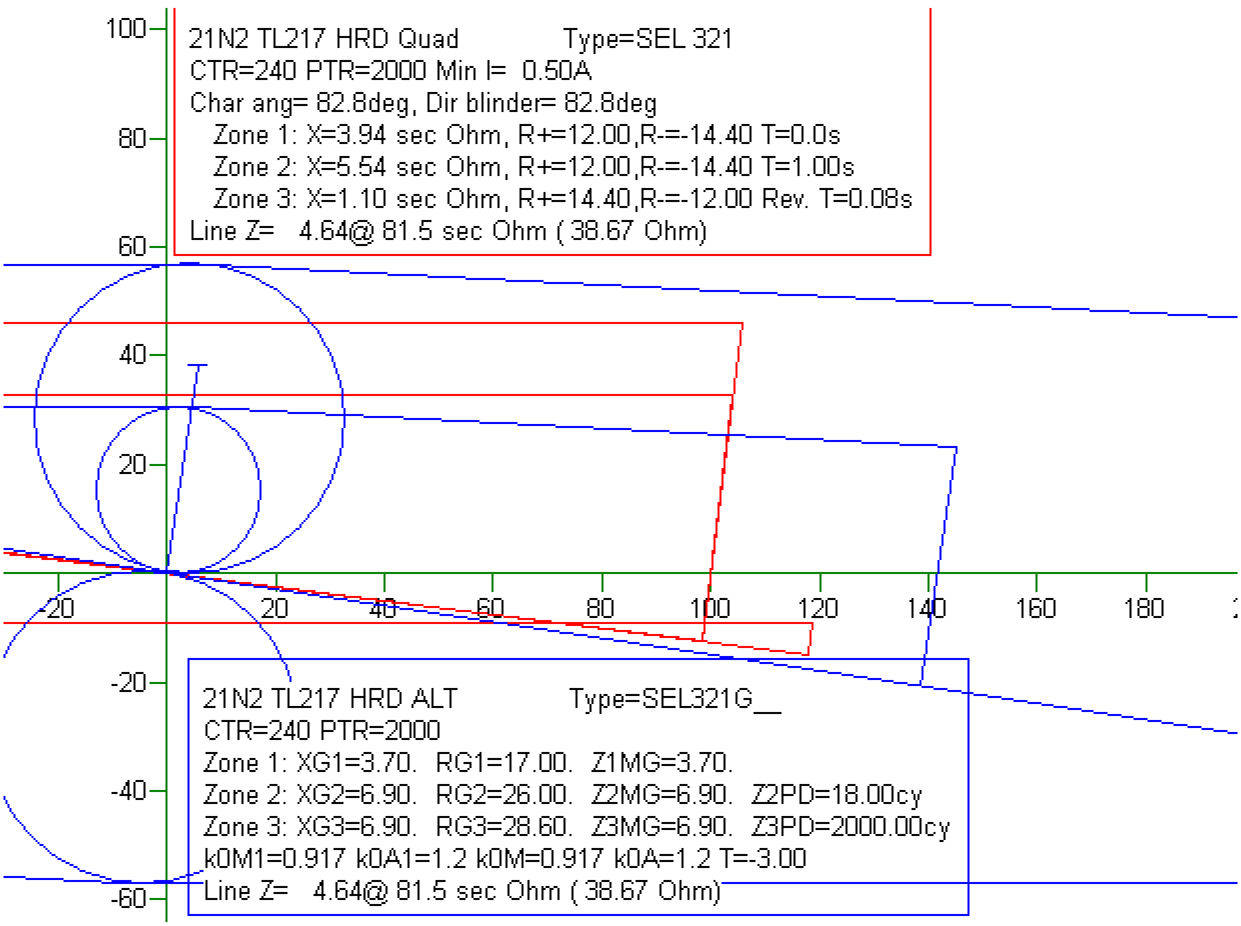


Figure 11 - Comparison between existing (red) and proposed new (blue) ground distance characteristics.

Protection Review for Five 230 kV Transmission Lines

Appendix L
Detailed settings review for HRD TL218 "P1" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador Hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Holyrood Terminal (HRD) terminal of circuit TL218. This 230 kV transmission circuit is from HRD to Oxen Pond (OPD).
The circuit runs parallel to Circuits TL201 and TL236 for some of its length.

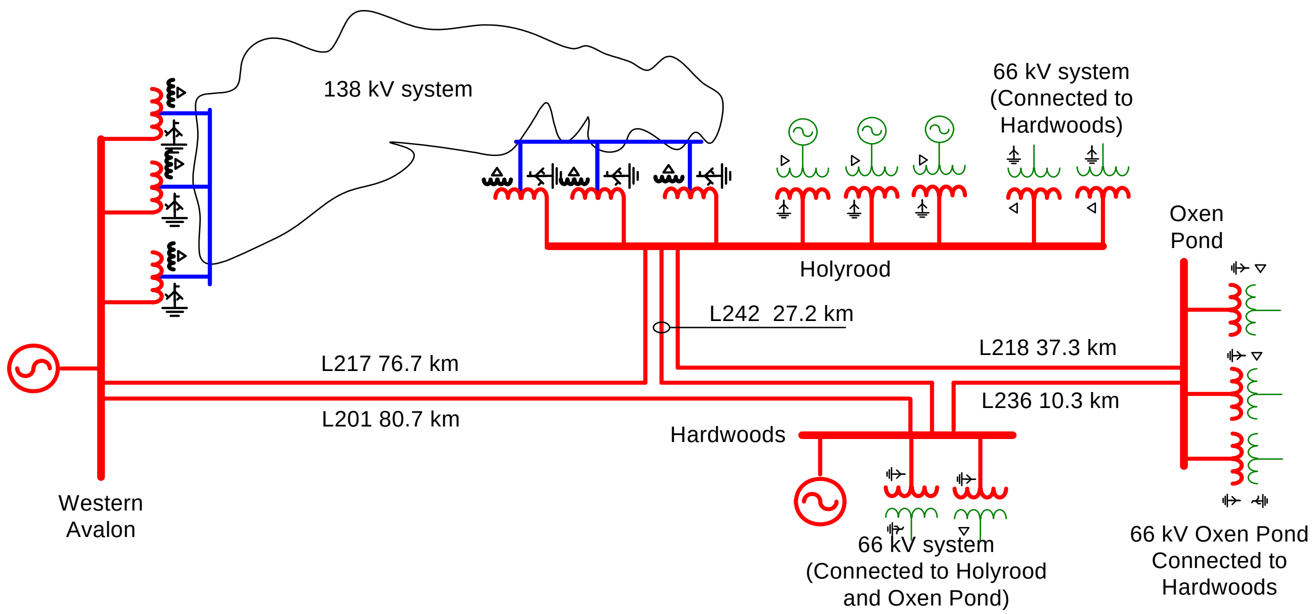


Figure 1 - System Single Line Diagram

Existing P1 protection systems are Areva LZFP111 (Optimho) systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $\quad kVbase := 230$ $\quad Ibase := \frac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\quad Zbase := \frac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at the line terminal.

CT ratio is: $CTR := \frac{1200}{5}$ VT ratio is: $VTR := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**NL HYDRO WITH MUTUALS FOR EAST COAST 230 kV LINE PN REVIEW 8 DEC.OLR**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with loads and shunts ignored.

Minimum fault current seen by each terminal (phase to phase, and SLG with 0 ohm fault resistance).

At HRD, with two units off line, and all parallel lines in service, for a fault at the remote terminal.

$ILLmin := 913$ A $ISLGminPH := 1068$ A $ISLGmin0seq := 414$ A

The optimho current level detectors that block the distance comparators in the event of line opening are fixed at 5% of the rated current, or 0.25 A secondary, or 60 A primary. They will have no difficulty in operating for minimum bolted fault levels. However, the ground distance elements are also supervised by a low set neutral current level detector (LDLSN that requires the neutral current to be greater than 10% of the maximum amplitude of phase difference current. This prevents the ground comparators from operating during close-in multiphase faults with CT errors. ASPEN OneLiner shows that for a bolted fault at the remote bus even under heavy load, there is sufficient neutral current (20% of maximum phase to phase fault current) that means this LDLSN function does not inhibit the ground distance comparator.

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind HRD $Z2minHRD := 1.0 + j \cdot 20.94$ ohms primary

Minimum source impedance behind OPD $Z2minOPD := 2.7 + j \cdot 30.9$ ohms primary

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L218 := 0.00355 + j \cdot 0.03354$ $Z0L218 := 0.01599 + j \cdot 0.1325$

$Z1Line := Z1L218 = 3.55 \times 10^{-3} + 0.034j$ pu $Z0Line := Z0L218 = 0.016 + 0.133j$ pu

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line \cdot Zbase$ $Z0Linephys := Z0Line \cdot Zbase$

$Z1Linephys = 1.9 + 17.7i$ ohms primary $Z0Linephys = 8.5 + 70.1i$ ohms primary

Converting primary ohms to secondary ohms gives:

$Z1Linesec := Z1Linephys \cdot \frac{CTR}{VTR}$ $Z0Linesec := Z0Linephys \cdot \frac{CTR}{VTR}$

$|Z1Linesec| = 2.14$ ohms sec $arg(Z1Linesec) = 84 \cdot deg$

$|Z0Linesec| = 8.472$ ohms sec $arg(Z0Linesec) = 83.12 \cdot deg$

Load Data

From 2011 System summer load case provided in start up information, the peak load (sum of TL218 and TL236) is given as 267MVA (split between TL218 and TL236). In the event of sudden loss of one line, peak load will be the sum of both line loads until operators can adjust loads. Therefore it is assumed that peak load for a short duration is 205 MVA

$Speak := 267$ MVA $Smax := Speak = 267$ MVA

However, new information from Peter Thomas (see email dated 9 December, 2012 subject "Re: FW: PSSE Files") indicates that peal load should be set up to carry 370 MVA under the conditions of TL218 out of service.

$Smax := 370$ MVA

P1 Relay Settings

Distance element reach settings

Note that resistive reaches are forced to be the same for all zones. Reactive reaches for phase and ground distance elements must be the same as each other.

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the HRD Station bus under light load conditions and both TL218 and TL236 lines in service. From ASPEN OneLiner, voltage at HRD for a 3 phase fault at OPD is 0.15 per unit. Since the voltage is less than 20%, this line is considered short, and a reduced zone 1 reach is recommended to increase security. Choose a setting of 80% of nominal.

$Z1P := 0.8 \cdot |Z1Linesec|$ $Z1P = 1.71$ Ohms secondary

Existing setting of 1.91 ohms is too high and should be reduced to at the most, 1.71 ohms secondary. However, the ground distance reach in the optimho has to be set the same as the phase distance reach; so we need to consider the ground faults too.

$Z1P = 1.71$ For phase faults only.

The worst case from the point of view of overreach of the zone 1 ground distance element is with TL236 out of service and grounded at both ends, and a close-in fault on the HV bus of one of the Oxen Pond transformers. For this case, the apparent impedance presented to the relay is only 1.99 ohms secondary (see Figure 2). This is 93% of the line impedance. So the reach of the zone 1 element should be reduced somewhat.

$Zapp\_ext := 1.99$ ohms $Zapp\_ang := 84.3deg$ This angle is close enough to the line angle to treat it as equal to the line angle.

$\frac{Zapp\_ext}{|Z1Linesec|} = 0.929$ The apparent impedance is reduced by about 7% mostly due to the effect of the parallel line being out of service and grounded at both ends but also partly due to the zero sequence current compensation factor being set slightly too high on this protection.

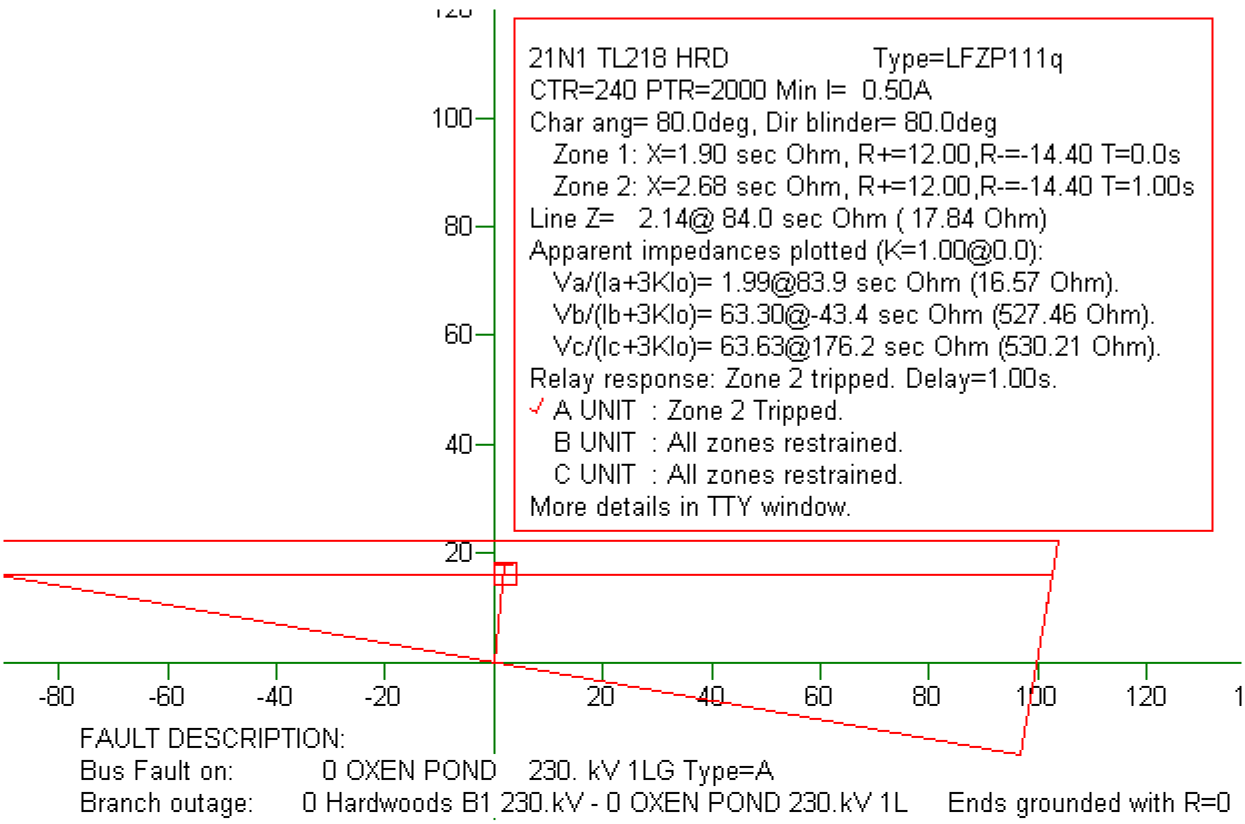


Figure 2 - Apparent impedance to a fault just beyond the remote terminal is reduced by 7% when TL242 line is out of service and grounded at both ends. Existing relay settings modeled in this figure.

The reach of the zone 1 ground distance element should be reduced to less than 85% of the line impedance to make it more secure against misoperation for an external fault with the parallel line out of service and grounded. **A more important constraint exists due to the short line and the high resistive reach** required in order to sense 100 ohm resistive faults near the middle of the line. The resistive reach of the zone 2 element (which is the same as the resistive reach of the zone 1 element) has to be set at about 12 ohms secondary. Such a long resistive coverage on the zone 1 element will not be secure when considering the apparent reactive component of the fault resistance added to the resistive component by load flow as shown in Figure 3. In addition, the VT and CT errors may cause additional possibility of overreach of the zone 1 for resistive external faults. Choose a setting of 60% of line which will underreach the remote bus more securely considering the large resistive reach.

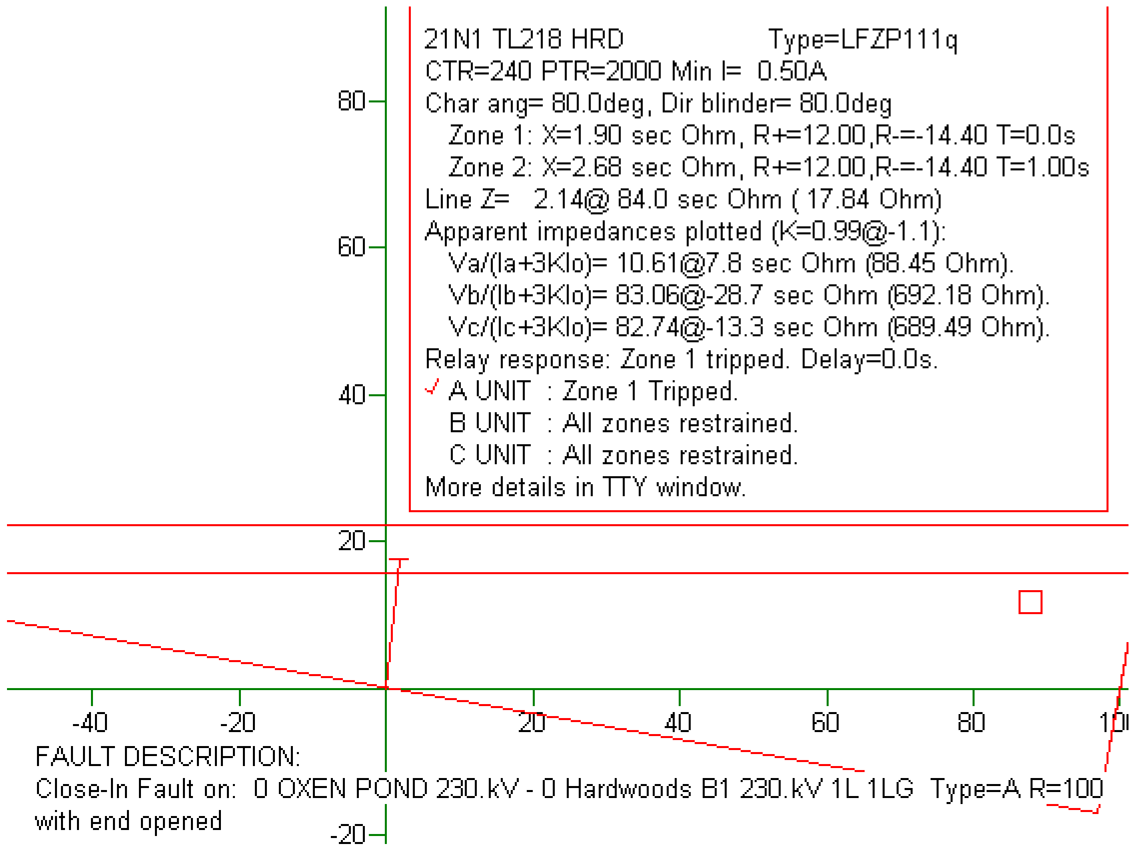


Figure 3 - Zone 1 element set at 85% with 12 ohms resistive reach operates for resistive out of zone fault.

Due to the sensitivity of the optimho quad element to the apparent reactive component of fault resistance, choose a per unit reach of the Zone 1 function of 0.6. This is more than 50% and allows overlap with zone 1 at remote terminal for many faults. We will need to depend on zone 2 POTT scheme for all faults.

$m := 0.6$ per unit

$Z1\_sec := \mathrm{round}(m \cdot |Z1Linesec|, 1)$ $Z1\_sec = 1.3$ Ohms secondary

$Z1pri := Z1\_sec \cdot \frac{VTR}{CTR} = 10.833$ Ohms primary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 2.68 ohms secondary (about 125%). However, in order to dependably reach a single line to ground fault at the remote terminal, it will be necessary to set the reach significantly further.

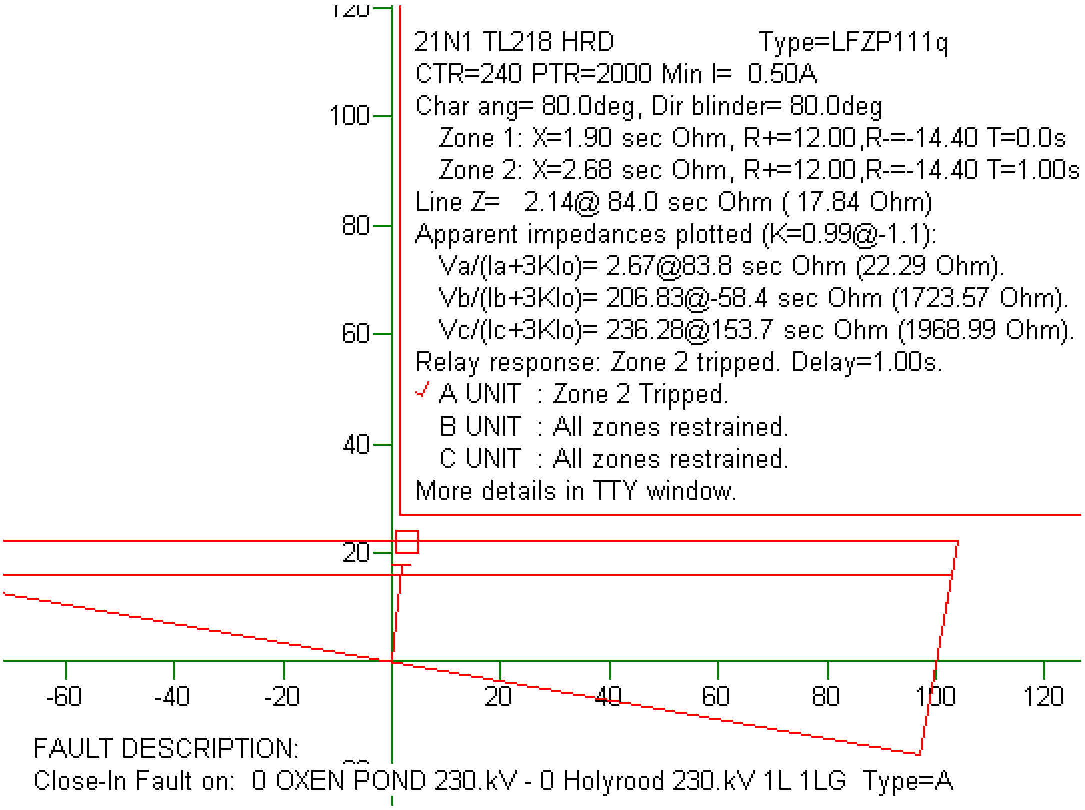


Figure 4 - Apparent impedance to a fault close to the remote terminal is increased by 20% when parallel line is in service (and two units off line at HRD).

As can be seen from Figure 4, the apparent impedance to a fault close to the remote terminal is increased when the parallel line is in service.

$Zapp\_int := 2.67$ Ohms secondary $Z2\_sec := 1.25 \cdot Zapp\_int = 3.337$ Choose a setting of 3.4

$Z2\_sec := 3.4$ $Z2\_sec = 3.4$ Ohms secondary $\frac{Z2\_sec}{|Z1Linesec|} = 158.803 \cdot \%$

$Z2\_pri := Z2\_sec \cdot \frac{VTR}{CTR} = 28.333$ Ohms primary

The zone 1 element is disabled from tripping on the existing P1 protection for TL236 at OPD. Further, this zone 2 element may overreach the OPD TL236 P2 zone 1 protection. The existing 1 second delay in tripping by this element will ensure coordination with the OPD zone 2 element.

$Z2\_TD := 1.0$ Seconds

In order to provide faster clearing of single line to ground faults on the whole line sequentially (in the absence of communications), a shorter reaching zone 4 element is recommended to be set, in the P2 protection with a shorter time delay. Faster communications independent protection is not critical for **both** the P1 and P2 protections. One or the other will be suitable.

Resistive reach

Check the sensitivity of the new settings to resistive faults near the middle of the line.

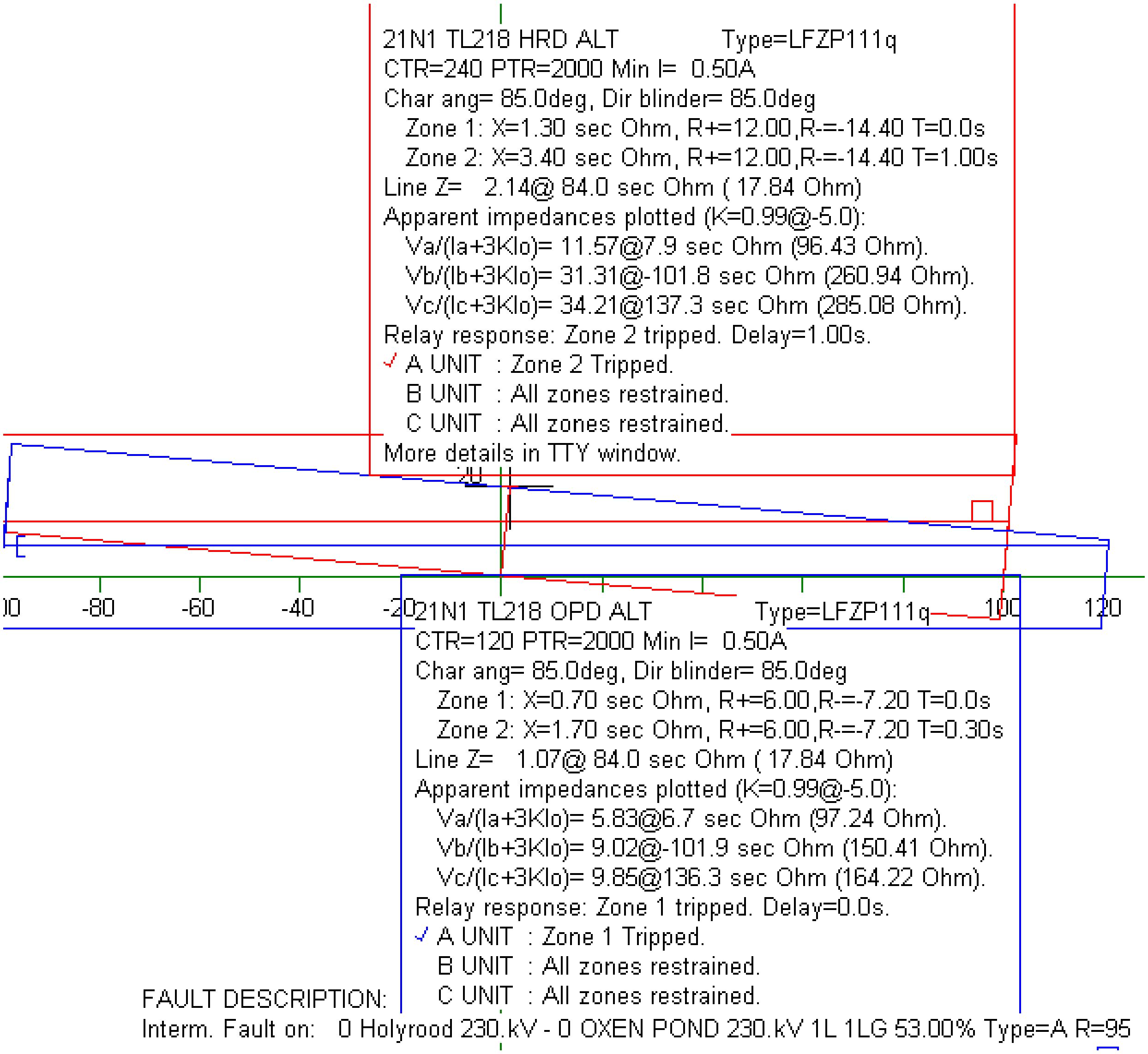


Figure 5 - Resistive fault coverage near the middle of the line.

As can be seen from Figure 5, the zone 2 elements at both ends will comfortably overlap for a 95 ohm resistive fault near the middle of the line. The zone 1 elements set at 60% at each end will not overlap for high resistive faults, but will overlap for less resistive faults.

The existing resistive reach setting of 12 ohms secondary will be suitable as long as the reach of the zone 1 element is reduced to 60% of the line.

$Rquad := 12$ ohms secondary

Load Encroachment logic

The optimho instruction manual recommends a margin of at least 10% between the impedance of the maximum load and the resistive reach of the quadrilateral distance element.

Check loadability of the Zone 2 phase distance element assuming worst case depressed voltage of a stressed system of 0.9 per unit.

$$Zloadmin := \frac{(0.9kVbase)^2}{Smax} \qquad Zloadmin = 115.808$$ Ohms primary (assume worst case at 30 degrees)

$$Zloadmin\_sec := Zloadmin \cdot \frac{CTR}{VTR} \qquad Zloadmin\_sec = 13.897$$

A 12 ohm secondary resistive reach is less than 90% of the load impedance at unity power factor and meets the Areva criterion as shown in Figure 6.

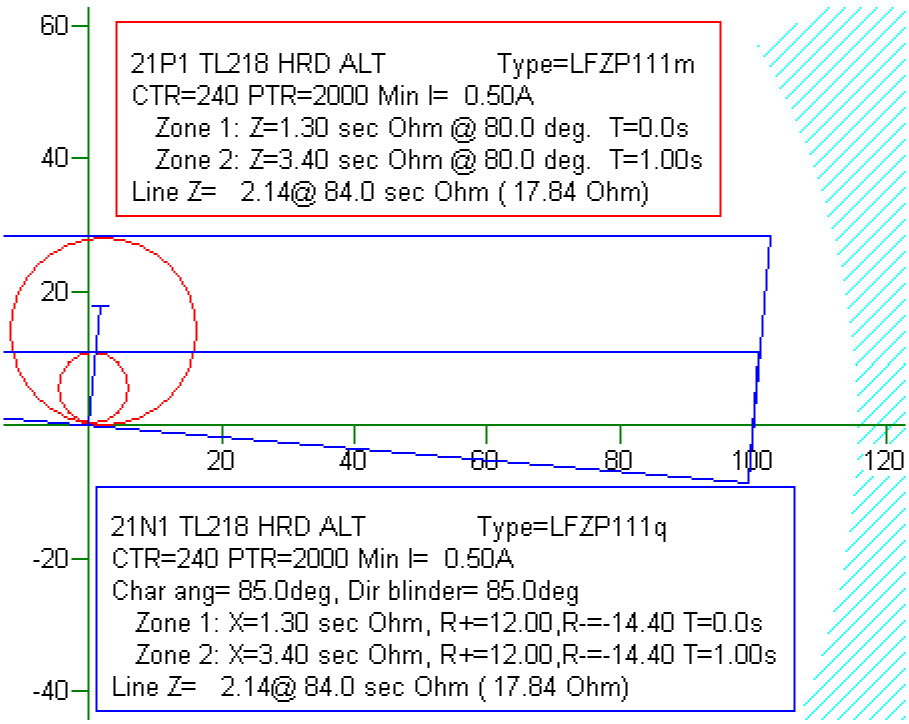


Figure 6 - Apparent impedance of load

Settings of K attenuators

KZPh Coarse setting common to all DISTANCE zones should be set as high as possible while below the required Zone 1 reach. The current level detectors vary inversely with KZph. Maximum setting available is 1.0

$KZPh := 1.0$

Zone 1 attenuators and angular selection

$In := 5$ $Z1\_sec = 1.3$ This is the desired secondary reach (previously calculated)

$$KZ1 := \frac{Z1\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ1 = 1.3 \qquad Z1sec\_reach := KZ1 \cdot KZPh \cdot \frac{5}{In} \qquad Z1sec\_reach = 1.3$$

$Z\theta PH := (\arg(Z1Linesec))$ $Z\theta PH = 83.958 \cdot deg$

Rounded to the nearest 5 degrees $Z\theta PH := 85$ Degrees (Increased from existing 80 degrees)

$Z\theta N := \arg(Z0Linesec - Z1Linesec)$ $Z\theta N = 82.835 \cdot deg$

Rounded to the nearest 5 degrees $Z\theta N := 80$ Degrees (same as eisting)

Zone 2 attenuators selection

$Z2\_sec = 3.4$ This is the desired secondary reach (previously calculated)

$$KZ2 := \frac{Z2\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ2 = 3.4$$

QUAD Resistive Reach setting

$Rquad = 12$ This is the desired secondary reach (previously calculated)

$$KR := \frac{Rquad}{\left(\frac{5}{In}\right)} \qquad KR = 12$$

Residual Compensation attenuators selection

Zero sequence current compensation for ground faults is provided by the KZN factor. Zero sequence mutual compensation is not used in this application (it causes extra complexity for only moderate gain in setting accuracy).

$$KZN := \frac{Z0Linesec - Z1Linesec}{3 \cdot Z1Linesec} \cdot KZPh \qquad KZN = 0.986 - 0.019j$$

$|KZN| = 0.99$ This is a reduction from the existing setting of 1.005

Switch On To Fault (SOTF) Protection.

If SOTF is enabled, it can be set to 200ms or 110 s after all poles of the line have been de-energized. The 110 s setting is intended to override automatic reclosing dead time. However it makes more sense to enable after the shorter time. Once the SOTF feature has been initiated, it remains in effect for 250ms after the line has been re-energized. The SOTF tripping options are:

a) Any distance comparator.
b) Any current level detector as long as a corresponding voltage level detector has not picked up within 20ms.
c) Either current or distance, as long as a corresponding voltage level detector has not picked up within 20ms.

SOTF := "Enabled"

SOTF_TIME := 0.20 Seconds

Elements_in_SOTF := "BOTH" (Both Comparators and current level detectors).

Power Swing Detector

This element will not be used. It will be left Blocked, and if there is a power swing, the distance elements will trip naturally.

VT Supervision

Set the VT supervision to BLOCK TRIP

Set the VT fail detection to SELF RESET.

Start Indication

This function will bring up information on the LCD screen of the relay if a start event occurs. This function will not be used.

START_INDICATION := "BLOCKED"

Communications assisted logic.

The existing communications assisted logic is permissive overreaching transfer trip, scheme **POR 1**. This scheme is familiar to Newfoundland and Labrador Hydro, and even though the POR 2 scheme offers the advantage of weak infeed echo, which would help the sensitivity to resistive faults, it is not recommended to change the existing scheme logic at this stage with years of experience on a product that is nearing the end of its useful life.

The POR 1 logic is a basic permissive overreaching transfer trip scheme but it does include current reversal timers to increase security against misoperation due to current reversal when a fault on the parallel line is cleared sequentially. The current reversal logic is achieved by a timer TP which will block permissive tripping and keying of permissive trip if the local zone 2 element does not pick up within a reasonable time of receiving permissive trip. The block will be maintained for a time delay of TD after the local zone 2 element picks up, or the received permissive trip signal resets.

The application of the current reversal timers is required only if the settings of the zone 2 comparators are greater than 1.5 times the line impedance .Although the reaches of these elements are only marginally less than 1.5 times the line impedance, there is no parallel line and there is infeed at each terminal that will minimize overreach. Therefore, the current reversal logic is not required, and the recommended default settings are as existing

$TP := 98$ ms

$TD := 0$ ms

Comparison of Existing (red) and Proposed alternative (ALT) settings.

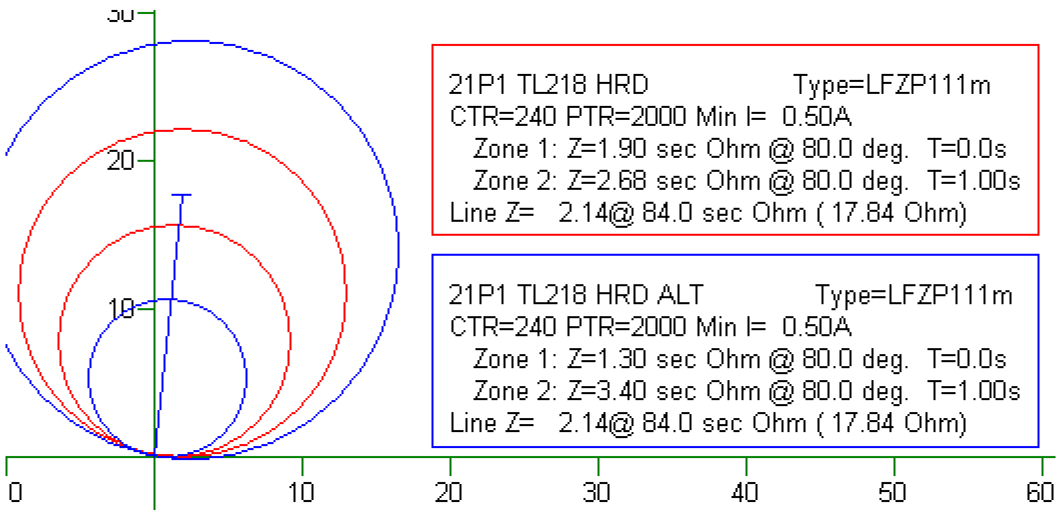


Figure 7 - Comparison of phase distance characteristics

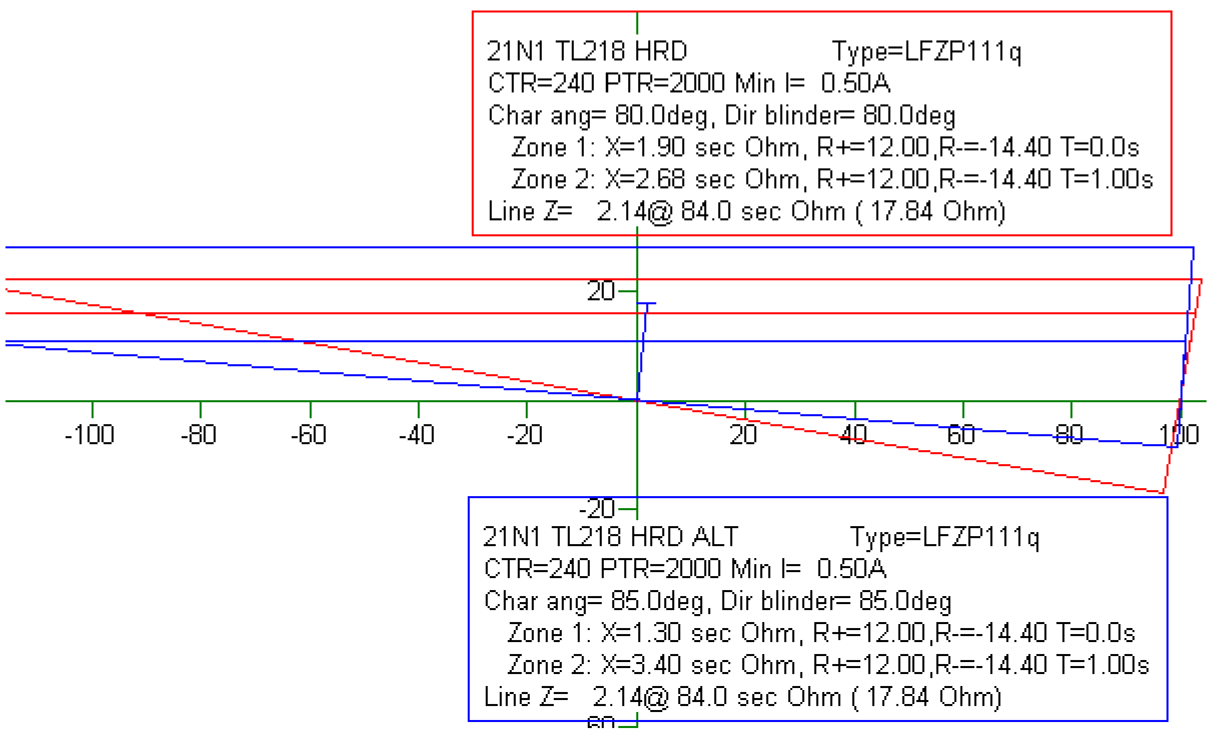


Figure 8 - Comparison of ground distance characteristics

Protection Review for Five 230 kV Transmission Lines

Appendix M
Detailed settings review for HRD TL218 "P2" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Holyrood (HRD) terminal of circuit TL218.
This 230 kV transmission circuit is from HRD to Oxen Pond (OPD).
The circuit runs parallel to Circuit TL242 and TL236 for parts of its length.

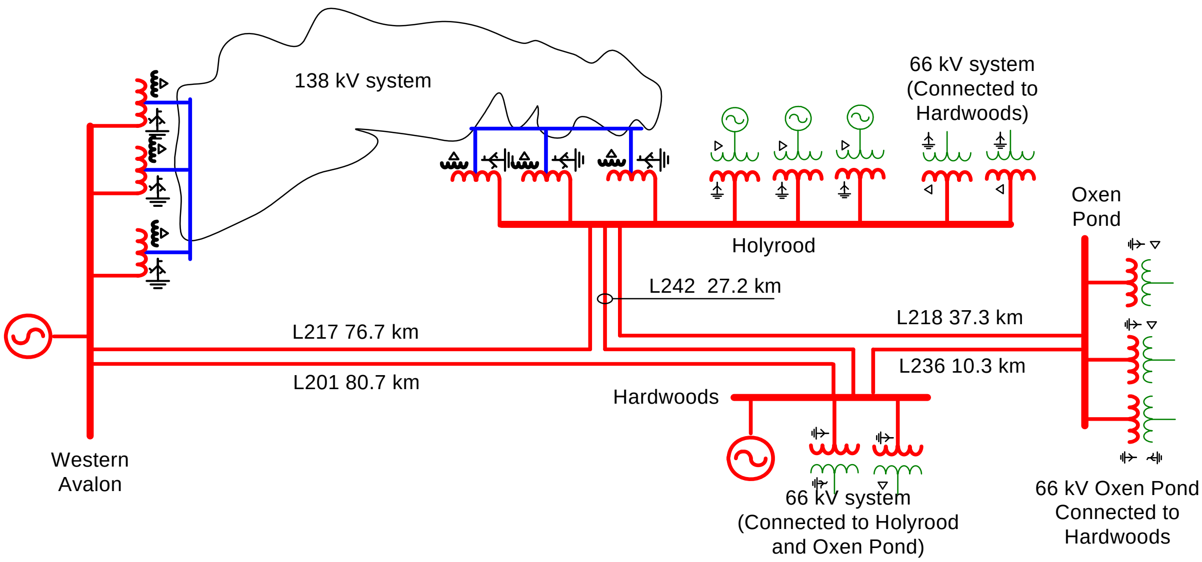


Figure 1 - System Single Line Diagram

Existing P2 protection systems are SEL321 systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $\quad$ $kVbase := 230$ $\quad$ $Ibase := \frac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\quad$ $Zbase := \frac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $CTR := \frac{1200}{5}$ $\quad$ VT ratio is: $VTR := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**NL HYDRO WITH MUTUALS FOR EAST COAST 230 kV LINE PN REVIEW 8 DEC.OLR**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with loads and shunts ignored.

Minimum fault current seen by each terminal (phase to phase, and SLG with 0 ohm fault resistance).

At HRD, with two units off line, and all parallel lines in service, for a fault at the remote terminal.

$I3Pmin := 1050$ A $ISLGminPH := 1068$ A $ISLGmin0seq := 414$ A

The current for a phase to phase fault would be lower, but the current supervision element of the SEL321 measures phase to phase currents, and the phase to phase current for a phase to phase fault is twice the phase current.

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind HRD $Z2minHRD := 1.0 + j \cdot 20.94$ ohms primary

$Z0minHRD := 0.34 + j \cdot 8.54$ ohms primary

Minimum source impedance behind OPD $Z2minOPD := 2.7 + j \cdot 30.9$ ohms primary

$Z0minOPD := 0.77 + j \cdot 15.46$ ohms primary

<u>Line impedances</u>.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L218 := 0.00355 + j \cdot 0.03354$ $Z0L218 := 0.01599 + j \cdot 0.1325$

$Z1Line := Z1L218 = 3.55 \times 10^{-3} + 0.034j$ pu $Z0Line := Z0L218 = 0.016 + 0.133j$ pu

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line \cdot Zbase$ $Z0Linephys := Z0Line \cdot Zbase$

$Z1Linephys = 1.9 + 17.7i$ ohms primary $Z0Linephys = 8.5 + 70.1i$ ohms primary

Converting primary ohms to secondary ohms gives:

$Z1Linesec := Z1Linephys \cdot \frac{CTR}{VTR}$ $Z0Linesec := Z0Linephys \cdot \frac{CTR}{VTR}$

$|Z1Linesec| = 2.14$ ohms sec $\arg(Z1Linesec) = 84 \cdot deg$

$|Z0Linesec| = 8.472$ ohms sec $\arg(Z0Linesec) = 83.12 \cdot deg$

Load Data

From 2011 System summer load case provided in start up information, the peak load (sum of TL218 and TL236) is given as 267 MVA (196 MVA in TL218 and 71 MVA TL236). In the event of sudden loss of one line, peak load will be the sum of both line loads until operators can adjust loads. Therefore it is assumed that peak load for a short duration is 267 MVA

$Smax\_TL218 := 196$ MVA $Smax\_TL236 := 71$ MVA $Smax := Smax\_TL218 + Smax\_TL236 = 267$ MVA

However, new information from Peter Thomas (see email dated 9 December, 2012 subject "Re: FW: PSSE Files") indicates that peal load should be set up to carry 370 MVA under the conditions of TL218 out of service.

$Smax := 370$ MVA

P2 Relay Settings

Minor changes to the set line impedances are recommended to assist fault locations.

$Z1MAG := |Z1Linesec|$ $Z1MAG = 2.14$ $Z1ANG := \frac{arg(Z1Linesec)}{deg}$ $Z1ANG = 84$

$Z0MAG := |Z0Linesec|$ $Z0MAG = 8.5$ $Z0ANG := \frac{arg(Z0Linesec)}{deg}$ $Z0ANG = 83.1$

$LL := 37.29$

In order to obtain sensitivity to 100 ohm single line to ground faults, the echo function will be needed. Enable three forward and one reverse zone.

$PMHOZ := 4$ $GMHOZ := 4$ $QUADZ := 4$ The zone 4 is used for faster communications independent tripping.

$DIR1 := F$ $DIR2 := F$ $DIR3 := R$ $DIR4 := F$

Mho phase distance functions

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the HRD Station bus under light load conditions with two units at HRD out of service and both TL218 and TL217 lines in service. From ASPEN OneLiner, voltage at HRD for a 3 phase fault at HRD is 0.15 per unit. Since the voltage is less than 20%, this line is considered short, and a reduced zone 1 reach is recommended to increase security. Choose a setting of 80% of nominal.

$Z1P := 0.8 \cdot |Z1Linesec|$ $Z1P = 1.71$ Ohms secondary

Existing setting of 1.90 ohms is too high, and should be reduced. $Z1P = 1.71$ Ohms secondary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 2.68 ohms secondary (about 125%) and is correct and should be retained.

$Z2P := 1.25 \cdot |Z1Linesec|$ $Z2P = 2.68$ Ohms secondary

$$Z2P\_pri := Z2P \cdot \frac{VTR}{CTR} = 22.302$$ Ohms primary

As can be seen from Figure 2, this element marginally overreaches the zone 1 on TL236 out of OPD without infeed. There is some infeed at OPD, but it is not very much. Choose a delay of 1 second, since a shorter reaching zone 4 element will be added.

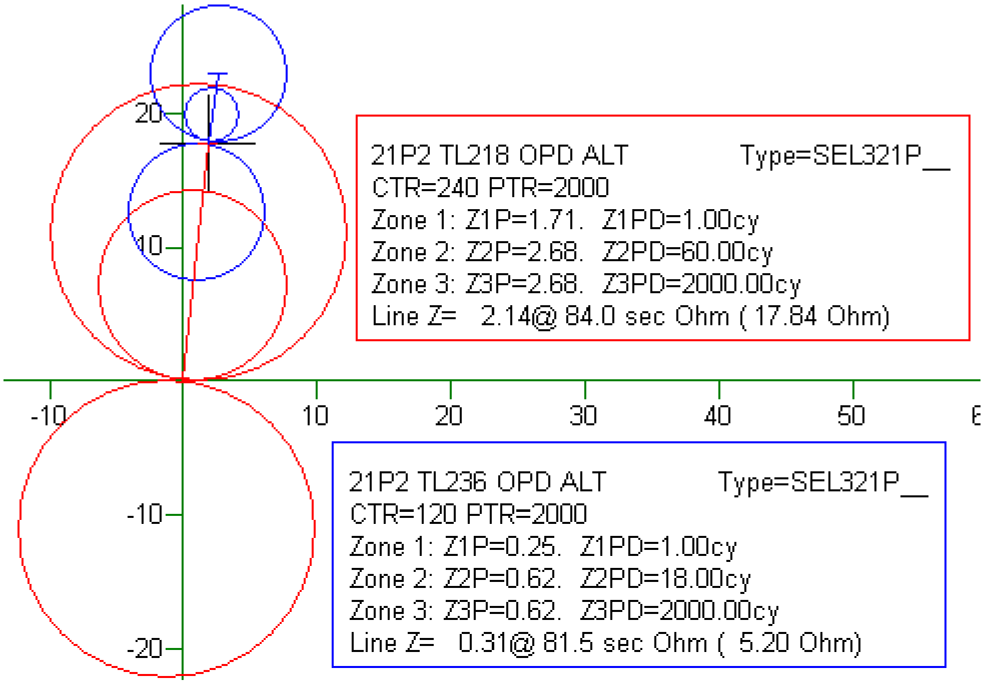


Figure 2 - HRD TL218 Zone 2 marginally overreaches OPD TL236 Zone 1 without infeed. Choose 1 second for the zone 2 timing at HRD.

Choose a one second delay for this element because it overreaches the remote TL236 zone 1, and also because there is no zone 1 trip on the remote TL236 P1 protection.

$Z2PD := 60$ Cycles Increased from existing 18 cycles

Zone 3

Set Zone 3 reverse element to reach further behind this terminal than the remote Zone 2. This function adds security for external faults. The element should always be more sensitive than the forward looking Zone 2 at the remote terminal. Set it the same as the remote Zone 2 using the line impedance as margin.

$Z3P := Z2P$ $Z3P = 2.7$ Ohms secondary

$$\frac{Z3P}{|Z1MAG|} = 125 \cdot \%$$ of line length This is a much higher than the existing setting, but provides additional security.

Zone 4

Set Zone4 at 110% of line to securely underreach the remote zone 1.

$Z4P := 1.1 \cdot |Z1Linesec|$ $Z4P = 2.36$ Ohms secondary

Set time delay at 18 cycles since this will underreach the remote zone 1.

$M4PT := 18$ cycles

Mho phase distance current supervision

If the current supervision elements can be set above load, they will be secure in the event that potential is lost. However given that loss of potential logic is available, it is recommended that only the zone 1 current supervision function be set above load. If potential is lost, it will be able to block tripping by Zone 2 before it trips on time delay or receives a permissive trip from the remote terminal.

For the point of view of current supervision being above maximum load, there is no need to worry about abnormal conditions. It would be a double contingency for the VT signal to be lost while the parallel line was out of service. Therefore, consider a maximum load of 196 MVA (with TL218 in service). The current supervision elements for the phase distance functions measure phase to phase currents.

$IPPmax\_normal := \frac{Smax\_TL218 \cdot 1000}{kVbase}$ $IPPmax\_normal = 852$ A primary

The current supervision elements use phase to phase currents for supervision of the phase distance functions; so the minimum phase to phase fault current will be root three times the minim phase fault current. Choose a margin of 50% of the minimum phase to phase fault current for dependability.

$IPPmin := 0.5I3Pmin \cdot \sqrt{3}$ $IPPmin = 909$ A primary

A setting of 912 A primary for 50PP1 will ensure the Zone 1 function operates for any fault under normal source conditions while remaining unable to trip on load due to loss of potential under any normal maximum load conditions. This is a higher than the existing setting, but is quite dependable.

$'50PP1 := 3.8$ A Sec $'50PP1 \cdot CTR = 912$ A primary

Since Zone 2, Zone 3 and zone 4 elements will be blocked by LOP function, set them at minimum. For zone 2, this is a little lower than the existing setting, but will be secure and dependable.

$'50PP2 := 1$ A Sec $'50PP3 := 1$ A Sec $'50PP4 := 1$ A Sec

<u>Ground Distance Protection</u>

The reach of the ground distance functions will be affected by mutual coupling to the parallel lines. These functions will tend to underreach the remote bus while the parallel lines are in service, and overreach the remote bus if a parallel line is out of service and grounded at both ends. Figure 3 shows that for a remote HV fault on a transformer, with 2L236 out of service and grounded, the apparent impedance of the line is reduced to about 1.99 ohms secondary instead of the nominal 2.14 ohms. This is 93% of the actual line impedance.

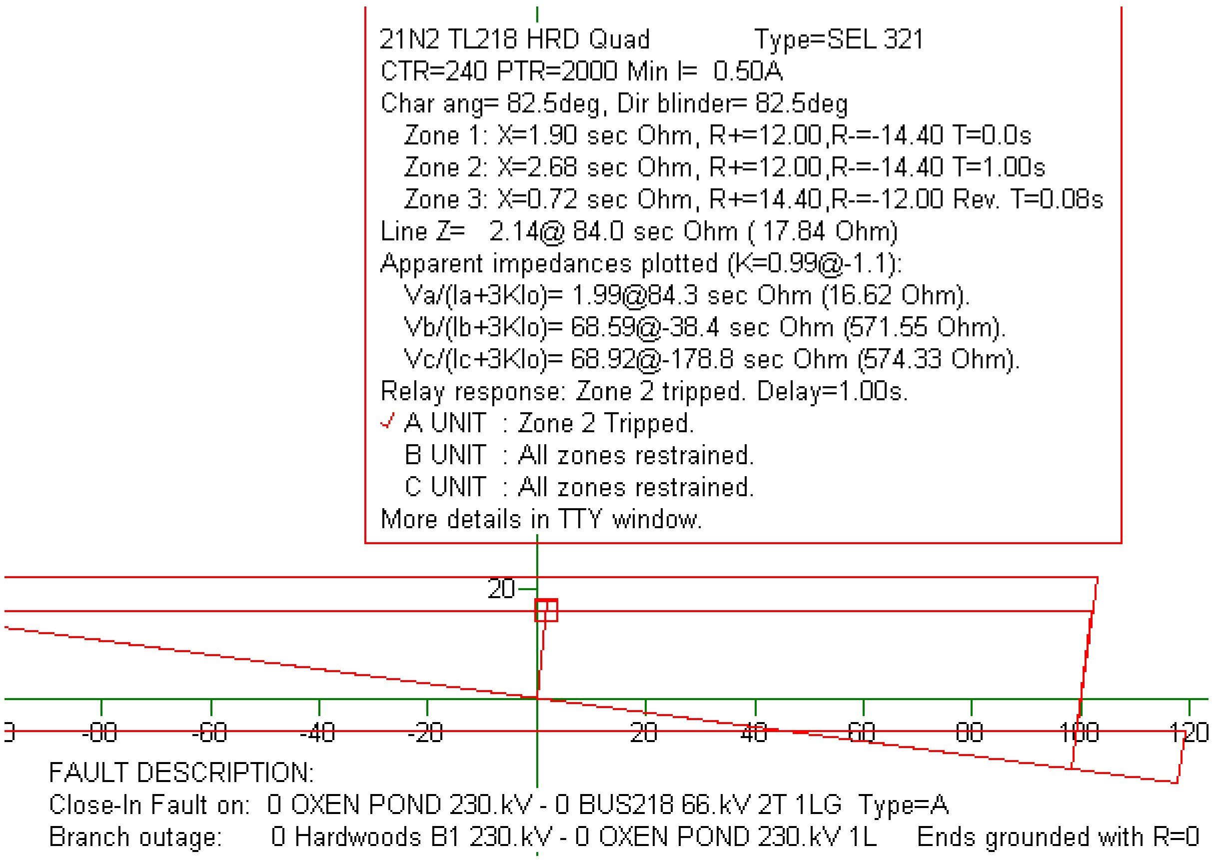


Figure 3 - Apparent impedance to a fault just beyond the remote terminal is reduced by 7% when TL236is out of service and grounded at both ends.

The reach of the zone 1 should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Considering that this line is short, choose a setting of 80% of line which will underreach the remote bus by 13% when the parallel line is out of service and grounded at both ends.

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.8$ per unit

$Z1MG := \mathrm{round}(m \cdot |Z1Linesec|, 1)$ $Z1MG = 1.7$ Ohms secondary

$XG1 := Z1MG$ $XG1 = 1.7$ Ohms secondary

Zone 1 Resistance

The resistive reach of the Zone 1 quad should provide enough sensitivity to trip the local terminal immediately without waiting for permission from the remote terminal for a severe fault that depresses the voltage significantly. Further, it should not allow the function to reach beyond the remote terminal due to errors in relay measurement or CT or VT. In general, a reasonable limit for resistive reach of a zone 1 function set at 85% of the line is 4 times the reactive reach. In the case of this line, the maximum recommended resistive reach for a zone 1 function set at 80% of the line will be calculated, and used as the limit for secure resistive reach.

XG1 is set at m per unit of the transmission line. The imaginary component of the line is

$ImXG1sec := Im(Z1Linesec)$ $\quad$ $ImXG1sec = 2.129$ ohms

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$RG1 := round[(1 - m) \cdot 20 \cdot ImXG1sec, 2]$

$RG1 = 8.52$ This is the maximum secure setting for the resistive reach but is below the proposed zone 1 resistive reach setting..

Use a maximum setting of 8 ohms for RG1 $\quad$ $RG1 := 8$ ohms secondary

With a resistive reach setting of 8 ohms, the HRD Zone 1 quad element will see an 60 ohm resistive SLG fault at close in (as shown in Figure 4). The Zone 1 element in the P1 protection and the Zone 2elements in this protection and the P1 protection will be depended upon to sense faults with resistance up to 100 ohms.

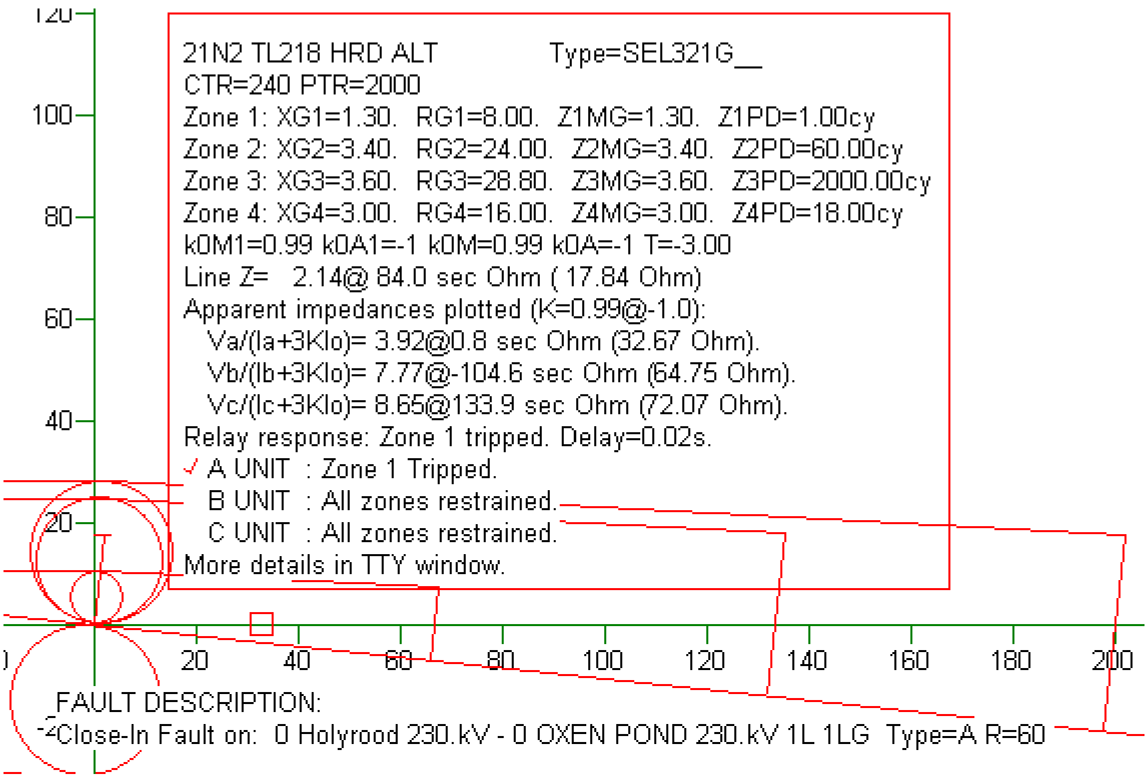


Figure 4 - HRD Zone 1 function if set with 8 ohm resistive reach, operates for a 60 ohm SLG fault close in to the local terminal.

Zone 2 Ground Distance Protection

The Zone 2 ground distance function will need to be set longer than the Zone 2 phase distance protection function because it will tend to underreach the remote terminal while the parallel line is in service. By simulation in ASPEN OneLiner it is found that the apparent impedance to a zero ohm fault close in to the remote terminal is 2.67 ohms secondary, or 24%% more than the actual line impedance. The reach of the Zone 2 ground distance element should be set at least to 1.25 times the apparent impedance.

$ZSLG\_remote := 2.67$ $\quad$ $Z2MG := 1.25 \cdot ZSLG\_remote = 3.337$ $\quad$ Choose a setting of 3.4

$Z2MG := 3.4$ $\quad$ $Z2MG = 3.4$ $\quad$ Ohms secondary $\quad$ $Z2MG \cdot \frac{VTR}{CTR} = 28.333$ $\quad$ Ohms primary

28.33

The quad element reactive reach will be set similarly to the mho.

$XG2 := Z2MG$ $\quad$ $XG2 = 3.4$ $\quad$ Ohms secondary

It would be desirable to set the resistive reach of the quad element to sense a 100 ohm SLG fault at 75% of the line with the local terminal weak. This would ensure overlap with the zone 1element at the remote terminal. However, that would require too much resistive reach. Therefore choose a setting to sense a 100 ohm SLG fault just past the mid point of the line, and depend on the echo function to provide coverage for high resistance faults in the region where the remote zone 1 won't operate.

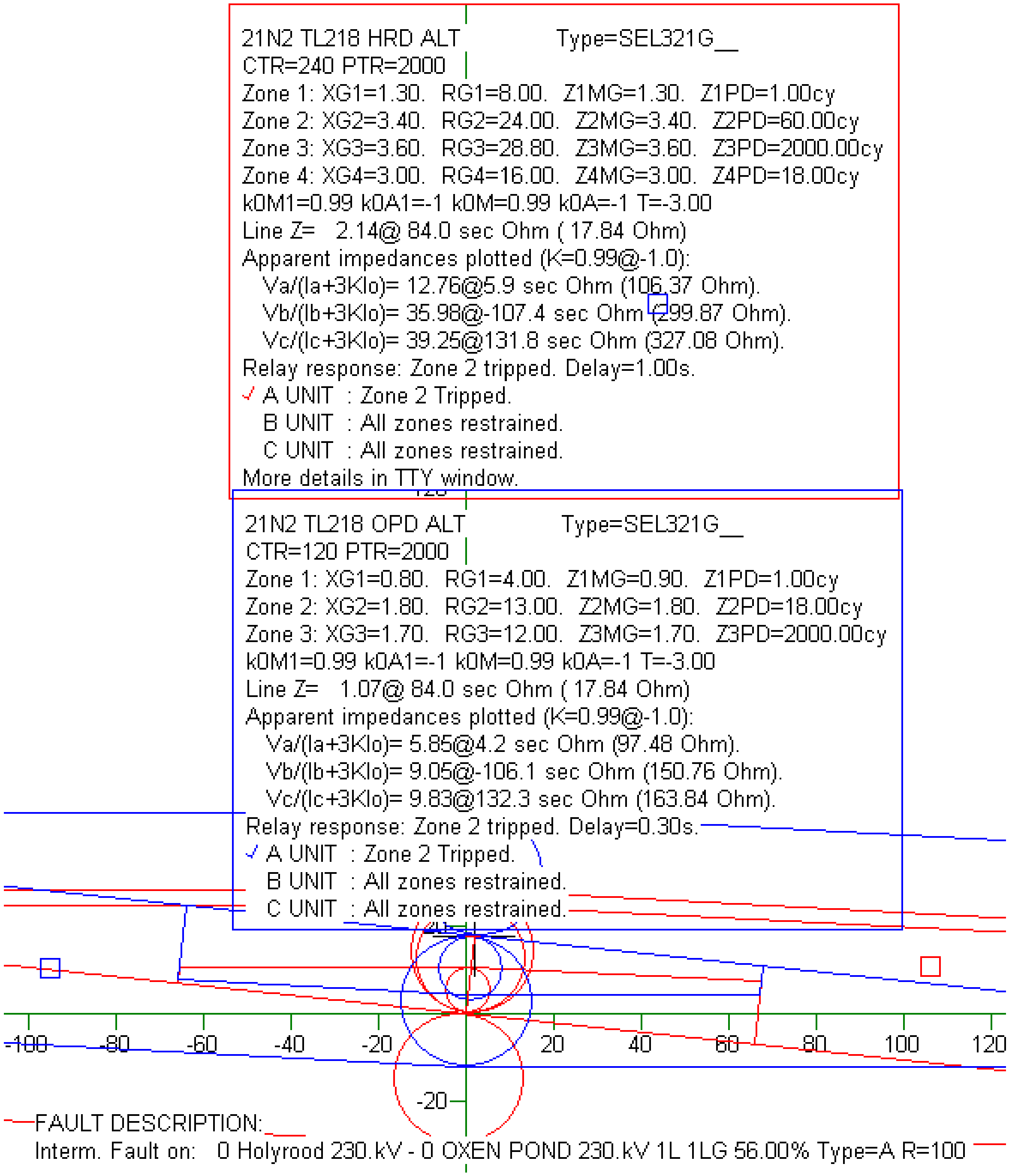
By trial and error from ASPEN it is found that a resistive reach of 25 ohms secondary will sense a 100 ohm SLG fault with an overlap with a similarly set remote zone 2 of 10% of the line length. See Figure 5. This will give positive overlap with the zone 2 element at the remote terminal. However since it will not overlap the Zone 1 element at the remote terminal, the permissive trip echo function will be required to ensure that a fault that is seen by the zone 2 element at only one terminal will still be cleared by the permissive trip logic.

Therefore, to avoid extremely large resistive reaches, and to retain sensitivity to 100 ohm resistive SLG faults, it is recommended that the echo function be enabled at both terminals.

$RG2 := 26$ $\quad$ Ohms secondary

The time delay of the zone 2 element will be set at 1 second since this element will overreach the OPD TL236 Zone 1 function (in fact there is no zone 1 function in the OPD TL236 P1 protection)

$Z2GD := 60$ $\quad$ cycles (same as existing)



<u>**Figure 5 - Quad elements overlap with remote quad elements and operate for 100 ohm resistive SLG near the mid line location.**</u>

Check that this resistive reach won't cause the zone 2 function to trip while a parallel line is open single phase, with heavy power flow. See Figure 6. Unusually heavy power flow has been simulated to challenge security.

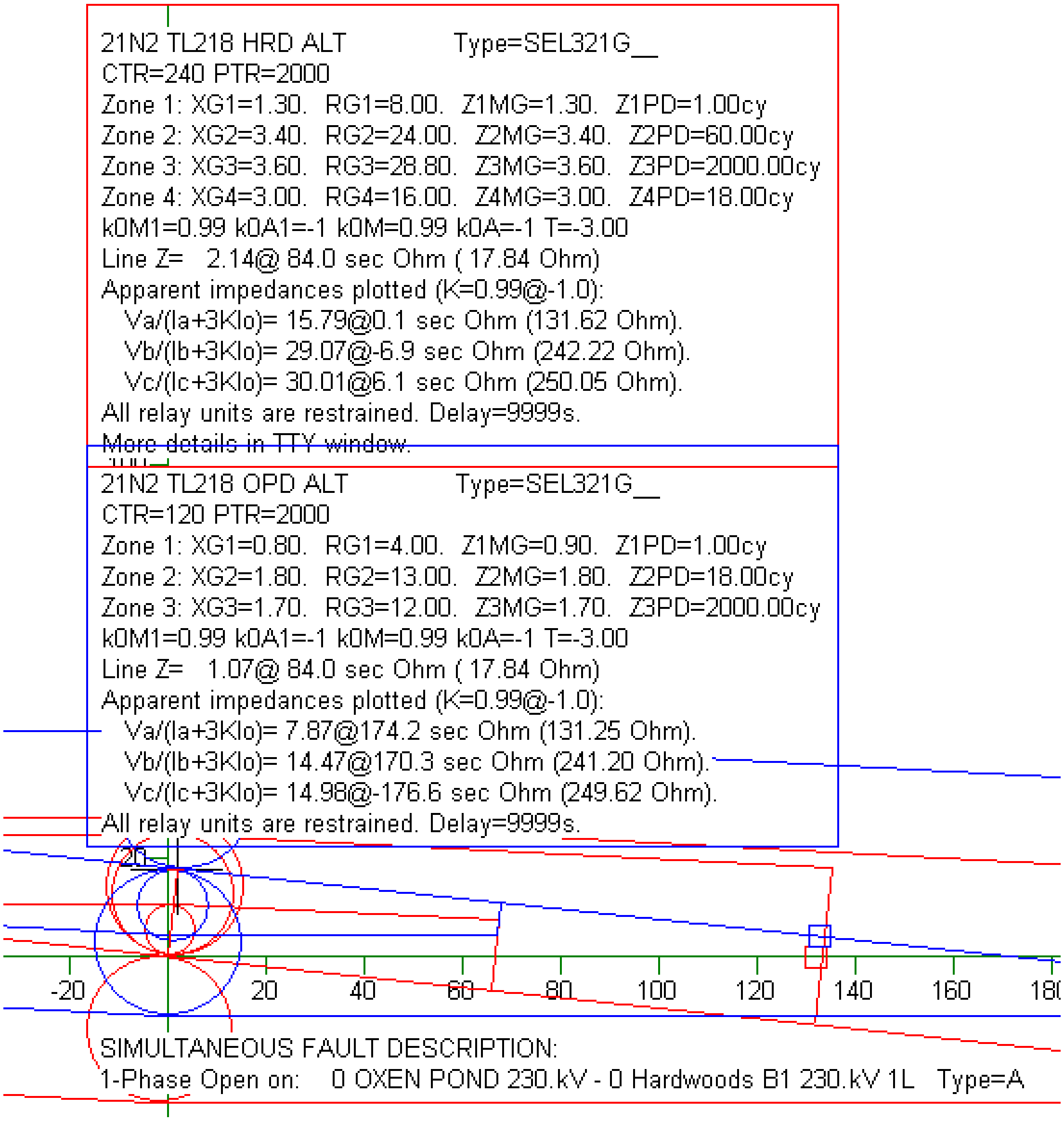


Figure 6 - Quad elements are secure with extremely heavy load flow (175 MVA in TL236 and 225 MVA in TL218) while TL218 is open single pole.

Zone 3

The zone 3 ground mho function will be set using the same principles as the zone 3 phase distance function. Use the setting for local zone 2 in secondary ohms as the remote zone 2.

$Z2MGrem := 30$ Ohms primary $Z3MG := Z2MGrem \cdot \frac{CTR}{VTR}$

$Z3MG = 3.6$ Ohms secondary

$\frac{Z3MG}{|Z1MAG|} = 168.1 \cdot \%$ of line length

This is much higher than the existing setting, but provides additional security.

$XG3 := Z3MG$ $XG3 = 3.6$ Ohms secondary

Set the Zone 3 quad resistive reach at 10% more than the remote Zone 2. Although the remote zone 2 has a different CT ratio, the setting is the same as the local zone 2 in primary ohms. Therefore use the setting for local zone 2 in secondary ohms as the remote zone 2.

$RG2rem := RG2$ Ohms secondary $RG3 := RG2rem \cdot 1.1$ $RG3 = 28.6$ Ohms secondary

Zone 4

The zone 4 ground mho function will be set to securely underreach the remote zone , similar to the zone 4 phase distance element.

$Z4MG := Z4P$ $Z4MG = 2.4$ Ohms secondary

$X4G := Z4P$ $X4G = 2.4$ Ohms secondary

The zone 4 resistive reach will be set to securely underreach the resistive reach of the OPD TL236 zone 1 with infeed from the transformers at OPD.

By trial and error it is found that a resistive reach setting of 8 ohms will underreach the remote TL236 zone 1 at OPD.

