newfoundland labrador hydro
a nalcor energy company

Hydro Place. 500 Columbus Drive.
P.O. Box 12400. St. John's. NL
Canada A1B 4K7
t. 709.737.1400 f. 709.737.1800
www.nlh.nl.ca

November 28, 2017

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 1 (revised) and Stage 2 reports.

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

- Operational Study – Stage 1 – Addition of the Maritime Link (revised), and
- Operational Study – Stage 2 – Maritime Link and Soldiers Pond Synchronous Condensers,

as referenced in item number 6. The Stage 1 operational study was revised to account for modification of the Maritime Link import/export plots to align with the convention of "Island Demand", referring to load+losses, as opposed to the original assumption of demand = load only.

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
Dennis Brown, Q.C. – Consumer Advocate
Danny Dumaresque

ecc: Roberta Frampton Benefiel – Grand Riverkeeper® Labrador
Larry Bartlett – Teck Resources Limited
Denis Fleming – Cox & Palmer

Engineering Support Services for:

RFI Studies

Newfoundland and Labrador Hydro

Attention: Mr. Rob Collett

Operational Studies: Maritime Link & Soldiers Pond Synchronous Condensers

Technical Note: TN1205.51.03
Date of issue: November 10, 2017

Prepared By:

TransGrid Solutions Inc.
100-78 Innovation Dr.
Winnipeg, MB R3T 6C2
CANADA

Disclaimer

This technical note was prepared by TransGrid Solutions Inc. (“TGS”), whose responsibility is limited to the scope of work as shown herein. TGS disclaims responsibility for the work of others incorporated or referenced herein. This technical note has been prepared exclusively for Newfoundland and Labrador Hydro and the project identified herein and must not be reused or modified without the prior written authorization of TGS.

Revisions

Project Name:	RFI Studies
Document Title:	Operational Studies: Maritime Link & Soldiers Pond Synchronous Condensers
Document Type:	Technical Note
Document No.:	TN1205.51.03
Last Action Date:	November 10, 2017

Rev. No.	Status	Prepared By	Checked By	Date	Comments
00	DFC	R. Ostash	M. Mohaddes	September 19, 2017	Issued for review by Hydro
01	IFC	R. Ostash		October 13, 217	Incorporated comments received by Hydro on Oct 6, 2017
02	IFA	R. Ostash		October 24, 2017	Incorporated comments received by Hydro on Oct 18, 2017
03	ABC	R. Ostash		November 10, 2017	Fixed ML import/export plots to refer to actual Island demand

Legend of Document Status:

Approved by Client	ABC
Draft for Comments	DFC
Issued for Comments	IFC
Issued for Approval	IFA

Issued for Information	IFI
Returned for Correction	RFC
Approval not Required	ANR

Table of Contents

1. Introduction

A previous operational study, referred to in this report as the "ML only" study[1], was performed to determine the system operating limits of the Newfoundland and Labrador Hydro (Hydro) Island Interconnected System for the period in time when the Maritime Link (ML) is in-service, but prior to the Labrador Island Link (LIL) coming in to service. The Soldiers Pond (SOP) synchronous condensers were assumed not to be in service for that study.

This current report describes the next operational study that was performed, which investigates the impact of placing the SOP synchronous condensers in to service. The LIL is still assumed not to be in service. The system operating limits determined in the ML only study are revisited in this study to identify any changes to these limits after the installation of the SOP synchronous condensers.

The majority of the system operating limits determined in the ML only study were required to prevent thermal overloading. These limits remain unchanged by the addition of the synchronous condensers. Rather, the reactive power output of the units may be used to maximize the power factor of the flows within a transmission corridor.

The SOP synchronous condensers can, however, have a significant effect on the dynamic performance of the system. Therefore, this study re-evaluates the ML import/export limits and the system operating limits that were required for the system to meet the dynamic performance criteria.

Additionally, a brief steady state voltage control study was performed to determine a reasonable voltage setpoint for the SOP synchronous condensers and to determine appropriate tap settings for the off-load tap-changers on the SOP synchronous condenser and station service transformers.

Please note that this study assumes that two of the three 175 MVA Soldiers Pond synchronous condensers are in service (i.e. one is out for maintenance).

For details related to study cases, models and methodology, please refer to the ML only study report.

[1] TN1205.50.04, "Operational Studies: Maritime Link ONLY", TransGrid Solutions, September 8, 2017.

2. ML Import/Export Limits

This section discusses the impact of the SOP synchronous condensers on the ML import/export limits that were defined in the ML only study.

Loss of the ML bipole is the defining contingency for determining the maximum ML import and export limits.

2.1 ML Import Limit

The addition of the SOP synchronous condensers increases the ML import limits by approximately 30-50 MW from the limits determined in the ML only study.

The blue and red lines in Figure 2-1 show the ML import limits plotted against the Island demand. These points were determined from a variety of operating conditions ranging from peak load to light load. To maintain some amount of safety margin, the green line was drawn at or below the lowest of these limits. It is recommended to limit the ML import level to be at or below the green line, depending on the Island demand level.

