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

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

Operational Study

Stage 3

Maritime Link, Soldiers Pond Synchronous Condensers, and Labrador Island Link Monopole

Engineering Support Services for:
RFI Studies

Newfoundland and Labrador Hydro

Attention: Mr. Rob Collett

Operational Studies: Maritime Link, SOP Syncs and LIL Monopole

Technical Note: TN1205.54.02
Date of issue: February 27, 2018

Prepared By:
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Disclaimer

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Revisions

Project Name:	RFI Studies
Document Title:	Operational Studies: Maritime Link, SOP Syncs and LIL Monopole
Document Type:	Technical Note
Document No.:	TN1205.54.02
Last Action Date:	February 27, 2018

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01	IFC	R. Brandt, R. Ostash	R. Ostash	February 2, 2018	Incorporated comments received from Hydro on January 17, 2018.
02	IFA	R. Brandt, R. Ostash	R. Ostash	February 27, 2018	Incorporated comments received from Hydro on Feburary 20, 2018.

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Approved by Client	ABC
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Table of Contents

1. Summary

Two previous operational studies were performed to determine the system operating limits of the Newfoundland and Labrador Hydro (Hydro) Island Interconnected System for the following periods in time:

1. "ML Only" study[1]; 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.
2. "ML and SOP Syncs"[2] study; when the Maritime Link (ML) and the Soldiers Pond (SOP) synchronous condensers are in-service, but prior to the Labrador Island Link (LIL) coming in to service.

This current report describes the next operational study that was performed, which investigates the impact of placing the LIL into service as a monopole operating at 225 MW (phase monopolar approach)[3]. The system operating limits determined in previous studies are revisited in this study to identify any changes to these limits after the installation of the LIL 225 MW monopole.

Steady state and dynamic analyses were performed for system intact conditions and for system conditions involving prior outages of 230 kV bulk system transmission lines.

The results of the study were analysed to ensure that the steady state and dynamic responses of the Island and Labrador systems met the system performance criteria as documented in Hydro's Transmission Planning Criteria. Where criteria violations were found, system operating limits and/or mitigation were determined to avoid these violations.

The base assumptions for this study are that two of the three 175 MVA Soldiers Pond synchronous condensers are in-service (i.e. one is out for maintenance), the MFA generators are not in-service, and the ML frequency controller is in-service. The LIL frequency controller is assumed not to be in-service in the phased monopolar approach. Sensitivity analysis was performed to assess the impact on the system operating limits of the following modifications to the base assumptions:

1. All three SOP synchronous condensers in-service
2. No SOP synchronous condensers in-service[4]
3. ML frequency controller out-of-service
4. ML out-of-service

[1] TN1205.50.04, "Operational Studies: Maritime Link ONLY", TransGrid Solutions, September 8, 2017.
[2] TN1205.51.03, "Operational Studies: Maritime Link & Soldiers Pond Synchronous Condensers", TransGrid Solutions, November 10, 2017.
[3] Bipole operation will be assessed in Stage IV of the operational studies.
[4] These operating limits will be followed when one SOP synchronous condenser is in service.

1.1 Interconnected Island System

1.1.1 System Intact Conditions

Previous operational studies found two issues in the Island system that require system operating limits.

1. Thermal loading in the 230 kV corridor between Bay d'Espoir and Soldiers Pond
2. ML import/export limits

This current operational study also investigates:

3. LIL transfer limits

1. Thermal loading in the 230 kV corridor between Bay d'Espoir (BDE) and Soldiers Pond (SOP)

The Island's major load centre is located on the east side of the Island on the Avalon peninsula, however the main hydro generation is located on the west side of the Island. This creates the potential for large power flows from west to east on the 230 kV lines between BDE and SOP. The most limiting segment of this corridor is the one between Western Avalon (WAV) and SOP.

Previous operational studies indicated that in order to avoid thermal overloads in this corridor, the total pre-contingency power flow from WAV to SOP (i.e. the sum of power flow on TL217 and TL201, as measured at WAV) should not be greater than the thermal rating of line TL201. The MVA rating of line TL201 as given in the PSSE base cases is summarized in Table 1-1.

Table 1-1. Thermal rating of TL201

Season	Thermal Rating TL201 (MVA)
Winter	322.2
Spring/Fall	260.2
Summer	175.5

Generally speaking, this system operating limit still applies because if the power flowing between WAV and SOP is greater than the thermal rating of TL201, and if T217 trips, then TL201 may become overloaded. However, once the LIL is in-service, the power infeed at Soldiers Pond from the LIL helps to off-load this corridor by supplying power directly to the Avalon peninsula and reducing the amount of power coming from Bay d'Espoir and further west in the system. In all of the power flow scenarios considered in the operational study with the LIL monopole in-service, no overloads were found during system intact conditions. This means that the power flow along the 230 kV corridor between BDE and SOP was not high enough to surpass this system operating limit under these conditions.

