Summary of and Comments on
LIL Study Reports
Issued in April 2020

Presented to:

**The Board of Commissioners of Public Utilities
Newfoundland and Labrador**

Presented by:

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1. Introduction

Hydro has for some time been engaged in a comprehensive review intended to determine the operating limits of the Newfoundland and Labrador Hydro (“Hydro”) Island Interconnected System (“IIS”). This review has been examining expected operation during and after interconnection of the facilities comprising the Lower Churchill Project (“LCP”). The LCP consists of generation being installed at Muskrat Falls, the Labrador Transmission Assets (“LTA”), and the Labrador Island Link (“LIL”). The studies also consider how operation of the Maritime Link (“ML”), which provides a connection to Nova Scotia, will affect system operation.

TransGrid Solutions, Inc. (“TGS”) has been supporting these efforts through the conduct of and reporting on a range of operational studies addressing various system configurations, conditions, and contingencies. Major contingencies examined include faults on the LIL high-voltage, direct-current (“HVDC”) lines, faults on the high-voltage, alternating-current (“HVAC”) lines in Labrador and in the IIS, LIL monopole and bipole loss, and loss of the ML. The LIL, like the ML, has two separate converters, or “poles.” The LIL can be operated as a monopole or as a bipole. Each of the two LIL poles has an individual continuous rating of 450MW. The TGS studies examine the results of postulated contingencies under a wide range of system loads, assumed IIS generation availabilities, and how many of the three Soldiers Pond synchronous condensers are operating.

Scenarios found to produce failures to meet Hydro’s planning criteria have undergone additional analysis to identify preventive and responsive actions. These actions might include measures (among others) like the application of operating limits on the LIL or on the ML, enhancements to overhead lines in the IIS, and long-term availability of generation sources on the Avalon Peninsula. Plans now under evaluation call for the retirement of generating capabilities at the three Holyrood steam units, and at Stephenville and Hardwoods.

Earlier study stages addressed transfer limits restricting LIL and ML power flows during the since suspended first operation of the LIL in monopole mode. That mode permitted the LIL to operate up to a maximum of 225 MW, well short of its full-power, 900MW capability. The TGS final Stage 4 studies address bipole and monopole LIL operation at full power (“Full-Power Operation”), with Muskrat Falls generators and Soldiers Pond synchronous condensers, and with and without the ML in operation. They also address system conditions, capabilities, and contingencies as the LIL ramps up to full-power, 900MW operation (“Initial Operation”). The studies also address lack of availability of some or all Soldiers Pond synchronous condensers. Binding and vibration issues (updated in our most recent quarterly report on LCP transition to operations) discovered during their installation heighten the importance of addressing the implications of their unavailability.

An April 15, 2020 Hydro letter provided three April 7, 2020 TGS-prepared technical notes describing these Stage 4 studies, their results, and measures identified to prevent and to respond to scenarios that would produce planning criteria violations or system operations issues:

- Stage 4D LIL Bipole: Transition to High Power Operation (TN 1205.71.07)
- Stage 4E LIL Bipole: High Power Operation (TN1205.72.03)
- Operational Considerations with 0 and 1 SOP Synchronous Condensers (TN1205.74.01).

This document reviews these three TGS technical notes and provides our comments on them.

2. Summary

a. Overall Comments on the TGS Studies

The three technical notes reporting the results of the TGS studies performed appear to reflect careful and thorough analysis. While addressing complex matters in a necessarily technical manner, the three notes robustly describe the results observed and the implications for IIS operation, as the LIL transitions to full power during its Initial Operation phase. This transition must employ interim control and protection software, which precludes full LIL functionality. Limits will remain until achievement of Full-Power Operation, which must await a final, fully effective software version. Long-standing and continuing problems in the development and testing of that software have produced this approach to bringing the LIL into Full-Power Operation.

The first of the three technical notes addresses the Initial Operation phase, the second addresses Full-Power Operation, and the third describes the implications of synchronous condenser unavailability during both of these phases.

The studies have significant implications for the Board's ongoing examination of reliability - - particularly with reference to assessing needs for continuing availability of generation on the Avalon Peninsula, during both Initial and Full-Power Operation. The findings with respect to synchronous condenser availability also bear attention during current efforts to get the LIL from Initial to Full-Power Operation, given materially uncertain schedule expectations for resolving binding and vibration issues affecting synchronous condenser availability and operation.

Recent information from Hydro indicates that management intends to limit LIL operation to a maximum of 225MW during upcoming commissioning activities. Following successful dynamic commissioning at 225MW, a trial operation period will follow, during which the LIL must operate continuously without a trip for a minimum of 30 days. The LIL operated continuously at 225MW for three days in 2018, when in monopole mode.

The sub-sections immediately following this one summarize observations and findings of the three technical notes, followed by sections describing each in more detail. These portions of this document discuss a number of activities or acknowledgments that we consider important, particularly with respect to the Board's current proceedings examining short- and long-term reliability and resource adequacy. We summarize them immediately below. The length of the list does not suggest concern with the scope or adequacy of the three technical notes we summarize. To the contrary, this list shows instead the complex and multi-faceted issues raised by difficulties to bring the LIL into operation, and the ways its availability and operation will affect the IIS thereafter. That the TGS work commissioned by Hydro has brought us to the point of being able to ask such questions speaks well to its value in advancing knowledge of the issues with which the Board and stakeholders must grapple over the remainder of this year.