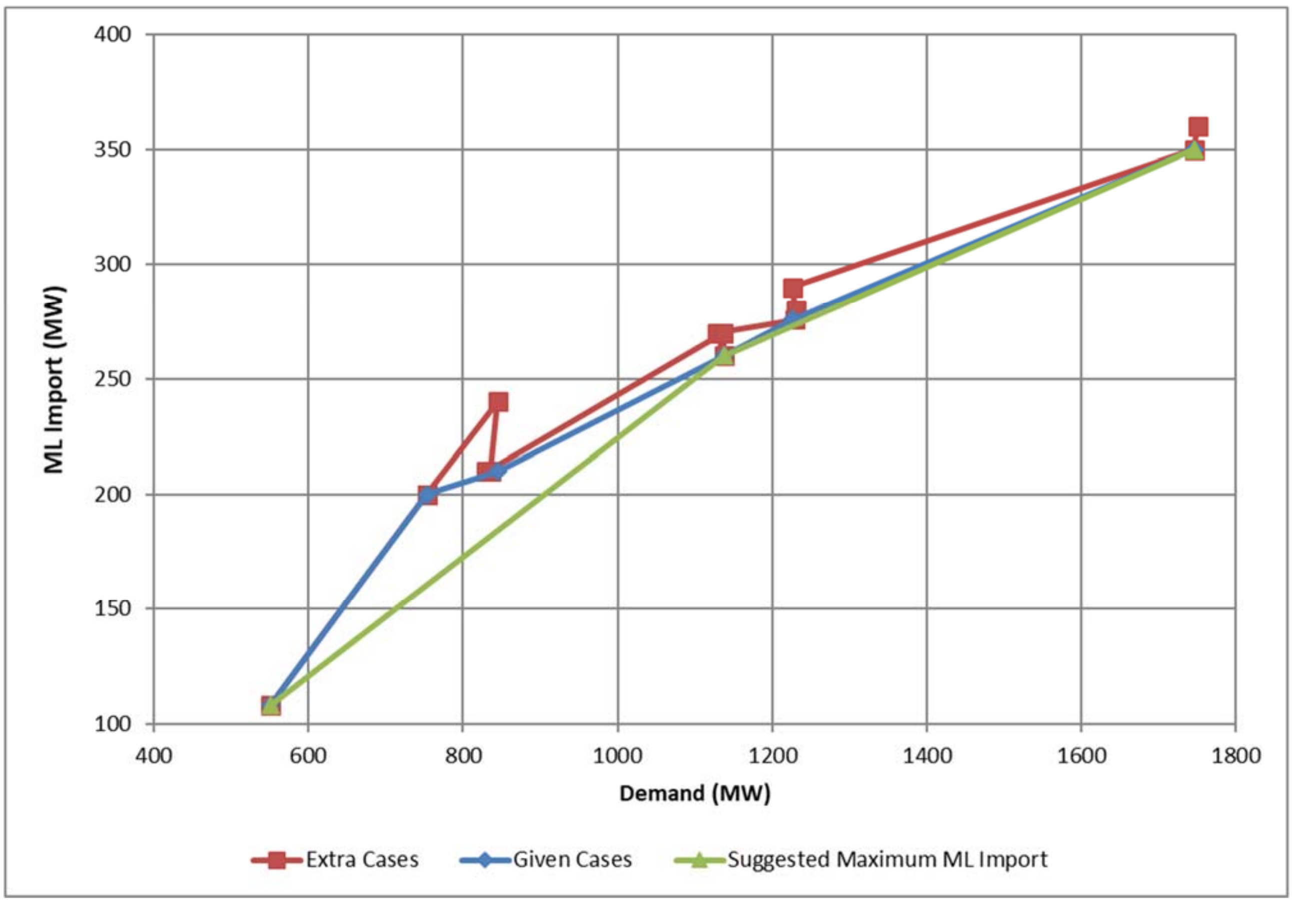

Figure 2-1. Maximum ML import level versus Island demand. ML + SOP syncs in-service.

The ML import limits in Figure 2-1 assume that two SOP syncs are in-service. Figure 2-2 shows the suggested maximum ML import limits if two SOP syncs are in-service (same as green line from Figure 2-1) and the suggested maximum ML import limits if three SOP syncs are in-service (purple line). Having the third SOP synchronous condenser in-service increases the ML import limit by approximately 20 MW.