2. ML Import/Export Limits

As indicated in the previous operational studies, loss of the ML bipole is the defining contingency for determining the maximum ML import and export limits.

a. **ML Import Limit**

Loss of the ML during import must not cause the frequency to drop below 58 Hz (controlled UFLS is allowed).

With the LIL monopole in-service, Figure 1-1 shows the recommended ML import limits. The limits are plotted against Island demand, with two (blue), three (green) and zero (red) SOP synchronous condensers in-service. The ML import limits are slightly reduced from the previous operational studies due to the fact that the LIL infeed has displaced generating units on the Island, but the LIL does not provide inertia to the system, resulting in a net reduction of inertia on the Island for otherwise similar Island demand scenarios. This means that in order to continue to meet the 58 Hz underfrequency criteria for loss of the ML bipole, the ML import limit must be reduced to compensate for the reduced levels of inertia on the Island.

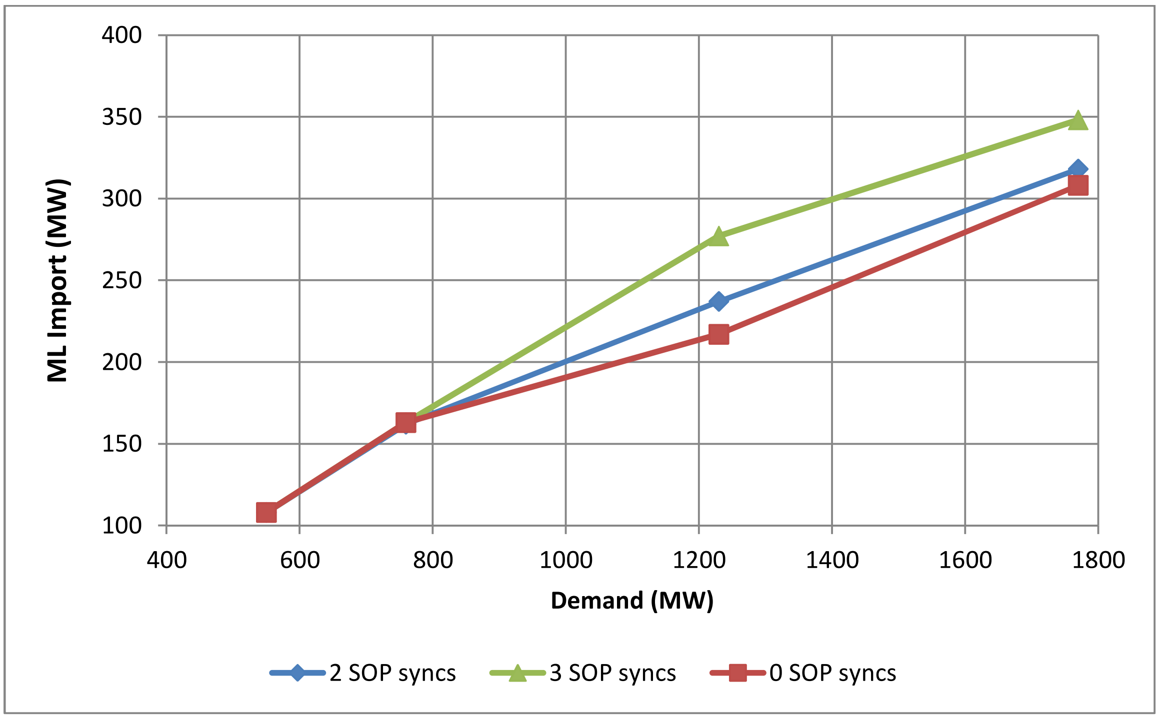

Figure 1-1. Maximum ML import levels – 2 (blue), 3 (green) and 0 (red) SOP synchronous condensers in-service

b. **ML Export Limit**

Loss of the ML while exporting results in an overfrequency on the Island. The ML export limits were identified to ensure that loss of the ML bipole does not result in the Island frequency rising above 62 Hz, and to ensure that the output of the Holyrood generators does not drop by more than 15 MW from their pre-fault operating points in response to the overfrequency.

Previous operational studies found that the number of Holyrood units that are on-line has a direct impact on the maximum allowable ML export level, regardless of Island demand level. A straight-line (horizontal) approximation of the maximum ML export level can be made for system operating conditions where one, two or three Holyrood generators are in-service (regardless of Island demand level). These maximum ML export limits are summarized in Table 1-2, and are valid for system conditions when the Island demand is greater than 750 MW. Similar to the ML import limits, the ML export limits are also slightly reduced from the previous operational studies due to the fact that the LIL infeed has displaced generating units on the Island, but the LIL does not provide inertia to the system, resulting in a net reduction of inertia on the Island for otherwise similar Island demand scenarios. This means that in order to continue to meet the 62 Hz overfrequency criteria and/or to ensure that the Holyrood generator outputs are not reduced by more than 15 MW following the loss of the ML bipole, the ML export limit must be reduced to compensate for the reduced levels of inertia on the Island.

