IN THE MATTER OF the *Electrical Power Control Act,* RSNL 1994, Chapter E-5.1 (the EPCA) and the *Public Utilities Act*, RSNL 1990, Chapter P-47 (the Act), and regulations thereunder;

AND IN THE MATTER OF an Application by Newfoundland and Labrador Hydro pursuant to Subsection 41(3) of the *Act*, for the approval of the replacement of the tap changer on transformer T5 at the Western Avalon Terminal Station.

TO: The Board of Commissioners of Public Utilities (the Board)

THE APPLICATION OF NEWFOUNDLAND AND LABRADOR HYDRO (Hydro) STATES THAT:

1. Hydro is a corporation continued and existing under the Hydro Corporation Act, 2007, is a public utility within the meaning of the Act and is subject to the provisions of the Electrical Power Control Act, 1994.

2. Hydro owns and operates the Western Avalon Terminal Station, located near Chapel Arm. The terminal station is critical to providing dependable service to the Avalon Peninsula. The largest transformer in this station is T5 which operates in parallel with transformers T3 and T4 to supply a significant portion of the Avalon Peninsula with reliable power.

3. In January 2014, the T5 transformer experienced a phase-to-phase fault which resulted in damage to the on load tap changer (OLTC) on the transformer. The T5 transformer is currently out of service due to the damaged OLTC.

4. Hydro's transmission planning criteria for 230/138 kV looped systems, including the Western Avalon – Holyrood 138 kV Loop, requires that there be significant transformer capacity to supply the peak load within the loop with the largest transformer in the loop not in service. This is consistent with an N-1 planning criteria. Repair to the T5 OLTC is necessary to ensure sufficient transformer capacity in the Western Avalon-Holyrood 138 kV Loop to meet transmission planning criteria.

5. Hydro is recommending replacement of the on load tap changer on transformer T5 as this is the least cost option over the long term. Details regarding Hydro's proposal to replace the on load tap changer are contained in the attached project proposal document.

6. The completion of the tap changer replacement on transformer T5 at the Western Avalon Terminal Station is required to ensure that Hydro can continue to provide safe, reliable and adequate service from this essential facility.

7. The estimated cost of this project is $1,452,500.

8. The Applicant submits that the proposed capital works and expenditures are necessary to ensure that this terminal station can continue to provide service which is safe and adequate and just and reasonable as required by Section 37 of the *Act*.

9. Therefore, Hydro makes Application that the Board make an Order approving, pursuant to Subsection 41(3) of the *Act*, the capital expenditure of $1,452,500 for the replacement of the on load tap changer on transformer T5 at the Western Avalon Terminal Station as set out in this Application and in the attached project description and justification document.

DATED at St. John's, in the Province of Newfoundland and Labrador, this 19th day of June, 2014.

Tracey Pennell

Tracey L. Pennell
Counsel for the Applicant
Newfoundland and Labrador Hydro
500 Columbus Drive P.O. Box 12400
St. John's, Newfoundland and Labrador
A1B 4K7
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Facsimile: (709) 737-1782

IN THE MATTER OF the *Electrical Power Control Act,* RSNL 1994, Chapter E-5.1 (the EPCA) and the *Public Utilities Act*, RSNL 1990, Chapter P-47 (the Act), and regulations thereunder;

AND IN THE MATTER OF an Application by Newfoundland and Labrador Hydro pursuant to Subsection 41(3) of the *Act*, for the approval of the replacement of the tap changer on transformer T5 at the Western Avalon Terminal Station.

AFFIDAVIT

I, Robert J. Henderson, Professional Engineer, of St. John's in the Province of Newfoundland and Labrador, make oath and say as follows:

1. I am Vice-President of Newfoundland and Labrador Hydro, the Applicant named in the attached Application.

2. I have read and understand the foregoing Application.

3. I have personal knowledge of the facts contained therein, except where otherwise indicated, and they are true to the best of my knowledge, information and belief.

SWORN at St. John's in the)
Province of Newfoundland and)
Labrador)
this 19 day of June 2014,)
before me:)

Barrister – Newfoundland and Labrador

Robert J. Henderson

A REPORT TO
THE BOARD OF COMMISSIONERS OF PUBLIC UTILITIES

REGISTERED PROFESSIONAL ENGINEER PEG Newfoundland and Labrador DAVID W. HICKS SIGNATURE June 17/2014 DATE NEWFOUNDLAND & LABRADOR	Electrical
	Mechanical
	Civil
	Protection & Control
	Transmission & Distribution
	Telecontrol
	System Planning

Replace T5 Tap Changer
Western Avalon Terminal Station

Newfoundland and Labrador Hydro

June 2014

newfoundland labrador hydro
a nalcor energy company

SUMMARY

This project is to replace the tap changer on transformer T5 at Western Avalon Terminal Station. This replacement will include the initial testing of the transformer, installing a new replacement tap changer, and commissioning the tap changer and transformer after replacement is complete.

The estimated cost for this project is $1,452,500.

TABLE OF CONTENTS

1 INTRODUCTION

Newfoundland and Labrador Hydro (Hydro) owns and operates the Western Avalon Terminal Station, located near Chapel Arm on the Avalon Peninsula. Figure 1 depicts the location of the Western Avalon Terminal Station. This terminal station is a critical connection point on the 230 kV network connecting hydro-electric generation with Avalon Peninsula load centers. In addition, the Western Avalon Terminal Station is the connection point for one end of the Western Avalon – Holyrood 138 kV Loop used to supply Newfoundland Power's regional customers from Blaketown to Conception Bay North and as far east as the town of Holyrood in Conception Bay South. Both Western Avalon and Holyrood Terminal Stations contain three 230/138 kV transformers. Each station contains two 41.7 MVA transformers and one 125 MVA transformer for a total installed transformer capacity of 416.8 MVA.

Figure 1: Western Avalon Terminal Station

In January of 2014, the 230/138 kV, 75/100/125 MVA transformer T5 at Western Avalon experienced a phase to phase fault which resulted in damage to the transformer's on load tap changer (OLTC). At present, Western Avalon T5 is out of service due to the damaged OLTC. Repair of the T5 OLTC is necessary to ensure sufficient transformer capacity in the Western Avalon – Holyrood 138 kV Loop to meet the transmission planning criteria. Figure 2 shows a portion of the single line diagram for the Western Avalon Terminal Station.

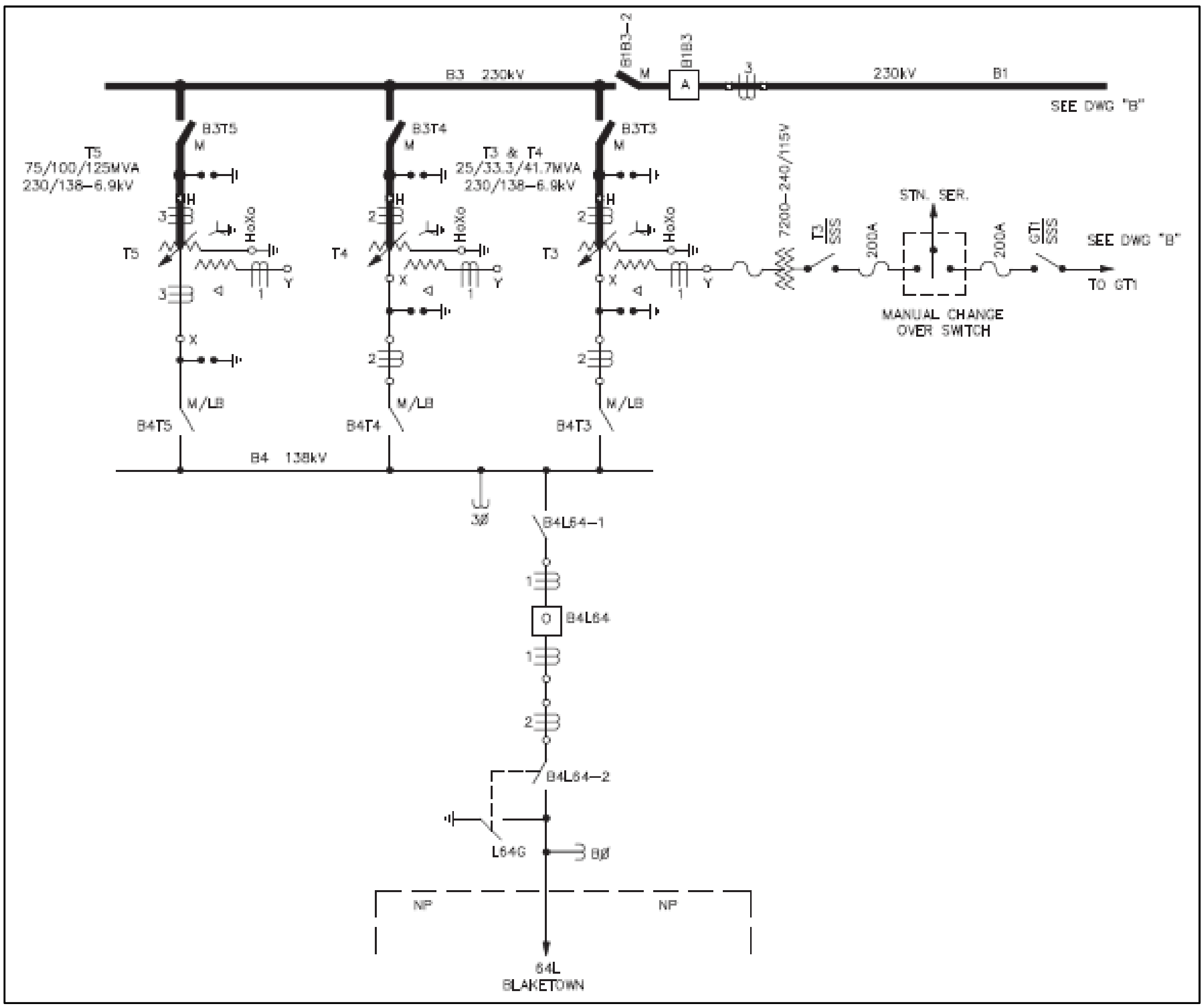


Figure 2: Portion of Western Avalon Single Line Diagram

It is noted that the last preventative maintenance performed on the T5 transformer was in 2012. This included an overhaul of the on load tap changer. There were no issues with the unit cited at that time. Figure 3 provides a picture of the Western Avalon T5 transformer.