RG4 := 8 Ohms secondary

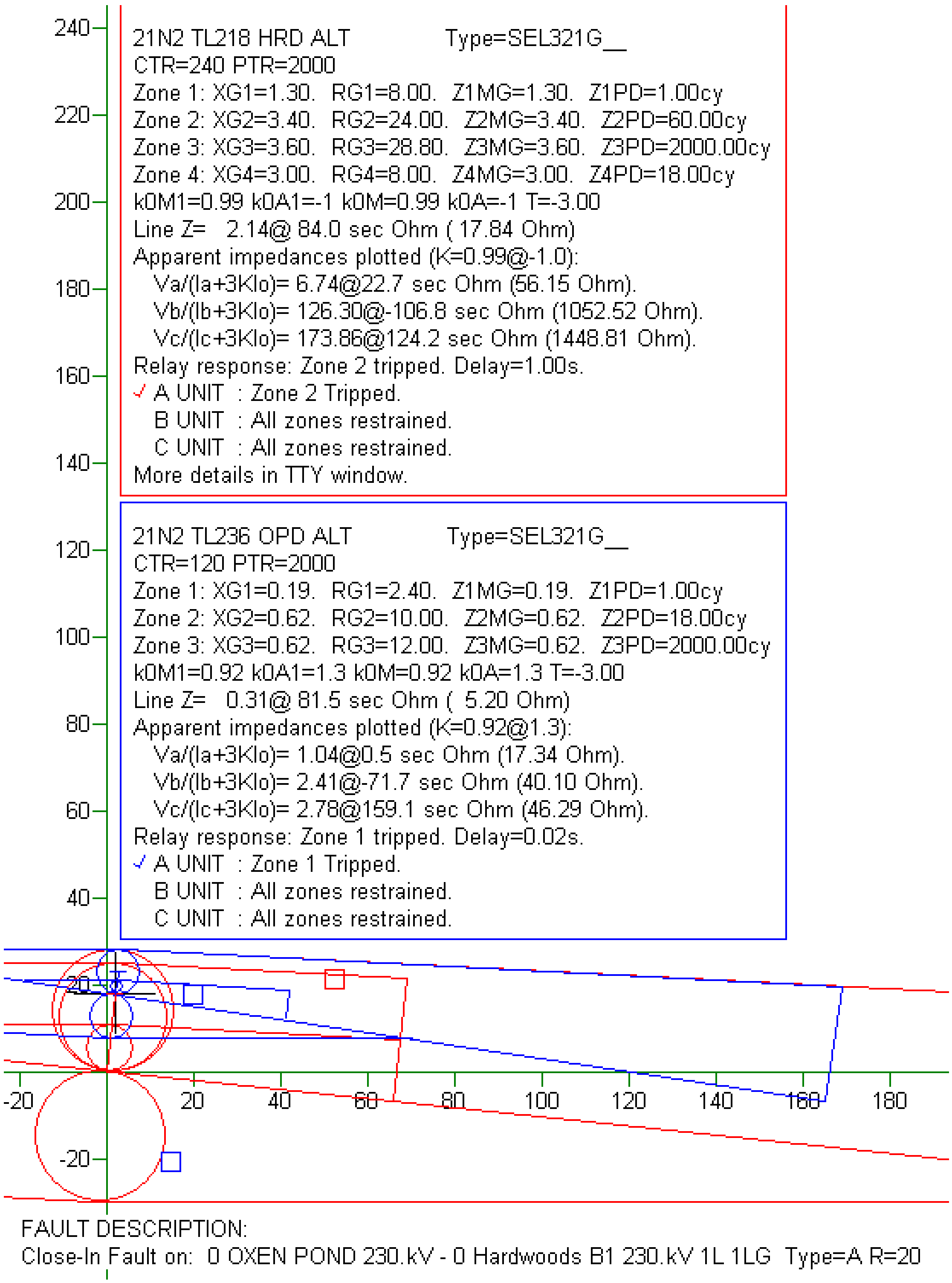


Figure 7 OPD TL236 Zone 1 senses a 20 ohm resistive SLG close in to OPD, which is not also sensed by HWD TL218 zone 4 element. Therefore HWD Zone 4 underreaches OPD zone 1 for resistive faults.

Ground distance current supervision

Since there is no concern about these elements operating on load, even with loss of potential, set all current supervision elements at minimum, for maximum sensitivity of the distance elements.

'50L1 := 0.5 A Sec '50L2 := 0.5 A Sec '50L3 := 0.5 A Sec '50L4 := 0.5 A Sec

'50G1 := 0.5 A Sec '50G2 := 0.5 A Sec '50G3 := 0.5 A Sec '50G4 := 0.5 A Sec

Note that due to heavy infeed of zero sequence currents from the local terminal for close-in faults, the ground overcurrent detectors will not operate for faults with more than a small amount of resistance close to the remote terminal. Therefore, we will have to rely on sequential clearing for that type of fault. However setting the current supervision at minimum allows maximum sensitivity.

Zero sequence current compensation

The zero sequence current compensation could be adjusted to compensate for the significant amount of mutual coupling. However as discussed in the settings of reaches of the ground distance elements we will accept underreach of the Zone 2 function for the normal case by setting it at 125% of the apparent impedance for a remote fault. Set the zero sequence current compensation as usual.

$$k01M := \left(\left|\frac{Z0Line - Z1Line}{3 \cdot Z1Line}\right|\right) \qquad k01M = 0.986$$

$$k01A := \left(\arg\left(\frac{Z0Line - Z1Line}{3 \cdot Z1Line}\right)\right) \qquad k01A = -1.12 \cdot deg$$

Set the overreaching zones the same as zone 1 $k0M := k01M$ $k0A := k01A$

$k0M = 0.986$ $k0A = -1.12 \cdot deg$

Settings are slightly different from existing due to small changes in line data.

Non Homogenous Angle Setting

Compare the angle of the remote zero sequence source impedance with the total zero sequence source impedance to the fault to determine this setting.

$$T := \arg\left(\frac{Z0minHRD + Z0Linephys + Z0minOPD}{Z0minOPD}\right) = -3 \cdot deg \qquad T = -3 \cdot deg$$

Out of step blocking and tripping

Not used in this application. There is a danger of out of step conditions arising. Historically no action has been taken to provide special tripping or blocking functions. Natural tripping during swings is accepted.

Load Encroachment logic

Check loadability of the Zone 2 phase distance element assuming worst case power factor of 0.87 simultaneous with worst case depressed voltage of a stressed system of 0.85 per unit. Note that units of kV squared match units of MVA. Note that quadrilateral elements are only used for the ground distance functions that are not sensitive to balanced three phase load. Therefore no need to worry about the reach of the quadrilateral elements.

$Zloadmin := \frac{(0.85kVbase)^2}{Smax}$ $Zloadmin = 103.298$ Ohms primary (assume worst case at 30 degrees)

Maximum reach of the Zone 2 element is at the line angle of 81 degrees. At 30 degrees, the reach will be given by

$Z2load := Z2P \cdot \cos[(Z1ANG - 30)deg]$ $Z2load = 1.575$ ohms secondary

$Z2load \cdot \frac{VTR}{CTR} = 13.122$ ohms primary

Since the reach of the Zone 2 element at 30 degrees is less than the apparent impedance of the maximum load, there is no need to apply load blinding logic. See Figure 7

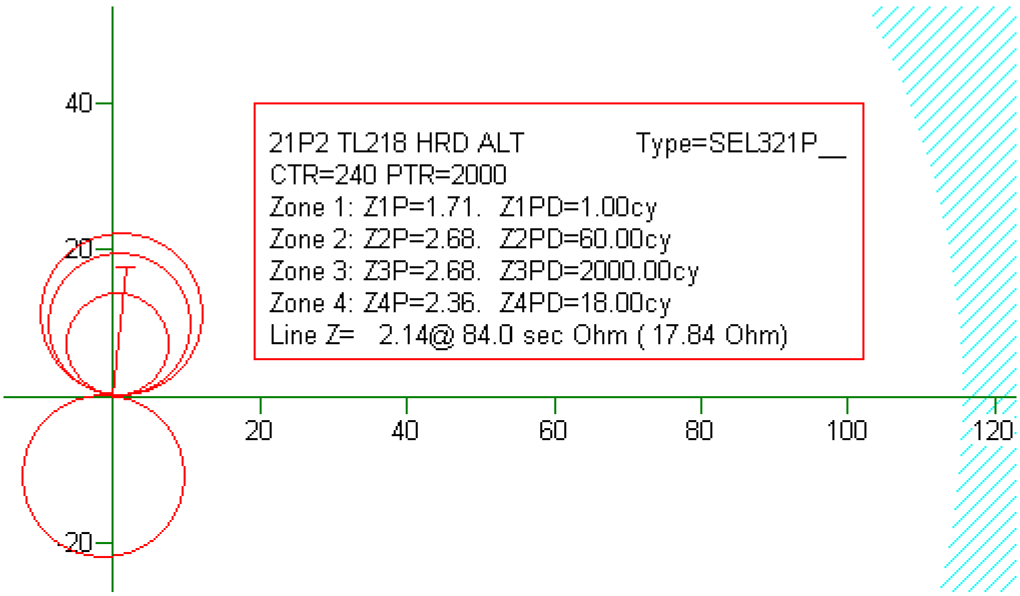


Figure 7 -Load impedance with respect to proposed new Mho function reaches.

Ground directional element

The SEL-321 application example recommends finding the minimum source impedance behind the terminal and setting the reverse and forward boundaries of the negative sequence directional element at the 1/3 and 2/3 points respectively.
In the negative sequence plane, the sum of the two source impedances and the line impedance is:

$$Z2total := Z2minHRD + Z1Linephys + Z2minOPD$$

The 1/3 point is $Z2\_1\_3 := \frac{Z2total}{3}$ The 2/3 point is $Z2\_2\_3 := \frac{2Z2total}{3}$

$Z2Rpri := Z2\_2\_3 - Z2minHRD$ $|Z2Rpri| = 25.593$

$Z2Fpri := Z2\_1\_3 - Z2minHRD$ $|Z2Fpri| = 2.412$

Converting the primary impedances to secondary ohms

$Z2R := Z2Rpri \cdot \frac{CTR}{VTR}$ $|Z2R| = 3.071$ Ohms secondary $\arg(Z2R) = 83.902 \cdot deg$

$Z2F := Z2Fpri \cdot \frac{CTR}{VTR}$ $|Z2F| = 0.289$ Ohms secondary $\arg(Z2F) = 69.133 \cdot deg$

Rounding down Z2F and rounding down Z2R gives:

$Z2F := 0.2$ Ohms secondary $Z2R := 3$ Ohms secondary

These are significantly lower than to the existing settings but are more secure.

Set the current level detectors at minimum level that will allow operation of the ground distance elements.

Due to the very small zero sequence current contribution to a single line to ground fault at the remote terminal, the negative sequence current contribution will always be higher than the zero sequence. Therefore there is no point in setting the forward looking negative sequence overcurrent elements any more sensitively than the zero sequence ground overcurrent supervision of the ground distance elements.

$'50QF := '50G2$ $'50QF = 0.5$ A secondary

Set the supervision function for the reverse looking element to be the same as, or a little more sensitive than the forward looking supervision element at the remote terminal.

$'50QR := 0.5$ A secondary

The positive sequence current restraint (a2) factor should be set just smaller than the ratio of the maximum load current (positive sequence) to the most sensitive current supervision element (50QR).

$I1maxpri := \frac{Smax \cdot 1000}{kVbase \cdot \sqrt{3}}$ $I1maxsec := \frac{I1maxpri}{CTR}$ $I1maxsec = 3.87$

Bearing in mind that the 50QR setting is in units of 3*I2

$\frac{'50QR}{3 \cdot I1maxsec} = 0.043$ Choose a value of $a2 := 0.04$

The proposed new setting of a2 is a little lower than the existing setting (0.05).

Phase time overcurrent element

This element is not used

Residual time overcurrent element

This element is used to provide the most sensitive backup protection. It will be a non directional element.

Set pickup to sense a higher resistance than 100 ohm SLG in the middle of the line with equal zero sequence current infeed from both ends. Choose a resistance of 200 ohms arbitrarily. Use a safety factor of 2 so that operating time is not infinity at this fault level.

$SF := 2$ Desensitization factor due to remote end infeed is $Dfactor := 2$ $Rf := 200$

$$'51NPU := round\left(\frac{kVbase \cdot 1000}{\sqrt{3} \cdot SF \cdot Dfactor \cdot Rf \cdot CTR}, 1\right) \qquad '51NPU = 0.7$$

The existing setting of 0.5 A is more sensitive than required to sense this mid line fault with arbitrary resistance. Since TL206 experience with the high resistance tree fault on 28th August 2009 has shown value in the existing setting, it will be retained.

$'51NPU := 0.5$ A secondary

Coordination checks show that existing time dial settings will coordinate with each other. See Figures 8 and 9

Coordination checks show that existing time dial settings will coordinate above existing remote protection (OPD TL236). However under maximum load conditions, if this line trips single phase, the neutral current during the open pole period will be sufficient to operate the 51N in less than one second. Although the reclose open pole dead time is about 45 cycles, the unbalance during the fault will also tend to operate the element. It is best to have an operating time due to unbalanced load flow during the oper pole period of not less than 1.3 seconds. The existing time dial setting will have to be increased to make this element secure during the open pole period with heavy load flow.

The existing settings on the TL236 protection will have to be slowed down for similar reasons. Therefore we have to check coordination above the new slower settings on TL236 as well as below the existing settings of protection on TL 217 and TL242.

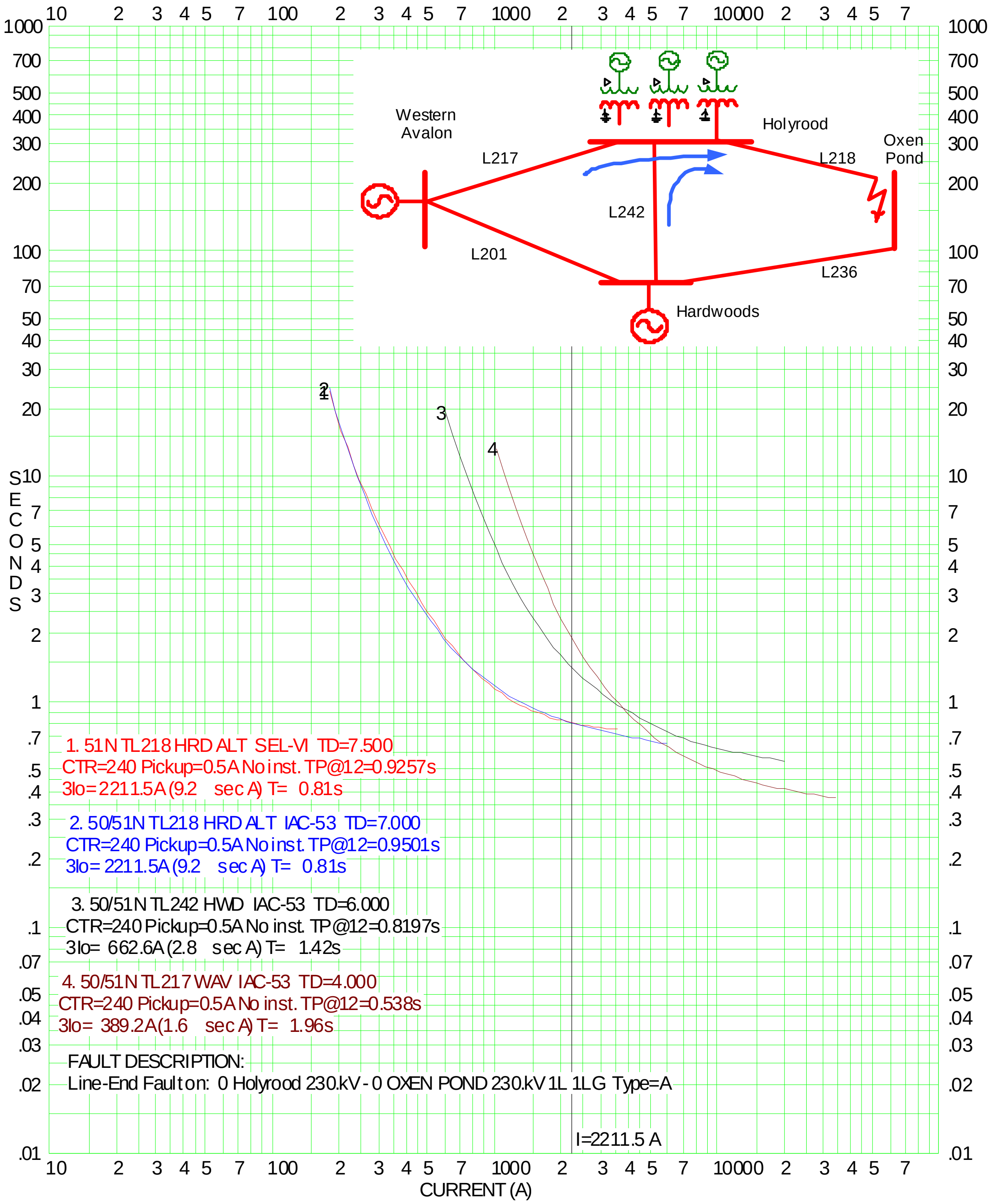
$'51NPU = 0.5$ A secondary $'51NPU \cdot CTR = 120$ A primary

$'51NTD := 7.5$ $'51NC := "U3"$ $'51NTC := "N"$ $'51NRS := "N"$

The time dial is proposed to be increased from existing 5 to 7.5 to be more secure during heavy load while one phase is open during a single phase trip and reclose operation.

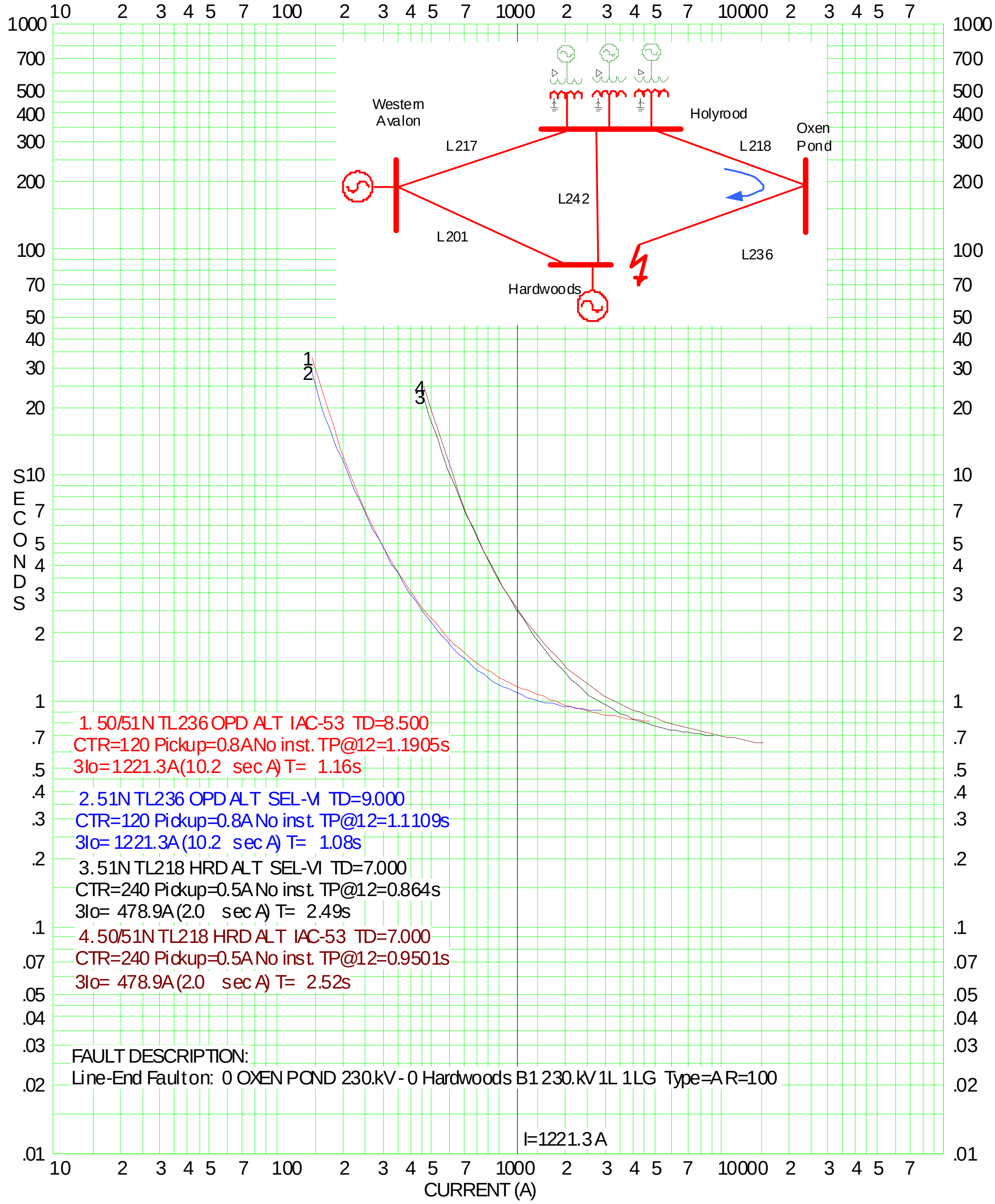
Check the coordination below the HWD TL242 51N and below the WAV TL217 51N for a line end fault on TL218 with two HRD units off line. This is the type of fault that will produce the most sensitivity (least desensitization) with respect to the backup protection on TL242 and TL217. see Figure 8. Coordination margin is satisfactory.

Check the coordination above the OPD TL236 protection for a LE fault. See Figure 9. It can be seen that the proposed new setting is only marginally slower than the proposed new OPD TL236 protection for a 0 ohm fault. For this type of fault we can rely on the 0.3 second time of the zone 2 ground distance function at OPD. For resistive faults the current will be much lower and the ground time overcurrent functions will coordinate satisfactorily.



EC 230-7	TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For	Coordination of HRD TL218 below WAV L217 and HWD L242	No. EC 230-7
Comment	Two units OOS at HRD	Date 13 Dec 2011

Figure 8 - coordination of ground time overcurrent elements for LE TL218 fault



EC 230-8	TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For	Coordination of OPD TL236 below HRD TL218	No. EC 230-8
Comment Z2G needed for coordination with RF <100 ohms		Date 13 Dec 2011

Figure 9 - coordination of ground time overcurrent elements for line end fault on TL236 close to HWD

Permissive Overreaching logic settings

EPOTT := "Y"

Z3RBD is set at remote breaker time plus channel reset time plus channel reset time plus zone 2 reset time. From review of fault records it appears that the breaker time is 3 cycles. Channel reset time is not easily determined from existing records but can conservatively be assumed to be 1 cycle, and relay reset time will also be about 1 cycle. Total time for Z3RBD is then 5 cycles.

Z3RBD := 5 cycles

Echo block delay timer blocks the echo after the local elements have picked up. This can be set relatively long since there is no significant need for the echo function shortly after the local terminal has just seen a fault but the remote terminal has not. Set at 10 cycles as per the example in the instruction manual.

EBLKD := 10 cycles

Echo time delay on pickup should be set to override noise on the communications so that it doesn't echo noise. Typical time according to the SEL application guide is 2 cycles. Since this delay only affects clearing time for relatively light (high resistance) faults that are sensed by zone 2 function at one end, the typical setting is acceptable.

ETDPU := 2 cycles

Echo duration should be long enough to ensure the permissive trip is received by the remote terminal and should also be shorter than the Z3RBD time to ensure that the reverse blocking will always be longer than any permissive trip received (including echo time stretching).

EDURD := 4 cycles

No need to enable week feed conversion to trip, since both terminals will be quite sensitive enough to detect high resistance faults after the remote terminal has cleared. Therefore we can accept sequential (or "step") clearing with no need for the added insecurity of weak infeed tripping.

EWFC := "N" **No other communications logic settings are required for this application.**

Switch on to Fault Settings

Switch on to fault logic will ensure the protection will operate when energizing the line onto a close-in three phase fault when there is no polarizing voltage available for the distance elements.

ESOTF := "Y"

The breaker close signal is not available to the relay. The 52A method of enable SOTF will be used. Therefore the Close end delay is not critical. Typical duration for enable SOTF is 10-15 cycles

ENCLO := "N" CLOEND := 0 EN52A := "Y" SOTFD := 15

Set 50H for high magnitude close-in multiphase faults with weakest source at HRD. It should be set less than 50% of the minimum close-in fault magnitude. Minimum close-in magnitude of a three phase fault with two units off line and TL242 out of service is 3000 A. Therefore desired maximum setting for 50H is 1500 A.

Imin3P_close_in := 3000

$$'50H := \frac{\text{Imin3P\_close\_in}}{2\text{CTR}} \qquad '50H = 6.25 \quad \text{A secondary}$$

Choose a setting of 6 A secondary for this element. '50H := 6 A secondary

Choose a setting for 52AEND less than the shortest reclose time. '52AEND := 30 cycles

The existing setting of 52AEND is 70 cycles. It is not known why the setting is set longer than the reclosing time.

Residual overcurrent settings.

Tripping directly by instantaneous ground overcurrent is not applicable because it is not phase selective. However it would be helpful to monitor steady state unbalance, and issue an alarm for continuous unbalance. Set the detector at minimum or just at the point necessary to override normal unbalances.

E50N := 1   '50N1 := 0.25

Negative Sequence overcurrent settings.

Similar to ground overcurrent, apply a negative sequence overcurrent element to initiate an alarm for steady state unbalances. Set the detector at minimum or just at the point necessary to override normal unbalances.

E50Q := 1   '50Q1 := 0.25

Voltage Element Settings

Similar to unbalance current monitoring, it is helpful to have an unbalance voltage monitor to detect steady state unbalances from the voltage supply.

EVOLT := "Y"

Set the zero sequence overvoltage element at 1% of rated voltage or just at the point necessary to override normal unbalances. The zero sequence voltage element measures 3 times the zero sequence voltage.

$'59N := 3 \cdot 0.01 \frac{kVbase \cdot 1000}{\sqrt{3} \cdot VTR}$ $'59N = 1.992$ Say $'59N := 2$ V secondary

Loss of Potential

Enable loss of potential settings. Advanced LOP settings are not available on this model of relay.

ELOP := "Y"   Time delay of 1.25 cycles is commonly used.   LOPD := 1.25

The 50 M element should be set above maximum load and below minimum fault current for a fault at the remote terminal under weak source conditions. The maximum load for this case should be normal maximum, not emergency maximum which only exists for a few minutes before the operator can act to reduce load.

$Imax\_normal := \frac{Smax\_TL218 \cdot 1000}{\sqrt{3} \cdot kVbase \cdot CTR} = 2.05$ A secondary

Minimum fault current for a remote three phase fault is   I3Pmin = 1050   A primary.

Minimum fault current for a remote phase to phase fault is 87% of the minimum three phase fault current level.

Dependability factor to be sure to operate for a minimum remote fault is chosen to be 1.6.   DF := 1.6

Maximum setting for 50M should be $\frac{0.87 I3Pmin}{DF \cdot CTR} = 2.379$ In this case a setting of 2.1 A secondary will be adequately dependable and secure.

'50M := 2.1   A secondary

The 59QL setting should be above normal maximum unbalance and below the level expected for a blown VT fuse. For a blown fuse, one phase voltage will be lost, and the negative sequence voltage will be roughly 33% of the nominal positive sequence voltage. Choose a setting of 15% of the nominal positive sequence voltage. This will be well above any normal unbalance.

$$'59QL := \mathrm{round}\left(\frac{0.15 \cdot kVbase \cdot 1000}{\sqrt{3} \cdot VTR}, 0\right) \qquad '59QL = 10 \text{ V secondary}$$

The 59PL setting should be less than the minimum voltage to be expected for a remote bus fault under weakest source conditions. There is no minimum setting (above zero) for this function. Choose a setting equal to half the voltage drop along the line impedance at the pickup setting of the 50M element.

$$'59PL := \mathrm{round}[0.5 \cdot ('50M \cdot |Z1Linesec|), 0] \qquad |'59PL| = 2$$

Miscellaneous Scheme Settings

Pole discoordinance logic is not being used. EPOLD := "N" SPPDD := "N/A"

Enable single pole tripping by distance elements only ESPT := "Y"

Enable single pole open ESPO := "Y"

Set single pole open time delay for future SPO conditions SPOD := 0.25

Note that SPOD was short enough to allow a transient operation when TL201 was reclosed with a fault on it during the fault of 7 March 2011. This transient operation was helpful to clear the fault more quickly than it otherwise would have cleared. SEL have been asked whether the SPOD setting of 0.5 would be better to increase the security.

3 Pole open reset delay to override small discrepancies in pole closing '3POD := 0.5

Stub line protection is not required ESTUB := "N" '50MFD := "N/A"

Trip unlatch logic not applied TULO := "N"

Logic variables and Miscellaneous timers

Minimum trip duration timer is set at 9 cycles as per the application example in the SEL-321 instruction manual.

TDURD := 9 Cycles

Trip during open pole time delay should be set longer than the reclose time. Existing reclose time is 55 cycles. This is acceptable.

TOPD := 55 Cycles

Existing logic variables are not used.

Since this line is short (voltage may be low at HRD for a fault near OPD), a 1 cycle security delay in zone 1 tripping is recommended to improve the security of this function against incorrect tripping for a fault beyond the OPD terminal.

LOGIC_X := "M1P+Z1P" TXPU := 1 cycle TXDO := 0 cycles

Add the use of ZT to trigger an alarm for sustained unbalance.

LOGIC_Z := "59N+50N1+50Q1" TZPU := 1200 cycles TZDO := 0 cycles

Tripping Logic

Permissive tripping is required only for instantaneous overreaching functions. No need for any functions that trip directly. Existing 51NT word in MTCS is not required.

MTCS := "M2P+Z2G"

Existing settings for unconditional tripping must be modified to include a 1 cycle delay for zone 1 tripping.

MTU := "XT+M2PT+Z2GT+ M4PT +Z4GT + 51NT"

No need for existing direct tripping zone 1 functions in the switch on to fault logic.

SOTF Tripping MTO := "M2P+Z2G+50H"

Event records will be triggered automatically by all trip events. Other event record triggers should be by starting of other elements to ensure capture of all relevant events. Events should be triggered by keying or receiving permissive trips to ensure separation of relay and teleprotection issues.

MER := "M2P+Z2G+51NP+LOP*52AA1+LOP*52AA2+KEY+PT+EKEY"

Outputs

Retain existing output assignments except add the continuous unbalance alarm to OUT15.

OUT15 := "LOP*50L+ZT"

Input Contact Assignment

It would be desirable to provide phase segregated inputs to the relay so that the quadrilateral functions could be disabled during single pole open conditions. it is not known if phase segregated auxiliary switches are available on the breakers.

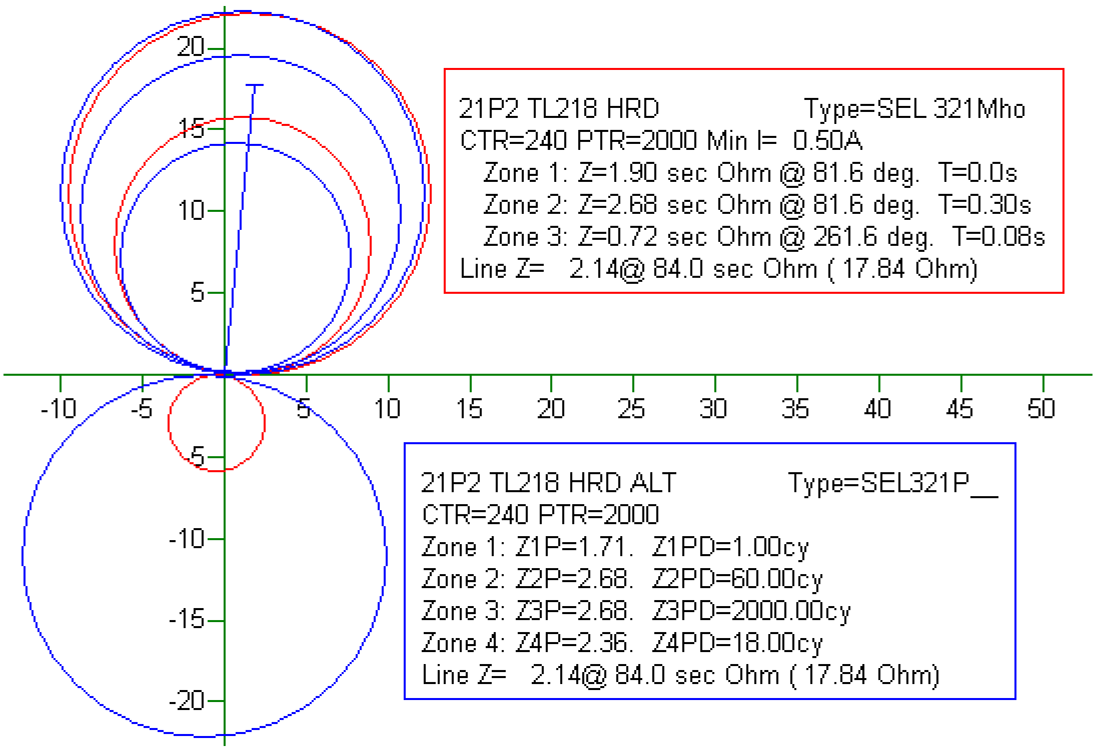


Figure 10 - Comparison between existing (red) and proposed new (blue) phase distance characteristics.

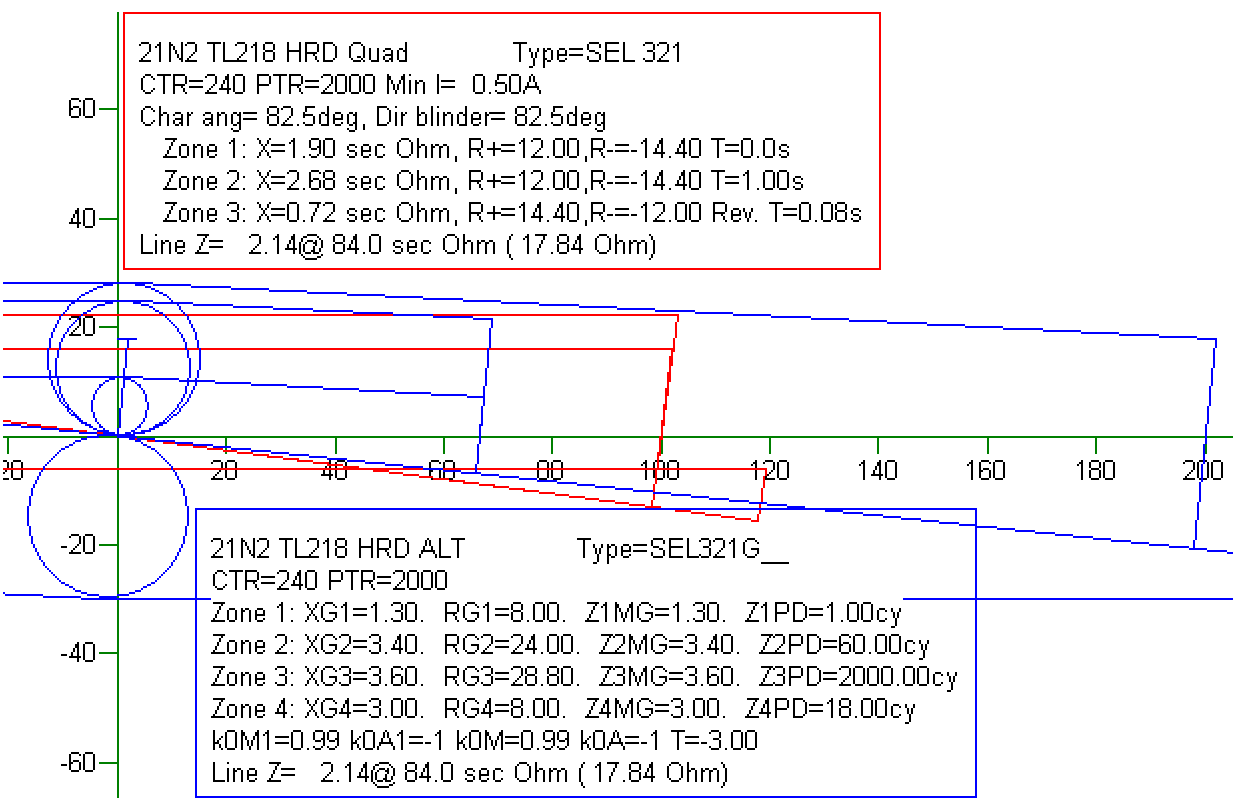


Figure 11 - Comparison between existing (red) and proposed new (blue) ground distance characteristics.

Protection Review for Five 230 kV Transmission Lines

Appendix L
Detailed settings review for OPD TL218 "P1" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador Hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Holyrood Terminal (OPD) terminal of circuit TL218. This 230 kV transmission circuit is from OPD to Oxen Pond (OPD).
The circuit runs parallel to Circuits TL201 and TL236 for some of its length.

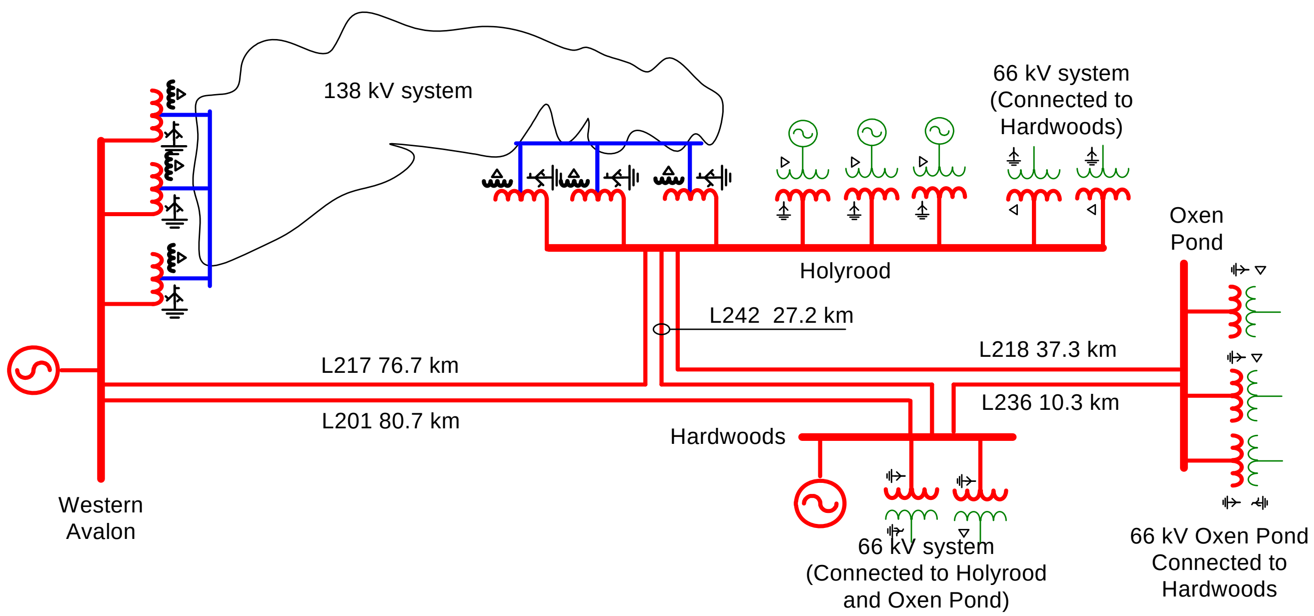


Figure 1 - System Single Line Diagram

Existing P1 protection systems are Areva LZFP111 (Optimho) systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $\quad$ $kVbase := 230$ $\quad$ $Ibase := \frac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\quad$ $Zbase := \frac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at the line terminal.

CT ratio is: $CTR := \frac{600}{5}$ $\quad$ VT ratio is: $VTR := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**NL HYDRO WITH MUTUALS FOR EAST COAST 230 kV LINE PN REVIEW 8 DEC.OLR**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with loads and shunts ignored.

Minimum fault current seen by each terminal (phase to phase, and SLG with 0 ohm fault resistance).

At OPD, with TL236 out of service, with 66kV sources modelled connected to the 66 kV side, there will be a weak source of positive sequence fault current at that station. There will be some infeed from the 66 kV side.

$ILLmin := 270$ A $ISLGminPH := 453$ A $ISLGmin0seq := 595$ A

The optimho current level detectors that block the distance comparators in the event of line opening are fixed at 5% of the rated current, or 0.25 A secondary, or 60 A primary. They will have no difficulty in operating for minimum bolted fault levels. However, the ground distance elements are also supervised by a low set neutral current level detector (LDLSN that requires the neutral current to be greater than 10% of the maximum amplitude of phase difference current. This prevents the ground comparators from operating during close-in multiphase faults with CT errors. ASPEN OneLiner shows that for a bolted fault at the remote bus even under heavy load, there is sufficient neutral current (20% of maximum phase to phase fault current) that means this LDLSN function does not inhibit the ground distance comparator.

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind OPD $Z2minOPD := 2.7 + j \cdot 30.9$ ohms primary

Minimum source impedance behind HRD $Z2minHRD := 1.0 + j \cdot 20.94$ ohms primary

<u>Line impedances</u>.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L218 := 0.00355 + j \cdot 0.03354$ $Z0L218 := 0.01599 + j \cdot 0.1325$

$Z1Line := Z1L218 = 3.55 \times 10^{-3} + 0.034j$ pu $Z0Line := Z0L218 = 0.016 + 0.133j$ pu

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line \cdot Zbase$ $Z0Linephys := Z0Line \cdot Zbase$

$Z1Linephys = 1.9 + 17.7i$ ohms primary $Z0Linephys = 8.5 + 70.1i$ ohms primary

Converting primary ohms to secondary ohms gives:

$Z1Linesec := Z1Linephys \cdot \frac{CTR}{VTR}$ $Z0Linesec := Z0Linephys \cdot \frac{CTR}{VTR}$

$|Z1Linesec| = 1.07$ ohms sec $\arg(Z1Linesec) = 84 \cdot deg$

$|Z0Linesec| = 4.236$ ohms sec $\arg(Z0Linesec) = 83.12 \cdot deg$

Load Data

From 2011 System summer load case provided in start up information, the peak load (sum of TL218 and TL236) is given as 267MVA (split between TL218 and TL236). In the event of sudden loss of one line, peak load will be the sum of both line loads until operators can adjust loads. Therefore it is assumed that peak load for a short duration is 205 MVA

$Speak := 267$ MVA $\quad$ $Smax := Speak = 267$ MVA

However, new information from Peter Thomas (see email dated 9 December, 2012 subject "Re: FW: PSSE Files") indicates that peal load should be set up to carry 370 MVA under the conditions of TL218 out of service.

$Smax := 370$ MVA

P1 Relay Settings

Distance element reach settings

Note that resistive reaches are forced to be the same for all zones. Reactive reaches for phase and ground distance elements must be the same as each other.

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the OPD Station bus under light load conditions and TL236 line out of service. From ASPEN OneLiner, voltage at OPD for a 3 phase fault at OPD is 0.04 per unit. Since the voltage is less than 20%, this line is considered short, and a reduced zone 1 reach is recommended to increase security. Choose a setting of 80% of nominal.

$Z1P := 0.8 \cdot |Z1Linesec|$ $\quad$ $Z1P = 0.86$ Ohms secondary

Existing setting of 0.952 ohms is too high and should be reduced to at the most, 0.86 ohms secondary. However, the ground distance reach in the optimho has to be set the same as the phase distance reach; so we need to consider the ground faults too.

$Z1P = 0.86$ For phase faults only.

The worst case from the point of view of overreach of the zone 1 ground distance element is with TL242 out of service and grounded at both ends, and a close-in fault on the HV bus of one of the Holyrood transformers. For this case, the apparent impedance presented to the relay is only 1.04 ohms secondary (see Figure 2). This is 97% of the line impedance. So the proposed 80% reach of the zone 1 element for phase faults should be OK as far as overreach due to a parallel line being out of service and grounded at both ends is concerned.

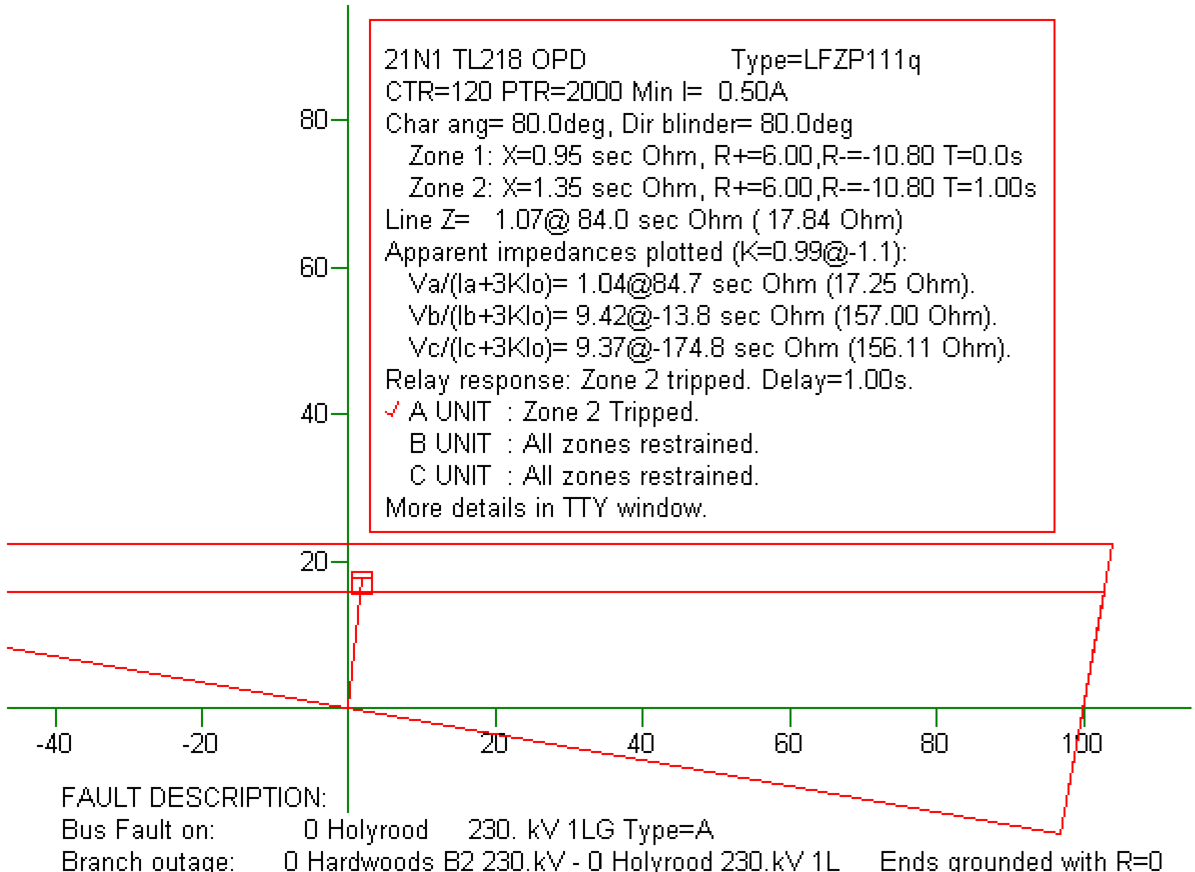


Figure 2 - Apparent impedance to a fault just beyond the remote terminal is reduced by 3% when TL242 line is out of service and grounded at both ends. Existing relay settings modeled in this figure.

The reach of the zone 1 ground distance element should be reduced to less than 85% of the line impedance to make it more secure against misoperation for an external fault with the parallel line out of service and grounded. **A more important constraint exists due to the short line and the high resistive reach** required in order to sense 100 ohm resistive faults near the middle of the line. The resistive reach of the zone 2 element (which is the same as the resistive reach of the zone 1 element) has to be set at about 12 ohms secondary. Such a long resistive coverage on the zone 1 element may not be secure when considering the VT and CT errors may cause additional possibility of overreach of the zone 1 for resistive external faults. Choose a setting of 80% of line which will underreach the remote bus by 17% when the parallel line is out of service and grounded at both ends.

Note that since power flow is normally into this terminal, the difference in voltage angles at each terminal due to power flow will not cause an overreaching effect. In fact, will more likely cause the zone 1 element to underreach due to power flow, but the 80% reactive reach setting will still be helpful to allow large resistive reach while retaining security.

Since power flow into the terminal will not cause insecurity, the most critical factor is VT and CT errors that might cause the reactive element to overreach if the resistive reach is set too long and under light load condtions.

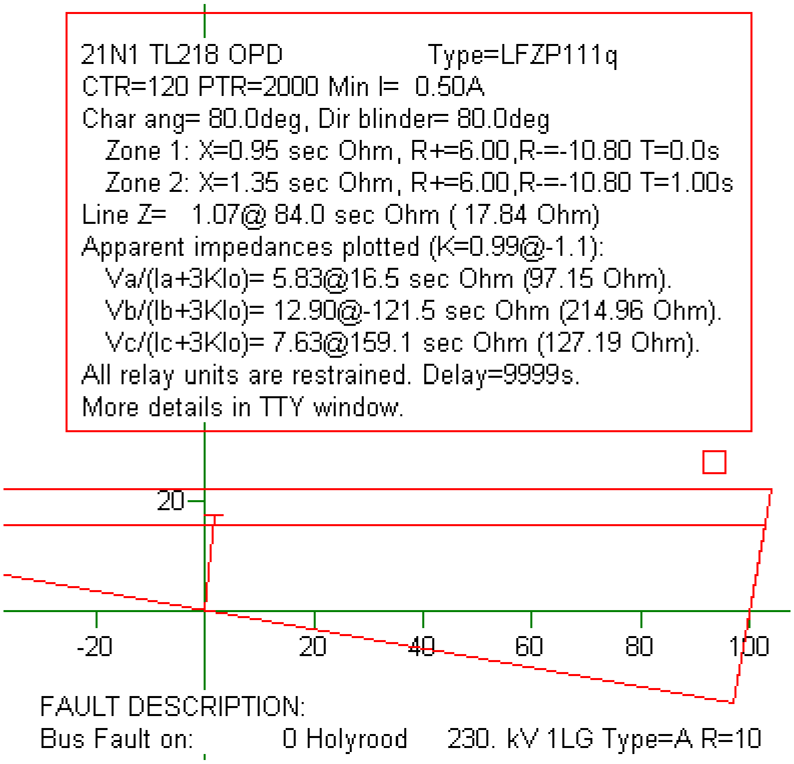


Figure 3 - Zone 1 element set at 80% with 12 ohms resistive reach underreaches for resistive out of zone fault.

Given that it would be desirable to have a resistive reach of 6 ohms secondary to cover a 100 ohm resistive SLG, the SEL formula to check the maximum recommended resistive reach for a zone 1 function set at 70% of the line and used as the limit for secure resistive reach.

$m := 0.7$ per unit

$Z1\_sec := \mathrm{round}(m \cdot |Z1Linesec|, 1)$ $Z1\_sec = 0.7$ Ohms secondary

$Z1pri := Z1\_sec \cdot \frac{VTR}{CTR} = 11.667$ Ohms primary

The imaginary component of the line is $ImXG1sec := \mathrm{Im}(Z1Linesec)$ $ImXG1sec = 1.065$ ohms

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$RG1 := \mathrm{round}[(1 - m) \cdot 20 \cdot ImXG1sec, 2]$

$RG1 = 6.39$ This is the maximum secure setting for the resistive reach.

Use a maximum setting of 6 ohms for RG1 $RG1 := 6$ ohms secondary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 1.35 ohms secondary (about 126%). However, in order to dependably reach a single line to ground fault at the remote terminal, it will be necessary to set the reach significantly further.

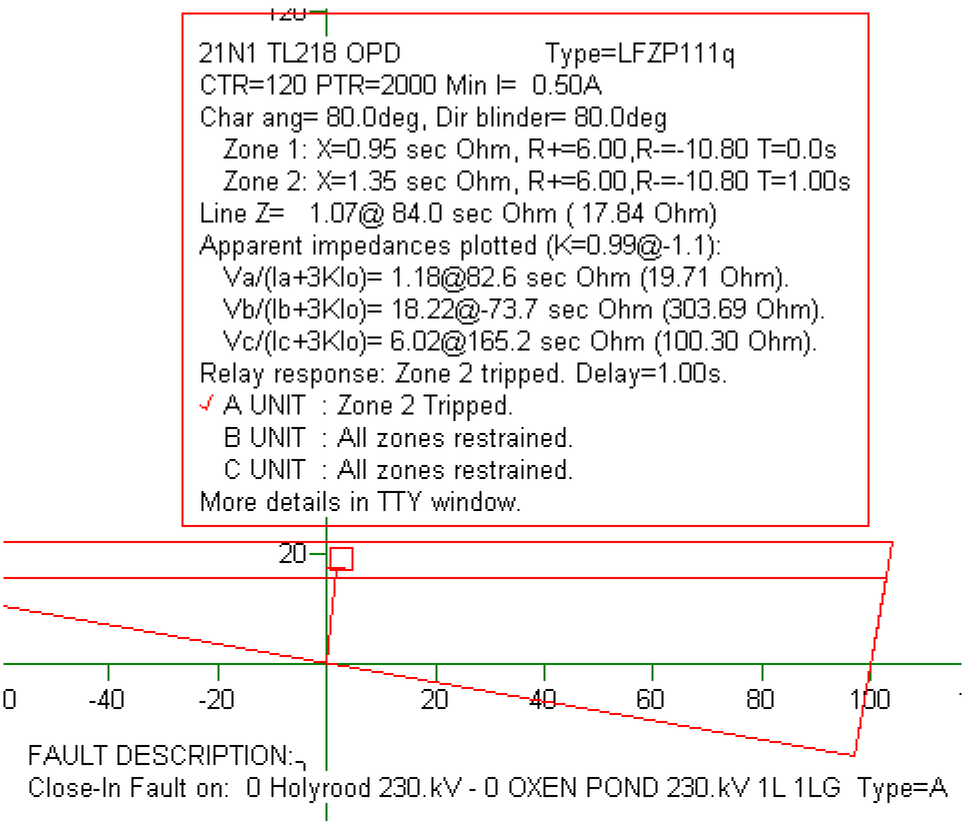


Figure 4 - Apparent impedance to a fault close to the remote terminal is increased by 10% when parallel line is in service.

As can be seen from Figure 4, the apparent impedance to a fault close to the remote terminal is increased when the parallel line is in service. We would like to overreach the apparent impedance significantly.

$Zapp\_int := 1.18$ Ohms secondary $Z2\_sec := 1.50 \cdot Zapp\_int = 1.77$ Choose a setting of 1.7

$Z2\_sec := 1.7$ $Z2\_sec = 1.7$ Ohms secondary $\frac{Z2\_sec}{|Z1Linesec|} = 158.803 \cdot \%$

$Z2\_pri := Z2\_sec \cdot \frac{VTR}{CTR} = 28.333$ Ohms primary

This setting will not reach far past the HRD terminal (see P2 calculations for this line) so there will be no problem with using the conventional zone 2 time delay and will still achieve coordination with instantaneous elements covering circuits beyond HRD. This is reduced from the existing 1 second setting.

$Z2\_TD := 0.3$ Seconds

Resistive reach

Check the sensitivity of the new settings to resistive faults near the middle of the line.

Figure 5 - Resistive fault coverage near the middle of the line.

As can be seen from Figure 5, the zone 2 elements at both ends will comfortably overlap for a 95 ohm resistive fault near the middle of the line. The zone 1 elements set at 60% at each end will not overlap for high resistive faults, but will overlap for less resistive faults.

The existing resistive reach setting of 12 ohms secondary will be suitable as long as the reach of the zone 1 element is reduced to 60% of the line.

$Rquad := 6$ ohms secondary

Load Encroachment logic

The optimho instruction manual recommends a margin of at least 10% between the impedance of the maximum load and the resistive reach of the quadrilateral distance element.

Check loadability of the Zone 2 phase distance element assuming worst case depressed voltage of a stressed system of 0.9 per unit.

$$Zloadmin := \frac{(0.9kVbase)^2}{Smax} \qquad Zloadmin = 115.808$$ Ohms primary (assume worst case at 30 degrees)

$$Zloadmin\_sec := Zloadmin \cdot \frac{CTR}{VTR} \qquad Zloadmin\_sec = 6.948$$

A 6 ohm secondary resistive reach is less than 90% of the load impedance at unity power factor and meets the Areva criterion as shown in Figure 6.

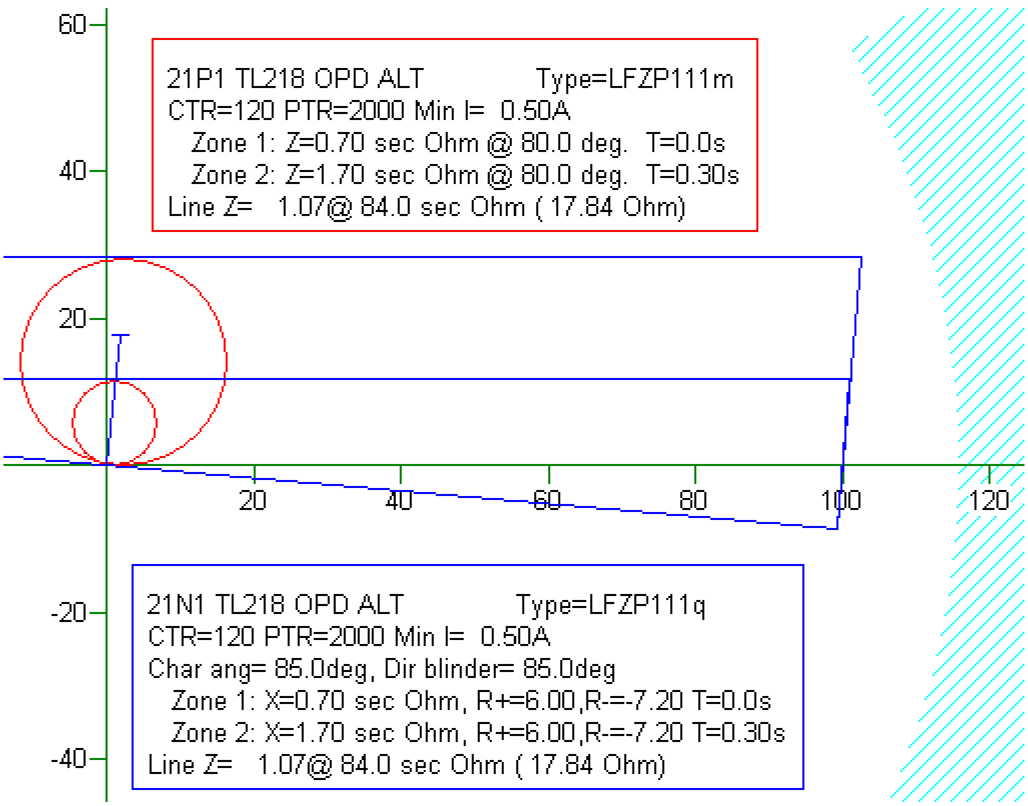


Figure 6 - Apparent impedance of load

Settings of K attenuators

KZPh Coarse setting common to all DISTANCE zones should be set as high as possible while below the required Zone 1 reach. The current level detectors vary inversely with KZph. Maximum setting available is 1.0

$KZPh := 0.7$

Zone 1 attenuators and angular selection

$In := 5$ $\quad Z1\_sec = 0.7$ This is the desired secondary reach (previously calculated)

$$KZ1 := \frac{Z1\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ1 = 1 \qquad Z1sec\_reach := KZ1 \cdot KZPh \cdot \frac{5}{In} \qquad Z1sec\_reach = 0.7$$

$Z\theta PH := (\arg(Z1Linesec))$ $\quad Z\theta PH = 83.958 \cdot deg$

Rounded to the nearest 5 degrees $\quad Z\theta PH := 85$ Degrees (Increased from existing 80 degrees)

$Z\theta N := \arg(Z0Linesec - Z1Linesec)$ $\quad Z\theta N = 82.835 \cdot deg$

Rounded to the nearest 5 degrees $\quad Z\theta N := 80$ Degrees (same as eisting)

Zone 2 attenuators selection

$Z2\_sec = 1.7$ This is the desired secondary reach (previously calculated)

$$KZ2 := \frac{Z2\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ2 = 2.4$$

QUAD Resistive Reach setting

$Rquad = 6$ This is the desired secondary reach (previously calculated)

$$KR := \frac{Rquad}{\left(\frac{5}{In}\right)} \qquad KR = 6$$

Residual Compensation attenuators selection

Zero sequence current compensation for ground faults is provided by the KZN factor. Zero sequence mutual compensation is not used in this application (it causes extra complexity for only moderate gain in setting accuracy).

$$KZN := \frac{Z0Linesec - Z1Linesec}{3 \cdot Z1Linesec} \cdot KZPh \qquad KZN = 0.69 - 0.014j$$

$|KZN| = 0.69$ This is a reduction from the existing setting of 0.957

Switch On To Fault (SOTF) Protection.

If SOTF is enabled, it can be set to 200ms or 110 s after all poles of the line have been de-energized. The 110 s setting is intended to override automatic reclosing dead time. However it makes more sense to enable after the shorter time. Once the SOTF feature has been initiated, it remains in effect for 250ms after the line has been re-energized. The SOTF tripping options are:

a) Any distance comparator.
b) Any current level detector as long as a corresponding voltage level detector has not picked up within 20ms.
c) Either current or distance, as long as a corresponding voltage level detector has not picked up within 20ms.

SOTF := "Enabled"

SOTF_TIME := 0.20 Seconds

Elements_in_SOTF := "BOTH" (Both Comparators and current level detectors).

Power Swing Detector

This element will not be used. It will be left Blocked, and if there is a power swing, the distance elements will trip naturally.

VT Supervision

Set the VT supervision to BLOCK TRIP

Set the VT fail detection to SELF RESET.

Start Indication

This function will bring up information on the LCD screen of the relay if a start event occurs. This function will not be used.

START_INDICATION := "BLOCKED"

Communications assisted logic.

The existing communications assisted logic is permissive overreaching transfer trip, scheme **POR 1**. This scheme is familiar to Newfoundland and Labrador Hydro, and even though the POR 2 scheme offers the advantage of weak infeed echo, which would help the sensitivity to resistive faults, it is not recommended to change the existing scheme logic at this stage with years of experience on a product that is nearing the end of its useful life.

The POR 1 logic is a basic permissive overreaching transfer trip scheme but it does include current reversal timers to increase security against misoperation due to current reversal when a fault on the parallel line is cleared sequentially. The current reversal logic is achieved by a timer TP which will block permissive tripping and keying of permissive trip if the local zone 2 element does not pick up within a reasonable time of receiving permissive trip. The block will be maintained for a time delay of TD after the local zone 2 element picks up, or the received permissive trip signal resets.

The application of the current reversal timers is required only if the settings of the zone 2 comparators are greater than 1.5 times the line impedance .Although the reaches of these elements are only marginally less than 1.5 times the line impedance, there is no parallel line and there is infeed at each terminal that will minimize overreach. Therefore, the current reversal logic is not required, and the recommended default settings are as existing

$TP := 98$ ms

$TD := 0$ ms

Comparison of Existing (red) and Proposed alternative (ALT) settings.

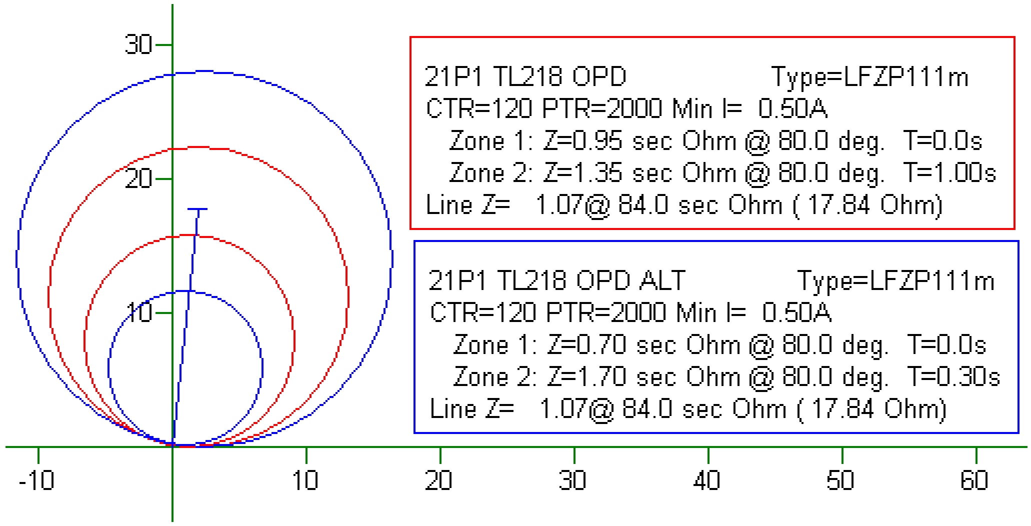


Figure 7 - Comparison of phase distance characteristics

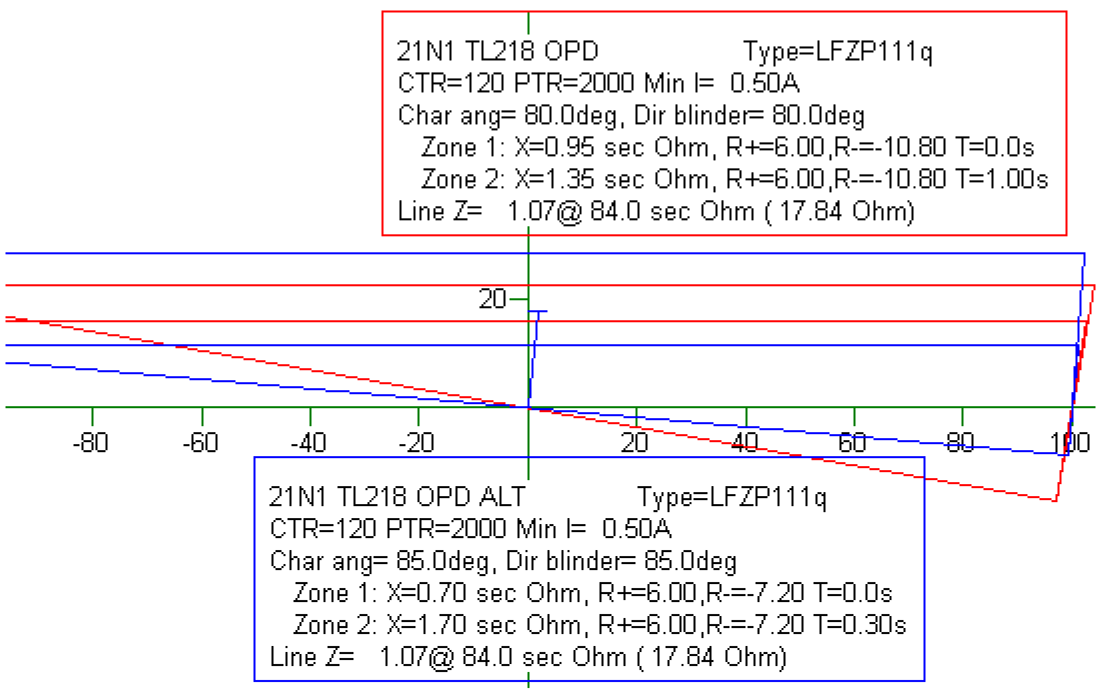


Figure 8 - Comparison of ground distance characteristics

Protection Review for Five 230 kV Transmission Lines

Appendix O
Detailed settings review for OPD TL218 "P2" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Oxen Pond (OPD) terminal of circuit TL218. This 230 kV transmission circuit is from OPD to Holyrood (HRD). The circuit runs parallel to Circuit TL242 and TL236 for parts of its length.

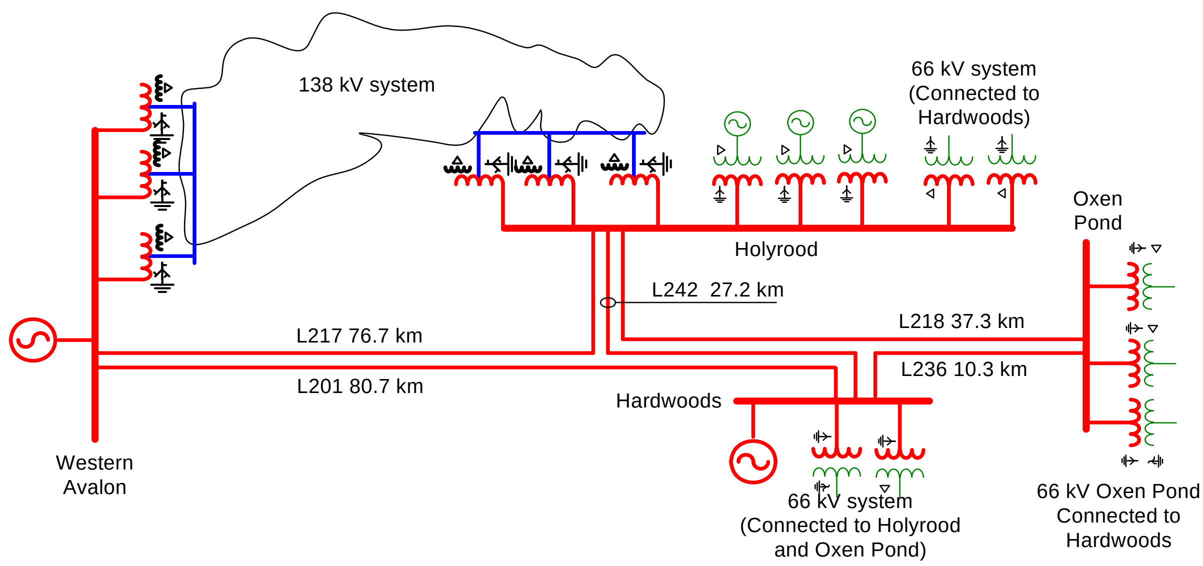


Figure 1 - System Single Line Diagram

Existing P2 protection systems are SEL321 systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $kVbase := 230$ $Ibase := \frac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $Zbase := \frac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $CTR := \frac{600}{5}$ VT ratio is: $VTR := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**NL HYDRO WITH MUTUALS FOR EAST COAST 230 kV LINE PN REVIEW 8 DEC.OLR**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with loads and shunts ignored.

Minimum fault current seen by each terminal (phase to phase, and SLG with 0 ohm fault resistance).

At OPD, with TL236 out of service, with zero sources modelled connected to the 66 kV side, there will be a weak source of positive sequence fault current at that station. There will be some infeed from the 66 kV side.

$I3Pmin := 310$ A $ISLGminPH := 453$ A $ISLGmin0seq := 595$ A

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the TL236 in service and with the remote end of the line open.

Minimum source impedance behind OPD $Z2minOPD := 2.7 + j\cdot 30.9$ ohms primary

$Z0minOPD := 0.77 + j\cdot 15.46$ ohms primary

Minimum source impedance behind HRD $Z2minHRD := 1.0 + j\cdot 20.94$ ohms primary

$Z0minHRD := 0.34 + j\cdot 8.54$ ohms primary

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L218 := 0.00355 + j\cdot 0.03354$ $Z0L218 := 0.01599 + j\cdot 0.1325$

$Z1Line := Z1L218 = 3.55\times 10^{-3} + 0.034j$ pu $Z0Line := Z0L218 = 0.016 + 0.133j$ pu

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line\cdot Zbase$ $Z0Linephys := Z0Line\cdot Zbase$

$Z1Linephys = 1.9 + 17.7i$ ohms primary $(Z0Linephys) = 8.5 + 70.1i$ ohms primary

Converting primary ohms to secondary ohms gives:

$Z1Linesec := Z1Linephys\cdot\frac{CTR}{VTR}$ $Z0Linesec := Z0Linephys\cdot\frac{CTR}{VTR}$

$|Z1Linesec| = 1.07$ ohms sec $\arg(Z1Linesec) = 84\cdot deg$

$|Z0Linesec| = 4.236$ ohms sec $\arg(Z0Linesec) = 83.12\cdot deg$

Load Data

From 2011 System summer load case provided in start up information, the peak load (sum of TL218 and TL236) is given as 267 MVA (196 MVA in TL218 and 71 MVA TL236). In the event of sudden loss of one line, peak load will be the sum of both line loads until operators can adjust loads. Therefore it is assumed that peak load for a short duration is 267 MVA

$Smax\_TL218 := 196$ MVA $\quad Smax\_TL236 := 71$ MVA $\quad Smax := Smax\_TL218 + Smax\_TL236 = 267$ MVA

However, new information from Peter Thomas (see email dated 9 December, 2012 subject "Re: FW: PSSE Files") indicates that peal load should be set up to carry 370 MVA under the conditions of TL236 out of service.

$Smax := 370$ MVA

The existing CT ratio of 600-5 is too low for such a heavy load, but the setting calculations will assume that maximum amount of load. At a later date, the existing CT ratio will have to be increased.

P2 Relay Settings

Minor changes to the set line impedances are recommended to assist fault locations.

$Z1MAG := |Z1Linesec|$ $\quad Z1MAG = 1.07$ $\quad Z1ANG := \frac{arg(Z1Linesec)}{deg}$ $\quad Z1ANG = 84$

$Z0MAG := |Z0Linesec|$ $\quad Z0MAG = 4.2$ $\quad Z0ANG := \frac{arg(Z0Linesec)}{deg}$ $\quad Z0ANG = 83.1$

$LL := 37.29$

In order to obtain sensitivity to 100 ohm single line to ground faults and to more faults, when TL236 is out of service), the echo function will be needed. Enable two forward and one reverse zone.