Table 1-2. 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)		
	2 SOP Syncs in-service	3 SOP Syncs in-service	0 SOP Syncs in-service
3	80	80	75
2	65	65	65
1	45	45	45
1 as synchronous condenser	115	120	90

When Island demand is less than 750 MW, the Holyrood units are either off-line or one Holyrood unit is on-line as a synchronous condenser. In these cases, the ML export limit is higher because the 62 Hz frequency limit is the defining criteria (since the 15 MW Holyrood generator criteria is no longer applicable).

Therefore, when Island demand is less than 750 MW, it is recommended to limit the ML export to the values shown in Figure 1-2, depending on how many SOP synchronous condensers are in-service.

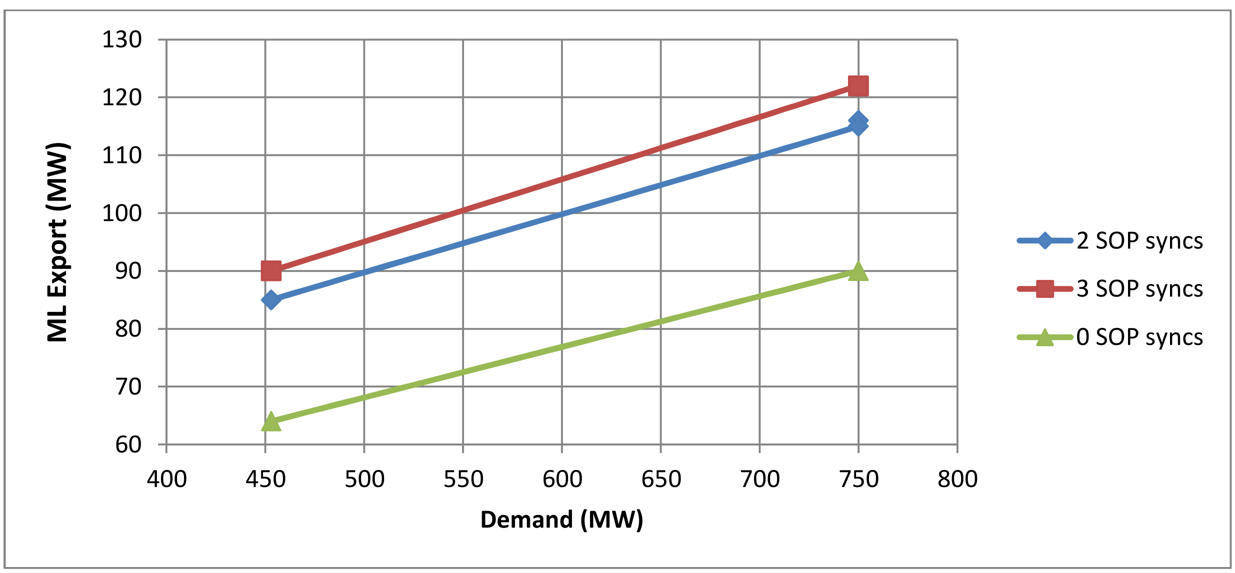

Figure 1-2. Island demand < 750 MW. Maximum ML export levels - 2 (blue), 3 (red) and 0 (green) SOP synchronous

3. LIL Transfer Limits

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 in all cases that were studied. Analysis was also performed to determine operational limits to ensure that there would be no underfrequnecy load shedding for loss of the LIL.

<u>If the ML or its frequency controller are out-of-service, LIL power transfer must be limited to 200 MW</u> in order to avoid triggering the 58 Hz block of loadshed following the loss of the LIL.

1.1.2 Prior Outage Conditions

There are several prior outage conditions that require system operating limits in the Interconnected Island System. These prior outages and their limits/mitigation are summarized in Table 1-3.