The list of key questions, acknowledgments, and confirmation of plans and schedules includes:

- The TGS work identifies the need for up to 120MW of generation on the Avalon Peninsula. These observations underscore the importance of prompt completion of the ongoing analysis of extending the life of at least some of the Holyrood steam units, now planned for retirement after the LCP reaches a steady state of operations consistent with its designed capabilities. Whether these steam units have the capability to respond adequately in meeting the remaining Avalon generation need forms a central part of the ongoing Hydro study.

- The TGS work highlights a number of critical changes that will come when the LIL becomes capable of reliably performing with all its intended capabilities under Full-Power Operation. Fully functional operation of the final LIL control and protection software comprises the most critical element in reaching this state. Hydro needs to press Nalcor to do all it can to secure completion of General Electric's work and to make progress, problems, risks, and schedule exposures clear to the Board and stakeholders, as the proceedings addressing reliability and resource adequacy continue.
- The TGS analyses demonstrated the importance of Soldiers Pond synchronous condenser availability. The completion of the condensers remains subject to significant uncertainties. It is important for Nalcor to identify temporary and permanent solutions promptly, and to provide a clear assessment of the impacts of unavailability or constrained operation on LIL completion, commissioning, and Initial Operation. Such information has a clear connection to and importance for the Board's current proceeding for addressing short- and long-term reliability and resource adequacy.
- General Electric reportedly has not yet agreed to power transfers in excess of 225MW in the absence of synchronous condenser availability. Hydro should make sure it always has from Nalcor a current understanding of the situation, and management should keep the Board informed monthly of efforts to get that decision made and assess its consequences.
- Potential thermal overloads resulting from single contingencies ("N-1") and from further events following them ("N-1-1") have been identified. Customer impacts of actions to prevent and respond to those contingencies remain to be studied. Operational protocols remain to be developed by Hydro to manage the relevant overload conditions, which could include limits on ML exports. Hydro should present a schedule for their completion.
- Full-Power Operation of the LIL at less than 2,833MVA requires General Electric approval, with PSCAD studies required to determine acceptable transfer limits. Hydro should present a schedule for their completion.
- A three-phase fault in the area near Soldiers Pond can cause a commutation failure (from a voltage disturbance preventing valve current from being transferred quickly enough to the next valve). Additional studies using the more appropriate PSCAD software to investigate this matter remain to be performed. Hydro should present a schedule for their completion.
- TGS also did not consider temporary HVDC overhead line faults, which Hydro has agreed are required. Hydro should present a plan and schedule for performing the required analysis.
- System instability resulting from a three-phase fault on line TL267 under some conditions at load flows above 650MW requires correction or a restriction on LIL operation. Hydro plans to address this threat through tuning of synchronous condenser system stabilizers. Delayed by coronavirus-related work, Hydro hopes still to complete the work this year. Hydro should report on the effectiveness of its solution as soon as it reasonably can.

- In response to our questions about restrictions General Electric has placed on LIL operation, Hydro stated that it has no role in what it termed a commercial matter. Hydro responded similarly when asked about responsibility for potential damage to LIL or other equipment connected to the ac network. Wherever responsibility lies, definitive answers to these questions should come soon enough to be considered in current proceedings examining reliability and resource adequacy.
- The analyses performed included consideration of the need for embedding an Automatic Stability Runback function in the ML to address outages that might cause too low a short circuit level at Bottom Brook. TGS had to perform manual activities to supplement the ML model available for conducting the analysis. Hydro should secure an updated ML model version to support more accurate future modeling.
- Hydro's calculation of maximum expected UFLS (at present 963MW) is not yet accompanied by a mapping of the areas affected, frequencies that will trigger disconnection by area, or load shed by area. Hydro plans to, and it should as promptly as possible, map this information upon identifying the specific feeders planned to be tripped. Similarly, Hydro should follow through on its plan, as stated to us, to provide an analysis of and estimates of likely restoration times. The resulting documentation of each should be made available as soon as possible.
- The TGS technical notes addressed a possible voltage collapse in the Bay d'Espoir - Soldiers Pond corridor, caused by a reactive power problem. Hydro should follow through on its plan, stated to us, to address this collapse as part of resource adequacy study activities.

b. LIL Limits During Initial Operation

The Stage 4D LIL Bipole: Transition to High Power Operation technical note summarizes the examination of IIS Initial Operation, as it transitions from low to full power. Pending use of fully-functional final software, LIL operation will use an interim version of the control and protection software, which does not include a number of important functions. The final version continues to be delayed by very substantial problems in its development by General Electric. Our series of ten quarterly reports addressing LCP transition from construction to operation detail those problems. The last updates progress to include key events during May of this year.

Initial Operation will not permit the LIL to use each pole's overload capability - - an important aspect of full bipole operation. Fully functional operation of the final software will allow the LIL to respond to the loss of a single pole by increasing the power on the remaining one. Concurrent loss of both poles during initial LIL operation will likely cause a reduction of system frequency sufficient to require disconnecting customers in numbers (potentially very large) sufficient to maintain required system frequency. System operation will require the use of such Under Frequency Load Shedding ("UFLS") unless, with the ML in operation, the run-back of the ML exports are sufficient to arrest the fall of the frequency, alone or in combination with IIS generation. UFLS will commence when the frequency falls to 59Hz and will continue until Island generation can deliver the remaining load.

Applicable planning criteria permit UFLS in the event of a bipole trip, but not for a trip of one pole. Frequency will fall in the event of a trip of one pole, but must remain above 59Hz. System operators will have to impose operating limits to satisfy this frequency limit under some conditions. For example, with the ML frequency controller unavailable and with no exports on the ML, loads on the LIL must be limited to 470MW during peak IIS load conditions and to 230MW during lightest IIS loads. Should there be ML exports to Nova Scotia at the time of single pole loss, the LIL load limits can be increased by the amount of those exports that can be decreased ("run-back").