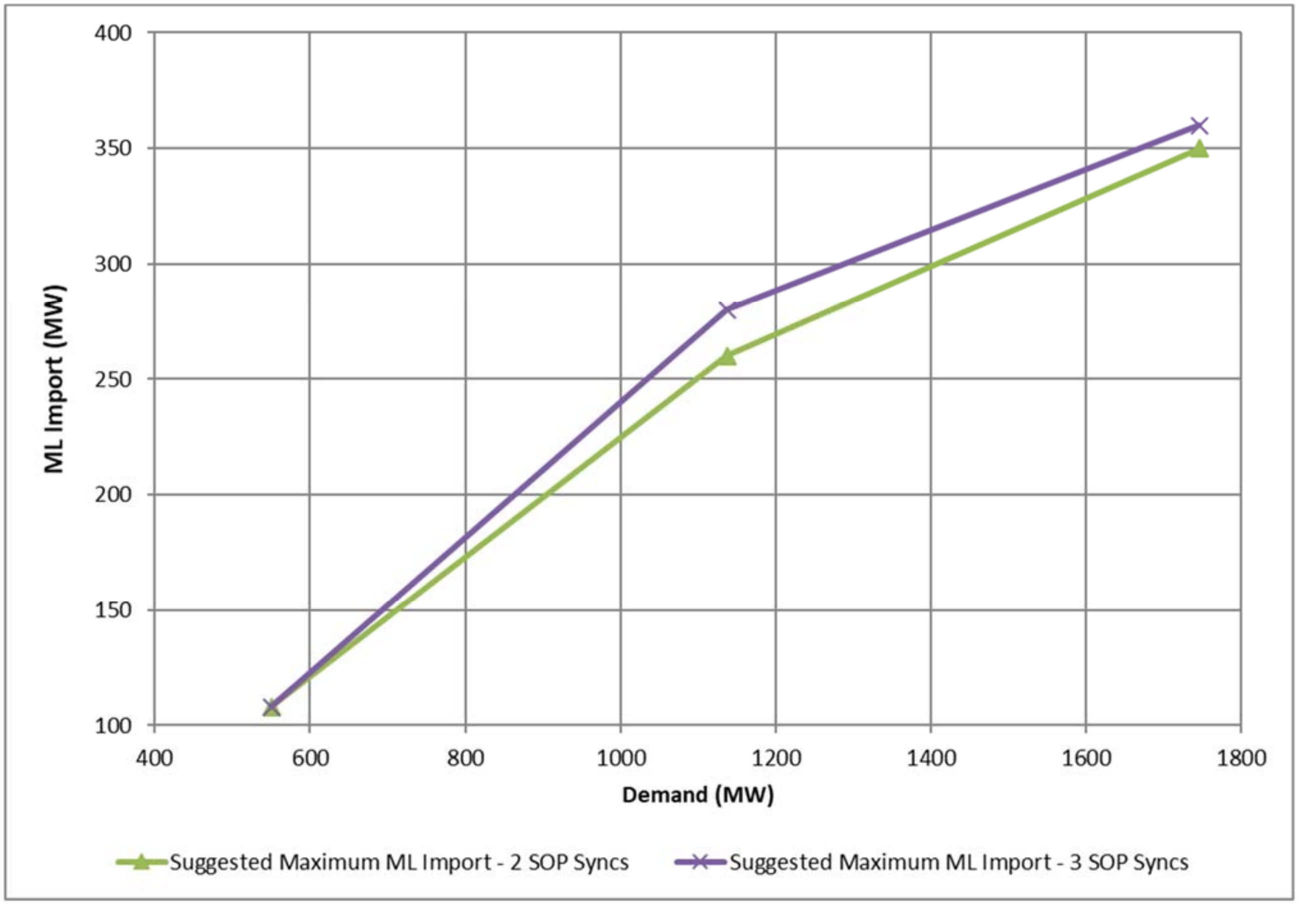

Figure 2-2. Suggested Maximum ML import limits – with two and three SOP syncs in-service

2.2 ML Export Limit

If one or more of the Holyrood units are on-line and operating as generators, the addition of the SOP synchronous condensers did not impact the ML export limit. This is because the ML export level was limited to ensure that loss of the ML bipole does not result in the Holyrood generators settling to a power level that is more than 15 MW[2] below their pre-contingency operating point. The SOP synchronous condensers had little impact to the settling point of the Holyrood generators, as shown in Figure 2-3, therefore, the ML export limits remain the same as the ML only study if the Holyrood unit(s) are operating as generators.

[2] As measured at 20 seconds of simulation time. Please note this criterion was defined by Hydro.

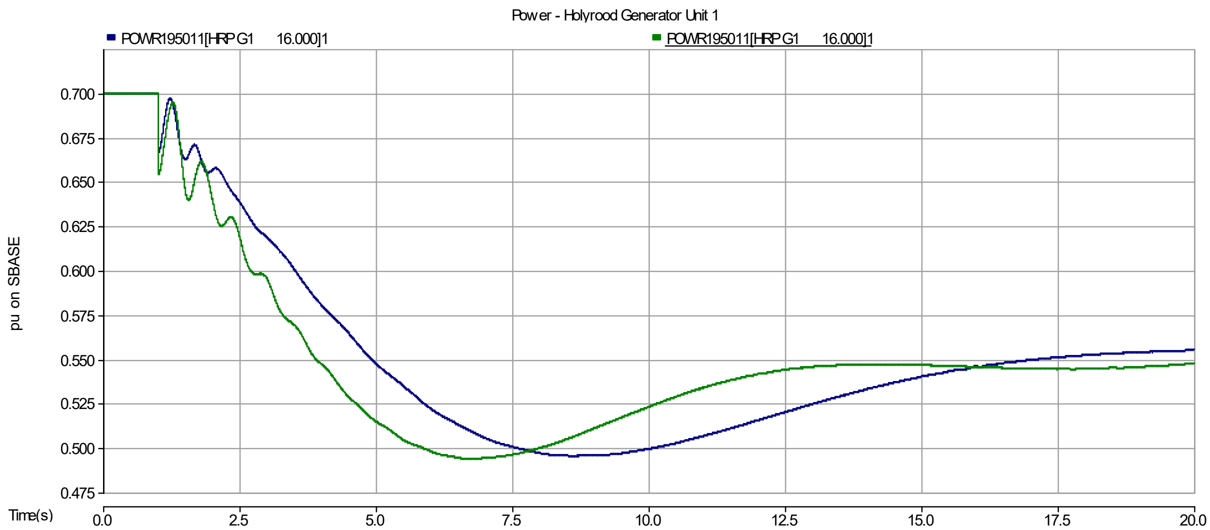

Figure 2-3. Holyrood power output after loss of ML bipole.
Green: without SOP syncs, Blue: with SOP syncs

If a Holyrood unit is operating as a synchronous condenser only (i.e. no Holyrood units on-line as generators), then the limiting criteria for determining the ML export limit is overfrequency, i.e. the system frequency must remain below 62 Hz. In this case, the addition of the SOP synchronous condensers increased the ML export limit by approximately 10-20 MW.

Figure 2-4 shows the maximum ML export limits plotted against Island demand for the scenario with the SOP synchronous condensers in service. The ML export limit is shown by four lines, each line representing either one Holyrood unit on-line as a synchronous condenser (purple), or one (green), two (blue) or three (red) Holyrood units on-line as generators.