Table 1-3. Prior outages requiring system operating limits in the IIS

Prior Outage	Next contingency	Issue	Mitigation
TL201/ TL217	TL217/ TL201	Thermal overloading of WAV-SOP underlying 138 kV system	Limit WAV-SOP flow to 90 MVA (west to east, as measured at WAV) *Please note that if the LIL and SOP synchronous condensers are out-of-service, the outage of TL217 or TL201 should only be planned during times when the Island system load is 1100 MW or less in order to avoid potential for 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) 175 MVA (summer/spring/fall)
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) 310 MVA (spring/fall) 210 MVA (summer)
TL232/ TL205	TL205/ TL232	Thermal overloading of 138 kV line TL224	Limit ML import to (as measured at BBK): 240 MW (winter) 200 MW (spring/fall) 120 MW (summer) Limit output of HLK generator to 40 MW.
TL211/ TL228	TL228/ TL211	Thermal overload of 138 kV lines TL223 and TL224	The overload was only observed for Case MON3 (intermediate loading, ML exporting). Limiting Hinds Lake generation to 40 MW mitigated the overload.
TL233/ TL234	TL234/ TL233	Thermal overload of 230 kV line TL211	Limit ML import to (as measured at BBK): 270 MW (winter) 220 MW (spring/fall) 100 MW (summer)
TL211	TL234	Thermal overload of 230 kV line TL269	Limit ML import to (as measured at BBK): 145 MW (summer)

Prior outages of 230 kV outlet lines at Bottom Brook (TL211, TL233 and TL269/TL263/TL234) significantly weaken the connection of the ML to the Island system. No system stability issues were observed in this study for these prior outages, however, results suggested numerical convergence issues. It is therefore recommended to that further analysis be performed in PSCAD to confirm results.

1.2 Labrador System

1.2.1 System Intact Conditions

Steady state voltage violations at the Muskrat Falls (MFA) 315 kV bus require system operating limits as defined in Table 1-4.

Table 1-4. Labrador system operating limits

<table>
<tr><th>Contingency</th><th>Issue</th><th>Mitigation</th></tr>
<tr><td>Loss of L3101 or L3102</td><td>Potential for voltage collapse</td><td>Limit LIL transfer as per table:
<table>
<tr><td rowspan="3">HVY Load[5] (MW)</td><td colspan="4">CHF Voltage (pu)</td></tr>
<tr><td>0.975</td><td>0.985</td><td>0.995</td><td>1.005</td></tr>
<tr><td colspan="4">LIL Transfer (MW)</td></tr>
<tr><td>35</td><td>145</td><td>160</td><td>175</td><td>185</td></tr>
<tr><td>45</td><td>135</td><td>150</td><td>160</td><td>175</td></tr>
<tr><td>55</td><td>125</td><td>140</td><td>150</td><td>165</td></tr>
<tr><td>65</td><td>115</td><td>128</td><td>140</td><td>155</td></tr>
<tr><td>75</td><td>100</td><td>115</td><td>125</td><td>135</td></tr>
<tr><td>80</td><td>95</td><td>108</td><td>120</td><td>130</td></tr>
<tr><td>90</td><td>80</td><td>93</td><td>105</td><td>118</td></tr>
<tr><td>100</td><td>65</td><td>75</td><td>86</td><td>103</td></tr>
</table></td></tr>
<tr><td>Loss of MFA filter</td><td>Voltage at MFA as low as 0.89 pu depending on system conditions</td><td>If LIL transfer limits are applied as per table above, then no issues for loss of MFA filter.

However, it should be noted that for phased monopolar approach, if an MFA filter trips, the LIL will also trip automatically since there are no redundant filters.</td></tr>
<tr><td>Loss of MFA reactor</td><td>Voltage at MFA as high as 1.166 pu depending on system conditions</td><td>Tripping an MFA filter helps to mitigate the issue, however it is not possible to trip one of the MFA filters, since loss of a filter will automatically cause the LIL to trip in the phase monopolar approach.

Therefore, if the MFA reactor trips, the LIL must also be tripped.</td></tr>
</table>

As is evident in Table 1-4, loss of L3101 or L3012 requires LIL power transfer to be limited. Hydro has expressed an interest in exploring the application of a Special Protection Scheme (SPS) to increase opportunities for power transfer over the LIL. This SPS will be explored in a separate study.

[5] These values do not include Muskrat Falls construction power loads. It is assumed that these loads are supplied by the 25 kV station service supply at Muskrat Fall Terminal Station 2.

1.2.2 Prior Outage Conditions

The system operating limits required under prior outage conditions in the Labrador system are summarized Table 1-5.

Table 1-5. Prior outages requiring system operating limits in the Labrador system

Prior Outage	Next contingency	Issue	Mitigation
L3101 / L3012	L3102 / L3011	LIL already out of service as per Table 1-4 for loss of L3101 or L3102	n/a

1.3 ML Frequency Controller

It was determined that the Island can provide up to 60 MW of power (in the most limiting of the cases that were studied) to Nova Scotia without experiencing underfrequency load shedding (UFLS).

Additionally, it was determined that the Island would require up to 100 MW of power from Nova Scotia in order to prevent UFLS for loss of the largest generator on the Island under the worst case system conditions.

2. Introduction

This technical note summarizes the operational studies that were performed to determine the 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.