Figure 3: Western Avalon T5 Transformer

2 PROJECT DESCRIPTION

This project addresses the replacement of the on load tap changer on the T5 transformer at Western Avalon Terminal Station. The scope of work will include the following:

2.1 Verification of transformer T5

- Drain the oil from the T5 transformer and tap changer;
- Pressurize the transformer with dry breathable air;
- Perform an internal inspection of transformer;
- Perform an internal inspection of the tap changer;
- Perform transformer winding resistance tests;
- Perform Transformer Turns Ratio Test (TTR);
- Perform Sweep Frequency Response Test on transformer; and
- Assess tests results (internal review with external validation) to verify transformer is in good condition to return to service.

2.2 Secure transformer and order parts

- Pressurize the transformer with dry air;
- Store transformer oil on site in tanks with secondary confinement via containment berms;
- Perform daily checks of the transformer dry air pressure and the containment berms under the oil storage tanks;
- Order tap changer; and
- Prepare contract documents for installation of the tap changer.

2.3 Install tap changer

- Purge the transformer of nitrogen;
- Pressurize the transformer with dry breathable air;

- Engineering to review and approve work methods for installation of new tap changer;
- Install protective barriers to protect transformer windings from welding and cutting operations to modify transformer the tank for the new tap changer;
- Modify the transformer tank;
- Remove protective barriers in order to install the new tap changer;
- Install the new tap changer into the tank; and
- Extend transformer winding leads and connect to the tap changer.

2.4 Clean-up and oil filling

- Spray down the inside of the transformer with oil;
- Jack one end of the transformer tank to pool oil for pumping out;
- Pump out the transformer;
- Wipe out the transformer;
- Perform final inspection of the transformer and work before filling with oil;
- Draw vacuum on the transformer as per transformer manufacturer recommendations;
- Refill the transformer with heated oil; and
- Degasify the transformer.

2.5 Test Transformer and Return to Service

- Engineering to consult with transformer manufacturer to determine the final tests required before energizing transformer and associated tap changer. The tests should include but not be limited to the:
    - Perform Megger Test;
    - Perform Winding Resistance Test;
    - Perform TTR Test;
    - Perform Doble Test; and

    - Execute the 6 year Preventative Maintenance (PM) on the transformer and tap changer.
- Remove isolation and energize transformer with load side disconnect open for 24 hours prior to loading transformer. Monitor transformer;
- Load transformer and monitor for another 24 hours; and
- Return to normal operation.

3 JUSTIFICATION

The 75/100/125 MVA transformer T5 at Western Avalon Terminal Station is one of six 230/138 kV transformers in the Western Avalon – Holyrood 138 kV Loop. Western Avalon also contains two 25/33.3/41.7 MVA transformers (designated T3 and T4). The Holyrood Terminal Station contains two 25/33.3/41.7 MVA, 230/138 kV transformers (designated T6 and T7) and a 75/100/125 MVA, 230/138 kV transformer (designated T8). The total installed transformer capacity in the Western Avalon – Holyrood 138 kV Loop equals 416.8 MVA. The transmission planning criteria applied to this loop requires that there be sufficient transformer capacity to supply the peak load within the loop with the largest transformer in the loop out of service. This is consistent with an N-1 planning criteria. Consequently, the transformer capacity with the largest unit out of service equals 291.8 MVA. By comparison the 2015 peak load[1] for the 138 kV loop is forecast to equal 120.1 MVA.

If Hydro were to not repair the Western Avalon T5 OLTC then the total installed transformer capacity in the Western Avalon – Holyrood 138 kV Loop equals 291.8 MVA. Applying the transmission planning criteria for loss of the largest transformer in the loop, Holyrood T8 is assumed to be out of service leaving four 41.7 MVA units, or 166.8 MVA in firm transformer capacity to supply the peak load. By comparison the 2018 peak load for the 138 kV loop is forecast to equal 122.4 MVA, or 73% of the firm transformer capacity. However, load flow analysis of the 2018 peak load for the Western Avalon – Holyrood 138 kV Loop reveals that if Western Avalon T5 is not returned to service and one of the 41.7 MVA units were to fail at Western Avalon (i.e. T4) the remaining 41.7 MVA unit at Western Avalon (i.e. T3) would be loaded to 113% of its rating despite there being adequate transformer capacity at Holyrood to supply the loop load. The load flow plot is provided in Figure 4.

[1] Newfoundland Power 2013 Infeed Load Forecast dated 2013-12-19

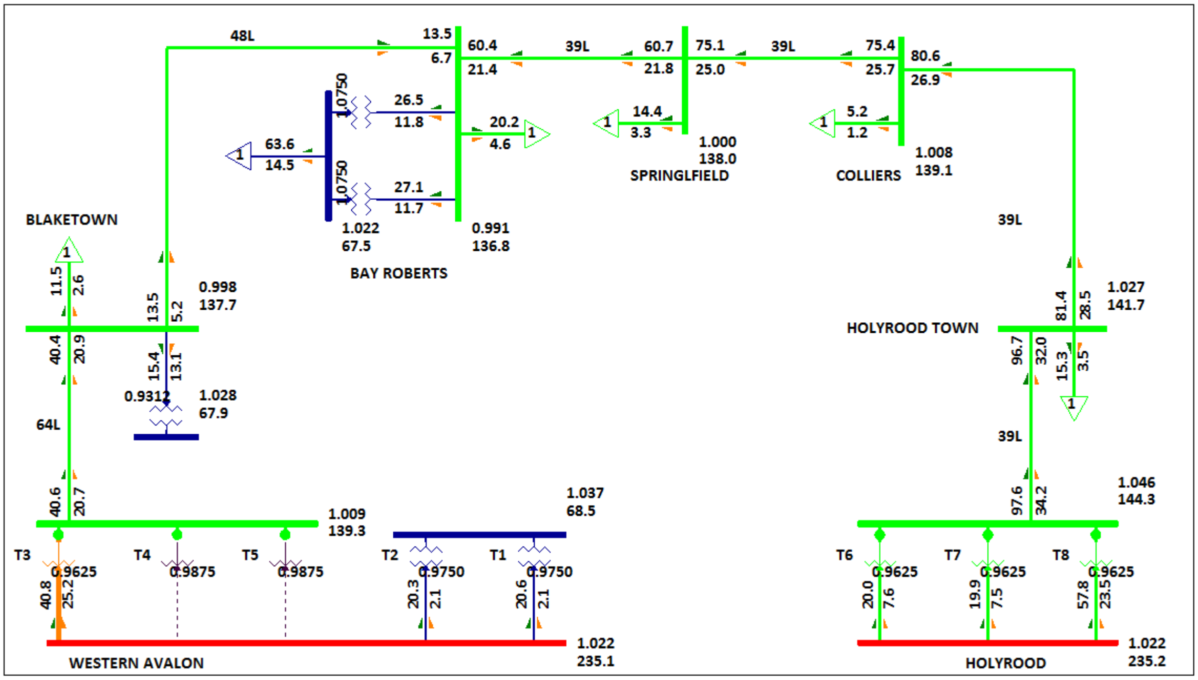


Figure 4: Western Avalon – Holyrood 138 kV Loop – 2018 Peak Load WAV T5 Not Repaired – WAV T4 Out of Service

In order to alleviate the overload on the lone Western Avalon 230/138 kV transformer, it would be necessary to open the 138 kV loop by taking 48L out of service between Blaketown and Bay Roberts. This action reduces the reliability of supply to customers supplied by the loop as Blaketown is radially fed from Western Avalon and Bay Roberts is radially fed from Holyrood. Returning Western Avalon T5 to service eliminates this risk and restores the Western Avalon – Holyrood 138 kV Loop to its pre January 2014 state.

Following the on load tap changer failure in January 2014, the transformer was removed from service and arrangements were made to drain the transformer tank so that manufacturers of both the transformer (CG Power) and the tap changer (Reinhausen) could perform an internal inspection of the equipment. This was completed in February 2014. CG Power reported that the transformer appears to be in good condition. The CG Power report is attached as Appendix A. In addition, another transformer manufacturer (ABB) was consulted to provide a second opinion. ABB prepared a report that validated the recommendations by CG Power, i.e., the Western Avalon transformer T5 is in good condition and able to be returned to service once the tap changer is replaced. The ABB report is attached as Appendix B. Reinhausen reported that the failure of the tap changer was due to a phase to phase fault which resulted in an electrical arc in the unit. Figure 5 shows pictures of the damaged T5 tap changer.

Figure 5: Damaged Tap Changer

The damaged tap changer is a Type H and is obsolete. Reinhausen has recommended that Hydro replace the Type H tap changer with a Type VV unit. The work required to install a Type VV tap changer involves enlarging the existing hole in the transformer for the new tap changer, manufacturing the tap changer fitting flanges, and extending leads from the transformer windings to the new tap changer. Hydro plans to contract this work out to CG Power, as they manufactured the transformer and have the expertise to complete the work efficiently.

The additional work required to install the new tap changer involves draining and refilling the transformer with oil, pressurizing the transformer with nitrogen and/or breathable dry air to perform the work, and daily monitoring of nitrogen and/or breathable dry air pressure and the oil containment berms. Commissioning tests will be conducted after the new tap changer is installed and prior to placing the unit back in service.

3.1 Existing System

The Western Avalon – Holyrood 138 kV Loop contains a total of six 230/138 kV power transformers. At the Western Avalon Terminal Station, two 41.7 MVA units (T3 and T4) are in service with a combined rated capacity of 83.4 MVA. Western Avalon T5 which has a rated capacity of 125 MVA, is currently out of service due to a failed on load tap changer. At Holyrood two 41.7 MVA units (T6 and T7) and one 125 MVA unit (T8) are in service for a total station capacity of 208.4 MVA. The total installed transformer capacity in the loop equals 291.8 MVA with Western Avalon T5 out of service. The transmission planning criteria requires that there be sufficient transformer capacity installed within the loop to supply peak load with the largest transformer in the loop out of service. Given that Western Avalon T5 is out of service, the firm transformer capacity equals 166.8 MVA (4 x 41.7 MVA) with Holyrood T8 out of service. The Newfoundland Power 2013 Infeed Load forecast indicates that the 2018 peak load for the 138 kV loop equals 122.4 MVA. While there is sufficient transformer capacity within the loop to supply the peak load should there be an outage to Holyrood T8, load flow analysis indicates that loss of Western Avalon T4 (41.7 MVA unit) will result in overload of the remaining transformer (T3 – 41.7 MVA) at Western Avalon.