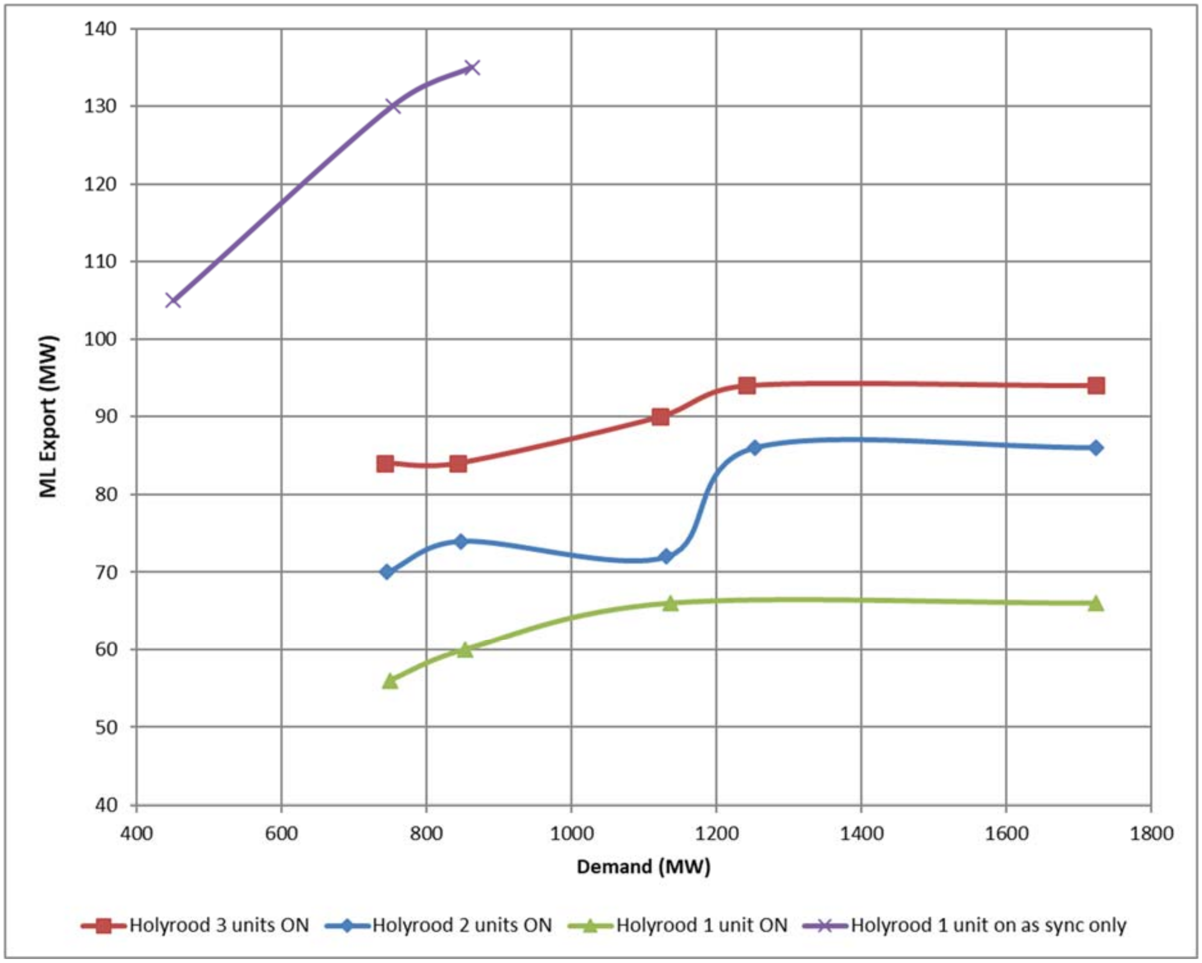

Figure 2-4. Maximum ML export level versus Island demand. ML + SOP syncs in service.

The following recommendations are made regarding the ML export limit:

1. **Island Demand > 750 MW**

If one or more Holyrood units are on-line as a generator(s), the ML export limits shown in Figure 2-4 do not vary greatly across the range of demand. Therefore, for Island demand greater than 750 MW, it is recommended to base the ML export limit on the number of Holyrood units that are on-line as generators, regardless of Island demand level. If the most limiting ML export limit is taken from each of these three lines, then the ML export limits could be defined by the values in Table 2-1, assuming the Island demand is greater than 750 MW. These limits ensure that the output of the Holyrood generators will not drop by more than 15 MW from the pre-contingency output following the loss of the ML bipole while exporting.

Table 2-1. ML Export Limits based on number of on-line Holyrood units (for Island demand greater than 750 MW)

Number of Holyrood Units on –line	ML Export Limit (MW)
3	85
2	70
1	55
1 as synchronous condenser	130

2. **Island Demand < 750 MW**

If the Island demand is less than 750 MW, it is recommended to limit ML export based on the straight line approximation in Figure 2-4, where one Holyrood unit is on-line as a synchronous condenser[3] (purple line). This line ensures that the Island frequency does not transiently rise above 62 Hz when the ML bipole is lost during export conditions.

[3] Please note that during extreme light load scenarios, when the Island load is less than 650 MW, it is not possible to run the system with even one Holyrood generator operating at minimum power of 70 MW because the rest of the Island is already at minimum generation and the ML export level cannot be lowered enough to keep the Holyrood generator from reducing its output by more than 15 MW if the ML bipole is lost.

3. System Operating Limits due to Transient Stability

There were two scenarios in the ML only study where the dynamic performance criteria were violated.

1. Three-phase fault at SOP on TL201 or TL217
2. Prior outage of TL201/ TL217, followed by a three-phase fault at SOP on TL217/TL201

This section discusses the impact of the SOP synchronous condensers on these scenarios.

3.1 Three-phase fault at SOP on TL201 or TL217

A system operating limit was not defined for a 3PF at SOP on TL201 or TL217 prior to the installation of the SOP synchronous condensers, however, the transient undervoltage criteria was violated slightly, i.e. the SOP voltage dipped to 0.79 pu more than 20 cycles after fault clearing, violating the 0.8 pu limit at 20 cycles.

With the addition of the SOP synchronous condensers, there is a significant improvement in voltage performance along the Bay d'Espoir – Soldiers Pond corridor, particularly in the second swing of the transient voltage. A 3PF at SOP on TL201 or TL217 no longer violates the transient voltage criteria as shown in Figure 3-1, which compares the SOP voltage with (green waveform) and without (blue waveform) the SOP synchronous condensers in service.

