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December 13, 2019

Board of Commissioners of Public Utilities
Prince Charles Building
120 Torbay Road, P.O. Box 21040
St. John's, NL A1A 5B2

Attention: **Ms. Cheryl Blundon**
Director of Corporate Services & Board Secretary

Dear Ms. Blundon**:**

Re: Investigation and Hearing into Supply Issues and Power Outages on the Island Interconnected System – Phase Two – The Liberty Consulting Group Eighth Quarterly Monitoring Report on the Integration of Power Supply Facilities to the Island Interconnected System – Further Information – Hydro's Comments

On November 15, 2019, The Liberty Consulting Group ("Liberty") filed its Eighth Quarterly Monitoring Report on the Integration of Power Supply Facilities to the Island Interconnected System ("Liberty Report"). On November 21, 2019, the Board of Commissioners of Public Utilities ("Board") requested that Newfoundland and Labrador Hydro ("Hydro") provide further information as a result of the findings in the Liberty Report, with established deadlines for provision of the information. On November 29, 2019, Hydro filed the initial response to the items in the November 21, 2019 letter, providing details for items 1 and 2, and the Phase II Overhead Transmission Lines Emergency Response Plan from item 5.[1] Hydro indicated that the information requested as items 3 and 4 in the Board's November 21, 2019 letter, as well as the PSCAD Dynamic Performance Study referenced in item 5, would be provided by December 13, 2019. This information, including an update on item 1, is discussed below.

Board Request #1

In its November 29, 2019 letter to the Board, Hydro noted that the independent third parties retained to monitor and report on the Labrador-Island Link ("LIL") performance were retained by Nalcor Energy ("Nalcor"). The resulting reports requested by the Board were provided to Nalcor under Nalcor's contractual arrangements with the third parties. The request by the Board continues to be under legal review by Nalcor and no additional information is available at this time.

Board Request #3

The Board requested that Hydro report on the investigation into the issue regarding firing angle ranges within the LIL Converter Stations, including details of the problem as well as the plan and schedule to address it.

[1] A draft version of that document was filed on November 29, 2019, in error. The correct, up to date, version of Report 1 was filed on December 12, 2019.

Hydro has developed a technical note, included with this letter as Attachment 1, in which it describes the potential firing angle limitation and summarizes the potential impacts to the Island Interconnected System if this limitation materializes. All past operational studies have been performed using a generic LIL model that was developed by TransGrid Solutions ("TransGrid"). In November 2019, GE provided a LIL PSSE model to Nalcor. This model has been provided to Hydro and TransGrid, who are in the process of incorporating it into transmission system models. Hydro and TransGrid will undertake analysis to reassess the potential firing angle concern using the GE model, which will better represent the actual control system of the LIL. Hydro will provide an update to the Board once the analysis is complete, anticipated to be on or before April 15, 2020.

Board Request #4

In its November 21, 2019, letter the Board referenced Liberty's discussion of binding/vibration at the Soldiers Pond Synchronous Condensers. The Board required Hydro to report on these two issues, including details of the problems and the investigation into their root causes, as well as a plan and schedule to address them.

During the commissioning phase of the synchronous condensers, high vibration was observed on Unit 3 and a binding issue was observed on Units 1 and 2. It is anticipated that the vibration issue observed on Unit 3 will appear on Units 1 and 2 once they are rotating; therefore, GE is pursuing a solution that is applicable to all units. Root cause investigations into both the vibration and binding issues are underway by GE and external experts.

Vibration

During dynamic commissioning, Unit 3 was operated at a speed of 900 RPM. During ramp up, resonance of the unit was observed at 860 RPM. During dynamic commissioning, it was found that Unit 3 experienced an unexpected resonance phenomenon at approximately 860 RPM which caused unacceptable vibration levels. Since it is close to the operating speed of 900 RPM and represents a material deviation from the design specification for the unit, further investigation to determine a mitigation plan was therefore required.

Several root causes are being investigated, as shown in Table 1. Testing of potential root causes has eliminated some scenarios.