$PMHOZ := 3 \quad GMHOZ := 3 \quad QUADZ := 3$

$DIR1 := F \quad DIR2 := F \quad DIR3 := R$

Mho phase distance functions

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the OPD Station bus under light load conditions with TL236 out of service. Without any fault study, it is clear that the voltage at OPD will be very low. Since the voltage will certainly be less than 20%, this line is considered short, and a reduced zone 1 reach is recommended to increase security. Choose a setting of 80% of nominal. A 1 cycle tripping delay will also be added for extra security.

$Z1P := 0.8 \cdot |Z1Linesec|$ $\quad Z1P = 0.86$ Ohms secondary

Existing setting of 0.95 ohms is too high, and should be reduced. $Z1P = 0.86$ Ohms secondary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 1.42 ohms secondary (about 133%) and is OK, but is better to be set longer (say 150%) for better speed when TL236 is out of service. It is better to have a longer zone 2 reach than shorter for a short line.

$Z2P := 1.5 \cdot |Z1Linesec|$ $\quad Z2P = 1.61$ Ohms secondary

As can be seen from Figure 2, this element does not overreach the zone 1 on TL242 out of HRD even without infeed. With infeed, the OPD reaches even less past HRD.

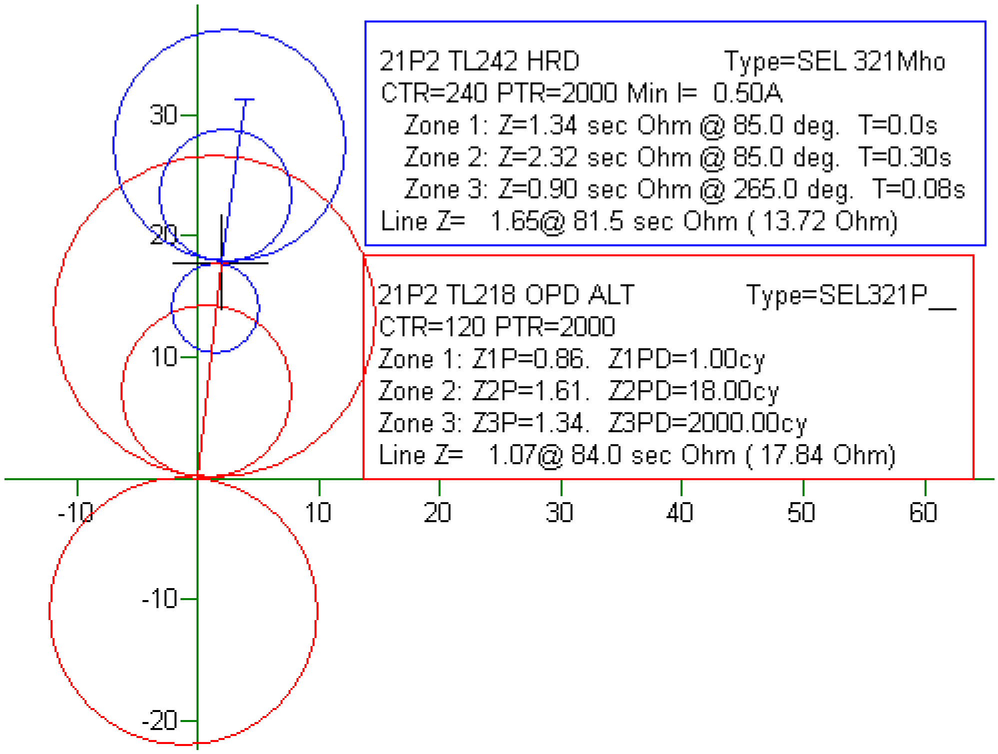


Figure 2 - OPD TL218 Zone 2 Underreaches HRD TLTL242 Zone 1 without infeed.

Because there is no danger of overreaching the remote instantaneous protection, choose the normal zone 2 time delay setting.

$Z2PD := 18$ Cycles Same as existing

Zone 3

Set Zone 3 reverse element to reach further behind this terminal than the remote Zone 2. This function adds security for external faults. The element should always be more sensitive than the forward looking Zone 2 at the remote terminal. Set it the same as the remote Zone 2 (in primary ohms) using the line impedance as margin.

$Z2\_rem\_pri := 22.3$ $Z3P := Z2\_rem\_pri \cdot \frac{CTR}{VTR}$ $Z3P = 1.34$ Ohms secondary

$\frac{Z3P}{|Z1MAG|} = 124.988 \cdot \%$ of line length This is a much higher than the existing setting, but provides additional security.

Mho phase distance current supervision

If the current supervision elements can be set above load, they will be secure in the event that potential is lost. However given that loss of potential logic is available, it is recommended that only the zone 1 current supervision function be set above load. If potential is lost, it will be able to block tripping by Zone 2 before it trips on time delay or receives a permissive trip from the remote terminal.

For the point of view of current supervision being above maximum load, there is no need to worry about abnormal conditions. It would be a double contingency for the VT signal to be lost while the parallel line was out of service. Therefore, consider a maximum load of 100 MVA (with TL236 in service). The current supervision elements for the phase distance functions measure phase to phase currents.

$$IPPmax\_normal := \frac{Smax\_TL218 \cdot 1000}{kVbase} \qquad IPPmax\_normal = 852 \text{ A primary}$$

The current supervision elements use phase to phase currents for supervision of the phase distance functions; so the minimum phase to phase fault current will be root three times the minim phase fault current. Choose a margin of 50% of the minimum phase to phase fault current for dependability.

$$IPPmin := 0.5I3Pmin \cdot \sqrt{3} \qquad IPPmin = 268 \qquad \text{A primary}$$

It is not possible to set the current supervision element for the zone 1 element higher than maximum load current and still ensure that it is dependable for faults when TL236 is out of service. Choose a setting for dependability, and hope the LOP function will be fast enough to block the zone 1 in the event of an LOP event..

$'50PP1 := 2$ A Sec $'50PP1 \cdot CTR = 240$ A primary

Since we will be applying weak source echo, we need to set the Zone 2 elements no more sensitively than the remote looking zone 3 at the HRD terminal. The HRD terminal uses 1200-5 CT ratio; so the minimum setting on the zone 3 current supervision element at that terminal is equivalent to 2 A secondary if a 600-5 CT ratio is used. The 50PP2 element needs to be set above minimum, at 2 A secondary. This is higher than desired and higher than existing, but cannot be avoided if we want to use the echo logic. The 2 A setting will still be dependable under weak source conditions when TL236 is out of service.

$'50PP2 := 2$ A Sec $'50PP3 := 1$ A Sec

Ground Distance Protection

The reach of the ground distance functions will be affected by mutual coupling to the parallel lines. These functions will tend to underreach the remote bus while the parallel lines are in service, and overreach the remote bus if a parallel line is out of service and grounded at both ends. Figure 3 shows that for a remote close in fault at HRD, with TL242 out of service and grounded, the apparent impedance of the line is reduced to about 1.04 ohms secondary instead of the nominal 1.07 ohms. This is 97% of the actual line impedance.

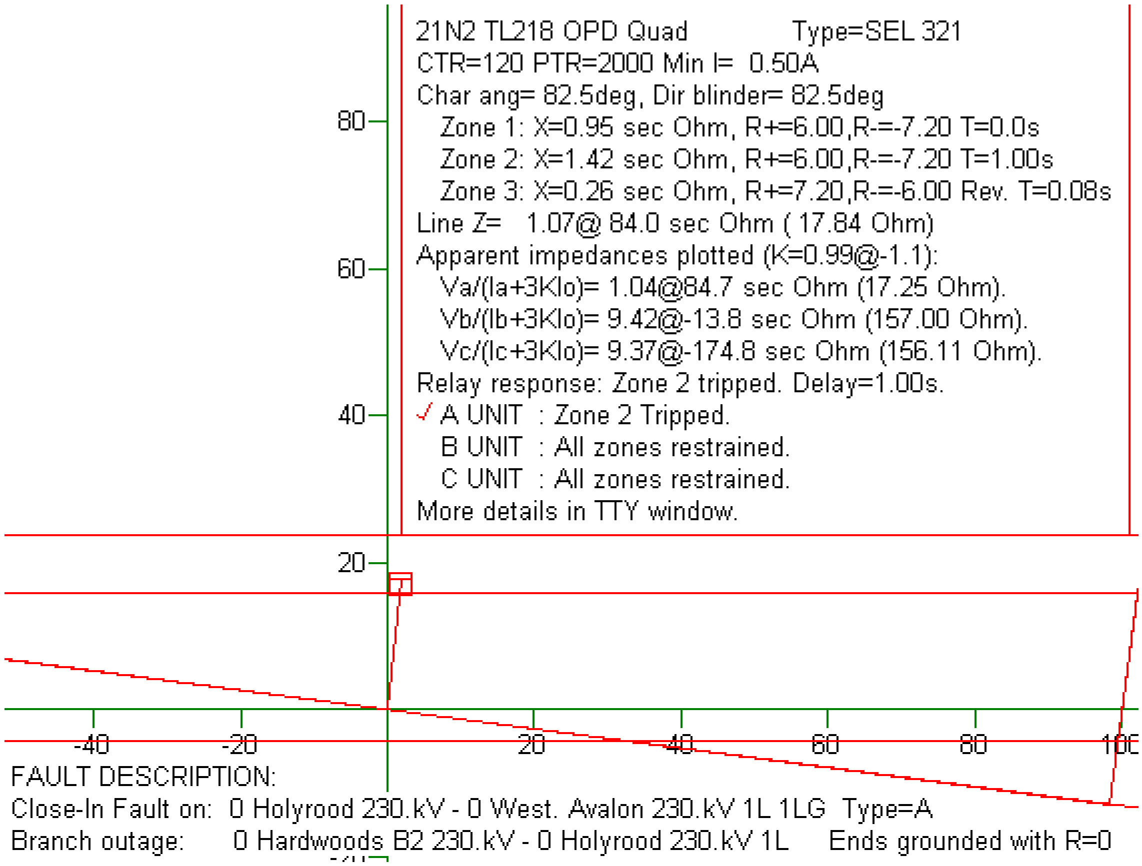


Figure 3 - Apparent impedance to a fault just beyond the remote terminal is reduced by 3% when TL242is out of service and grounded at both ends.

The reach of the zone 1 should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Considering that this line is short, choose a setting of 80% of line which will underreach the remote bus by 17% when the parallel line is out of service and grounded at both ends.

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.8$ per unit

$Z1MG := \mathrm{round}(m \cdot |Z1Linesec|, 1)$ $Z1MG = 0.9$ Ohms secondary

$XG1 := Z1MG$ $XG1 = 0.9$ Ohms secondary

Zone 1 Resistance

The resistive reach of the Zone 1 quad should provide enough sensitivity to trip the local terminal immediately without waiting for permission from the remote terminal for a severe fault that depresses the voltage significantly. Further, it should not allow the function to reach beyond the remote terminal due to errors in relay measurement or CT or VT. In general, a reasonable limit for resistive reach of a zone 1 function set at 85% of the line is 4 times the reactive reach. In the case of this line, the maximum recommended resistive reach for a zone 1 function set at 80% of the line will be calculated, and used as the limit for secure resistive reach.

XG1 is set at m per unit of the transmission line. The imaginary component of the line is

$ImXG1sec := Im(Z1Linesec)$ $\quad$ $ImXG1sec = 1.065$ ohms

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$$RG1 := round[(1 - m)\cdot 20\cdot ImXG1sec, 2]$$

$RG1 = 4.26$ This is the maximum secure setting for the resistive reach but is below the proposed zone 1 resistive reach setting..

Use a maximum setting of 4 ohms for RG1 $\quad$ $RG1 := 4$ ohms secondary

With a resistive reach setting of 4 ohms, the OPD Zone 1 quad element will see an 40 ohm resistive SLG fault at close in (as shown in Figure 4). The Zone 1 element in the P1 protection and the Zone 2elements in this protection and the P1 protection will be depended upon to sense faults with resistance up to 100 ohms.

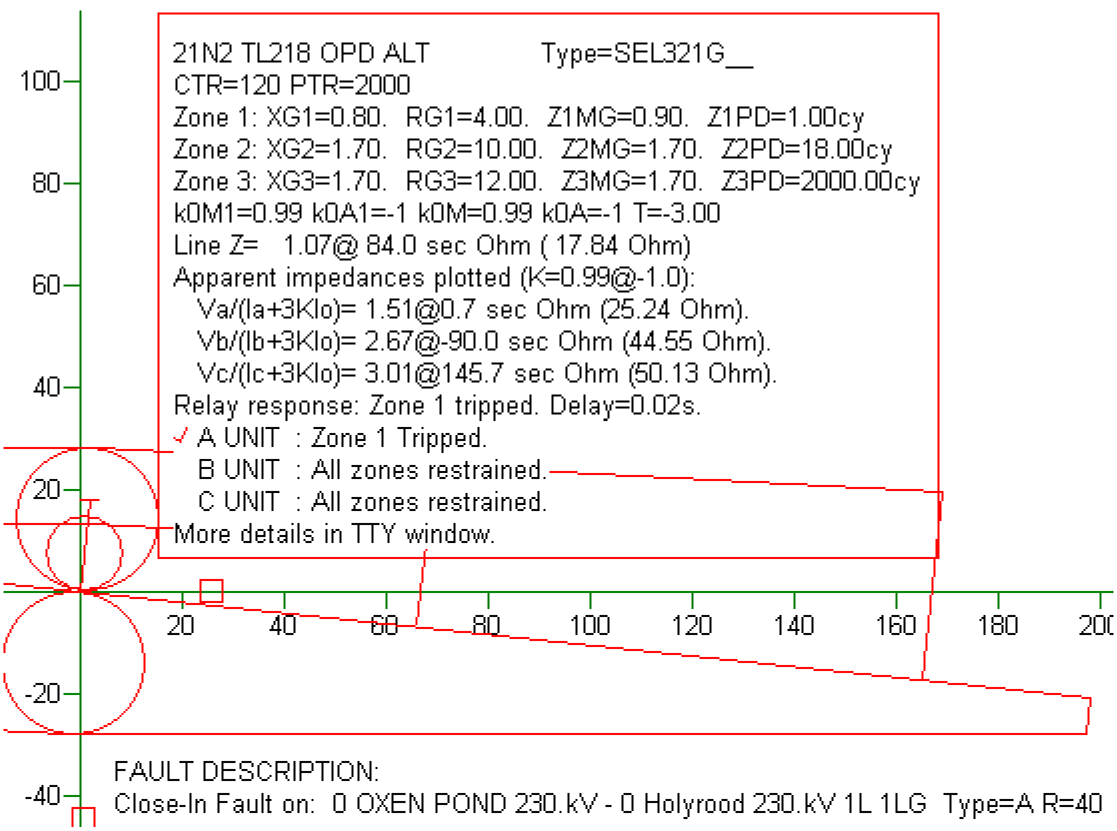


Figure 4 - OPD Zone 1 function if set with 16 ohm resistive reach, operates for a 40 ohm SLG fault close in to the local terminal.

Zone 2 Ground Distance Protection

The Zone 2 ground distance function will need to be set longer than the Zone 2 phase distance protection function because it will tend to underreach the remote terminal while the parallel line is in service. By simulation in ASPEN OneLiner it is found that the apparent impedance to a zero ohm fault close in to the remote terminal is 1.18 ohms secondary, or 10%% more than the actual line impedance. The reach of the Zone 2 ground distance element should be set at least to 1.25 times the apparent impedance and preferably higher for a short line like this. Choose a reach of 150% of the apparent impedance for good speed and sensitivity when this terminal is weak. This setting will not reach far past HRD with heavy infeed there.

$ZSLG\_remote := 1.18$ $Z2MG := 1.5 \cdot ZSLG\_remote = 1.77$ Choose a setting of 1.8

$Z2MG := 1.8$ $Z2MG = 1.8$ Ohms secondary $Z2MG \cdot \frac{VTR}{CTR} = 30$ Ohms primary

The quad element reactive reach will be set similarly to the mho.

$XG2 := Z2MG$ $XG2 = 1.8$ Ohms secondary

It would be desirable to set the resistive reach of the quad element to sense a 100 ohm SLG fault at 75% of the line with the local terminal weak. This would ensure overlap with the zone 1element at the remote terminal. However, that would require too much resistive reach. Therefore choose a setting to sense a 100 ohm SLG fault just past the mid point of the line with the local terminal normal, and depend on the echo function to provide coverage for high resistance faults in the region where the remote zone 1 won't operate. If this terminal is weak, we will need to depend on sequential clearing of high resistance faults.

By trial and error from ASPEN it is found that a resistive reach of 13 ohms secondary will sense a 100 ohm SLG fault with an overlap with a similarly set remote zone 2 of 6% of the line length. See Figure 5. This will give positive overlap with the zone 2 element at the remote terminal. However since it will not overlap the Zone 1 element at the remote terminal, the permissive trip echo function will be required to ensure that a fault that is seen by the zone 2 element at only one terminal will still be cleared by the permissive trip logic.

Therefore, to avoid extremely large resistive reaches, and to retain sensitivity to 100 ohm resistive SLG faults, it is recommended that the echo function be enabled at both terminals.

$RG2 := 13$ Ohms secondary

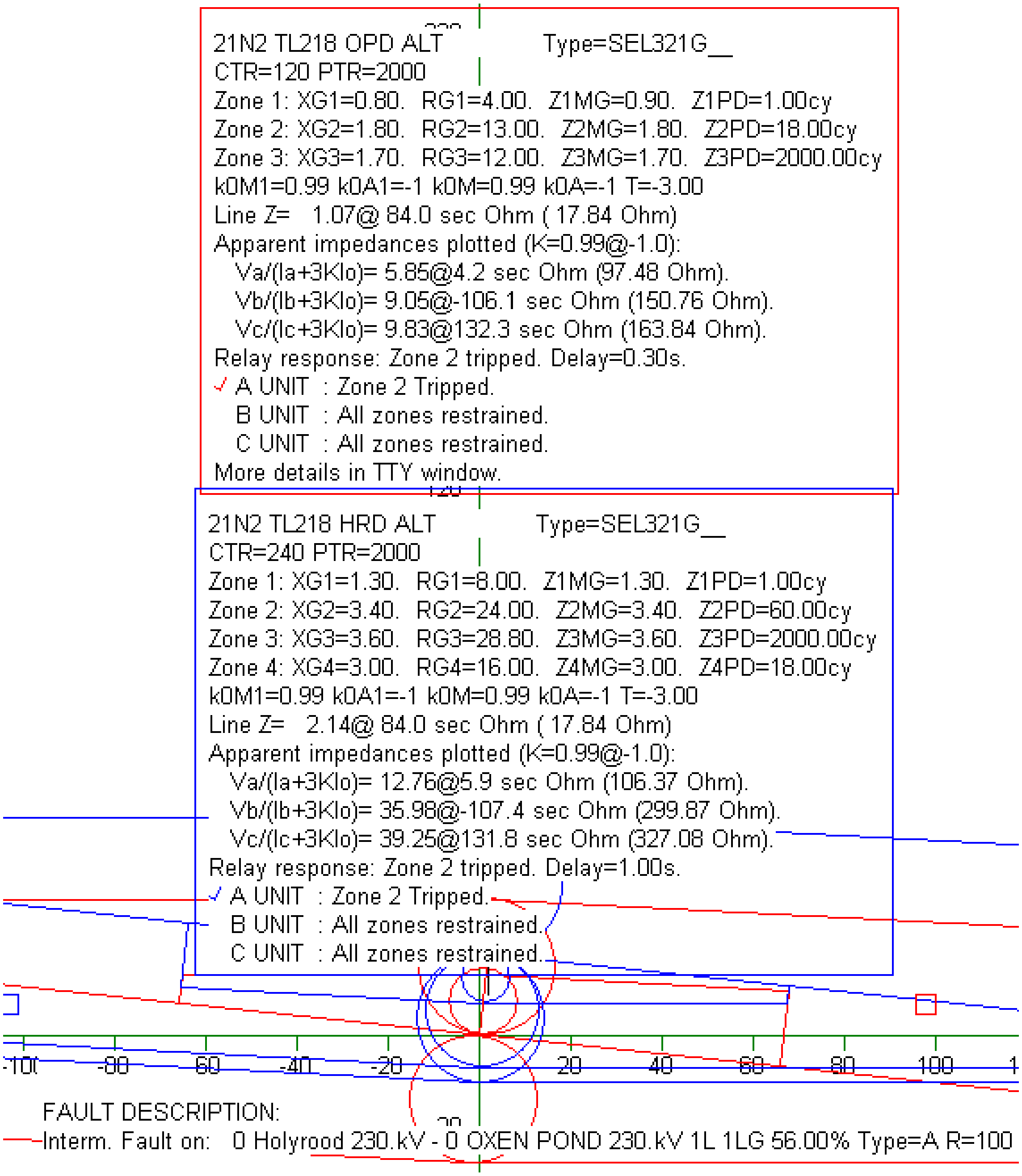


Figure 5 - Quad elements overlap with remote quad elements and operate for 100 ohm resistive SLG near the mid line location.

Check that this resistive reach won't cause the zone 2 function to trip while a parallel line is open single phase, with heavy power flow. See Figure 6. Unusually heavy power flow has been simulated to challenge security.

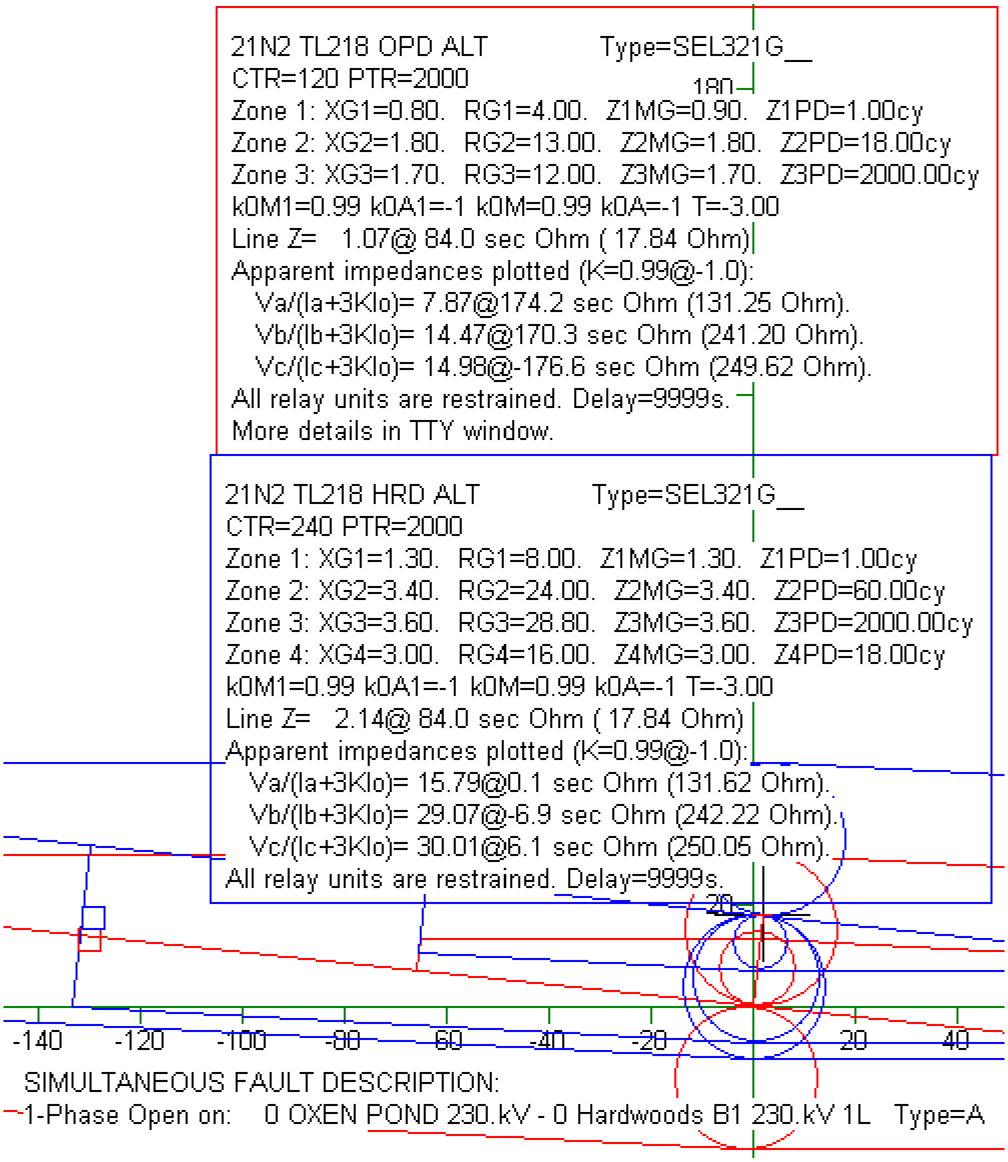


Figure 6 - Quad elements are secure with extremely heavy load flow (175 MVA in TL236 and 225 MVA in TL218) while TL218 is open single pole.

Zone 3

The zone 3 ground mho function will be set using the same principles as the zone 3 phase distance function. Use the setting for local zone 2 in secondary ohms as the remote zone 2.

$Z2MGrem := 28.33$ Ohms Primary $Z3MG := Z2MGrem \cdot \frac{CTR}{VTR}$

$Z3MG = 1.7$ Ohms secondary

$\frac{Z3MG}{|Z1MAG|} = 158.8 \cdot \%$ of line length

This is much higher than the existing setting, but provides additional security.

$XG3 := Z3MG$ $XG3 = 1.7$ Ohms secondary

Set the Zone 3 quad resistive reach at 10% more than the remote Zone 2. Although the remote zone 2 has a different CT ratio, the setting is the same as the local zone 2 in primary ohms. Therefore use the setting for local zone 2 in secondary ohms as the remote zone 2.

$RG2rem := RG2$ Ohms secondary $RG3 := RG2rem \cdot 1.1$ $RG3 = 14.3$ Ohms secondary

Ground distance current supervision

Since there is no concern about these elements operating on load, even with loss of potential, set all current supervision elements at minimum except zone 2. Zone 2 must be set at 1 A to retain coordination with Z3 ground elements at HRD.

$'50L1 := 0.5$ A Sec $'50L2 := 1$ A Sec $'50L3 := 0.5$ A Sec

$'50G1 := 0.5$ A Sec $'50G2 := 1$ A Sec $'50G3 := 0.5$ A Sec

Note that due to heavy infeed of zero sequence currents from the local terminal for close-in faults, the ground overcurrent detectors will not operate for faults with more than a small amount of resistance close to the remote terminal. Therefore, we will have to rely on sequential clearing for that type of fault. However setting the current supervision at minimum(except for zone 2) allows maximum sensitivity.

Zero sequence current compensation

The zero sequence current compensation could be adjusted to compensate for the significant amount of mutual coupling. However as discussed in the settings of reaches of the ground distance elements we will accept underreach of the Zone 2 function for the normal case by setting it at 125% of the apparent impedance for a remote fault. Set the zero sequence current compensation as usual.

$k01M := \left(\left| \frac{Z0Line - Z1Line}{3 \cdot Z1Line} \right| \right)$ $k01M = 0.986$

$k01A := \left(\arg\left(\frac{Z0Line - Z1Line}{3 \cdot Z1Line} \right) \right)$ $k01A = -1.12 \cdot deg$

Set the overreaching zones the same as zone 1 $k0M := k01M$ $k0A := k01A$

$k0M = 0.986$ $k0A = -1.12 \cdot deg$

Settings are slightly different from existing due to small changes in line data.

Non Homogenous Angle Setting

Compare the angle of the remote zero sequence source impedance with the total zero sequence source impedance to the fault to determine this setting.

$$T := \arg\left(\frac{Z0minHRD + Z0Linephys + Z0minOPD}{Z0minHRD}\right) = -3.5 \cdot deg \qquad T = -4 \cdot deg$$

Out of step blocking and tripping

Not used in this application. There is a danger of out of step conditions arising. Historically no action has been taken to provide special tripping or blocking functions. Natural tripping during swings is accepted.

Load Encroachment logic

Check loadability of the Zone 2 phase distance element assuming worst case power factor of 0.87 simultaneous with worst case depressed voltage of a stressed system of 0.85 per unit. Note that units of kV squared match units of MVA. Note that quadrilateral elements are only used for the ground distance functions that are not sensitive to balanced three phase load. Therefore no need to worry about the reach of the quadrilateral elements.

$$Zloadmin := \frac{(0.85kVbase)^2}{Smax} \qquad Zloadmin = 103.298$$ Ohms primary (assume worst case at 30 degrees)

Maximum reach of the Zone 2 element is at the line angle of 81 degrees. At 30 degrees, the reach will be given by

$$Z2load := Z2P \cdot \cos[(Z1ANG - 30)deg] \qquad Z2load = 0.945$$ ohms secondary

$$Z2load \cdot \frac{VTR}{CTR} = 15.747$$ ohms primary

Since the reach of the Zone 2 element at 30 degrees is less than the apparent impedance of the maximum load, there is no need to apply load blinding logic. See Figure 7

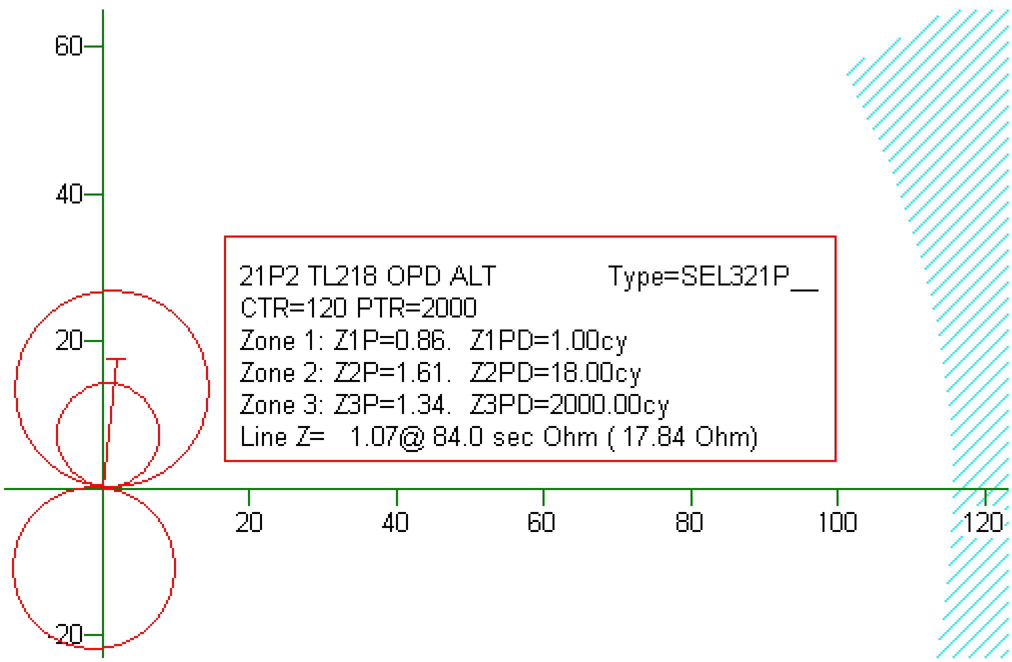


Figure 7 -Load impedance with respect to proposed new Mho function reaches.

Ground directional element

The SEL-321 application example recommends finding the minimum source impedance behind the terminal and setting the reverse and forward boundaries of the negative sequence directional element at the 1/3 and 2/3 points respectively.

In the negative sequence plane, the sum of the two source impedances and the line impedance is:

$Z2total := Z2minOPD + Z1Linephys + Z2minHRD$

The 1/3 point is $Z2\_1\_3 := \frac{Z2total}{3}$ The 2/3 point is $Z2\_2\_3 := \frac{2Z2total}{3}$

$Z2Rpri := Z2\_2\_3 - Z2minOPD$ $Z2Rpri = 1.019 + 15.488j$

$Z2Fpri := Z2\_1\_3 - Z2minOPD$ $Z2Fpri = -0.841 - 7.706j$ Desired set point for Z2F is negative.

Converting the primary impedances to secondary ohms

$Z2R := Z2Rpri \cdot \frac{CTR}{VTR}$ $|Z2R| = 0.931$ Ohms secondary $\arg(Z2R) = 86.237 \cdot deg$

$Z2F := Z2Fpri \cdot \frac{CTR}{VTR}$ $|Z2F| = 0.465$ Ohms secondary $\arg(Z2F) = -96.226 \cdot deg$

Rounding down Z2F and rounding down Z2R gives:

$Z2F := -0.5$ Ohms secondary $Z2R := 0.9$ Ohms secondary

These are close to the existing settings with differences likely due to different fault study model.

Set the current level detectors at minimum level that will allow operation of the ground distance elements.

Due to the very small zero sequence current contribution to a single line to ground fault at the remote terminal, the negative sequence current contribution will always be higher than the zero sequence. Therefore there is no point in setting the forward looking negative sequence overcurrent elements any more sensitively than the zero sequence ground overcurrent supervision of the ground distance elements.

$'50QF := '50G2$ $'50QF = 1$ A secondary (This is higher than existing due to the need to coordinate with the remote reverse looking 50QR)

Set the supervision function for the reverse looking element to be the same as, or a little more sensitive than the forward looking supervision element at the remote terminal.

$'50QR := 0.5$ A secondary

The positive sequence current restraint (a2) factor should be set just smaller than the ratio of the maximum load current (positive sequence) to the most sensitive current supervision element (50QR).

$I1maxpri := \frac{Smax \cdot 1000}{kVbase \cdot \sqrt{3}}$ $I1maxsec := \frac{I1maxpri}{CTR}$ $I1maxsec = 7.74$

Bearing in mind that the 50QR setting is in units of 3*I2

$\frac{'50QR}{3 \cdot I1maxsec} = 0.022$ Choose a value of $a2 := 0.02$ The proposed is the same as the existing setting (0.02).

Phase time overcurrent element

This element is not used

Residual time overcurrent element

This element is used to provide the most sensitive backup protection. It will be a non directional element.

Set pickup to sense a higher resistance than 100 ohm SLG in the middle of the line with equal zero sequence current infeed from both ends. Choose a resistance of 200 ohms arbitrarily. Use a safety factor of 2 so that operating time is not infinity at this fault level.

$SF := 2$ Desensitization factor due to remote end infeed is $Dfactor := 2$ $Rf := 200$

$$'51NPU := \mathrm{round}\left(\frac{kVbase \cdot 1000}{\sqrt{3} \cdot SF \cdot Dfactor \cdot Rf \cdot CTR}, 1\right) \qquad '51NPU = 1.4$$

The existing setting of 0.5 A is more sensitive than required to sense this mid line fault with arbitrary resistance. Since TL206 experience with the high resistance tree fault on 28th August 2009 has shown value in the existing setting, it will be retained.

$'51NPU := 1$ A secondary

Coordination checks show that existing time dial settings will coordinate above remote protection. See Figure 9. However under maximum load conditions, if this line trips single phase, the neutral current during the open pole period will be sufficient to operate the 51N in less than one second. Although the reclose open pole dead time is about 45 cycles, the unbalance during the fault will also tend to operate the element. It is best to have an operating time due to unbalanced load flow during the oper pole period of not less than 1.3 seconds. The existing time dial setting will have to be increased to make this element secure during the open pole period with heavy load flow.

$'51NPU = 1$ A secondary $'51NPU \cdot CTR = 120$ A primary

$'51NTD := 7.5$ $'51NC := "U3"$ $'51NTC := "N"$ $'51NRS := "N"$

The time dial is proposed to be increased from existing 5 to 7.5 to be more secure during heavy load while one phase is open during a single phase trip and reclose operation.

Check the coordination below the HWD TL236 51N for a line end fault on TL218 with the proposed new, slower setting. This is the type of fault that will produce the most sensitivity (least desensitization) with respect to the backup protection on TL236. see Figure 8. Even with new (slower) ALT settings, coordination margin is satisfactory. Note that coordination margin would not be satisfactory for a fault with low resistance. However, we can depend on the 0.3 second definite time zone 2 ground distance element to clear low resistance faults promptly. With the time ground overcurrent elements we are primarily concerned with high resistance faults.

Check the coordination above the HRD TL217 protection for line end faults. See Figure 9. It can be seen that the existing setting is comfortably slower than the HRD TL217 protection for a 0 ohm fault. The proposed new settings are even slower; so there will be no difficulty coordinating above remote protection.

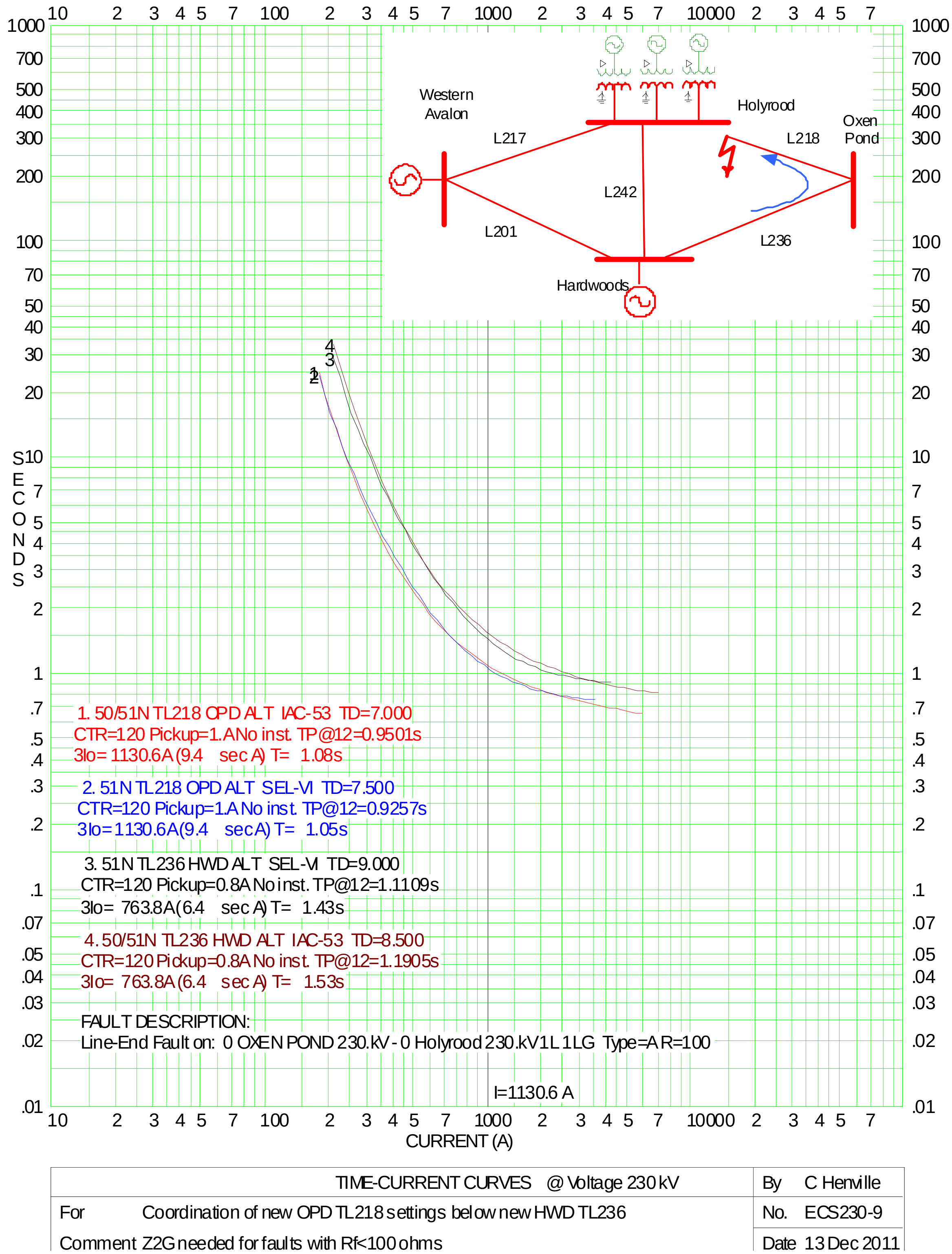
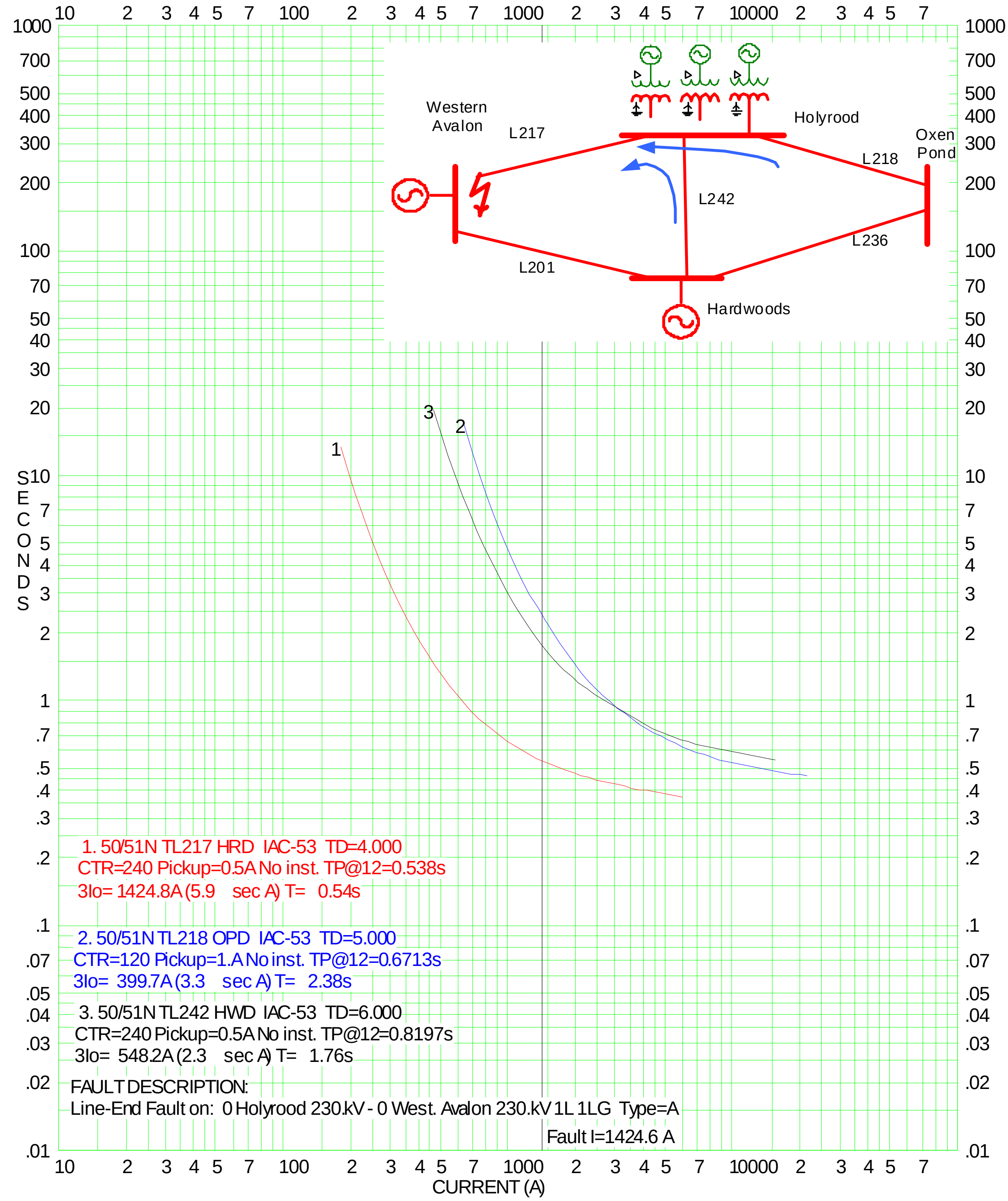


Figure 8 - coordination of ground time overcurrent elements for LE TL218 fault



EC 230-6	TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For Coordination of HRD TL217 below OPD L218 and HWD L242		No. EC 230-6
Comment Two units out of service at HRD.		Date 29 Sep 2011

Figure 9 - coordination of ground time overcurrent elements for line end fault on TL217 (with existing OPD TL218 settings. Proposed new settings are slower)

Permissive Overreaching logic settings

EPOTT := "Y"

Z3RBD is set at remote breaker time plus channel reset time plus channel reset time plus zone 2 reset time. From review of fault records it appears that the breaker time is 3 cycles. Channel reset time is not easily determined from existing records but can conservatively be assumed to be 1 cycle, and relay reset time will also be about 1 cycle. Total time for Z3RBD is then 5 cycles.

Z3RBD := 5 cycles

Echo block delay timer blocks the echo after the local elements have picked up. This can be set relatively long since there is no significant need for the echo function shortly after the local terminal has just seen a fault but the remote terminal has not. Set at 10 cycles as per the example in the instruction manual.

EBLKD := 10 cycles

Echo time delay on pickup should be set to override noise on the communications so that it doesn't echo noise. Typical time according to the SEL application guide is 2 cycles. Since this delay only affects clearing time for relatively light (high resistance) faults that are sensed by zone 2 function at one end, the typical setting is acceptable.

ETDPU := 2 cycles

Echo duration should be long enough to ensure the permissive trip is received by the remote terminal and should also be shorter than the Z3RBD time to ensure that the reverse blocking will always be longer than any permissive trip received (including echo time stretching).

EDURD := 4 cycles

No need to enable week feed conversion to trip, since both terminals will be quite sensitive enough to detect high resistance faults after the remote terminal has cleared. Therefore we can accept sequential (or "step") clearing with no need for the added insecurity of weak infeed tripping.

EWFC := "N" **No other communications logic settings are required for this application.**

Switch on to Fault Settings

Switch on to fault logic will ensure the protection will operate when energizing the line onto a close-in three phase fault when there is no polarizing voltage available for the distance elements.

ESOTF := "Y"

The breaker close signal is not available to the relay. The 52A method of enable SOTF will be used. Therefore the Close end delay is not critical. Typical duration for enable SOTF is 10-15 cycles

ENCLO := "N" CLOEND := 0 EN52A := "Y" SOTFD := 15

Set 50H for high magnitude close-in multiphase faults with weakest source at OPD. It should be set less than 50% of the minimum close-in fault magnitude. Minimum close-in magnitude of a three phase fault with TL236 out of service is 1500 A. Therefore desired maximum setting for 50H is 750 A.

Imin3P_close_in := 1500

$$'50H := \frac{Imin3P\_close\_in}{2CTR} \qquad '50H = 6.25 \quad \text{A secondary}$$

Choose a setting of 6 A secondary for this element. '50H := 6 A secondary

Choose a setting for 52AEND less than the shortest reclose time. '52AEND := 30 cycles

The existing setting of 52AEND is 40 cycles. It is not known why the setting is set so long.

Residual overcurrent settings.

Tripping directly by instantaneous ground overcurrent is not applicable because it is not phase selective. However it would be helpful to monitor steady state unbalance, and issue an alarm for continuous unbalance. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50N := 1$ $\quad$ $'50N1 := 0.25$

Negative Sequence overcurrent settings.

Similar to ground overcurrent, apply a negative sequence overcurrent element to initiate an alarm for steady state unbalances. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50Q := 1$ $\quad$ $'50Q1 := 0.25$

Voltage Element Settings

Similar to unbalance current monitoring, it is helpful to have an unbalance voltage monitor to detect steady state unbalances from the voltage supply.

EVOLT := "Y"

Set the zero sequence overvoltage element at 1% of rated voltage or just at the point necessary to override normal unbalances. The zero sequence voltage element measures 3 times the zero sequence voltage.

$$'59N := 3 \cdot 0.01 \frac{kVbase \cdot 1000}{\sqrt{3} \cdot VTR} \qquad '59N = 1.992 \qquad \text{Say} \quad '59N := 2 \quad \text{V secondary}$$

Loss of Potential

Enable loss of potential settings. Advanced LOP settings are not available on this model of relay.

ELOP := "Y" $\qquad$ Time delay of 1.25 cycles is commonly used. $\qquad$ $LOPD := 1.25$

The 50 M element should be set above maximum load and below minimum fault current for a fault at the remote terminal under weak source conditions. The maximum load for this case should be normal maximum, not emergency maximum which only exists for a few minutes before the operator can act to reduce load.

$$Imax\_normal := \frac{Smax\_TL218 \cdot 1000}{\sqrt{3} \cdot kVbase \cdot CTR} = 4.1 \text{ A secondary}$$

Minimum fault current for a remote three phase fault is $\quad I3Pmin = 310 \quad$ A primary.

Minimum fault current for a remote phase to phase fault is 87% of the minimum three phase fault current level.

Dependability factor to be sure to operate for a minimum remote fault is chosen to be 1.6. $\quad DF := 1.6$

Maximum setting for 50M should be $\dfrac{0.87 I3Pmin}{DF \cdot CTR} = 1.405$

In this case a setting of 1 A secondary will be adequately dependable however it will not necessarily be secure in the event of a loss of potential event.

$'50M := 1$ A secondary

The 59QL setting should be above normal maximum unbalance and below the level expected for a blown VT fuse. For a blown fuse, one phase voltage will be lost, and the negative sequence voltage will be roughly 33% of the nominal positive sequence voltage. Choose a setting of 15% of the nominal positive sequence voltage. This will be well above any normal unbalance.

$$'59QL := \mathrm{round}\left(\frac{0.15 \cdot kVbase \cdot 1000}{\sqrt{3} \cdot VTR}, 0\right) \qquad '59QL = 10 \text{ V secondary}$$

The 59PL setting should be less than the minimum voltage to be expected for a remote bus fault under weakest source conditions. There is no minimum setting (above zero) for this function. Choose a setting equal to half the voltage drop along the line impedance at the pickup setting of the 50M element.

$$'59PL := \mathrm{round}[0.5 \cdot ('50M \cdot |Z1Linesec|), 0] \qquad |'59PL| = 1$$

Miscellaneous Scheme Settings

Pole discoordinance logic is not being used. EPOLD := "N" SPPDD := "N/A"

Enable single pole tripping by distance elements only ESPT := "Y"

Enable single pole open ESPO := "Y"

Set single pole open time delay for future SPO conditions SPOD := 0.25

Note that SPOD was short enough to allow a transient operation when TL201 was reclosed with a fault on it during the fault of 7 March 2011. This transient operation was helpful to clear the fault more quickly than it otherwise would have cleared. SEL have been asked whether the SPOD setting of 0.5 would be better to increase the security.

3 Pole open reset delay to override small discrepancies in pole closing '3POD := 0.5

Stub line protection is not required ESTUB := "N" '50MFD := "N/A"

Trip unlatch logic not applied TULO := "N"

Logic variables and Miscellaneous timers

Minimum trip duration timer is set at 9 cycles as per the application example in the SEL-321 instruction manual.

TDURD := 9 Cycles

Trip during open pole time delay should be set longer than the reclose time. Existing reclose time is 55 cycles. This is acceptable.

TOPD := 55 Cycles

Existing logic variables are not used.

Since this line is short (voltage may be low at HRD for a fault near OPD), a 1 cycle security delay in zone 1 tripping is recommended to improve the security of this function against incorrect tripping for a fault beyond the OPD terminal.

LOGIC_X := "M1P+Z1P" TXPU := 1 cycle TXDO := 0 cycles

Add the use of ZT to trigger an alarm for sustained unbalance.

LOGIC_Z := "59N+50N1+50Q1" TZPU := 1200 cycles TZDO := 0 cycles

Tripping Logic

Permissive tripping is required only for instantaneous overreaching functions. No need for any functions that trip directly. Existing 51NT word in MTCS is not required.

MTCS := "M2P+Z2G"

Existing settings for unconditional tripping must be modified to include a 1 cycle delay for zone 1 tripping.

MTU := "XT+M2PT+Z2GT+51NT"

No need for existing direct tripping zone 1 functions in the switch on to fault logic.

SOTF Tripping MTO := "M2P+Z2G+50H"

Event records will be triggered automatically by all trip events. Other event record triggers should be by starting of other elements to ensure capture of all relevant events. Events should be triggered by keying or receiving permissive trips to ensure separation of relay and teleprotection issues.

MER := "M2P+Z2G+51N+LOP*52AA1+LOP*52AA2+KEY+PT+EKEY"

Outputs

Retain existing output assignments except add the continuous unbalance alarm to OUT15.

OUT15 := "LOP*50L+ZT"

Input Contact Assignment

It would be desirable to provide phase segregated inputs to the relay so that the quadrilateral functions could be disabled during single pole open conditions. it is not known if phase segregated auxiliary switches are available on the breakers.

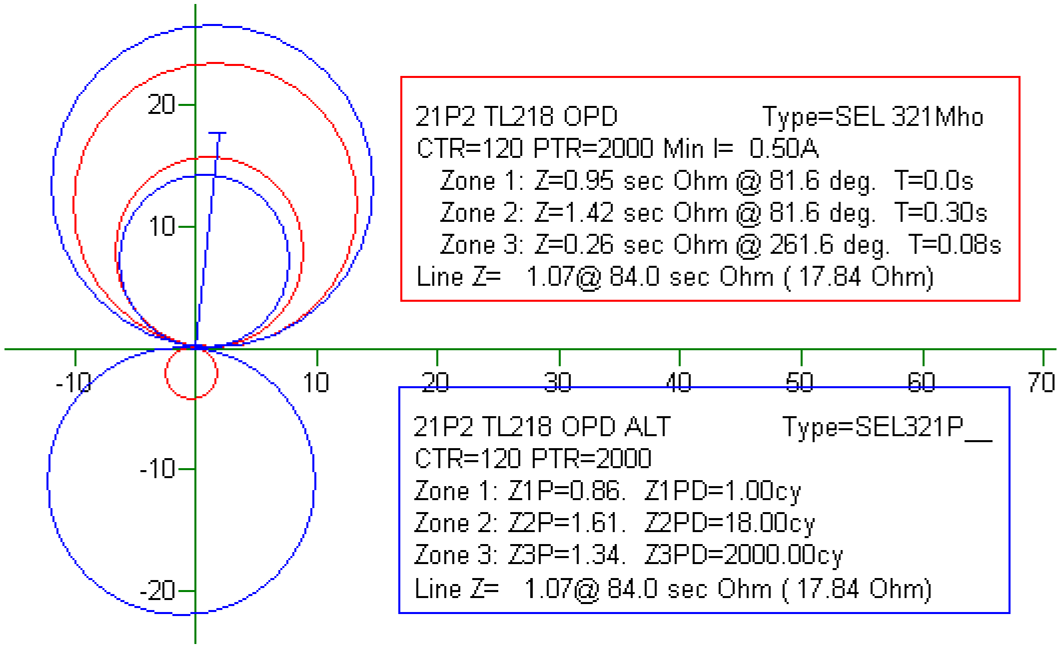


Figure 10 - Comparison between existing (red) and proposed new (blue) phase distance characteristics.

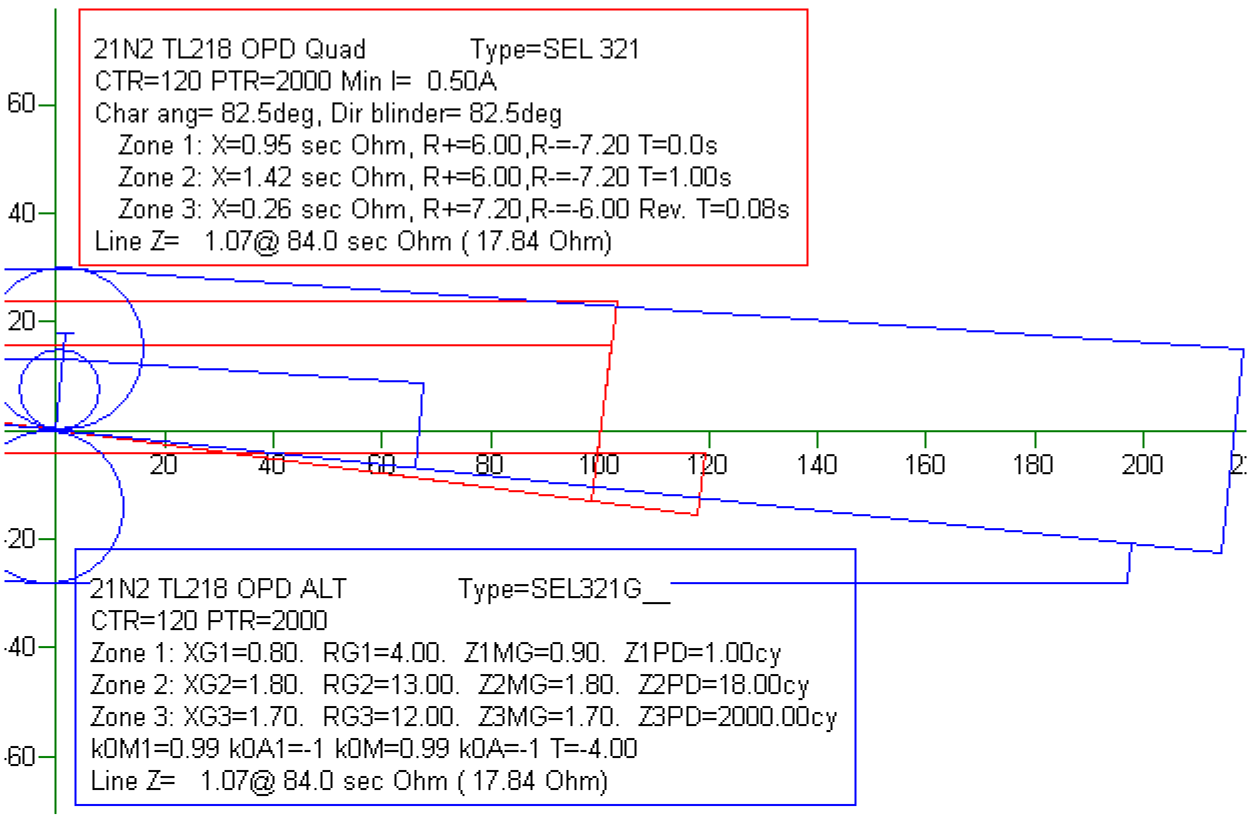


Figure 11 - Comparison between existing (red) and proposed new (blue) ground distance characteristics.

Protection Review for Five 230 kV Transmission Lines

Appendix P
Detailed settings review for OPD TL236 "P1" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador Hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Oxen Pond Terminal (OPD) terminal of circuit TL236. This 230 kV transmission circuit is from OPD to Hardwoods (HWD).
The circuit runs parallel to Circuit TL218 for most of its length.

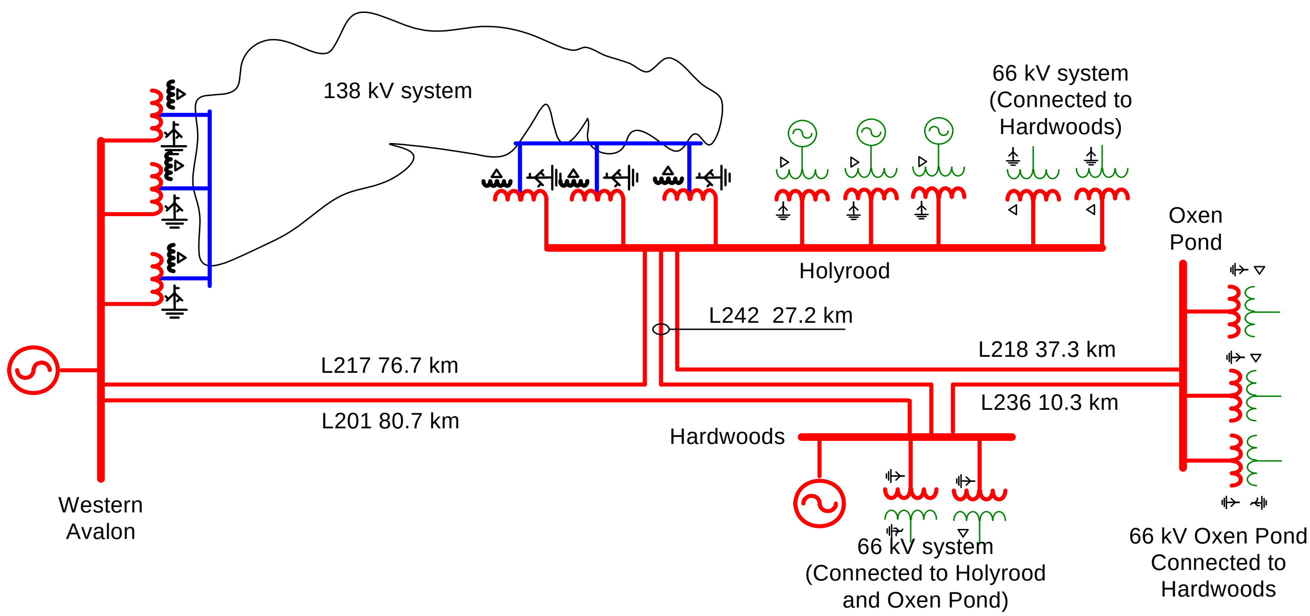


Figure 1 - System Single Line Diagram

Existing P1 protection systems are Areva LZFP111 (Optimho) systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $kVbase := 230$ $Ibase := \frac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $Zbase := \frac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at the line terminal.

CT ratio is: $CTR := \frac{600}{5}$ VT ratio is: $VTR := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case “**NL HYDRO WITH MUTUALS FOR EAST COAST 230 kV LINE PN REVIEW 8 DEC.OLR**” with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with loads and shunts ignored.

Minimum fault current seen by each terminal (phase to phase, and SLG with 0 ohm fault resistance).

At OPD, with TL218 out of service, with the weak source connected to the 66 kV side modelled, there will be a weak source of positive sequence fault current at that station. The 66 kV supply to OPD is from Hardwoods; so for a close in 3 phase fault at HWD, there is negligible contribution from OPD with TL218 OOS.

$ILLmin := 1.4$ A $\quad ISLGminPH := 781$ A $\quad ISLGmin0seq := 1706$ A

The optimho current level detectors that block the distance comparators in the event of line opening are fixed at 5% of the rated current, or 0.25 A secondary, or 60 A primary. They will have no difficulty in operating for minimum bolted fault levels. However, the ground distance elements are also supervised by a low set neutral current level detector (LDLSN that requires the neutral current to be greater than 10% of the maximum amplitude of phase difference current. This prevents the ground comparators from operating during close-in multiphase faults with CT errors. ASPEN OneLiner shows that for a bolted fault at the remote bus even under heavy load, there is sufficient neutral current (20% of maximum phase to phase fault current) that means this LDLSN function does not inhibit the ground distance comparator.

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind OPD $\quad Z2minOPD := 2.4 + j \cdot 33.4$ ohms primary

Minimum source impedance behind HWD $\quad Z2minHWD := 2.0 + j \cdot 26.7$ ohms primary

<u>Line impedances</u>.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L236 := 0.00146 + j \cdot 0.00973 \qquad Z0L236 := 0.00491 + j \cdot 0.03672$

$Z1Line := Z1L236 = 0.0015 + 0.0097j$ pu $\qquad Z0Line := Z0L236 = 0.005 + 0.037j$ pu

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line \cdot Zbase \qquad Z0Linephys := Z0Line \cdot Zbase$

$Z1Linephys = 0.77 + 5.15i$ ohms primary $\qquad Z0Linephys = 2.6 + 19.42i$ ohms primary

Converting primary ohms to secondary ohms gives:

$$Z1Linesec := Z1Linephys \cdot \frac{CTR}{VTR} \qquad Z0Linesec := Z0Linephys \cdot \frac{CTR}{VTR}$$

$|Z1Linesec| = 0.31$ ohms sec $\qquad \arg(Z1Linesec) = 81.5 \cdot deg$

$|Z0Linesec| = 1.176$ ohms sec $\qquad \arg(Z0Linesec) = 82.38 \cdot deg$

Load Data

From 2011 System summer load case provided in start up information, the peak load (sum of TL236 and TL236) is given as 267MVA (split between TL236 and TL236). In the event of sudden loss of one line, peak load will be the sum of both line loads until operators can adjust loads. Therefore it is assumed that peak load for a short duration is 205 MVA

$Speak := 267$ MVA $Smax := Speak = 267$ MVA

However, new information from Peter Thomas (see email dated 9 December, 2012 (subject "Re: FW: PSSE Files") indicates that peak load should be set up to carry 370 MVA under the conditions of TL218 out of service.

$Smax := 370$ MVA

P1 Relay Settings

Distance element reach settings

Note that resistive reaches are forced to be the same for all zones. Reactive reaches for phase and ground distance elements must be the same as each other.

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the OPD Station bus under light load conditions and TL236 line out of service. From ASPEN OneLiner, voltage at OPD for a 3 phase fault at OPD is 0.04 per unit. Since the voltage is less than 20%, this line is considered short, and a reduced zone 1 reach would normally be recommended to increase security. However, since the resisitve reach of the zone 1 element has to be the same as that of the zone 2, which is very high, in order to sense resistive single line to ground faults, the zone 1 ground element will have to be disabled, that means the zone 1 phase distance element also has to be disabled, because it is not possible to disable the ground distance element without also disabling the phase distance element. Choose the existing (arbitrary) setting of 0.92 ohm for the zone 1 reach

$Z1P := 0.92$ Ohms secondary

As noted above, the zone 1 ground distance needs to be disabled, because the resistive reach of the zone 2 ground distance function has to be set to cover about a 100 ohm fault at a point on the line where the contributions from each terminal are roughly equal. Choose the setting of the zone 1 phase and ground distance elements to be the existing (arbitrary) setting of 0.92 ohms secondary.

$Z1\_sec := 0.92$

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 0.92 ohms secondary (about 300%). This is a very long setting, but will not overreach any instantaneous protection at the remote terminal; even without infeed, so is quite accetpable.

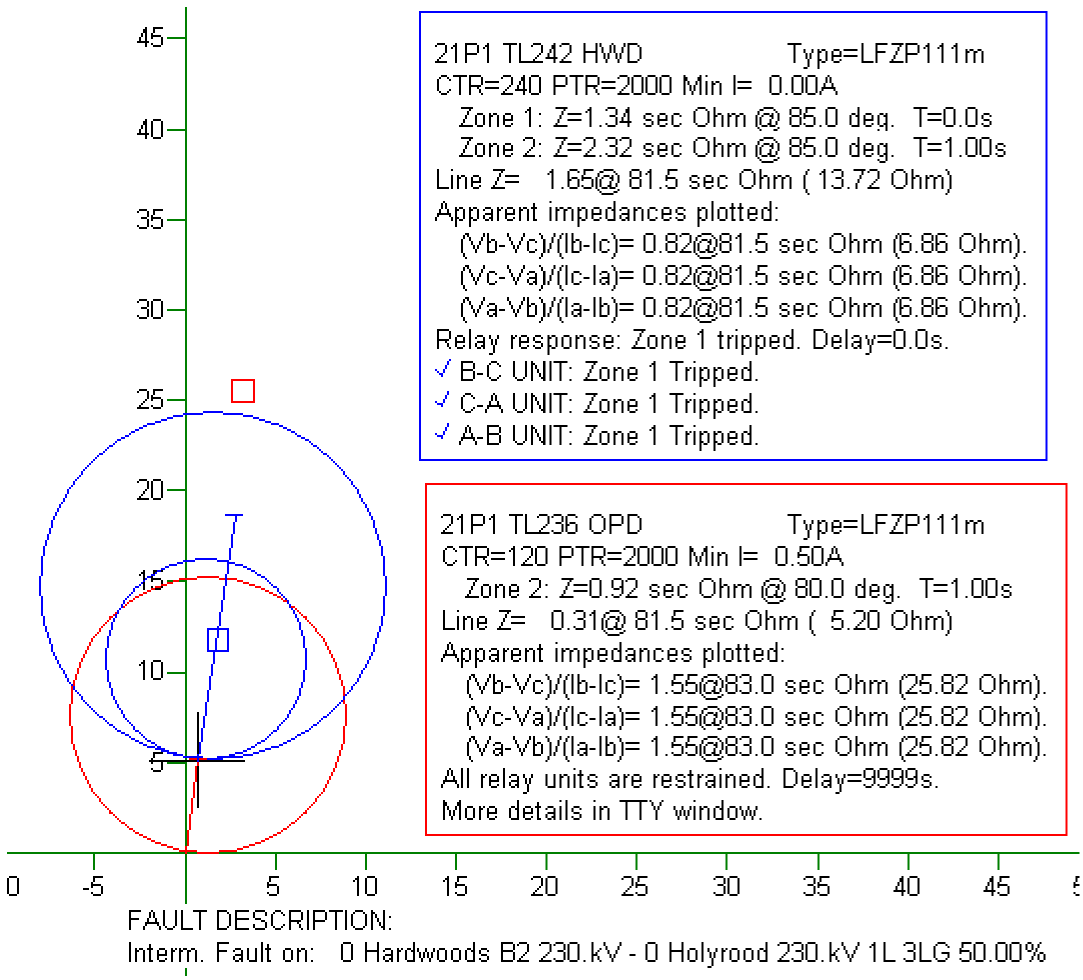


Figure 2 - Zone 2 underreaches remote shortest zone 1, even without infeed.

As can be seen from Figure 2, the apparent impedance to a fault beyond the remote terminal is increased significantly due to infeed. Therefore the existing setting of 0.92 ohms is good.

$Z2\_sec := 0.92$ $Z2\_sec = 0.92$ Ohms secondary $\frac{Z2\_sec}{|Z1Linesec|} = 294.6 \cdot \%$

$Z2\_pri := Z2\_sec \cdot \frac{VTR}{CTR} = 15.333$ Ohms primary

This setting will not reach far past the HRD terminal so there will be no problem with using the conventional zone 2 time delay and will still achieve coordination with instantaneous elements covering circuits beyond HWD. This is reduced from the existing 1 second setting.

$Z2\_TD := 0.3$ Seconds

Resistive reach

Check the sensitivity of the new settings to resistive faults near the middle of the line.

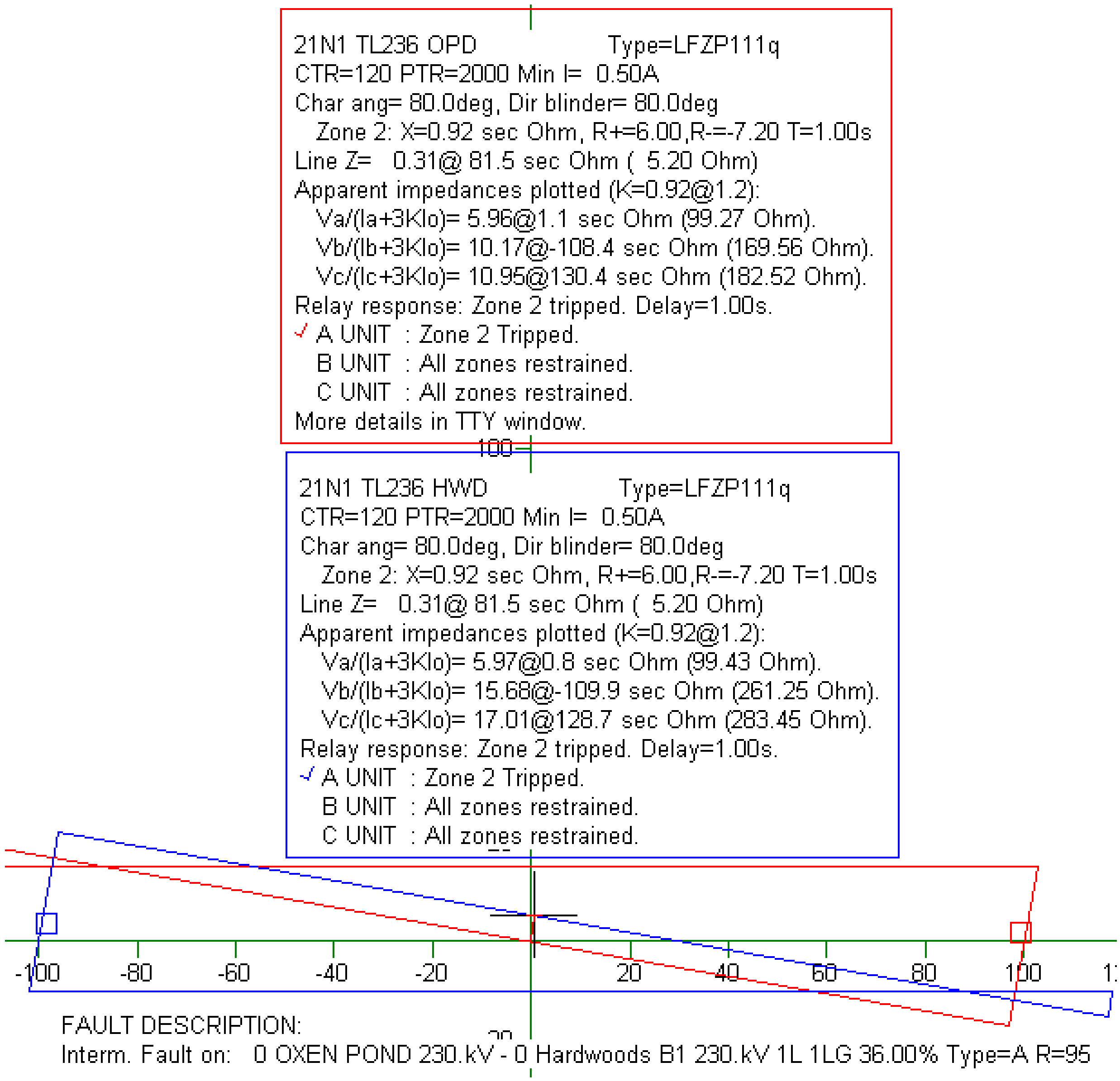


Figure 3 - Resistive fault coverage near the middle of the line.