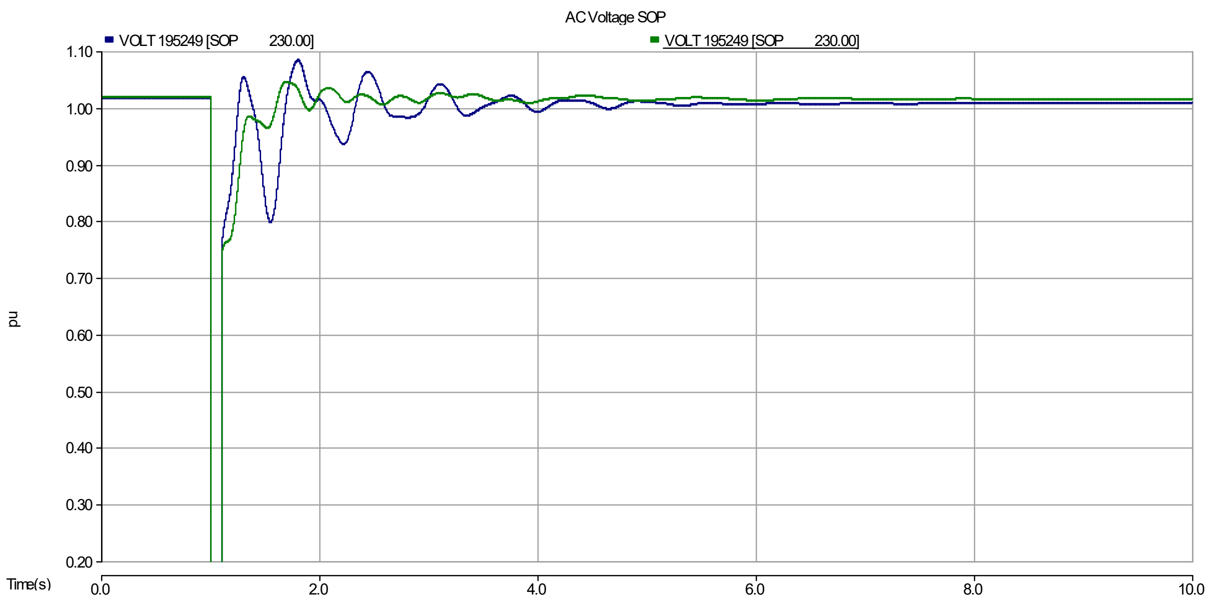

Figure 3-1. 3PF at SOP on TL217. ML + SOP syncs.
Green: with SOP syncs, Blue: without SOP syncs

3.2 Prior outage of TL201 or TL217

Prior to the addition of the synchronous condensers, if there was a prior outage of TL201 or TL217, and then if a three-phase fault occurred at SOP on TL201 or TL217 (whichever was not out-of-service), the system became unstable or violated the transient voltage criteria if the Island demand was greater than 1000 MW and if the power flowing from WAV to SOP was more than 90 MVA. The higher the demand, the worse the system response. This contingency severs the 230 kV connection between Western Avalon and Soldiers Pond, leaving it connected only through the underlying 138 kV transmission system.

The addition of the SOP synchronous condensers improves the dynamic performance of the system under this scenario. With the SOP synchronous condensers in service, the system no longer becomes unstable, although violation of the transient undervoltage criteria still results if the Island demand is greater than 1400 MW. Figure 3-2 shows the SOP voltage response during peak demand of 1600 MW (blue waveform) and during a lower demand of 1400 MW (green waveform) with the SOP synchronous condensers in service. It is evident that the transient voltage performance violates criteria in the peak load case, but at 1400 MW demand the transient voltage meets criteria.

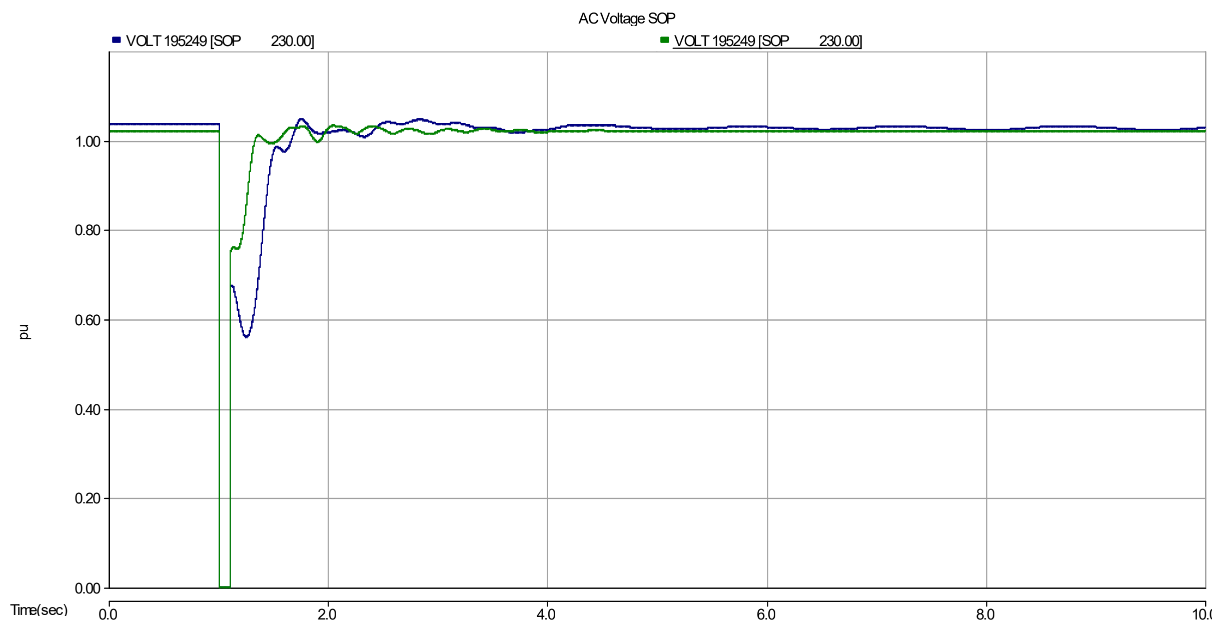

Figure 3-2. 3PF on TL201 during a prior outage of TL217. ML + SOP syncs.
Green: 1400 MW demand, Blue: 1735 MW demand