Steady state and dynamic analyses were performed on a set of PSSE base cases that were provided by Hydro.

The results of the study were analysed to ensure that the Interconnected Island and Labrador systems steady state and dynamic responses met the system performance criteria as documented in Hydro's Transmission Planning Criteria. Where criteria violations were discovered, system operating limits and/or mitigation were determined to prevent these violations.

2.1 Scope of Study

The main focus of the study is on the Primary Transmission System. This system includes the following:

- 230 kV transmission system on the Island of Newfoundland
- 138 kV transmission system from Deer Lake to Stony Brook
- LIL
- ML
- 315 kV transmission systems in Labrador[6]

Please note that only transmission line and generator contingencies were considered for this study. Outages of other transmission elements such as transformers were not considered as they would require operational procedures which are outside of the scope of this work.

[6] Operational studies relating to contingencies in the 735 kV network are to be performed by Hydro-Québec TransÉnergie.

3. Study Models

The assumptions for the base case setup are as follows:

- No MFA generators in-service
- Two (2) SOP synchronous condensers in-service
- ML frequency controller in-service
- LIL frequency controller out-of-service
- Happy Valley is fed from 315/138 kV transformers at MFA

Sensitivity analysis is performed for the following variations to the base assumptions:

- Three (3) SOP synchronous condensers in-service
- No SOP synchronous condensers in-service
- ML frequency controller out-of-service
- ML out-of-service

3.1 System Diagrams

The IIS in the area of Soldiers Pond is shown in Figure 3-1.

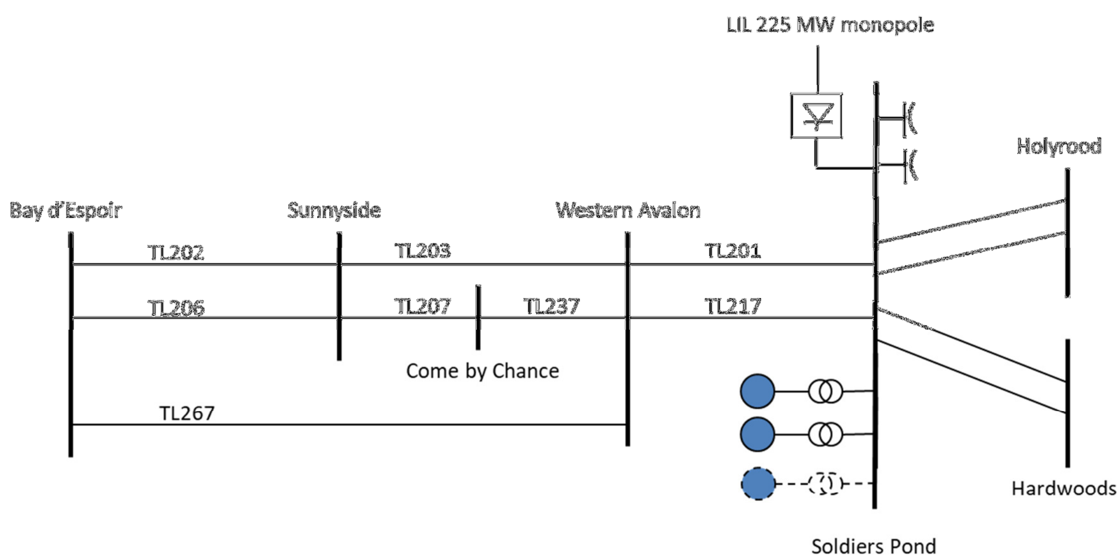

Figure 3-1. IIS near Soldiers Pond

The Labrador system around Muskrat Falls is shown in Figure 3-2.