As can be seen from Figure 3, the zone 2 elements at both ends will comfortably overlap for a 95 ohm resistive fault near the middle of the line (35%-39% from OPD).

The existing resistive reach setting of 6 ohms secondary will be suitable.

$Rquad := 6$ ohms secondary

Load Encroachment logic

The optimho instruction manual recommends a margin of at least 10% between the impedance of the maximum load and the resistive reach of the quadrilateral distance element.

Check loadability of the Zone 2 phase distance element assuming worst case depressed voltage of a stressed system of 0.9 per unit.

$$Zloadmin := \frac{(0.9kVbase)^2}{Smax} \qquad Zloadmin = 115.808$$ Ohms primary (assume worst case at 30 degrees)

$$Zloadmin\_sec := Zloadmin \cdot \frac{CTR}{VTR} \qquad Zloadmin\_sec = 6.948$$

A 6 ohm secondary resistive reach is less than 90% of the load impedance at unity power factor and meets the Areva criterion as shown in Figure 6.

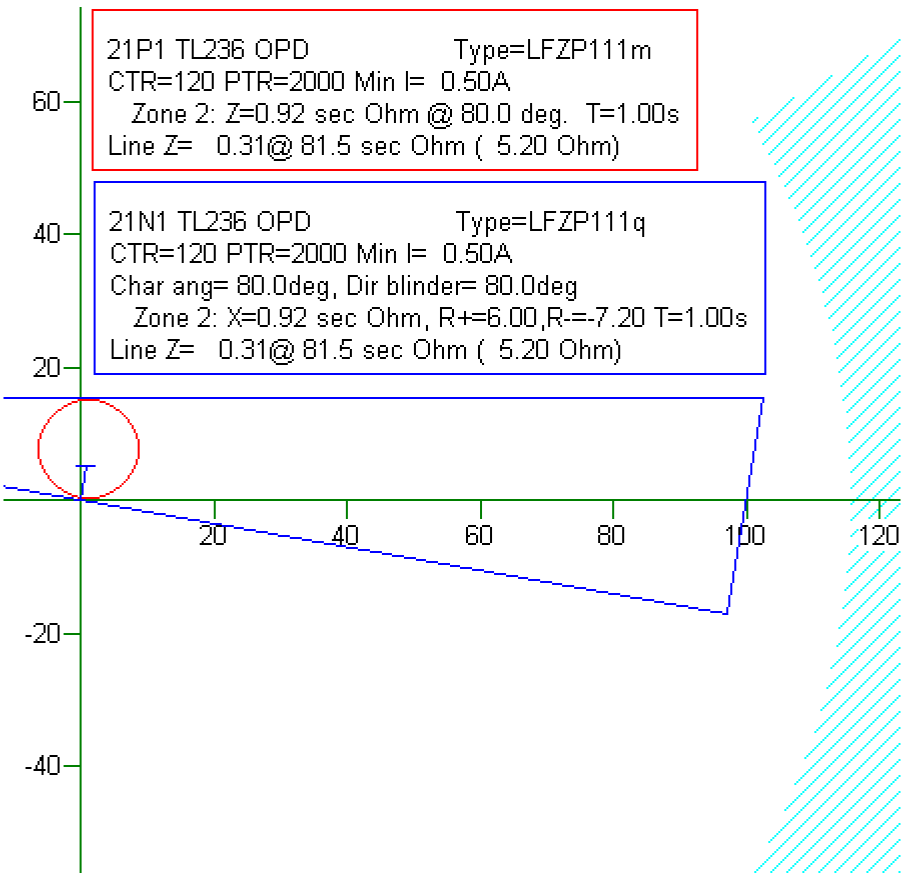


Figure 6 - Apparent impedance of load

Settings of K attenuators

The instruction manual recommends that the KZph element be set as high as possible to maximize the sensitivity up to the maximum possible setting of 1. In this case, the Zone 2 setting will be equal to the zone 1 (since the zone 1 is not used) and the zone 2 setting desired is 0.92 ohms.

Therefore the existing setting of KZph should be increased to obtain the maximum possible sensitivity.

$KZPh := 0.92$

Zone 1 attenuators and angular selection

$In := 5$ $Z1\_sec = 0.92$ This is the desired secondary reach (previously calculated)

$KZ1 := \dfrac{Z1\_sec}{\left(KZPh \cdot \dfrac{5}{In}\right)}$ $KZ1 = 1$ $Z1sec\_reach := KZ1 \cdot KZPh \cdot \dfrac{5}{In}$ $Z1sec\_reach = 0.92$

$Z\theta PH := (\arg(Z1Linesec))$ $Z\theta PH = 81.466 \cdot deg$

Rounded to the nearest 5 degrees $Z\theta PH := 80$ Degrees

$Z\theta N := \arg(Z0Linesec - Z1Linesec)$ $Z\theta N = 82.716 \cdot deg$

Rounded to the nearest 5 degrees $Z\theta N := 80$ Degrees (same as eisting)

Zone 2 attenuators selection

$Z2\_sec = 0.9$ This is the desired secondary reach (previously calculated)

$KZ2 := \dfrac{Z2\_sec}{\left(KZPh \cdot \dfrac{5}{In}\right)}$ $KZ2 = 1$

QUAD Resistive Reach setting

$Rquad = 6$ This is the desired secondary reach (previously calculated)

$KR := \dfrac{Rquad}{\left(\dfrac{5}{In}\right)}$ $KR = 6$

Residual Compensation attenuators selection

Zero sequence current compensation for ground faults is provided by the KZN factor. Zero sequence mutual compensation is not used in this application (it causes extra complexity for only moderate gain in setting accuracy).

$KZN := \dfrac{Z0Linesec - Z1Linesec}{3 \cdot Z1Linesec} \cdot KZPh$ $KZN = 0.848 + 0.018j$

$|KZN| = 0.85$ This is a reduction from the existing setting of 0.957

Switch On To Fault (SOTF) Protection.

If SOTF is enabled, it can be set to 200ms or 110 s after all poles of the line have been de-energized. The 110 s setting is intended to override automatic reclosing dead time. However it makes more sense to enable after the shorter time. Once the SOTF feature has been initiated, it remains in effect for 250ms after the line has been re-energized. The SOTF tripping options are:

a) Any distance comparator.
b) Any current level detector as long as a corresponding voltage level detector has not picked up within 20ms.
c) Either current or distance, as long as a corresponding voltage level detector has not picked up within 20ms.

SOTF := "Enabled"

SOTF_TIME := 0.20 Seconds

Elements_in_SOTF := "BOTH" (Both Comparators and current level detectors).

Power Swing Detector

This element will not be used. It will be left Blocked, and if there is a power swing, the distance elements will trip naturally.

VT Supervision

Set the VT supervision to BLOCK TRIP

Set the VT fail detection to SELF RESET.

Start Indication

This function will bring up information on the LCD screen of the relay if a start event occurs. This function will not be used.

START_INDICATION := "BLOCKED"

Communications assisted logic.

The existing communications assisted logic is permissive overreaching transfer trip, scheme **POR 1**. This scheme is familiar to Newfoundland and Labrador Hydro, and even though the POR 2 scheme offers the advantage of weak infeed echo, which would help the sensitivity to resistive faults, it is not recommended to change the existing scheme logic at this stage with years of experience on a product that is nearing the end of its useful life.

The POR 1 logic is a basic permissive overreaching transfer trip scheme but it does include current reversal timers to increase security against misoperation due to current reversal when a fault on the parallel line is cleared sequentially. The current reversal logic is achieved by a timer TP which will block permissive tripping and keying of permissive trip if the local zone 2 element does not pick up within a reasonable time of receiving permissive trip. The block will be maintained for a time delay of TD after the local zone 2 element picks up, or the received permissive trip signal resets.

The application of the current reversal timers is required only if the settings of the zone 2 comparators are greater than 1.5 times the line impedance .Although the reaches of these elements are only marginally less than 1.5 times the line impedance, there is no parallel line and there is infeed at each terminal that will minimize overreach. Therefore, the current reversal logic is not required, and the recommended default settings are as existing

$TP := 98$ ms

$TD := 0$ ms

Comparison of Existing (red) and Proposed alternative (ALT) settings.

The main change to the proposed alternate settings is to change the setting of the KZPH element to maximimze sensitivity. Also the zone 2 timer setting could be reduced from the existing 1 second to 0.3 seconds. There are no proposed changes to the existing reach settings.

Protection Review for Five 230 kV Transmission Lines

Appendix Q
Detailed settings review for OPD TL236 "P2" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Oxen Pond (OPD) terminal of circuit TL236. This 230 kV transmission circuit is from OPD to Hardwoods (HWD). The circuit runs parallel to Circuit TL218 for most of its length.

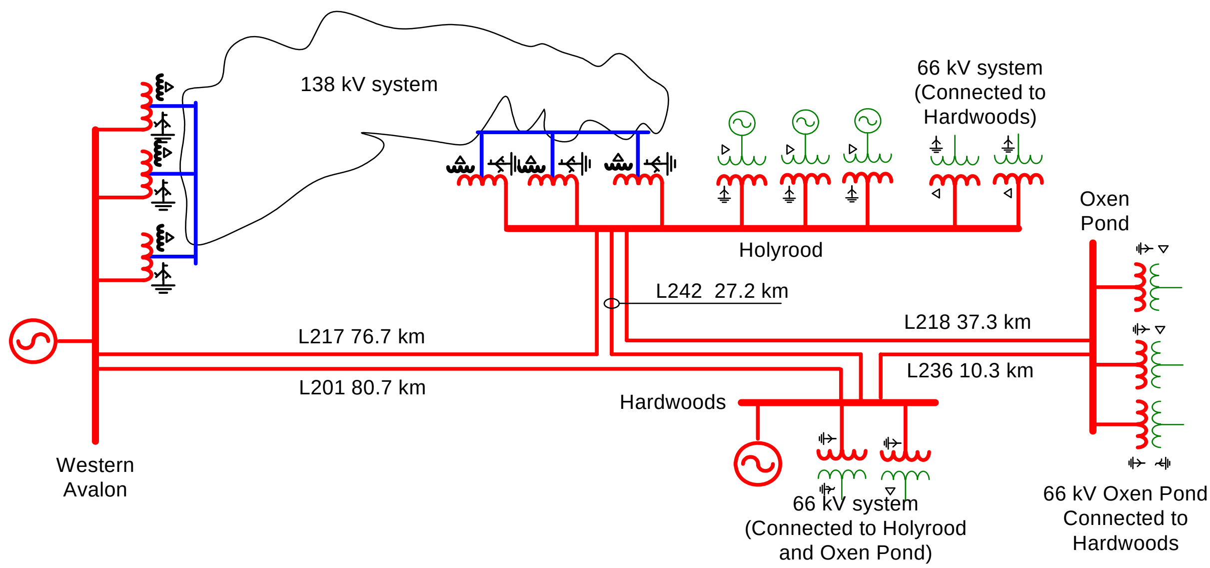


Figure 1 - System Single Line Diagram

Existing P2 protection systems are SEL321 systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$$\text{MVAbase} := 100 \qquad \text{kVbase} := 230 \qquad \text{Ibase} := \frac{\text{MVAbase}\cdot 1000}{\text{kVbase}\cdot\sqrt{3}} \qquad \text{Zbase} := \frac{\text{kVbase}^2}{\text{MVAbase}}$$

$$j := \sqrt{-1}$$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $\text{CTR} := \frac{600}{5}$ VT ratio is: $\text{VTR} := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**NL HYDRO WITH MUTUALS FOR EAST COAST 230 kV LINE PN REVIEW 8 DEC.OLR**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with loads and shunts ignored.

Minimum fault current seen by each terminal (phase to phase, and SLG with 0 ohm fault resistance).

At OPD, with TL218 out of service, with the weak source connected to the 66 kV side modelled, there will be a weak source of positive sequence fault current at that station. The 66 kV supply to OPD is from Hardwoods; so for a close in 3 phase fault at HWD, there is negligible contribution from OPD with TL218 OOS.

$I3Pmin := 3$ A $\quad ISLGminPH := 781$ A $\quad ISLGmin0seq := 1706$

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with TL218 in service and with the remote end of the line open.

Minimum source impedance behind OPD $\quad Z2minOPD := 2.4 + j\cdot 33.4$ ohms primary

$Z0minOPD := 0.72 + j\cdot 19.32$ ohms primary

Minimum source impedance behind HWD $\quad Z2minHWD := 2.0 + j\cdot 26.7$ ohms primary

$Z0minHWD := 0.89 + j\cdot 17.49$ ohms primary

<u>Line impedances</u>.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L236 := 0.00146 + j\cdot 0.00973 \qquad Z0L236 := 0.00491 + j\cdot 0.03672$

$Z1Line := Z1L236 = 0.0015 + 0.0097j$ pu $\qquad Z0Line := Z0L236 = 0.005 + 0.037j$

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line\cdot Zbase \qquad Z0Linephys := Z0Line\cdot Zbase$

$Z1Linephys = 0.8 + 5.1i$ ohms primary $\qquad (Z0Linephys) = 2.6 + 19.4i$ ohms primary

Converting primary ohms to secondary ohms gives:

$$Z1Linesec := Z1Linephys\cdot\frac{CTR}{VTR} \qquad Z0Linesec := Z0Linephys\cdot\frac{CTR}{VTR}$$

$|Z1Linesec| = 0.31$ ohms sec $\qquad arg(Z1Linesec) = 81.5\cdot deg$

$|Z0Linesec| = 1.176$ ohms sec $\qquad arg(Z0Linesec) = 82.38\cdot deg$

Load Data

From 2011 System summer load case provided in start up information, the peak load (sum of TL236 and TL236) is given as 267 MVA (196 MVA in TL236 and 71 MVA TL236). In the event of sudden loss of one line, peak load will be the sum of both line loads until operators can adjust loads. Therefore it is assumed that peak load for a short duration is 267 MVA

$Smax\_TL236 := 196$ MVA $Smax\_TL236 := 71$ MVA $Smax := Smax\_TL236 + Smax\_TL236 = 142$ MVA

However, new information from Peter Thomas (see email dated 9 December, 2012 subject "Re: FW: PSSE Files") indicates that peal load should be set up to carry 370 MVA under the conditions of TL218 out of service.

$Smax := 370$ MVA

The existing CT ratio of 600-5 is too low for such a heavy load, but the setting calculations will assume that maximum amount of load. At a later date, the existing CT ratio will have to be increased.

P2 Relay Settings

Minor changes to the set line impedances are recommended to assist fault locations.

$Z1MAG := |Z1Linesec|$ $Z1MAG = 0.31$ $Z1ANG := \frac{arg(Z1Linesec)}{deg}$ $Z1ANG = 81.5$

$Z0MAG := |Z0Linesec|$ $Z0MAG = 1.18$ $Z0ANG := \frac{arg(Z0Linesec)}{deg}$ $Z0ANG = 82.4$

$LL := 10.338$

In order to obtain sensitivity to 100 ohm single line to ground faults (and to more faults, when TL218 is out of service), the echo function will be needed. Enable two forward and one reverse zone.

$PMHOZ := 3$ $GMHOZ := 3$ $QUADZ := 3$

$DIR1 := F$ $DIR2 := F$ $DIR3 := R$

Mho phase distance functions

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the OPD Station bus under light load conditions with TL218 out of service. Without any fault study, it is clear that the voltage at OPD will be very low. Since the voltage will certainly be less than 20%, this line is considered short, and a reduced zone 1 reach is recommended to increase security. Choose a setting of 80% of nominal. A 1 cycle tripping delay will also be added for extra security.

$Z1P := 0.8 \cdot |Z1Linesec|$ $Z1P = 0.25$ Ohms secondary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 0.92 ohms secondary (about 300%) and is OK. It is better to have a longer zone 2 reach than shorter for a short line.

$Z2P := 2.96 \cdot |Z1Linesec|$ $Z2P = 0.92$ Ohms secondary

As can be seen from Figure 2, this element does not overreach the zone 1 on TL242 out of HWD even without infeed. With infeed, the OPD reaches even less past HWD.

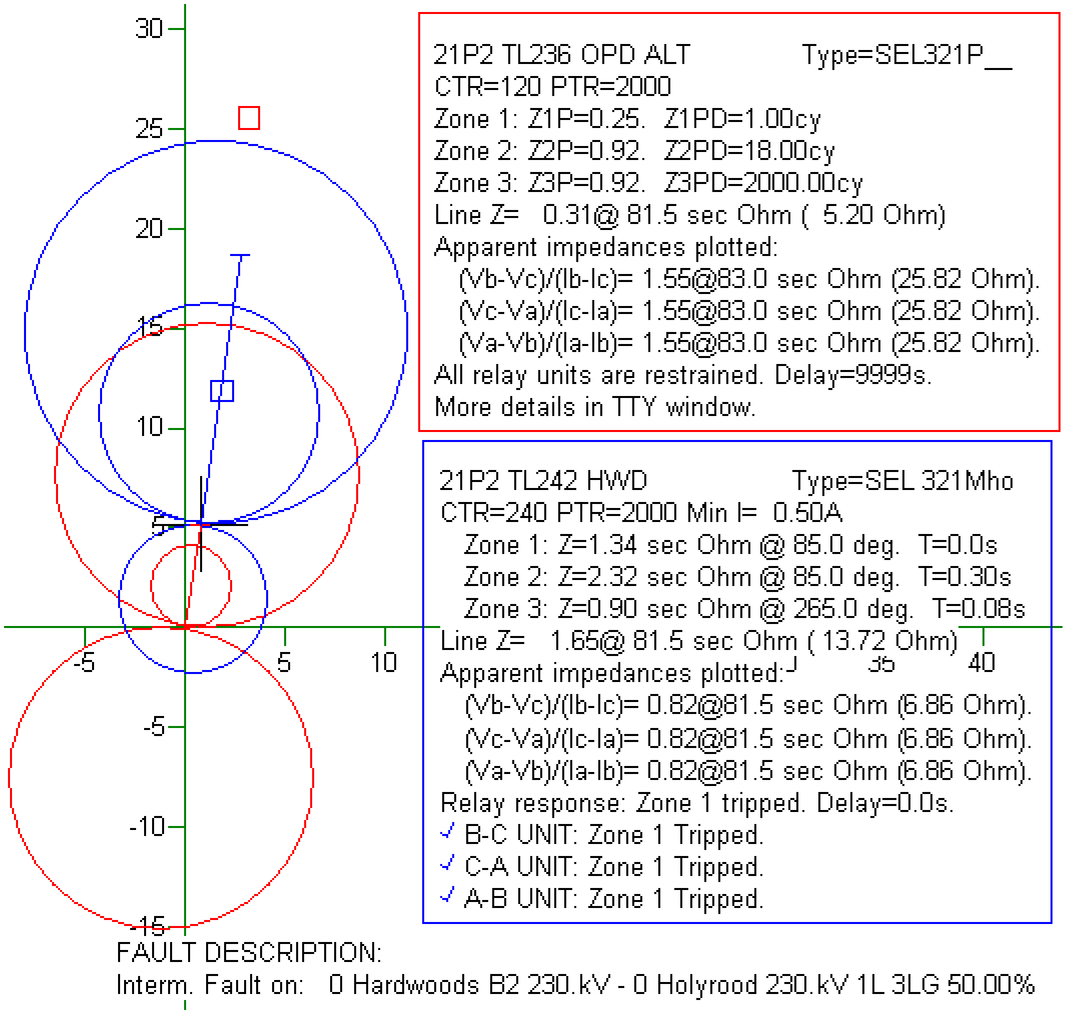


Figure 2 - OPD TL236 Zone 2 Underreaches HRD TL242 Zone 1 without infeed.

Because there is no danger of overreaching the remote instantaneous protection, choose the normal zone 2 time delay setting.

$Z2PD := 18$ Cycles Same as existing

Zone 3

Set Zone 3 reverse element to reach further behind this terminal than the remote Zone 2. This function adds security for external faults. The element should always be more sensitive than the forward looking Zone 2 at the remote terminal. Set it the same as the remote Zone 2 (in primary ohms) using the line impedance as margin.

$Z2\_rem\_pri := 15.33$ $\quad Z3P := Z2\_rem\_pri \cdot \frac{CTR}{VTR}$ $\quad Z3P = 0.92$ Ohms secondary

$\frac{Z3P}{|Z1MAG|} = 294.536 \cdot \%$ of line length

This is a little higher than the existing setting, but provides additional security.

Mho phase distance current supervision

If the current supervision elements can be set above load, they will be secure in the event that potential is lost. However given that loss of potential logic is available, it is recommended that only the zone 1 current supervision function be set above load. If potential is lost, it will be able to block tripping by Zone 2 before it trips on time delay or receives a permissive trip from the remote terminal.

For the point of view of current supervision being above maximum load, there is no need to worry about abnormal conditions. It would be a double contingency for the VT signal to be lost while the parallel line was out of service. Therefore, consider a maximum load of 100 MVA (with TL218 in service). The current supervision elements for the phase distance functions measure phase to phase currents.

$$IPPmax\_normal := \frac{Smax\_TL236 \cdot 1000}{kVbase} \qquad IPPmax\_normal = 309 \quad \text{A primary}$$

The current supervision elements use phase to phase currents for supervision of the phase distance functions; so the minimum phase to phase fault current will be root three times the minim phase fault current. Choose a margin of 50% of the minimum phase to phase fault current for dependability.

$$IPPmin := 0.5I3Pmin \cdot \sqrt{3} \qquad IPPmin = 3 \qquad \text{A primary}$$

It is not possible to set the current supervision element for the zone 1 element higher than maximum load current and still ensure that it is dependable for faults when TL218 is out of service. Choose the minimum setting for dependability, and hope the LOP function will be fast enough to block the zone 1 in the event of an LOP event..

$'50PP1 := 1$ A Sec $'50PP1 \cdot CTR = 120$ A primary

Since we will be applying weak source echo, we need to set the Zone 2 elements no more sensitively than the remote looking zone 3 at the HRD terminal. The HRD terminal uses 600-5 CT ratio same as this terminal; so the minimum setting ((same as existing) will be applicable.

$'50PP2 := 1$ A Sec $'50PP3 := 1$ A Sec

Ground Distance Protection

The reach of the ground distance functions will be affected by mutual coupling to the parallel lines. These functions will tend to underreach the remote bus while the parallel lines are in service, and overreach the remote bus if a parallel line is out of service and grounded at both ends. Figure 3 shows that for a remote close in fault at HRD, with TL218 out of service and grounded, the apparent impedance of the line is not reduced significantly. This is probably due to a relatively weak mutual coupling.

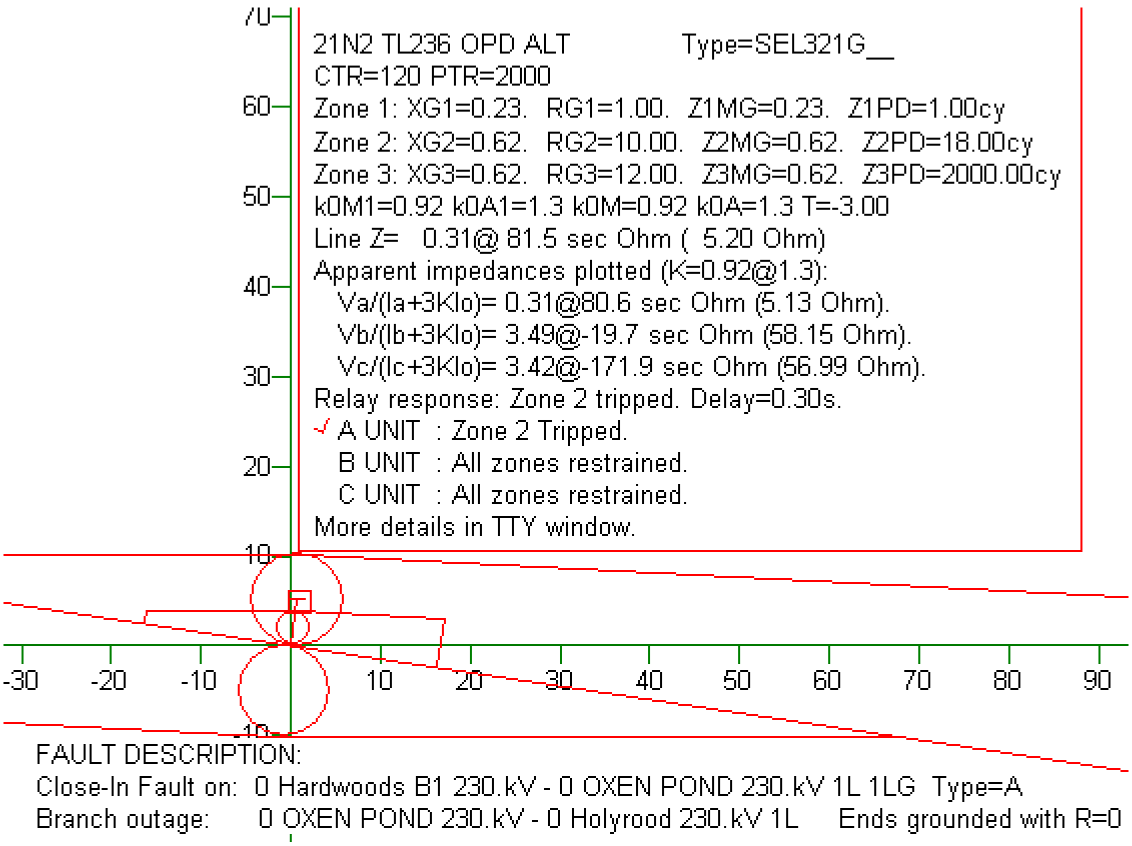


Figure 3 - Apparent impedance to a fault just beyond the remote terminal is not reduced significantly when TL218 is out of service and grounded at both ends.

The reach of the zone 1 should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Considering that this line is very short, choose a setting of 60% of line which will underreach the remote bus in all circumstances and will also allow a larger resistive reach than if the reach was set to 80%

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.6$ per unit

$Z1MG := \mathrm{round}(m \cdot |Z1Linesec|, 2)$ $Z1MG = 0.19$ Ohms secondary

$XG1 := Z1MG$ $XG1 = 0.19$ Ohms secondary

Zone 1 Resistance

The resistive reach of the Zone 1 quad should provide enough sensitivity to trip the local terminal immediately without waiting for permission from the remote terminal for a severe fault that depresses the voltage significantly. Further, it should not allow the function to reach beyond the remote terminal due to errors in relay measurement or CT or VT. In general, a reasonable limit for resistive reach of a zone 1 function set at 85% of the line is 4 times the reactive reach. In the case of this line, the maximum recommended resistive reach for a zone 1 function set at 80% of the line will be calculated, and used as the limit for secure resistive reach.

XG1 is set at m per unit of the transmission line. The imaginary component of the line is

$ImXG1sec := Im(Z1Linesec)$ $\quad ImXG1sec = 0.309$ ohms

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$RG1 := round[(1 - m) \cdot 20 \cdot ImXG1sec, 2]$

$RG1 = 2.47$ This is the maximum secure setting for the resistive reach but is below the proposed zone 1 resistive reach setting..

Use a maximum setting of 2.4 ohms for RG1 $\quad RG1 := 2.4$ ohms secondary

With a resistive reach setting of 2.4 ohms, the OPD Zone 1 quad element will see a 20 ohm resistive SLG fault at close in (as shown in Figure 4). This is the longest resistive reach that can be securely set with such a short line. The Zone 2elements in this protection and the P1 protection will be depended upon to sense faults with resistance up to 100 ohms. This P2 protection will also have the echo function to help sensitivity to resistive faults.

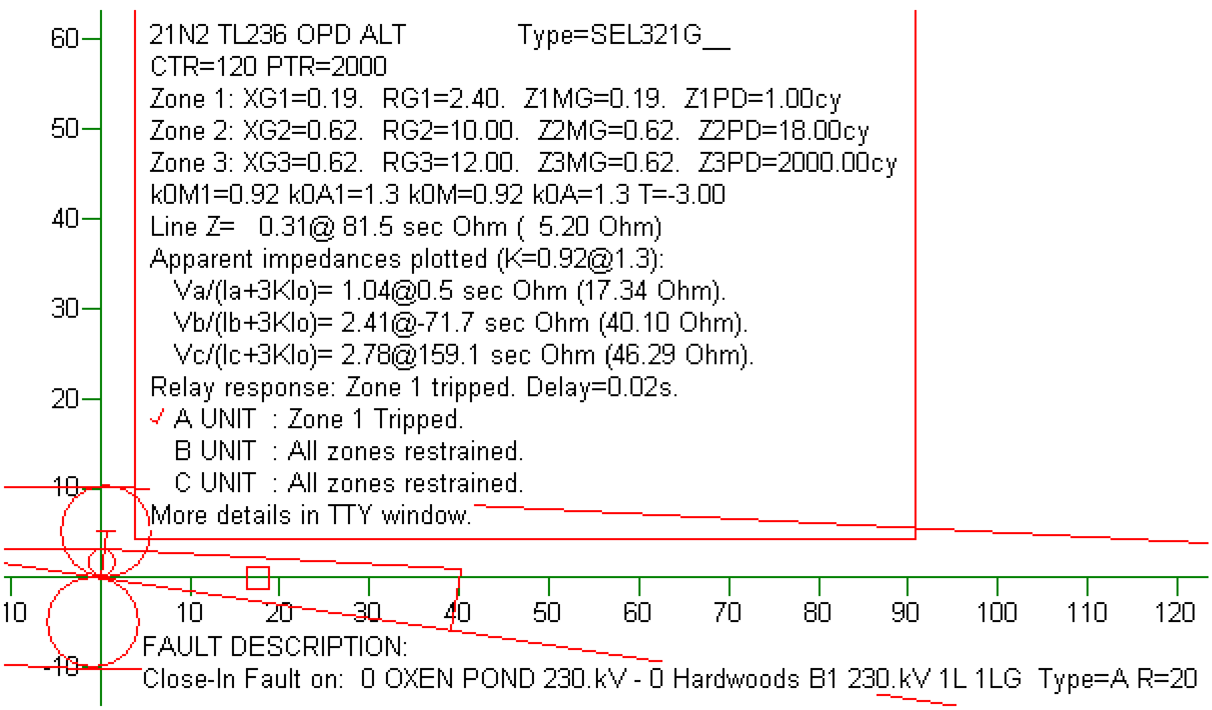


Figure 4 - OPD Zone 1 function if set with 2.4 ohm resistive reach, operates for a 20 ohm SLG fault at close in to the local terminal.

Zone 2 Ground Distance Protection

The Zone 2 ground distance function will need to be set similar to the Zone 2 phase distance protection function because it will tend to underreach the remote terminal while the parallel line is in service. The existing setting is 296% of the line impedance and unrerreaches the zone 1 element on the shortest line out of HWD so should be retained.

$Z2MG := Z2P$ $Z2MG = 0.92$ Ohms secondary

$$Z2MG \cdot \frac{VTR}{CTR} = 15.406$$ Ohms primary

The quad element reactive reach will be set similarly to the mho.

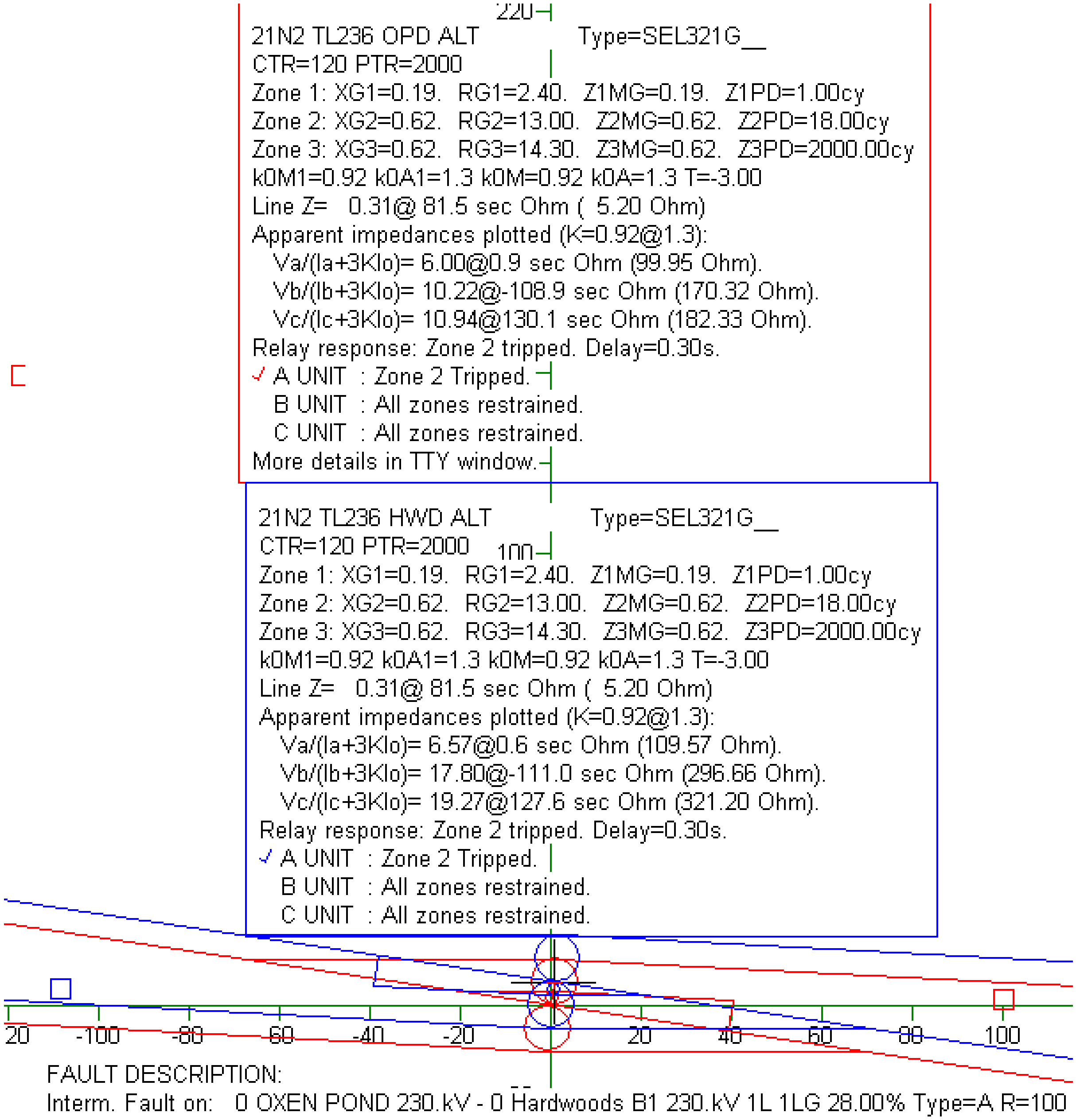
$XG2 := Z2MG$ $XG2 = 0.92$ Ohms secondary

It would be desirable to set the resistive reach of the quad element to sense a 100 ohm SLG fault at 75% of the line with the local terminal weak. This would ensure overlap with the zone 1element at the remote terminal. However, that would require too much resistive reach. Therefore choose a setting to sense a 100 ohm SLG fault just past the mid point of the line with the local terminal normal, and depend on the echo function to provide coverage for high resistance faults in the region where the remote zone 1 won't operate. If this terminal is weak, we will need to depend on sequential clearing of high resistance faults.

By trial and error from ASPEN it is found that a resistive reach of 13 ohms secondary will sense a 100 ohm SLG fault with an overlap (with a similarly set remote zone 2) of 30% of the line length. See Figure 5. This will give positive overlap with the zone 2 element at the remote terminal. However since it will not overlap the Zone 1 element at the remote terminal, the permissive trip echo function will be required to ensure that a fault that is seen by the zone 2 element at only one terminal will still be cleared by the permissive trip logic.

Therefore, to avoid extremely large resistive reaches, and to retain sensitivity to 100 ohm resistive SLG faults, it is recommended that the echo function be enabled at both terminals.

$RG2 := 13$ Ohms secondary



<u>Figure 5 - Quad elements overlap with remote quad elements and operate for 100 ohm resistive SLG from 14% to 42% of the line.</u>

Check that this resistive reach won't cause the zone 2 function to trip while a parallel line is open single phase, with heavy power flow. See Figure 6. Unusually heavy power flow has been simulated to challenge security.

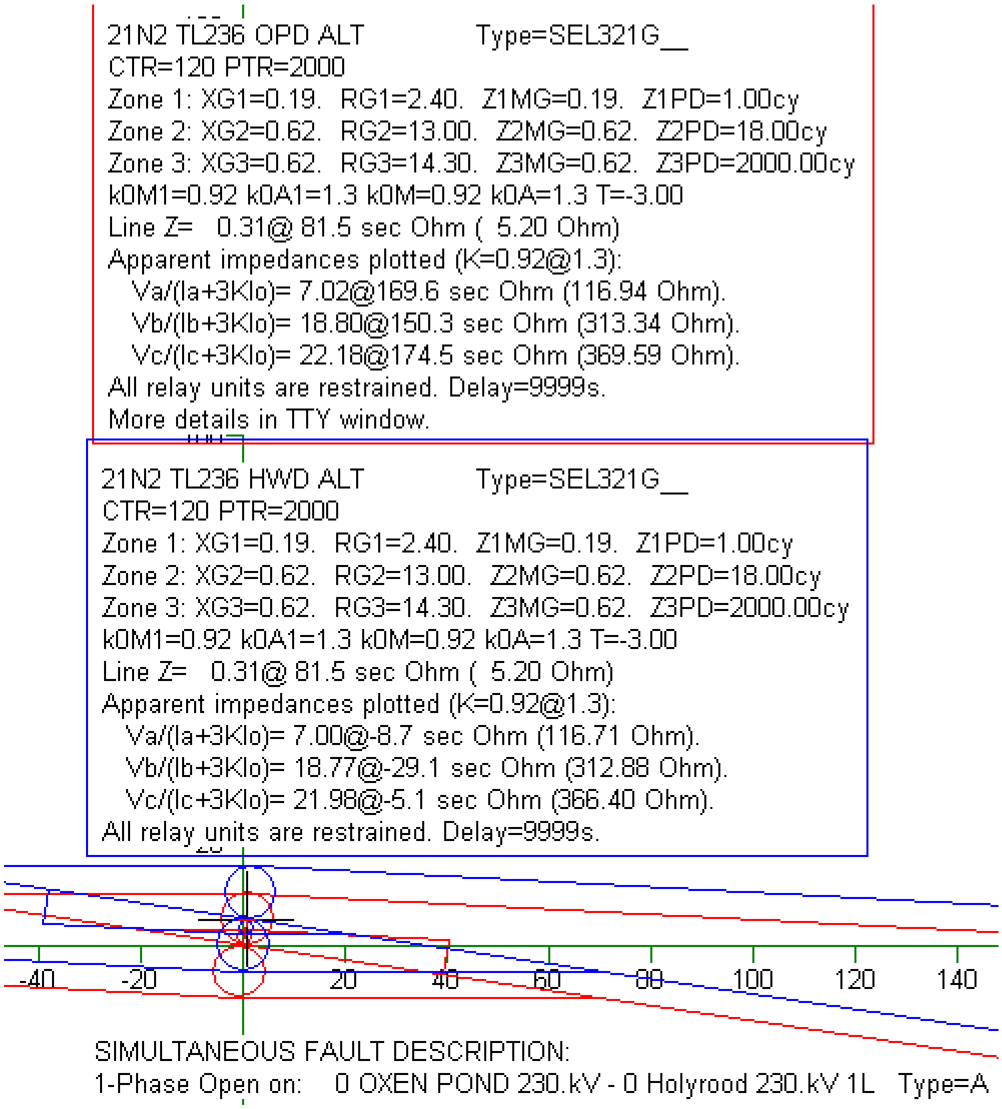


Figure 6 - Quad elements are secure with extremely heavy load flow (172 MVA in TL236 and 223 MVA in TL218) while TL218 is open single pole.

Zone 3

The zone 3 ground mho function will be set using the same principles as the zone 3 phase distance function. Use the setting for local zone 2 in secondary ohms as the remote zone 2.

$Z2MGrem := 15.33$ Ohms Primary $\quad Z3MG := Z2MGrem \cdot \frac{CTR}{VTR}$

$Z3MG = 0.92$ Ohms secondary

$\frac{Z3MG}{|Z1MAG|} = 294.5 \cdot \%$ of line length

This is higher than the existing setting but provides better security.

$XG3 := Z3MG \quad XG3 = 0.9$ Ohms secondary

Set the Zone 3 quad resistive reach at 10% more than the remote Zone 2. The setting is the same as the local zone 2 in primary and secondary ohms. Therefore use the setting for local zone 2 in secondary ohms as the remote zone 2.

$RG2rem := RG2$ Ohms secondary $\quad RG3 := RG2rem \cdot 1.1 \quad RG3 = 14.3$ Ohms secondary

Ground distance current supervision

Since there is no concern about these elements operating on load, even with loss of potential, set all current supervision elements at minimum.

$'50L1 := 0.5$ A Sec $\quad '50L2 := 0.5$ A Sec $\quad '50L3 := 0.5$ A Sec

$'50G1 := 0.5$ A Sec $\quad '50G2 := 0.5$ A Sec $\quad '50G3 := 0.5$ A Sec

Note that due to heavy infeed of zero sequence currents from the local terminal for close-in faults, the ground overcurrent detectors will not operate for faults with a large amount of resistance close to the remote terminal. Therefore, we will have to rely on sequential clearing for that type of fault. However setting the current supervision at minimum allows maximum sensitivity.

Zero sequence current compensation

The zero sequence current compensation could be adjusted to compensate for the significant amount of mutual coupling. However as discussed in the settings of reaches of the ground distance elements we will accept underreach of the Zone 2 function for the normal case by setting it at 125% of the apparent impedance for a remote fault. Set the zero sequence current compensation as usual.

$$k01M := \left(\left|\frac{Z0Line - Z1Line}{3 \cdot Z1Line}\right|\right) \qquad k01M = 0.922$$

$$k01A := \left(\left(\arg\left(\frac{Z0Line - Z1Line}{3 \cdot Z1Line}\right)\right)\right) \qquad k01A = 1.2 \cdot deg$$

Set the overreaching zones the same as zone 1 $\quad k0M := k01M \quad k0A := k01A$

$k0M = 0.922 \quad k0A = 1.2 \cdot deg$

Settings are slightly different from existing due to small changes in line data.

Non Homogenous Angle Setting

Compare the angle of the remote zero sequence source impedance with the total zero sequence source impedance to the fault to determine this setting.

$$T := \arg\left(\frac{Z0minHWD + Z0Linephys + Z0minOPD}{Z0minHWD}\right) = -1.4 \cdot deg \qquad T = -1 \cdot deg$$

Out of step blocking and tripping

Not used in this application. There is a danger of out of step conditions arising. Historically no action has been taken to provide special tripping or blocking functions. Natural tripping during swings is accepted.

Load Encroachment logic

Check loadability of the Zone 2 phase distance element assuming worst case power factor of 0.87 simultaneous with worst case depressed voltage of a stressed system of 0.85 per unit. Note that units of kV squared match units of MVA. Note that quadrilateral elements are only used for the ground distance functions that are not sensitive to balanced three phase load. Therefore no need to worry about the reach of the quadrilateral elements.

$$Zloadmin := \frac{(0.85kVbase)^2}{Smax} \qquad Zloadmin = 103.298$$ Ohms primary (assume worst case at 30 degrees)

Maximum reach of the Zone 2 element is at the line angle of 81 degrees. At 30 degrees, the reach will be given by

$$Z2load := Z2P\cdot\cos[(Z1ANG - 30)deg] \qquad Z2load = 0.576$$ ohms secondary

$$Z2load\cdot\frac{VTR}{CTR} = 9.598$$ ohms primary

Since the reach of the Zone 2 element at 30 degrees is less than the apparent impedance of the maximum load, there is no need to apply load blinding logic. See Figure 7

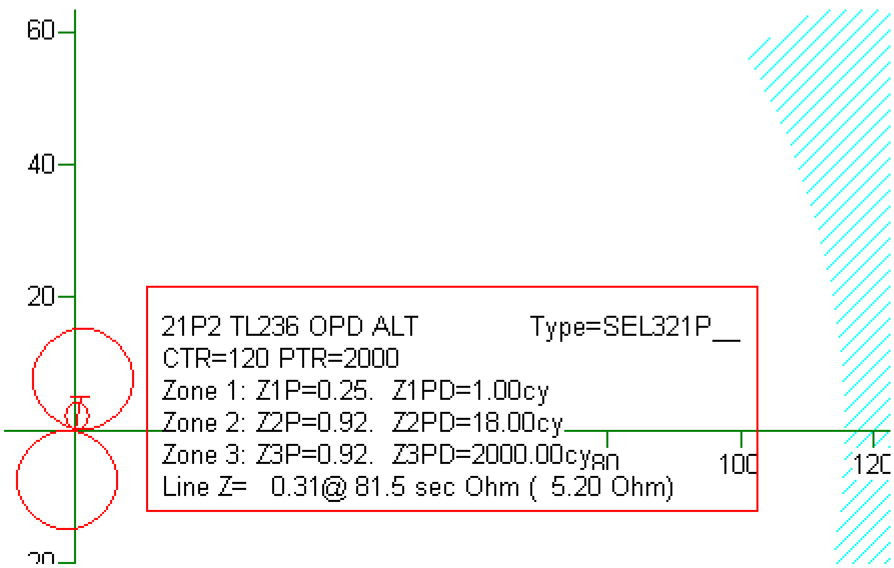


Figure 7 -Load impedance with respect to proposed new Mho function reaches.

Ground directional element

The SEL-321 application example recommends finding the minimum source impedance behind the terminal and setting the reverse and forward boundaries of the negative sequence directional element at the 1/3 and 2/3 points respectively.

In the negative sequence plane, the sum of the two source impedances and the line impedance is:

$$Z2total := Z2minOPD + Z1Linephys + Z2minHWD$$

The 1/3 point is $Z2\_1\_3 := \frac{Z2total}{3}$ The 2/3 point is $Z2\_2\_3 := \frac{2Z2total}{3}$

$Z2Rpri := Z2\_2\_3 - Z2minOPD$ $Z2Rpri = 1.048 + 10.098j$

$Z2Fpri := Z2\_1\_3 - Z2minOPD$ $Z2Fpri = -0.676 - 11.651j$ Desired set point for Z2F is negative.

Converting the primary impedances to secondary ohms

$Z2R := Z2Rpri\cdot\frac{CTR}{VTR}$ $|Z2R| = 0.609$ Ohms secondary $\arg(Z2R) = 84.074\cdot deg$

$Z2F := Z2Fpri\cdot\frac{CTR}{VTR}$ $|Z2F| = 0.7$ Ohms secondary $\arg(Z2F) = -93.32\cdot deg$

Rounding down Z2F and rounding down Z2R gives:

$Z2F := -0.7$ Ohms secondary $Z2R := 0.6$ Ohms secondary

These are higher than the existing settings with differences likely due to different fault study model.

Set the current level detectors at minimum level that will allow operation of the ground distance elements.

Due to the very small zero sequence current contribution to a single line to ground fault at the remote terminal, the negative sequence current contribution will always be higher than the zero sequence. Therefore there is no point in setting the forward looking negative sequence overcurrent elements any more sensitively than the zero sequence ground overcurrent supervision of the ground distance elements.

$'50QF := '50G2$ $'50QF = 0.5$

Set the supervision function for the reverse looking element to be the same as, or a little more sensitive than the forward looking supervision element at the remote terminal.

$'50QR := 0.5$ A secondary

The positive sequence current restraint (a2) factor should be set just smaller than the ratio of the maximum load current (positive sequence) to the most sensitive current supervision element (50QR).

$I1maxpri := \frac{Smax\cdot 1000}{kVbase\cdot\sqrt{3}}$ $I1maxsec := \frac{I1maxpri}{CTR}$ $I1maxsec = 7.74$

Bearing in mind that the 50QR setting is in units of 3*I2

$\frac{'50QR}{3\cdot I1maxsec} = 0.022$ Choose a value of $a2 := 0.02$ The proposed is the same as the existing setting (0.02).

Phase time overcurrent element

This element is not used

Residual time overcurrent element

This element is used to provide the most sensitive backup protection. It will be a non directional element.

Set pickup to sense a higher resistance than 100 ohm SLG in the middle of the line with equal zero sequence current infeed from both ends. Choose a resistance of 200 ohms arbitrarily. Use a safety factor of 2 so that operating time is not infinity at this fault level.

$SF := 2$ Desensitization factor due to remote end infeed is $Dfactor := 2$ $Rf := 200$

$$'51NPU := \text{round}\left(\frac{kVbase \cdot 1000}{\sqrt{3} \cdot SF \cdot Dfactor \cdot Rf \cdot CTR}, 1\right) \qquad '51NPU = 1.4$$

The existing setting of 0.5 A is more sensitive than required to sense this mid line fault with arbitrary resistance. Since TL206 experience with the high resistance tree fault on 28th August 2009 has shown value in the existing setting, it will be retained.

$'51NPU := 1$ A secondary

Coordination checks show that the existing time dial settings will coordinate above remote protection. See Figure 9. However under maximum load conditions, if this line trips single phase, the neutral current during the open pole period will be sufficient to operate the 51N in less than one second. Although the reclose open pole dead time is about 45 cycles, the unbalance during the fault will also tend to operate the element. It is best to have an operating time due to unbalanced load flow during the oper pole period of not less than 1.3 seconds. The existing time dial setting will have to be increased to make this element secure during the open pole period with heavy load flow.

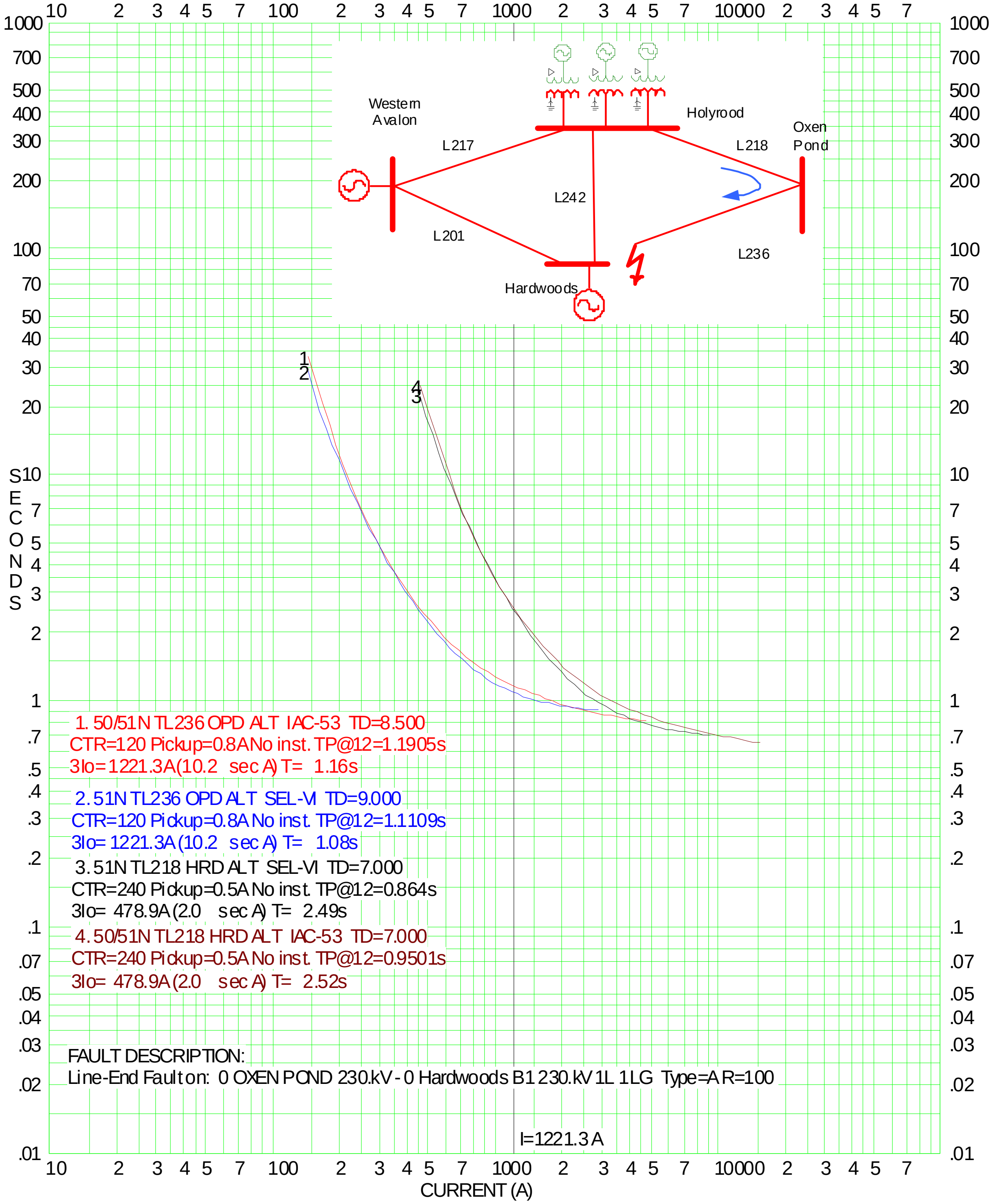
$'51NPU = 1$ A secondary $'51NPU \cdot CTR = 120$ A primary

$'51NTD := 9$ $'51NC := "U3"$ $'51NTC := "N"$ $'51NRS := "N"$

The time dial is proposed to be increased from existing 6 to 9 to be more secure during heavy load while one phase is open during a single phase trip and reclose operation.

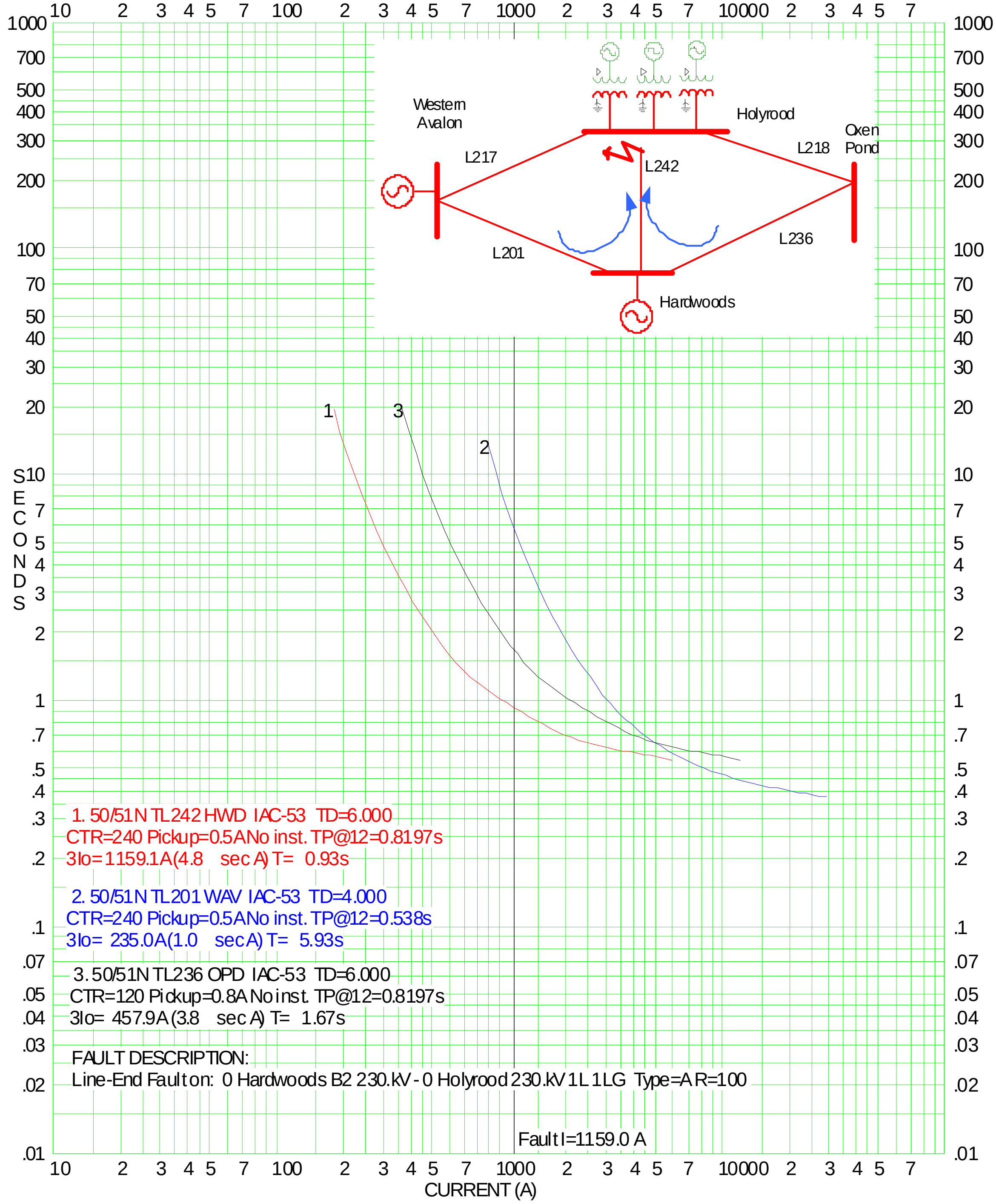
Check the coordination below the HRD TL218 51N for a line end fault on TL236 with the proposed new, slower setting. This is the type of fault that will produce the most sensitivity (least desensitization) with respect to the backup protection on TL218. see Figure 8. Even with new (slower) ALT settings, coordination margin is satisfactory. Note that coordination margin would not be satisfactory for a fault with low resistance. However, we can depend on the 0.3 second definite time zone 2 ground distance element to clear low resistance faults promptly. With the time ground overcurrent elements we are primarily concerned with high resistance faults.

Check the coordination above the HWD TL242 protection for line end faults. See Figure 9. It can be seen that the existing setting is comfortably slower than the HRD TL217 protection for a 0 ohm fault. The proposed new settings are even slower; so there will be no difficulty coordinating above remote protection.



EC 230-8	TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For	Coordination of OPD TL236 below HRD TL218	No. EC 230-8
Comment	Z2G needed for coordination with RF <100 ohms	Date 13 Dec 2011

Figure 8 - coordination of ground time overcurrent elements for LE TL236 fault



	TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For	Coordination of HWD TL242 below WAV L201 and OPD L236	No. EC 230-5
Comment	Z1G and Z2G needed for coordination with RF<100 ohms	Date 29 Sep 2011

Figure 9 - coordination of ground time overcurrent elements for line end fault on TL242 (with existing OPD TL236 settings. Proposed new settings are slower)

Permissive Overreaching logic settings

EPOTT := "Y"

Z3RBD is set at remote breaker time plus channel reset time plus channel reset time plus zone 2 reset time. From review of fault records it appears that the breaker time is 3 cycles. Channel reset time is not easily determined from existing records but can conservatively be assumed to be 1 cycle, and relay reset time will also be about 1 cycle. Total time for Z3RBD is then 5 cycles.

Z3RBD := 5 cycles

Echo block delay timer blocks the echo after the local elements have picked up. This can be set relatively long since there is no significant need for the echo function shortly after the local terminal has just seen a fault but the remote terminal has not. Set at 10 cycles as per the example in the instruction manual.

EBLKD := 10 cycles

Echo time delay on pickup should be set to override noise on the communications so that it doesn't echo noise. Typical time according to the SEL application guide is 2 cycles. Since this delay only affects clearing time for relatively light (high resistance) faults that are sensed by zone 2 function at one end, the typical setting is acceptable.

ETDPU := 2 cycles

Echo duration should be long enough to ensure the permissive trip is received by the remote terminal and should also be shorter than the Z3RBD time to ensure that the reverse blocking will always be longer than any permissive trip received (including echo time stretching).

EDURD := 4 cycles

No need to enable week feed conversion to trip, since both terminals will be quite sensitive enough to detect high resistance faults after the remote terminal has cleared. Therefore we can accept sequential (or "step") clearing with no need for the added insecurity of weak infeed tripping.

EWFC := "N" **No other communications logic settings are required for this application.**

Switch on to Fault Settings

Switch on to fault logic will ensure the protection will operate when energizing the line onto a close-in three phase fault when there is no polarizing voltage available for the distance elements.

ESOTF := "Y"

The breaker close signal is not available to the relay. The 52A method of enable SOTF will be used. Therefore the Close end delay is not critical. Typical duration for enable SOTF is 10-15 cycles

ENCLO := "N" CLOEND := 0 EN52A := "Y" SOTFD := 15

Set 50H for high magnitude close-in multiphase faults with weakest source at OPD. It should be set less than 50% of the minimum close-in fault magnitude. Minimum close-in magnitude of a three phase fault with TL218 out of service is 1500 A. Therefore desired maximum setting for 50H is 750 A.

Imin3P_close_in := 1500

$$'50H := \frac{Imin3P\_close\_in}{2CTR} \qquad '50H = 6.25 \quad \text{A secondary}$$

Choose a setting of 6 A secondary for this element. '50H := 6 A secondary

Choose a setting for 52AEND less than the shortest reclose time. '52AEND := 30 cycles

The existing setting of 52AEND is 40 cycles. It is not known why the setting is set so long.

Residual overcurrent settings.

Tripping directly by instantaneous ground overcurrent is not applicable because it is not phase selective. However it would be helpful to monitor steady state unbalance, and issue an alarm for continuous unbalance. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50N := 1$ $\quad$ $'50N1 := 0.25$

Negative Sequence overcurrent settings.

Similar to ground overcurrent, apply a negative sequence overcurrent element to initiate an alarm for steady state unbalances. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50Q := 1$ $\quad$ $'50Q1 := 0.25$

Voltage Element Settings

Similar to unbalance current monitoring, it is helpful to have an unbalance voltage monitor to detect steady state unbalances from the voltage supply.

EVOLT := "Y"

Set the zero sequence overvoltage element at 1% of rated voltage or just at the point necessary to override normal unbalances. The zero sequence voltage element measures 3 times the zero sequence voltage.

$$'59N := 3 \cdot 0.01 \frac{kVbase \cdot 1000}{\sqrt{3} \cdot VTR} \qquad '59N = 1.992 \qquad \text{Say} \quad '59N := 2 \ \text{V secondary}$$

Loss of Potential

Enable loss of potential settings. Advanced LOP settings are not available on this model of relay.

ELOP := "Y" $\quad$ Time delay of 1.25 cycles is commonly used. $\quad$ $LOPD := 1.25$

The 50 M element should be set above maximum load and below minimum fault current for a fault at the remote terminal under weak source conditions. The maximum load for this case should be normal maximum, not emergency maximum which only exists for a few minutes before the operator can act to reduce load.

$$Imax\_normal := \frac{Smax\_TL236 \cdot 1000}{\sqrt{3} \cdot kVbase \cdot CTR} = 1.485 \ \text{A secondary}$$

Minimum fault current for a remote three phase fault is $\quad I3Pmin = 3 \quad$ A primary.

the 50M element cannot be set low enough to ensure it is above maximum load yet below the minimum fault current since the minimum fault current is so low. Therefore it will be set at the same level as the phase distance current supervision element for maximum dependability, and we will have to accept that under loss of potential conditions, there may be an undesirable trip of the P2 protection. The phase distance current supervision is 1 A phase to phase, which corresponds to a phase current of 0.57 A for a three phase fault.

$'50M := 0.6$ $\quad$ A secondary $\quad$ This is considerably less than existing, but is required for dependability when this source is weak.

The 59QL setting should be above normal maximum unbalance and below the level expected for a blown VT fuse. For a blown fuse, one phase voltage will be lost, and the negative sequence voltage will be roughly 33% of the nominal positive sequence voltage. Choose a setting of 15% of the nominal positive sequence voltage. This will be well above any normal unbalance.

$'59QL := \mathrm{round}\left(\frac{0.15\cdot kVbase\cdot 1000}{\sqrt{3}\cdot VTR},0\right)$ $'59QL = 10$ V secondary

The 59PL setting should be less than the minimum voltage to be expected for a remote bus fault under weakest source conditions. There is no minimum setting (above zero) for this function. Choose a setting equal to 50% the voltage drop along the line impedance at the pickup setting of the 50M element.

$'59PL := \mathrm{round}[0.5\cdot('50M\cdot|Z1Linesec|),1]$ $|'59PL| = 0.1$

Such a low setting probably renders the loss of potential function not useful for 3 phase loss of potential, but this is unavoidable under such weak source conditions.

Miscellaneous Scheme Settings

Pole discoordinance logic is not being used. EPOLD := "N" SPPDD := "N/A"

Enable single pole tripping by distance elements only ESPT := "Y"

Enable single pole open ESPO := "Y"

Set single pole open time delay for future SPO conditions SPOD := 0.25

Note that SPOD was short enough to allow a transient operation when TL201 was reclosed with a fault on it during the fault of 7 March 2011. This transient operation was helpful to clear the fault more quickly than it otherwise would have cleared. SEL have been asked whether the SPOD setting of 0.5 would be better to increase the security.

3 Pole open reset delay to override small discrepancies in pole closing '3POD := 0.5

Stub line protection is not required ESTUB := "N" '50MFD := "N/A"

Trip unlatch logic not applied TULO := "N"

Logic variables and Miscellaneous timers

Minimum trip duration timer is set at 9 cycles as per the application example in the SEL-321 instruction manual.

TDURD := 9 Cycles

Trip during open pole time delay should be set longer than the reclose time. Existing reclose time is 55 cycles. This is acceptable.

TOPD := 55 Cycles

Existing logic variables are not used.

Since this line is short (voltage may be low at HRD for a fault near OPD), a 1 cycle security delay in zone 1 tripping is recommended to improve the security of this function against incorrect tripping for a fault beyond the OPD terminal.

LOGIC_X := "M1P+Z1P" TXPU := 1 cycle TXDO := 0 cycles

Add the use of ZT to trigger an alarm for sustained unbalance.

LOGIC_Z := "59N+50N1+50Q1" TZPU := 1200 cycles TZDO := 0 cycles

Tripping Logic

Permissive tripping is required only for instantaneous overreaching functions. No need for any functions that trip directly. Existing 51NT word in MTCS is not required.

MTCS := "M2P+Z2G"

Existing settings for unconditional tripping must be modified to include a 1 cycle delay for zone 1 tripping.

MTU := "XT+M2PT+Z2GT+51NT"

No need for existing direct tripping zone 1 functions in the switch on to fault logic.

SOTF Tripping MTO := "M2P+Z2G+50H"

Event records will be triggered automatically by all trip events. Other event record triggers should be by starting of other elements to ensure capture of all relevant events. Events should be triggered by keying or receiving permissive trips to ensure separation of relay and teleprotection issues.

MER := "M2P+Z2G+51N+LOP*52AA1+LOP*52AA2+KEY+PT+EKEY"

Outputs

Retain existing output assignments except add the continuous unbalance alarm to OUT15.

OUT15 := "LOP*50L+ZT"

Input Contact Assignment

It would be desirable to provide phase segregated inputs to the relay so that the quadrilateral functions could be disabled during single pole open conditions. it is not known if phase segregated auxiliary switches are available on the breakers.

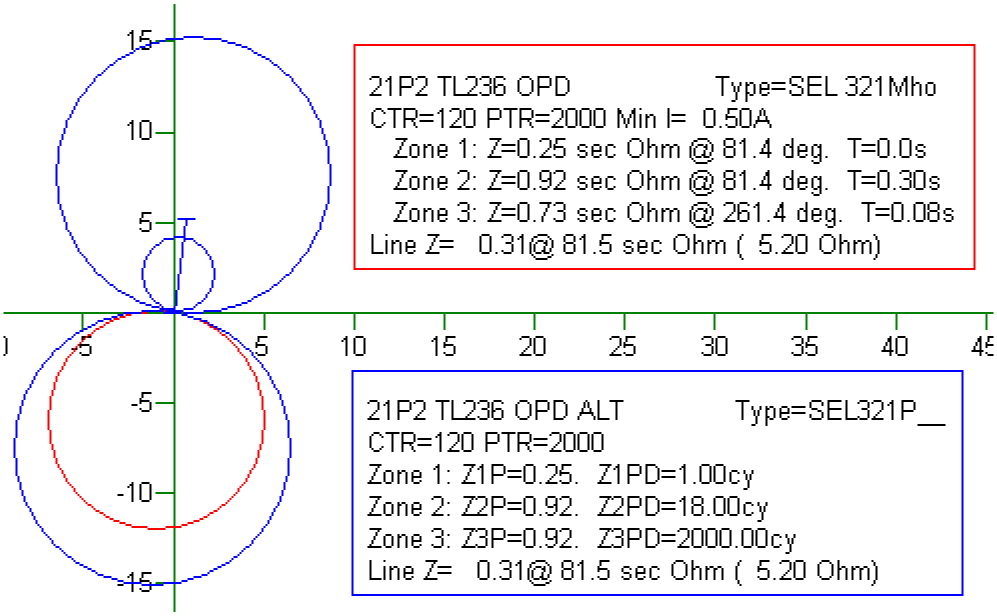


Figure 10 - Comparison between existing (red) and proposed new (blue) phase distance characteristics.

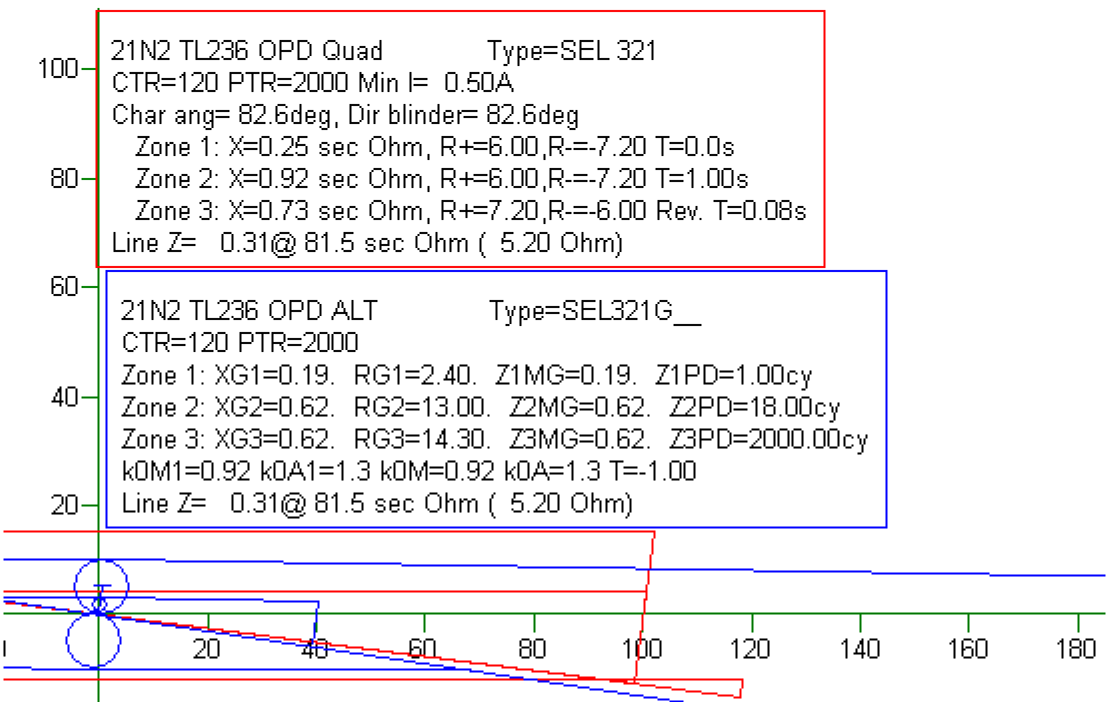


Figure 11 - Comparison between existing (red) and proposed new (blue) ground distance characteristics.

Protection Review for Five 230 kV Transmission Lines

Appendix R
Detailed settings review for HWD TL236 "P1" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador Hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Hardwoods Terminal (HWD) terminal of circuit TL236. This 230 kV transmission circuit is from HWD to Oxen Pond (OPD).
The circuit runs parallel to Circuit TL218 for most of its length.