3.1.1 Operating Regime

Hydro's 230/138 kV transformers, such as T5 at Western Avalon Terminal Station, are equipped with On Load Tap Changers (OLTC) to regulate the output (138 kV) voltage within acceptable levels. An OLTC achieves this by changing the ratio of the windings within the transformer by altering the number of turns in one winding of the transformer. Without this OLTC regulation capability, system voltage would fluctuate outside acceptable standards as load changes.

3.1.2 Age of the Transformer

Transformer T5 at the Western Avalon Terminal Station is 25 years old. The existing tap changer is original to the unit.

3.1.3 Major Work/Upgrades

Transformer T5 tap changer was overhauled 2012.

3.2 Operating Experience

The Western Avalon Terminal Station is critical to providing reliable service to customers within the Western Avalon – Holyrood 138 kV Loop. Operation of the 138 kV loop with all six 230/138 kV transformers in service ensures reliable supply.

3.2.1 Reliability Performance

With Western Avalon T5 out of service, the transformer capacity in the western Avalon – Holyrood 138 kV Loop is reduced. While failure of Holyrood T8 with Western Avalon T5 out of service does not result in overload of the remaining four transformers in the loop, loss of a 41.7 MVA transformer at Western Avalon will result in overload of the remaining 41.7 MVA unit at Western Avalon if T5 is not returned to service. Without T5 returned to service, the overload on the lone Western Avalon 230/138 kV transformer can only be alleviated through opening the 138 kV loop, which in turn reduces the overall reliability of the loop.

With Western Avalon T5 out of service the configuration of the 138 kV loop and underlying 66 kV transmission between Western Avalon and Bay Roberts can have adverse impacts on the transformer loading at Western Avalon. With Western Avalon T5 out of service on January 8, 2014 there were customer outages due to overload trips to T3 and T4, during restoration procedures as summarized in the following table.

Table 1: T3 & T4 Overloading

Transformer Tripped (Overloaded)	Date/Time	Duration of Outage
T3	2014-01-08 / 17:45 hrs.	5 minutes
T4	2014-01-08 / 17:49 hrs.	3 minutes

3.2.1.1 Outage Statistics

Table 2 lists forced outage data for tap changers similar to the unit in T5. The data was compiled by CEA for the period from 2008 to 2012 and can be found in their Annual Report pertaining to "Forced Outage Performance of Transmission Equipment".

Table 2: Tap Changer Failures (CEA 5 Year, 2008-2012)

Area	Number of Outages	Mean Duration of Outages (Hours)
NL Hydro	3	8.5
Canada	77	239.3

3.2.2 Legislative or Regulatory Requirements

CSA Standards recommend guidelines for acceptable voltage limits.

3.2.3 Safety Performance

Voltage regulation on the system is crucial to the safe operation of the electrical grid and ultimately the safety of the customers.

3.2.4 Environmental Performance

The environmental requirements will be considered and followed for this project, but the main driver for the work is to restore T5 back to operating condition for reliable service to the Avalon Peninsula.

3.2.5 Industry Experience

Other utilities have had tap changer failures, as reported by CEA.

3.2.6 Vendor Recommendations

Reinhausen has internally inspected the tap changer and recommends that it be replaced with a new Type VV tap changer. The existing, damaged tap changer, Type H, is obsolete. CG Power has internally inspected the transformer windings and found them to be in good condition.

3.2.7 Maintenance or Support Arrangements

There are no external maintenance or support arrangements in place for T5 transformer at Western Avalon Terminal Station. Routine maintenance work is performed by Hydro staff.

3.2.8 Maintenance History

Table 3 below indicates the work orders (since 2007) for the maintenance associated with the T5 tap changer in Western Avalon Terminal Station.

Table 3: Work Orders Associated With T5 Tap Changer

Year	Description
2007	Tap Changer Oil Sample
2008	Tap Changer Oil Sample
2008	T5 Preventative Maintenance
2009	Tap Changer Problem – Timer Changed
2012	Tap Changer Oil Samples (2)
2012	Tap Changer Overhauled by Tap Changer OEM
2012	T5 Preventative Maintenance
2014	T5/Tap Changer Internal Inspection (Post Failure)

3.2.9 Historical Information

Transformer T5 at Western Avalon Terminal Station has been in service for 25 years providing reliable system voltage.

3.2.10 Anticipated Useful Life

According to the Reinhausen, the Type VV tap changer operates under vacuum and has a much longer service life expectancy than the oil operated Type H that it is replacing.

3.3 Forecast Customer Growth

This project is not required to accommodate customer growth.

3.4 Development of Alternatives

An alternative to replacing the tap changer would be to replace the entire transformer with a new unit. Given the transformer windings are in good condition, replacing the tap changer is the most viable option.

3.5 Evaluation of Alternatives

CG Power and Reinhausen conducted an internal inspection of transformer T5 and recommended the installation of a new tap changer as the transformer windings are in good condition.

3.5.1 Energy Efficiency Benefits

There is no energy efficiency benefits anticipated related to the completion of this inspection.

4 CONCLUSION

Transformer T5 at the Western Avalon Terminal Station has been in service for 25 years providing power to major areas on the Avalon Peninsula. Preventative maintenance and periodic oil sampling has ensured reliable service for that time period. The failure of the tap changer appears to be consistent with those experienced by other utilities across Canada. Transformer tests and an internal inspection by both Reinhausen and CG Power have confirmed that the transformer is in good condition. Based on this assessment, it is recommended that a new tap changer be installed as the most appropriate option to restore transformer T5 to an operational condition.

4.1 Budget Estimate

The budget estimate for this project is shown in Table 4.

Table 4: Budget Estimate

Project Cost: *($ x1,000)*	2014	2015	Beyond	Total
Material Supply	215.4	0.0	0.0	215.4
Labour	341.6	0.0	0.0	341.6
Consultant	42.4	0.0	0.0	42.4
Contract Work	542.9	0.0	0.0	542.9
Other Direct Costs	29.3	0.0	0.0	29.3
Interest and Escalation	46.6	0.0	0.0	46.6
Contingency	234.3	0.0	0.0	234.3
TOTAL	**1,452.5**	**0.0**	**0.0**	**1,452.5**

4.2 Project Schedule

This project will be completed in 2014 and the anticipated schedule is outlined in Table 5.

Table 5: Project Schedule

2014 Scheduled Work Items			
Activity		**Start Date**	**End Date**
Planning	Scope, schedule and budget review	February	May
Design/Procurement	Prepare Specification for Major Inspection	June	July
Installation/Inspection	Complete Inspection	Aug	Sept
Commissioning	Complete Commissioning	Sept	Sept
Closeout	Project Closeout	Oct	Oct

APPENDIX A

OEM (CG Power) Recommendation on Transformer T5

Newfoundland and Labrador Hydro – Internal Inspection Review

Serial # 61-00-69167 – Federal Pioneer

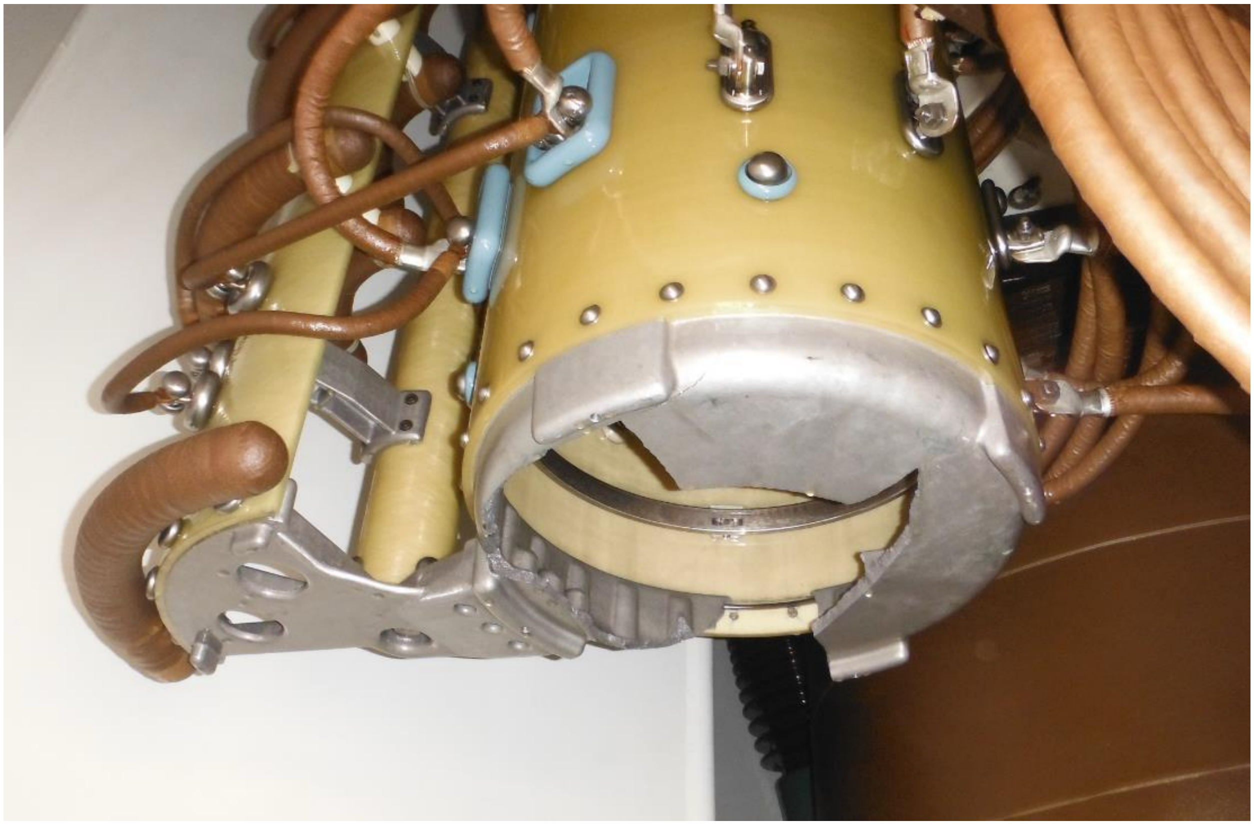
Internal investigation on T5 unit due to tap changer malfunction

On Saturday February 22, 2014, CG performed an internal inspection of unit, serial #61-00-69167, to investigate the integrity of the active assembly after the tap changer blow up.