The lack of LIL frequency control and run-back have significant impacts on maximum ML imports and exports, assuming that no generation from Holyrood is available:

- 300MW on imports and 150MW on exports during high IIS loads
- 225MW on imports and 75MW on exports during low IIS loads.

Availability of generation from the Holyrood steam units lowers the limits, depending on the number of units available, because the units have limited capability for step changes in power output. With two Holyrood steam units operating, ML export limits fall to less than 55MW, and to less than 45MW when one Holyrood unit is in operation.

Experience indicates that, in their first stage of operation, HVDC schemes like the LIL experience bipole trips in numbers greater than those permitted by specifications (*i.e.*, no more than 1 in every 10 years). LIL bipole trips can cause loss of loads and voltage collapse caused by lack of reactive power control. Voltage collapse can produce a complete system black out.

Availability of some of the three Soldiers Pond synchronous condensers can provide control to prevent voltage collapse. Our most recent quarterly report addressing LCP transition to operations discusses the issues presently clouding completion and commissioning of those condensers. Pending their availability, Hydro will require 120MW of generation on the Avalon Peninsula to assure prevention of voltage collapse at time of peak loads on the IIS. The required amounts of such generation drop significantly and eventually disappear as load levels decrease or as one or two condensers are assumed to be operating. The ability of the Holyrood units to supply the needed generation requires clarification, because these units have a very limited fast power change capability.

c. LIL Limits After High Power Operation

The Stage 4E LIL Bipole: High Power Operation technical note assesses system operation after the LIL completes its transition from Initial to Full-Power Operation, making the following steady-state, long-term assumptions:

- The LIL has become fully operational with all required control and protection systems functions (including final General Electric software)
- Three synchronous condensers are available at Soldiers Pond
- The three Holyrood steam generating units and the Stephenville and Hardwoods generation units have been retired permanently
- Holyrood Unit 3 continues to operate as a synchronous generator
- A new UFLS scheme has been designed.

A LIL bipole trip will have the same consequences under Full-Power Operation as under Initial Operation. The difference, when operating under a fully-effective final software version, lies in the consequences of a monopole trip. With the ability to run-back exports over the ML to Nova Scotia, the LIL can operate at its full 900MW capability, when Island demand exceeds 1,400MW. At lower Island demand levels, the LIL's operating limit falls, as assumed levels of ML exports do. Without the ML in operation, the LIL can operate at maximum level of 750MW at maximum Island loads. That operating limit falls to 500MW for Island loads at about 950MW.

This technical note showed no need for constraints on ML operation, assuming availability of the LIL frequency controller. A trip of one or both ML poles will not adversely affect IIS operation in these circumstances.

The study included the determination of thermal overloads in the IIS resulting from single contingencies ("N-1") and from further events following them ("N-1-1"). System operators will respond with measures to limit their consequences for the system and its components and for customers. Customer impacts following system operators' responsive actions remain to be quantified. The note also describes some Bottom Brook area ac line outages that may produce ML instability requiring the imposition of operating limits.

d. LIL Limits with Zero and One Synchronous Condenser Operating

The three new synchronous condensers under installation at Soldiers Pond as part of LCP have experienced binding and vibration issues whose solutions remain under examination. Their commissioning will not meet schedule requirements. Our quarterly reports addressing LCP transition to operations describe the potential for work to correct the issues observed as extending into 2021. This third technical note, Operational Considerations with 0 and 1 SOP Synchronous Condensers, examined system operation before the full complement of Soldiers Pond synchronous condensers becomes operational. We summarize its key observations and findings in the next paragraphs.

Harmonic Filters - - AC harmonic filters reduce to an acceptable level the harmonic distortion that operation of the HVDC converters will produce. These filters are switched in and out as the power on the LIL is increased and decreased, in order to control the ac voltage. Harmonic analysis by TGS has determined that the LIL can operate up to its full 900MW capability with just two filters. However, this assessment considers only harmonics. Reactive power/ac voltage control considerations produce a need for five in-service filters to support LIL operation at 900MW, to provide sufficient system voltage support.

Switching in a filter causes the voltage to rise. The ac voltage drops when switching out the filter. The voltage step resulting from the switching of a filter depends on the strength of the network (its short circuit level, or "SCL"). The SCL increases with more generation or synchronous condensers in service. Applicable planning criteria prescribe voltage step limits, which depend on the number of switching operations per day. With no synchronous condensers available, at least one Holyrood generating unit must be in service to permit switching the first two filters into service. Switching a third filter into service requires two Holyrood units in service. Five filters require all three Holyrood generating units in service. TGS found that having one synchronous condenser in service produced no violation of voltage step limits, even with no Holyrood generating units available.

