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March 15, 2018

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

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

Dear Ms. Blundon:

Re: The Board's Investigation and Hearing into Supply Issues and Power Outages on the Island Interconnected System – Operational Studies – Stage 3 reports

Further to Hydro's correspondence of August 4, 2017, please find attached the following reports:

- Operational Study – Stage 3 – Maritime Link, Soldiers Pond Synchronous Condensers, and Labrador Island Link Monopole; and
- Operational Study – Stage 3 – Maximization of LIL Power Transfer using SPS (phased monopolar approach).

Should you have any questions, please contact the undersigned.

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

Geoffrey P. Young
Corporate Secretary & General Counsel

GPY/bs

cc: Gerard Hayes – Newfoundland Power
Paul Coxworthy – Stewart McKelvey Stirling Scales
ecc: Roberta Frampton Benefiel – Grand Riverkeeper® Labrador
Larry Bartlett – Teck Resources Limited
Dennis Brown, Q.C. – Consumer Advocate
Danny Dumaresque
Denis Fleming – Cox & Palmer

Operational Study

Stage 3

Operational Study – Stage 3 – Maximization of LIL Power Transfer using SPS (phased monopolar approach)

Engineering Support Services for:

RFI Studies

Newfoundland and Labrador Hydro

Attention: Mr. Rob Collett

Maximization of LIL Power Transfer using SPS (phased monopolar approach)

Technical Note: TN1205.55.01
Date of issue: March 5, 2018

Prepared By:
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Revisions

Project Name:	RFI Studies
Document Title:	Maximization of LIL Power Transfer using SPS (phased monopolar approach)
Document Type:	Final Technical Note
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Rev. No.	Status	Prepared By	Checked By	Date	Comments
00	DFC	R. Brandt, R. Ostash	R. Ostash	February 13, 2018	Preliminary draft Issued for review by Hydro
01	IFA	R. Brandt, R. Ostash	R. Ostash	March 5, 2018	Updated report based on comments received from Hydro on March 5, 2018.

Legend of Document Status:

Approved by Client	ABC
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Approval not Required	ANR

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1. Summary

A previous operational study[1] was performed to identify system operating limits of the Newfoundland and Labrador Hydro (Hydro) power system for the period when the Maritime Link (ML), the Soldiers Pond (SOP) synchronous condensers and the Labrador Island Link (LIL) as a 225 MW monopole are in-service (phased monopolar approach), but prior to the Muskrat Falls generators being in-service.

This previous study identified reduced LIL power transfer limits (below 225 MW) for three reasons:

1. to prevent the potential for voltage collapse and to ensure that the 315 kV Muskrat Falls voltage remains above 0.9 pu in case one of the two 315 kV Muskrat Falls – Churchill Falls lines (L3101 or L3102) trips or is out-of-service
2. to maintain 0.95 pu steady state voltage at the 315 kV Muskrat Falls bus during certain n-0 conditions (worst conditions are minimum Churchill Falls 735 kV bus voltage and peak Happy Valley load)
3. if the ML or the ML frequency controller is out-of-service, to prevent the Island frequency from dropping below 58 Hz following the loss of the LIL

This report investigates alternatives for special protection systems (SPS) with the aim of maximizing LIL power transfer capacity during the phased monopolar approach. The most limiting of these reasons is the first one; loss of L3101 or L3102. Three SPS alternatives were evaluated with the goal of optimizing the LIL power transfer for loss of L3101 or L3102.

1.1 Preferred Solution

Based on the study results, Hydro has indicated that their preferred option for an SPS is to trip the LIL, its filters and the reactor if line L3101 or L3102 trips or is out-of-service. With this SPS in place, Table 1-1 summarizes the two sets of operating limits for LIL power transfer; one if the ML and its frequency controller are in-service, and another if the ML or its frequency controller are out-of-service.