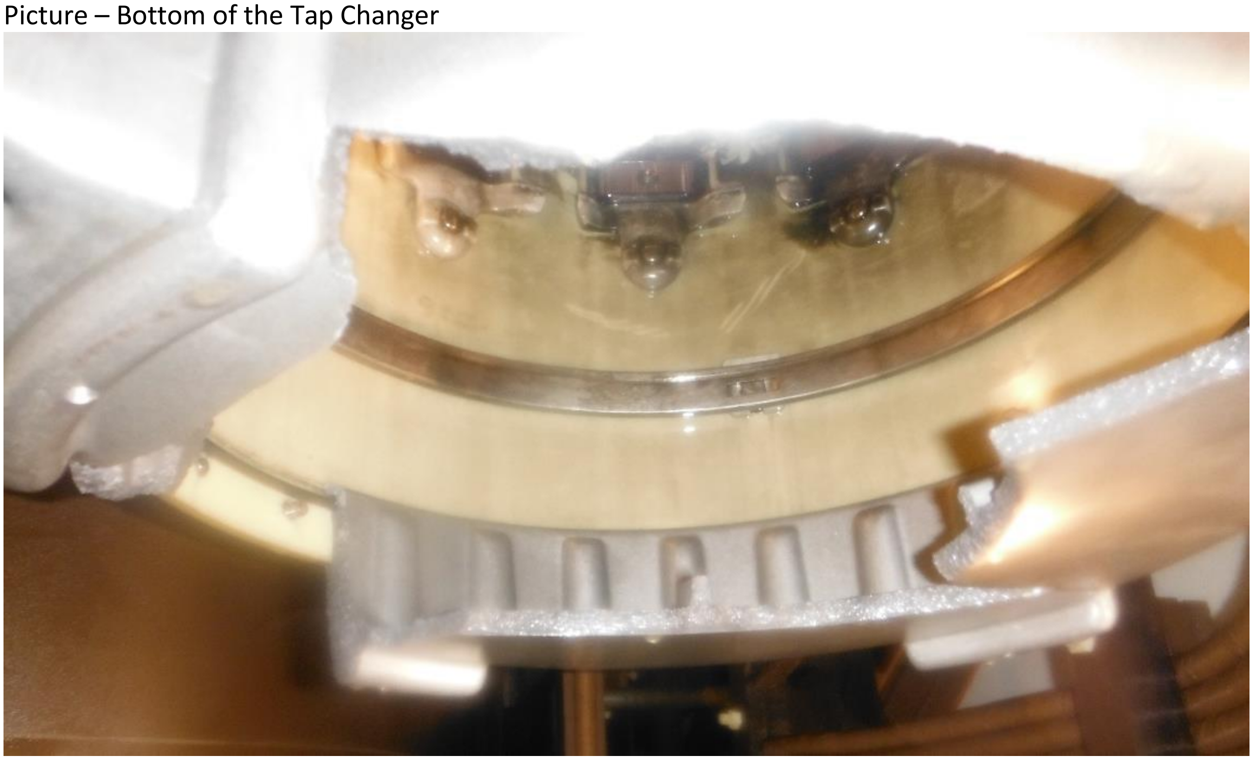
On opening the man hole cover at the tap changer end it was noticed that there were large amounts of metal and hardware from the bottom of the tap changer that was laying on the floor beneath the tap changer. Once inside CG removed all the parts from the unit and then proceeded with the inspection. CG checked all the tap connections and connections then worked around the active assembly looking for deformities or anything that may be damaged.

It was concluded that all lead work and connections were solid with no adverse effect to the active assembly. It is however my recommendation that the unit be flushed and the floor cleaned after the new tap changer is installed.

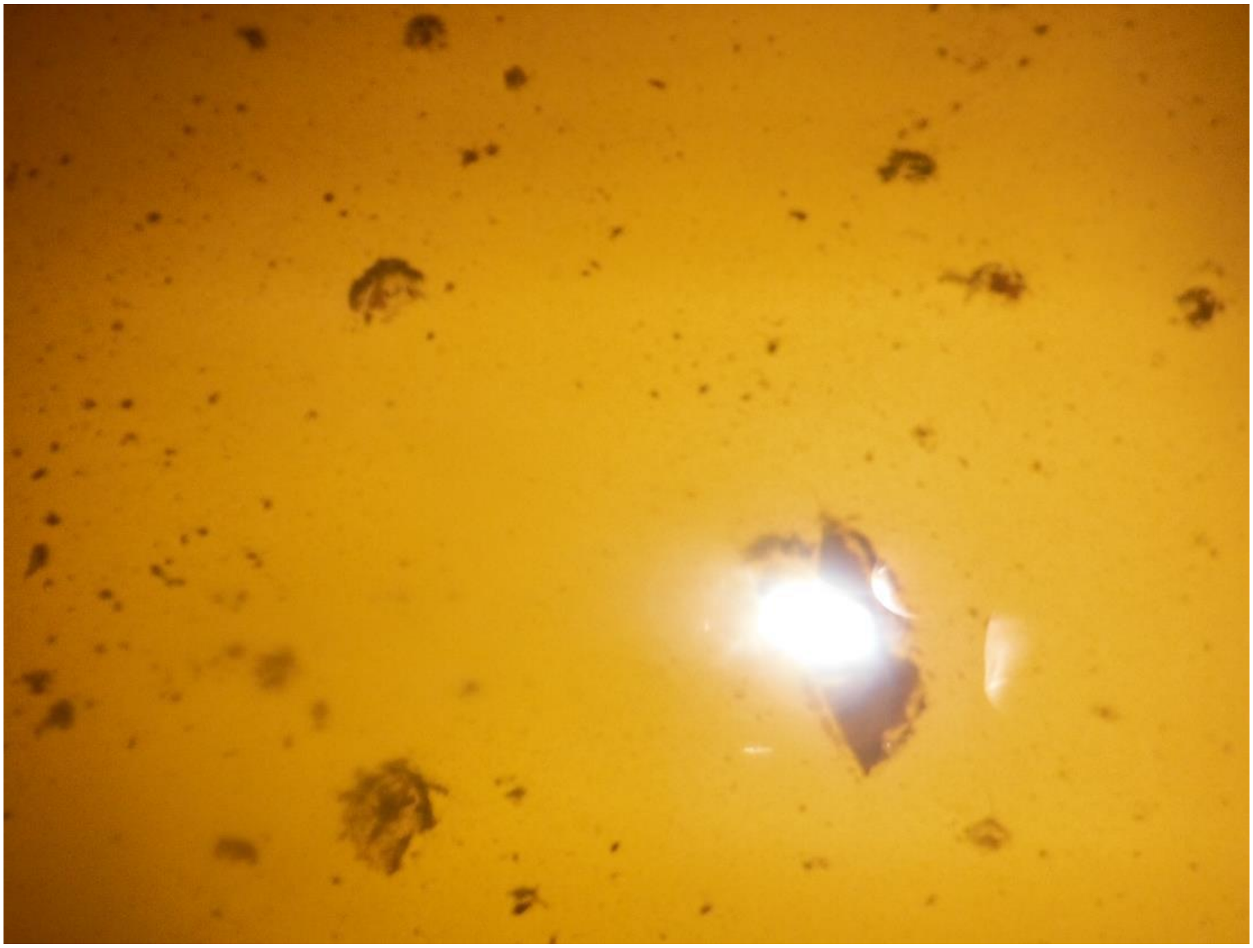
Picture – Below the Tap Changer on the shelf in the Transformer.



Picture – Bottom of the Tap Changer



Picture – Bottom of the Tap Changer



Picture – Bottom of the tank

Oil Sample and Winding Resistance Test Analysis

- After reviewing the previous Winding Resistance results and MR's post failure test results
    - Comparing the information that was provided, CG does not see any anomalies
- Oil Samples
    - It would appear the cellulose was not in the arch path during the tap changer failure
    - Prior to any further electrical testing the transformer will required to be oil filled and hot oil circulated to remove the combustible gases that were found in the samples
- Regarding the ambient temperature and Doble testing, the testing can be performed as the tests will be reviewed by CG test group in comparison to the testing completed in the factory.
- In addition to the standard field testing; visual inspection, winding resistance test, and TTR, it is recommended to perform the excitation current test, to further validate the integrity of the transformer.
- Please note that even after the unit has been modified with the new tap changer and the field testing is complete, CG is not liable for any damages subsequent to the repair of the Transformer

<u>Next Steps</u>

- CG will review the new tap changer modification requirements and provide a quote to completed modification to the transformer and required material, including the installation
    - CG can provide this service turnkey and work with the contractors for the oil processing and welding as well. Please provide feedback.
- Newfoundland and Labrador Hydro to determine if the oil filling and circulation is completed before the tap changer repair or after the repair is completed.

APPENDIX B

OEM (ABB) Recommendation on Transformer T5

CONDITION ASSESSMENT OF FEDERAL PIONEER TRANSFORMER AT WESTERN AVALON STATION FOR NALCOR ENERGY

TRANSFORMER SERIAL # 61-00-69167

PREPARED BY

ABB Inc.

Transformer Remanufacturing & Engineering Services (TRES)
Brampton, ON Canada

ABB Project Number: 566283

Prepared by:	James Li P.Eng Senior Transformer Design Engineer
Reviewed by:	Mustafa Lahloub P.Eng Engineering Manager, TRES Brampton
Approved by:	Ed G. teNyenhuis M.Eng P.Eng. Technical Manager, TRES Canada

May 02, 2014; Rev 0

Rev 0 May 2, 2014 Initial issue

Executive Summary

A condition assessment report of FPE transformer with serial number 61-00-69167 at the Western Avalon station site was completed.