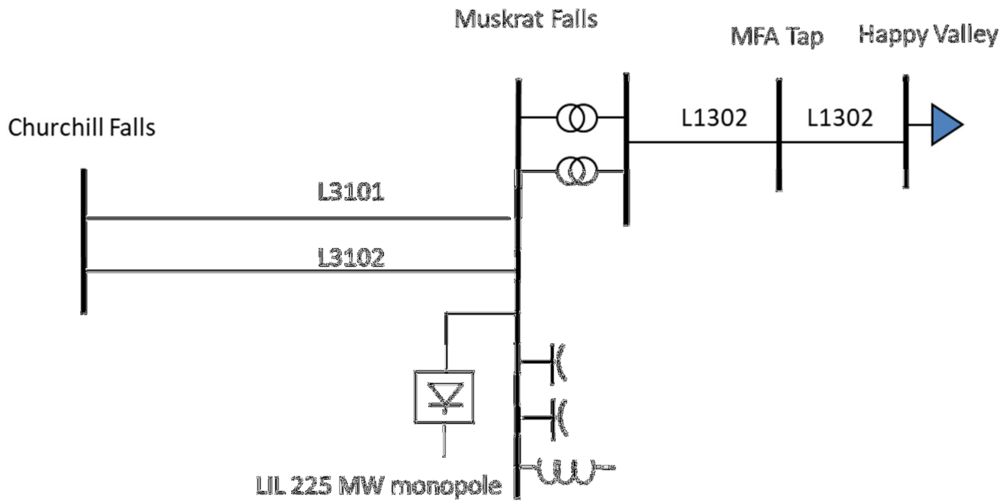

Figure 3-2. Labrador system near Muskrat Falls

3.2 PSSE Base Cases

Hydro created a set of PSSE version 33 base cases to represent the Island and Labrador systems at peak, shoulder and light load scenarios, with the ML link operating in both import and export conditions. These cases were based on the year 2018 and were designed to maximize production from hydraulic resources. Table 3-1 lists these base cases.

Table 3-1: Base cases provided by Hydro

Number	Load Condition	Island Demand (MW)	ML Import/ Export (MW)	LIL LAB to NF Flow (MW)	NF to NS Flow	Island Generation
MON1	Peak	1727.8	146 EX	225	Max export while maintaining reserve	Max while maintaining reserve
MON2	Peak	1753.9	207 IM	225	Max import	Adjust to maintain reserve
MON3	Intermediate	1246.2	376 EX	225	Max export while maintaining reserve	Max while maintaining reserve
MON4	Intermediate	1221.6	90 IM	225	Max import	Adjust to maintain reserve
MON5	Light	762.9	294 EX	225	Max export while maintaining reserve	Minimum Generation
MON6	Light	759.1	165 IM	52	Max import while maintaining reserve	Minimum Generation
MON7	Light	756.7	294 EX	225	Max export while maintaining reserve	Minimum Generation
MON8	Peak	1724.2	146 EX	225	Max export while maintaining reserve	Max while maintaining reserve

Number	Load Condition	Island Demand (MW)	ML Import/ Export (MW)	LIL LAB to NF Flow (MW)	NF to NS Flow	Island Generation
MON9	Medium Light	1072.3	137 EX	225	Max export while maintaining reserve	Minimum Generation
MON10	Low Intermediate	1277.2	153 EX	225	Max export while maintaining reserve	Max while maintaining reserve
MON11	Medium Light	872.7	180 IM	84	Max import while maintaining reserve	Minimum Hydro Generation
MON12	Low Intermediate	995.2	205 IM	130	Max import while maintaining reserve	Minimum Hydro Generation
MON13	Extreme Light	448.3	120 EX	82	Max export while maintaining reserve	Minimum Generation
MON14	Extreme Light	451.2	140 EX	86	Max export while maintaining reserve	Minimum Generation
MON15	Peak	1738.3	0	225	ML out-of-service	Max while maintaining reserve
MON16	Intermediate	1227.9	0	225	ML out-of-service	Adjust to maintain reserve
MON17	Light	754.6	0	225	ML out-of-service	Minimum Generation
MON18	Extreme Light	455.2	0	0	ML out-of-service	Minimum Generation

Please note that cases MON1 through MON6 are the base cases that were used to perform the full steady state and dynamic analysis.

Cases MON7 through MON14 were provided solely for the purpose of defining the ML import/export limits during the loss of the ML bipole over a wider range of operating scenarios, and therefore these cases were not used to study the full steady state and dynamic analyses. The loss of the ML bipole was studied with these cases.

Cases MON15 through MON18 were provided in order to study the impact of having the ML out-of-service.

3.3 Dynamic Models

3.3.1 Island System

The PSSE v33 dynamic study package, including a set of python files, was provided to setup the system for dynamic simulation. This study package included all of the dynamic models needed to run the system.

3.3.2 Maritime Link

The ML is represented in dynamics using ABB's detailed VSC model, *Abb_Hvdc_Light_Maritime_v220-MTM-2.dll.*

This ML frequency controller (*Abb_Hvdc_Light_FrqDml_User.dll*) is modelled with MW output limits of 60 MW export/100 MW import (in total for both ML poles). The deadband on the frequency controller was set to +/- 0.5 Hz.

This model also includes a damping controller, but its application was beyond the scope of this investigation[7].

3.3.3 Labrador Island Link

The LIL is represented in dynamics using PSSE standard library model CDC7.

The LIL frequency controller is assumed to be out-of-service for this study.

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

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

- MFA: 2x72 MVAR filters (both Type A), 1x150 MVAR reactor[8]
- SOP: 2x75 MVAR filters (one Type A, one Type B)

The LIL uses metallic return when operating as a monopole. The resistance of the HVdc line was modeled as 38.18 ohms.