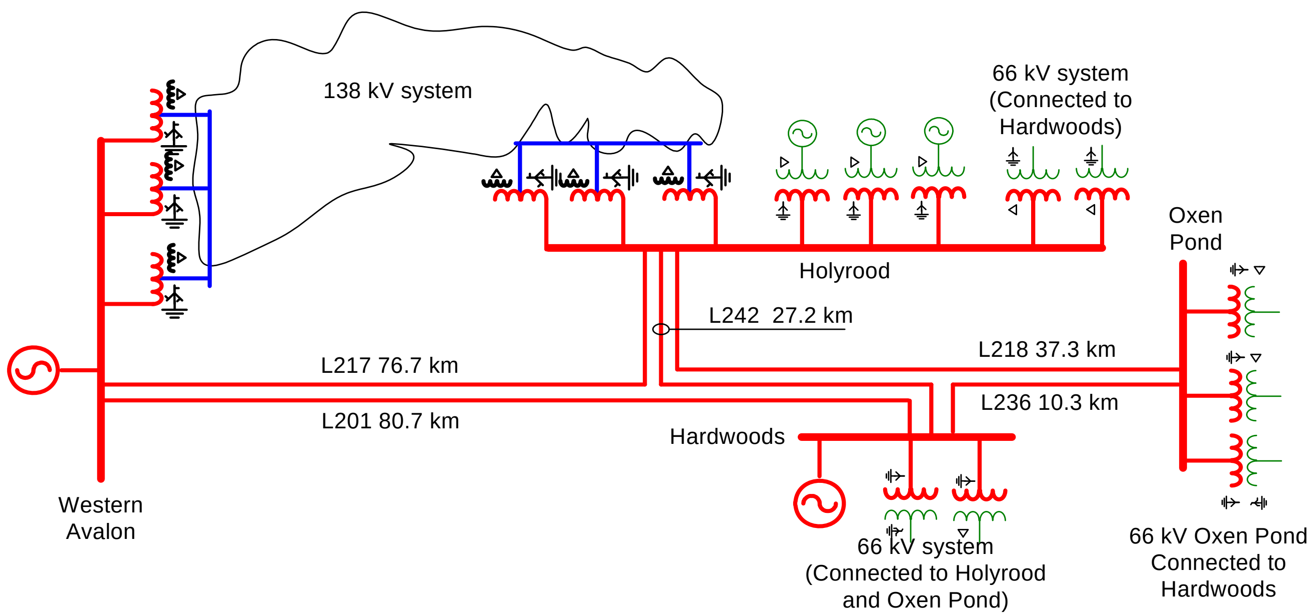


Figure 1 - System Single Line Diagram

Existing P1 protection systems are Areva LZFP111 (Optimho) systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $\quad$ $kVbase := 230$ $\quad$ $Ibase := \frac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\quad$ $Zbase := \frac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at the line terminal.

CT ratio is: $CTR := \frac{600}{5}$ $\quad$ VT ratio is: $VTR := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**NL HYDRO WITH MUTUALS FOR EAST COAST 230 kV LINE PN REVIEW 8 DEC.OLR**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with loads and shunts ignored.

Minimum fault current seen by each terminal (phase to phase, and SLG with 0 ohm fault resistance).

At HWD, the weakest condition for faults near OPD is when the B1B2 bus tie breaker is out of service.

$ILLmin := 1284$ A $\quad ISLGminPH := 1581$ A $\quad ISLGmin0seq := 1275$ A

The optimho current level detectors that block the distance comparators in the event of line opening are fixed at 5% of the rated current, or 0.25 A secondary, or 60 A primary. They will have no difficulty in operating for minimum bolted fault levels. However, the ground distance elements are also supervised by a low set neutral current level detector (LDLSN that requires the neutral current to be greater than 10% of the maximum amplitude of phase difference current. This prevents the ground comparators from operating during close-in multiphase faults with CT errors. ASPEN OneLiner shows that for a bolted fault at the remote bus even under heavy load, there is sufficient neutral current (60% of maximum phase to phase fault current) that means this LDLSN function does not inhibit the ground distance comparator.

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind HWD $\quad Z2minHWD := 2.0 + j \cdot 26.7$ ohms primary

Minimum source impedance behind OPD $\quad Z2minOPD := 2.4 + j \cdot 33.4$ ohms primary

Line impedances.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L236 := 0.00146 + j \cdot 0.00973 \quad Z0L236 := 0.00491 + j \cdot 0.03672$

$Z1Line := Z1L236 = 0.0015 + 0.0097j$ pu $\quad Z0Line := Z0L236 = 0.005 + 0.037j$ pu

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line \cdot Zbase \quad Z0Linephys := Z0Line \cdot Zbase$

$Z1Linephys = 0.77 + 5.15i$ ohms primary $\quad Z0Linephys = 2.6 + 19.42i$ ohms primary

Converting primary ohms to secondary ohms gives:

$$Z1Linesec := Z1Linephys \cdot \frac{CTR}{VTR} \qquad Z0Linesec := Z0Linephys \cdot \frac{CTR}{VTR}$$

$|Z1Linesec| = 0.31$ ohms sec $\quad arg(Z1Linesec) = 81.5 \cdot deg$

$|Z0Linesec| = 1.176$ ohms sec $\quad arg(Z0Linesec) = 82.38 \cdot deg$

Load Data

From 2011 System summer load case provided in start up information, the peak load (sum of TL236 and TL236) is given as 267MVA (split between TL236 and TL236). In the event of sudden loss of one line, peak load will be the sum of both line loads until operators can adjust loads. Therefore it is assumed that peak load for a short duration is 205 MVA

$Speak := 267$ MVA $Smax := Speak = 267$ MVA

However, new information from Peter Thomas (see email dated 9 December, 2012 (subject "Re: FW: PSSE Files") indicates that peak load should be set up to carry 370 MVA under the conditions of TL218 out of service.

$Smax := 370$ MVA

P1 Relay Settings

Distance element reach settings

Note that resistive reaches are forced to be the same for all zones. Reactive reaches for phase and ground distance elements must be the same as each other.

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the HWD Station bus under light load conditions and Breaker B1B2 out of service. From ASPEN OneLiner, voltage at HWD for a 3 phase fault at OPD is 0.06 per unit. Since the voltage is less than 20%, this line is considered short, and a reduced zone 1 reach would normally be recommended to increase security. However, since the resisitve reach of the zone 1 element has to be the same as that of the zone 2, which is very high, in order to sense resistive single line to ground faults, the zone 1 ground element will have to be disabled, that means the zone 1 phase distance element also has to be disabled, because it is not possible to disable the ground distance element without also disabling the phase distance element. Choose the existing (arbitrary) setting of 0.92 ohm for the zone 1 reach

$Z1P := 0.92$ Ohms secondary

As noted above, the zone 1 ground distance needs to be disabled, because the resistive reach of the zone 2 ground distance function has to be set to cover about a 100 ohm fault at a point on the line where the contributions from each terminal are roughly equal. Choose the setting of the zone 1 phase and ground distance elements to be the existing (arbitrary) setting of 0.92 ohms secondary.

$Z1\_sec := 0.92$

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 0.92 ohms secondary (about 300%). This is a very long setting, but will not overreach any instantaneous protection at the remote terminal; even without infeed, so is quite accetpable.

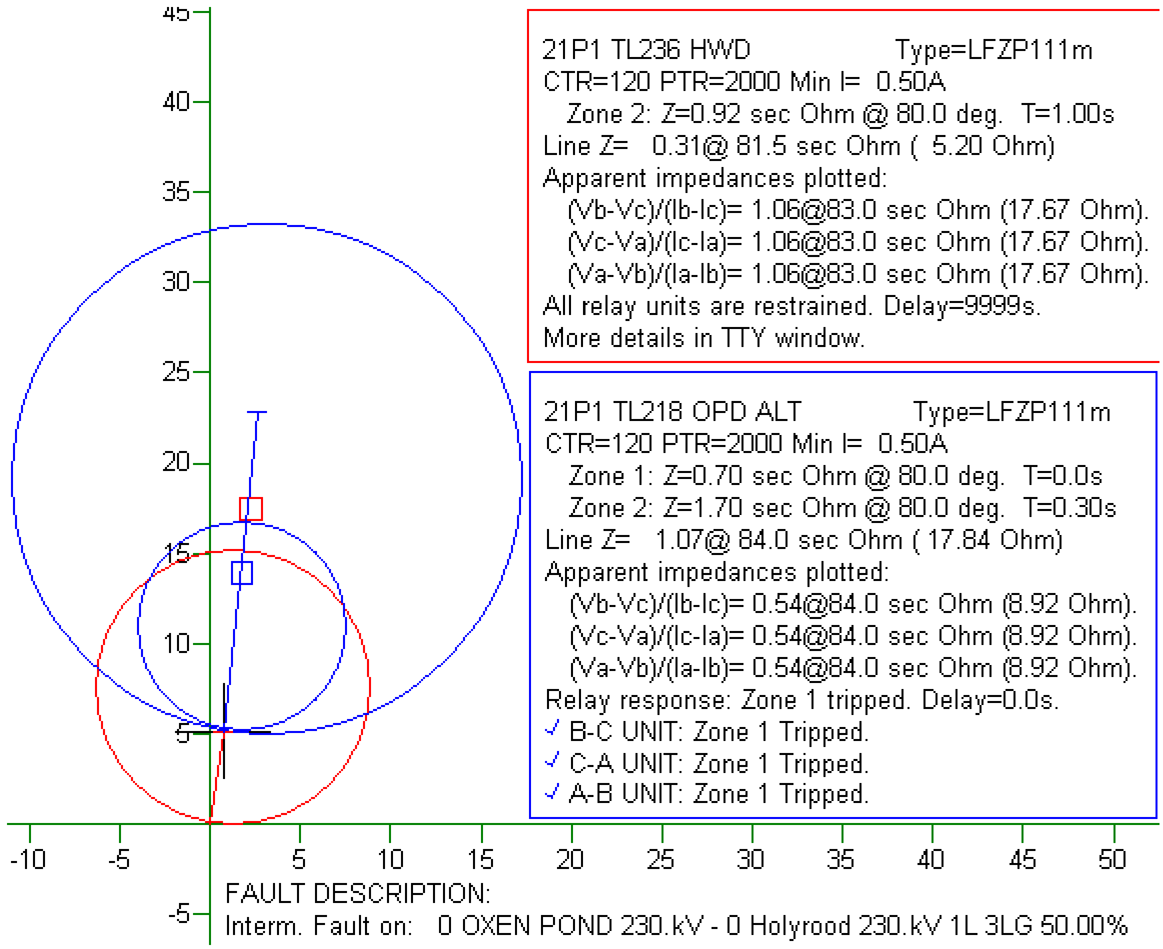


Figure 2 - Zone 2 underreaches remote shortest zone 1, even without infeed.

As can be seen from Figure 2, the apparent impedance to a fault beyond the remote terminal is increased significantly due to infeed. Therefore the existing setting of 0.92 ohms is good.

$Z2\_sec := 0.92$ $\quad$ $Z2\_sec = 0.92$ $\quad$ Ohms secondary $\quad$ $\dfrac{Z2\_sec}{|Z1Linesec|} = 294.6 \cdot \%$

$Z2\_pri := Z2\_sec \cdot \dfrac{VTR}{CTR} = 15.333$ $\quad$ Ohms primary

This setting will not reach far past the OPD terminal so there will be no problem with using the conventional zone 2 time delay and will still achieve coordination with instantaneous elements covering circuits beyond HWD. This is reduced from the existing 1 second setting.

$Z2\_TD := 0.3$ $\quad$ Seconds

Resistive reach

Check the sensitivity of the new settings to resistive faults near the middle of the line.

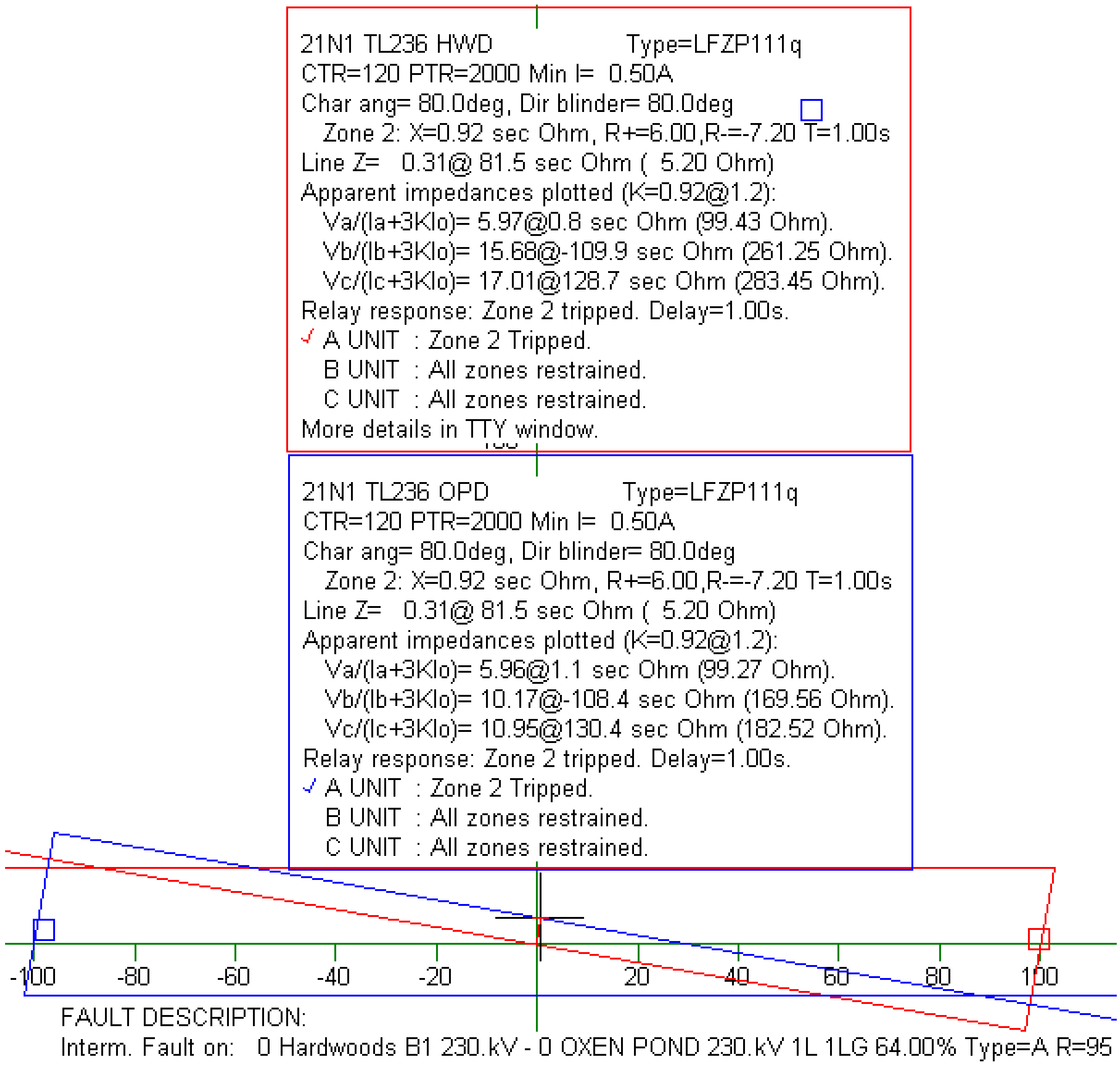


Figure 3 - Resistive fault coverage near the middle of the line.

As can be seen from Figure 3, the zone 2 elements at both ends will comfortably overlap for a 95 ohm resistive fault near the middle of the line (61%-65% from HWD).

The existing resistive reach setting of 6 ohms secondary will be suitable.

Rquad := 6 ohms secondary

Load Encroachment logic

The optimho instruction manual recommends a margin of at least 10% between the impedance of the maximum load and the resistive reach of the quadrilateral distance element.

Check loadability of the Zone 2 phase distance element assuming worst case depressed voltage of a stressed system of 0.9 per unit.

$$Zloadmin := \frac{(0.9kVbase)^2}{Smax} \qquad Zloadmin = 115.808$$ Ohms primary (assume worst case at 30 degrees)

$$Zloadmin\_sec := Zloadmin \cdot \frac{CTR}{VTR} \qquad Zloadmin\_sec = 6.948$$

A 6 ohm secondary resistive reach is less than 90% of the load impedance at unity power factor and meets the Areva criterion as shown in Figure 6.

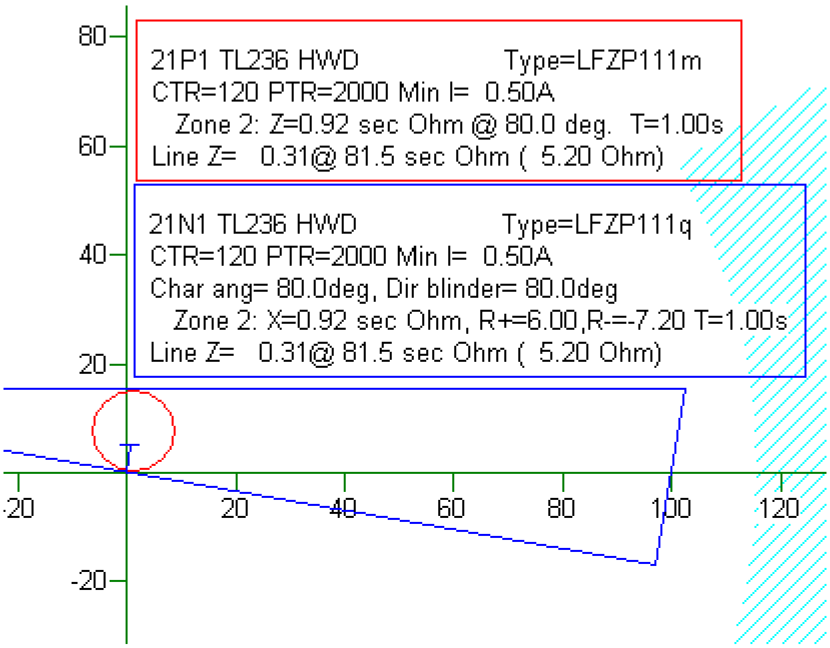


Figure 6 - Apparent impedance of load

Settings of K attenuators

The instruction manual recommends that the KZph element be set as high as possible to maximize the sensitivity up to the maximum possible setting of 1. In this case, the Zone 2 setting will be equal to the zone 1 (since the zone 1 is not used) and the zone 2 setting desired is 0.92 ohms.

Therefore the existing setting of KZph should be increased to obtain the maximum possible sensitivity.

$KZPh := 0.92$

Zone 1 attenuators and angular selection

$In := 5$ $Z1\_sec = 0.92$ This is the desired secondary reach (previously calculated)

$$KZ1 := \frac{Z1\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ1 = 1 \qquad Z1sec\_reach := KZ1 \cdot KZPh \cdot \frac{5}{In} \qquad Z1sec\_reach = 0.92$$

$Z\theta PH := (\arg(Z1Linesec))$ $Z\theta PH = 81.466 \cdot deg$

Rounded to the nearest 5 degrees $Z\theta PH := 80$ Degrees

$Z\theta N := \arg(Z0Linesec - Z1Linesec)$ $Z\theta N = 82.716 \cdot deg$

Rounded to the nearest 5 degrees $Z\theta N := 80$ Degrees (same as eisting)

Zone 2 attenuators selection

$Z2\_sec = 0.9$ This is the desired secondary reach (previously calculated)

$$KZ2 := \frac{Z2\_sec}{\left(KZPh \cdot \frac{5}{In}\right)} \qquad KZ2 = 1$$

QUAD Resistive Reach setting

$Rquad = 6$ This is the desired secondary reach (previously calculated)

$$KR := \frac{Rquad}{\left(\frac{5}{In}\right)} \qquad KR = 6$$

Residual Compensation attenuators selection

Zero sequence current compensation for ground faults is provided by the KZN factor. Zero sequence mutual compensation is not used in this application (it causes extra complexity for only moderate gain in setting accuracy).

$$KZN := \frac{Z0Linesec - Z1Linesec}{3 \cdot Z1Linesec} \cdot KZPh \qquad KZN = 0.848 + 0.018j$$

$|KZN| = 0.85$ This is a reduction from the existing setting of 0.957

Switch On To Fault (SOTF) Protection.

If SOTF is enabled, it can be set to 200ms or 110 s after all poles of the line have been de-energized. The 110 s setting is intended to override automatic reclosing dead time. However it makes more sense to enable after the shorter time. Once the SOTF feature has been initiated, it remains in effect for 250ms after the line has been re-energized. The SOTF tripping options are:

a) Any distance comparator.
b) Any current level detector as long as a corresponding voltage level detector has not picked up within 20ms.
c) Either current or distance, as long as a corresponding voltage level detector has not picked up within 20ms.

SOTF := "Enabled"

SOTF_TIME := 0.20 Seconds

Elements_in_SOTF := "BOTH" (Both Comparators and current level detectors).

Power Swing Detector

This element will not be used. It will be left Blocked, and if there is a power swing, the distance elements will trip naturally.

VT Supervision

Set the VT supervision to BLOCK TRIP

Set the VT fail detection to SELF RESET.

Start Indication

This function will bring up information on the LCD screen of the relay if a start event occurs. This function will not be used.

START_INDICATION := "BLOCKED"

Communications assisted logic.

The existing communications assisted logic is permissive overreaching transfer trip, scheme **POR 1**. This scheme is familiar to Newfoundland and Labrador Hydro, and even though the POR 2 scheme offers the advantage of weak infeed echo, which would help the sensitivity to resistive faults, it is not recommended to change the existing scheme logic at this stage with years of experience on a product that is nearing the end of its useful life.

The POR 1 logic is a basic permissive overreaching transfer trip scheme but it does include current reversal timers to increase security against misoperation due to current reversal when a fault on the parallel line is cleared sequentially. The current reversal logic is achieved by a timer TP which will block permissive tripping and keying of permissive trip if the local zone 2 element does not pick up within a reasonable time of receiving permissive trip. The block will be maintained for a time delay of TD after the local zone 2 element picks up, or the received permissive trip signal resets.

The application of the current reversal timers is required only if the settings of the zone 2 comparators are greater than 1.5 times the line impedance .Although the reaches of these elements are only marginally less than 1.5 times the line impedance, there is no parallel line and there is infeed at each terminal that will minimize overreach. Therefore, the current reversal logic is not required, and the recommended default settings are as existing

$TP := 98$ ms

$TD := 0$ ms

Comparison of Existing (red) and Proposed alternative (ALT) settings.

The main change to the proposed alternate settings is to change the setting of the KZPH element to maximimze sensitivity. Also the zone 2 timer setting could be reduced from the existing 1 second to 0.3 seconds. There are no proposed changes to the existing reach settings.

Protection Review for Five 230 kV Transmission Lines

Appendix S
Detailed settings review for HWD TL236 "P2" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Hardwoods (HWD) terminal of circuit TL236. This 230 kV transmission circuit is from HWD to Oxen Pond (OPD). The circuit runs parallel to Circuit TL218 for most of its length.

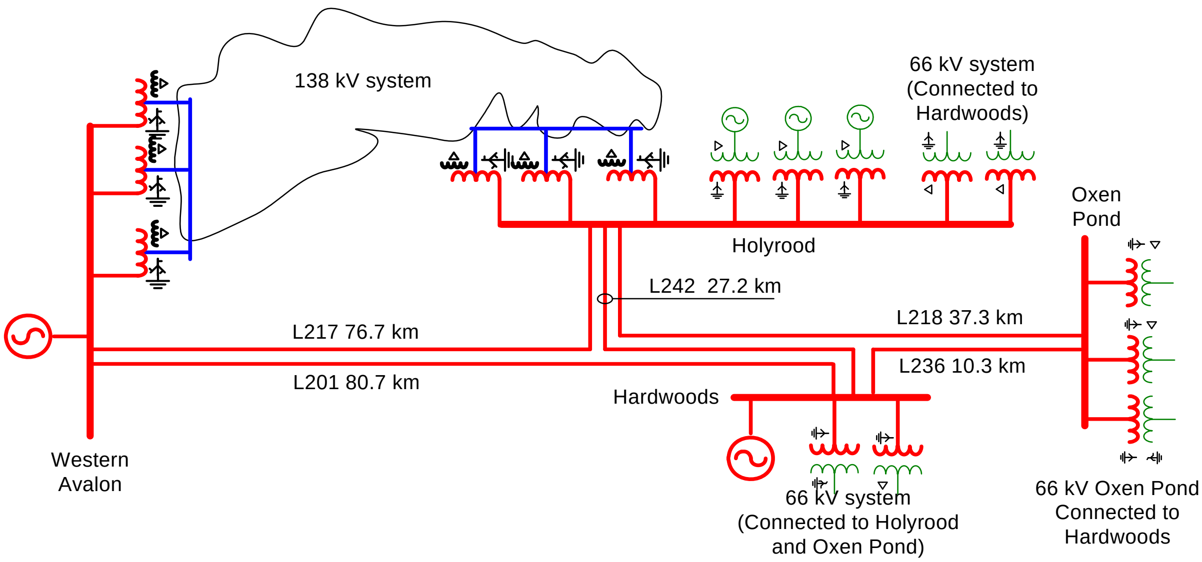


Figure 1 - System Single Line Diagram

Existing P2 protection systems are SEL321 systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$$MVAbase := 100 \qquad kVbase := 230 \qquad Ibase := \frac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}} \qquad Zbase := \frac{kVbase^2}{MVAbase}$$

$$j := \sqrt{-1}$$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $CTR := \frac{600}{5}$ VT ratio is: $VTR := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**NL HYDRO WITH MUTUALS FOR EAST COAST 230 kV LINE PN REVIEW 8 DEC.OLR**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with loads and shunts ignored.

Minimum fault current seen by each terminal (phase to phase, and SLG with 0 ohm fault resistance).

At HWD, with TL242 out of service, with the weak source connected to the 66 kV side of OPD modelled, there will minimum contribution to a fault at the remote (OPD) terminal.

$I3Pmin := 1536$ A $\quad ISLGminPH := 1769$ A $\quad ISLGmin0seq := 1653$

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the TL236 in service and with the remote end of the line open.

Minimum source impedance behind HWD $\quad Z2minHWD := 2.0 + j \cdot 26.7$ ohms primary

$Z0minHWD := 0.89 + j \cdot 17.49$ ohms primary

Minimum source impedance behind OPD $\quad Z2minOPD := 2.4 + j \cdot 33.4$ ohms primary

$Z0minOPD := 0.72 + j \cdot 19.32$ ohms primary

<u>Line impedances</u>.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L236 := 0.00146 + j \cdot 0.00973 \qquad Z0L236 := 0.00491 + j \cdot 0.03672$

$Z1Line := Z1L236 = 0.0015 + 0.0097j$ pu $\qquad Z0Line := Z0L236 = 0.005 + 0.037j$

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line \cdot Zbase \qquad Z0Linephys := Z0Line \cdot Zbase$

$Z1Linephys = 0.8 + 5.1i$ ohms primary $\qquad (Z0Linephys) = 2.6 + 19.4i$ ohms primary

Converting primary ohms to secondary ohms gives:

$$Z1Linesec := Z1Linephys \cdot \frac{CTR}{VTR} \qquad Z0Linesec := Z0Linephys \cdot \frac{CTR}{VTR}$$

$|Z1Linesec| = 0.31$ ohms sec $\qquad arg(Z1Linesec) = 81.5 \cdot deg$

$|Z0Linesec| = 1.176$ ohms sec $\qquad arg(Z0Linesec) = 82.38 \cdot deg$

Load Data

From 2011 System summer load case provided in start up information, the peak load (sum of TL236 and TL236) is given as 267 MVA (196 MVA in TL236 and 71 MVA TL236). In the event of sudden loss of one line, peak load will be the sum of both line loads until operators can adjust loads. Therefore it is assumed that peak load for a short duration is 267 MVA

$Smax\_TL236 := 196$ MVA $Smax\_TL236 := 71$ MVA $Smax := Smax\_TL236 + Smax\_TL236 = 142$ MVA

However, new information from Peter Thomas (see email dated 9 December, 2012 subject "Re: FW: PSSE Files") indicates that peal load should be set up to carry 370 MVA under the conditions of TL218 out of service.

$Smax := 370$ MVA

The existing CT ratio of 600-5 is too low for such a heavy load, but the setting calculations will assume that maximum amount of load. At a later date, the existing CT ratio will have to be increased.

P2 Relay Settings

Minor changes to the set line impedances are recommended to assist fault locations.

$Z1MAG := |Z1Linesec|$ $Z1MAG = 0.31$ $Z1ANG := \frac{arg(Z1Linesec)}{deg}$ $Z1ANG = 81.5$

$Z0MAG := |Z0Linesec|$ $Z0MAG = 1.18$ $Z0ANG := \frac{arg(Z0Linesec)}{deg}$ $Z0ANG = 82.4$

$LL := 10.338$

In order to obtain sensitivity to 100 ohm single line to ground faults, the echo function will be needed. Enable two forward and one reverse zone.

$PMHOZ := 3$ $GMHOZ := 3$ $QUADZ := 3$

$DIR1 := F$ $DIR2 := F$ $DIR3 := R$

Mho phase distance functions

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the OPD Station bus under light load conditions with TL242 out of service. The voltage at HWD for an OPD fault in this condition is 6%, therefore, this line is considered short, and a reduced zone 1 reach is recommended to increase security. Choose a setting of 80% of nominal. A 1 cycle tripping delay will also be added for extra security.

$Z1P := 0.8 \cdot |Z1Linesec|$ $Z1P = 0.25$ Ohms secondary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 0.86 ohms secondary (about 277%) and is OK, but for consistency with the P1 protection change the setting to 0.92 ohms secondary (about 295%). It is better to have a longer zone 2 reach than shorter for a short line.

$Z2P := 2.95 \cdot |Z1Linesec|$ $Z2P = 0.92$ Ohms secondary

As can be seen from Figure 2, this element does not overreach the zone 1 on TL218 out of OPD even without infeed. With infeed, the HWD TL236 protection reaches even less past OPD.

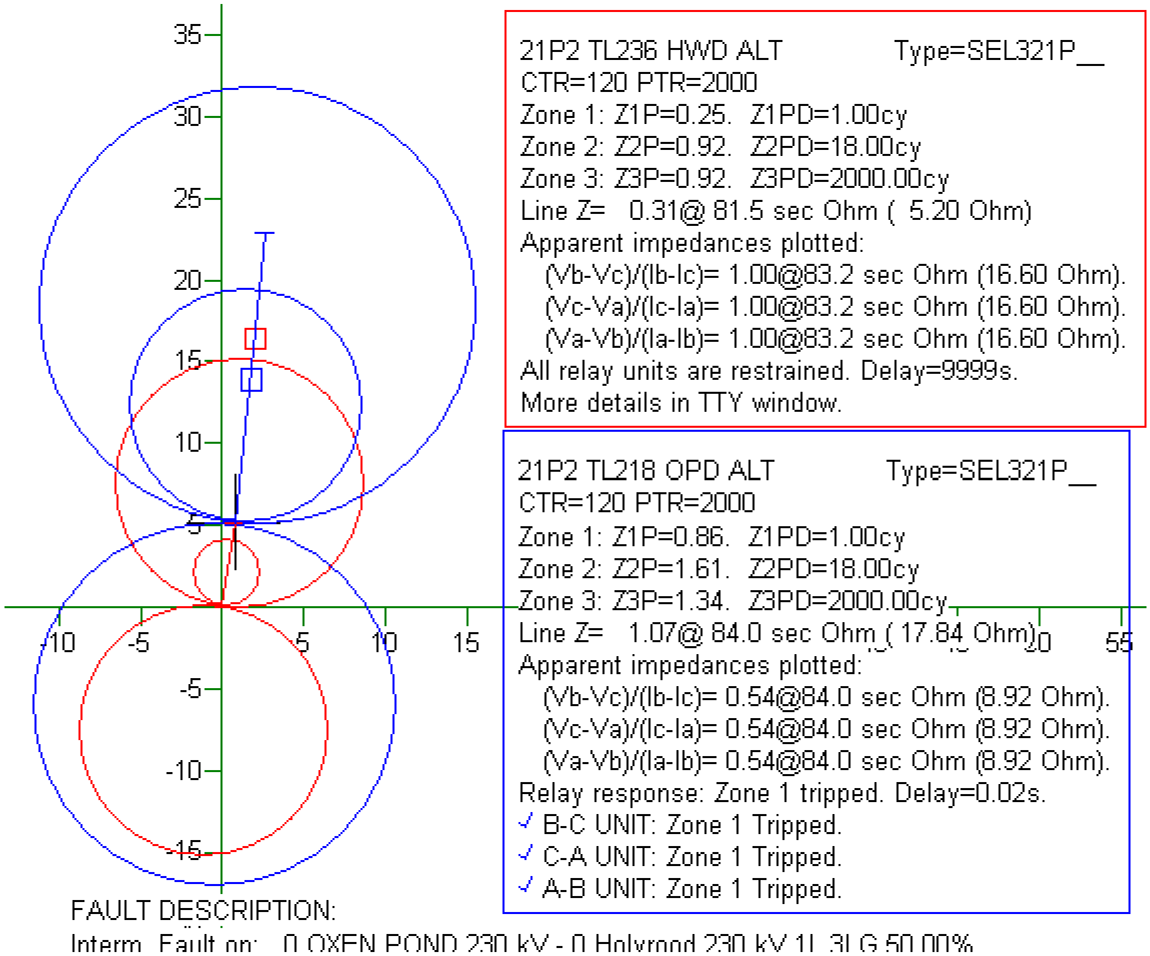


Figure 2 - HWD TL236 Zone 2 Underreaches HRD TL242 Zone 1 without infeed.

Because there is no danger of overreaching the remote instantaneous protection, choose the normal zone 2 time delay setting.

$Z2PD := 18$ Cycles Same as existing

Zone 3

Set Zone 3 reverse element to reach further behind this terminal than the remote Zone 2. This function adds security for external faults. The element should always be more sensitive than the forward looking Zone 2 at the remote terminal. Set it the same as the remote Zone 2 (in primary ohms) using the line impedance as margin.

$Z2\_rem\_pri := 15.33$ $\quad Z3P := Z2\_rem\_pri \cdot \frac{CTR}{VTR}$ $\quad Z3P = 0.92$ Ohms secondary

$$\frac{Z3P}{|Z1MAG|} = 294.5\cdot\%$$ of line length   This is a little higher than the existing setting, but provides additional security.

Mho phase distance current supervision

If the current supervision elements can be set above load, they will be secure in the event that potential is lost. However given that loss of potential logic is available, it is recommended that only the zone 1 current supervision function be set above load. If potential is lost, it will be able to block tripping by Zone 2 before it trips on time delay or receives a permissive trip from the remote terminal.

For the point of view of current supervision being above maximum load, there is no need to worry about abnormal conditions. It would be a double contingency for the VT signal to be lost while the parallel line was out of service. Therefore, consider a maximum load of 100 MVA (with TL218 in service). The current supervision elements for the phase distance functions measure phase to phase currents.

$$IPPmax\_normal := \frac{Smax\_TL236\cdot 1000}{kVbase} \qquad IPPmax\_normal = 309$$ A primary

The current supervision elements use phase to phase currents for supervision of the phase distance functions; so the minimum phase to phase fault current will be root three times the minim phase fault current. Choose a margin of 50% of the minimum phase to phase fault current for dependability.

$$IPPmin := 0.5I3Pmin\cdot\sqrt{3} \qquad IPPmin = 1330$$ A primary

A setting of 720 A primary will be quite sensitive enough and will be secure while the load stays below the CT rated current of 600 A. This setting is slightly lower than existing 815 A primary.

$'50PP1 := 6$ A Sec $'50PP1\cdot CTR = 720$ A primary

Since we will be applying weak source echo, we need to set the Zone 2 elements no more sensitively than the remote looking zone 3 at the HRD terminal. The HRD terminal uses 600-5 CT ratio same as this terminal; so the minimum setting (same as existing) will be applicable.

$'50PP2 := 1$ A Sec $'50PP3 := 1$ A Sec

Ground Distance Protection

The reach of the ground distance functions will be affected by mutual coupling to the parallel lines. These functions will tend to underreach the remote bus while the parallel lines are in service, and overreach the remote bus if a parallel line is out of service and grounded at both ends. Figure 3 shows that for a remote close in fault at OPD, with TL218 out of service and grounded, the apparent impedance of the line is reduced by about 6%.

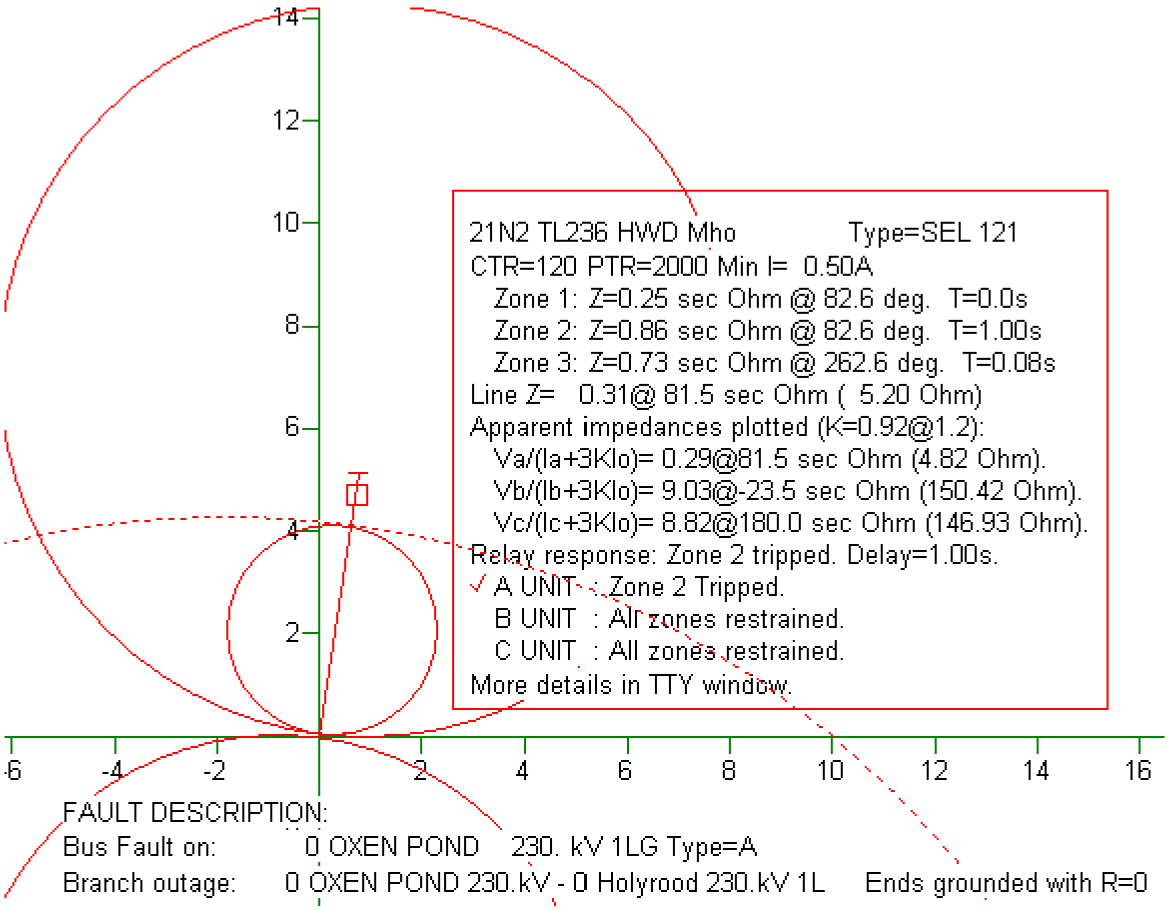


Figure 3 - Apparent impedance to a fault just beyond the remote terminal is reduced by about 6% when TL218 is out of service and grounded at both ends.

The reach of the zone 1 should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Considering that this line is very short, choose a setting of 60% of line which will underreach the remote bus in all circumstances and will also allow a larger resistive reach than if the reach was set to 80%

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.6$ per unit

$Z1MG := \mathrm{round}(m \cdot |Z1Linesec|, 2)$ $Z1MG = 0.19$ Ohms secondary

$XG1 := Z1MG$ $XG1 = 0.19$ Ohms secondary

Zone 1 Resistance

The resistive reach of the Zone 1 quad should provide enough sensitivity to trip the local terminal immediately without waiting for permission from the remote terminal for a severe fault that depresses the voltage significantly. Further, it should not allow the function to reach beyond the remote terminal due to errors in relay measurement or CT or VT. In general, a reasonable limit for resistive reach of a zone 1 function set at 85% of the line is 4 times the reactive reach. In the case of this line, the maximum recommended resistive reach for a zone 1 function set at 80% of the line will be calculated, and used as the limit for secure resistive reach.

XG1 is set at m per unit of the transmission line. The imaginary component of the line is

$ImXG1sec := Im(Z1Linesec)$ $ImXG1sec = 0.309$ ohms

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$RG1 := round[(1 - m) \cdot 20 \cdot ImXG1sec, 2]$

$RG1 = 2.47$ This is the maximum secure setting for the resistive reach but is below the proposed zone 1 resistive reach setting..

Use a maximum setting of 2.4 ohms for RG1 $RG1 := 2.4$ ohms secondary

With a resistive reach setting of 2.4 ohms, the HWD Zone 1 quad element will see a 20 ohm resistive SLG fault at close in (as shown in Figure 4). This is the longest resistive reach that can be securely set with such a short line. The Zone 2elements in this protection and the P1 protection will be depended upon to sense faults with resistance up to 100 ohms. This P2 protection will also have the echo function to help sensitivity to resistive faults.

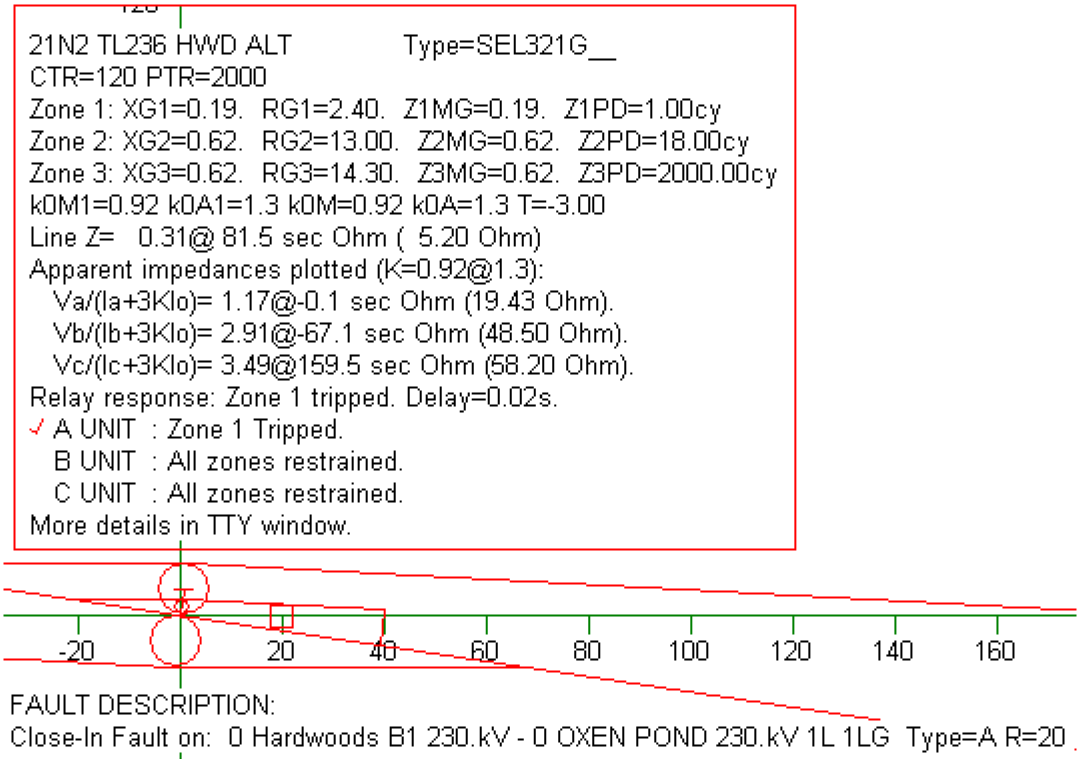


Figure 4 - HWD Zone 1 function if set with 2.4 ohm resistive reach, operates for a 20 ohm SLG fault close in to the local terminal.

Zone 2 Ground Distance Protection

The Zone 2 ground distance function will need to be set similar to the Zone 2 phase distance protection function because it will tend to underreach the remote terminal while the parallel line is in service. The existing setting is 296% of the line impedance and unrerreaches the zone 1 element on the shortest line out of OPD so should be retained.

$Z2MG := Z2P$ $\quad Z2MG = 0.92$ Ohms secondary $\quad Z2MG \cdot \frac{VTR}{CTR} = 15.354$ Ohms primary

The quad element reactive reach will be set similarly to the mho.

$XG2 := Z2MG$ $\quad XG2 = 0.92$ Ohms secondary

It would be desirable to set the resistive reach of the quad element to sense a 100 ohm SLG fault at 75% of the line with the local terminal weak. This would ensure overlap with the zone 1element at the remote terminal. However, that would require too much resistive reach. Therefore choose a setting to sense a 100 ohm SLG fault just past the mid point of the line with the local terminal normal, and depend on the echo function to provide coverage for high resistance faults in the region where the remote zone 1 won't operate. If this terminal is weak, we will need to depend on sequential clearing of high resistance faults.

By trial and error from ASPEN it is found that a resistive reach of 13 ohms secondary will sense a 100 ohm SLG fault with an overlap (with a similarly set remote zone 2) of 30% of the line length. See Figure 5. This will give positive overlap with the zone 2 element at the remote terminal. However since it will not overlap the Zone 1 element at the remote terminal, the permissive trip echo function will be required to ensure that a fault that is seen by the zone 2 element at only one terminal will still be cleared by the permissive trip logic.

Therefore, to avoid extremely large resistive reaches, and to retain sensitivity to 100 ohm resistive SLG faults, it is recommended that the echo function be enabled at both terminals.

$RG2 := 13$ Ohms secondary

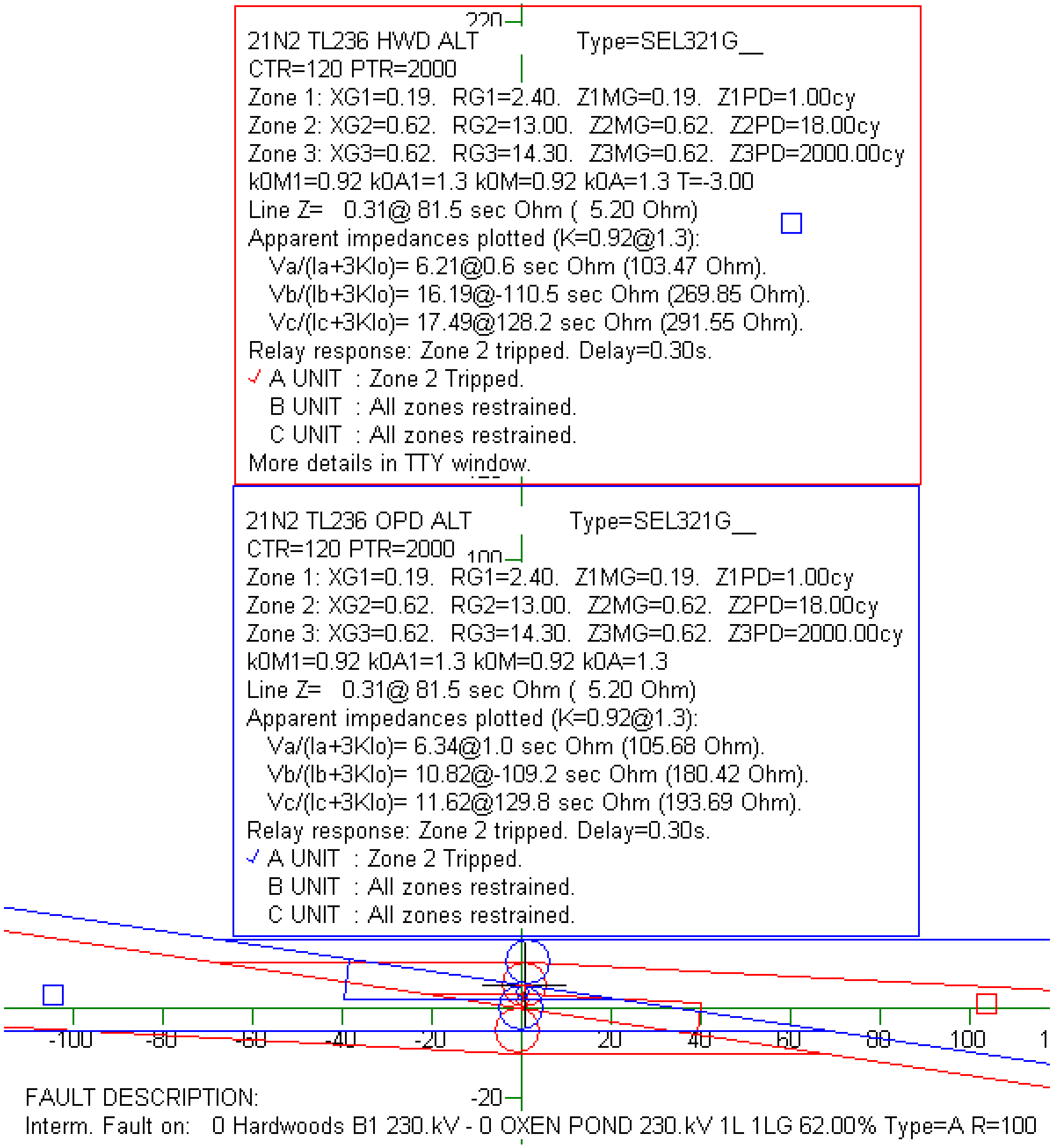


Figure 5 - Quad elements overlap with remote quad elements and operate for 100 ohm resistive SLG from 52% to 86% of the line.

Check that this resistive reach won't cause the zone 2 function to trip while a parallel line is open single phase, with heavy power flow. See Figure 6. Unusually heavy power flow has been simulated to challenge security.

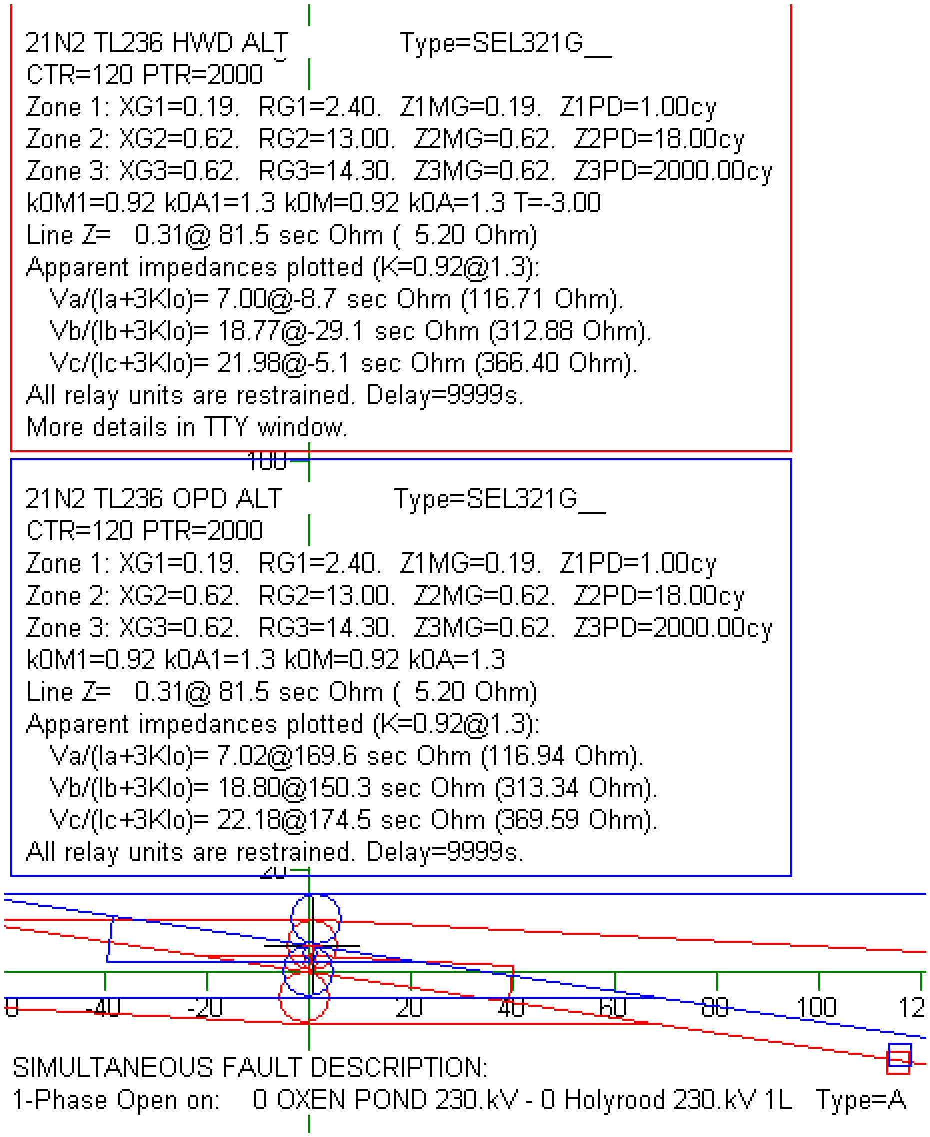


Figure 6 - Quad elements are secure with extremely heavy load flow (172 MVA in TL236 and 223 MVA in TL218) while TL218 is open single pole.

Zone 3

The zone 3 ground mho function will be set using the same principles as the zone 3 phase distance function. Use the setting for local zone 2 in secondary ohms as the remote zone 2.

$Z2MGrem := 15.33$ Ohms Primary $\quad Z3MG := Z2MGrem \cdot \frac{CTR}{VTR}$

$Z3MG = 0.92$ Ohms secondary

$\frac{Z3MG}{|Z1MAG|} = 294.5 \cdot \%$ of line length

This is higher than the existing setting but provides better security.

$XG3 := Z3MG \quad XG3 = 0.9$ Ohms secondary

Set the Zone 3 quad resistive reach at 10% more than the remote Zone 2. The setting is the same as the local zone 2 in primary and secondary ohms. Therefore use the setting for local zone 2 in secondary ohms as the remote zone 2.

$RG2rem := RG2$ Ohms secondary $\quad RG3 := RG2rem \cdot 1.1 \quad RG3 = 14.3$ Ohms secondary

Ground distance current supervision

Since there is no concern about these elements operating on load, even with loss of potential, set all current supervision elements at minimum.

$'50L1 := 0.5$ A Sec $\quad '50L2 := 0.5$ A Sec $\quad '50L3 := 0.5$ A Sec

$'50G1 := 0.5$ A Sec $\quad '50G2 := 0.5$ A Sec $\quad '50G3 := 0.5$ A Sec

Note that due to heavy infeed of zero sequence currents from the local terminal for close-in faults, the ground overcurrent detectors will not operate for faults with a large amount of resistance close to the remote terminal. Therefore, we will have to rely on sequential clearing for that type of fault. However setting the current supervision at minimum allows maximum sensitivity.

Zero sequence current compensation

The zero sequence current compensation could be adjusted to compensate for the significant amount of mutual coupling. However as discussed in the settings of reaches of the ground distance elements we will accept underreach of the Zone 2 function for the normal case by setting it at 125% of the apparent impedance for a remote fault. Set the zero sequence current compensation as usual.

$$k01M := \left(\left|\frac{Z0Line - Z1Line}{3 \cdot Z1Line}\right|\right) \qquad k01M = 0.922$$

$$k01A := \left(\left(\arg\left(\frac{Z0Line - Z1Line}{3 \cdot Z1Line}\right)\right)\right) \qquad k01A = 1.2 \cdot deg$$

Set the overreaching zones the same as zone 1 $\quad k0M := k01M \quad k0A := k01A$

$k0M = 0.922$ $k0A = 1.2 \cdot deg$

Settings are slightly different from existing due to small changes in line data.

Non Homogenous Angle Setting

Compare the angle of the remote zero sequence source impedance with the total zero sequence source impedance to the fault to determine this setting.

$$T := \arg\left(\frac{Z0minHWD + Z0Linephys + Z0minOPD}{Z0minOPD}\right) = -2.1 \cdot deg \qquad T = -2 \cdot deg$$

Out of step blocking and tripping

Not used in this application. There is a danger of out of step conditions arising. Historically no action has been taken to provide special tripping or blocking functions. Natural tripping during swings is accepted.

Load Encroachment logic

Check loadability of the Zone 2 phase distance element assuming worst case power factor of 0.87 simultaneous with worst case depressed voltage of a stressed system of 0.85 per unit. Note that units of kV squared match units of MVA. Note that quadrilateral elements are only used for the ground distance functions that are not sensitive to balanced three phase load. Therefore no need to worry about the reach of the quadrilateral elements.

$\text{Zloadmin} := \frac{(0.85\text{kVbase})^2}{\text{Smax}}$ $\text{Zloadmin} = 103.298$ Ohms primary (assume worst case at 30 degrees)

Maximum reach of the Zone 2 element is at the line angle of 81 degrees. At 30 degrees, the reach will be given by

$\text{Z2load} := \text{Z2P}\cdot\cos[(\text{Z1ANG} - 30)\text{deg}]$ $\text{Z2load} = 0.574$ ohms secondary

$\text{Z2load}\cdot\frac{\text{VTR}}{\text{CTR}} = 9.565$ ohms primary

Since the reach of the Zone 2 element at 30 degrees is less than the apparent impedance of the maximum load, there is no need to apply load blinding logic. See Figure 7

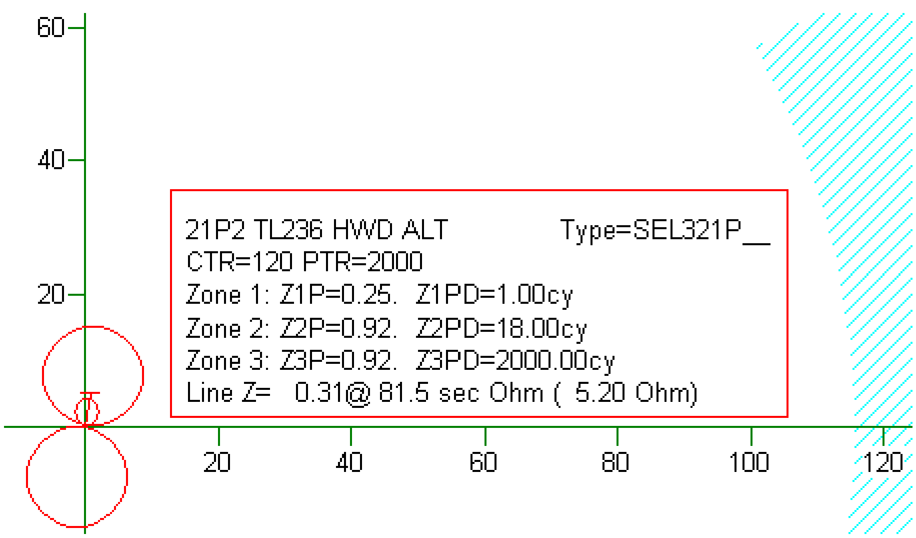


Figure 7 -Load impedance with respect to proposed new Mho function reaches.

Ground directional element

The SEL-321 application example recommends finding the minimum source impedance behind the terminal and setting the reverse and forward boundaries of the negative sequence directional element at the 1/3 and 2/3 points respectively.

In the negative sequence plane, the sum of the two source impedances and the line impedance is:

$$Z2total := Z2minHWD + Z1Linephys + Z2minOPD$$

The 1/3 point is $Z2\_1\_3 := \frac{Z2total}{3}$ The 2/3 point is $Z2\_2\_3 := \frac{2Z2total}{3}$

$Z2Rpri := Z2\_2\_3 - Z2minHWD$ $Z2Rpri = 1.448 + 16.798j$

$Z2Fpri := Z2\_1\_3 - Z2minHWD$ $Z2Fpri = -0.276 - 4.951j$ Desired set point for Z2F is negative.

Converting the primary impedances to secondary ohms

$Z2R := Z2Rpri \cdot \frac{CTR}{VTR}$ $|Z2R| = 1.012$ Ohms secondary $\arg(Z2R) = 85.073 \cdot deg$

$Z2F := Z2Fpri \cdot \frac{CTR}{VTR}$ $|Z2F| = 0.298$ Ohms secondary $\arg(Z2F) = -93.189 \cdot deg$

Rounding down Z2F and rounding down Z2R gives:

$Z2F := -0.3$ Ohms secondary $Z2R := 1$ Ohms secondary

These are slightly different from the existing settings with differences likely due to different fault study model.

Set the current level detectors at minimum level that will allow operation of the ground distance elements.

Due to the reduced zero sequence current contribution to a single line to ground fault at the remote terminal, the negative sequence current contribution will always be higher than the zero sequence. Therefore there is no point in setting the forward looking negative sequence overcurrent elements any more sensitively than the zero sequence ground overcurrent supervision of the ground distance elements.

$'50QF := '50G2$ $'50QF = 0.5$

Set the supervision function for the reverse looking element to be the same as, or a little more sensitive than the forward looking supervision element at the remote terminal.

$'50QR := 0.5$ A secondary

The positive sequence current restraint (a2) factor should be set just smaller than the ratio of the maximum load current (positive sequence) to the most sensitive current supervision element (50QR).

$I1maxpri := \frac{Smax \cdot 1000}{kVbase \cdot \sqrt{3}}$ $I1maxsec := \frac{I1maxpri}{CTR}$ $I1maxsec = 7.74$

Bearing in mind that the 50QR setting is in units of 3*I2

$\frac{'50QR}{3 \cdot I1maxsec} = 0.022$ Choose a value of $a2 := 0.02$ The proposed is the same as the existing setting (0.02).

Phase time overcurrent element

This element is not used

Residual time overcurrent element

This element is used to provide the most sensitive backup protection. It will be a non directional element.

Set pickup to sense a higher resistance than 100 ohm SLG in the middle of the line with equal zero sequence current infeed from both ends. Choose a resistance of 200 ohms arbitrarily. Use a safety factor of 2 so that operating time is not infinity at this fault level.

$SF := 2$ Desensitization factor due to remote end infeed is $Dfactor := 2$ $Rf := 200$

$$'51NPU := round\left(\frac{kVbase \cdot 1000}{\sqrt{3} \cdot SF \cdot Dfactor \cdot Rf \cdot CTR}, 1\right) \qquad '51NPU = 1.4$$

The existing setting of 0.5 A is more sensitive than required to sense this mid line fault with arbitrary resistance. Since TL206 experience with the high resistance tree fault on 28th August 2009 has shown value in the existing setting, it will be retained.

$'51NPU := 1$ A secondary

Coordination checks show that existing time dial settings will coordinate above existing remote protection (OPD TL218). However under maximum load conditions, if this line trips single phase, the neutral current during the open pole period will be sufficient to operate the 51N in less than one second. Although the reclose open pole dead time is about 45 cycles, the unbalance during the fault will also tend to operate the element. It is best to have an operating time due to unbalanced load flow during the oper pole period of not less than 1.3 seconds. The existing time dial setting will have to be increased to make this element secure during the open pole period with heavy load flow.

The existing settings on the TL218 protection will have to be slowed down for similar reasons. Therefore we have to check coordination above the new slower settings on TL218 as well as below the existing settings of protection on TL 201 and TL242.

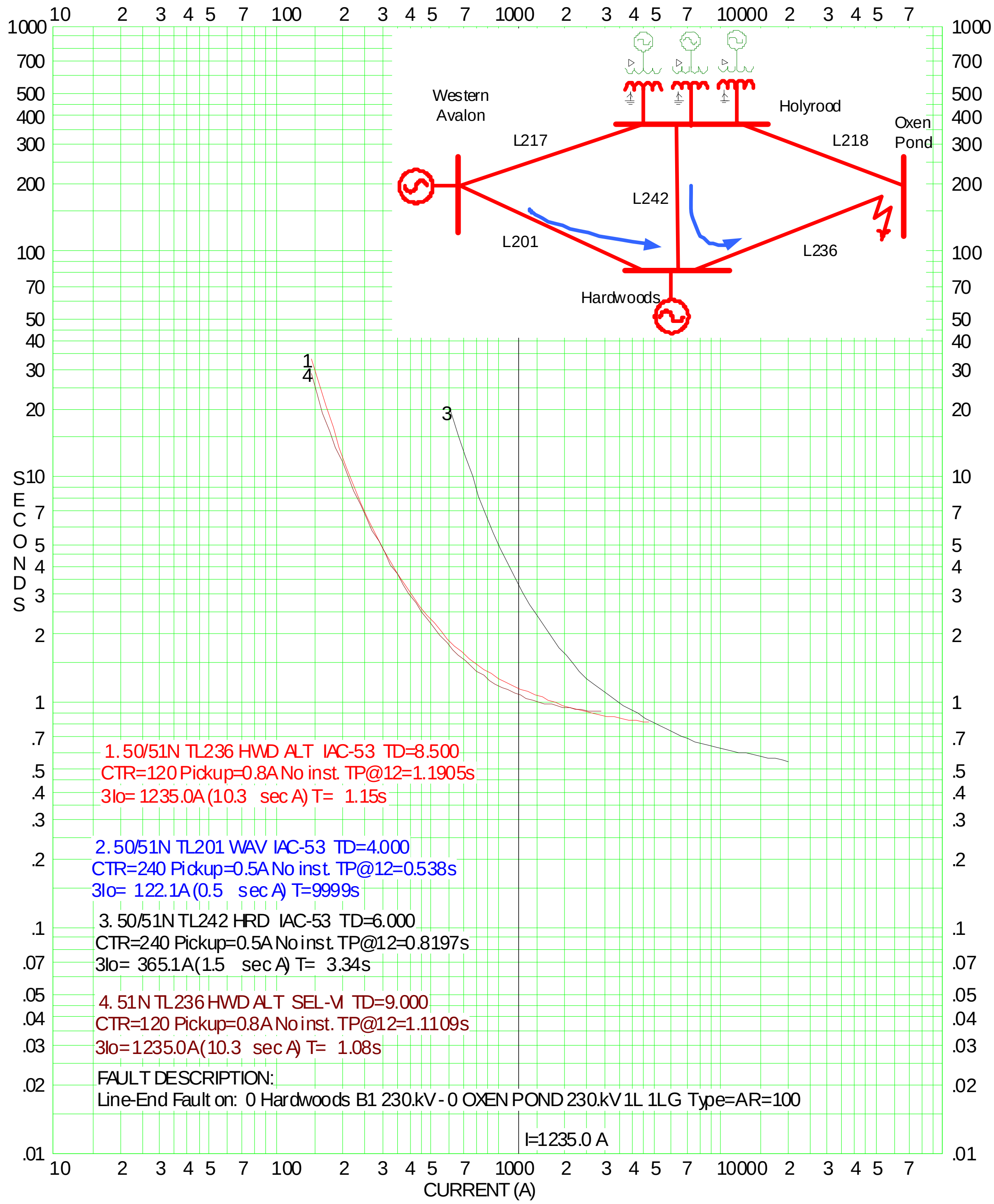
$'51NPU = 1$ A secondary $'51NPU \cdot CTR = 120$ A primary

$'51NTD := 9$ $'51NC := "U3"$ $'51NTC := "N"$ $'51NRS := "N"$

The time dial is proposed to be increased from existing 6 to 9 to be more secure during heavy load while one phase is open during a single phase trip and reclose operation.

Check the coordination below the HRD TL242 and WAV TL201 51N for a line end fault on TL236 with the proposed new, slower setting. This is the type of fault that will produce the most sensitivity (least desensitization) with respect to the backup protection on TL242 and TL201. see Figure 8. Even with new (slower) ALT settings, coordination margin is satisfactory. Note that coordination margin would not be satisfactory for a fault with low resistance. However, we can depend on the definite time zone 2 ground distance element to clear low resistance faults promptly. With the time ground overcurrent elements we are primarily concerned with high resistance faults.

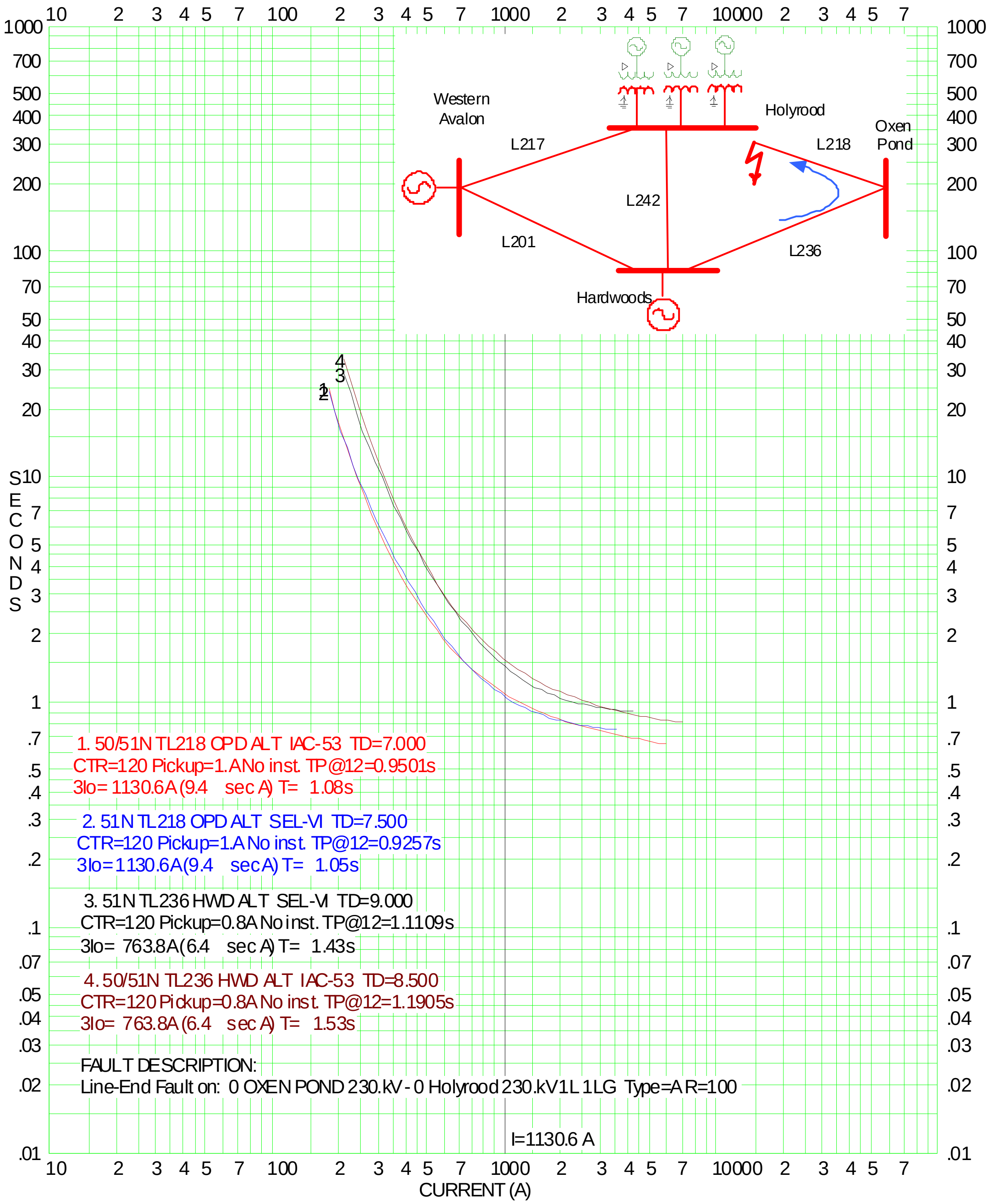
Check the coordination above the OPD TL218 protection for a LE fault. See Figure 9. It can be seen that the proposed new setting is only marginally slower than the proposed new OPD TL218 protection for a 0 ohm fault. For this type of fault we can rely on the 0.3 second time of the zone 2 ground distance function at OPD. For resistive faults the current will be much lower and the ground time overcurrent functions will coordinate satisfactorily.



TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For Coordination of HWD L236 below HRD TL242 and WAV TL201	No. ECS230-10

Comment Coordination requires Z2G for RF<100 ohms Date 13 Dec 2011

Figure 8 - coordination of ground time overcurrent elements for LE TL236 fault



TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For Coordination of new OPD TL218 settings below new HWD TL236	No. ECS230-9

Comment Z2G needed for faults with Rf<100 ohms Date 13 Dec 2011

<u>Figure 9</u> - coordination of ground time overcurrent elements for line end fault on TL218

Permissive Overreaching logic settings

EPOTT := "Y"

Z3RBD is set at remote breaker time plus channel reset time plus channel reset time plus zone 2 reset time. From review of fault records it appears that the breaker time is 3 cycles. Channel reset time is not easily determined from existing records but can conservatively be assumed to be 1 cycle, and relay reset time will also be about 1 cycle. Total time for Z3RBD is then 5 cycles.