The DGA results showed that:

- The concentration of Hydrogen (H2), Methane (CH4), and Ethane (C2H6) are all normal for the years before the LTC failure.
- The Ethylene (C2H4) level has rising after 2009 but with a very slow increasing rate at 0.0027ppm/day before LTC failure.
- Traces of Acetylene (C2H2) have been found in the oil samples before 2009 - it dropped to zero after 2009.
- The carbon oxide level have been normal. The ratio of the carbon oxides suggests that the concentrations are due to the normal aging process of the transformer.
- The oil samples from this transformer have consistently shown high oxygen concentrations (>20,000 ppm).
- The oil DGA analysis for the oil sample taken on March 14, 2014 shows trace of C2H2 (3ppm).

The oil physical results showed that:

- All the measured breakdown voltage (BDV) are well above the suggested minimum limit by Doble except the tests for the year of 2002, 2003 and 2004 - those tests were performed per ASTM D1816-2, the results are far below the recommended minimum value (50kV/mm).
- The interfacial tension values are between 30 and 36 dynes/cm2 in last few years. The suggested minimum value is 32 dynes/cm2.
- The inhibitor values were not measured for the oil samples.
- The measured Acid Numbers for the oil samples in past years are all below the recommended maximum limits.
- The measured power factor values are somewhat higher than normal even though the results at 25°C/100°C are all below the IEEE recommended limits.
- The oil samples taken from the main tank show moisture content of less than 10 ppm except the sample in 2004.
- The measured power factor @ 25°C is 0.141% for oil sample taken on Mar.14, 2014.

The Power factor measurement showed that:

- Doble overall test results on April 11 are all above the maximum limit 0.5%.
- The latest C1 power factor and capacitance test values on April 11, 2014 for all bushings are normal.
- The latest C2 capacitance test on April 11, 2014 for all bushings are acceptable,
- The excitation current test results from 2012 are all acceptable.
- The excitation current test results on April 11, 2014 are normal.

The measured winding resistance in 2012 shows that results are consistent between phases.

The insulation tests performed in 2012 show results in Mega Ohms - this should be confirmed if this is really Giga ohms.

The (PI) index is lower than the ABB recommended value of 2.0 for HV/LV to ground.

The measured winding resistance in 2014 after LTC failure shows that they are all consistent between phases.

The ratio test result at contact # 2 (0/-) shows 1.604. This should be compared to results from factory test report.

This transformer may be wet and have some contaminations (perhaps carbon from the LTC failure). This is most probably what is causing the higher than normal power factor results.

Overall, there is no indication that damage has occurred to the windings due to the LTC failure.

Prior to returning the unit to service, the following should be done for this transformer. If these actions are done and everything is confirmed then ABB recommends to return the unit to service.

- Perform SFRA test (compare the traces between phases to confirm that there was no movement in the windings during the failure)
- Confirm the insulation resistance test results (in G-ohms not Mega ohms)
- After installing new tap changer, perform complete testing before energization. Compare the measured results to the factory test report.
- Hot oil circulate within the transformer, filter, and degas the oil.

Below are general recommendations that should be done with regards to this transformer

- Test BDV according to ASTM D1816-97 and indicate the gap used in the report.
- Always measure oil power factor at 25°C and 100°C.
- Add diaphragm to the conservator.
- Measure the inhibitor in the oil and add oxidation inhibitor to oil if it is in lower range.
- All gauges and accessories including WTI, OTI and PRD should be checked and calibrated.
- Always compare the resistance test results between factory and site test with temperature correction.
- Measure the bushings power factor and capacitance annually if possible. If the power factor is on the rise or the capacitance is changing, it should be considered to replace or refurbish the bushings.

Table of Contents

1. Introduction

This report represents a condition assessment of Federal Pioneer transformer with serial # 61-00-69167 at the Western Avalon station site. The unit was made by Federal Pioneer in Winnipeg, Canada in 1989.

The design parameters and identification of the transformer are shown in **Table 1** below.

This transformer experienced an OLTC failure that occurred on 01/04/2014 with response from protective relay RS 2001 of the OLTC – per MR report "Investigation Report TS14S17en"

The internal inspection was performed by CG Power System Canada on 02/22/2014 - per CG Report "Newfoundland and Labrador Hydro – Internal Inspection Review"

The investigation showed that the incident did not occur during an operation of the OLTC. A phase to phase flashover occurred in oil insulating distance within the selector switch drive shaft, namely between OLTC inner screening rings of phases V and W.

A review of the transformer maintenance history, inspection reports and test data is completed.

Table 1 – Transformer Identification

Manufacturer	Federal Pioneer
Rating	75/100/125 MVA, ONAN/ONAN/ONAF, 65°C Rise, 3Ph, 60Hz Three Phase Autotransformer
Voltage	HV: 230000 + 5 / - 15 % LV: 138000 V TV: Grounded Externally
Lightning Insulation Levels	HV: 950 kV; LV: 650 kV; HV0/LV0: 95 kV
Core/Winding	No Information Available
LTC	MR Type: H III 400 D – 145 – 10 19 3W
Cooling Equipment	No Information Available
Customer ID	Western Avalon T5
Manufacturing Date	1989 in Winnipeg, Manitoba.

2 Dissolved Gas in Oil Analysis (DGA)

Below is the report of the DGA data for the period from 1990 to 2014. The gas signatures for this transformer are shown in **Figure 1** to **Figure 3**.

The following is noted for the transformer DGA history:

- The concentration of Hydrogen (H2) has been well below condition level one of IEEE C57.104-2008 guide since 1990. The concentration jumped to 610ppm after the LTC failure occurred in 2014.
- The Methane (CH4) and Ethane (C2H6) have been well below the condition level one of the IEEE C57.104-2008 guide since 1990. The concentration of CH4 jumped to 287ppm after the LTC failure occurred in 2014.
- The Ethylene (C2H4) level has been well below condition level one (50 ppm) of the IEEE C57.104-2008 guide before 2009. As can be seen from **Figure 1** below, the concentration of C2H4 elevated after 2009, however the generation rate is very low at 0.0027 ppm/day until the LTC failure occurred in 2014.
- Traces of Acetylene (C2H2) have been found in the oil samples before 2009. It dropped to zero after 2009, and then jumped to 232ppm after the LTC failure occurred in 2014.
- The carbon oxide level have been below the IEEE C57.104-2008 guide condition level one since 1990. The CO2/CO ratio is between 4 and 6. The normal CO2/CO ratios are typically in the range of 5-9. The ratio of the carbon oxides suggests that the concentrations are due to the normal aging process of the transformer.
- The presence of large concentrations of oxygen in the oil can promote the formation of acids in the oil and cellulose and accelerate the aging rate of the cellulose insulation. It is recommended that the concentration of oxygen in the transformer be less than 2000 ppm (Refer to CIGRE report 323 – Aging of Cellulose in Mineral-Oil Insulated Transformers). The oil samples from this transformer have consistently shown high oxygen concentrations (>20,000 ppm). The source of this high oxygen is the free-breathing oil conservator. It is recommended to measure oxidation inhibitor in the oil to see if the inhibitor has been consumed up. It is highly recommended to add inhibitor to the oil if it is below the suggested limit. As well, to reduce the oxygen in the transformer oil and eliminate the uncertainty concerning the gas generation, it is recommended to add a conservator diaphragm. The diaphragm prevents oil from coming in contact with the air. This will prevent moisture, excessive atmospheric gases from dissolving into the oil and it also helps to keep all gases generated by the transformer in oil for more accurate diagnostics.