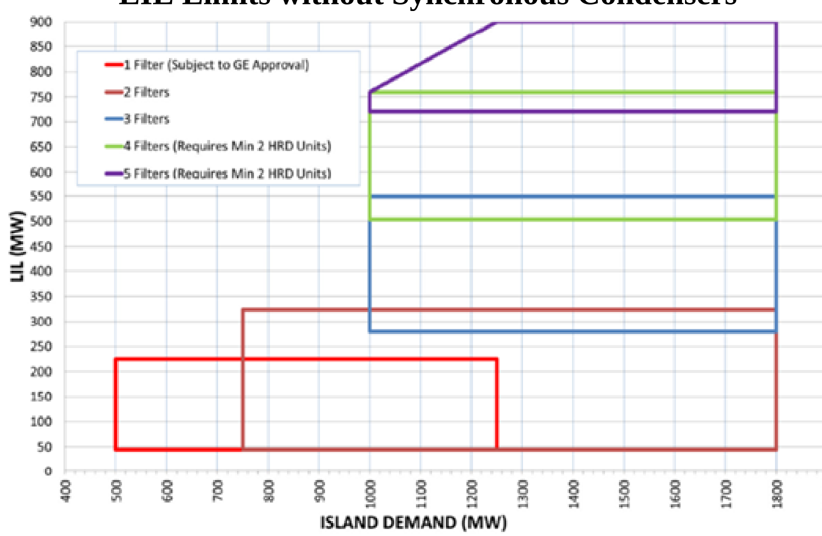
Minimum Short Circuit Level - - Full-Power Operation of the LIL requires a minimum Soldiers Pond SCL of at least 2,833 MVA, achievable only with one synchronous condenser and all three Holyrood units in service. Full-power LIL operation at less than 2,833MVA requires approval by General Electric, who will perform PSCAD studies to validate acceptable transfer limits. A PSCAD study program defines the converter in high detail, including the switching operation of the converter valves, making studies of very fast events possible.

LIL Limits with No Synchronous Condensers in Service - - The next figure shows the limits on LIL operation with no Soldiers Pond synchronous condensers in service. A number of pre-conditions apply in enabling testing of this capability without any SCs, including:

- LIL operation requires a minimum of one Holyrood unit in service as a generator or as a synchronous condenser
- The third Soldiers Pond filter bank can only be placed in service when Island Demand exceeds 1000 MW, this is to avoid overvoltage conditions
- Avoiding unacceptable voltage deviations requires two or more Holyrood units online to place the fourth Soldiers Pond filter bank in service (General Electric's switching scheme limits LIL capacity to 550 MW with less than four filters in service).

TGS has observed the potential for multiple commutation failures in the event of a three-phase fault in the area near the Soldiers Pond converter station. A commutation failure is caused when the valve current cannot be transferred quickly enough to the next valve and is usually caused by a voltage disturbance. Commutation failures delays the recovery of power transmission. PSCAD studies are required to determine whether such commutation failures will occur or if the system voltage may collapse. Performance of such studies remains pending.

LIL Limits without Synchronous Condensers



LIL "Deblocking" - - Deblocking marks the start of the converter; *i.e.*, the sequential firing of the thyristors to create a voltage output at the HVDC terminals, and the flow of current when the converter at the other end has also been deblocked. LIL deblocking (commencement of firing converter valves) involves relatively fast ramping of power to a minimum of 45MW. Deblocking requires one energized ac harmonic filter. The converter absorbs an increasing amount of reactive power as power grows. Stable operation requires reactive power/voltage control - - achieved by switching in and out the ac harmonic filters. TGS analyses found that LIL deblocking cannot occur with an Island demand below 500MW, without at least one synchronous condenser in service. At high Island demands, one synchronous condenser and at least two Holyrood units must be in operation to avoid voltage collapse.

Other TGS Findings - - The LIL must operate within the limits identified in the Stage 4D study (as a function of IIS demand and ML power flow) to comply with transmission planning criteria. A Dynamic Performance study performed using PSSE software identified the possibility of unacceptable commutation failures after the clearance of faults near the Soldiers Pond converter station. Additional studies performed using the more appropriate tool (PSCAD software) remain pending.

3. Stage 4D LIL Bipole: Transition to High Power Operation

a. Study Description

This technical note sought to determine: (a) the maximum power flows that the LIL and ML can carry (transfer limits) under a variety of conditions, and (b) the megawatts of Avalon Peninsula generation required be available to avoid voltage collapse or system instability under a range of conditions, as the IIS transitions from Initial to Full-Power Operation. The note considers a number of factors affecting those limits, as more equipment comes into service during this transition period:

- Operation of the Holyrood Thermal Plant ("Holyrood") - - now determined to be required during an LCP-phase-in period
- Differing numbers of the three Soldiers Pond synchronous condensers in-service
- LIL operation in either monopole or bipole modes
- LIL operation without frequency control
- LIL operation without 2pu 10-minute overload capability when one pole is lost - - this capability will not exist during the transition period
- Number of Soldiers Pond and Muskrat Falls filters needed to meet IEC harmonic distortion limits.

This April 7, 2020 technical note updates a version dated September 25, 2019 (received in February 2020). That earlier technical note described analyses based on a generic model, later determined to have limited the firing angle range of the converter. The analyses described in the updated report used a LIL PSSE model provided that General Electric provided. This note also reversed the assumption that Holyrood would have ceased to provide any thermal generation by the time of this transition period - - assuming instead that Holyrood continues through the entire period studied assumed. This study also addressed scenarios with from zero to three synchronous condensers in operation at Soldiers Pond.

It also studied cases involving single pole and bipole LIL trips, under scenarios positing from zero to three Soldiers Pond synchronous condensers operating. Our latest quarterly transition-to-operations monitoring report discusses binding and vibration issues surrounding synchronous condenser completion and commissioning. Preferred means for solving vibration issues remain under examination and their execution may extend into 2021.