Table 1: Vibration Analysis Results

Potential Root Causes	Status of Investigation
Bearing Oil Film Stiffness	Determined to be low probability.
Bearing Housing Stiffness	Stiffeners (anti-tilt brackets) installed on both flywheel and collector end bearing housings. Stiffeners did not resolve vibration issue.
Bearing Support Structure Stiffness (Halfmoon)	Halfmoon bearing support structure design under review.
Sole Plates Anchoring, Bolting, and Quality of Interfaces between Stator and Foundations	Bolt torque has been rechecked. Bolt over-torque tests yielded no significant improvements.
Concrete Foundation	Based on field test results, foundation resonance behaviour found to be at approximately 900 RPM. Third-party consultant FZA, LLC to develop a detailed model to analyse the effectiveness of corrective actions.
Rotor and Shaft Line	Determined to be low probability. GE repeated the shaft line critical speed calculations using a fully integrated ANSYS Finite Element Analysis model, indicating critical speed to be at 24.8 Hz which is well above operating speed (15 Hz).

Ontario Power Group, an external specialist hired by Nalcor, is preparing to conduct a comprehensive Operating Deflection Shape ("ODS") vibration test on Unit 3 and its foundation. The test is planned for completion in December 2019 with a report to follow.

Binding

Units 1 and 2 have not been successfully rotated. During manual rotation checks it was observed that the units required an excessive force to rotate, indicating a binding element. Further tests have shown excessive bearing deflection is causing contact and binding of the bearing.

Several root causes are being investigated, as shown in Table 2. Testing of potential root causes has eliminated some scenarios.

Table 2: Binding Analysis Results

Potential Root Causes	Status of Investigation
Tilting of the bearing housing	Corrected via installation of anti-tilt brackets. Did not correct the binding issue.
Unbalanced lift oil pressure	Orifice modifications failed to correct the issue.
Alignment of the bearing in the housing	Bearing alignment test conducted, results are pending.
Lift oil twin pocket design	Spare bearing shipped to machine shop for lift oil pocket redesign from a twin to a single lift pocket.
Bearing/housing apex point	Bearing housing to be modified to include circumferential slot. Bearing housing removal ongoing; re-machining estimated in January 2020.

Schedule

A minimum of two synchronous condensers are required to operate the LIL at full capacity.

Hydro undertook transient stability studies in PSSE to assess system impacts of having fewer than two Soldiers Pond synchronous condensers in service. The analysis involved a review of the maximum LIL capacity at the reduced short circuit levels that would be present in such conditions.

The results of this study indicated that the generic LIL models that were developed by TransGrid for the purposes of operational studies cannot be used for an indication of system performance at low short circuit levels. Rather, the simulations result in mathematical non-convergence. Table 3 illustrates the results of the analysis, showing the highest LIL transfers that produced stable solutions in the PSSE analysis. These values serve for discussion and planning purposes only.

Table 3: Transfer Limits under Generic LIL Model

Available Holyrood TGS[2] and Soldiers Pond Units	LIL Transfer Limit[3] (MW)
Holyrood Unit 3 as synchronous condenser	360
Holyrood Unit 3 as synchronous condenser + one other Soldiers Pond or Holyrood synchronous condenser	560

Hydro and TransGrid are working to integrate LIL models provided by GE to further assess LIL performance at low short circuit levels. Nalcor is also undertaking a PSCAD analysis to assess system performance at reduced short circuit levels. Upon the conclusion of these studies in January 2020, Hydro and Nalcor will establish LIL transfer limits.

On the basis of the data in Table 3, determined using the generic LIL models, synchronous condensers do not appear to impact LIL commissioning at low power and, therefore, are not currently on the critical path as two of the synchronous condenser units are expected in March 2020.

GE's current schedule is to have all three synchronous condensers commissioned by May 2020: two in March 2020 and one in May 2020. Pending the outcome of the root cause investigations and resolution of the issues, there is risk that the schedule may extend beyond May 2020. Identification of the root cause and the determination of corrective action effectiveness are needed before revising the schedule. As previously noted, it is anticipated that the ODS vibration analysis will be completed by year-end 2019. Hydro will provide an update to the Board regarding the status into the investigation of the issues on the synchronous condensers by January 31, 2020.