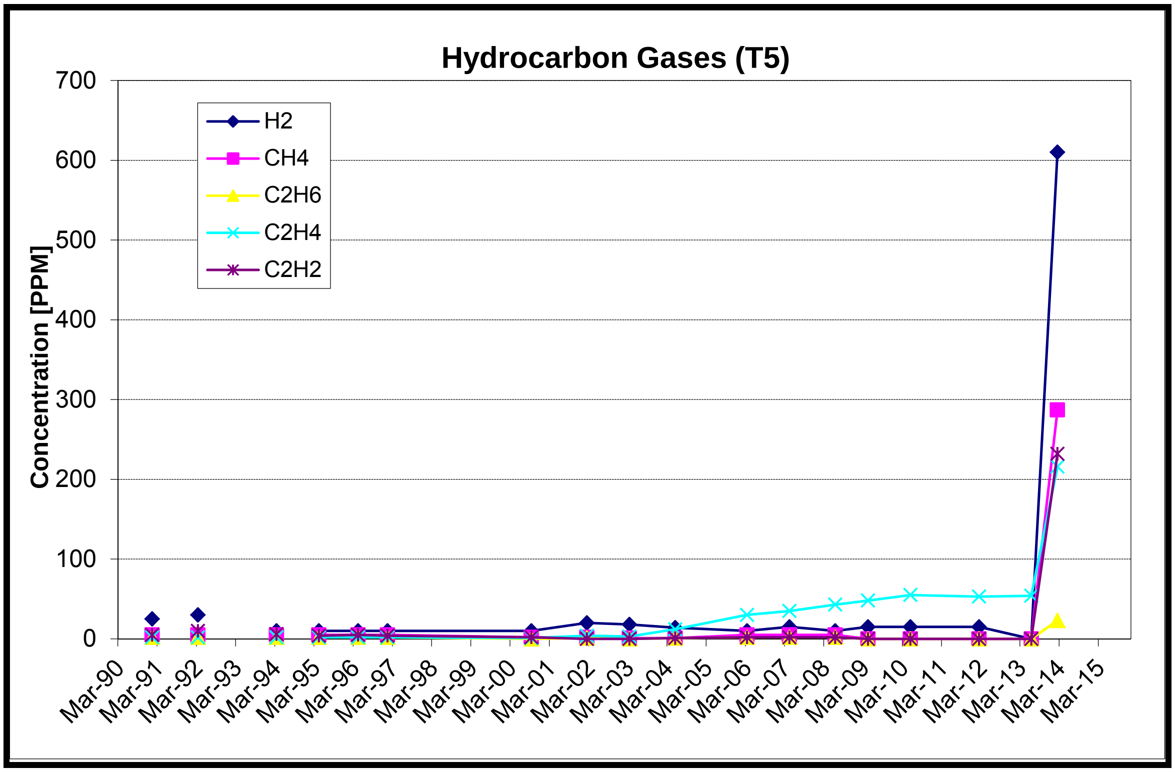


Figure 1 - Hydrocarbon Gas Concentrations

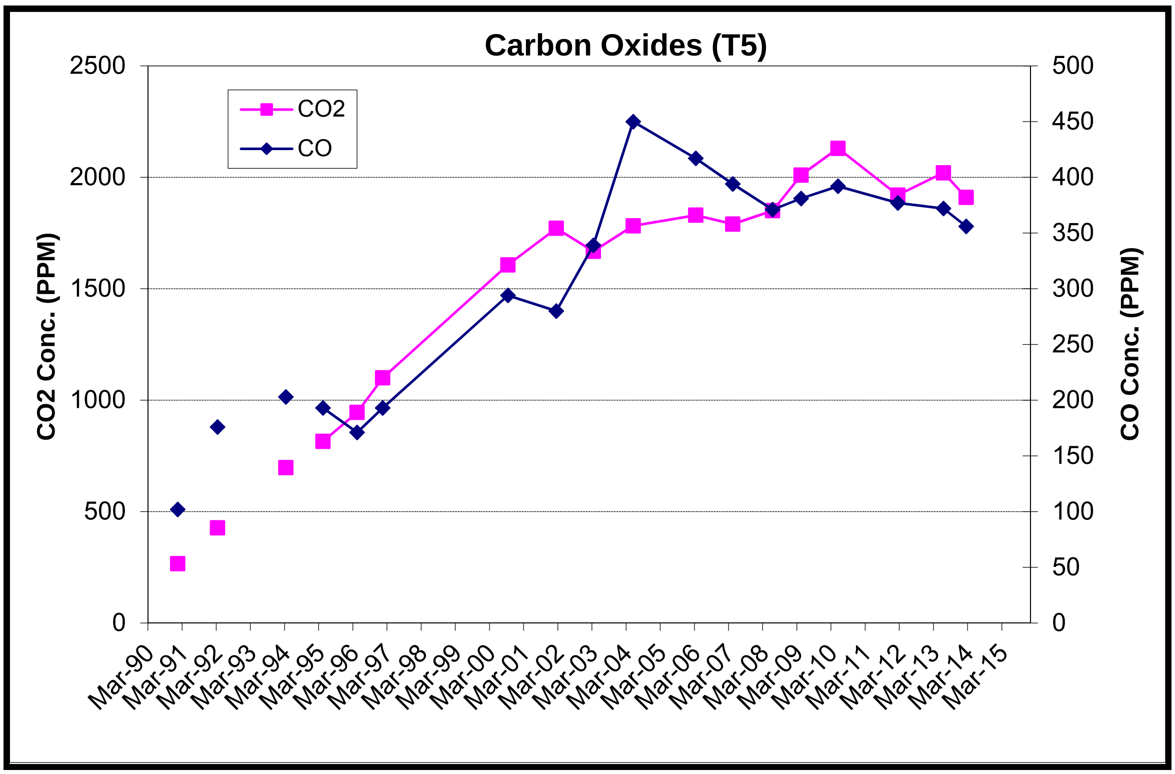


Figure 2 - Carbon Oxides Gas Concentrations

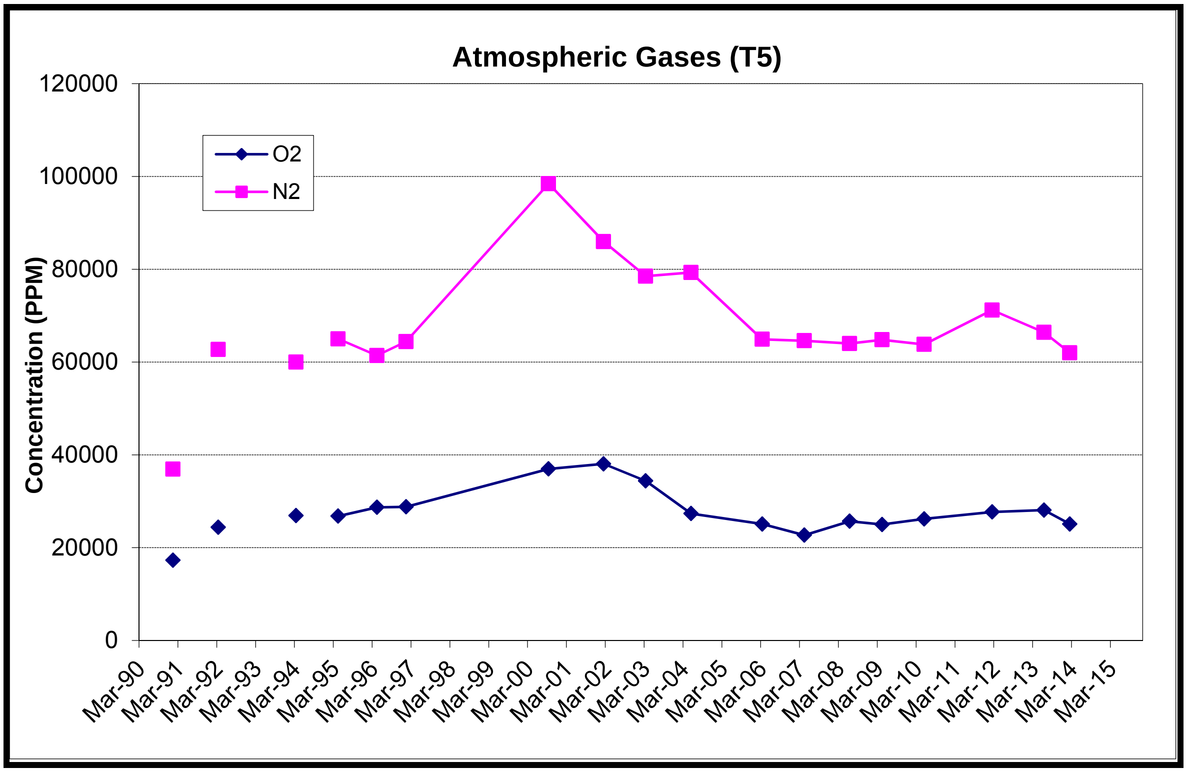


Figure 3 – Atmospheric Gases Concentrations

Table 2 below shows the results for DGA analysis for the oil sample taken on March 14, 2014 (after degassing). There are still traces of C2H2 (3ppm) found in the oil sample. <u>It is recommended to re-sample to confirm the level of C2H2.</u>

Table 2 – Oil Sample Taken on March 14, 2014

	Sample Date	14-Mar-14
	Laboratory No.	5047266
	Container No.	26923
	Temperature (°C)	25
H_2	Hydrogen (ppm)	1
CH_4	Methane (ppm)	<1
C_2H_6	Ethane (ppm)	<1
C_2H_4	Ethylene (ppm)	3
C_2H_2	Acetylene (ppm)	3
CO	Carbon monoxide (ppm)	5
CO_2	Carbon dioxide (ppm)	257
N_2	Nitrogen (ppm)	41601
O_2	Oxygen (ppm)	11215
	Total Gas (ppm)	53085
	Total Combustible Gas (ppm)	12

3 General Oil Quality

Below is the report of the oil quality data results since 1990. The history of the oil quality data measured for this transformer is shown in **Table 3** below.

The following can be observed:

- All the measured breakdown voltage (BDV) are well above the suggested minimum limit by Doble (30kV/mm) for ≥ 230kV transformers with service aged insulating oil except the tests for the years of 2002, 2003, and 2004. Those tests were performed per ASTM D1816-2 and the results (RED in **Table 3** below) are far below the recommended minimum value (50kV/mm) by IEEE C57.106-2002. It is recommended to test BDV according to ASTM D1816-97 with alternate measurement of 0.04" and 0.08" respectively for gaps.
- The interfacial tension values are between 30 and 36 dynes/cm2 in the last few years. The suggested minimum value is 32 dynes/cm2 by IEEE C57.106-2002 for ≥ 230kV transformers. Lower values may indicate oil soluble contaminants and oxidation products in oil.
- The inhibitor values were not measured for the oil samples. It is believed that the inhibitor has been consumed up due to the high concentration of oxygen in the oil. The acceptable range is between 0.08 and 0.30%. Oxygen inhibitors are helpful to minimize the effects of oxidation of oil. The first choice of attack by oxygen in the oil is the inhibitor molecules. This keeps the oil free from oxidation and its harmful by-products. As transformer ages, the oxidation inhibitor is used up and need to be replaced. It is highly recommended to measure the inhibitor in oil and add oxidation inhibitor to oil if it is below the suggested limit.
- The measured Acid Numbers for the oil samples in past years are all below the recommended maximum limits (0.10 mg KOH/g) by IEEE C57.106-2002 for ≥ 230kV transformers.
- The measured power factor values are somewhat higher than what is normally seen even though the results at 25°C/100°C are all below the maximum limits suggested by IEEE C57.106-2002. Ionic contaminants can often pass undetected at 25°C but will reveal their presence as unacceptably high readings in the 100°C test. The higher than normal power factor results may indicate the oil possibly being contaminated.
- IEEE C57.106-2002 Table 5 recommends that the maximum limit of water content in oil for 230kV transformers is not to exceed 10 ppm. The oil samples taken from the main tank show moisture content of less than 10 ppm except the sample taken in 2004.