If the SPS fails to operate, it is possible that the transmission system in eastern Labrador will experience voltage collapse (if Churchill Falls voltage is near its lower operating range, and if Happy Valley load is near is upper range), or that the steady state voltage at Muskrat Falls will drop below 0.9 pu. However, it is extremely unlikely that the SPS will fail since the SPS shall be designed to have full redundancy.

[1] TGS report TN1205.54.01, “Operational Studies: Maritime Link, SOP Syncs and LIL Monopole”, Feb. 2, 2018.

Table 1-1. LIL Power Transfer Limits

SPS in place	System Condition	LIL Transfer Limit [2,3]				
Cross-trip LIL, filters and reactor for loss of L3101 or L3102	ML (and ML frequency controller) in-service		CHF Voltage (pu)			
		HVY Load (MW)	0.975	0.985	0.995	1.005
			LIL Transfer (MW)			
		35	225	225	225	225
		45	220	225	225	225
		55	215	225	225	225
		65	205	220	225	225
		75	185	210	225	225
		80	180	202	225	225
		90	165	190	215	225
		100	155	175	200	225
	ML (or ML frequency controller) out-of-service		CHF Voltage (pu)			
		HVY Load (MW)	0.975	0.985	0.995	1.005
			LIL Transfer (MW)			
		35	200	200	200	200
		45	200	200	200	200
		55	200	200	200	200
		65	200	200	200	200
		75	185	200	200	200
		80	180	200	200	200
		90	165	190	200	200
		100	155	175	200	200

[2] Orange cells – Limit LIL power transfer in order to maintain 0.95 pu voltage during n-0 conditions
[3] Green cells – Limit LIL power transfer in order to prevent Island frequency from dropping below 58 Hz following the loss of the LIL

2. Background

This technical note investigates a special protection system (SPS) that would be triggered following the loss of one of the two 315 kV lines between Muskrat Falls and Churchil Falls (L3101 or L3102) in order to maximize LIL power transfer. Without an SPS, system operating limits must be imposed to limit the LIL power transfer to prevent the possibility of voltage collapse and to keep the voltage at Muskrat Falls above 0.9 pu in case L3101 or L3102 trips. The LIL power transfer limits determined in the previous study are provided in Table 2-1. The limits are given over the expected operating range of Churchill Falls 735 kV voltage and Happy Valley load (being fed off Muskrat Falls 138 kV tap).

Table 2-1. LIL power transfer limits from previous study[4]

	CHF Voltage (pu)			
HVY Load (MW)	0.975	0.985	0.995	1.005
	LIL Transfer (MW)			
35	145	160	175	185
45	135	150	160	175
55	125	140	150	165
65	115	128	140	155
75	100	115	125	135
80	95	108	120	130
90	80	93	105	118
100	65	75	86	103

The SPS alternatives were evaluated by performing steady state and dynamic analyses on a set of light, intermediate and peak load PSSE base cases.

The results of the study were analysed to ensure that the Labrador system's steady state and dynamic responses met the system performance criteria as documented in Hydro's Transmission Planning Criteria.

[4] In order to prevent voltage collapse and keep MFATS2 voltage above 0.9 pu following loss of L3101 or L3102.

3. Study Models and Criteria

The Labrador system is the area of focus for this study[5].

3.1 Labrador System

No Muskrat Falls (MFA) generators were in-service for this study.

The Labrador system around Muskrat Falls is shown in Figure 3-1.