Since the 90 MVA power flow limit was required to prevent thermal overloading of the underlying 138 kV transmission system, this limit remains unchanged from the ML only study.

Table 3-1 shows the new operating limit required for a prior outage of TL201 or TL217 after the SOP synchronous condensers are in service.

Table 3-1. Updated system operating limit for prior outage of TL201 or TL217

Prior Outage	Next contingency	Issue	Mitigation
TL201/ TL217	TL217/ TL201	Thermal overloading of WAV-SOP underlying 138 kV system; Violation of transient undervoltage criteria	Limit WAV-SOP flow to 90 MVA (west to east) **AND** only plan the outage during times when the Island system load is **1400 MW** or less. If the load is higher than 1400 MW, even if the flow in the corridor is limited to 90 MVA, this scenario violates the transient undervoltage criteria.

4. ML Frequency Controller

4.1 Support from Nova Scotia to avoid UFLS

Prior to the addition of the synchronous condensers, the Island system needed to receive 100 MW from the Nova Scotia system in order to avoid underfrequency load shedding (UFLS) for loss of the largest generator under worst case system conditions, which was BDE unit 7 in power flow case ML3.

With the SOP synchronous condensers in service, the 100 MW requirement from the ML only study is reduced to 90 MW.

4.2 Support to Nova Scotia while avoiding UFLS

Prior to the addition of the SOP synchronous condensers, the Island system could provide 60 MW to the Nova Scotia system without resulting in underfrequency load shedding (UFLS) on the Island.

With the SOP synchronous condensers in service, the Island can provide up to 70 MW of support to Nova Scotia instead of 60 MW, while avoiding UFLS under the worst case system conditions. Table 4-1 summarizes the maximum power support that the Island can provide to Nova Scotia for the various power flow cases used in the study.

Table 4-1. MW Support to Nova Scotia while avoiding UFLS

Case	Island demand level	ML Export/Import	Power from Island to Nova Scotia without UFLS (MW)
ML1	Peak	Export	100
ML2	Peak	Import	90
ML3	Intermediate	Export	70
ML4	Intermediate	Import	80
ML5	Light	Export	70
ML6	Light	Import	70

5. Steady State Voltage Control at Soldiers Pond

A brief investigation of the steady state voltage control at SOP was performed. Two aspects were considered; the voltage control setpoint of the SOP synchronous condensers, and the tap settings of the off-load tap changers on the SOP synchronous condenser and station service transformers.

5.1 Voltage control setpoint

The SOP synchronous condensers can either be set to control the voltage at their own terminal bus or at a remote bus, namely the SOP 230 kV bus. The majority of the generators on the Island system are set to control their own terminal bus voltage. However, improved system performance is found with the SOP synchronous condensers controlling the 230 kV SOP bus voltage. This will have an advantage when the LIL comes in to service, as keeping the bus voltage controlled will help to minimize filter switching.

Based on the various power flow cases used in the study, the steady state voltage around SOP was often around 1.02 pu or 1.03 pu, but it ranged anywhere from 1.0 pu to 1.045 pu.

A voltage control setpoint of 1.02 pu was tested in the steady state cases and it worked well, provided that the voltage control setpoint of the Holyrood units were coordinated with the SOP setpoint to avoid, for example, the Holyrood units producing a large amount of reactive power and the SOP synchronous condensers absorbing reactive power, or vice versa.

In order to properly coordinate the reactive power output at Soldiers Pond and Holyrood, it was found that at peak load, the voltage control setpoints of the two locations could be set equal or slightly lower at Holyrood, and as the demand level decreases, the voltage control setpoint at Holyrood should also decrease, with SOP setpoint staying at 1.02 pu. Table 5-1 summarizes the voltage control setpoints at SOP and Holyrood, and the resulting reactive power output of the SOP synchronous condensers and the total reactive power output from the Holyrood generators (units 1-3 and CT).

Table 5-1. Coordination of voltage setpoints at SOP and Holyrood

Case	Island Demand Level	Voltage setpoint (pu)					Q output (MVAR)	
		SOP syncs	Holy-rood 1	Holy-rood 2	Holy-rood 3	Holy-rood CT	Total SOP syncs	Total Holyrood
ML1	Peak	1.02	1.01	1.01	1.01	0.99	+46	+147
ML2	Peak	1.02	1.01	1.01	n/a	0.99	+54	+113
ML3	Intermediate	1.02	1.0	1.0	1.0	n/a	+27	+99
ML4	Intermediate	1.02	1.0	n/a	n/a	n/a	+27	+42
ML5	Light	1.02	0.98	0.98	n/a	n/a	+4	+4
ML6	Light	1.02	n/a	n/a	0.99	0.99	+13	+33

Case	Island Demand Level	Voltage setpoint (pu)					Q output (MVAR)	
		SOP syncs	Holy-rood 1	Holy-rood 2	Holy-rood 3	Holy-rood CT	Total SOP syncs	Total Holyrood
ML13	Extreme Light	1.02	n/a	n/a	0.975	n/a	+2	+1

On the basis of this analysis, 1.02 pu may be used as a typical voltage setpoint for the SOP synchronous condensers under normal operation. Operators may adjust Holyrood and SOP voltage setpoints at their discretion in response to changing system conditions.The reactive power output of the Holyrood units and the SOP synchronous condensers should be monitored by the operators, who should manually adjust the voltage control setpoints of the Holyrood generators (and/or SOP synchronous condensers) if the reactive power sharing is not as desired.