The TGS analyses did not consider temporary HVDC overhead line faults. Management has, however, agreed to perform a study considering such faults, and to provide an update when completed.

b. The Technical Note's Major Conclusions

1. ML Effects on LIL Power Flows

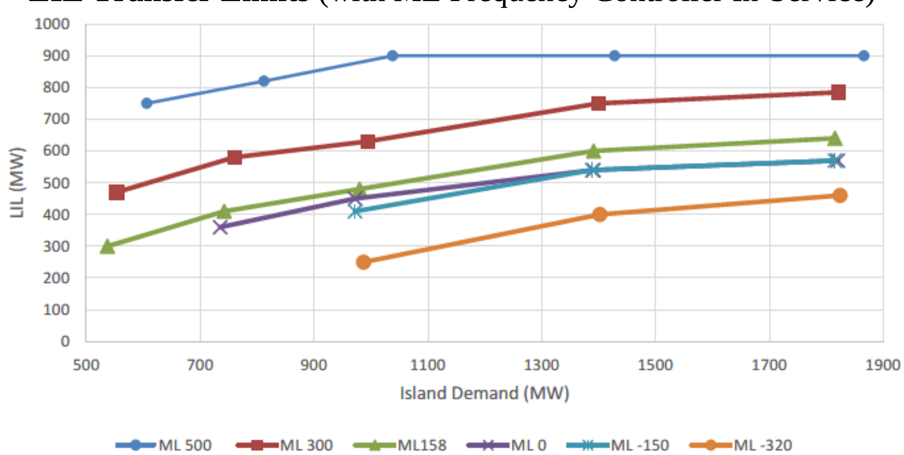
Critical determinants of maximum permissible LIL loads (to ensure that loss of one pole will not cause IIS frequency to drop below 59 Hz or produce UFLS) include:

- Loads on the IIS
- Whether and how much the ML is exporting or importing
- Whether the ML frequency controller is in service.

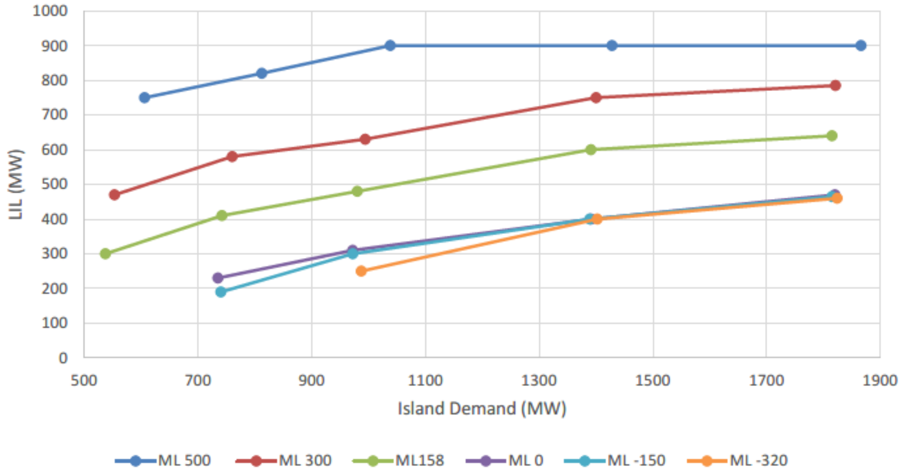
The analysis performed assumed the ability to run-back exports or imports on the ML is always available.

The next two figures show these LIL transfer limits as a function of demand on the IIS, considering the factors controlling them. The colored lines show these LIL limits at varying ranges of ML operation, from exporting 500MW (blue) to importing 320 MW (orange). The figures demonstrate, as expected, that the LIL's ability to bring power to the IIS depends heavily on the magnitude and direction of power flow on the ML. The impact of ML frequency control, which may not always be available, also affects maximum power flows.

LIL Transfer Limits (with ML Frequency Controller In-Service)



LIL Transfer Limits (with ML Frequency Controller Not In-Service)



2. The Need for Avalon Generation

Analysis undertaken for Hydro concludes that a bipole trip during the LIL's Initial Operation requires that generation on the Avalon peninsula be available. Such generation is needed to avoid voltage collapse and instability/electromechanical oscillations. The technical note also found a need for generation to avoid system collapse in the event of a three-phase fault on the transmission line between Bay d'Espoir and the Avalon. The amount of such generation depends on the number of synchronous condensers available, as the next chart demonstrates. The "None" entries are qualified; *i.e.*, 0 unless required to meet IIS demand and MS exports.

Required Avalon Generation

IIS Demand (MW)	Avalon Generation (MW)			
	0 SOP Syncs	1 SOP Sync	2 SOP Syncs	3 SOP Syncs
1750-1850	120	70	40	None*
1700-1750	70	15	None*	None*
1600-1700	30	None*	None*	None*

The technical note also identified electromechanical oscillation issues in the event of a LIL bipole failure while two or three synchronous condensers are operating. Such issues likely result from a lack of tuning of the Power System Stabilizers. Without tuning, the following limits would be required on power flowing eastward from Bay d'Espoir toward the Avalon:

- Three synchronous condensers operating: 510MW
- Two synchronous condensers operating: 540MW.

The report also concludes that, at load flows above 650MW, system instability may result following a three-phase fault on line TL267, thus requiring a restriction on LIL operation. Hydro recognizes the need for tuning of the synchronous condenser system stabilizers to control oscillations on the long transmission lines traversing the Bay d'Espoir to Avalon corridor. Hydro has incorporated this work as a priority item in its capital planning. However, the tuning may face delay, with coronavirus work restrictions inhibiting use of external resources to collect existing data, and to perform required stabilizer tuning. Nevertheless, management hopes to complete the work this year.