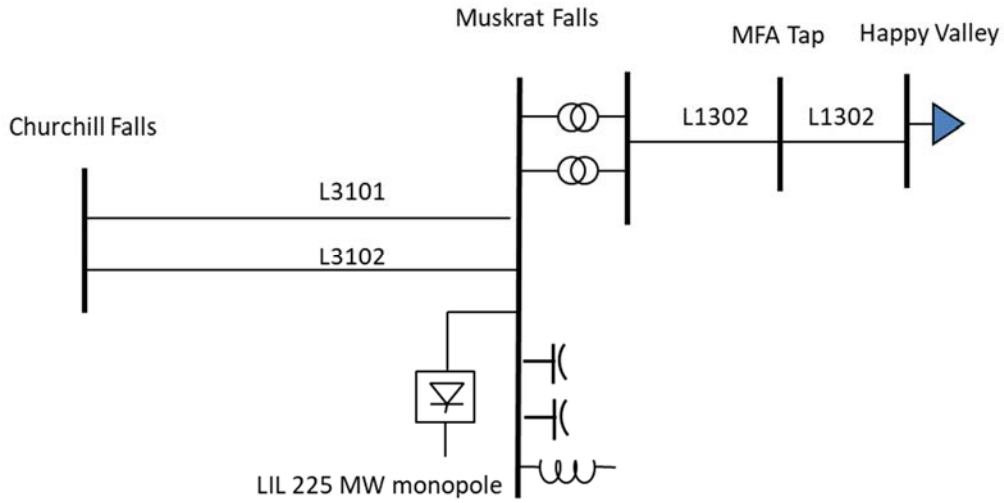

Figure 3-1. Labrador system near Muskrat Falls

3.2 LIL

It was assumed that the following LIL reactive power elements were in-service:

- MFA: 2x72 MVAR filters (both Type A), 1x150 MVAR reactor
- SOP: 2x75 MVAR filters (one Type A, one Type B)

Since meeting the lower limit of voltage criteria was the goal of this study, the LIL was setup such that the firing angle at the rectifier was at or near the upper limit of 16 degrees, to represent the maximum reactive power consumption of the LIL rectifier.

Please note that during the phased monopolar approach, both LIL filters are required to be in-service. If one of the filters trips, the LIL and the 150 MVAR reactor will also automatically trip.

3.3 Study Criteria

The applicable Transmission Planning Criteria for this study is summarized as follows:

[5] Considerations relating to the Interconnected Island System are presented in Operational Studies: Maritime Link, SOP Syncs and LIL Monopole.

- Steady state voltage : 0.95 pu – 1.05 pu during n-0 conditions
- Steady state voltage : 0.90 pu – 1.1 pu during n-1 conditions

3.4 PSSE Base Cases

Table 3-1 lists the base cases that were used to analyze the Labrador system in this study.

Table 3-1: Base cases provided by Hydro

Number	Load Condition	Island Demand (MW)	LIL LAB to NF Flow (MW)
MON1	Peak	1727.8	225
MON3	Intermediate	1246.2	225
MON5	Light	762.9	225

The Happy Valley load and the Churchill Falls 735 kV bus voltage were varied in these bases cases in order to study the system over the expected operating ranges:

- Churchill Falls 735 kV voltage – from 0.975 pu to 1.005 pu
- Happy Valley load – from 35 MW to 100 MW

4. Maximization of LIL Power Transfer Limits

Reduced LIL power transfer limits (below 225 MW) are necessary for three reasons:

1. to prevent the potential for voltage collapse and to ensure that the 315 kV Muskrat Falls voltage remains above 0.9 pu in case one of the two 315 kV Muskrat Falls – Churchill Falls lines (L3101 or L3102) trips or is out-of-service
2. to maintain 0.95 pu steady state voltage at the 315 kV Muskrat Falls bus during certain n-0 (worst conditions are minimum Churchill Falls 735 kV bus voltage and peak Happy Valley load)
3. if the ML or the ML frequency controller is out-of-service, to prevent the Island frequency from dropping below 58 Hz following the loss of the LIL

The most limiting of these reasons is the first one; loss of L3101 or L3102. Three SPS alternatives were evaluated with the goal of maximizing the LIL power transfer for loss of L3101 or L3102.

4.1 SPS Alternative 1: Cross-Trip the MFA Reactor

In order to support the Muskrat Falls voltage following the loss of L3101 or L3102, an SPS to cross-trip the MFA reactor was modeled.