3.3.4 Coordinated Runbacks of the HVdc Links

Controllers associated with coordinated runbacks of the HVdc links are assumed not to be in service as part of the phase monopolar approach of the LIL. These controllers will be activated as part of bipole operation and will be studied as part of Stage IV of the operational studies.

[7] Damping controller functionality will be investigated as part of Stage IV of the operational studies, which involves the long term operation of the NL interconnected system with Muskrat Falls and both HVdc links operating at rated capacity.

[8] The 150 MVARreactor is installed at Muskrat Falls Terminal Station 2 for the interim operation of the transmission system prior to the in-service of Muskrat Falls generators.

4. Study Methodology

This section describes the methodology for the steady state and dynamic analyses that were performed.

1. First, the steady state analysis was performed to determine the system operating limits needed to meet the steady state performance criteria. The base cases were modified accordingly.
2. Then, the dynamic analysis was performed on these modified base cases to determine the system operating limits needed to meet the dynamic criteria. The base cases were again modified accordingly.
3. Finally, the steady state analysis was repeated on the base cases as modified by the dynamic analysis to ensure that these modifications did not create any new steady state violations.

4.1 Steady State Analysis

Steady state contingency analysis was performed on the system to determine if there are any violations of the steady state voltage criteria or any thermal overloading of transmission lines. Hydro's Transmission Planning criteria are summarized in Section 4.1.2 below.

PSSE activity ACCC was used to perform an N-1 analysis on the Island's bulk system and on the Labrador system. Bus voltages and loading of the transmission lines in the bulk systems were monitored. If a violation of criteria was found, the generation on the system was re-dispatched and/or the ML import/export level or the LIL power transfer level was adjusted to mitigate the violation.

4.1.1 Contingencies

All single contingencies in the Island and Labrador bulk systems (not including 735 kV) were included in the steady state analysis. Note that this study considered the special protection scheme (SPS) that cross trips TL247 (and the Cat Arm generation) when TL248 trips.

4.1.2 Criteria

The following thermal and voltage limits were used in the steady state analysis:

- Thermal Limits[9]:
    - Rate A: Summer – 30^{0}C Ambient
    - Rate B: Spring/fall – 15^{0}C Ambient
    - Rate C: Winter – 0^{0}C Ambient
- Voltage Limits:
    - Normal: Minimum = 0.95 pu; Maximum = 1.05 pu
    - Emergency: Minimum = 0.90 pu; Maximum = 1.10 pu

[9] Transmission line thermal ratings are calculated in accordance with IEEE Standard 738-2012 – Calculating the Current-Temperature Relationship of Bare Overhead Conductors.

4.2 Dynamic Analysis

Dynamic analysis was performed on the system to determine if there are any violations of the transient analysis criteria. Hydro's Transmission Planning criteria are summarized in Section 4.2.2 below.

System disturbances were simulated, and the resulting bulk system voltages, generator power/speed, frequencies, line power flows as well as ML voltages, currents, power and reactive power were monitored.

Three-phase faults (3PF), single-pole autoreclose (SPAR) faults with successful and unsuccessful reclose, and 3PF on the largest on-line generator were tested.

4.2.1 Contingencies

Table 4-1 is the table of ac system contingencies that was provided by Hydro for the dynamic analysis.

Three-phase faults (3PF) were simulated at both ends of a transmission line, with a 6-cycle clearing time.

Single pole auto-reclose (SPAR) faults were simulated at both ends of a transmission line as detailed in Table 4-1.

In addition to ac system contingencies, ML and LIL contingencies were also simulated, including:

- Loss of ML pole (permanent)
- Loss of ML bipole (permanent)
- DC line fault followed by loss of ML pole (permanent)
- Loss of LIL monopole (permanent)
- Loss of a 72 MVAR filter at MFA
- Loss of the 150 MVAR reactor at MFA
- Loss of a 75 MVAR filter at SOP

Table 4-1. AC contingencies for dynamic analysis

Line Name	Volt. (kV)	Station 1	Station 2	Faulted Bus	SUCCESSFUL SPAR Clearing Time (cycles)*	UN-SUCCESSFUL SPAR Clearing Time (cycles)*	Notes
L3101	315	Muskrat Falls	Churchill Falls	195300	5-1-50-9 (RESTORE)	5-1-50-3 (TRIP)	
				195320	5-1-49-11 (RESTORE)	5-1-49-3 (TRIP)	
TL201	230	Soldiers Pond	Western Avalon	195249	5-1-49-11 (RESTORE)	5-1-49-3 (TRIP)	
				195229	5-1-50-9 (RESTORE)	5-1-50-3 (TRIP)	
TL202	230	Bay d'Espoir	Sunnyside	195221	5-1-29-11 (RESTORE)	5-1-29-3 (TRIP)	