Management was not prepared to address impact of oscillations and instability on the need for generation capacity on Avalon, should the stabilizer tuning not relieve the 540 and 510 MW restrictions. Management has assumed that it will be able to perform required stabilizer tuning before Holyrood generation retirement, which has now been extended through the first stages of LCP operation.

c. Other Details

1. Model Confirmation

Given the use of an updated model, we asked for confirmation that the General Electric PSSE model of the LIL had been validated against PSCAD and/or RTDS study results. Management stated that validation against PSCAD models (more detailed and used for short timescale studies) and Real Time Digital Simulator RTDS results (*i.e.*, results from Factory Acceptance Testing, addressed in our most recent quarterly report of Transition to Operations progress and status) remains ongoing. Minor, but not material or concerning differences have understandably been observed, given that the tools have somewhat different objectives. Hydro has not observed the results of this Nalcor-performed verification.

2. Nova Scotia Position on Run Backs and Run Ups

Hydro reports that it has confirmed agreement from Nova Scotia to ML run-back in the event of LIL single pole and bipole loss, stating that the Nova Scotia system operator's role in import/export power flows will consider the possibility that such actions may be required. Hydro also confirmed that, despite the fact that the highest load at Muskrat Falls Table 2-2 was 810MW, the studies included power flows of 900MW.

3. Confirming Values Used

Hydro reported to us that total inertia of the generators in the IIS plus synchronous condensers for as studied amounted to 4,000 to 6,000 MW for the generators during peak season. Each synchronous condenser will contribute some 1,372MWs, with each Holyrood unit contributing about 500MWs.

4. Study of Temporary LIL Faults

Hydro has not yet studied temporary faults on the HVDC overhead lines, considering the impacts that the number of synchronous condensers in service at the time of such faults may have. However, Hydro will do so and it expects to issue in the coming weeks a separate technical note. That note will also address restrikes.

5. LIL Run-Back and Run-Up

The absence of LIL run-back and run-up capability substantially restricts ML power flows. The current LIL software version recently used for Factory Acceptance testing earlier in May does not support this capability. Installation of this capacity will be included in the final LIL software.

6. Harmonic Filter Testing

We asked whether General Electric has undertaken harmonic studies addressing equipment distortion and stresses, given that the ac network at Muskrat Falls and at Soldiers Pond will differ from the specified network conditions. Management reported General Electric's statement that harmonic filter design accommodates worst-case harmonics. General Electric reportedly has identified no harmonic constraints or limitations.

7. Waiving LIL Limits with Synchronous Condensers Not in Service

General Electric reportedly has not yet agreed to power transfers in excess of 225MW in the absence of synchronous condenser availability. However, General Electric reportedly has not declared it impossible to transmit more than 225MW either. It is not clear whether determining the limits and risks involved would require additional studies or tests.

We asked Hydro about restrictions General Electric has placed on operation under such conditions, Hydro responded that it had no role in such commercial matters. Hydro responded similarly when asked about responsibility for potential damage to LIL or other equipment connected to the ac network.

4. Stage 4E LIL Bipole: High Power Operation

a. Study Description

This second, April 7, 2020 TransGrid Solutions Inc. technical note assesses the consequences of monopole and bipole LIL Full-Power Operation, following the completion of work necessary to give it full functionality, including frequency control and 2 pu 10-minute overload capability. It assumes that Avalon Peninsula generation resources at Holyrood, Stephenville, and Hardwood have been retired, with Holyrood Unit 3 operating as a synchronous condenser, along with those newly installed at Soldiers Pond. The analyses performed by TGS assume the availability of two synchronous condensers.

The analysis sought to determine limits required to be placed on power carried by the LIL to avoid UFLS in the event of the loss of a single pole, and maintain stability of the IIS in the event of a bipole trip. The technical note addresses LIL transfer limits under a variety of IIS loads and a range of ML import and export conditions. TGS examined limits with and without the LIL frequency controller in service. All cases assume availability of ML run-back. For example, when exporting 500MW, the ML will be run-back to 0MW in the event of the trip of one or both LIL poles. Activating run-back will leave no further support available from the ML. Frequency support from the ML is available only when it is operating in the range of
-150MW to +150MW.

The technical note also addresses a number of other important factors affecting IIS performance after the LIL reaches Full-Power Operation and the legacy generation sources on the Avalon Peninsula are assumed to be retired:

- Updated ML transfer limits recognizing the availability of LIL frequency controller action
- Steady state thermal and voltage analysis of the IIS under N-1 and N-1-1 conditions

- Preliminary analysis of dynamic response of IIS under N-1 three-phase fault ("3PF") conditions
- ML transfer limits under N-1 and N-1-1 conditions (N-1-1 considers a prior 230 kV line outage)
- Summary of ML emergency actions.

The technical note examines an important and broad range of conditions and contingencies, but does not address one aspect of performance that we consider important; *i.e.*, an analysis of the dynamic behavior of the LIL during and after temporary faults on the HVDC overhead line. Some studies performed several years ago did address this issue, but they came before significant changes to the LIL's controls and models. Our recent discussions with Hydro indicated managements agreement to perform studies of temporary faults on the HVDC line, assuming both single line faults and simultaneous faults on both poles. Re-strikes, which are not uncommon, will also be simulated.

b. The Technical Note's Major Conclusions

1. LIL Transfer Limits

Hydro has updated its UFLS response scheme for application in protecting the ISS from complete shutdown under a bipole outage, after the LIL has reached Full-Power Operation. The UFLS scheme produces trips of load segments when the frequency drops below 59Hz, and additional load trips for every additional 0.1Hz until the final step at 58.2Hz, if necessary. The worst-case UFLS could produce disconnection of IIS customers representing 963MW of IIS load. When operating with the fully functional, final control and protection and software version, each pole of the LIL will provide the overload capabilities and system benefits described earlier. That capability, however, will not always compensate fully for the capability lost, because of resulting increases in power loss. The LIL capability limits take this reduced power capability after the trip of a pole into account. The study shows that the loss of one pole is more restrictive than the loss of the bipole for some cases.