Board Request #5

The report entitled "Common PSCAD Dynamic Performance Study Report" was provided to Labrador-Island Link Limited Partnership in confidence under the terms of its agreement with Grid Solutions ULC. Permission was sought from Grid Solutions ULC to disclose the document; however, such permission

[2] Holyrood Thermal Generating Station ("Holyrood TGS")
[3] Measured at Muskrat Falls.

was not received and as a result the report cannot be shared at this time. Meanwhile, should Liberty have specific questions related to dynamic performance, they may be answerable by Nalcor personnel without requiring the disclosure of confidential information.

Should you have any questions or comments about any of the enclosed, please contact the undersigned.

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

Geoffrey P. Young, Q.C.
Corporate Secretary & General Counsel
GPY/sk

cc: **Newfoundland Power**
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Attachment 1

TP-TN-085 Overview of Potential LIL Firing Angle Limitation and System Impacts

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TP-TN-085

Overview of Potential LIL Firing Angle Limitation and System Impacts

Purpose

In a letter to Hydro on November 21, 2019, the Board of Commissioners of Public Utilities ("Board") requested further information relating to concerns raised by The Liberty Consulting Group ("Liberty") in its most recent quarterly report[1]. One of these concerns relating to the Labrador Island Link ("LIL") was defined as follows:

> *"A potentially serious converter station control software issue related to the firing angle range is discussed on pages 6-8 of the Report. Please provide by December 13, 2019 a report that fully describes the problem, the status of the investigation into the issue, and the plan and schedule for addressing it".*

The purpose of this technical note is to describe the issue relating to the potential firing angle limitation and to summarize the potential impacts to the Island Interconnected System ("IIS") if this limitation materializes.

Summary of Potential Firing Angle Limitation

The firing angle of a line-commutated converter HVdc system, such as the LIL, is the primary mechanism for the control of power flow. As illustrated in the figure below, a change in the firing angle (as known as the delay angle) changes the dc voltage of the converter (Vdc). Changing the converter voltage in the dc circuit will change the power flow. The ability of the LIL to adjust power flow in response to a sudden system change is therefore a function of the firing angle range. The firing angle range is a parameter that impacts the ratings and control philosophy of an HVdc system. Adjustment of the firing angle range outside the specification would require modifications to the HVdc control system as well as a review of equipment rating and performance specifications to determine the equipment's ability to operate outside the specified firing angle range.

[1] The Eighth Quarterly Monitoring Report on the Integration of Power Supply Facilities to the Island, Liberty Consulting Group, November 15, 2019.