This option works when the LIL is transferring 225 MW, but if the LIL is operating at less than 225 MW, the Muskrat Falls voltage has the potential to violate the upper limit of 1.1 pu when the reactor is cross-tripped. The worst case condition for high voltage occurs at minimum LIL power transfer of 45 MW during light Happy Valley load and high Churchill Falls voltage (> 1pu), which results in a voltage of nearly 1.17 pu at Muskrat Falls.

If it were possible to also cross-trip an MFA filter with the reactor, then this SPS option may be feasible. However, as mentioned in Section 3.2, during the phased monopolar approach, both MFA filters are required to be in-service when the LIL is in-service, therefore this SPS is not an option.

4.2 SPS Alternative 2: Cross-Trip the LIL, MFA Filters and Reactor

An alternate SPS was modeled to cross-trip the LIL, MFA filters and the reactor following the loss of L3101 or L3102.

This SPS mitigated all issues related to low steady state voltage at Muskrat Falls following the loss of L3101 or L3102. There were also no dynamic issues observed with this SPS in place.

Hydro indicated that this SPS (cross-trip LIL, MFA filters and reactor) is their preferred alternative.

It is noted that the SPS can be armed and disarmed automatically using parameters from the SCADA system to ensure that it is only triggered when required.

4.2.1 Impacts to Island System

If the LIL is cross-tripped following the loss of L3101 or L3102, the Island system will experience an underfrequency load shedding event.

The previous operational study[6] looked at the impact of the loss of the LIL infeed on the Island system over a large range of operating conditions. The conclusions from that study stated that:

- If the ML and its frequency controller are in-service, the LIL is able to transfer the full 225 MW, since the Island frequency remains above 58 Hz for loss of the LIL monopole.
- If LIL transfers are reduced to the range of 150 MW to 175 MW, UFLS can be avoided. In accordance with good utility practice, LIL transfers can be reduced to these levels in the event of lightning, high winds, or icing.
- **If the ML or its frequency controller are out-of-service, LIL power transfer must be limited to 200 MW** in order to avoid triggering the 58 Hz block of loadshed following the loss of the LIL.

4.3 SPS Alternative 3: Cross-Trip of Happy Valley Load

A third SPS was modeled to cross-trip loads at Happy Valley following the loss of L3101 or L3102. Upon review, this alternative was not acceptable for the following reasons:

- The complexity of restoration of Happy Valley loads using L1301 would result in extended outages to customers. This restoration procedure would require the switching of large feeders, capacitor banks, and the start up of the Happy Valley GT for active power and/or reactive power.
- Forecasted peak loads in Happy Valley loads cannot be met when the system is supplied by L1301.

The SPS described in Section 4.2 would have a far less significant customer impact. As discussed, LIL transfers could be curtailed during operating conditions when the probability of a trip is increased. In the event that UFLS occurs, customers would be restored within ten minutes as per Hydro's current operating practices.

4.4 System Intact (n-0) Power Transfer Limits

If SPS alternative 2 is implemented (cross-trip LIL, filters and reactor following loss of L3101 or L3102), the most limiting conditions for LIL power transfer become system intact (n-0) conditions in Labrador at the Muskrat Falls 315 kV bus.

Transmission Planning Criteria states that the minimum voltage limit during (n-0) conditions is 0.95 pu. Depending on the Churchill Falls 735 kV bus voltage and the load at Happy Valley, the Muskrat Falls voltage can be lower than 0.95 pu if the LIL is transferring the full 225 MW.