2. Requirement for Avalon Generation

The report finds a requirement for a minimum amount of Avalon generation to be in-service when IIS demand is greater than 1,600 MW. This generation is required to avoid voltage collapse around the mid-point of the Bay d'Espoir - Soldiers Pond 230kV corridor. The issue is covered in the updated Stage 4D LIL Bipole: Transition to High Power Operation report. The amounts of generation are as listed above in section 3.b.2.

3. Thermal Overload of IIS Transmission Lines

Analysis of trips of ac lines connecting the ML during N-1 and N-1-1 conditions found that a number of cases would cause line overloading. It is assumed that constraints on operation of the ML would be imposed to prevent such overloads from causing damage. The technical note does not include an analysis of the potential impact of N-1 and N-1-1 outages of other transmission lines in the IIS. Such a study may be part of the routine studies performed by Hydro, but its omission from this report should be justified.

4. ML Transfer Limits

The technical note defines the ML transfer limits with the LIL frequency controller in service. The limits ensure that UFLS will not occur in the event of the trip of the Maritime link Bipole or Pole. For operation with the ML frequency controller out of service, see the discussion and figures in Section 3.b.1 hereof.

5. Preliminary Dynamic Analysis

This analysis addressed the potential need for embedding an Automatic Stability Runback function in the ML to eliminate adverse consequences, should transmission outages cause too low a short circuit level at Bottom Brook. The ML model appears not to have included this function, but the actions resulting from the runback action were implemented manually by TGS. No unacceptable issues resulted. However, an updated version of the ML model should be requested, to enable more accurate modelling by Hydro in the future. Hydro reported that it will request an update from Emera, agreeing that it would reduce the chance of study errors because of the present need for work arounds.

6. Steady State Analysis of the ISS

The report summarizes overloads that would occur during N-1 and N-1-1 situations for a large range of lines and at different IIS loading scenarios. Initiation of this type of analysis reflects a sound approach for addressing differing possible load flows across the IIS.

7. ML Operation under Weak Bottom Brook Conditions

A main advantage of the voltage sourced converter technology used for the ML lies in its ability to work with low short circuit levels, because the converter can regulate ac voltage magnitude. However, the ML appears not to have been designed for operation at low short circuit levels. Therefore, the imposition of operating constraints during outages of lines through which the ML connects, will be required. The worst case involves coincident outages of the T211 and T233 lines. This case produces the lowest short circuit levels, ranging from 335MVA to 404MVA. The technical note states that the ML will not be able to operate in bipole mode, but can support 35MW export to 50MW import in monopolar operation.

c. Other Details

1. Expected UFLS Levels and Locations

Hydro confirmed that the maximum expected load shed when frequency reaches 58.2Hz is at present 963MW, assuming peak load conditions. The load shed will concentrate on the Avalon Peninsula; *i.e.*, where most of the load exists. Work to optimize UFLS will continue over the coming months, but Hydro does not anticipate large change. A table showing the latest version of the updated UFLS scheme is not yet available. Hydro does not have a map showing the areas affected, the frequencies that will trigger disconnection by area, or the load shed by area. However, after identification of the specific feeders planned to be tripped, such information could be mapped.

Hydro was also unable to project the differences in restoration times (by block or percentage) that assistance from the ML would offer. Hydro did observe that it would give top priority to keeping the system intact during restoration, which has in the past has led to energizing small blocks at a time. In the future, the availability of the ML and the LIL, both with frequency control capability, will make it possible to energize larger blocks, shortening restoration time. Hydro has not yet analyzed restoration times, but will develop a technical note on UFLS restoration at a later date.

2. Bay d'Espoir -Soldiers Pond Corridor Voltage Collapse

A reactive power problem underlies a possible voltage collapse in the Bay d'Espoir - Soldiers Pond corridor. Hydro will address this collapse as part of resource adequacy study activities.

3. Labrador Power Flow Changes

We asked about impacts of disturbances caused by Labrador power flow changes resulting from LIL frequency controller response to ML export and import losses. Hydro stated that Stage 4C analysis identified the need for synchro phasors and the tripping of a single Muskrat Falls generator in the event of a 900MW transmission capability loss due to a bipole trip.

5. Operational Considerations with 0 and 1 SOP Synchronous Condensers

a. Study Description

This Technical Note (TN1205.74.01) summarizes considerations applicable to the commissioning and operation of the LIL with the final control and protection software, considering two operating scenarios:

- No synchronous condensers have come into service at Soldiers Pond
- Only one of the planned condensers is in operation at Soldiers Pond
- Holyrood generation remains in service.

The synchronous condensers increase the IIS system short circuit level (SCL) and support system stability.

b. The Technical Note's Major Conclusions

1. Harmonics

Previous analysis of harmonics (distortions of current and voltage) identified transfer limits during LIL transition from Initial to Full-Power Operation, considering varying numbers of filters in service, including zero synchronous condensers operating at Soldiers Pond. The analysis found that, from a harmonics-only perspective, the LIL can operate to its full ratings (675 MW monopole and 900MW bipole) with two filters in service (an A and a B type or an A and a 2B type).