Z3RBD := 5 cycles

Echo block delay timer blocks the echo after the local elements have picked up. This can be set relatively long since there is no significant need for the echo function shortly after the local terminal has just seen a fault but the remote terminal has not. Set at 10 cycles as per the example in the instruction manual.

EBLKD := 10 cycles

Echo time delay on pickup should be set to override noise on the communications so that it doesn't echo noise. Typical time according to the SEL application guide is 2 cycles. Since this delay only affects clearing time for relatively light (high resistance) faults that are sensed by zone 2 function at one end, the typical setting is acceptable.

ETDPU := 2 cycles

Echo duration should be long enough to ensure the permissive trip is received by the remote terminal and should also be shorter than the Z3RBD time to ensure that the reverse blocking will always be longer than any permissive trip received (including echo time stretching).

EDURD := 4 cycles

No need to enable week feed conversion to trip, since both terminals will be quite sensitive enough to detect high resistance faults after the remote terminal has cleared. Therefore we can accept sequential (or "step") clearing with no need for the added insecurity of weak infeed tripping.

EWFC := "N" **No other communications logic settings are required for this application.**

Switch on to Fault Settings

Switch on to fault logic will ensure the protection will operate when energizing the line onto a close-in three phase fault when there is no polarizing voltage available for the distance elements.

ESOTF := "Y"

The breaker close signal is not available to the relay. The 52A method of enable SOTF will be used. Therefore the Close end delay is not critical. Typical duration for enable SOTF is 10-15 cycles

ENCLO := "N" CLOEND := 0 EN52A := "Y" SOTFD := 15

Set 50H for high magnitude close-in multiphase faults with weakest source at HWD. It should be set less than 50% of the minimum close-in fault magnitude. Minimum close-in magnitude of a three phase fault with TL242 out of service is 2089 A. Therefore desired maximum setting for 50H is 1000 A.

Imin3P_close_in := 2089

$$'50H := \frac{Imin3P\_close\_in}{2CTR} \qquad '50H = 8.704 \quad \text{A secondary}$$

Choose a setting of 6 A secondary for this element. '50H := 6 A secondary

Choose a setting for 52AEND less than the shortest reclose time. '52AEND := 30 cycles

The existing setting of 52AEND is 40 cycles. It is not known why the setting is set so long.

Residual overcurrent settings.

Tripping directly by instantaneous ground overcurrent is not applicable because it is not phase selective. However it would be helpful to monitor steady state unbalance, and issue an alarm for continuous unbalance. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50N := 1$ $\quad$ $'50N1 := 0.25$

Negative Sequence overcurrent settings.

Similar to ground overcurrent, apply a negative sequence overcurrent element to initiate an alarm for steady state unbalances. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50Q := 1$ $\quad$ $'50Q1 := 0.25$

Voltage Element Settings

Similar to unbalance current monitoring, it is helpful to have an unbalance voltage monitor to detect steady state unbalances from the voltage supply.

$EVOLT := "Y"$

Set the zero sequence overvoltage element at 1% of rated voltage or just at the point necessary to override normal unbalances. The zero sequence voltage element measures 3 times the zero sequence voltage.

$$'59N := 3 \cdot 0.01 \frac{kVbase \cdot 1000}{\sqrt{3} \cdot VTR} \qquad '59N = 1.992$$

Say $'59N := 2$ V secondary

Loss of Potential

Enable loss of potential settings. Advanced LOP settings are not available on this model of relay.

$ELOP := "Y"$ $\quad$ Time delay of 1.25 cycles is commonly used. $\quad$ $LOPD := 1.25$

The 50 M element should be set above maximum load and below minimum fault current for a fault at the remote terminal under weak source conditions. The maximum load for this case should be normal maximum, not emergency maximum which only exists for a few minutes before the operator can act to reduce load.

$$Imax\_normal := \frac{Smax\_TL236 \cdot 1000}{\sqrt{3} \cdot kVbase \cdot CTR} = 1.485$$

A secondary

Minimum fault current for a remote three phase fault is $I3Pmin = 1536$ A primary.

Minimum fault current for a remote phase to phase fault is 87% of the minimum three phase fault current level.

Dependability factor to be sure to operate for a minimum remote fault is chosen to be 1.6. $\quad$ $DF := 1.6$

Maximum setting for 50M should be $\dfrac{0.87 I3Pmin}{DF \cdot CTR} = 6.96$ $\quad$ In this case a setting of 6 A secondary will be adequately dependable and secure.

$'50M := 6$ A secondary

The 59QL setting should be above normal maximum unbalance and below the level expected for a blown VT fuse.

For a blown fuse, one phase voltage will be lost, and the negative sequence voltage will be roughly 33% of the nominal positive sequence voltage. Choose a setting of 15% of the nominal positive sequence voltage. This will be well above any normal unbalance.

$$'59QL := \mathrm{round}\left(\frac{0.15 \cdot kVbase \cdot 1000}{\sqrt{3} \cdot VTR}, 0\right) \qquad '59QL = 10 \text{ V secondary}$$

The 59PL setting should be less than the minimum voltage to be expected for a remote bus fault under weakest source conditions. There is no minimum setting (above zero) for this function. Choose a setting equal to 50% the voltage drop along the line impedance at the pickup setting of the 50M element.

$$'59PL := \mathrm{round}[0.5 \cdot ('50M \cdot |Z1Linesec|), 1] \qquad |'59PL| = 0.9$$

Such a low setting may render the loss of potential function not useful for 3 phase loss of potential, but this is unavoidable under such short line conditions.

Miscellaneous Scheme Settings

Pole discoordinance logic is not being used. EPOLD := "N" SPPDD := "N/A"

Enable single pole tripping by distance elements only ESPT := "Y"

Enable single pole open ESPO := "Y"

Set single pole open time delay for future SPO conditions SPOD := 0.25

Note that SPOD was short enough to allow a transient operation when TL201 was reclosed with a fault on it during the fault of 7 March 2011. This transient operation was helpful to clear the fault more quickly than it otherwise would have cleared. SEL have been asked whether the SPOD setting of 0.5 would be better to increase the security.

3 Pole open reset delay to override small discrepancies in pole closing '3POD := 0.5

Stub line protection is not required ESTUB := "N" '50MFD := "N/A"

Trip unlatch logic not applied TULO := "N"

Logic variables and Miscellaneous timers

Minimum trip duration timer is set at 9 cycles as per the application example in the SEL-321 instruction manual.

TDURD := 9 Cycles

Trip during open pole time delay should be set longer than the reclose time. Existing reclose time is 55 cycles. This is acceptable.

TOPD := 55 Cycles

Existing logic variables are not used.

Since this line is short (voltage may be low at HRD for a fault near HWD), a 1 cycle security delay in zone 1 tripping is recommended to improve the security of this function against incorrect tripping for a fault beyond the

HWD terminal.

LOGIC_X := "M1P+Z1P"	TXPU := 1	cycle	TXDO := 0	cycles

Add the use of ZT to trigger an alarm for sustained unbalance.

LOGIC_Z := "59N+50N1+50Q1"	TZPU := 1200	cycles	TZDO := 0	cycles

Tripping Logic

Permissive tripping is required only for instantaneous overreaching functions. No need for any functions that trip directly. Existing 51NT word in MTCS is not required.

MTCS := "M2P+Z2G"

Existing settings for unconditional tripping must be modified to include a 1 cycle delay for zone 1 tripping.

MTU := "XT+M2PT+Z2GT+51NT"

No need for existing direct tripping zone 1 functions in the switch on to fault logic.

SOTF Tripping MTO := "M2P+Z2G+50H"

Event records will be triggered automatically by all trip events. Other event record triggers should be by starting of other elements to ensure capture of all relevant events. Events should be triggered by keying or receiving permissive trips to ensure separation of relay and teleprotection issues.

MER := "M2P+Z2G+51NP+LOP*52AA1+LOP*52AA2+KEY+PT+EKEY"

Outputs

Retain existing output assignments except add the continuous unbalance alarm to OUT15.

OUT15 := "LOP*50L+ZT"

Input Contact Assignment

It would be desirable to provide phase segregated inputs to the relay so that the quadrilateral functions could be disabled during single pole open conditions. it is not known if phase segregated auxiliary switches are available on the breakers.

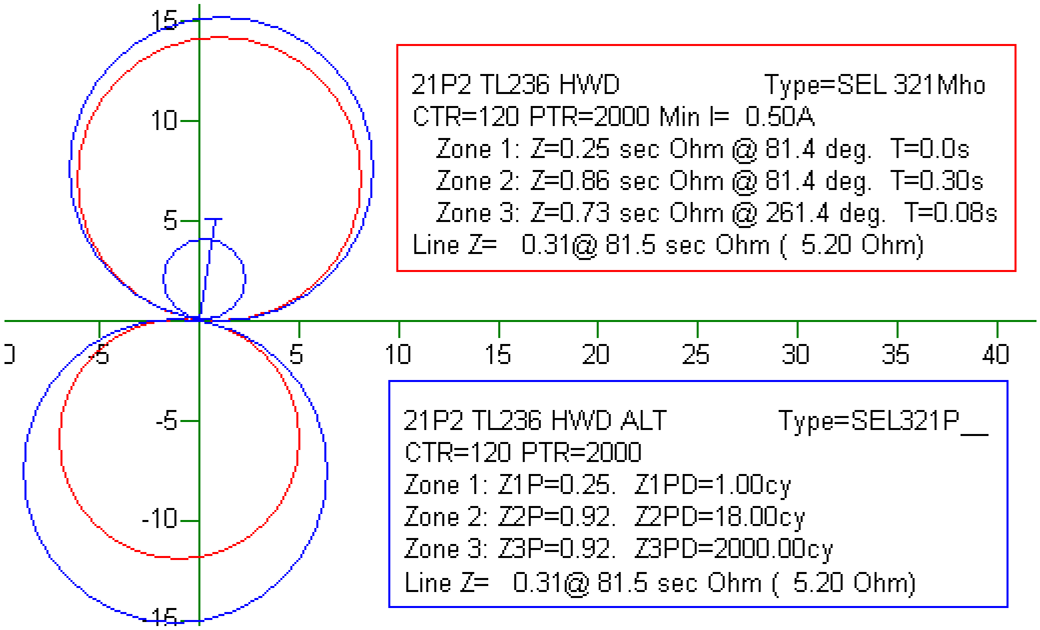


Figure 10 - Comparison between existing (red) and proposed new (blue) phase distance characteristics.

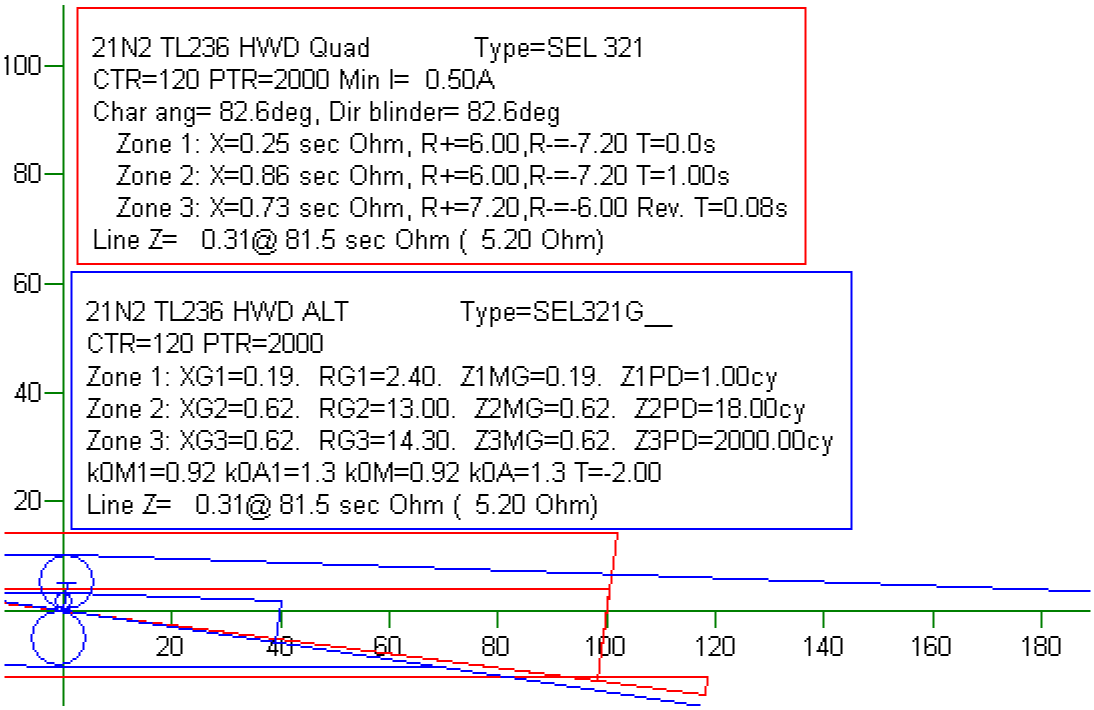


Figure 11 - Comparison between existing (red) and proposed new (blue) ground distance characteristics.

Protection Review for Five 230 kV Transmission Lines

Appendix T
Detailed settings review for HRD TL242 "P1" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador Hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Holyrood Terminal (HRD) terminal of circuit TL242. This 230 kV transmission circuit is from HRD to Hardwoods (HWD).
The circuit runs parallel to Circuits TL201 and TL218 for some of its length.

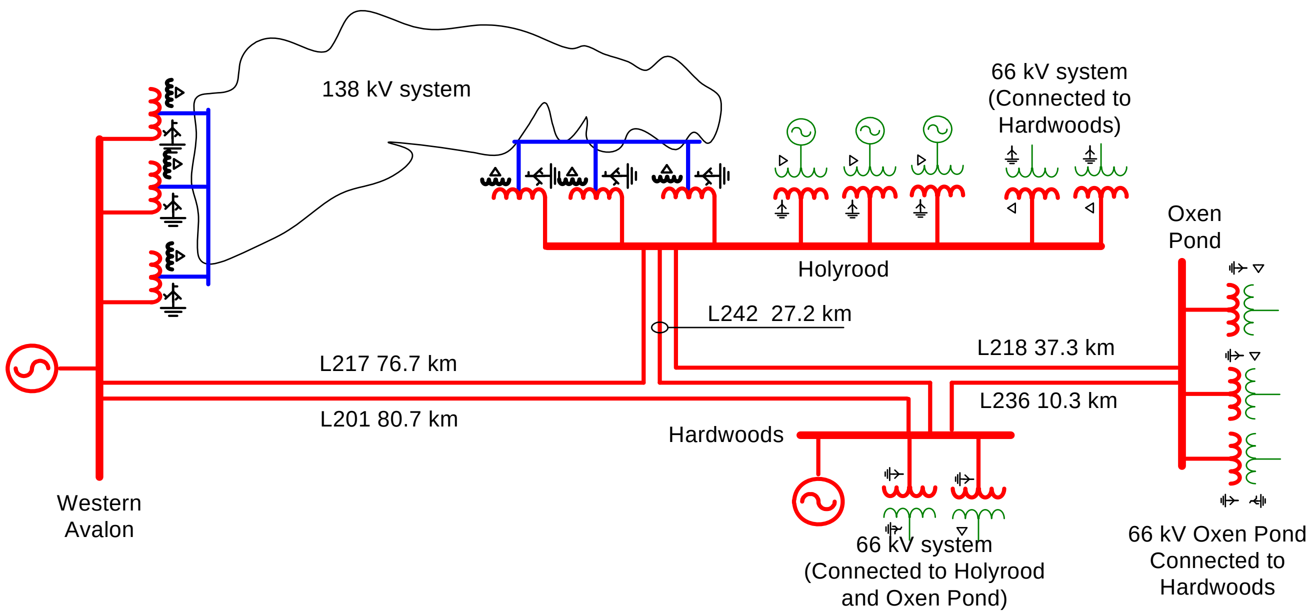


Figure 1 - System Single Line Diagram

Existing P1 protection systems are Areva LZFP111 (Optimho) systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$\text{MVAbase} := 100$ $\quad$ $\text{kVbase} := 230$ $\quad$ $\text{Ibase} := \dfrac{\text{MVAbase}\cdot 1000}{\text{kVbase}\cdot\sqrt{3}}$ $\quad$ $\text{Zbase} := \dfrac{\text{kVbase}^2}{\text{MVAbase}}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at the line terminal.

CT ratio is: $\text{CTR} := \dfrac{1200}{5}$ $\quad$ VT ratio is: $\text{VTR} := \dfrac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**NL HYDRO WITH MUTUALS FOR EAST COAST 230 kV LINE PN REVIEW 8 DEC.OLR**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with loads and shunts ignored.

Minimum fault current seen by each terminal (phase to phase, and SLG with 0 ohm fault resistance).

At HRD, with two units off line out of service, and all other lines in service, for a fault at the remote terminal.

$ILLmin := 1020$ A $ISLGminPH := 1217$ A $ISLGmin0seq := 631$ A

The optimho current level detectors that block the distance comparators in the event of line opening are fixed at 5% of the rated current, or 0.25 A secondary, or 60 A primary. They will have no difficulty in operating for minimum bolted fault levels. However, the ground distance elements are also supervised by a low set neutral current level detector (LDLSN that requires the neutral current to be greater than 10% of the maximum amplitude of phase difference current. This prevents the ground comparators from operating during close-in multiphase faults with CT errors. ASPEN OneLiner shows that for a bolted fault at the remote bus even under heavy load, there is sufficient neutral current (32% of maximum phase to phase fault current) that means this LDLSN function does not inhibit the ground distance comparator.

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind HRD $Z2minHRD := 0.99 + j \cdot 21.04$ ohms primary

Minimum source impedance behind HWD $Z2minHWD := 2.38 + j \cdot 29.83$ ohms primary

<u>Line impedances</u>.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L242 := 0.00383 + j \cdot 0.02565$ $Z0L242 := 0.0129 + j \cdot 0.09653$

$Z1Line := Z1L242 = 3.83 \times 10^{-3} + 0.026j$ pu $Z0Line := Z0L242 = 0.013 + 0.097j$ pu

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line \cdot Zbase$ $Z0Linephys := Z0Line \cdot Zbase$

$Z1Linephys = 2 + 13.6i$ ohms primary $Z0Linephys = 6.8 + 51.1i$ ohms primary

Converting primary ohms to secondary ohms gives:

$Z1Linesec := Z1Linephys \cdot \frac{CTR}{VTR}$ $Z0Linesec := Z0Linephys \cdot \frac{CTR}{VTR}$

$|Z1Linesec| = 1.65$ ohms sec $\arg(Z1Linesec) = 81.5 \cdot deg$

$|Z0Linesec| = 6.182$ ohms sec $\arg(Z0Linesec) = 82.39 \cdot deg$

Load Data

From 2011 System summer load case provided in start up information, the peak load (sum of TL242 and TL236) is given as 340 MVA (split between TL242 and TL201). In the event of sudden loss of one line, peak load will be the sum of both line loads until operators can adjust loads. Therefore it might be assumed that peak load for a short duration is 340 MVA

$Speak := 340$ MVA $Smax := Speak = 340$ MVA

P1 Relay Settings

Distance element reach settings

Note that resistive reaches are forced to be the same for all zones. Reactive reaches for phase and ground distance elements must be the same as each other.

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the HRD Station bus under light load conditions and both TL242 and TL236 lines in service. From ASPEN OneLiner, voltage at HRD for a 3 phase fault at HWD is 0.15 per unit. Since the voltage is less than 20%, this line is considered short, and a reduced zone 1 reach is recommended to increase security. Choose a setting of 80% of nominal.

$Z1P := 0.8 \cdot |Z1Linesec|$ $Z1P = 1.32$ Ohms secondary

Existing setting of 1.34 ohms is a little too high and should be reduced to at the most, 1.32 ohms secondary. However, the ground distance reach in the optimho has to be set the same as the phase distance reach; so we need to consider the ground faults too.

$Z1P = 1.32$ For phase faults only.

The worst case from the point of view of overreach of the zone 1 ground distance element is with Hardwoods B1B2 open, and a close-in fault on the HV bus of one of the Hardwoods transformers. For this case, the apparent impedance presented to the relay is only 1.55 ohms secondary (see Figure 2). This is 94% of the line impedance. So the reach of the zone 1 element should be reduced somewhat.

$Zapp\_ext := 1.49$ ohms $Zapp\_ang := 82$ deg This angle is close enough to the line angle to treat it as equal to the line angle.

$$\frac{Zapp\_ext}{|Z1Linesec|} = 0.905$$

The apparent impedance is reduced by about 10% mostly due to the effect of the HWD B1B2 breaker being open, but also partly due to the zero sequence current compensation factor being set slightly too high on this protection.

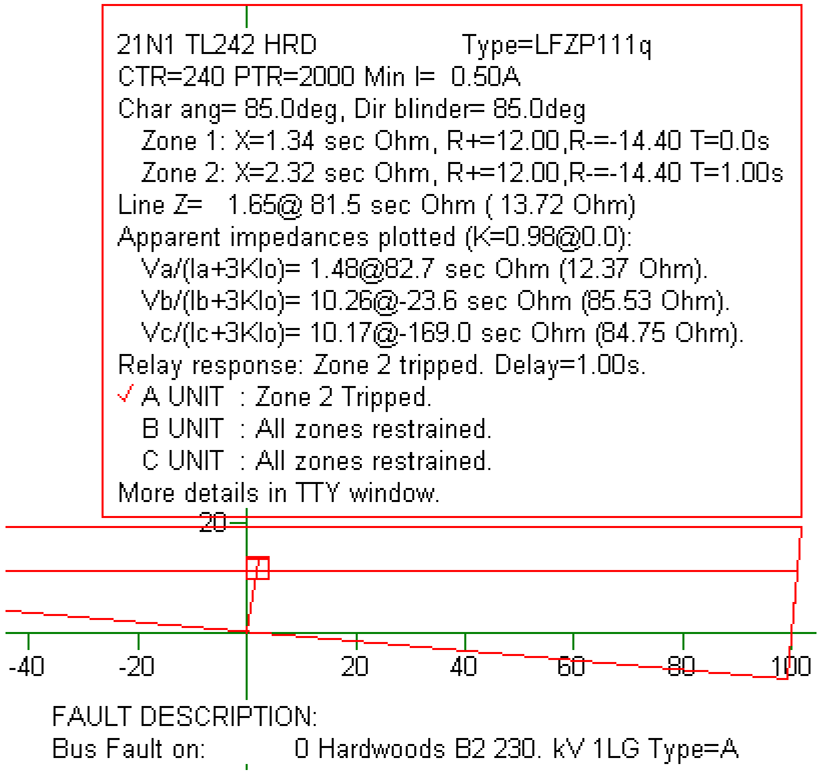


Figure 2 - Apparent impedance to a fault just beyond the remote terminal is reduced by 10% when HWD B1B2 is open. Existing relay settings modeled in this figure.

The reach of the zone 1 ground distance element should be reduced to less than 85% of the line impedance to make it more secure against misoperation for an external fault with the parallel line out of service and grounded. **A more important constraint exists due to the short line and the high resistive reach** required in order to sense 100 ohm resistive faults near the middle of the line. The resistive reach of the zone 2 element (which is the same as the resistive reach of the zone 1 element) has to be set at about 12 ohms secondary. Such a long resistive coverage on the zone 1 element will not be secure when considering the apparent reactive component of the fault resistance added to the resistive component by load flow as shown in Figure 3. In addition, the VT and CT errors may cause additional possibility of overreach of the zone 1 for resistive external faults. Choose a setting of 60% of line which will underreach the remote bus more securely, even with a large resistive reach.

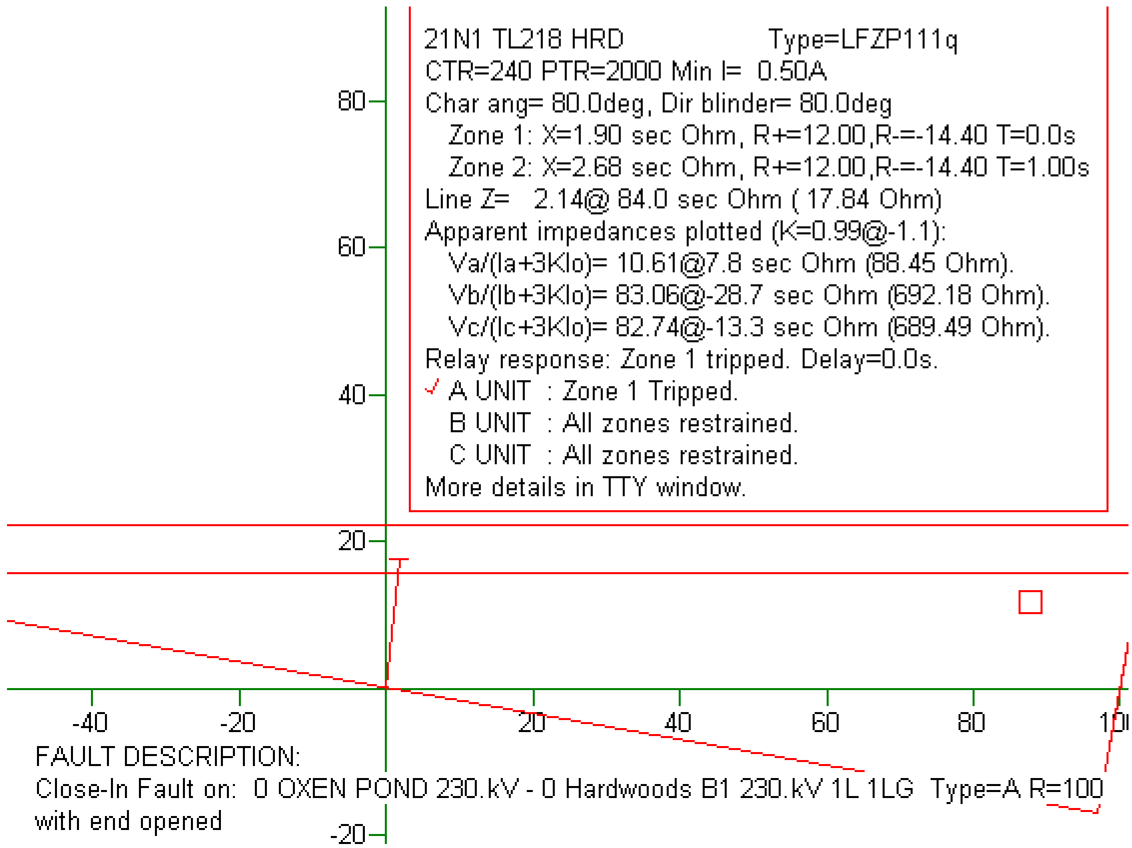


Figure 3 - Zone 1 element set at 85% with 12 ohms resistive reach operates for resistive out of zone fault.

Due to the sensitivity of the optimho quad element to the apparent reactive component of fault resistance, choose a per unit reach of the Zone 1 function of 0.6. This is more than 50% and allows overlap with zone 1 at remote terminal for many faults. We will need to depend on zone 2 POTT scheme for all faults.

$m := 0.6$ per unit

$Z1\_sec := \mathrm{round}(m \cdot |Z1Linesec|, 1)$ $Z1\_sec = 1$ Ohms secondary

$Z1pri := Z1\_sec \cdot \dfrac{VTR}{CTR} = 8.333$ Ohms primary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 2.32 ohms secondary (about 140%). This could provide secure coverage.

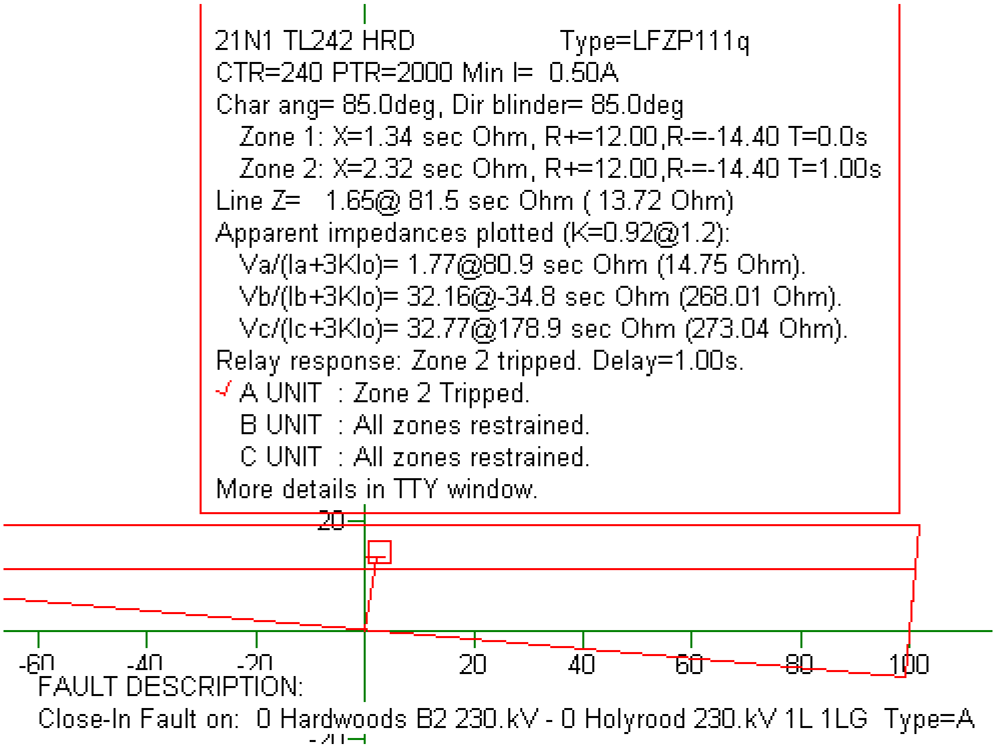


Figure 4 - Apparent impedance to a fault close to the remote terminal is increased by 7% when parallel line is in service (and two units off line at HRD).

As can be seen from Figure 4, the apparent impedance to a fault close to the remote terminal is increased when the parallel line is in service. Check what is the overreach of the existing zone 2 setting.

$Zapp\_int := 1.77$ Ohms secondary $Z2\_sec := 1.3 \cdot Zapp\_int = 2.301$ Choose a setting of 2.32

$Z2\_sec := 2.32$ $Z2\_sec = 2.32$ Ohms secondary $\dfrac{Z2\_sec}{|Z1Linesec|} = 140.921 \cdot \%$

$Z2\_pri := Z2\_sec \cdot \dfrac{VTR}{CTR} = 19.333$ Ohms primary

The zone 1 element is disabled from tripping on the existing P1 protection for TL236 at HWD. Further, this zone 2 element may overreach the HWD TL236 P2 zone 1 protection. The existing 1 second delay in tripping by this element will ensure coordination with the HWD zone 2 element.

$Z2\_TD := 1.0$ Seconds

In order to provide faster clearing of single line to ground faults on the whole line sequentially (in the absence of communications), a shorter reaching zone 4 element is recommended to be set, in the P2 protection with a shorter time delay. Faster communications independent protection is not critical for **both** the P1 and P2 protections. One or the other will be suitable.

Resistive reach

Check the sensitivity of the new settings to resistive faults near the middle of the line.

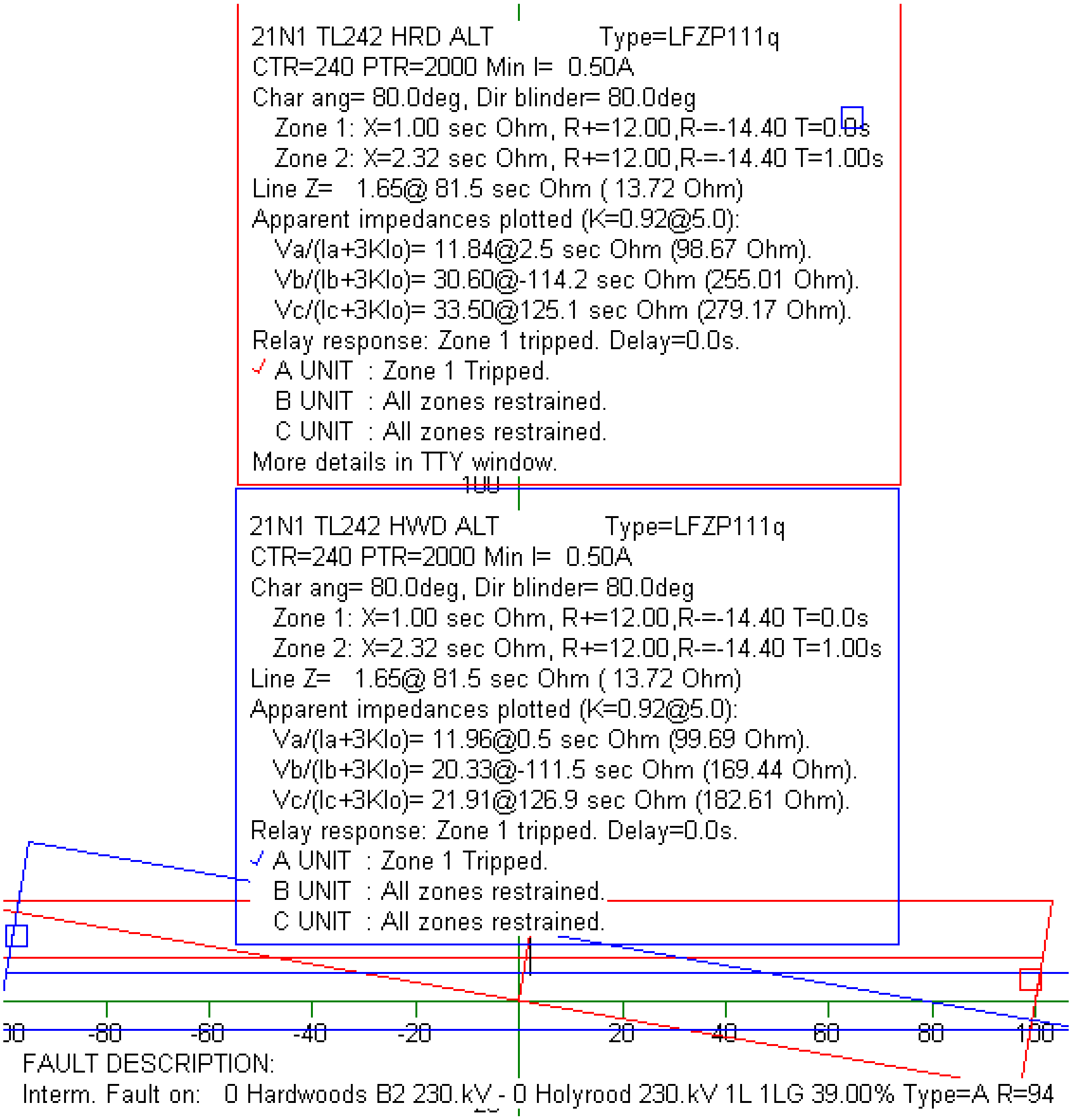


Figure 5 - Resistive fault coverage near the middle of the line.

As can be seen from Figure 5, the zone 2 elements at both ends will overlap for a 94 ohm resistive fault near the middle of the line.

The existing resistive reach setting of 12 ohms secondary will be suitable as long as the reach of the zone 1 element is reduced to 60% of the line.

Rquad := 12 ohms secondary

Load Encroachment logic

The optimho instruction manual recommends a margin of at least 10% between the impedance of the maximum load and the resistive reach of the quadrilateral distance element.

Check loadability of the Zone 2 phase distance element assuming worst case depressed voltage of a stressed system of 0.9 per unit.

$$Zloadmin := \frac{(0.9kVbase)^2}{Smax} \qquad Zloadmin = 126.026$$ Ohms primary (assume worst case at 30 degrees)

$$Zloadmin\_sec := Zloadmin \cdot \frac{CTR}{VTR} \qquad Zloadmin\_sec = 15.123$$

A 12 ohm secondary resistive reach is less than 90% of the load impedance at unity power factor and meets the Areva criterion as shown in Figure 6.

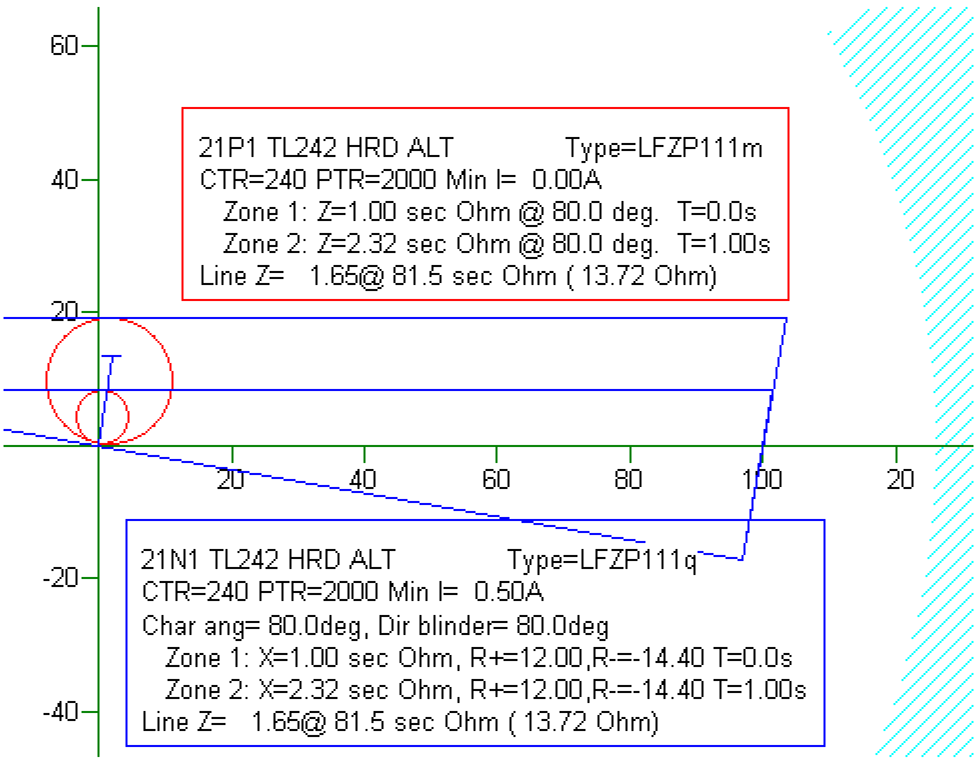


Figure 6 - Apparent impedance of load

Settings of K attenuators

KZPh Coarse setting common to all DISTANCE zones should be set as high as possible while below the required Zone 1 reach. The current level detectors vary inversely with KZph. Maximum setting available is 1.0

$KZPh := 1.0$

Zone 1 attenuators and angular selection

$In := 5$ $Z1\_sec = 1$ This is the desired secondary reach (previously calculated)

$KZ1 := \dfrac{Z1\_sec}{\left(KZPh \cdot \dfrac{5}{In}\right)}$ $KZ1 = 1$ $Z1sec\_reach := KZ1 \cdot KZPh \cdot \dfrac{5}{In}$ $Z1sec\_reach = 1$

$Z\theta PH := (\arg(Z1Linesec))$ $Z\theta PH = 81.507 \cdot deg$

Rounded to the nearest 5 degrees $Z\theta PH := 80$ Degrees (decreased from existing 85 degrees)

$Z\theta N := \arg(Z0Linesec - Z1Linesec)$ $Z\theta N = 82.708 \cdot deg$

Rounded to the nearest 5 degrees $Z\theta N := 85$ Degrees (same as existing)

Zone 2 attenuators selection

$Z2\_sec = 2.3$ This is the desired secondary reach (previously calculated)

$KZ2 := \dfrac{Z2\_sec}{\left(KZPh \cdot \dfrac{5}{In}\right)}$ $KZ2 = 2.32$ (same as eisting)

QUAD Resistive Reach setting

$Rquad = 12$ This is the desired secondary reach (previously calculated)

$KR := \dfrac{Rquad}{\left(\dfrac{5}{In}\right)}$ $KR = 12$ (same as existing)

Residual Compensation attenuators selection

Zero sequence current compensation for ground faults is provided by the KZN factor. Zero sequence mutual compensation is not used in this application (it causes extra complexity for only moderate gain in setting accuracy).

$KZN := \dfrac{Z0Linesec - Z1Linesec}{3 \cdot Z1Linesec} \cdot KZPh$ $KZN = 0.918 + 0.019j$

$|KZN| = 0.92$ This is a reduction from the existing setting of 0.98

Switch On To Fault (SOTF) Protection.

If SOTF is enabled, it can be set to 200ms or 110 s after all poles of the line have been de-energized. The 110 s setting is intended to override automatic reclosing dead time. However it makes more sense to enable after the shorter time. Once the SOTF feature has been initiated, it remains in effect for 250ms after the line has been re-energized. The SOTF tripping options are:

a) Any distance comparator.
b) Any current level detector as long as a corresponding voltage level detector has not picked up within 20ms.
c) Either current or distance, as long as a corresponding voltage level detector has not picked up within 20ms.

SOTF := "Enabled"

SOTF_TIME := 0.20 Seconds

Elements_in_SOTF := "BOTH" (Both Comparators and current level detectors).

Power Swing Detector

This element will not be used. It will be left Blocked, and if there is a power swing, the distance elements will trip naturally.

VT Supervision

Set the VT supervision to BLOCK TRIP

Set the VT fail detection to SELF RESET.

Start Indication

This function will bring up information on the LCD screen of the relay if a start event occurs. This function will not be used.

START_INDICATION := "BLOCKED"

Communications assisted logic.

The existing communications assisted logic is permissive overreaching transfer trip, scheme **POR 1**. This scheme is familiar to Newfoundland and Labrador Hydro, and even though the POR 2 scheme offers the advantage of weak infeed echo, which would help the sensitivity to resistive faults, it is not recommended to change the existing scheme logic at this stage with years of experience on a product that is nearing the end of its useful life.

The POR 1 logic is a basic permissive overreaching transfer trip scheme but it does include current reversal timers to increase security against misoperation due to current reversal when a fault on the parallel line is cleared sequentially. The current reversal logic is achieved by a timer TP which will block permissive tripping and keying of permissive trip if the local zone 2 element does not pick up within a reasonable time of receiving permissive trip. The block will be maintained for a time delay of TD after the local zone 2 element picks up, or the received permissive trip signal resets.

The application of the current reversal timers is required only if the settings of the zone 2 comparators are greater than 1.5 times the line impedance .Although the reaches of these elements are only marginally less than 1.5 times the line impedance, there is no parallel line and there is infeed at each terminal that will minimize overreach. Therefore, the current reversal logic is not required, and the recommended default settings are as existing

$TP := 98$ ms

$TD := 0$ ms

Comparison of Existing (red) and Proposed alternative (ALT) settings.

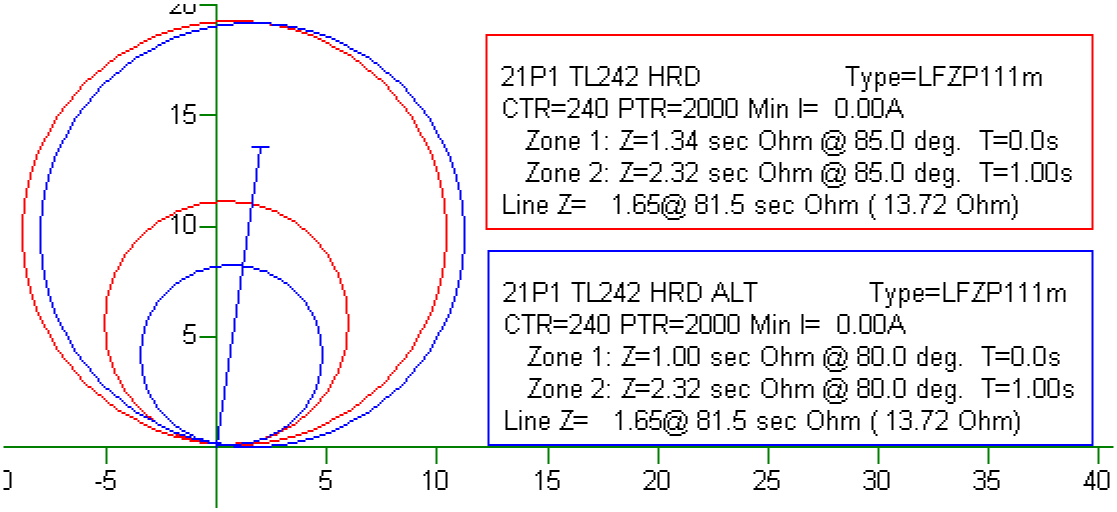


Figure 7 - Comparison of phase distance characteristics

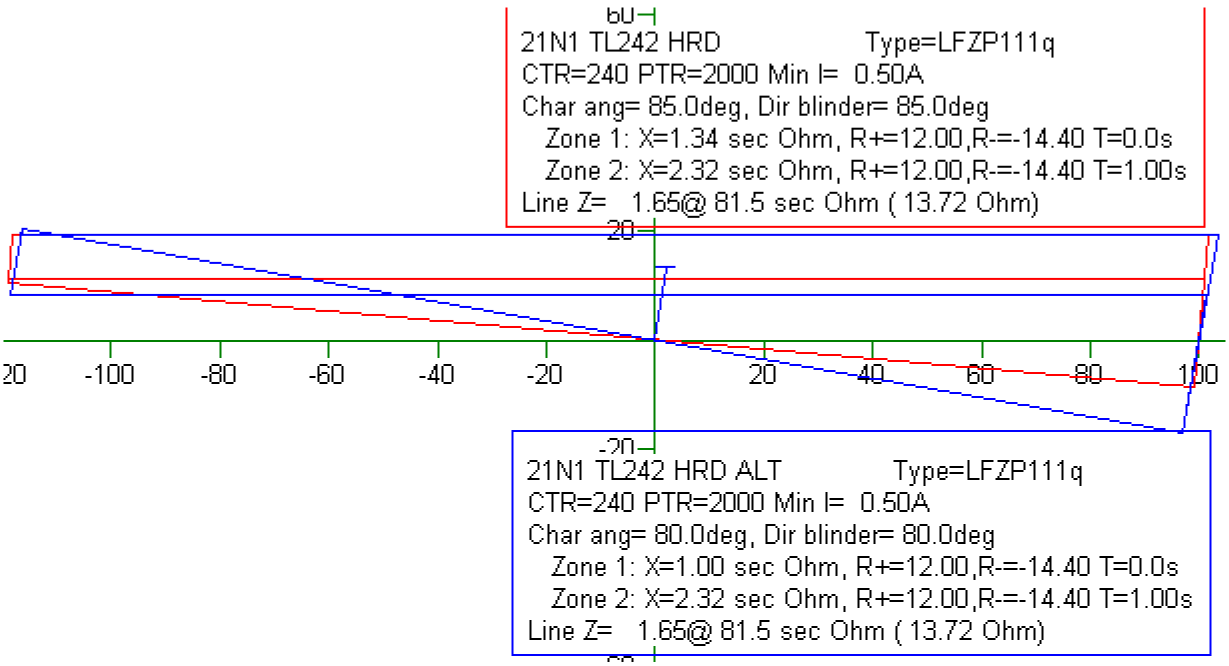


Figure 8 - Comparison of ground distance characteristics

Protection Review for Five 230 kV Transmission Lines

Appendix U
Detailed settings review for HRD TL242 "P2" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Holyrood (HRD) terminal of circuit TL242.
This 230 kV transmission circuit is from HRD to Oxen Pond (HWD).
The circuit runs parallel to Circuit TL242 and TL236 for parts of its length.

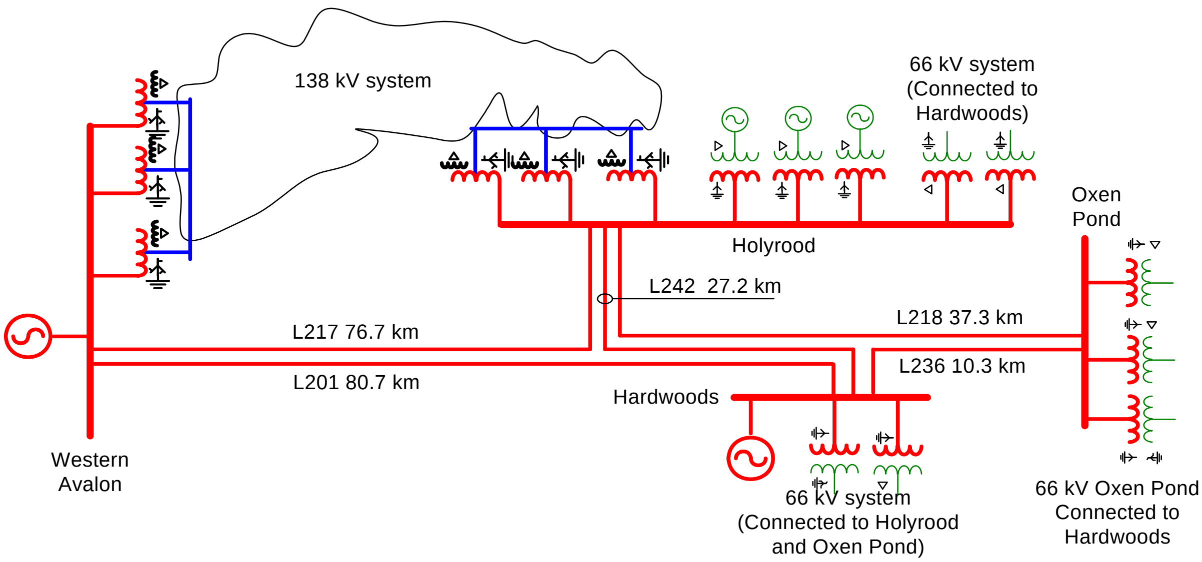


Figure 1 - System Single Line Diagram

Existing P2 protection systems are SEL321 systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $\quad$ $kVbase := 230$ $\quad$ $Ibase := \frac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\quad$ $Zbase := \frac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $CTR := \frac{1200}{5}$ $\quad$ VT ratio is: $VTR := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**NL HYDRO WITH MUTUALS FOR EAST COAST 230 kV LINE PN REVIEW 8 DEC.OLR**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with loads and shunts ignored.

Minimum fault current seen by each terminal (phase to phase, and SLG with 0 ohm fault resistance).

At HRD, with two units off line, and all parallel lines in service, for a fault at the remote terminal.

$I3Pmin := 1152$ A $ISLGminPH := 1217$ A $ISLGmin0seq := 631$ A

The current for a phase to phase fault would be lower, but the current supervision element of the SEL321 measures phase to phase currents, and the phase to phase current for a phase to phase fault is twice the phase current.

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind HRD $Z2minHRD := 0.99 + j \cdot 21.04$ ohms primary

$Z0minHRD := 0.3267 + 8.624j$ ohms primary

Minimum source impedance behind HWD $Z2minHWD := 2.38 + j \cdot 29.83$ ohms primary

$Z0minHWD := 0.777 + 13.944j$ ohms primary

<u>Line impedances</u>.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L242 := 0.00383 + j \cdot 0.02565$ $Z0L242 := 0.0129 + j \cdot 0.09653$

$Z1Line := Z1L242 = 3.83 \times 10^{-3} + 0.026j$ pu $Z0Line := Z0L242 = 0.013 + 0.097j$

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line \cdot Zbase$ $Z0Linephys := Z0Line \cdot Zbase$

$Z1Linephys = 2 + 13.6i$ ohms primary $Z0Linephys = 6.8 + 51.1i$ ohms primary

Converting primary ohms to secondary ohms gives:

$$Z1Linesec := Z1Linephys \cdot \frac{CTR}{VTR} \qquad Z0Linesec := Z0Linephys \cdot \frac{CTR}{VTR}$$

$|Z1Linesec| = 1.65$ ohms sec $arg(Z1Linesec) = 81.5 \cdot deg$

$|Z0Linesec| = 6.182$ ohms sec $arg(Z0Linesec) = 82.39 \cdot deg$

Load Data

From 2011 System summer load case provided in start up information, the peak load (sum of TL242 and TL236) is giv as 340 MVA (split between TL242 and TL201). In the event of sudden loss of one line, peak load will be the sum of bo line loads until operators can adjust loads. Therefore it might be assumed that peak load for a short duration is 340 MV

$Smax\_TL242 := 230$ MVA $\qquad Smax\_TL201 := 110$ MVA

$Smax := Smax\_TL242 + Smax\_TL201 = 340$ MVA

P2 Relay Settings

Minor changes to the set line impedances are recommended to assist fault locations.

$Z1MAG := |Z1Linesec|$ $\quad Z1MAG = 1.65$ $\qquad Z1ANG := \dfrac{\arg(Z1Linesec)}{deg}$ $\quad Z1ANG = 81.5$

$Z0MAG := |Z0Linesec|$ $\quad Z0MAG = 6.2$ $\qquad Z0ANG := \dfrac{\arg(Z0Linesec)}{deg}$ $\quad Z0ANG = 82.4$

$LL := 37.29$

In order to obtain sensitivity to 100 ohm single line to ground faults, the echo function will be needed. Enable three forward and one reverse zone.

$PMHOZ := 4$ $\qquad GMHOZ := 4$ $\qquad QUADZ := 4$

The zone 4 is used for faster communications independent tripping.

$DIR1 := F$ $\quad DIR2 := F$ $\quad DIR3 := R$ $\qquad DIR4 := F$

Mho phase distance functions

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the HRD Station bus under light load conditions with two units at HRD out of service and both TL218 and TL217 lines in service. From ASPEN OneLiner, voltage at HRD for a 3 phase fault at HRD is 0.15 per unit. Since the voltage is less than 20%, this line is considered short, and a reduced zone 1 reach is recommended to increase security. Choose a setting of 80% of nominal.

$Z1P := 0.8 \cdot |Z1Linesec|$ $\qquad Z1P = 1.32$ Ohms secondary

Existing setting of 1.34 ohms is a little too high, and should be reduced.

$Z1P = 1.32$ Ohms secondary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 2.32 ohms secondary (about 140%) and is good and should be retained.

$Z2P := 1.41 \cdot |Z1Linesec|$ $\qquad Z2P = 2.32$ Ohms secondary

$$Z2P\_pri := Z2P \cdot \frac{VTR}{CTR} = 19.344 \quad \text{Ohms primary}$$

As can be seen from Figure 2, this element overreaches the zone 1 on TL236 out of HWD without infeed. The infeed at HWD however results in underreach. Choose a delay of 1 second for this zone 2, since a shorter reaching zone 4 element will be added.

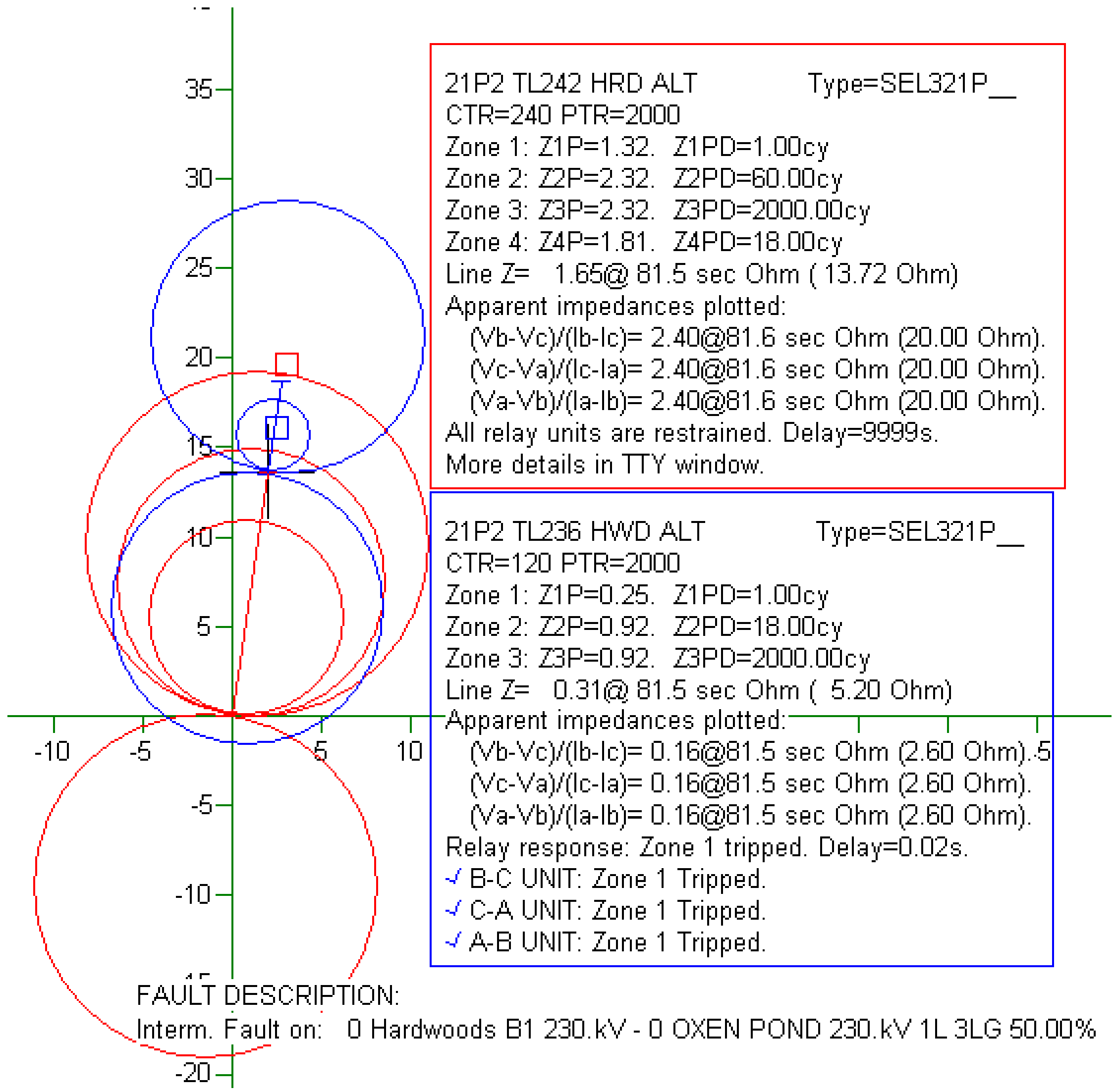


Figure 2 - HRD TL242 Zone 2 overreaches HWD TL236 Zone 1 without infeed. Choose 1 second for the zone 2 timing at HRD since we will have a shorter reaching faster Zone 4 anyway.

Choose a one second delay for this element because it overreaches the remote TL236 zone 1, without infeed and also because there is no zone 1 trip on the remote TL236 P1 protection.

$Z2PD := 60$ Cycles Increased from existing 18 cycles

Zone 3

Set Zone 3 reverse element to reach further behind this terminal than the remote Zone 2. This function adds security for external faults. The element should always be more sensitive than the forward looking Zone 2 at the remote terminal. Set it the same as the remote Zone 2 using the line impedance as margin.

$Z3P := Z2P$ $\quad Z3P = 2.32$ Ohms secondary

$\frac{Z3P}{|Z1MAG|} = 141 \cdot \%$ of line length This is a much higher than the existing setting, but provides additional security.

Zone 4

Set Zone4 at 110% of line to securely underreach the remote zone 1.

$Z4P := 1.1 \cdot |Z1Linesec|$ $\quad Z4P = 1.81$ Ohms secondary

Set time delay at 18 cycles since this will underreach the remote zone 1.

$M4PT := 18$ cycles

Mho phase distance current supervision

If the current supervision elements can be set above load, they will be secure in the event that potential is lost. However given that loss of potential logic is available, it is recommended that only the zone 1 current supervision function be set above load. If potential is lost, it will be able to block tripping by Zone 2 before it trips on time delay or receives a permissive trip from the remote terminal.

For the point of view of current supervision being above maximum load, there is no need to worry about abnormal conditions. It would be a double contingency for the VT signal to be lost while the parallel line was out of service. Therefore, consider a maximum load of 196 MVA (with TL218 in service). The current supervision elements for the phase distance functions measure phase to phase currents.

$IPPmax\_normal := \frac{Smax\_TL242 \cdot 1000}{kVbase}$ $\quad IPPmax\_normal = 1000$ A primary

The current supervision elements use phase to phase currents for supervision of the phase distance functions; so the minimum phase to phase fault current will be root three times the minim phase fault current. Choose a margin of 50% of the minimum phase to phase fault current for dependability.

$IPPmin := 0.5 I3Pmin \cdot \sqrt{3}$ $\quad IPPmin = 998$ A primary

A setting of 960 A primary for 50PP1 will ensure the Zone 1 function operates for any fault under normal source conditions while remaining unable to trip on load due to loss of potential under any but the highest normal maximum load conditions. This is a higher than the existing setting, but is quite dependable.

$'50PP1 := 4$ A Sec $\quad '50PP1 \cdot CTR = 960$ A primary

Since Zone 2, Zone 3 and zone 4 elements will be blocked by LOP function, set them at minimum. For zone 2, this is a little lower than the existing setting, but will be secure and dependable.

$'50PP2 := 1$ A Sec $\quad '50PP3 := 1$ A Sec $\quad '50PP4 := 1$ A Sec

Ground Distance Protection

The reach of the ground distance functions will be affected by mutual coupling to the parallel lines. These functions will tend to underreach the remote bus while the parallel lines are in service, and overreach the remote bus under other conditions. Figure 3 shows that for a remote HV fault on a transformer, with HWD B1B2 open, the apparent impedance of the line is reduced to about 1.49 ohms secondary instead of the nominal 1.65ohms. This is 90% of the actual line impedance.

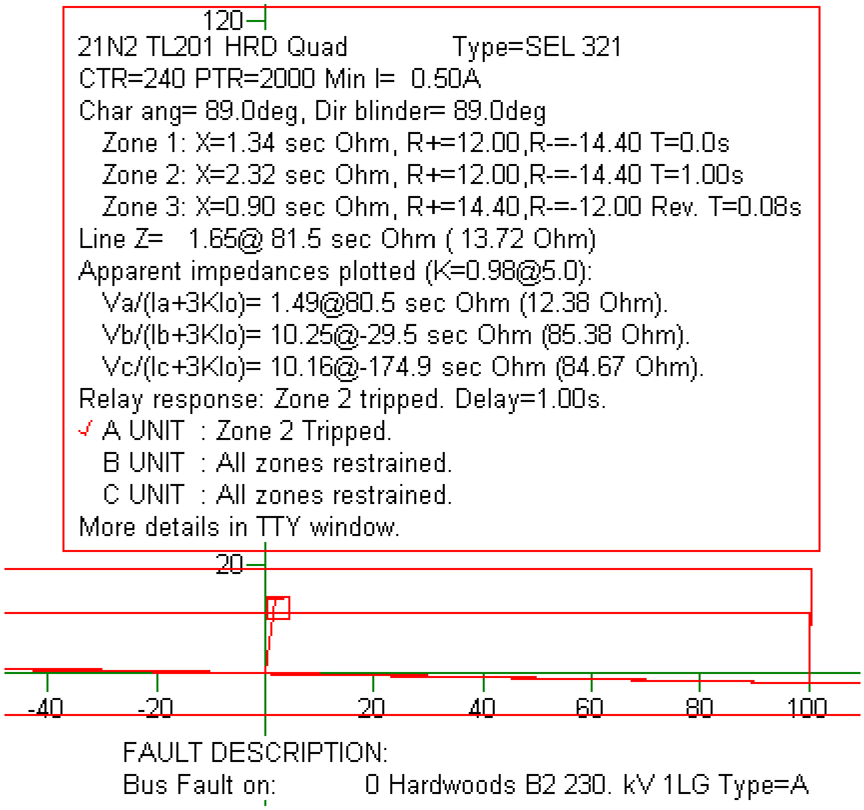


Figure 3 - Apparent impedance to a fault just beyond the remote terminal is reduced by 10% when TL236is out of service and grounded at both ends. with the existing settings and relay model)

When the zero sequence current compensation factor is reduced from the existing 0.98 to 0.92, the overreach effect will be reduced

The reach of the zone 1 should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Considering that this line is short, choose a setting of 75% of line which will underreach the remote bus by 15% when HWD B1B2 is open

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.75$ per unit

$Z1MG := \mathrm{round}(m\cdot|Z1Linesec|, 1)$ $Z1MG = 1.2$ Ohms secondary

$XG1 := Z1MG$ $XG1 = 1.2$ Ohms secondary

Zone 1 Resistance

The resistive reach of the Zone 1 quad should provide enough sensitivity to trip the local terminal immediately without waiting for permission from the remote terminal for a severe fault that depresses the voltage significantly. Further, it should not allow the function to reach beyond the remote terminal due to errors in relay measurement or CT or VT. In general, a reasonable limit for resistive reach of a zone 1 function set at 85% of the line is 4 times the reactive reach. In the case of this line, the maximum recommended resistive reach for a zone 1 function set at 80% of the line will be calculated, and used as the limit for secure resistive reach.

XG1 is set at m per unit of the transmission line. The imaginary component of the line is

$ImXG1sec := Im(Z1Linesec)$ $\qquad ImXG1sec = 1.628$ ohms

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$RG1 := round[(1 - m) \cdot 20 \cdot ImXG1sec, 2]$

$RG1 = 8.14$ This is the maximum secure setting for the resistive reach but is below the proposed zone 1 resistive reach setting..

Use a setting of 6 ohms for RG1 $\qquad RG1 := 6$ ohms secondary

With a resistive reach setting of 6 ohms, the HRD Zone 1 quad element will see a 45 ohm resistive SLG fault at close in (as shown in Figure 4). The Zone 1 element in the P1 protection and the Zone 2elements in this protection and the P1 protection will be depended upon to sense faults with resistance up to 100 ohms.

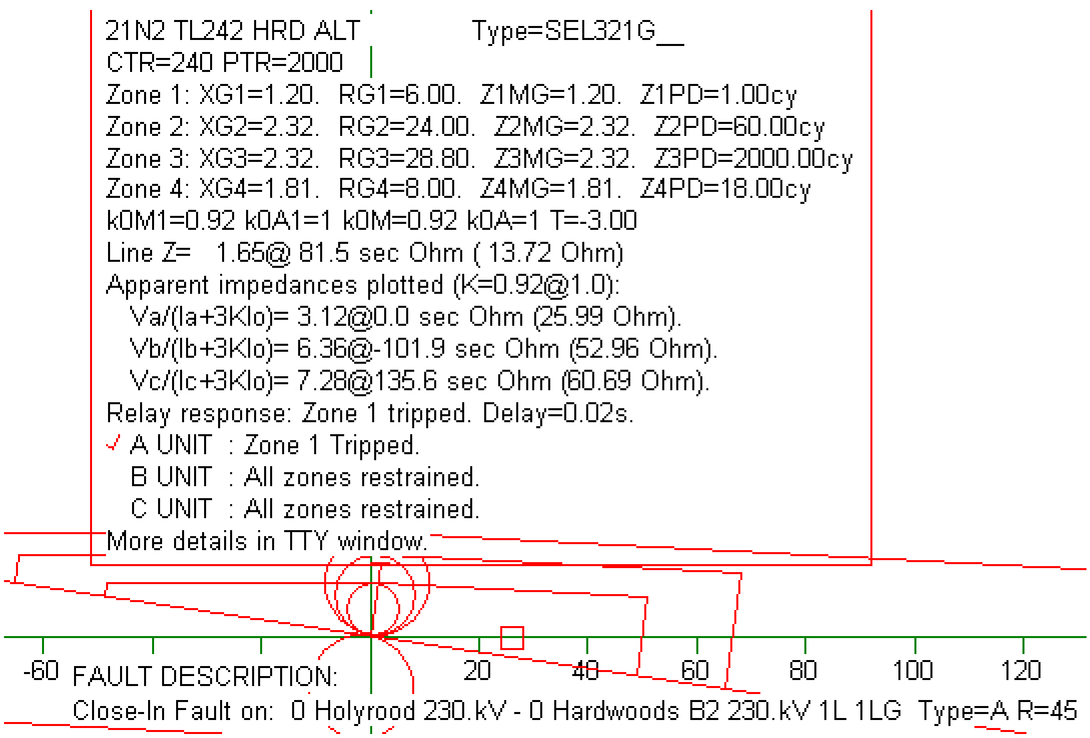


Figure 4 - HRD Zone 1 function if set with 6 ohm resistive reach, operates for a 60 ohm SLG fault close in to the local terminal.

Zone 2 Ground Distance Protection

The Zone 2 ground distance function may need to be set longer than the Zone 2 phase distance protection function because it will tend to underreach the remote terminal while the parallel line is in service. By simulation in ASPEN OneLiner it is found that the apparent impedance to a zero ohm fault close in to the remote terminal is 1.77 ohms secondary, or 7% more than the actual line impedance. The reach of the Zone 2 ground distance element should be set at least to 1.25 times the apparent impedance. Check existing setting of 2.32 ohms sec.

$ZSLG\_remote := 1.77$ $Z2MG := 1.3 \cdot ZSLG\_remote = 2.301$ Choose a setting of 2.32

$Z2MG := 2.32$ $Z2MG = 2.32$ Ohms secondary $Z2MG \cdot \frac{VTR}{CTR} = 19.333$ Ohms primary

The quad element reactive reach will be set similarly to the mho.

$XG2 := Z2MG$ $XG2 = 2.32$ Ohms secondary

It would be desirable to set the resistive reach of the quad element to sense a 100 ohm SLG fault at 75% of the line with the local terminal weak. This would ensure overlap with the zone 1element at the remote terminal. However, that would require too much resistive reach. Therefore choose a setting to sense a 100 ohm SLG fault just past the mid point of the line, and depend on the echo function to provide coverage for high resistance faults in the region where the remote zone 1 won't operate.

By trial and error from ASPEN it is found that a resistive reach of 25 ohms secondary will sense a 100 ohm SLG fault with an overlap with a similarly set remote zone 2 of 10% of the line length. See Figure 5. This will give positive overlap with the zone 2 element at the remote terminal. However since it will not overlap the Zone 1 element at the remote terminal, the permissive trip echo function will be required to ensure that a fault that is seen by the zone 2 element at only one terminal will still be cleared by the permissive trip logic.

Therefore, to avoid extremely large resistive reaches, and to retain sensitivity to 100 ohm resistive SLG faults, it is recommended that the echo function be enabled at both terminals.

$RG2 := 25$ Ohms secondary

The time delay of the zone 2 element will be set at 1 second since this element will overreach the HWD TL236 Zone 1 function (in fact there is no zone 1 function in the HWD TL236 P1 protection)

$Z2GD := 60$ cycles (same as existing)

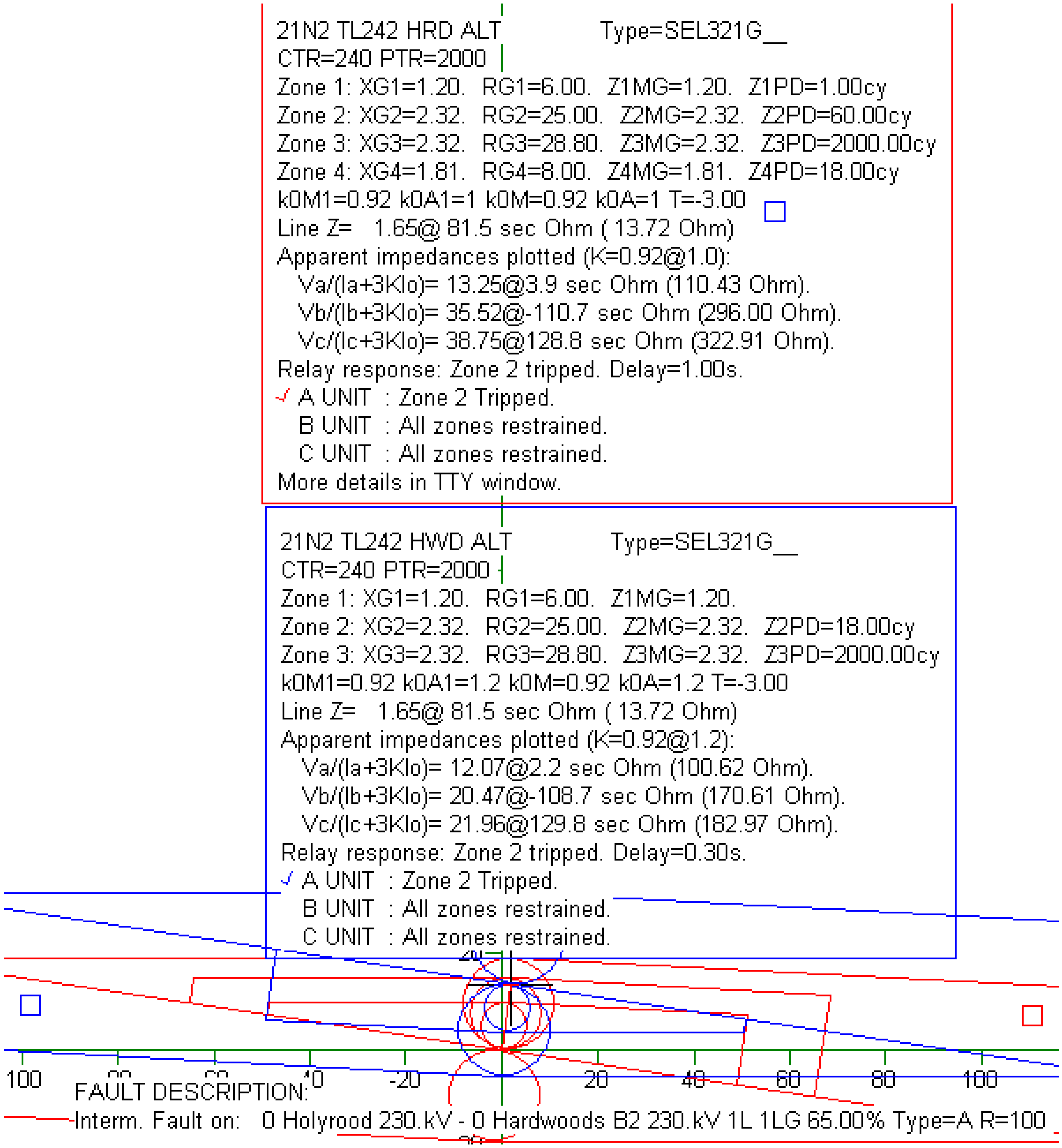


Figure 5 - Quad elements overlap with remote quad elements and operate for 100 ohm resistive SLG near the mid line location.