Note: *the dielectric breakdown voltage marked in RED in the Table 3 below was tested per ASTM D1816-2mm. All others were tested per ASTM D877.*

Table 3 - Oil Quality Data (Main Tank)

Sample Date	Fluid Temp (^oC)	Dielectric Breakdown D877 (kV)	Acid Number D974 (mg KOH/g)	Interfacial Tension D971 (dynes/cm)	Visual Condition D1524	Power Factor 25 / 100°C D924 (%)	Water (ppm)	% Satur.	Inhibitor (%)
03/29/1990	25	49.2	0.004	47.0	-	-/-	0	0	-
09/18/1991	25	47.2	0.004	44.0	-	-/-	0	0	-
05/19/1993	25	45.6	0.004	46.0	-	-/-	0	0	-
10/07/1994	25	46.2	0.004	45.0	-	-/-	0	0	-
09/01/2000	-	-	-	-	-	-/-	9	-	-
02/22/2002	35	29	0.009	38.6	Clear/Bright	0.14/-	5	5	-
03/26/2003	30	26	0.010	35.2	Clear/Bright	0.18/-	6	7	-
05/11/2004	7	31	0.010	40.6	Clear/Bright	0.17/-	7	23	-
03/30/2006	-	45.9	0.014	36.1	Clear/Bright	0.163/-	5	-	-
04/11/2007	-	35.3	0.003	33.9	Clear/Bright	0.055/-	5	-	-
06/06/2008	-	38.8	0.008	30.0	Clear/Bright	0.058/-	3	-	-
04/28/2009	35	47.0	0.010	32.8	Clear/Bright	0.216/3.15	4	4	-
05/18/2010	35	42.0	0.020	31.0	Clear/Bright	0.051/1.82	5	5	-
02/08/2012	35	31.0	0.020	30.2	Clear/Bright	0.080/3.32	2	2	-
06/25/2013	45	-	0.010	33.5	Clear/Bright	0.172/3.21	3	2	-
02/12/2014	0	41.0	0.010	33.3	Clear/Bright	0.152/3.55	2	9	-

Table 4 below shows that the measured power factor @ 25°C is 0.141% for oil sample taken on March 14, 2014, which is below the suggested maximum limit, but higher than normal for recently degased oil. It is recommended to re-sample to verify the power factor at both 25°C/100°C.

Table 4 – Oil Sample Taken on March 14, 2014

D1533	Moisture (ppm)	10
D971	Interfacial Tension (dynes/cm)	37.8
D974	Acid Number (mg KOH/g)	0.015
D1500	Color Number	<1.5
D1524	Visual Examination	Clear & Bright
D877	Dielectric BV (kV)	50
D1816	Dielectric BV (kV)	
D924	Power Factor (% at 25 °C)	0.141
D924	Power Factor (% at 100 °C)	
D2668	Oxidation Inhibitor (%)	
D1298	Specific Gravity	0.861
D88	Viscosity (SUS)	
D97	Pour Point (°C)	
D92	Flash Point (°C)	
D92	Fire Point (°C)	
D1807	Refractive Index	
D1275	Corrosive Sulfur	

4 Power Factor Measurement

Doble power factor tests were performed on July 2012. The tests were also performed at tap 5 after failure of LTC on March 15, 2014 and April 11, 2014. Jumpers were added externally to the LTC cylinder to simulate the connections where the LTC supposed to be. The test results are shown in **Tables 5 & 7**.

The latest bushing Doble tests performed on April 11, 2014 are shown in **Tables 8 & 9.**

The excitation current test was performed on March 15, 2014 at tap position 5 with jumpers added as mentioned above after LTC failure, and then the test was repeated on April 11, 2014 due to the unexpected current deviations between phases 1 and 3. The results are shown in **Table 10** along with the excitation current test results from 2012 at different taps.

The following can be seen:

- The Doble overall test was performed at -5°C on March 15. This is not recommended by Doble. Since the power factor at temperatures below freezing point of water may not be sensitive to water in the winding insulation.
- The Doble overall test results on April 11 are all above the maximum limit 0.5%, the capacitance for CH jumped from 5856.8pF to 6029.6pF. This should be further investigated.
- The latest C1 power factor and capacitance test values on April 11, 2014 for all bushings are normal. IEEE Standard C57.19.01 specifies a limit of 0.5% for C1 power factor for oil impregnated paper insulated bushings. All bushings C1 power factors are well below 0.5%. The C1 power factor is the important diagnostic test to use in judging the condition of the bushing. ABB recommends that the bushings be replaced whenever the power factor is double the nameplate value or the capacitance increases by 10% or more from nameplate value.
- The latest C2 capacitance test on April 11, 2014 for all bushings is acceptable.
- The excitation current test results from 2012 are all acceptable.
- The excitation current test results on March 15, 2014 at tap 5 indicate an issue with the losses. The results of the repeated excitation current test on April 11, 2014 for phase 3 are very close to that of phase 1.

Table 5 – Overall Doble Test on July 25, 2012 (24°C)

Meas.	Test kV	mA	Watts	%PF corr	Corr Fctr	Cap(pF)	IR_{auto}	IR_{man}
CH + CHT	10.000	38.655	1.232		0.99	10253.6		
CH	10.000	21.978	0.6610	0.30	0.99	5829.7	G	
CHT(UST)	10.000	16.641	0.5630	0.34	0.99	4414.3	G	
CHT		16.677	0.571	0.34	0.99	4423.900	G	
CT + CHT	2.000	54.933	2.169		0.99	14571.2		
CT	2.000	38.288	1.608	0.42	0.99	10155.9	G	
CHT(UST)	2.000	16.647	0.5560	0.33	0.99	4415.7	G	
CHT		16.645	0.561	0.34	0.99	4415.300	G	

Table 6 – Overall Doble Test on March 15, 2014 (-5°C)

Meas.	Test kV	mA	Watts	%PF corr	Corr Fctr	Cap(pF)	IR_{auto}	IR_{man}
CH + CHT	10.011	38.699	1.297		0.94	10265.1		
CH	10.006	22.080	0.6110	0.26	0.94	5856.8	G	
CHT(UST)	10.006	16.618	0.6770	0.39	0.94	4408.1	G	
CHT		16.619	0.686	0.39	0.94	4408.300	G	
CT + CHT	2.000	55.043	2.329		0.94	14600.3		
CT	2.000	38.421	1.632	0.39	0.94	10191.3	G	
CHT(UST)	2.000	16.624	0.6760	0.39	0.94	4409.6	G	
CHT		16.622	0.697	0.39	0.94	4409.000	G	

Table 7 – Overall Doble Test on April 11, 2014 (10°C)

Meas.	Test kV	mA	Watts	%PF corr	Corr Fctr	Cap(pF)	IR_{auto}	IR_{man}
CH + CHT	10.007	39.370	3.200		1.36	10442.7		
CH	10.005	22.733	2.495	1.50	1.36	6029.6	D	
CHT(UST)	10.005	16.624	0.6620	0.54	1.36	4409.7	G	
CHT		16.637	0.705	0.57	1.36	4413.100	G	
CT + CHT	2.000	55.001	2.192		1.36	14589.4		
CT	2.000	38.378	1.527	0.54	1.36	10180.0	G	
CHT(UST)	2.000	16.624	0.6490	0.53	1.36	4409.7	G	
CHT		16.623	0.665	0.54	1.36	4409.400	G	

Table 8 – C1 Test on Bushings on April 11, 2014

Bushing C1

ID	Serial	NP %PF	NP Cap	Test kV	mA	Watts	%PF corr	Corr Fctr	Cap(pF)	IR_{auto}	IR_{man}
H1	273414	.33	383	10.007	1.412	0.0380	0.27	1.00	374.66	G	
H2	273415	.26	382	10.006	1.417	0.0290	0.20	1.00	375.96	G	
H3	273416	.26	379	10.007	1.470	0.0340	0.23	1.00	389.95	G	
X1	272494	.26	350	10.007	1.308	0.0300	0.23	1.00	346.96	G	
X2	272516	.33	350	10.007	1.297	0.0280	0.22	1.00	344.08	G	
X3	272495	.30	356	10.006	1.317	0.0370	0.28	1.00	349.33	G	
N	272556	.23	532	10.006	1.985	0.0430	0.22	1.00	526.59	G	

Table 9 – C2 Test on Bushings on April 11, 2014

Bushing C2

ID	Serial #	NP %PF	NP Cap	Test kV	mA	Watts	%PF corr	Corr Fctr	Cap(pF)	IR_{auto}	IR_{man}
H1	273414		697	2.000	2.837	0.1140	0.40	1.00	752.45	D	
H2	273415		712	2.000	2.924	0.1360	0.47	1.00	775.62	G	
H3	273416		616	2.000	2.523	0.0660	0.26	1.00	669.27	D	
X1	272494		623	2.000	2.456	0.0810	0.33	1.00	651.59	G	
X2	272516		609	2.000	2.513	0.0570	0.23	1.00	666.47	G	
X3	272495		576	2.000	2.279	0.0660	0.29	1.00	604.59	D	

Table 10– Comparison of Excitation Current Test

Exciting Current Tests							
LTC Tap Position	H1-H0		H2-H0		H3-H0		Test Date
	ma	watts	ma	watts	ma	watts	
1	13.946	138.92	8.876	84.216	14.122	141.03	July 2012
5	15.670	156.29	9.902	98.567	**16.691**	**162.93**	**Mar 2014**
5	16.054	160.39	10.197	98.052	**16.294**	**162.89**	**Apr 2014**
9	16.464	162.77	10.29	101.29	16.384	161.84	July 2012
17	20.05	194.01	12.453	124.46	19.855	193.69	July 2012

5 Maintenance Test Results

Some electrical testing was performed during scheduled maintenance in October 2008 and July 2012. This included winding resistance, insulation resistance (Megger) and polarity index. The test results performed in 2012 are shown in **Table 11** and **Table 12** below.

- The measured resistances on all HV phases (H-X) are consistent; however there are no factory test results for comparison.
- The latest insulation test was performed in 2012 and results for HL-G show 1.42 Mega and 2.34 Mega for 1 min. and 10 min. respectively (it is believed to be in G-ohms not Mega ohms, this needs to be confirmed). The (PI) index 1.62 is lower than the ABB recommended value of 2.0 for HV/LV to ground.
- The measured insulation resistance in 2012 for core ground is 500 Mega-ohms, which is acceptable; however it is lower than normal.

The winding resistance tests were performed after LTC failure with LTC out of circuit by adding jumper leads with spring loaded clamp connections on all contacts with tap changer pre-selector switch on (0/+) and one measurement for contact #2 with the pre-selector switch on (0/-). The results are shown below in **Table 13**.