5.2 Tap settings

With the SOP synchronous condensers controlling the SOP 230 kV to 1.02 pu, it was found that keeping the tap settings of both the SOP synchronous condenser transformers and of the SOP station service transformers to 1.0 worked well and kept the 600 V, 13.8 kV and 25 kV bus voltages in the range of 1.01 pu to 1.035 pu. Table 5-2 summarizes these results.

Table 5-2. SOP low side voltages, taps set to 1.0

Case	Island Demand Level	Voltages (pu)		
		13.8 kV	25 kV	600 V
ML1	Peak	1.032	1.033	1.01-1.025
ML2	Peak	1.034	1.035	1.01-1.025
ML3	Intermediate	1.027	1.027	1.01-1.02
ML4	Intermediate	1.027	1.027	1.01-1.02
ML5	Light	1.021	1.021	1.01
ML6	Light	1.023	1.023	1.01
ML13	Extreme Light	1.021	1.021	1.01-1.02

Alternatively, if the taps on the 230 kV winding of the SOP synchronous condenser transformers are set to 1.025, then the 13.8 kV and 25 kV bus voltages are kept closer to 1.0 pu, and the 600 V bus voltages are closer to around 0.99 pu.

Table 5-3 summarizes these results.

Table 5-3. SOP low side voltages, 230 kV winding tap set to 1.025

Case	Island Demand Level	Voltages (pu)		
		13.8 kV	**25 kV**	**600 V**
ML1	Peak	1.007	1.008	0.985-1.0
ML2	Peak	1.009	1.01	0.985-1.0
ML3	Intermediate	1.002	1.002	0.985-0.995
ML4	Intermediate	1.002	1.003	0.985-0.995
ML5	Light	0.996	0.996	0.985
ML6	Light	0.998	0.998	0.985
ML13	Extreme Light	0.996	0.996	0.985

Using the 1.025 tap setting, which keeps the SOP low side voltages nearer to 1.0 pu, would allow for more up and down flexibility on the voltage control setpoint of the SOP synchronous condensers before violating steady state voltage criteria on the low side of the SOP transformers. On this basis, this tap setting is preferred.

5.3 Future study

A more comprehensive reactive power study involving the SOP synchronous condenser voltage control setpoint and the filter switching scheme of the LIL will be performed as part of the next stages of the operational studies.

6. Conclusions

The following system operating limits/guidelines are recommended for the period in time when the ML and the SOP synchronous condensers are in-service, but prior to the LIL being in-service.

6.1 System Intact

There are several contingencies that require system operating limits. These contingencies and their limits/mitigation are summarized in Table 6-1.

Table 6-1. System Intact Operating Limits/Guidelines (ML + SOP syncs)

<table>
<tr><th>Contingency</th><th>Issue</th><th>Mitigation</th></tr>
<tr><td>TL217</td><td>Thermal overloading of TL201</td><td>Limit WAV-SOP flow to (west to east, as measured at WAV):
320 MVA (winter)
260 MVA (spring/fall)
175 MVA (summer)</td></tr>
<tr><td>Loss of ML Bipole</td><td>Ensure frequency does not drop below 58 Hz.</td><td>Limit ML import (as measured at BBK) as defined in Figure 6-1.</td></tr>
<tr><td>Loss of ML Bipole</td><td>Ensure frequency does not rise above 62 Hz.

Ensure power output of the Holyrood generators does not settle more than 15 MW[4] lower than the pre-contingency output.</td><td>Limit ML export (as measured at BBK) as follows if Island demand > 750 MW.
<table><tr><th>Number of Holyrood Units on –line</th><th>ML Export Limit (MW)</th></tr><tr><td>3</td><td>85</td></tr><tr><td>2</td><td>70</td></tr><tr><td>1</td><td>55</td></tr><tr><td>1 as synchronous condenser</td><td>130</td></tr></table>
If Island demand < 750 MW, limit ML export (as measured at BBK) as defined in Figure 6-2.</td></tr>
</table>

[4] As measured at simulation time of 20 seconds during the study.