Check that this resistive reach won't cause the zone 2 function to trip while a parallel line is open single phase, with heavy power flow. See Figure 6. Unusually heavy power flow has been simulated to challenge security.

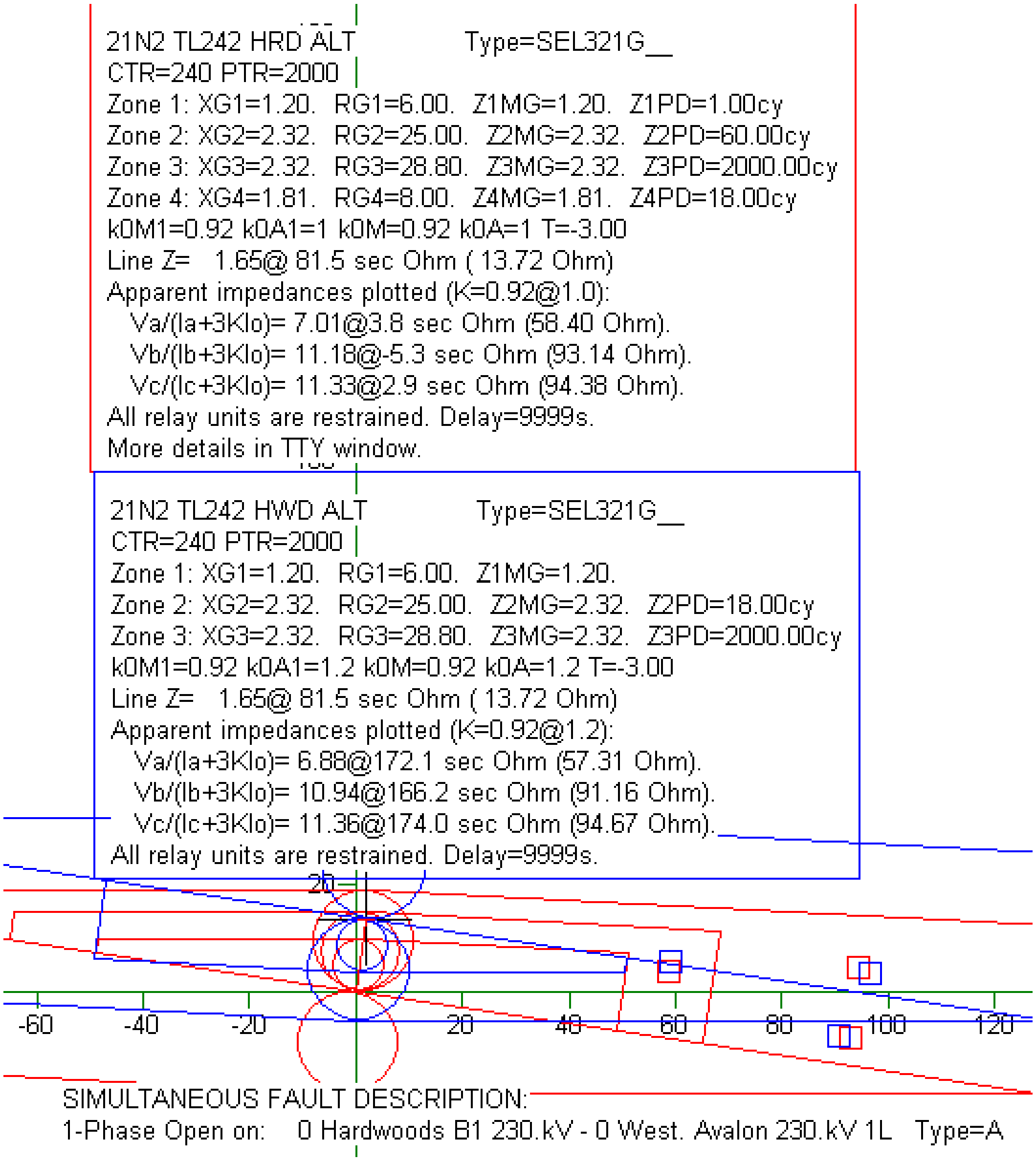


Figure 6 - Quad elements are secure with extremely heavy load flow (600 MVA in TL242 and 244 MVA in TL201) while TL201 is open single pole.

Zone 3

The zone 3 ground mho function will be set using the same principles as the zone 3 phase distance function. Use the setting for local zone 2 in secondary ohms as the remote zone 2.

$Z2MGrem := 19.33$ Ohms primary $\quad Z3MG := Z2MGrem \cdot \frac{CTR}{VTR}$

$Z3MG = 2.32$ Ohms secondary

$\frac{Z3MG}{|Z1MAG|} = 140.9 \cdot \%$ of line length

This is much higher than the existing setting, but provides additional security.

$XG3 := Z3MG \quad XG3 = 2.3$ Ohms secondary

Set the Zone 3 quad resistive reach at 10% more than the remote Zone 2. The setting is the same as the local zone 2 in secondary ohms. Therefore use the setting for local zone 2 in secondary ohms as the remote zone 2.

$RG2rem := RG2$ Ohms secondary $\quad RG3 := RG2rem \cdot 1.1 \quad RG3 = 27.5$ Ohms secondary

Zone 4

The zone 4 ground mho function will be set to securely underreach the remote zone , similar to the zone 4 phase distance element.

$Z4MG := Z4P \quad Z4MG = 1.8$ Ohms secondary

$X4G := Z4P \quad X4G = 1.8$ Ohms secondary

The zone 4 resistive reach will be set to securely underreach the resistive reach of the HWD TL236 zone 1 with infeed from the transformers at HWD.

By trial and error it is found that a resistive reach setting of 8 ohms will underreach the remote TL236 zone 1 at HWD.

RG4 := 8 Ohms secondary

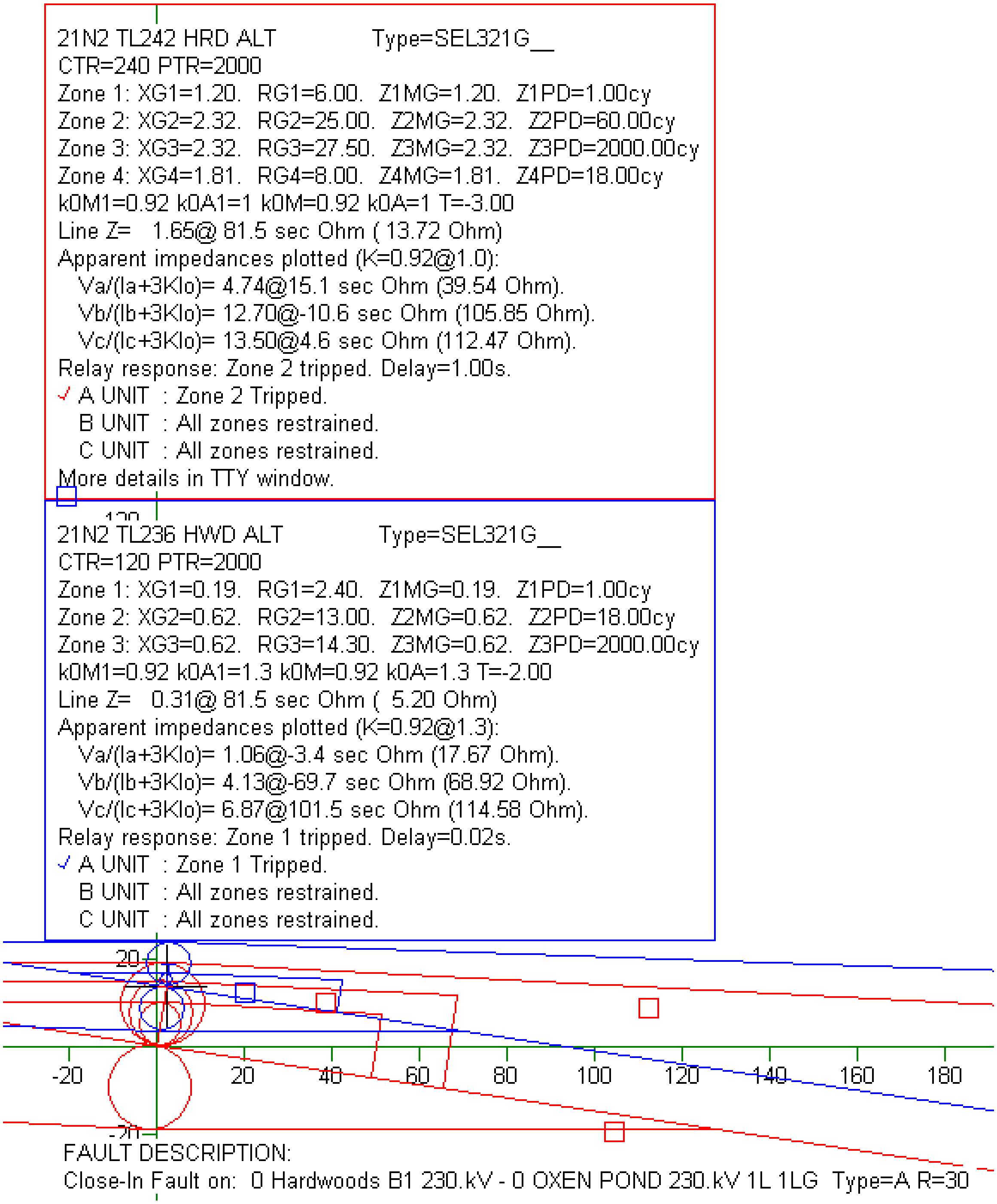


Figure 7 HWD TL236 Zone 1 senses a 30 ohm resistive SLG close in to HWD, which is not also sensed by HRD TL242 zone 4 element. Therefore HRD TL242 Zone 4 underreaches HWD TL236 zone 1 for resistive faults.

Ground distance current supervision

Since there is no concern about these elements operating on load, even with loss of potential, set all current supervision elements at minimum, for maximum sensitivity of the distance elements.

$'50L1 := 0.5$ A Sec $'50L2 := 0.5$ A Sec $'50L3 := 0.5$ A Sec $'50L4 := 0.5$ A Sec

$'50G1 := 0.5$ A Sec $'50G2 := 0.5$ A Sec $'50G3 := 0.5$ A Sec $'50G4 := 0.5$ A Sec

Note that due to heavy infeed of zero sequence currents from the local terminal for close-in faults, the ground overcurrent detectors will not operate for faults with more than a small amount of resistance close to the remote terminal. Therefore, we will have to rely on sequential clearing for that type of fault. However setting the current supervision at minimum allows maximum sensitivity.

Zero sequence current compensation

The zero sequence current compensation could be adjusted to compensate for the significant amount of mutual coupling. However as discussed in the settings of reaches of the ground distance elements we will accept underreach of the Zone 2 function for the normal case by setting it at 125% of the apparent impedance for a remote fault. Set the zero sequence current compensation as usual.

$$k01M := \left(\left|\frac{Z0Line - Z1Line}{3 \cdot Z1Line}\right|\right) \qquad k01M = 0.92$$

$$k01A := \left(\arg\left(\frac{Z0Line - Z1Line}{3 \cdot Z1Line}\right)\right) \qquad k01A = 1.2 \cdot deg$$

Set the overreaching zones the same as zone 1 $k0M := k01M$ $k0A := k01A$

$k0M = 0.92$ $k0A = 1.2 \cdot deg$

Settings are slightly different from existing due to small changes in line data.

Non Homogenous Angle Setting

Compare the angle of the remote zero sequence source impedance with the total zero sequence source impedance to the fault to determine this setting.

$$T := \arg\left(\frac{Z0minHWD + Z0Linephys + Z0minHRD}{Z0minHWD}\right) = -3 \cdot deg \qquad T = -3 \cdot deg$$

Out of step blocking and tripping

Not used in this application. There is a danger of out of step conditions arising. Historically no action has been taken to provide special tripping or blocking functions. Natural tripping during swings is accepted.

Load Encroachment logic

Check loadability of the Zone 2 phase distance element assuming worst case power factor of 0.87 simultaneous with worst case depressed voltage of a stressed system of 0.85 per unit. Note that units of kV squared match units of MVA. Note that quadrilateral elements are only used for the ground distance functions that are not sensitive to balanced three phase load. Therefore no need to worry about the reach of the quadrilateral elements.

$$\text{Zloadmin} := \frac{(0.85\text{kVbase})^2}{\text{Smax}} \qquad \text{Zloadmin} = 112.412$$ Ohms primary (assume worst case at 30 degrees)

Maximum reach of the Zone 2 element is at the line angle of 81 degrees. At 30 degrees, the reach will be given by

$$\text{Z2load} := \text{Z2P}\cdot\cos[(\text{Z1ANG} - 30)\text{deg}] \qquad \text{Z2load} = 1.445$$ ohms secondary

$$\text{Z2load}\cdot\frac{\text{VTR}}{\text{CTR}} = 12.04$$ ohms primary

Since the reach of the Zone 2 element at 30 degrees is less than the apparent impedance of the maximum load, there is no need to apply load blinding logic. See Figure 7

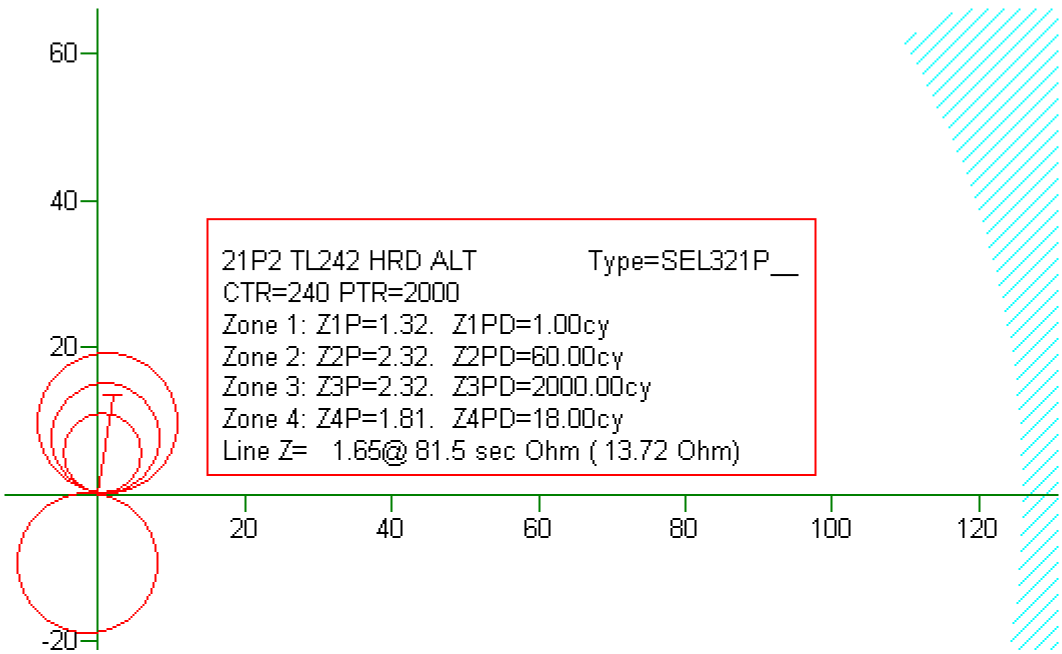


Figure 7 -Load impedance with respect to proposed new Mho function reaches.

Ground directional element

The SEL-321 application example recommends finding the minimum source impedance behind the terminal and setting the reverse and forward boundaries of the negative sequence directional element at the 1/3 and 2/3 points respectively.

In the negative sequence plane, the sum of the two source impedances and the line impedance is:

$$Z2total := Z2minHRD + Z1Linephys + Z2minHWD$$

The 1/3 point is $Z2\_1\_3 := \frac{Z2total}{3}$ The 2/3 point is $Z2\_2\_3 := \frac{2Z2total}{3}$

$Z2Rpri := Z2\_2\_3 - Z2minHRD$ $\quad |Z2Rpri| = 22.074$

$Z2Fpri := Z2\_1\_3 - Z2minHRD$ $\quad |Z2Fpri| = 0.92$

Converting the primary impedances to secondary ohms

$Z2R := Z2Rpri \cdot \frac{CTR}{VTR}$ $\quad |Z2R| = 2.649$ Ohms secondary $\quad arg(Z2R) = 83.216 \cdot deg$

$Z2F := Z2Fpri \cdot \frac{CTR}{VTR}$ $\quad |Z2F| = 0.11$ Ohms secondary $\quad arg(Z2F) = 28.529 \cdot deg$

Rounding down Z2F and rounding down Z2R gives:

$Z2F := 0.1$ Ohms secondary $\quad Z2R := 2.6$ Ohms secondary

These are significantly lower than to the existing settings but are more secure.

Set the current level detectors at minimum level that will allow operation of the ground distance elements.

Due to the very small zero sequence current contribution to a single line to ground fault at the remote terminal, the negative sequence current contribution will always be higher than the zero sequence. Therefore there is no point in setting the forward looking negative sequence overcurrent elements any more sensitively than the zero sequence ground overcurrent supervision of the ground distance elements.

$'50QF := '50G2$ $\quad '50QF = 0.5$ A secondary

Set the supervision function for the reverse looking element to be the same as, or a little more sensitive than the forward looking supervision element at the remote terminal.

$'50QR := 0.5$ A secondary

The positive sequence current restraint (a2) factor should be set just smaller than the ratio of the maximum load current (positive sequence) to the most sensitive current supervision element (50QR).

$I1maxpri := \frac{Smax \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\quad I1maxsec := \frac{I1maxpri}{CTR}$ $\quad I1maxsec = 3.556$

Bearing in mind that the 50QR setting is in units of 3*I2

$\frac{'50QR}{3 \cdot I1maxsec} = 0.047$ Choose a value of $\quad a2 := 0.05$

The proposed setting of a2 the same as existing setting (0.05).

Phase time overcurrent element

This element is not used

Residual time overcurrent element

This element is used to provide the most sensitive backup protection. It will be a non directional element.

Set pickup to sense a higher resistance than 100 ohm SLG in the middle of the line with equal zero sequence current infeed from both ends. Choose a resistance of 200 ohms arbitrarily. Use a safety factor of 2 so that operating time is not infinity at this fault level.

$SF := 2$ Desensitization factor due to remote end infeed is $Dfactor := 2$ $Rf := 200$

$$'51NPU := round\left(\frac{kVbase \cdot 1000}{\sqrt{3} \cdot SF \cdot Dfactor \cdot Rf \cdot CTR}, 1\right) \qquad '51NPU = 0.7$$

The existing setting of 0.5 A is more sensitive than required to sense this mid line fault with arbitrary resistance. Since TL206 experience with the high resistance tree fault on 28th August 2009 has shown value in the existing setting, it will be retained.

$'51NPU := 0.5$ A secondary

Coordination checks show that existing time dial settings will coordinate with each other. See Figures 8 and 9

Coordination checks show that existing time dial settings will coordinate above existing remote protection (HWD TL236). Even under maximum load conditions, if this line trips single phase, the neutral current during the open pole period will not be sufficient to operate the 51N in less than one second.

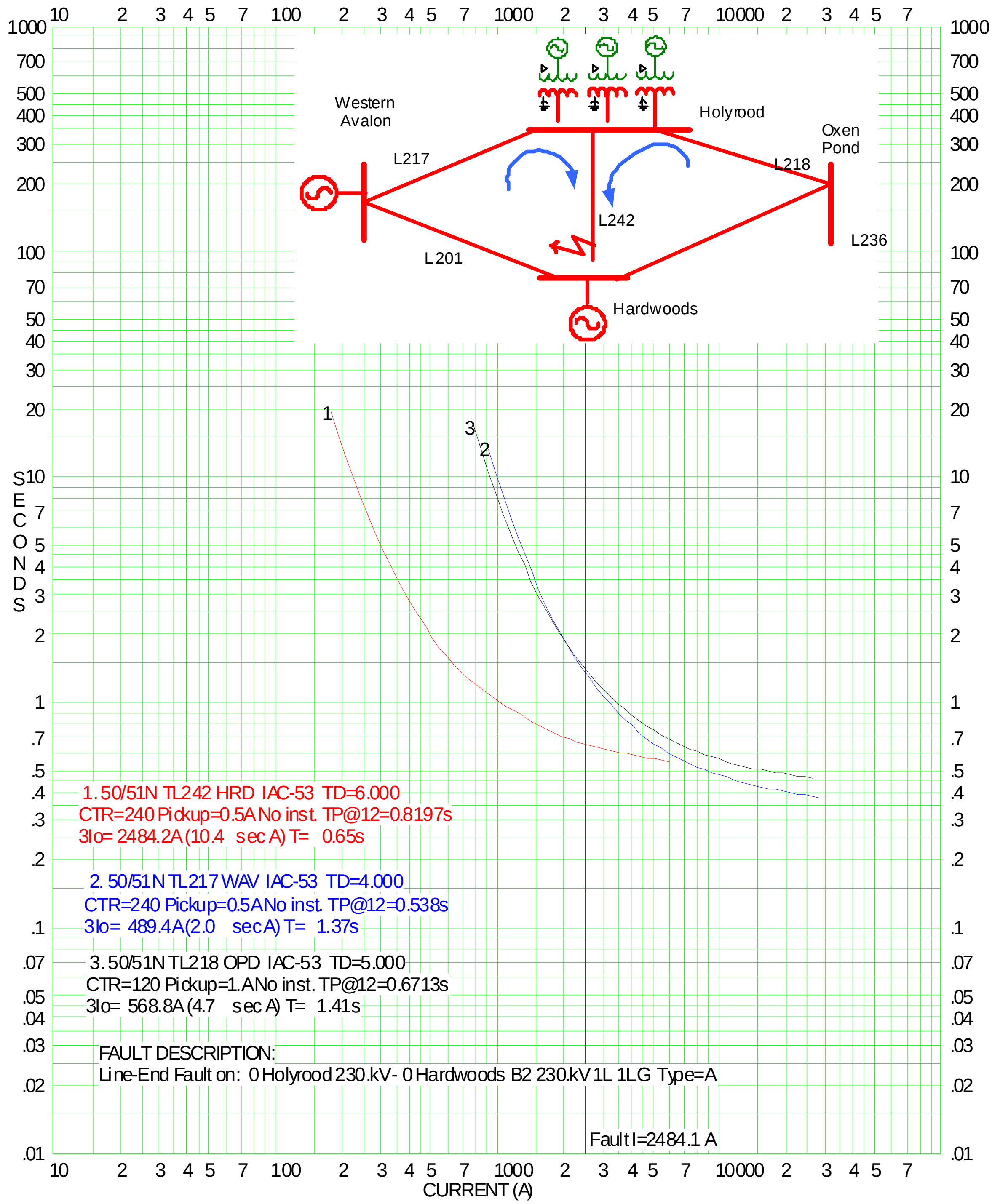
The existing settings on the TL236 protection are proposed to be slowed down to improve security during single pole tripping of TL236 under heavy load. Therefore we have to check coordination above the new slower settings on TL236 as well as below the existing settings of protection on TL 217 and TL218.

$'51NPU = 0.5$ A secondary $'51NPU \cdot CTR = 120$ A primary

$'51NTD := 6.0$ $'51NC := "U3"$ $'51NTC := "N"$ $'51NRS := "N"$

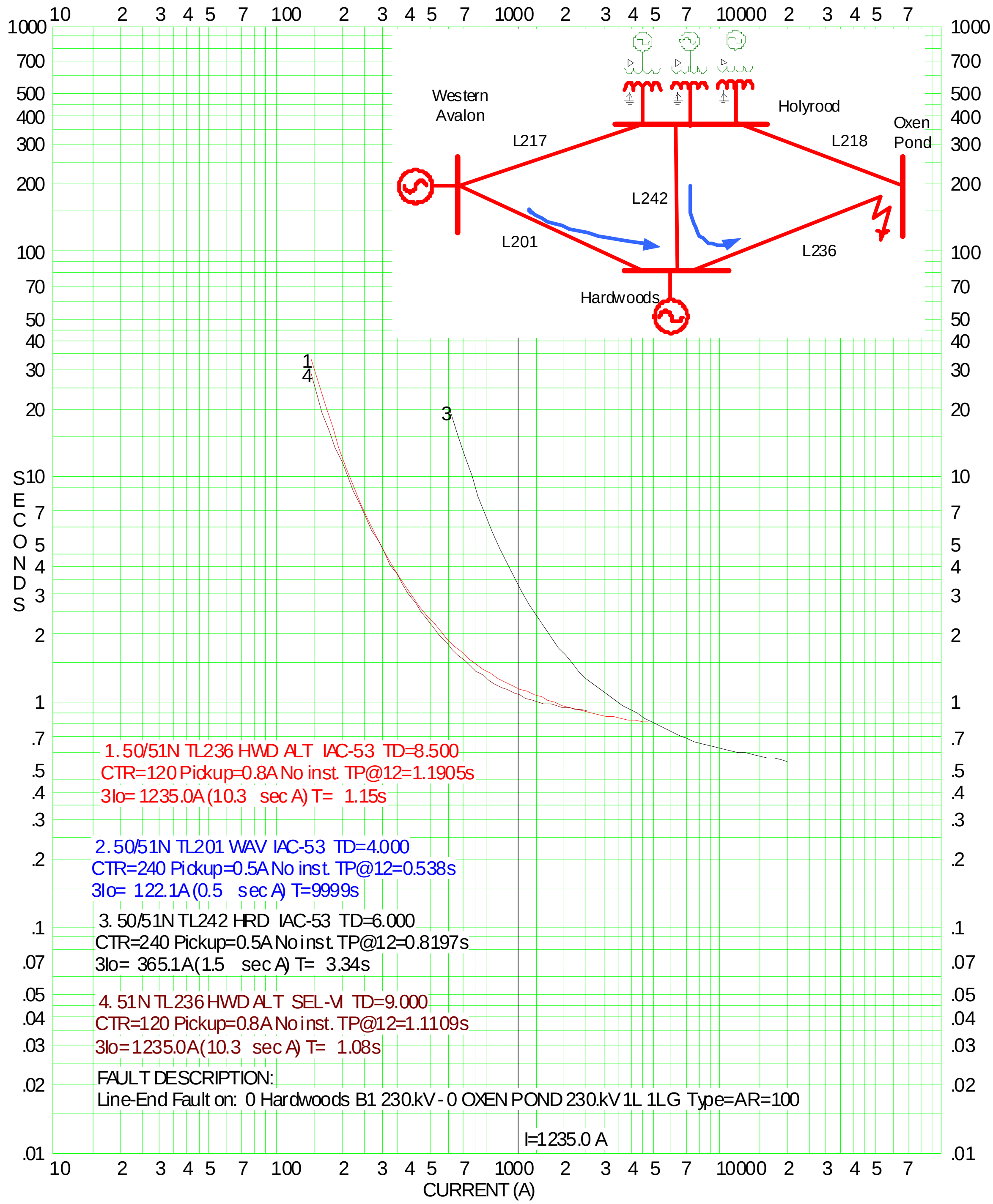
Check the coordination below the OPD TL218 51N and below the WAV TL217 51N for a line end fault on TL242 with two HRD units off line. This is the type of fault that will produce the most sensitivity (least desensitization) with respect to the backup protection on TL218 and TL217. see Figure 8. Coordination margin is satisfactory. It can be seen from Figure 8 that the coordination is good even below the exiting 51N settings of OPD TL218. With the proposed new (slower) settings for OPD TL218, the coordination margin will be even larger.

Check the coordination above the HWD TL236 protection for a LE fault. See Figure 9. It can be seen that the existing setting is only marginally slower than the proposed new HWD TL236 protection for large fault currents. For this type of fault we can rely on the 0.3 second time of the zone 2 ground distance function at HWD. For resistive faults the current will be much lower and the ground time overcurrent functions will coordinate satisfactorily.



TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For HRD L242 coordinates below WAV L217 and OPD L218	No. EC 230-3
Comment Two units at HRD off line (summer)	Date 29 Sept 2011

Figure 8 - coordination of ground time overcurrent elements for LE TL242 fault



TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For Coordination of HWD L236 below HRD TL242 and WAV TL201	No. ECS230-10
Comment Coordination requires Z2G for RF<100 ohms	Date 13 Dec 2011

Figure 9 - coordination of ground time overcurrent elements for line end fault on TL236 close to HWD

Permissive Overreaching logic settings

EPOTT := "Y"

Z3RBD is set at remote breaker time plus channel reset time plus channel reset time plus zone 2 reset time. From review of fault records it appears that the breaker time is 3 cycles. Channel reset time is not easily determined from existing records but can conservatively be assumed to be 1 cycle, and relay reset time will also be about 1 cycle. Total time for Z3RBD is then 5 cycles.

Z3RBD := 5 cycles

Echo block delay timer blocks the echo after the local elements have picked up. This can be set relatively long since there is no significant need for the echo function shortly after the local terminal has just seen a fault but the remote terminal has not. Set at 10 cycles as per the example in the instruction manual.

EBLKD := 10 cycles

Echo time delay on pickup should be set to override noise on the communications so that it doesn't echo noise. Typical time according to the SEL application guide is 2 cycles. Since this delay only affects clearing time for relatively light (high resistance) faults that are sensed by zone 2 function at one end, the typical setting is acceptable.

ETDPU := 2 cycles

Echo duration should be long enough to ensure the permissive trip is received by the remote terminal and should also be shorter than the Z3RBD time to ensure that the reverse blocking will always be longer than any permissive trip received (including echo time stretching).

EDURD := 4 cycles

No need to enable week feed conversion to trip, since both terminals will be quite sensitive enough to detect high resistance faults after the remote terminal has cleared. Therefore we can accept sequential (or "step") clearing with no need for the added insecurity of weak infeed tripping.

EWFC := "N" **No other communications logic settings are required for this application.**

Switch on to Fault Settings

Switch on to fault logic will ensure the protection will operate when energizing the line onto a close-in three phase fault when there is no polarizing voltage available for the distance elements.

ESOTF := "Y"

The breaker close signal is not available to the relay. The 52A method of enable SOTF will be used. Therefore the Close end delay is not critical. Typical duration for enable SOTF is 10-15 cycles

ENCLO := "N" CLOEND := 0 EN52A := "Y" SOTFD := 15

Set 50H for high magnitude close-in multiphase faults with weakest source at HRD. It should be set less than 50% of the minimum close-in fault magnitude. Minimum close-in magnitude of a three phase fault with two units off line and TL242 out of service is 3000 A. Therefore desired maximum setting for 50H is 1500 A.

Imin3P_close_in := 3000

$$'50H := \frac{Imin3P\_close\_in}{2CTR} \qquad '50H = 6.25 \quad \text{A secondary}$$

Choose a setting of 6 A secondary for this element. '50H := 6 A secondary

Choose a setting for 52AEND less than the shortest reclose time. '52AEND := 30 cycles

The existing setting of 52AEND is 70 cycles. It is not known why the setting is set longer than the reclosing time.

Residual overcurrent settings.

Tripping directly by instantaneous ground overcurrent is not applicable because it is not phase selective. However it would be helpful to monitor steady state unbalance, and issue an alarm for continuous unbalance. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50N := 1$ $'50N1 := 0.25$

Negative Sequence overcurrent settings.

Similar to ground overcurrent, apply a negative sequence overcurrent element to initiate an alarm for steady state unbalances. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50Q := 1$ $'50Q1 := 0.25$

Voltage Element Settings

Similar to unbalance current monitoring, it is helpful to have an unbalance voltage monitor to detect steady state unbalances from the voltage supply.

EVOLT := "Y"

Set the zero sequence overvoltage element at 1% of rated voltage or just at the point necessary to override normal unbalances. The zero sequence voltage element measures 3 times the zero sequence voltage.

$$'59N := 3 \cdot 0.01 \frac{kVbase \cdot 1000}{\sqrt{3} \cdot VTR} \qquad '59N = 1.992$$

Say $'59N := 2$ V secondary

Loss of Potential

Enable loss of potential settings. Advanced LOP settings are not available on this model of relay.

ELOP := "Y" Time delay of 1.25 cycles is commonly used. $LOPD := 1.25$

The 50 M element should be set above maximum load and below minimum fault current for a fault at the remote terminal under weak source conditions. The maximum load for this case should be normal maximum, not emergency maximum which only exists for a few minutes before the operator can act to reduce load.

$$Imax\_normal := \frac{Smax\_TL242 \cdot 1000}{\sqrt{3} \cdot kVbase \cdot CTR} = 2.406$$ A secondary

Minimum fault current for a remote three phase fault is $I3Pmin = 1152$ A primary.

Minimum fault current for a remote phase to phase fault is 87% of the minimum three phase fault current level.

Dependability factor to be sure to operate for a minimum remote fault is chosen to be 1.6. $DF := 1.6$

Maximum setting for 50M should be $\frac{0.87 I3Pmin}{DF \cdot CTR} = 2.61$ In this case a setting of 2.5 A secondary will be adequately dependable and secure.

$'50M := 2.5$ A secondary

The 59QL setting should be above normal maximum unbalance and below the level expected for a blown VT fuse. For a blown fuse, one phase voltage will be lost, and the negative sequence voltage will be roughly 33% of the nominal positive sequence voltage. Choose a setting of 15% of the nominal positive sequence voltage. This will be well above any normal unbalance.

$$'59QL := \mathrm{round}\left(\frac{0.15 \cdot kVbase \cdot 1000}{\sqrt{3} \cdot VTR}, 0\right) \qquad '59QL = 10 \text{ V secondary}$$

The 59PL setting should be less than the minimum voltage to be expected for a remote bus fault under weakest source conditions. There is no minimum setting (above zero) for this function. Choose a setting equal to half the voltage drop along the line impedance at the pickup setting of the 50M element.

$$'59PL := \mathrm{round}[0.5 \cdot ('50M \cdot |Z1Linesec|), 0] \qquad |'59PL| = 2$$

Miscellaneous Scheme Settings

Pole discoordinance logic is not being used. EPOLD := "N" SPPDD := "N/A"

Enable single pole tripping by distance elements only ESPT := "Y"

Enable single pole open ESPO := "Y"

Set single pole open time delay for future SPO conditions SPOD := 0.25

Note that SPOD was short enough to allow a transient operation when TL201 was reclosed with a fault on it during the fault of 7 March 2011. This transient operation was helpful to clear the fault more quickly than it otherwise would have cleared. SEL have been asked whether the SPOD setting of 0.5 would be better to increase the security.

3 Pole open reset delay to override small discrepancies in pole closing '3POD := 0.5

Stub line protection is not required ESTUB := "N" '50MFD := "N/A"

Trip unlatch logic not applied TULO := "N"

Logic variables and Miscellaneous timers

Minimum trip duration timer is set at 9 cycles as per the application example in the SEL-321 instruction manual.

TDURD := 9 Cycles

Trip during open pole time delay should be set longer than the reclose time. Existing reclose time is 55 cycles. This is acceptable.

THWD := 55 Cycles

Existing logic variables are not used.

Since this line is short (voltage may be low at HRD for a fault near HWD), a 1 cycle security delay in zone 1 tripping is recommended to improve the security of this function against incorrect tripping for a fault beyond the HWD terminal.

LOGIC_X := "M1P+Z1P" TXPU := 1 cycle TXDO := 0 cycles

Add the use of ZT to trigger an alarm for sustained unbalance.

LOGIC_Z := "59N+50N1+50Q1" TZPU := 1200 cycles TZDO := 0 cycles

Tripping Logic

Permissive tripping is required only for instantaneous overreaching functions. No need for any functions that trip directly. Existing 51NT word in MTCS is not required.

MTCS := "M2P+Z2G"

Existing settings for unconditional tripping must be modified to include a 1 cycle delay for zone 1 tripping.

MTU := "XT+M2PT+Z2GT+ M4PT +Z4GT + 51NT"

No need for existing direct tripping zone 1 functions in the switch on to fault logic.

SOTF Tripping MTO := "M2P+Z2G+50H"

Event records will be triggered automatically by all trip events. Other event record triggers should be by starting of other elements to ensure capture of all relevant events. Events should be triggered by keying or receiving permissive trips to ensure separation of relay and teleprotection issues.

MER := "M2P+Z2G+51NP+LOP*52AA1+LOP*52AA2+KEY+PT+EKEY"

Outputs

Retain existing output assignments except add the continuous unbalance alarm to OUT15.

OUT15 := "LOP*50L+ZT"

Input Contact Assignment

It would be desirable to provide phase segregated inputs to the relay so that the quadrilateral functions could be disabled during single pole open conditions. it is not known if phase segregated auxiliary switches are available on the breakers.

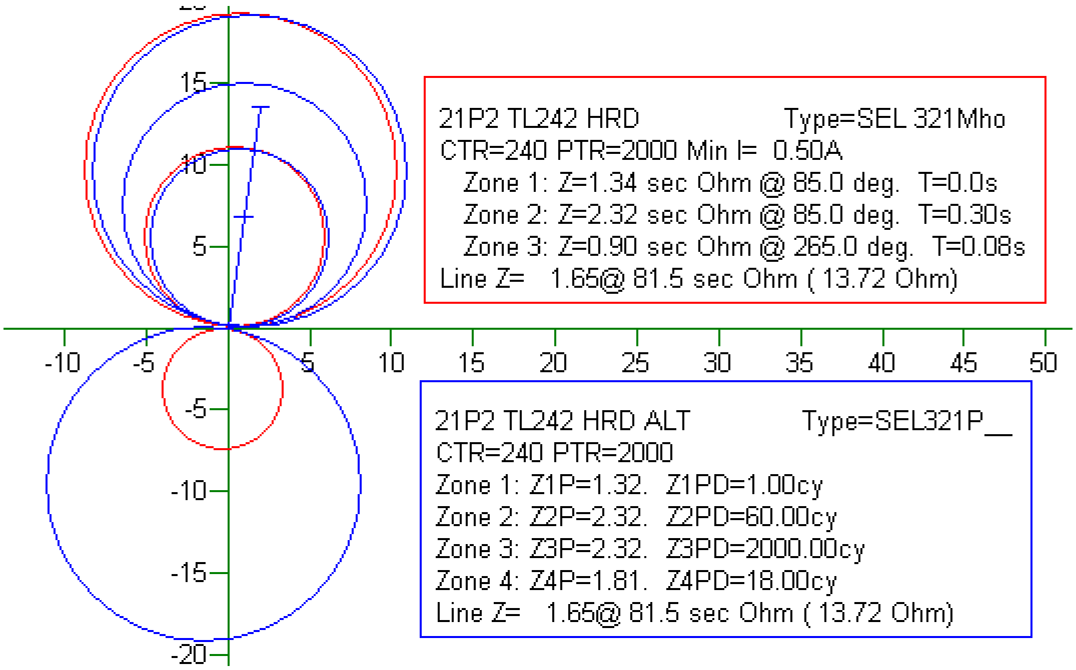


Figure 10 - Comparison between existing (red) and proposed new (blue) phase distance characteristics.

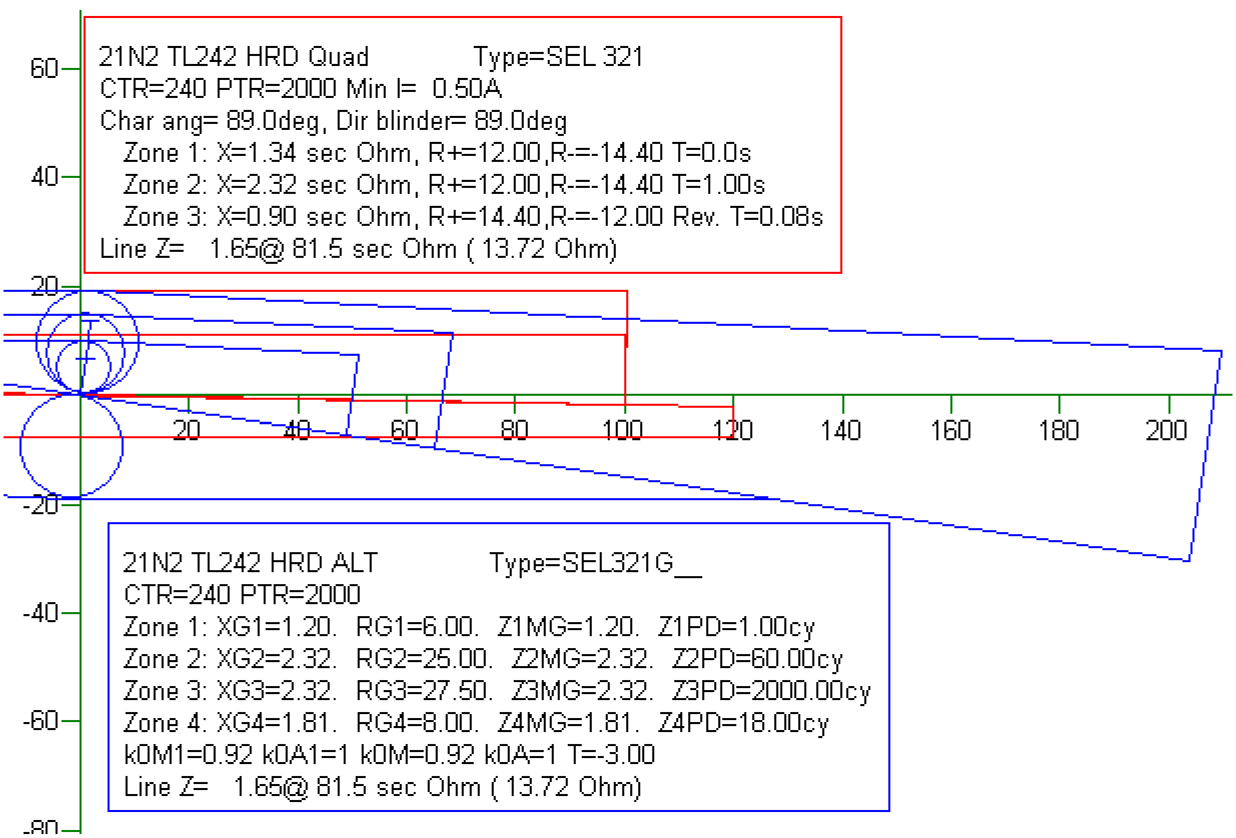


Figure 11 - Comparison between existing (red) and proposed new (blue) ground distance characteristics.

Protection Review for Five 230 kV Transmission Lines

Appendix V
Detailed settings review for HWD TL242 "P1" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador Hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Hardwoos Terminal (HWD) terminal of circuit TL242. This 230 kV transmission circuit is from HWD to Holyrood (HWD).
The circuit runs parallel to Circuits TL201 and TL218 for some of its length.

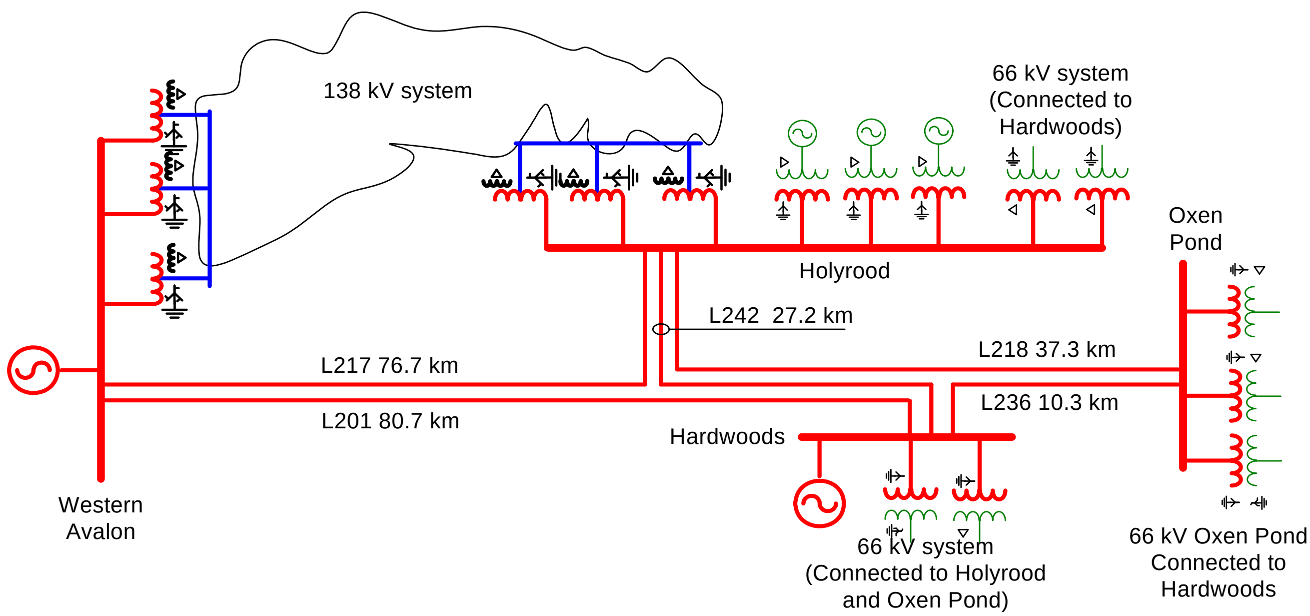


Figure 1 - System Single Line Diagram

Existing P1 protection systems are Areva LZFP111 (Optimho) systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $\quad$ $kVbase := 230$ $\quad$ $Ibase := \frac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\quad$ $Zbase := \frac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at the line terminal.

CT ratio is: $CTR := \frac{1200}{5}$ $\quad$ VT ratio is: $VTR := \frac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**NL HYDRO WITH MUTUALS FOR EAST COAST 230 kV LINE PN REVIEW 8 DEC.OLR**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with loads and shunts ignored.

Minimum fault current seen by each terminal (phase to phase, and SLG with 0 ohm fault resistance).

At HWD, with TL201 out of service, with 66kV sources modelled connected to the 66 kV side, there will be a weak source of positive sequence fault current at that station. There will be some infeed from the 66 kV side.

$ILLmin := 270$ A $\quad$ $ISLGminPH := 536$ A $\quad$ $ISLGmin0seq := 698$ A

The optimho current level detectors that block the distance comparators in the event of line opening are fixed at 5% of the rated current, or 0.25 A secondary, or 60 A primary. They will have no difficulty in operating for minimum bolted fault levels. However, the ground distance elements are also supervised by a low set neutral current level detector (LDLSN that requires the neutral current to be greater than 10% of the maximum amplitude of phase difference current. This prevents the ground comparators from operating during close-in multiphase faults with CT errors. ASPEN OneLiner shows that for a bolted fault at the remote bus even under heavy load, there is sufficient neutral current (20% of maximum phase to phase fault current) that means this LDLSN function does not inhibit the ground distance comparator.

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the parallel line in service and with the remote end of the line open.

Minimum source impedance behind HWD $\quad Z2minHWD := 2.38 + j \cdot 29.83$ ohms primary

Minimum source impedance behind HRD $\quad Z2minHRD := 0.99 + j \cdot 21.04$ ohms primary

<u>Line impedances</u>.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L242 := 0.00383 + j \cdot 0.02565 \qquad Z0L242 := 0.0129 + j \cdot 0.09653$

$Z1Line := Z1L242 = 3.83 \times 10^{-3} + 0.026j$ pu $\qquad Z0Line := Z0L242 = 0.013 + 0.097j$ pu

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line \cdot Zbase \qquad Z0Linephys := Z0Line \cdot Zbase$

$Z1Linephys = 2 + 13.6i$ ohms primary $\qquad Z0Linephys = 6.8 + 51.1i$ ohms primary

Converting primary ohms to secondary ohms gives:

$Z1Linesec := Z1Linephys \cdot \frac{CTR}{VTR} \qquad Z0Linesec := Z0Linephys \cdot \frac{CTR}{VTR}$

$|Z1Linesec| = 1.65$ ohms sec $\qquad arg(Z1Linesec) = 81.5 \cdot deg$

$|Z0Linesec| = 6.182$ ohms sec $\qquad arg(Z0Linesec) = 82.39 \cdot deg$

Load Data

From 2011 System summer load case provided in start up information, the peak load (sum of TL242 and TL201) is given as 340 MVA (split between TL242 and TL201). In the event of sudden loss of one line, peak load will be the sum of both line loads until operators can adjust loads. Therefore it might be assumed that peak load for a short duration is 340 MVA

$Speak := 340$ MVA $\quad$ $Smax := Speak = 340$ MVA

P1 Relay Settings

Distance element reach settings

Note that resistive reaches are forced to be the same for all zones. Reactive reaches for phase and ground distance elements must be the same as each other.

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the HRD Station bus with TL201 line out of service. From ASPEN OneLiner, voltage at HWD for a 3 phase fault at HRD is 0.04 per unit. Since the voltage is less than 20%, this line is considered short, and a reduced zone 1 reach is recommended to increase security. Choose a setting of 80% of nominal.

$Z1P := 0.8 \cdot |Z1Linesec|$ $\quad$ $Z1P = 1.32$ Ohms secondary

Existing setting of 1.34 ohms is a little too high and should be reduced to at the most, 1.32 ohms secondary. However, the ground distance reach in the optimho has to be set the same as the phase distance reach; so we need to consider the ground faults too.

$Z1P = 1.32$ For phase faults only.

The worst case from the point of view of overreach of the zone 1 ground distance element is with TL217 out of service and grounded at both ends, and a close-in fault on the HV bus of one of the Holyrood transformers. For this case, the apparent impedance presented to the relay is 1.58 ohms secondary (see Figure 2). This is 96% of the line impedance. So the proposed 80% reach of the zone 1 element for phase faults should be OK as far as overreach due to a parallel line being out of service and grounded at both ends is concerned.

Note that the sero sequence current compensation factor KZN is set at 0.98 in the existing settings, and this is not optimal considering the existing line data shows a required setting of 0.92. This high existing setting also causes a small amount of overreach of the existing zone 1 element.

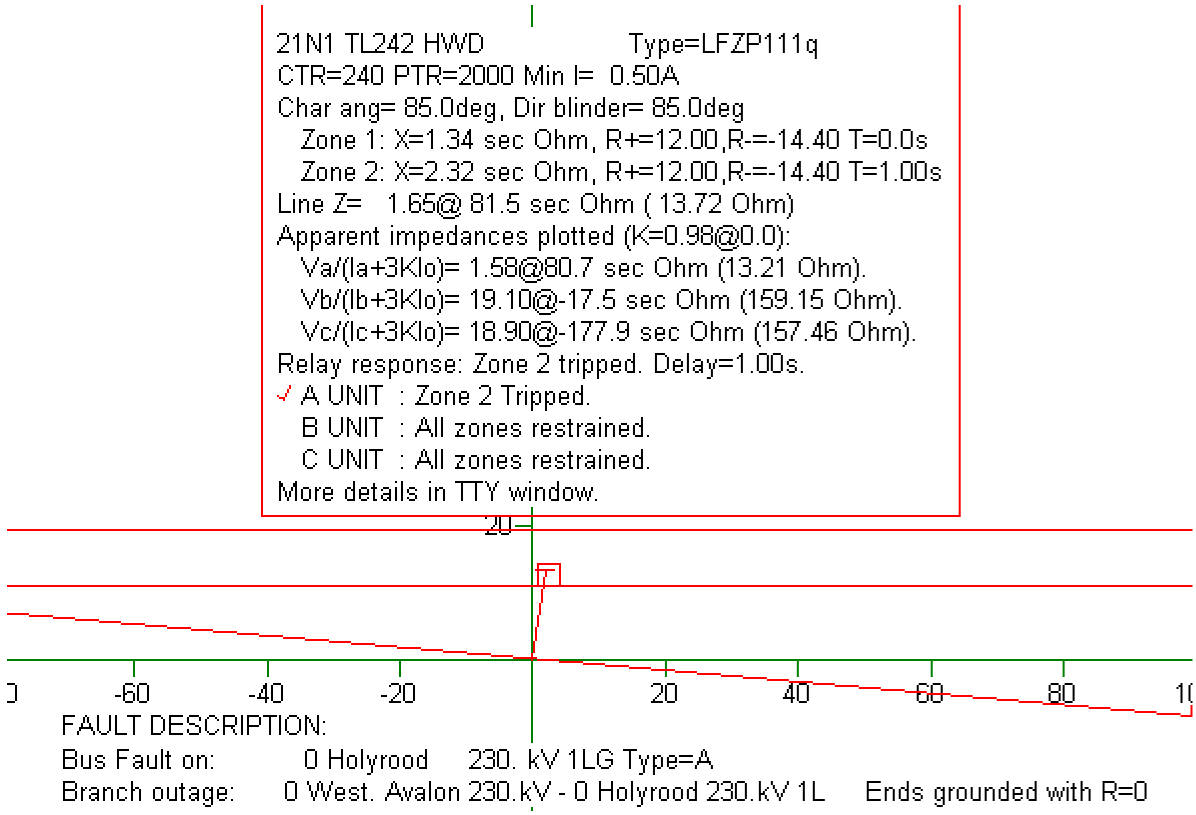


Figure 2 - Apparent impedance to a fault just beyond the remote terminal is reduced by 4% when TL217 line is out of service and grounded at both ends. Existing relay settings modeled in this figure.

The reach of the zone 1 ground distance element should be reduced to less than 85% of the line impedance to make it more secure against misoperation for an external fault with the parallel line out of service and grounded. **A more important constraint exists due to the short line and the high resistive reach** required in order to sense 100 ohm resistive faults near the middle of the line. The resistive reach of the zone 2 element (which is the same as the resistive reach of the zone 1 element) has to be set at about 12 ohms secondary. Such a long resistive coverage on the zone 1 element may not be secure when considering the VT and CT errors may cause additional possibility of overreach of the zone 1 for resistive external faults. Choose a setting of 60% of line which will more securely underreach the remote bus, considering the long resistive reach setting required.

Note that since power flow is normally into this terminal, the difference in voltage angles at each terminal due to power flow will not cause an overreaching effect. In fact, will more likely cause the zone 1 element to underreach due to power flow, but the 60% reactive reach setting will still be helpful to allow large resistive reach while retaining security.

Since power flow into the terminal will not cause insecurity, the most critical factor is VT and CT errors that might cause the reactive element to overreach if the resistive reach is set too long and under light load condtions.

Given that it would be desirable to have a resistive reach of 6 ohms secondary to cover a 100 ohm resistive SLG, the SEL formula to check the maximum recommended resistive reach for a zone 1 function set at 60% of the line and used as the limit for secure resistive reach.

$m := 0.6$ per unit

$Z1\_sec := \mathrm{round}(m \cdot |Z1Linesec|, 1)$ $Z1\_sec = 1$ Ohms secondary

$Z1pri := Z1\_sec \cdot \frac{VTR}{CTR} = 8.333$ Ohms primary

The imaginary component of the line is $ImXG1sec := \mathrm{Im}(Z1Linesec)$ $ImXG1sec = 1.628$ ohms

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$RG1 := \mathrm{round}[(1 - m) \cdot 20 \cdot ImXG1sec, 2]$

$RG1 = 13.03$ This is the maximum secure setting for the resistive reach.

Use a maximum setting of 12 ohms for RG1 $RG1 := 12$ ohms secondary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 2.32 ohms secondary (about 140%). However, in order to dependably reach a single line to ground fault at the remote terminal, it may be necessary to set the reach significantly further.

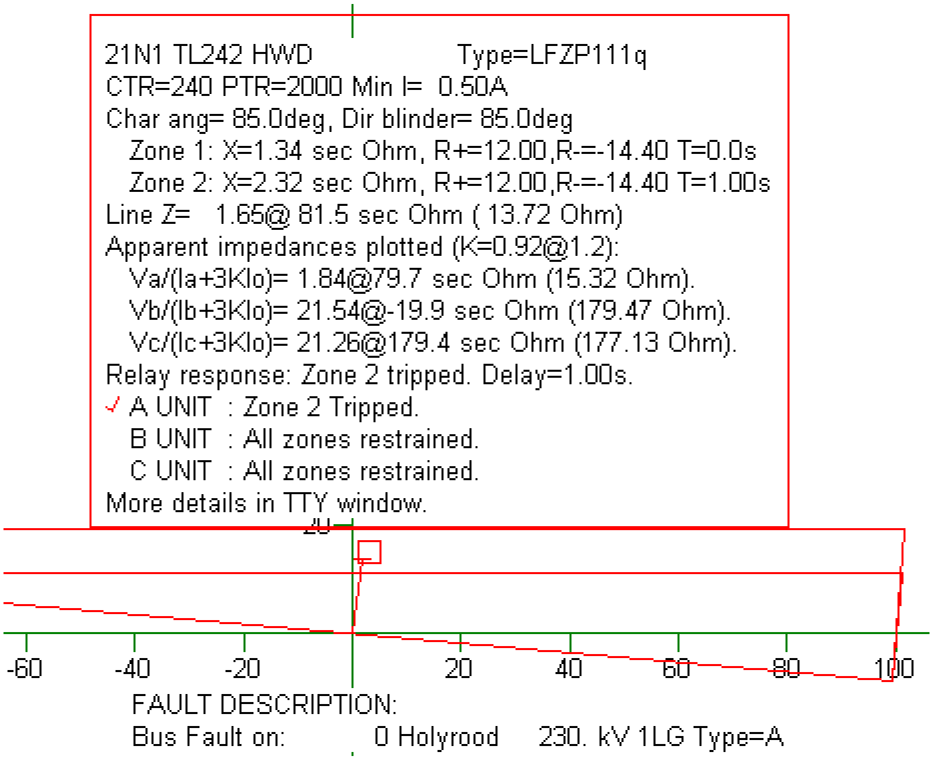


Figure 3 - Apparent impedance to a fault close to the remote terminal is increased by 10% when parallel line is in service.

As can be seen from Figure 3, the apparent impedance to a fault close to the remote terminal is increased when the parallel line is in service. We would like to overreach the apparent impedance significantly.

$Zapp\_int := 1.84$ Ohms secondary $Z2\_sec := 1.25 \cdot Zapp\_int = 2.3$ Choose a setting of 2.32

$Z2\_sec := 2.32$ $Z2\_sec = 2.32$ Ohms secondary $\frac{Z2\_sec}{|Z1Linesec|} = 140.921 \cdot \%$

$Z2\_pri := Z2\_sec \cdot \frac{VTR}{CTR} = 19.333$ Ohms primary

This setting will not reach far past the HRD terminal (see P2 calculations for this line) so there will be no problem with using the conventional zone 2 time delay and will still achieve coordination with instantaneous elements covering circuits beyond HRD. This is reduced from the existing 1 second setting.

$Z2\_TD := 0.3$ Seconds

Resistive reach

Check the sensitivity of the new settings to resistive faults near the middle of the line.

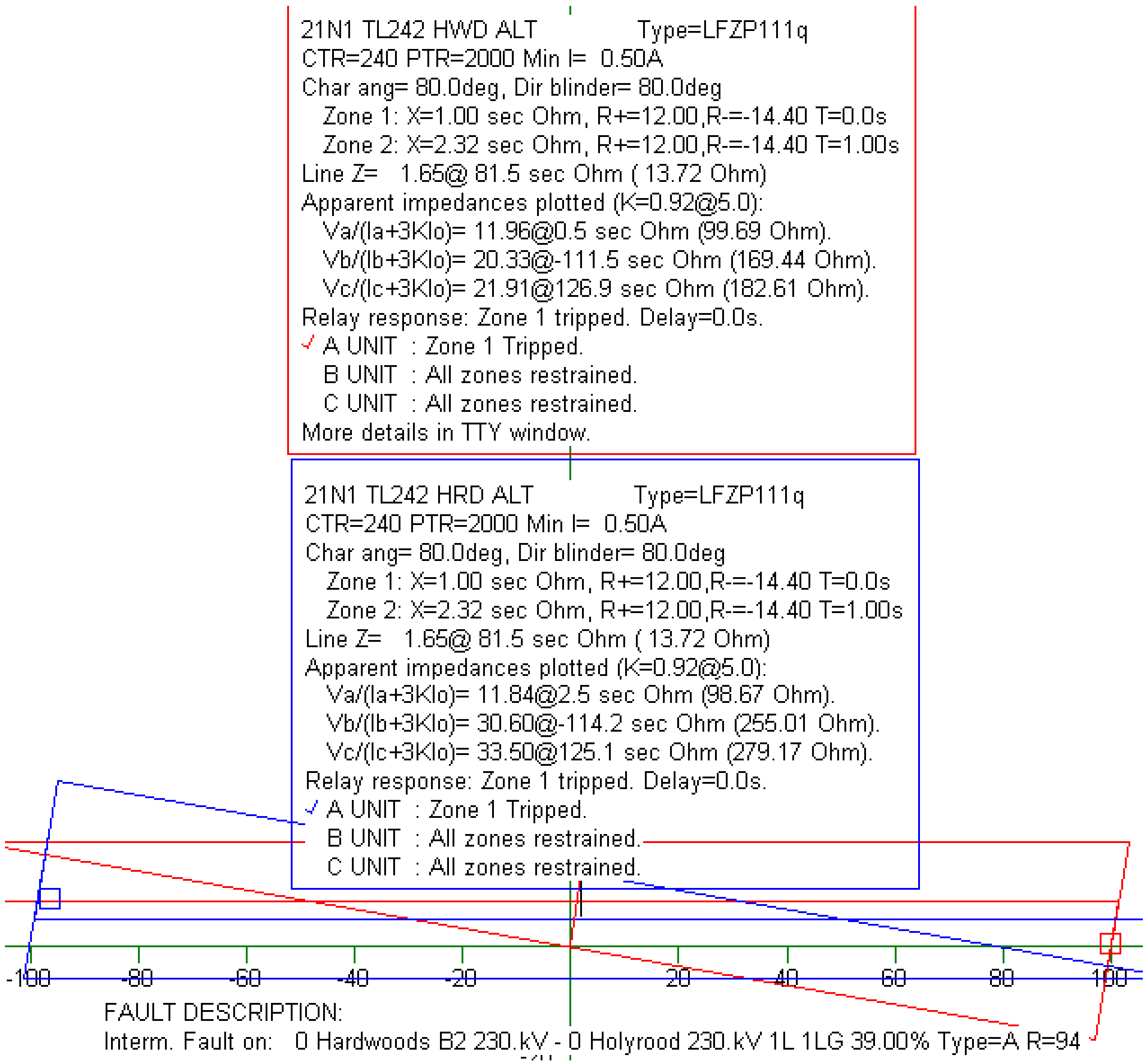


Figure 4 - Resistive fault coverage near the middle of the line.

As can be seen from Figure 4, the zone 2 elements at both ends will overlap for a 94 ohm resistive fault near the middle of the line. The zone 1 elements set at 60% at each end will not overlap for high resistive faults, but will overlap for less resistive faults.

The existing resistive reach setting of 12 ohms secondary will be suitable as long as the reach of the zone 1 element is reduced to 60% of the line.

Rquad := 12 ohms secondary

Load Encroachment logic

The optimho instruction manual recommends a margin of at least 10% between the impedance of the maximum load and the resistive reach of the quadrilateral distance element.

Check loadability of the Zone 2 phase distance element assuming worst case depressed voltage of a stressed system of 0.9 per unit.

$$Zloadmin := \frac{(0.9kVbase)^2}{Smax} \qquad Zloadmin = 126.026$$ Ohms primary (assume worst case at 30 degrees)

$$Zloadmin\_sec := Zloadmin \cdot \frac{CTR}{VTR} \qquad Zloadmin\_sec = 15.123$$

A 6 ohm secondary resistive reach is less than 90% of the load impedance at unity power factor and meets the Areva criterion as shown in Figure 5.

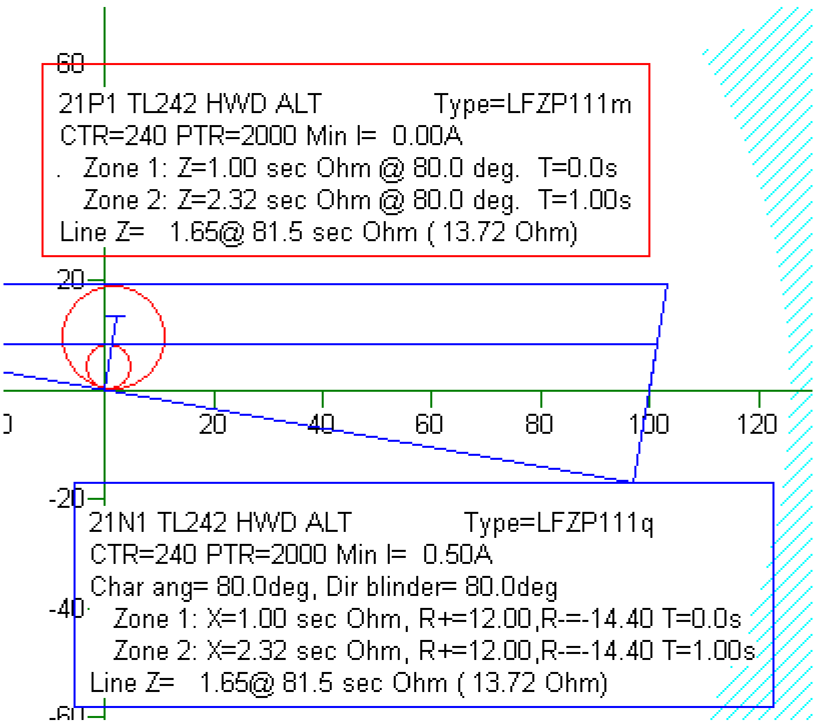


Figure 5 - Apparent impedance of load

Settings of K attenuators

KZPh Coarse setting common to all DISTANCE zones should be set as high as possible while below the required Zone 1 reach. The current level detectors vary inversely with KZph. Maximum setting available is 1.0

$KZPh := 1$

Zone 1 attenuators and angular selection

$In := 5$ $Z1\_sec = 1$ This is the desired secondary reach (previously calculated)

$KZ1 := \dfrac{Z1\_sec}{\left(KZPh \cdot \dfrac{5}{In}\right)}$ $KZ1 = 1$ $Z1sec\_reach := KZ1 \cdot KZPh \cdot \dfrac{5}{In}$ $Z1sec\_reach = 1$

$Z\theta PH := (\arg(Z1Linesec))$ $Z\theta PH = 81.507 \cdot deg$

Rounded to the nearest 5 degrees $Z\theta PH := 80$ Degrees (decreased from existing 85 degrees)

$Z\theta N := \arg(Z0Linesec - Z1Linesec)$ $Z\theta N = 82.708 \cdot deg$

Rounded to the nearest 5 degrees $Z\theta N := 85$ Degrees (same as existing)

Zone 2 attenuators selection

$Z2\_sec = 2.3$ This is the desired secondary reach (previously calculated)

$KZ2 := \dfrac{Z2\_sec}{\left(KZPh \cdot \dfrac{5}{In}\right)}$ $KZ2 = 2.32$

QUAD Resistive Reach setting

$Rquad = 12$ This is the desired secondary reach (previously calculated)

$KR := \dfrac{Rquad}{\left(\dfrac{5}{In}\right)}$ $KR = 12$

Residual Compensation attenuators selection

Zero sequence current compensation for ground faults is provided by the KZN factor. Zero sequence mutual compensation is not used in this application (it causes extra complexity for only moderate gain in setting accuracy).

$KZN := \dfrac{Z0Linesec - Z1Linesec}{3 \cdot Z1Linesec} \cdot KZPh$ $KZN = 0.918 + 0.019j$

$|KZN| = 0.92$ This is a reduction from the existing setting of 0.98

Switch On To Fault (SOTF) Protection.

If SOTF is enabled, it can be set to 200ms or 110 s after all poles of the line have been de-energized. The 110 s setting is intended to override automatic reclosing dead time. However it makes more sense to enable after the shorter time. Once the SOTF feature has been initiated, it remains in effect for 250ms after the line has been re-energized. The SOTF tripping options are:

a) Any distance comparator.
b) Any current level detector as long as a corresponding voltage level detector has not picked up within 20ms.
c) Either current or distance, as long as a corresponding voltage level detector has not picked up within 20ms.

SOTF := "Enabled"

SOTF_TIME := 0.20 Seconds

Elements_in_SOTF := "BOTH" (Both Comparators and current level detectors).

Power Swing Detector

This element will not be used. It will be left Blocked, and if there is a power swing, the distance elements will trip naturally.

VT Supervision

Set the VT supervision to BLOCK TRIP

Set the VT fail detection to SELF RESET.

Start Indication

This function will bring up information on the LCD screen of the relay if a start event occurs. This function will not be used.

START_INDICATION := "BLOCKED"

Communications assisted logic.

The existing communications assisted logic is permissive overreaching transfer trip, scheme **POR 1**. This scheme is familiar to Newfoundland and Labrador Hydro, and even though the POR 2 scheme offers the advantage of weak infeed echo, which would help the sensitivity to resistive faults, it is not recommended to change the existing scheme logic at this stage with years of experience on a product that is nearing the end of its useful life.

The POR 1 logic is a basic permissive overreaching transfer trip scheme but it does include current reversal timers to increase security against misoperation due to current reversal when a fault on the parallel line is cleared sequentially. The current reversal logic is achieved by a timer TP which will block permissive tripping and keying of permissive trip if the local zone 2 element does not pick up within a reasonable time of receiving permissive trip. The block will be maintained for a time delay of TD after the local zone 2 element picks up, or the received permissive trip signal resets.

The application of the current reversal timers is required only if the settings of the zone 2 comparators are greater than 1.5 times the line impedance .Although the reaches of these elements are only marginally less than 1.5 times the line impedance, there is no parallel line and there is infeed at each terminal that will minimize overreach. Therefore, the current reversal logic is not required, and the recommended default settings are as existing

$TP := 98$ ms

$TD := 0$ ms

Comparison of Existing (red) and Proposed alternative (ALT) settings.