2. Short Circuit Level

LIL design specifications require a Short Circuit Level of at least 2,833 MVA at Soldiers Pond for full-power operation. Any lower level requires the approval of General Electric and validation of acceptable transfer limits through PSCAD analysis. TGS analyzed light-load conditions, assuming minimum IIS generation and varying number of Holyrood units in- service. That analysis demonstrated that achieving an SCL in excess of 2,833MVA before all Soldiers Pond synchronous condensers are in-service requires both:

- Operation of the three Holyrood units
- Availability of one synchronous condenser.

We asked whether General Electric has addressed its willingness to commission the LIL at high power without a synchronous condenser; *i.e.*, with an SCL below the specified 2,833MVA level. Hydro responded that commercial (as opposed to planning) issues such as this one, fell outside of Hydro's purview, residing with Nalcor management.

3. Voltage change during Filter Switching

Switching filters causes a voltage change; voltage rises upon filter connection and drops when the filter is switched out. Synchronous condensers mitigate voltage change by increasing the short circuit level. The voltage change can cause a disturbance visible to customers. Therefore, the planning levels include a limit on the number of switching operations. Increasing the number of switching operations reduces the allowable voltage change. The study applied a five percent voltage change limit with no synchronous condensers operating, which is the limit for less than four switching operations per day. The analysis showed that two Holyrood units must be on line to comply with that limit. The study considered the specific filters required to be in service at specific loads. It established a maximum allowable LIL load of 550MW in the absence of at least one synchronous condenser and two Holyrood units in service.

We asked why frequency and number of filter switching operations per day is not limiting the permissible voltage change to less than five percent. Hydro replied that the issue will be managed operationally (*e.g.*, by starting additional generation to limit disturbance), if considered necessary.

The study's five percent voltage change limit permits no more than four switching operations per day. During commissioning, the number of filter switching operations per day is likely to be significantly higher than four.

4. Steady State Voltage

The analyses conducted addressed system voltage as a function of the number of Holyrood units and synchronous condensers (zero or one) in operation, with the harmonic filters being energized and de-energized. Reaching 900MW requires five filters to be in service. The harmonic filters need to be energized one-by-one, as the converter is deblocked and starts to increase the power flow, with filters being energized at relevant power flows. Similarly, it is necessary to de-energize filters as the power reduces, with the final filter being switched off when the converters are blocked.

The principal issue appears to concern control of the ac voltage. High voltage raises concern at low IIS demand levels, with low voltage a concern at times of high IIS demand. Without a synchronous condenser, it appears difficult to navigate through the energization of harmonic filter energization and de-energization, even with three Holyrood units, because of the risk of voltages becoming either too high or low. Having at least one synchronous condenser in service eases the situation, but at peak demand all three Holyrood units need to be in service to meet demand and to support the IIS voltage. Also, either a synchronous condenser or the Holyrood combustion turbine must be in service to prevent voltage collapse.

The results indicate that LIL commissioning over the full range of loads will require detailed study, to ensure no negative IIS impacts from the tests.

5. Dynamic Performance

Assuming no Soldiers Pond synchronous condensers in operation, TGS examined IIS operation by imposing a three-phase fault on a Holyrood generating unit (producing a transformer and generator unit trip). The LIL, as expected, failed commutation during the fault, but in two cases also experienced commutation failures during fault recovery. TGS described the latter failures as "not usually considered to be acceptable." The LIL specification states that there should be no commutation failures during fault recovery. Reducing LIL power transfers avoids commutation failures during low IIS load levels, but not at peak loads. The LIL's commutation performance requires further study using a PSCAD model; the PSSE tool employed is not accurate for assessing such performance.

Hydro stated that the cases selected excluded Holyrood Unit 3, which has synchronous condenser capabilities. Hydro also stated that the PSCAD underway now will produce another technical note when completed.

6. High Power Summer Tests

The technical note referred to high-power tests "intended to test the LIL at 900 MW transfer while the ML is exporting 500 MW. It went on to set forth guidelines for their conduct:

- Follow LIL transfer limits defined for Stage 4D: with the ML exporting 500 MW, the LIL may transfer 900 MW for IIS demand levels of 1,250 MW or above, and assumes ML run-back to reduce exports to zero for a LIL single or bipole trip.
- An appropriate number of Holyrood units in-service, as determined by the studies in this note, considering IIS demand levels and whether zero or one synchronous condenser is assumed to be in-service.

c. Other Details

1. LIL Pre-Commissioning Planning and Further Testing

We observed that the analyses have demonstrated that LIL commissioning, considering the full range of loads and the potential for zero or one synchronous condensers in service, will require detailed planning and supporting studies, to ensure that no negative impacts to the IIS due to conduct of the tests. Hydro confirmed that it expects to perform such planning and studies for high-power testing.

2. LIL Commissioning Without Synchronous Condenser Availability

We sought to determine Hydro's confidence that, given the results of the analysis, LIL commissioning could proceed effectively in terms of IIS impacts without the availability of any synchronous condensers. Hydro responded that only a narrow range of system operating conditions will support commissioning. We asked whether Hydro planned to run studies for actual operating conditions that will exist during each commissioning test, assuming successful tests and unsuccessful tests. Hydro responded that it will perform such studies when test failures could result in material IIS impacts. We consider careful preparation for and testing of all systems before the performance of commissioning tests as necessary. Studies identifying and scoping the potential risks that tests will create for the ISS, particularly some of the high-power tests, should be undertaken. This work is necessary to mitigate properly the risk of large scale UFLS or, in the worst case, voltage collapse and its consequences for customers on the ISS.