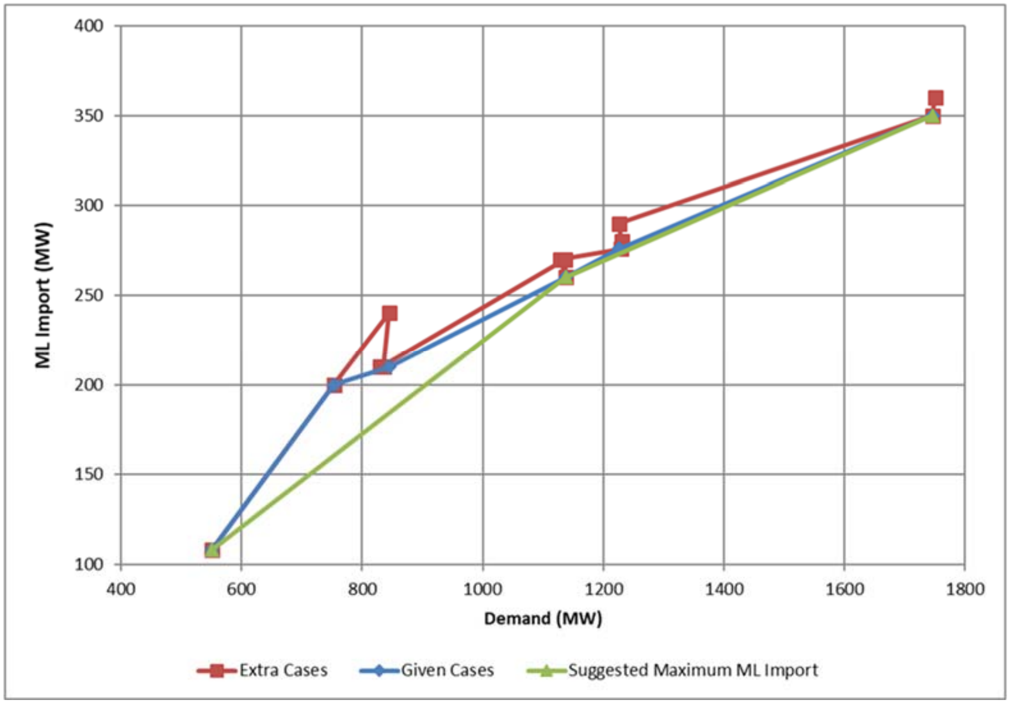

Figure 6-1. Maximum ML import level versus Island demand. ML + SOP syncs

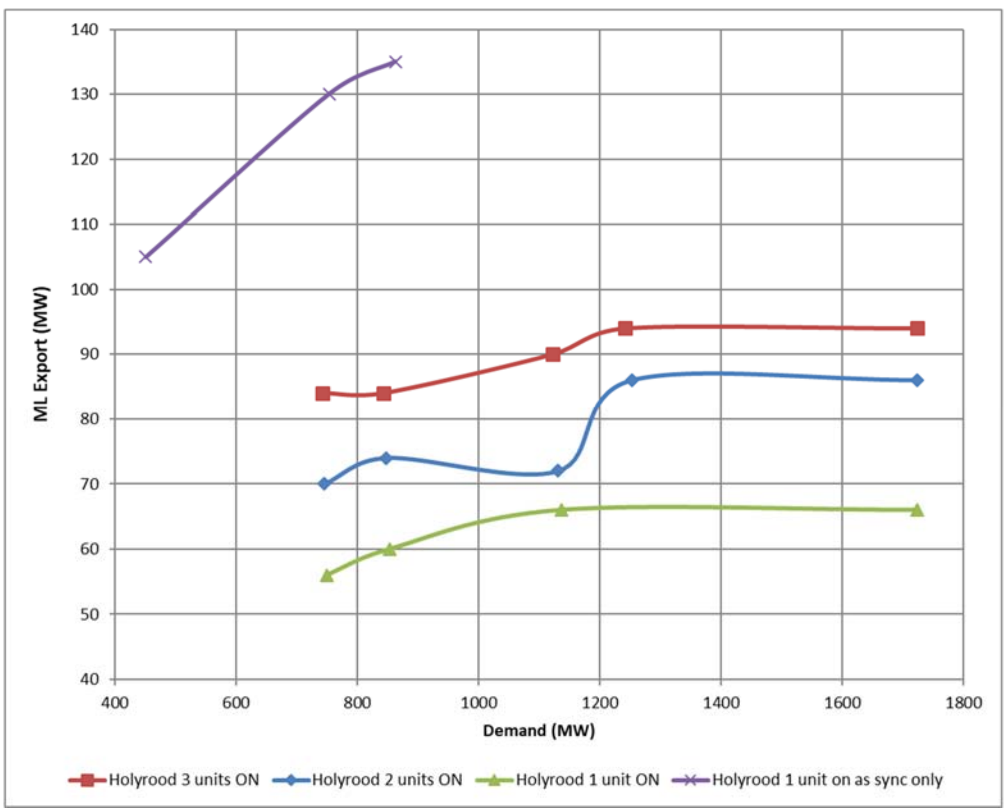

Figure 6-2. Maximum ML export level versus Island demand. ML + SOP syncs

6.2 Prior Outage Conditions

There are several prior outage conditions that require system operating limits. These prior outages and their limits/mitigation are summarized in Table 6-2.

Table 6-2. Prior Outage Operating Limits/Guidelines (ML + SOP syncs)

Prior Outage	Next contingency	Issue	Mitigation
TL201/ TL217	TL217/ TL201	Thermal overloading of WAV-SOP underlying 138 kV system; Violation of transient undervoltage criteria if Island demand > 1400 MW	Limit WAV-SOP flow to 90 MVA (west to east, as measured at WAV) **AND** only plan the outage during times when the Island system load is 1400 MW or less If the load is higher than 1400 MW, even if the flow in the corridor is limited to 90 MVA, this scenario has the potential to violate the transient undervoltage criteria and/or result in system instability.
TL203/ TL207 or TL237	TL207 or TL237/ TL203	Thermal overloading of 230 kV line TL267	Limit SSD-WAV flow (eastward, as measured at SSD): 200 MVA (winter) 180 MVA (summer)
TL202 or TL206/ TL267	TL267/ TL202 or TL206	Thermal overloading of 230 kV line TL202 or TL206	Limit eastward flow out of BDE (as measured at BDE) to: 375 MVA (winter) 315 MVA (spring/fall) 220 MVA (summer)
TL232/ TL205	TL205/ TL232	Thermal overloading of 138 kV line TL224	Limit ML import (as measured at BBK) to: 275 MW (winter) 185 MW (spring/fall) 165 MW (summer)
TL211/ TL228	TL228/ TL211	Thermal overload of 138 kV lines TL223 and TL224	The overload was only observed for Case ML3 (intermediate loading, with ML exporting). Limiting Hinds Lake generation to 40 MW mitigated the overload.
TL233/ TL234	TL234/ TL223	Thermal overload of 230 kV line TL211	Limit ML import (as measured at BBK) to: 270 MW (winter) 220 MW (spring/fall) 100 MW (summer)