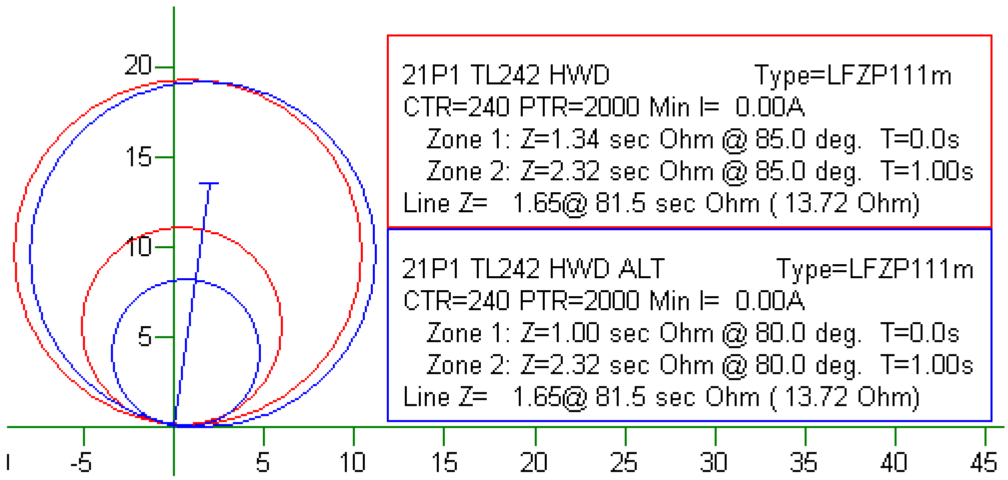


Figure 6 - Comparison of phase distance characteristics

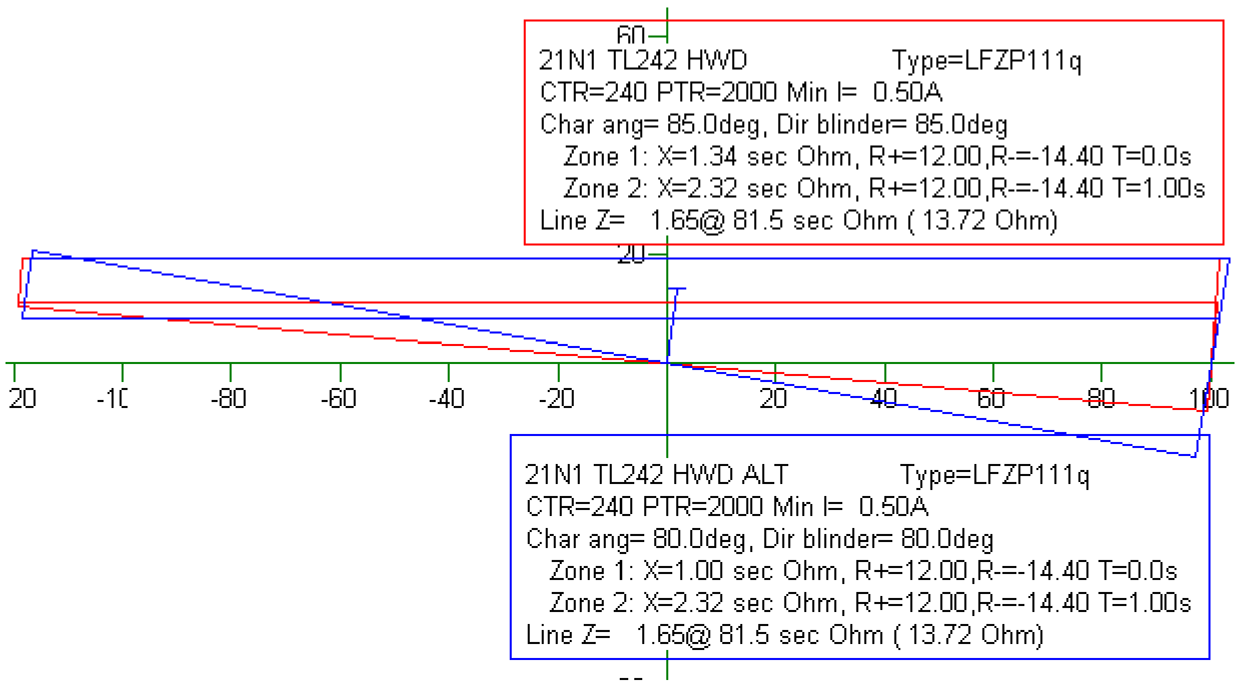


Figure 7 - Comparison of ground distance characteristics

Protection Review for Five 230 kV Transmission Lines

Appendix W
Detailed settings review for HWD TL242 "P2" protection.

Settings recommended to be changed from existing are highlighted.

Prepared for:
Newfoundland and Labrador hydro

Prepared by: C. F. Henville, Henville Consulting Inc.

Scope

To review the existing settings of the P1 protection systems for the Hardwoods (HWD) terminal of circuit TL242. This 230 kV transmission circuit is from HWD to Holyrood (HRD). The circuit runs parallel to Circuit TL201 and TL218 for parts of its length.

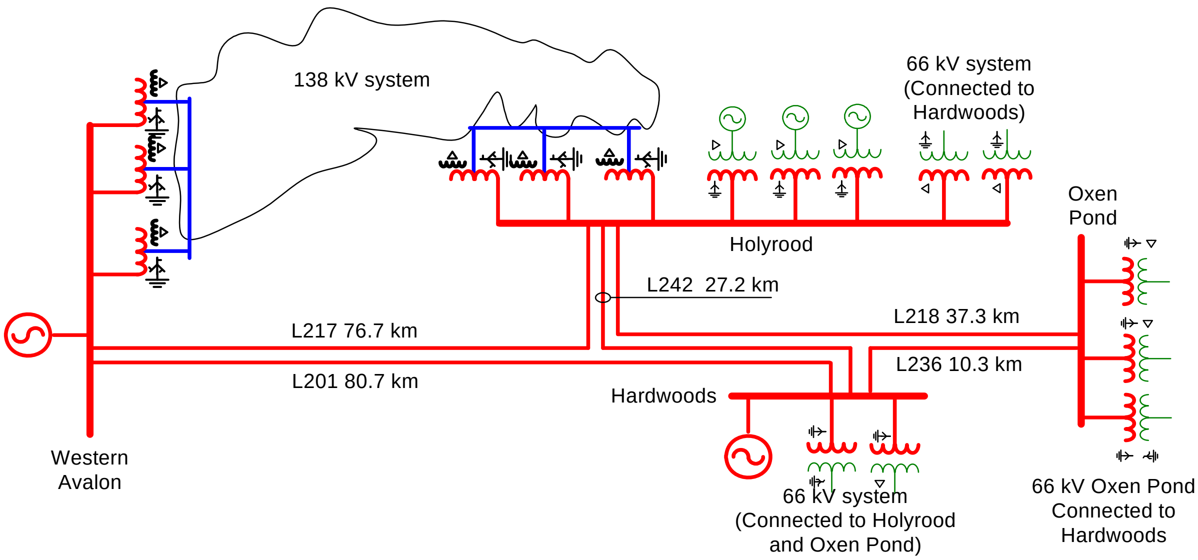


Figure 1 - System Single Line Diagram

Existing P2 protection systems are SEL321 systems with permissive overreaching transfer trip and single phase tripping and reclosing. Automatic reclosing is provided by external logic.

Definitions

$MVAbase := 100$ $\quad$ $kVbase := 230$ $\quad$ $Ibase := \dfrac{MVAbase \cdot 1000}{kVbase \cdot \sqrt{3}}$ $\quad$ $Zbase := \dfrac{kVbase^2}{MVAbase}$

$j := \sqrt{-1}$

Instrument Transformers

Two breakers are provided at each line terminal.

CT ratio is: $CTR := \dfrac{1200}{5}$ $\quad$ VT ratio is: $VTR := \dfrac{2000}{1}$

Accuracies of instrument transformers are not reviewed. Since this protection has been in service for more than 10 years, it is assumed that experience has shown they are satisfactory. Fault levels are not changing from the initial application so duties of maximum currents through CTs have not increased significantly.

Fault Study Results

Using ASPEN OneLiner Case "**NL HYDRO WITH MUTUALS FOR EAST COAST 230 kV LINE PN REVIEW 8 DEC.OLR**" with zero sequence mutual coupling added. Faults are simulated from "From a linear network solution" fault option with loads and shunts ignored.

Minimum fault current seen by each terminal (phase to phase, and SLG with 0 ohm fault resistance).

At HWD, with TL201 out of service, with sources modelled connected to the 66 kV side, there will be a weak source of positive sequence fault current at that station. There will be some infeed from the 66 kV side.

$I3Pmin := 380$ A $\quad ISLGminPH := 536$ A $\quad ISLGmin0seq := 698$ A

Calculate the minimum source impedances behind each terminal. This will be with all generation on line, with the TL236 in service and with the remote end of the line open.

Minimum source impedance behind HWD $\quad Z2minHWD := 2.38 + j\cdot 29.83$ ohms primary

$Z0minHWD := 0.777 + 13.944j$ ohms primary

Minimum source impedance behind HRD $\quad Z2minHRD := 0.99 + j\cdot 21.04$ ohms primary

$Z0minHRD := 0.3267 + 8.624j$ ohms primary

<u>Line impedances</u>.

Line impedances (per unit on 230 kV, 100 MVA base):

$Z1L242 := 0.00383 + j\cdot 0.02565 \qquad Z0L242 := 0.0129 + j\cdot 0.09653$

$Z1Line := Z1L242 = 3.83\times 10^{-3} + 0.026j$ pu $\qquad Z0Line := Z0L242 = 0.013 + 0.097j$ pu

Converting the per unit values to primary ohms gives

$Z1Linephys := Z1Line\cdot Zbase \qquad Z0Linephys := Z0Line\cdot Zbase$

$Z1Linephys = 2 + 13.6i$ ohms primary $\qquad (Z0Linephys) = 6.8 + 51.1i$ ohms primary

Converting primary ohms to secondary ohms gives:

$Z1Linesec := Z1Linephys\cdot\frac{CTR}{VTR} \qquad Z0Linesec := Z0Linephys\cdot\frac{CTR}{VTR}$

$|Z1Linesec| = 1.65$ ohms sec $\qquad arg(Z1Linesec) = 81.5\cdot deg$

$|Z0Linesec| = 6.182$ ohms sec $\qquad arg(Z0Linesec) = 82.39\cdot deg$

Load Data

From 2011 System summer load case provided in start up information, the peak load (sum of TL242 and TL201) is giv
as 340 MVA (split between TL242 and TL201). In the event of sudden loss of one line, peak load will be the sum of bo
line loads until operators can adjust loads. Therefore it might be assumed that peak load for a short duration is 340 MV

$Smax\_TL242 := 230$ MVA $Smax\_TL201 := 110$ MVA $Smax := Smax\_TL242 + Smax\_TL201 = 340$ MVA

P2 Relay Settings

Minor changes to the set line impedances are recommended to assist fault locations.

$Z1MAG := |Z1Linesec|$ $Z1MAG = 1.65$ $Z1ANG := \dfrac{\arg(Z1Linesec)}{deg}$ $Z1ANG = 81.5$

$Z0MAG := |Z0Linesec|$ $Z0MAG = 6.2$ $Z0ANG := \dfrac{\arg(Z0Linesec)}{deg}$ $Z0ANG = 82.4$

$LL := 37.29$

In order to obtain sensitivity to 100 ohm single line to ground faults and to more faults, when TL236 is out of service), the echo function will be needed. Enable two forward and one reverse zone.

$PMHOZ := 3$ $GMHOZ := 3$ $QUADZ := 3$

$DIR1 := F$ $DIR2 := F$ $DIR3 := R$

Mho phase distance functions

Zone 1

NL Hydro normal practice is to set Zone 1 reach to 85% of line impedance. This will be OK if line is long and voltages for line end fault are greater than 20% of nominal. Check the maximum source impedance to a fault at the HWD Station bus under light load conditions with TL201 out of service. From ASPEN OneLiner, voltage at HWD for a 3 phase fault at HRD is 0.04 per unit. Since the voltage is less than 20%, this line is considered short, and a reduced zone 1 reach is recommended to increase security. Choose a setting of 80% of nominal.

$Z1P := 0.8 \cdot |Z1Linesec|$ $Z1P = 1.32$ Ohms secondary

Existing setting of 1.34 ohms is a little too high, and should be reduced. $Z1P = 1.32$ Ohms secondary

Zone 2

NL Hydro normal practice is to set Zone 2 reach to125%-130% of line impedance

Existing setting is 2.32 ohms secondary (about 140%) and is OK. It is better to have a longer zone 2 reach than shorter for a short line.

$Z2P := 1.41 \cdot |Z1Linesec|$ $Z2P = 2.32$ Ohms secondary

As can be seen from Figure 2, this element does not overreach the zone 1 on TL218 out of HRD without infeed. With infeed, the HWD reaches even less past HRD.

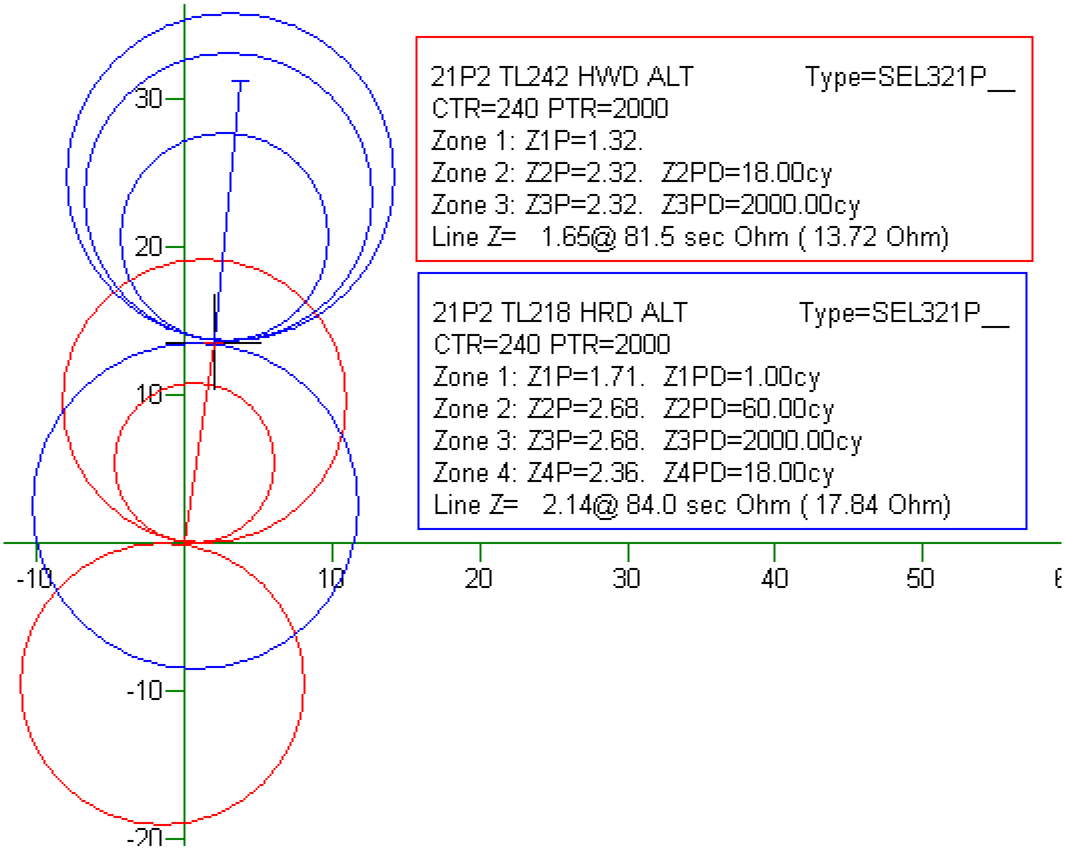


Figure 2 - HWD TL242 Zone 2 Underreaches HRD TL218 Zone 1 without infeed.

Because there is no danger of overreaching the remote instantaneous protection, choose the normal zone 2 time delay setting.

$Z2PD := 18$ Cycles Same as existing

Zone 3

Set Zone 3 reverse element to reach further behind this terminal than the remote Zone 2. This function adds security for external faults. The element should always be more sensitive than the forward looking Zone 2 at the remote terminal. Set it the same as the remote Zone 2 (in primary ohms) using the line impedance as margin.

$Z2\_rem\_pri := 19.33$ $Z3P := Z2\_rem\_pri \cdot \frac{CTR}{VTR}$ $Z3P = 2.32$ Ohms secondary

$\frac{Z3P}{|Z1MAG|} = 140.897 \cdot \%$ of line length This is a much higher than the existing setting, but provides additional security.

Mho phase distance current supervision

If the current supervision elements can be set above load, they will be secure in the event that potential is lost. However given that loss of potential logic is available, it is recommended that only the zone 1 current supervision function be set above load. If potential is lost, it will be able to block tripping by Zone 2 before it trips on time delay or receives a permissive trip from the remote terminal.

For the point of view of current supervision being above maximum load, there is no need to worry about abnormal conditions. It would be a double contingency for the VT signal to be lost while the parallel line was out of service. Therefore, consider a maximum load of 230 MVA (with TL201 in service). The current supervision elements for the phase distance functions measure phase to phase currents.

$IPPmax\_normal := \dfrac{Smax\_TL242 \cdot 1000}{kVbase}$ $IPPmax\_normal = 1000$ A primary

The current supervision elements use phase to phase currents for supervision of the phase distance functions; so the minimum phase to phase fault current will be root three times the minim phase fault current. Choose a margin of 50% of the minimum phase to phase fault current for dependability.

$IPPmin := 0.5 I3Pmin \cdot \sqrt{3}$ $IPPmin = 329$ A primary

It is not possible to set the current supervision element for the zone 1 element higher than maximum load current and still ensure that it is dependable for faults when TL236 is out of service. Choose the minimum setting for dependability, and hope the LOP function will be fast enough to block the zone 1 in the event of an LOP event.

$'50PP1 := 1.$ A Sec $'50PP1 \cdot CTR = 240$ A primary

Since we will be applying weak source echo, we need to set the Zone 2 elements no more sensitively than the remote looking zone 3 at the HRD terminal. The remote terminal CT ratio is the same as at this terminal, so the minimum setting of the current supervision elements at both terminals will be appropriate.

$'50PP2 := 2$ A Sec $'50PP3 := 1$ A Sec

The zone 1 and zone 2 supervision element settings are slightly more sensitive than existing, but are better for dependability.

Ground Distance Protection

The reach of the ground distance functions will be affected by mutual coupling to the parallel lines. These functions will tend to underreach the remote bus while the parallel lines are in service, and overreach the remote bus if a parallel line is out of service and grounded at both ends. Figure 3 shows that for a remote close in fault at HRD, with TL242 out of service and grounded, the apparent impedance of the line is reduced to about 1.59 ohms secondary instead of the nominal 1.65 ohms. This is 96% of the actual line impedance.

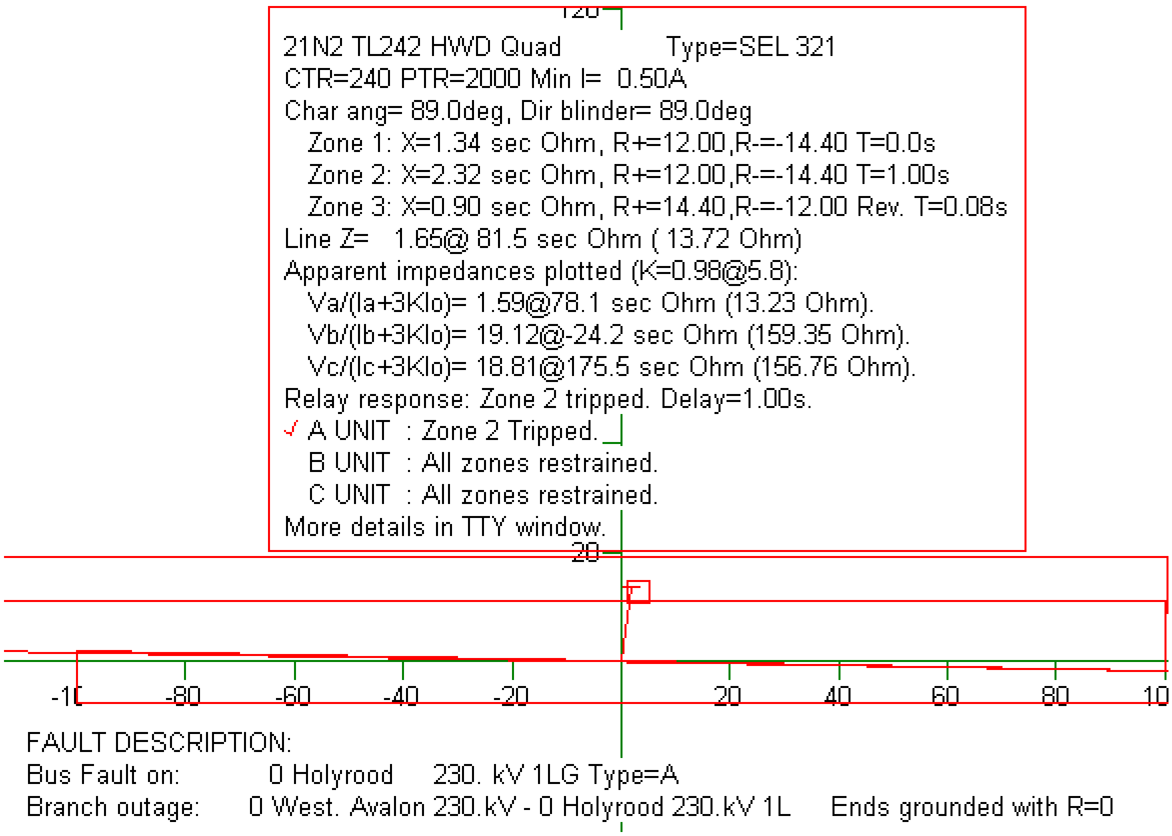


Figure 3 - Apparent impedance to a fault just beyond the remote terminal is reduced by 4% when TL217is out of service and grounded at both ends. Existing relay settings modeled in this figure.

The reach of the zone 1 should be reduced to less than 85% of the line impedance to make it more secure against misoperation for a fault. Considering that this line is short, choose a setting of 75% of line which will underreach the remote bus by 21% when TL217 is out of service and grounded at both ends.

Let the per unit reach of the Zone 1 function be m% of the line. $m := 0.75$ per unit

$Z1MG := \mathrm{round}(m \cdot |Z1Linesec|, 1)$ $\quad Z1MG = 1.2$ Ohms secondary

$XG1 := Z1MG$ $\quad XG1 = 1.2$ Ohms secondary

This is a little less than existing.

Zone 1 Resistance

The resistive reach of the Zone 1 quad should provide enough sensitivity to trip the local terminal immediately without waiting for permission from the remote terminal for a severe fault that depresses the voltage significantly. Further, it should not allow the function to reach beyond the remote terminal due to errors in relay measurement or CT or VT. In general, a reasonable limit for resistive reach of a zone 1 function set at 85% of the line is 4 times the reactive reach. In the case of this line, the maximum recommended resistive reach for a zone 1 function set at 80% of the line will be calculated, and used as the limit for secure resistive reach.

XG1 is set at m per unit of the transmission line. The imaginary component of the line is

$ImXG1sec := Im(Z1Linesec)$ $\quad ImXG1sec = 1.628$ ohms

The maximum advisable resistive reach can be found from the equation (3) in **Appendix A Quadrilateral Reactive Reach Versus Resistive Reach Setting Guideline** from the paper **Digital Communications for Power System Protection: Security, Availability, and Speed.** This paper is obtainable at www.selinc.com.

From this equation, the maximum advisable resistive reach, assuming angular maximum errors of 3 degrees, in measurement by CTs, VTs and the relay, can be determined.

$RG1 := round[(1 - m) \cdot 20 \cdot ImXG1sec, 2]$ $\quad RG1 = 8.14$

This is the max. secure setting for the resistive reach but is below the proposed zone 1 resistive reach setting.

Use a maximum setting of 6 ohms for RG1 $\quad RG1 := 6$ ohms secondary

With a resistive reach setting of 6 ohms, the HWD Zone 1 quad element will see an 40 ohm resistive SLG fault at close in (as shown in Figure 4). The Zone 1 element in the P1 protection and the Zone 2elements in this protection and the P1 protection will be depended upon to sense faults with resistance up to 100 ohms.

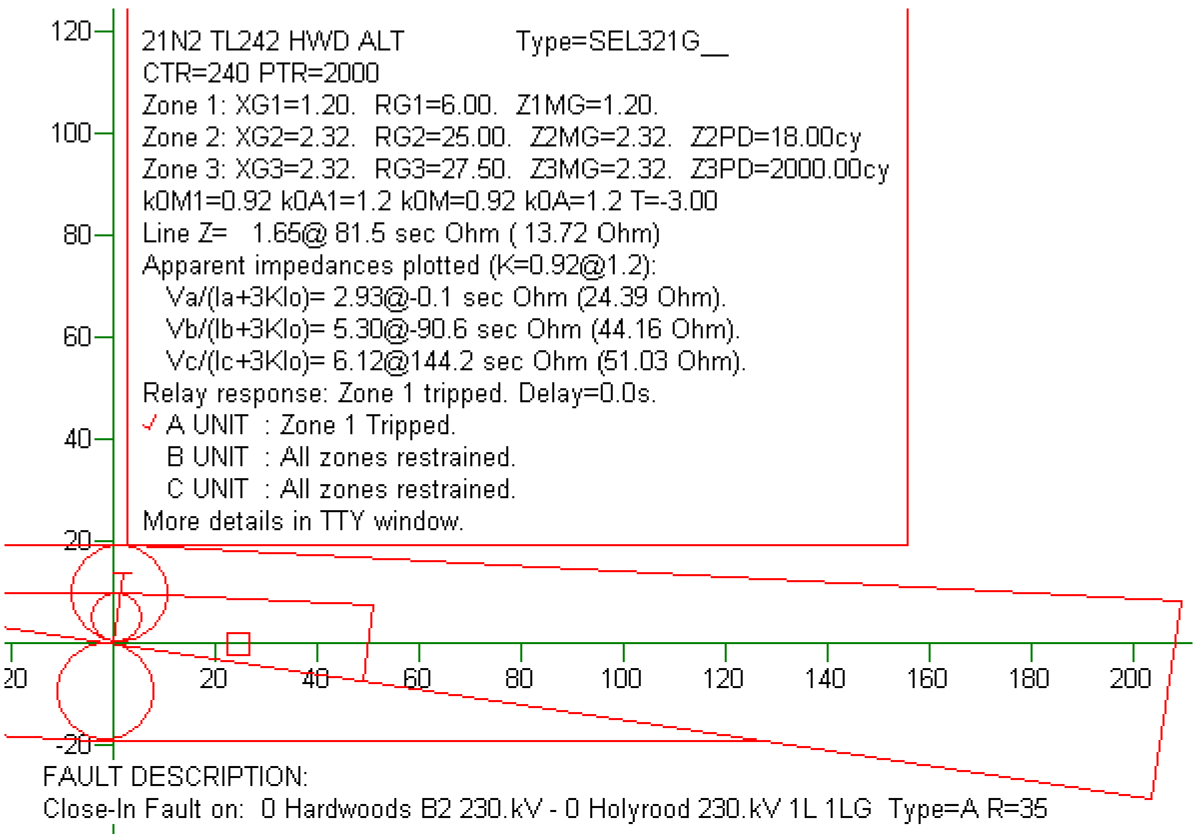


Figure 4 - HWD Zone 1 function if set with 16 ohm resistive reach, operates for a 35 ohm SLG fault close in to the local terminal.

Zone 2 Ground Distance Protection

The Zone 2 ground distance function will need to be set longer than the Zone 2 phase distance protection function because it will tend to underreach the remote terminal while the parallel line is in service. By simulation in ASPEN OneLiner it is found that the apparent impedance to a zero ohm fault close in to the remote terminal is 1.84 ohms secondary, or 11% more than the actual line impedance. The reach of the Zone 2 ground distance element should be set at least to 1.25 times the apparent impedance. The existing setting is 126% of the apparent impedance, and this will be acceptable.

$ZSLG\_remote := 1.84$ $\quad Z2MG := 1.26 \cdot ZSLG\_remote = 2.32$ $\quad$ Choose a setting of 2.32

$Z2MG := 2.32$ $\quad Z2MG = 2.32$ $\quad$ Ohms secondary $\quad Z2MG \cdot \frac{VTR}{CTR} = 19.333$ Ohms primary

The quad element reactive reach will be set similarly to the mho.

$XG2 := Z2MG$ $\quad XG2 = 2.32$ $\quad$ Ohms secondary

It would be desirable to set the resistive reach of the quad element to sense a 100 ohm SLG fault at 75% of the line with the local terminal weak. This would ensure overlap with the zone 1element at the remote terminal. However, that would require too much resistive reach. Therefore choose a setting to sense a 100 ohm SLG fault just past the mid point of the line with the local terminal normal, and depend on the echo function to provide coverage for high resistance faults in the region where the remote zone 1 won't operate. If this terminal is weak, we will need to depend on sequential clearing of high resistance faults.

By trial and error from ASPEN it is found that a resistive reach of 25 ohms secondary will sense a 100 ohm SLG fault with an overlap with a similarly set remote zone 2. See Figure 5. This will give positive overlap with the zone 2 element at the remote terminal. However since it will not overlap the Zone 1 element at the remote terminal, the permissive trip echo function will be required to ensure that a fault that is seen by the zone 2 element at only one terminal will still be cleared by the permissive trip logic.

Therefore, to avoid extremely large resistive reaches, and to retain sensitivity to 100 ohm resistive SLG faults, it is recommended that the echo function be enabled at both terminals.

$RG2 := 25$ $\quad$ Ohms secondary

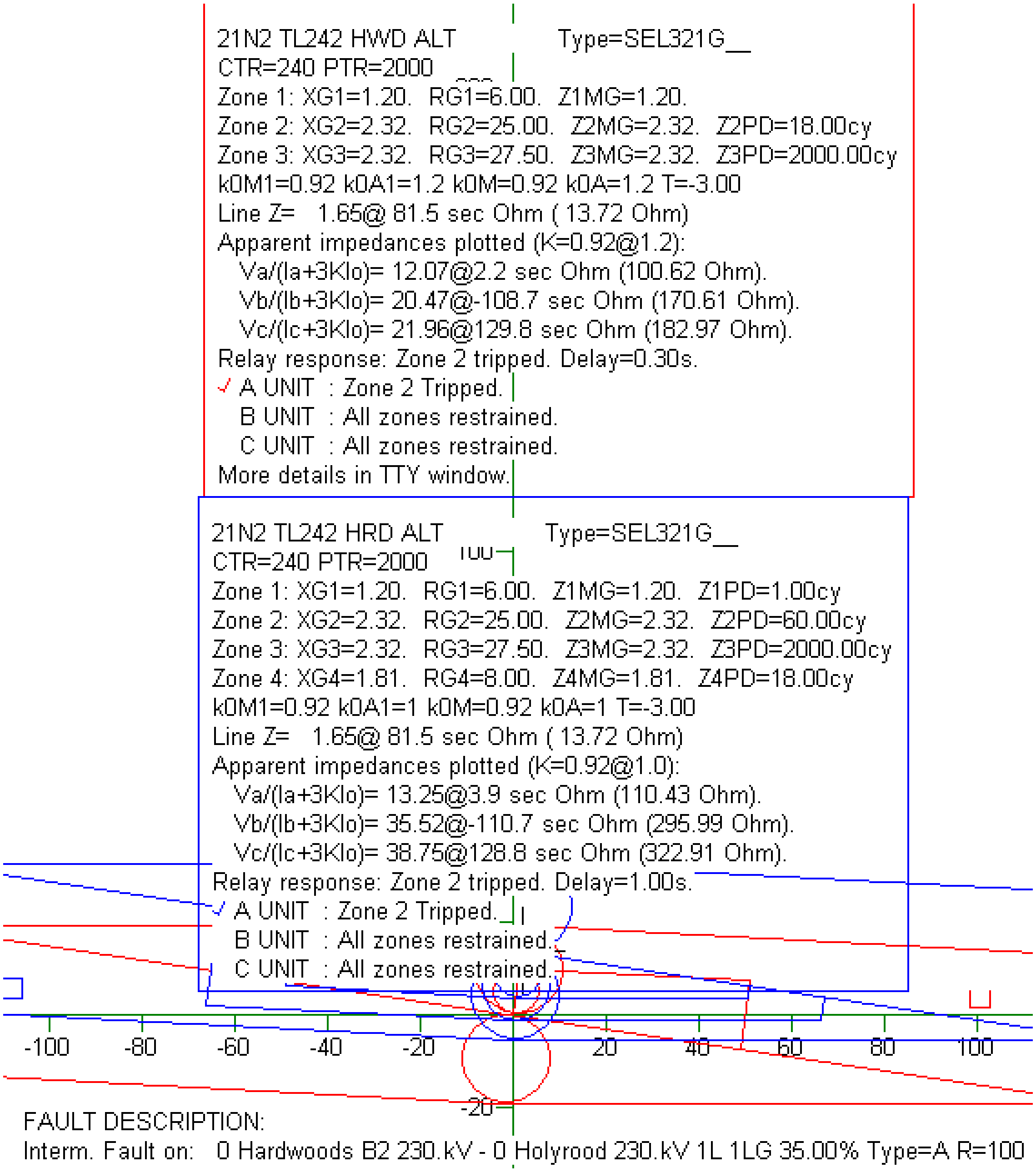


Figure 5 - Quad elements overlap with remote quad elements and operate for 100 ohm resistive SLG near the mid line location.

Check that this resistive reach won't cause the zone 2 function to trip while a parallel line is open single phase, with heavy power flow. See Figure 6. Unusually heavy power flow has been simulated to challenge security.

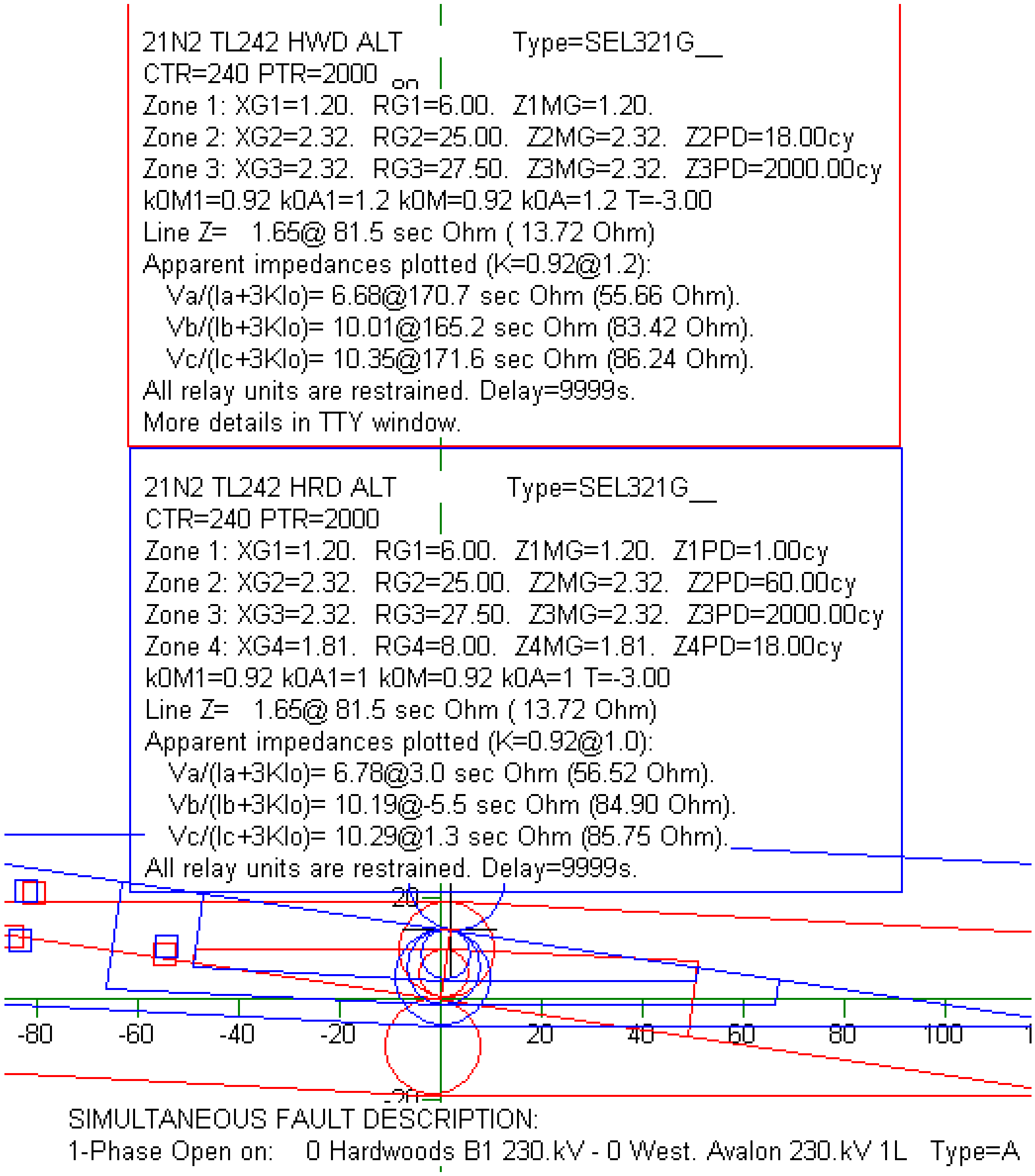


Figure 6 - Quad elements are secure with extremely heavy load flow (600 MVA in TL242 and 244 MVA in TL201) while TL201 is open single pole.

Zone 3

The zone 3 ground mho function will be set using the same principles as the zone 3 phase distance function. Use the setting for local zone 2 in secondary ohms as the remote zone 2.

$Z2MGrem := 19.333$ Ohms Primary $\quad Z3MG := Z2MGrem \cdot \frac{CTR}{VTR}$

$Z3MG = 2.3$ Ohms secondary

$\frac{Z3MG}{|Z1MAG|} = 140.9 \cdot \%$ of line length

This is much higher than the existing setting, but provides additional security.

$XG3 := Z3MG \quad XG3 = 2.32$ Ohms secondary

Set the Zone 3 quad resistive reach at 10% more than the remote Zone 2. Although the remote zone 2 has a different CT ratio, the setting is the same as the local zone 2 in primary ohms. Therefore use the setting for local zone 2 in secondary ohms as the remote zone 2.

$RG2rem := RG2$ Ohms secondary $\quad RG3 := RG2rem \cdot 1.1 \quad RG3 = 27.5$ Ohms secondary

Ground distance current supervision

Since there is no concern about these elements operating on load, even with loss of potential, set all current supervision elements at minimum except zone 2. Zone 2 must be set at 1 A to retain coordination with Z3 ground elements at HRD.

'50L1 := 0.5 A Sec '50L2 := 1 A Sec '50L3 := 0.5 A Sec

'50G1 := 0.5 A Sec '50G2 := 1 A Sec '50G3 := 0.5 A Sec

Note that due to heavy infeed of zero sequence currents from the local terminal for close-in faults, the ground overcurrent detectors will not operate for faults with more than a small amount of resistance close to the remote terminal. Therefore, we will have to rely on sequential clearing for that type of fault. However setting the current supervision at minimum(except for zone 2) allows maximum sensitivity.

Zero sequence current compensation

The zero sequence current compensation could be adjusted to compensate for the significant amount of mutual coupling. However as discussed in the settings of reaches of the ground distance elements we will accept underreach of the Zone 2 function for the normal case by setting it at 125% of the apparent impedance for a remote fault. Set the zero sequence current compensation as usual.

$$k01M := \left(\left| \frac{Z0Line - Z1Line}{3 \cdot Z1Line} \right| \right) \qquad k01M = 0.92$$

$$k01A := \left(\arg\left(\frac{Z0Line - Z1Line}{3 \cdot Z1Line} \right) \right) \qquad k01A = 1.2 \cdot deg$$

Set the overreaching zones the same as zone 1 $\quad k0M := k01M \quad k0A := k01A$

$k0M = 0.92 \quad k0A = 1.2 \cdot deg$

Settings are slightly different from existing due to small changes in line data.

Non Homogenous Angle Setting

Compare the angle of the remote zero sequence source impedance with the total zero sequence source impedance to the fault to determine this setting.

$$T := \arg\left(\frac{Z0minHWD + Z0Linephys + Z0minHRD}{Z0minHRD}\right) = -4\cdot deg \qquad T = -4\cdot deg$$

Out of step blocking and tripping

Not used in this application. There is a danger of out of step conditions arising. Historically no action has been taken to provide special tripping or blocking functions. Natural tripping during swings is accepted.

Load Encroachment logic

Check loadability of the Zone 2 phase distance element assuming worst case power factor of 0.87 simultaneous with worst case depressed voltage of a stressed system of 0.85 per unit. Note that units of kV squared match units of MVA. Note that quadrilateral elements are only used for the ground distance functions that are not sensitive to balanced three phase load. Therefore no need to worry about the reach of the quadrilateral elements.

$$Zloadmin := \frac{(0.85kVbase)^2}{Smax} \qquad Zloadmin = 112.412$$ Ohms primary (assume worst case at 30 degrees)

Maximum reach of the Zone 2 element is at the line angle of 81 degrees. At 30 degrees, the reach will be given by

$$Z2load := Z2P \cdot \cos[(Z1ANG - 30)deg] \qquad Z2load = 1.445$$ ohms secondary

$$Z2load \cdot \frac{VTR}{CTR} = 12.04$$ ohms primary

Since the reach of the Zone 2 element at 30 degrees is less than the apparent impedance of the maximum load, there is no need to apply load blinding logic. See Figure 7

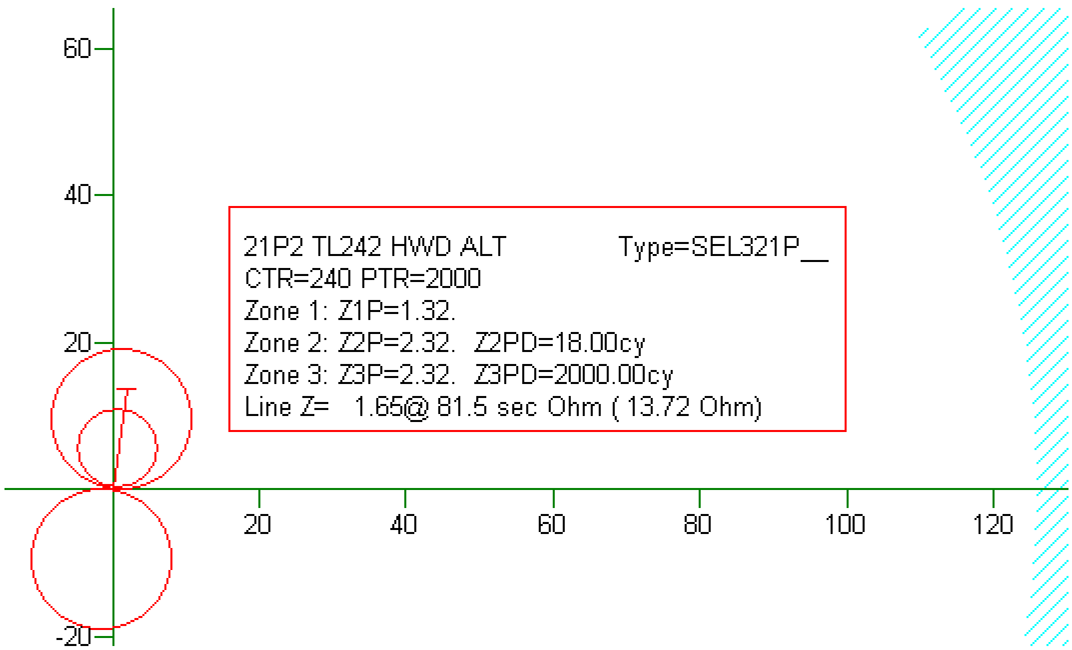


Figure 7 -Load impedance with respect to proposed new Mho function reaches.

Ground directional element

The SEL-321 application example recommends finding the minimum source impedance behind the terminal and setting the reverse and forward boundaries of the negative sequence directional element at the 1/3 and 2/3 points respectively.
In the negative sequence plane, the sum of the two source impedances and the line impedance is:

$Z2total := Z2minHWD + Z1Linephys + Z2minHRD$

The 1/3 point is $Z2\_1\_3 := \frac{Z2total}{3}$ The 2/3 point is $Z2\_2\_3 := \frac{2Z2total}{3}$

$Z2Rpri := Z2\_2\_3 - Z2minHWD$ $Z2Rpri = 1.217 + 13.129j$

$Z2Fpri := Z2\_1\_3 - Z2minHWD$ $Z2Fpri = -0.581 - 8.35j$ Desired set point for Z2F is negative.

Converting the primary impedances to secondary ohms

$Z2R := Z2Rpri \cdot \frac{CTR}{VTR}$ $|Z2R| = 1.582$ Ohms secondary $\arg(Z2R) = 84.703 \cdot deg$

$Z2F := Z2Fpri \cdot \frac{CTR}{VTR}$ $|Z2F| = 1.004$ Ohms secondary $\arg(Z2F) = -93.982 \cdot deg$

Rounding Z2F and rounding down Z2R gives:

$Z2F := -1.0$ Ohms secondary $Z2R := 1.5$ Ohms secondary

These are much lower than the existing settings but are required to avoid overlap of forward and reverse looking elements at opposite ends.

Set the current level detectors at minimum level that will allow operation of the ground distance elements.

Due to the very small zero sequence current contribution to a single line to ground fault at the remote terminal, the negative sequence current contribution will always be higher than the zero sequence. Therefore there is no point in setting the forward looking negative sequence overcurrent elements any more sensitively than the zero sequence ground overcurrent supervision of the ground distance elements.

$'50QF := '50G2$ $'50QF = 1$ A secondary (This is higher than existing due to the need to coordinate with the remote reverse looking 50QR)

Set the supervision function for the reverse looking element to be the same as, or a little more sensitive than the forward looking supervision element at the remote terminal.

$'50QR := 0.5$ A secondary

The positive sequence current restraint (a2) factor should be set just smaller than the ratio of the maximum load current (positive sequence) to the most sensitive current supervision element (50QR).

$I1maxpri := \frac{Smax \cdot 1000}{kVbase \cdot \sqrt{3}}$ $I1maxsec := \frac{I1maxpri}{CTR}$ $I1maxsec = 3.556$

Bearing in mind that the 50QR setting is in units of 3*I2

$\frac{'50QR}{3 \cdot I1maxsec} = 0.047$ Choose a value of $a2 := 0.05$ The proposed is the same as the existing setting (0.05).

Phase time overcurrent element

This element is not used

Residual time overcurrent element

This element is used to provide the most sensitive backup protection. It will be a non directional element.

Set pickup to sense a higher resistance than 100 ohm SLG in the middle of the line with equal zero sequence current infeed from both ends. Choose a resistance of 200 ohms arbitrarily. Use a safety factor of 2 so that operating time is not infinity at this fault level.

$SF := 2$ Desensitization factor due to remote end infeed is $Dfactor := 2$ $Rf := 200$

$$'51NPU := \text{round}\left(\frac{kVbase \cdot 1000}{\sqrt{3} \cdot SF \cdot Dfactor \cdot Rf \cdot CTR}, 1\right) \qquad '51NPU = 0.7$$

The existing setting of 0.5 A is more sensitive than required to sense this mid line fault with arbitrary resistance. Since TL206 experience with the high resistance tree fault on 28th August 2009 has shown value in the existing setting, it will be retained.

$'51NPU := 1$ A secondary

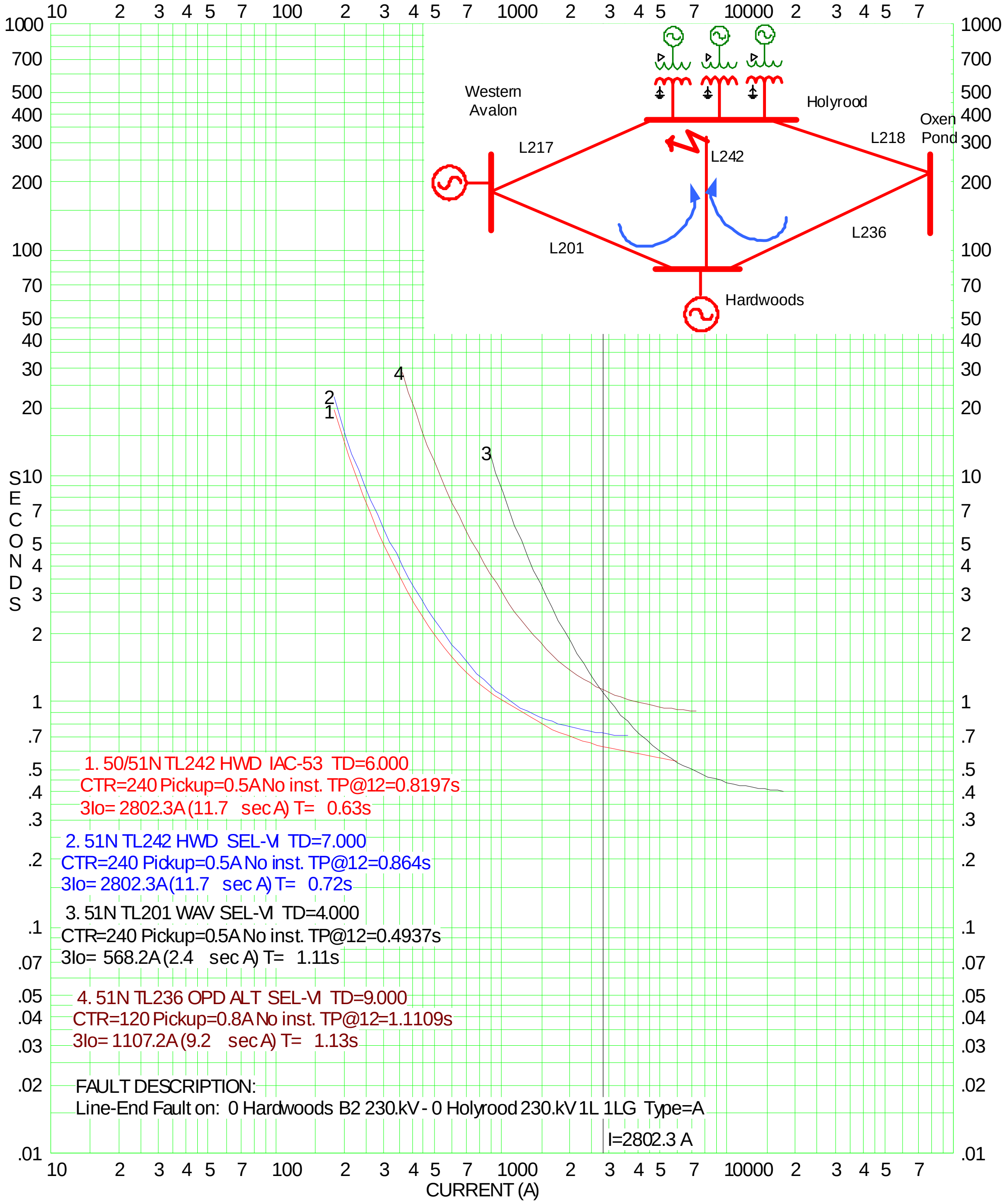
Coordination checks show that existing time dial settings will coordinate above remote protections for TL217 and TL218. See Figure 9 and Figure 10.

$'51NPU = 1$ A secondary $'51NPU \cdot CTR = 240$ A primary

$'51NTD := 7.0$ $'51NC := "U3"$ $'51NTC := "N"$ $'51NRS := "N"$

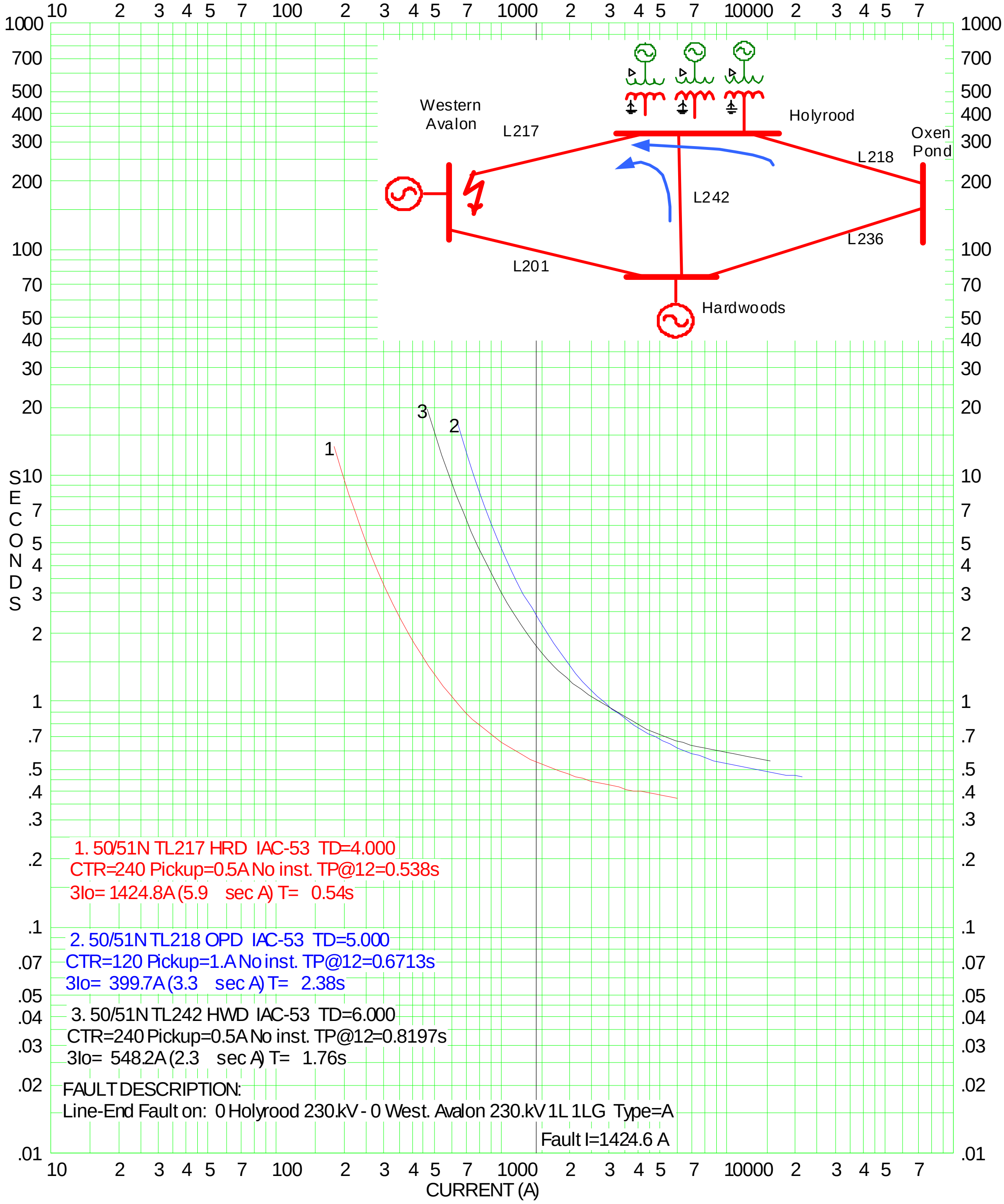
Check the coordination below the HWD TL236 and WAV TL201 51N for a line end fault on TL242 with the existing setting. This is the type of fault that will produce the most sensitivity (least desensitization) with respect to the backup protections on TL201 and TL236. see Figure 8. Note that coordination margin is small for a fault with low resistance. However, we can depend on the 0.3 second definite time zone 2 ground distance element to clear low resistance faults promptly. With the time ground overcurrent elements we are primarily concerned with high resistance faults.

Check the coordination above the HRD TL217 protection for line end faults (see Figure 9) and proposed new (slower) HRD TL218 for line end faults (see Figure 10). It can be seen that the existing setting is comfortably slower than the remote protections for a 0 ohm fault.



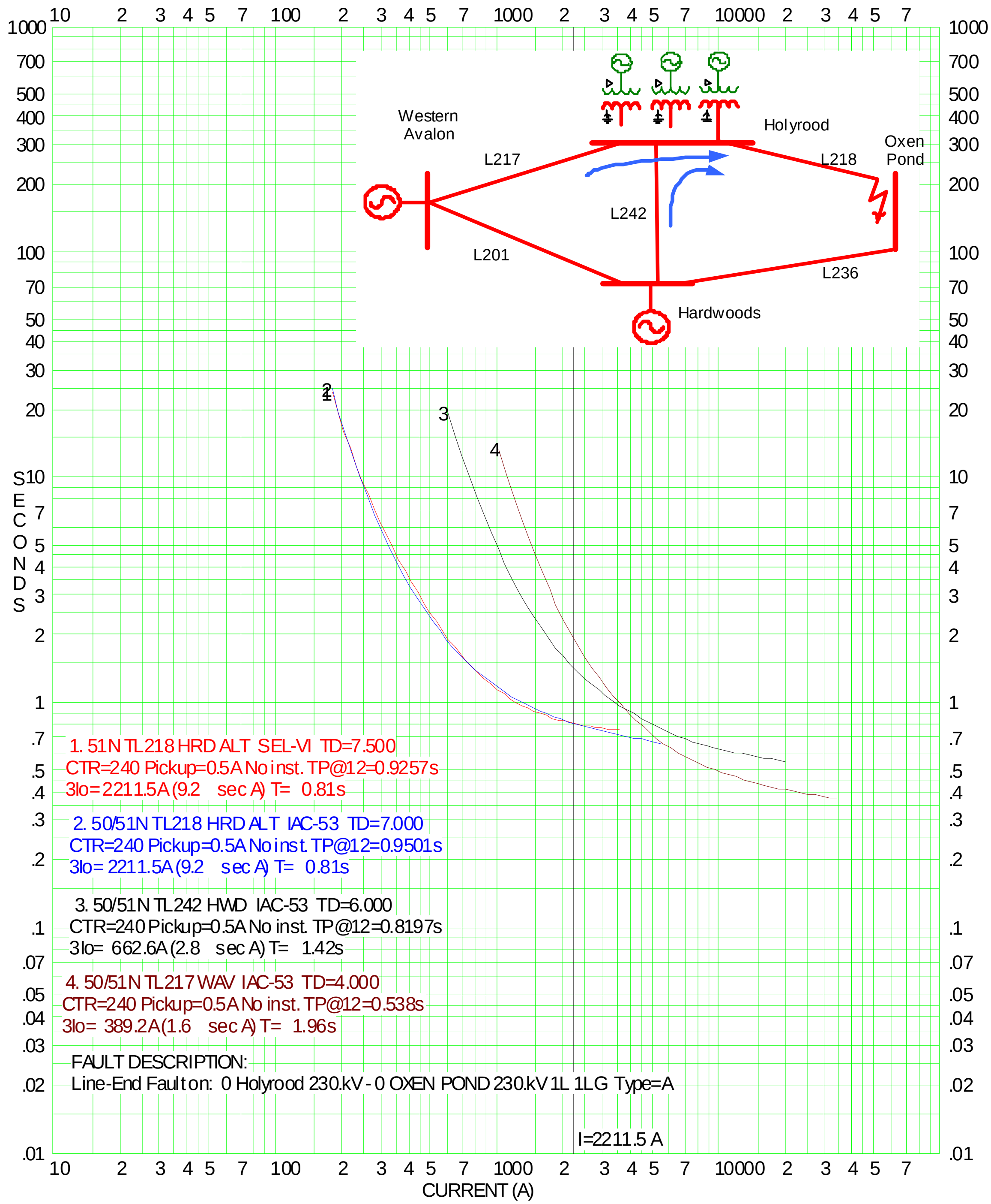
TIME-CURRENT CURVES @ Voltage 230 kV		By C. Henville
For	Coordination of TL242 51N below backup protections	No. EC230-5
Comment		Date 30 Dec 2011

Figure 8 - coordination of ground time overcurrent elements for LE TL242 fault



EC 230-6	TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For Coordination of HRD TL217 below OPD L218 and HWD L242		No. EC 230-6
Comment Two units out of service at HRD.		Date 29 Sep 2011

Figure 9 - coordination of ground time overcurrent elements for line end fault on TL217



EC 230-7	TIME-CURRENT CURVES @ Voltage 230 kV	By C Henville
For	Coordination of HRD TL218 below WAV L217 and HWD L242	No. EC 230-7
Comment Two units OOS at HRD		Date 13 Dec 2011

Figure 10 - coordination of ground time overcurrent elements for line end fault on TL218 (with proposed new, slower) TL218 settings.

Permissive Overreaching logic settings

EPOTT := "Y"

Z3RBD is set at remote breaker time plus channel reset time plus channel reset time plus zone 2 reset time. From review of fault records it appears that the breaker time is 3 cycles. Channel reset time is not easily determined from existing records but can conservatively be assumed to be 1 cycle, and relay reset time will also be about 1 cycle. Total time for Z3RBD is then 5 cycles.

Z3RBD := 5 cycles

Echo block delay timer blocks the echo after the local elements have picked up. This can be set relatively long since there is no significant need for the echo function shortly after the local terminal has just seen a fault but the remote terminal has not. Set at 10 cycles as per the example in the instruction manual.

EBLKD := 10 cycles

Echo time delay on pickup should be set to override noise on the communications so that it doesn't echo noise. Typical time according to the SEL application guide is 2 cycles. Since this delay only affects clearing time for relatively light (high resistance) faults that are sensed by zone 2 function at one end, the typical setting is acceptable.

ETDPU := 2 cycles

Echo duration should be long enough to ensure the permissive trip is received by the remote terminal and should also be shorter than the Z3RBD time to ensure that the reverse blocking will always be longer than any permissive trip received (including echo time stretching).

EDURD := 4 cycles

No need to enable week feed conversion to trip, since both terminals will be quite sensitive enough to detect high resistance faults after the remote terminal has cleared. Therefore we can accept sequential (or "step") clearing with no need for the added insecurity of weak infeed tripping.

EWFC := "N" **No other communications logic settings are required for this application.**

Switch on to Fault Settings

Switch on to fault logic will ensure the protection will operate when energizing the line onto a close-in three phase fault when there is no polarizing voltage available for the distance elements.

ESOTF := "Y"

The breaker close signal is not available to the relay. The 52A method of enable SOTF will be used. Therefore the Close end delay is not critical. Typical duration for enable SOTF is 10-15 cycles

ENCLO := "N" CLOEND := 0 EN52A := "Y" SOTFD := 15

Set 50H for high magnitude close-in multiphase faults with weakest source at HWD. It should be set less than 50% of the minimum close-in fault magnitude. Minimum close-in magnitude of a three phase fault with TL236 out of service is 1500 A. Therefore desired maximum setting for 50H is 750 A.

Imin3P_close_in := 1500

$$'50H := \frac{Imin3P\_close\_in}{2CTR} \qquad '50H = 3.125 \quad \text{A secondary}$$

Choose a setting of 6 A secondary for this element. '50H := 6 A secondary

Choose a setting for 52AEND less than the shortest reclose time. '52AEND := 30 cycles

The existing setting of 52AEND is 40 cycles. It is not known why the setting is set so long.

Residual overcurrent settings.

Tripping directly by instantaneous ground overcurrent is not applicable because it is not phase selective. However it would be helpful to monitor steady state unbalance, and issue an alarm for continuous unbalance. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50N := 1$ $\quad$ $'50N1 := 0.25$

Negative Sequence overcurrent settings.

Similar to ground overcurrent, apply a negative sequence overcurrent element to initiate an alarm for steady state unbalances. Set the detector at minimum or just at the point necessary to override normal unbalances.

$E50Q := 1$ $\quad$ $'50Q1 := 0.25$

Voltage Element Settings

Similar to unbalance current monitoring, it is helpful to have an unbalance voltage monitor to detect steady state unbalances from the voltage supply.

EVOLT := "Y"

Set the zero sequence overvoltage element at 1% of rated voltage or just at the point necessary to override normal unbalances. The zero sequence voltage element measures 3 times the zero sequence voltage.

$$'59N := 3 \cdot 0.01 \frac{kVbase \cdot 1000}{\sqrt{3} \cdot VTR} \qquad '59N = 1.992 \qquad \text{Say} \quad '59N := 2 \quad \text{V secondary}$$

Loss of Potential

Enable loss of potential settings. Advanced LOP settings are not available on this model of relay.

ELOP := "Y" $\qquad$ Time delay of 1.25 cycles is commonly used. $\qquad$ $LHWD := 1.25$

The 50 M element should be set above maximum load and below minimum fault current for a fault at the remote terminal under weak source conditions. The maximum load for this case should be normal maximum, not emergency maximum which only exists for a few minutes before the operator can act to reduce load.

$$Imax\_normal := \frac{Smax\_TL242 \cdot 1000}{\sqrt{3} \cdot kVbase \cdot CTR} = 2.406 \text{ A secondary}$$

Minimum fault current for a remote three phase fault is $\quad I3Pmin = 380 \quad$ A primary.

Minimum fault current for a remote phase to phase fault is 87% of the minimum three phase fault current level.

Dependability factor to be sure to operate for a minimum remote fault is chosen to be 1.6. $\quad DF := 1.6$

Maximum setting for 50M should be $\dfrac{0.87 I3Pmin}{DF \cdot CTR} = 0.861$

In this case a setting of 0.5 A secondary will be adequately dependable however it will not necessarily be secure in the event of a loss of potential event.

$'50M := 0.5$ A secondary

The 59QL setting should be above normal maximum unbalance and below the level expected for a blown VT fuse. For a blown fuse, one phase voltage will be lost, and the negative sequence voltage will be roughly 33% of the nominal positive sequence voltage. Choose a setting of 15% of the nominal positive sequence voltage. This will be well above any normal unbalance.

$$'59QL := \mathrm{round}\left(\frac{0.15 \cdot kVbase \cdot 1000}{\sqrt{3} \cdot VTR}, 0\right) \qquad '59QL = 10 \text{ V secondary}$$

The 59PL setting should be less than the minimum voltage to be expected for a remote bus fault under weakest source conditions. There is no minimum setting (above zero) for this function. Choose a setting equal to half the voltage drop along the line impedance at the pickup setting of the 50M element. It is recognized and accepted that this very low setting for 59PL may not adequately detect a loss of potential event, but we do not want to compromise the dependability of this protection for remote faults when this terminal is weak.

$$'59PL := \mathrm{round}[0.5 \cdot ('50M \cdot |Z1Linesec|), 1] \qquad |'59PL| = 0.4$$

Miscellaneous Scheme Settings

Pole discoordinance logic is not being used. EPOLD := "N" SPPDD := "N/A"

Enable single pole tripping by distance elements only ESPT := "Y"

Enable single pole open ESPO := "Y"

Set single pole open time delay for future SPO conditions SPOD := 0.25
Note that SPOD was short enough to allow a transient operation when TL201 was reclosed with a fault on it during the fault of 7 March 2011. This transient operation was helpful to clear the fault more quickly than it otherwise would have cleared. SEL have been asked whether the SPOD setting of 0.5 would be better to increase the security.

3 Pole open reset delay to override small discrepancies in pole closing '3POD := 0.5

Stub line protection is not required ESTUB := "N" '50MFD := "N/A"

Trip unlatch logic not applied TULO := "N"

Logic variables and Miscellaneous timers

Minimum trip duration timer is set at 9 cycles as per the application example in the SEL-321 instruction manual.

TDURD := 9 Cycles

Trip during open pole time delay should be set longer than the reclose time. Existing setting is 33 cycles. This should be extended to 66 cycles.

TOPD := 66 Cycles

Existing logic variables are not used.

Since this line is short (voltage may be low at HRD for a fault near OPD), a 1 cycle security delay in zone 1 tripping is recommended to improve the security of this function against incorrect tripping for a fault beyond the OPD terminal.

LOGIC_X := "M1P+Z1P" TXPU := 1 cycle TXDO := 0 cycles

Add the use of ZT to trigger an alarm for sustained unbalance.

LOGIC_Z := "59N+50N1+50Q1" TZPU := 1200 cycles TZDO := 0 cycles

Tripping Logic

Permissive tripping is required only for instantaneous overreaching functions. No need for any functions that trip directly. Existing 51NT word in MTCS is not required.

MTCS := "M2P+Z2G"

Existing settings for unconditional tripping must be modified to include a 1 cycle delay for zone 1 tripping.

MTU := "XT+M2PT+Z2GT+51NT"

No need for existing direct tripping zone 1 functions in the switch on to fault logic.

SOTF Tripping MTO := "M2P+Z2G+50H"

Event records will be triggered automatically by all trip events. Other event record triggers should be by starting of other elements to ensure capture of all relevant events. Events should be triggered by keying or receiving permissive trips to ensure separation of relay and teleprotection issues.

MER := "M2P+Z2G+51NP+LOP*52AA1+KEY+PT+EKEY"

Outputs

Retain existing output assignments except add the continuous unbalance alarm to OUT15.

OUT15 := "LOP*50L+ZT"

Input Contact Assignment

It would be desirable to provide phase segregated inputs to the relay so that the quadrilateral functions could be disabled during single pole open conditions. it is not known if phase segregated auxiliary switches are available on the breakers.

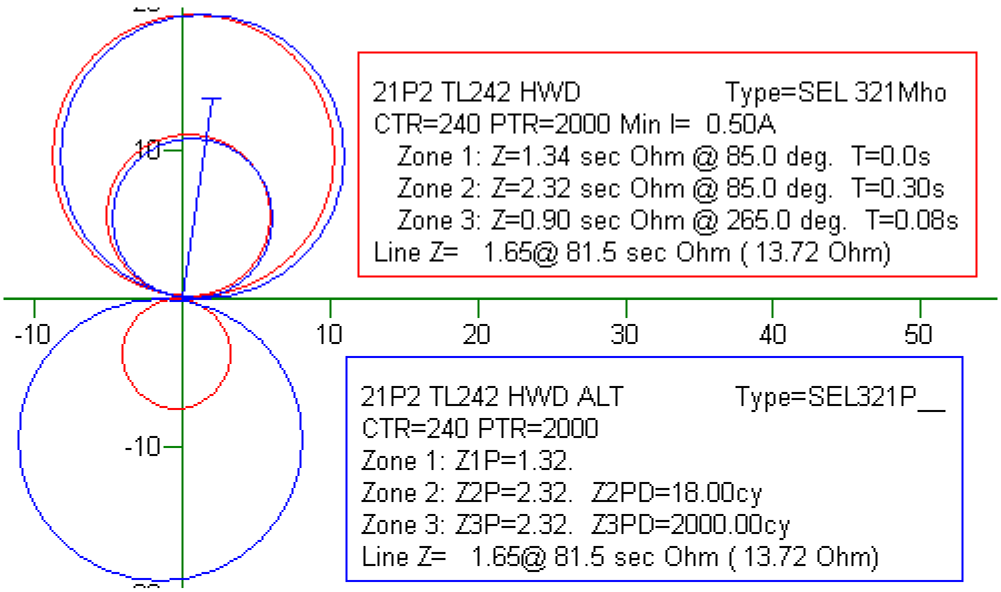


Figure 11 - Comparison between existing (red) and proposed new (blue) phase distance characteristics.

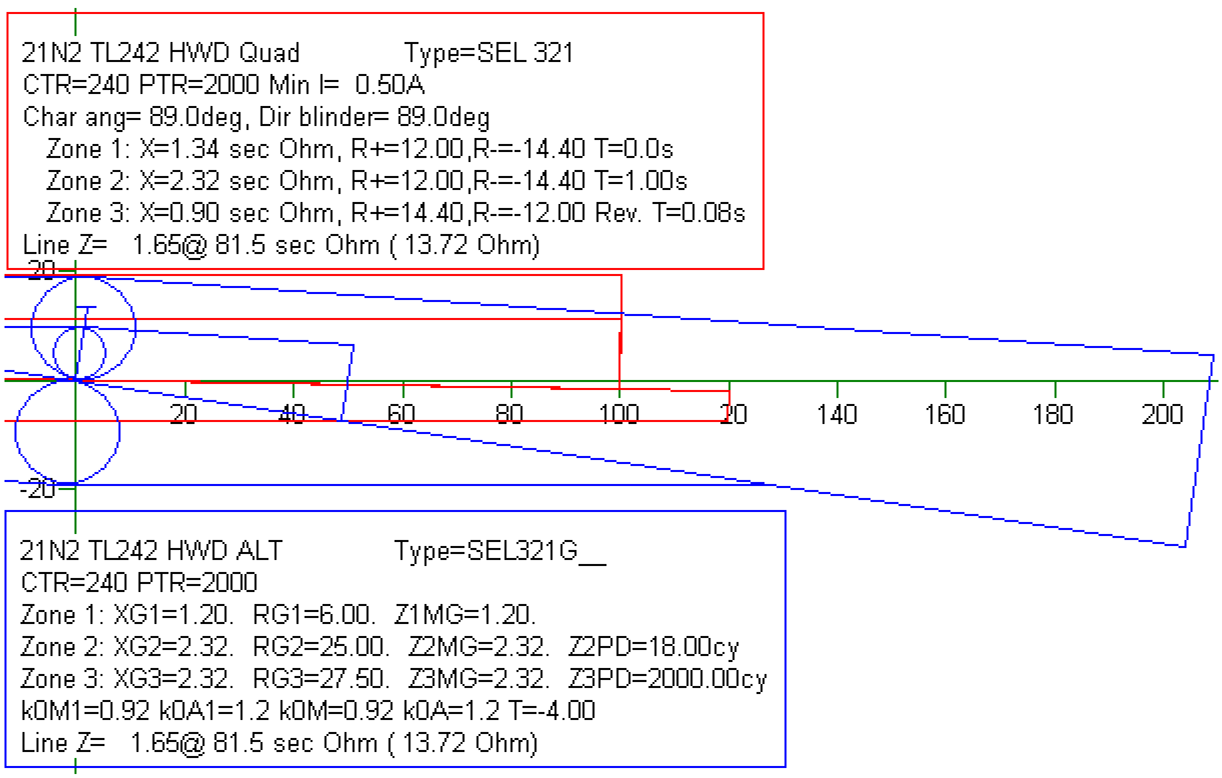


Figure 12 - Comparison between existing (red) and proposed new (blue) ground distance characteristics.