The ratio test was performed only at one tap – contact # 2 with pre-selector on (0/-) as shown in **Table 14** below.

- The measured resistances on windings are consistent on all taps. However the connections to bushings are not included and the temperature for the resistance tests was not specified. The measured resistances values are approximately double the results of the test in 2012. Most probably this test was HV to neutral rather than HV to LV in 2012.
- The ratio test result at contact # 2 (0/-) shows 1.604, the calculated ratio is 1.5625 at tap position 10. This should be compared to factory test results.

Table 11 – Resistance Test @ 20°C in 2012

	H1 – X1	H2 X2	H3 – X3	Current: RANGE – 500mA % current 107.1	Resistance RANGE 2m
1	.325	.325	.324		
2	.318	.318	.318		
3	.313	.313	.312		
4	.307	.307	.306		
5	.302	.302	.302		
6	.295	.295	.295		
7	.290	.290	.289		
8	.284	.284	.284		
9	.277	.277	.277		
10	.284	.284	.284		
11	.290	.290	.290		
12	.295	.295	.295		
13	.302	.302	.302		
14	.307	.307	.307		
15	.313	.313	.313		
16	.318	.318	.318		
17	.325	.325	.325		

Table 12 – Insulation Resistance Test and Polarity Index Test in 2012

DIELECTRIC ABSORBTION (5 KV): 10 MIN. ÷ 1 MIN. = INDEX			
H-LG	1 Min. Mega Ω	10 Min. Mega Ω	Index. %
L-HG	1 Min. Mega Ω	10 Min. Mega Ω	Index. %
HL-G	1 Min. 1.42 Mega Ω	10 Min. 2.34 Mega Ω	Index. 1.62 %
CORE GROUND: (500 Volt test)			
Externally Connected Yes ✓ No ____			
RESISTOR: (Ohms) 253.6	CORE GROUND: (Mega Ohms) 500		

Table 13 – Resistance Test @ ??°C in 2014 after LTC Failure

Preselector Switch Position	Contact #	Phase	% Current	Resistance
0 / +	1	A	106.3	0.755
		B	106.3	0.754
		C	106.3	0.757
	2	A	106.3	0.750
		B	106.3	0.749
		C	106.3	0.751
	3	A	105.4	0.742
		B	105.2	0.743
		C	105.2	0.743
	4	A	106.4	0.738
		B	106.4	0.738
		C	105.3	0.739
	5	A	106.3	0.734
		B	106.3	0.733
		C	106.3	0.735
	6	A	106.4	0.728
		B	106.3	0.727
		C	106.3	0.729
	7	A	106.3	0.723
		B	106.4	0.722
		C	106.4	0.723
	8	A	106.3	0.717
		B	106.3	0.716
		C	106.4	0.718
	9	A	106.3	0.711
		B	106.3	0.710
		C	106.3	0.712
	K	A	106.3	0.711
		B	106.4	0.709
		C	106.3	0.710
0/-	2	A	106.3	0.717
		B	106.4	0.716
		C	106.3	0.718

Table 14 – Ratio Test in 2014 after LTC Failure

0/-	2	A	106.3	0.717	Performed TTR for this Tap Calculated: 1.6042 Measured: 1.604
		B	106.4	0.716	
		C	106.3	0.718	

6 Maintenance History

The maintenance history information was available since 2004. Scheduled maintenance has been regularly performed on this unit and the following was noted:

- Oil sample was taken for PCB test for tap changer in 2004.
- Silica-Gel was replaced in 2007.
- Oil level gauge for LTC was replaced in 2008.
- Two of radiator valves were replaced in 2008.
- Oil level gauge for conservator was replaced in 2009.
- The two winding temperature gauges were replaced in 2012 due to moisture accumulating inside the gauges.
- New silica gel container installed in 2012.
- Oil sample for LTC was taken for DGA analysis in 2007, 2008, and 2012.
- The dielectric oil test for oil samples in 2012 from main tank and LTC diverter show 44kV and 25kV per ASTM D-1816, however no distance gap was mentioned in the document.
- The gas relay and the associated cables were replaced in 2012.
- The alarm and trip settings for winding temperature gauge were found to be set at 115°C and 125°C respectively in 2012.
- The alarm and trip settings for top oil temperature gauge were found to be set at 90°C and 110°C respectively in 2012.
- The last maintenance on OLTC was performed by Technical Service of Reinhausen Group in 2012.

7 Conclusions

A condition assessment report of FPE transformer with serial number 61-00-69167 at the Western Avalon station site was completed.

The DGA results showed that:

- The concentration of Hydrogen (H2), Methane (CH4), and Ethane (C2H6) are all normal for the years before the LTC failure.
- The Ethylene (C2H4) level has rising after 2009 but with a very slow increasing rate at 0.0027ppm/day before LTC failure.
- Traces of Acetylene (C2H2) have been found in the oil samples before 2009 - it dropped to zero after 2009.
- The carbon oxide level have been normal. The ratio of the carbon oxides suggests that the concentrations are due to the normal aging process of the transformer.
- The oil samples from this transformer have consistently shown high oxygen concentrations (>20,000 ppm).
- The oil DGA analysis for the oil sample taken on March 14, 2014 shows trace of C2H2 (3ppm).

The oil physical results showed that:

- All the measured breakdown voltage (BDV) are well above the suggested minimum limit by Doble except the tests for the year of 2002, 2003 and 2004 - those tests were performed per ASTM D1816-2, the results are far below the recommended minimum value (50kV/mm).
- The interfacial tension values are between 30 and 36 dynes/cm2 in last few years. The suggested minimum value is 32 dynes/cm2.
- The inhibitor values were not measured for the oil samples.
- The measured Acid Numbers for the oil samples in past years are all below the recommended maximum limits.
- The measured power factor values are somewhat higher than normal even though the results at 25°C/100°C are all below the IEEE recommended limits.
- The oil samples taken from the main tank show moisture content of less than 10 ppm except the sample in 2004.
- The measured power factor @ 25°C is 0.141% for oil sample taken on Mar.14, 2014.

The Power factor measurement showed that:

- Doble overall test results on April 11 are all above the maximum limit 0.5%.
- The latest C1 power factor and capacitance test values on April 11, 2014 for all bushings are normal.
- The latest C2 capacitance test on April 11, 2014 for all bushings are acceptable,
- The excitation current test results from 2012 are all acceptable.
- The excitation current test results on April 11, 2014 are normal.

The measured winding resistance in 2012 shows that results are consistent between phases.

The insulation tests performed in 2012 show results in Mega Ohms - this should be confirmed if this is really Giga ohms.

The (PI) index is lower than the ABB recommended value of 2.0 for HV/LV to ground.

The measured winding resistance in 2014 after LTC failure shows that they are all consistent between phases.

The ratio test result at contact # 2 (0/-) shows 1.604. This should be compared to results from factory test report.

This transformer may be wet and have some contaminations (perhaps carbon from the LTC failure). This is most probably what is causing the higher than normal power factor results.

Overall, there is no indication that damage has occurred to the windings due to the LTC failure.

8 Recommendations

Prior to returning the unit to service, the following should be done for this transformer. If these actions are done and everything is confirmed then ABB recommends to return the unit to service.

- Perform SFRA test (compare the traces between phases to confirm that there was no movement in the windings during the failure)
- Confirm the insulation resistance test results (in G-ohms not Mega ohms)
- After installing new tap changer, perform complete testing before energization. Compare the measured results to the factory test report.
- Hot oil circulate within the transformer, filter, and degas the oil.

Below are general recommendations that should be done with regards to this transformer

- Test BDV according to ASTM D1816-97 and indicate the gap used in the report.
- Always measure oil power factor at 25°C and 100°C.
- Add diaphragm to the conservator.
- Measure the inhibitor in the oil and add oxidation inhibitor to oil if it is in lower range.
- All gauges and accessories including WTI, OTI and PRD should be checked and calibrated.
- Always compare the resistance test results between factory and site test with temperature correction.
- Measure the bushings power factor and capacitance annually if possible. If the power factor is on the rise or the capacitance is changing, it should be considered to replace or refurbish the bushings.

(DRAFT ORDER)
NEWFOUNDLAND AND LABRADOR
BOARD OF COMMISSIONERS OF PUBLIC UTILITIES

AN ORDER OF THE BOARD

NO. P.U. __ (2014)

IN THE MATTER OF the *Electrical Power Control Act,* RSNL 1994, Chapter E-5.1 (the EPCA) and the *Public Utilities Act*, RSNL 1990, Chapter P-47 (the *"Act"*), and regulations thereunder;

AND

AND IN THE MATTER OF an Application by Newfoundland and Labrador Hydro pursuant to Subsection 41(3) of the *Act*, for the approval of the replacement of the tap changer on transformer T5 at the Western Avalon Terminal Station.

WHEREAS Newfoundland and Labrador Hydro ("Hydro") is a corporation continued and existing under the *Hydro Corporation Act, 2007*, is a public utility within the meaning of the Act, and is subject to the provisions of the *EPCA;* and

WHEREAS Subsection 41(3) of the Act requires that a public utility not proceed with the construction, purchase or lease of improvements or additions to its property where:

a) the cost of construction or purchase is in excess of $50,000; or
b) the cost of the lease is in excess of $5,000 in a year of the lease,

without prior approval of the Board; and

WHEREAS in Order No. P.U. 42(2013) the Board approved Hydro's 2014 Capital Budget; and

WHEREAS on June 19, 2014 Hydro applied to the Board for approval to replace the tap changer on transformer T5 at the Western Avalon Terminal Station (the "Application"); and

WHEREAS the Board is satisfied that the 2014 supplemental capital expenditure for the replacement of the on load tap changer on transformer T5 at the Western Avalon Terminal Station is necessary to allow Hydro to provide service and facilities which are safe and adequate and just and reasonable.

<u>IT IS THEREFORE ORDERED THAT:</u>

1. The proposed capital expenditure of $1,452,500 for the replacement of the on load tap changer on transformer T5 at the Western Avalon Terminal Station is approved.

2. Hydro shall pay all expenses of the Board arising from this Application.

DATED at St. John's, Newfoundland and Labrador, this day of , .