With SPS alternative 2 implemented, Table 4-1 summarizes the LIL power transfer limits over the expected operating range of Churchill Falls 735 kV voltage and Happy Valley load in order to keep the Muskrat Falls bus voltage at or above 0.95 pu during (n-0) conditions. The cells in orange denote the

[6] TGS report TN1205.54.01, "Operational Studies: Maritime Link, SOP Syncs and LIL Monopole", Feb. 2, 2018.

reduced LIL power transfer limits that are necessary to maintain 0.95 pu voltage at Muskrat Falls during (n-0) conditions. Please note that these limits increase slightly if the LIL is operating at a firing angle less than 16 degrees.

Table 4-1. LIL Power Transfer Limits[7]

	CHF Voltage (pu)			
HVY Load (MW)	0.975	0.985	0.995	1.005
	LIL Transfer (MW)			
35	225	225	225	225
45	220	225	225	225
55	215	225	225	225
65	205	220	225	225
75	185	210	225	225
80	180	202	225	225
90	165	190	215	225
100	155	175	200	225

4.4.1 ML or ML Frequency Controller out-of-service

As stated in Section 4.2.1, if the ML or its frequency controller are out-of-service, LIL power transfer must be limited to 200 MW in order to avoid triggering the 58 Hz block of loadshed on the Island. In this case, LIL power transfer limits would be as per Table 4-2. The cells in orange denote the reduced LIL power transfer limits that are necessary to maintain 0.95 pu voltage at Muskrat Falls during n-0 conditions. The cells in green denote the reduced LIL power transfer limits that are necessary to maintain frequency above 58 Hz on the Island following the loss of the LIL.

Table 4-2. LIL Power Transfer Limits[8] if ML or its frequency controller out-of-service

	CHF Voltage (pu)			
HVY Load (MW)	0.975	0.985	0.995	1.005
	LIL Transfer (MW)			
35	200	200	200	200
45	200	200	200	200
55	200	200	200	200
65	200	200	200	200
75	185	200	200	200
80	180	200	200	200
90	165	190	200	200
100	155	175	200	200

[7] Assumes LIL, MFA filters and reactor are cross-tripped for loss of L3101 or L3102.
[8] Assumes LIL, MFA filters and reactor are cross-tripped for loss of L3101 or L3102.

5. Conclusions

Hydro has indicated that their preferred option for an SPS is to trip the LIL, its filters and the reactor if line L3101 or L3102 trips or is out-of-service. With this SPS in place, Table 5-1 summarizes the two sets of operating limits for LIL power transfer; one if the ML and its frequency controller are in-service, and another if the ML or its frequency controller are out-of-service.

If the SPS fails to operate, it is possible that the Labrador system will experience voltage collapse (if Churchill Falls voltage is near its lower operating range, and if Happy Valley load is near is upper range), or that the steady state voltage at Muskrat Falls will drop below 0.9 pu. However, it is extremely unlikely that the SPS will fail since the SPS shall be designed to have full redundancy.

Table 5-1. LIL Power Transfer Limits

SPS in place	System Condition	LIL Transfer Limit [9,10]				
Cross-trip LIL, filters and reactor for loss of L3101 or L3102	ML (and ML frequency controller) in-service		CHF Voltage (pu)			
		HVY Load (MW)	0.975	0.985	0.995	1.005
			LIL Transfer (MW)			
		35	225	225	225	225
		45	220	225	225	225
		55	215	225	225	225
		65	205	220	225	225
		75	185	210	225	225
		80	180	202	225	225
		90	165	190	215	225
		100	155	175	200	225
	ML (or ML frequency controller) out-of-service		CHF Voltage (pu)			
		HVY Load (MW)	0.975	0.985	0.995	1.005
			LIL Transfer (MW)			
		35	200	200	200	200
		45	200	200	200	200
		55	200	200	200	200
		65	200	200	200	200
		75	185	200	200	200
		80	180	200	200	200
		90	165	190	200	200
		100	155	175	200	200

[9] Orange cells – Limited LIL power transfer to maintain 0.95 pu voltage during n-0 conditions
[10] Green cells – Limited LIL power transfer to ensure Island frequency above 58 Hz following the loss of the LIL