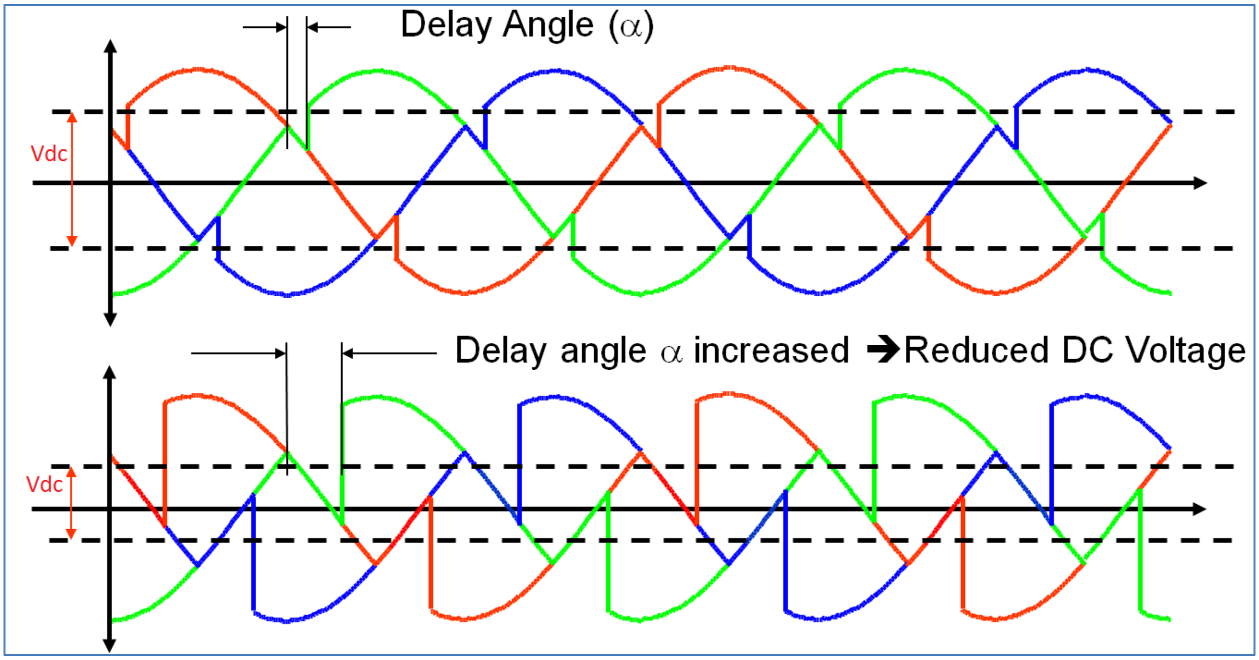

Figure 1 – Firing Angle of a Line-Commutated Converter HVdc System

The potential firing angle limitation was identified by Hydro and TransGrid Solutions ("TGS") as part of the operational studies performed in support of the integration of assets for the Lower Churchill Project. The analysis associated with these studies was performed using PSSE software from Siemens PTI. Due to challenges associated with the provision of a working PSSE model of the LIL from GE[2], Hydro engaged TGS in 2017 to develop a generic model of the LIL for the purposes of operational studies. This model was developed as per the following description:[3]

> *"TGS used PSSE library model: CDC7T to model the generic LIL HVDC. This is the best library model available to model LCC HVDC systems as it includes some generic controllers in it. The GE provided report "Common HVDC Models for use in PSSE" (version A5) was followed to determine most of the model parameters and the controllers were tuned to match the performance of the PSCAD model of the LIL HVDC provided by GE."*

This model used a steady-state firing angle range of 10 to 16 degrees[4] and has been used by TGS for all of their analysis, including the Stage IVD operational study[5], which involves an assessment of the LIL for near-term operation as the transition is made to full power operation. This study report identified a

[2] LIL PSSE models were provided by GE in 2016. However, these models included software issues that would not permit their incorporation into Hydro's Newfoundland and Labrador transmission system models. These issues were not resolved as GE system study resources were committed to other project priorities as a focus was put on PSCAD analysis.

[3] PSSE Generic Model Development for LIL HVDC, TGS, March 29, 2017

[4] LCP-COM-LCC-PES-054-002-DR - Main Scheme Parameter Design Report, GE, June 2014

[5] Stage 4D LIL Bipole: Transition to High Power Operation, TGS, September 20, 2019

series of LIL transfer limits and includes the following description of the impacts of the limited firing angle range:

> *"…LIL power transfer limits must be enforced to ensure that the IIS frequency does not drop below 59 Hz for loss of a LIL pole. Note that if a LIL pole is lost, it is assumed that the healthy LIL pole will pick up the transfer that was lost on the other LIL pole, up to its rating of 450 MW.*
>
> *As per the results presented in the following sections, the pole compensation process described above is restricted in some cases due to the limited firing angle range of the LIL. This limited range is such that converter transformer tapchanger operation may be required before full compensation can be achieved. Therefore there is a capacity shortfall in the seconds required for the tapchanger operation to occur. This may require ML frequency controller response, ML run back action or load limitation on the LIL to prevent underfrequency load shedding."*

System Response Considerations

As described in the previous section, the potential firing angle limitation was found to impact pole compensation where the healthy pole of the LIL must instantaneously double its power flow to compensate for the loss of power on the other pole. This may be an issue for the IIS as a capacity shortfall will result in frequency decay and a possible customer interruption through underfrequency load shedding (UFLS)[6] if other planned actions are not available. As per Transmission Planning Criteria to avoid an UFLS operation, the system will be operated when the bipole is operational such that the loss of a pole willl not result in frequency deviations below 59 Hz.

As part of operational studies, Hydro has investigated the system response following the trip of a LIL pole under bipole operation using the TGS developed LIL model. The system response and impacts are dependent on the factors listed below.

1. **LIL Monopole Resistance**
   When a pole is removed from service, the LIL must transmit power over a single pole conductor and the electrode instead of over the two pole conductors of a bipole. For example, in a case where the LIL is sending 450 MW over both poles and one pole trips, the healthy pole must instantaneously increase its sending end power from 225 MW to 450 MW. As a result of the loss of the pole, the resistance of the LIL increases from 19.29 Ω to 31.44 Ω. This increased resistance will result in a reduction in the power delivered at Soldiers Pond. In the case where 450 MW is being sent from Muskrat Falls, the power at Soldiers Pond is reduced from 433 MW to 396 MW, a deficit of 37 MW. In the case where 900 MW is being sent from Muskrat Falls, and the overload capability is operational the power at Soldiers Pond is reduced from 829 MW to 660 MW, a deficit of 169 MW. The resulting capacity deficits will result in a capacity shortfall within the IIS without additional system control action.

[6] Under the existing scheme underfrequency load shedding will begin to occur when the frequency is suppressed to 58.8 Hz.

2. **LIL Overload Capability**

   The LIL sending end power cannot exceed 450 MW per pole unless overload functionality is available. Overload functionality will therefore enable pole compensation at higher power orders. To achieve the overload result without UFLS, the LIL would require an adequate firing angle range to give a rapid response. The initial LIL bipole software release scheduled for early 2020 will not include overload capability. However, this feature will be available as part of the final version of the LIL software, scheduled to be released later in the year.

3. **LIL Frequency Controller**

   The basis of design for the LIL includes frequency controller functionality that will allow the LIL to respond to frequency deviations within the IIS and by modulating its active power output. For example, in the case of a pole trip as described above, the LIL would increase its sending end power to compensate, up to the maximum pole overload capability, to meet the capacity shortfall due to increased losses. To rapidly increase the sending end power, the LIL would require an adequate firing angle range. The initial LIL bipole software release scheduled for early 2020 will not include a frequency controller. However, this feature will be available as part of the final version of the LIL software, scheduled to be released later in the year.

4. **Response of the Maritime Link**

   As noted above, the Maritime Link ("ML") is available to respond in the event of the loss of a LIL pole. The ML is equipped with frequency controller and runback functionality. The ML frequency controller is currently set to respond with up to 150 MW of incremental capacity if the IIS experiences a frequency deviation in excess of +/- 0.5 Hz. The operation of the LIL and ML will be coordinated such that the loss of a pole or bipole on one link will result in a corrective action taken by the other. For example, the ML is expected to respond to the loss of a LIL pole with either a runback when there is export occurring or through frequency controller action when there is not. It is expected to provide compensation for higher power orders on the LIL for which the LIL maximum pole compensation cannot eliminate the deficit.

System Response Results

As described above, potential additional pole compensation limitations were identified in the Stage IVD operational study for firing angle range limitations. The results of this analysis were such that it was found that under certain conditions there is a potential for a requirement to have LIL power transfers prior to the loss of a pole limited to avoid violations to Transmission Planning Criteria where the frequency was found to fall below 59 Hz.

If the potential firing angle range limit were to materialize and it were confirmed through additional studies that projected customer impacts were unacceptable, the limits on the LIL would be quantified and IIS supply adequacy impacts would be evaluated.

Recommendations for Further Analysis

As described above, all operational studies have been performed using the generic LIL model that was developed by TGS. In November of 2019, a LIL PSSE model was provided to Nalcor Energy by GE. This model has been provided to Hydro and TGS, who are in the process of incorporating it into transmission system models. Due to challenges with the Fortran code of the PSSE models provided by GE, this process is expected to take several weeks. Once the model is incorporated, Hydro and TGS will undertake analysis to reassess the potential firing angle concern using the GE model, which will better represent the actual control system of the LIL. This technical analysis will be completed in the first quarter of 2020.

Throughout this process Hydro will consult with Nalcor Energy to understand the extent of the firing angle limitations as the design of the HVdc control system is advanced. The system impacts of any limitations will be evaluated and appropriate solutions will be developed.

Document Summary

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Revision History

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1	R. Collett	Initial Release	2019/12/12

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