Line Name	Volt. (kV)	Station 1	Station 2	Faulted Bus	SUCCESSFUL SPAR Clearing Time (cycles)*	UN-SUCCESSFUL SPAR Clearing Time (cycles)*	Notes
				195222	5-1-30-9 (RESTORE)	5-1-30-3 (TRIP)	
TL203	230	Sunnyside	Western Avalon	195222	5-1-29-11 (RESTORE)	5-1-29-3 (TRIP)	
				195229	5-1-30-9 (RESTORE)	5-1-30-3 (TRIP)	
TL207	230	Sunnyside	Come-by-Chance	195222	5-1-44-11 (RESTORE)	5-1-44-3 (TRIP)	Two capacitor banks (2 x 38.35 MVAR) cross-trip at CBC on line trip
				195227	5-1-45-9 (RESTORE)	5-1-45-3 (TRIP)	
TL209	230	Bottom Brook	Stephen-ville	195205	N/A		
TL211	230	Massey Drive	Bottom Brook	195208	5-1-29-16 (RESTORE)	5-1-29-3 (TRIP)	
				195205	5-1-30-14 (RESTORE)	5-1-30-3 (TRIP)	
TL218	230	Holyrood	Oxen Pond	195234	5-1-30-14 (RESTORE)	5-1-30-3 (TRIP)	
				195238	5-1-29-16 (RESTORE)	5-1-29-3 (TRIP)	
TL228	230	Buchans	Massey Drive	195215	5-1-29-21 (RESTORE)	5-1-29-3 (TRIP)	
				195208	5-1-30-19 (RESTORE)	5-1-30-3 (TRIP)	
TL231	230	Bay d'Espoir	Stony Brook	195221	5-1-29-11 (RESTORE)	5-1-29-3 (TRIP)	
				195216	5-1-30-9 (RESTORE)	5-1-30-3 (TRIP)	
TL232	230	Stony Brook	Buchans	195216	5-1-29-21 (RESTORE)	5-1-29-3 (TRIP)	
				195215	5-1-30-19 (RESTORE)	5-1-30-3 (TRIP)	
TL233	230	Bottom Brook	Buchans	195205	5-1-39-19 (RESTORE)	5-1-39-3 (TRIP)	
				195215	5-1-40-21 (RESTORE)	5-1-40-3 (TRIP)	
TL234	230	Bay d'Espoir	Upper Salmon	195221	5-1-29-16 (RESTORE)	5-1-29-3 (TRIP)	
				195220	5-1-30-14 (RESTORE)	5-1-30-3 (TRIP)	
TL236	230	Hardwoods	Oxen Pond	195236	5-1-30-14 (RESTORE)	5-1-30-3 (TRIP)	
				195238	5-1-29-16 (RESTORE)	5-1-29-3 (TRIP)	

Line Name	Volt. (kV)	Station 1	Station 2	Faulted Bus	SUCCESSFUL SPAR Clearing Time (cycles)*	UN-SUCCESSFUL SPAR Clearing Time (cycles)*	Notes
TL237	230	Come-by-Chance	Western Avalon	195227	5-1-30-9 (RESTORE)	5-1-30-3 (TRIP)	Two capacitor banks (2 x 38.35 MVAR) cross-trip at CBC on line trip
				195229	5-1-29-11 (RESTORE)	5-1-29-3 (TRIP)	
TL247	230	Cat Arm	Deer Lake	195210	5-1-29-31 (RESTORE)	5-1-29-3 (TRIP)	
				195209	5-1-30-29 (RESTORE)	5-1-30-3 (TRIP)	
TL248	230	Massey Drive	Deer Lake	195208	5-1-29-16 (RESTORE)	5-1-29-3 (TRIP)	Cross-trip of TL247 between DLK and CAT plus CAT generation on line trip
				195209	5-1-30-14 (RESTORE)	5-1-30-3 (TRIP)	
TL263	230	Upper Salmon	Granite Canal	195220	5-1-30-14 (RESTORE)	5-1-30-3 (TRIP)	
				195218	5-1-29-16 (RESTORE)	5-1-29-3 (TRIP)	
TL266	230	Soldier Pond	Hardwoods	195249	5-1-29-21 (RESTORE)	5-1-29-3 (TRIP)	
				195236	5-1-30-19 (RESTORE)	5-1-30-3 (TRIP)	
TL267	230	Bay d'Espoir	Western Avalon	195221	5-1-29-16 (RESTORE)	5-1-29-3 (TRIP)	
				195229	5-1-30-14 (RESTORE)	5-1-30-3 (TRIP)	
TL268	230	Soldier Pond	Holyrood	195249	5-1-29-16 (RESTORE)	5-1-29-3 (TRIP)	
				195234	5-1-30-14 (RESTORE)	5-1-30-3 (TRIP)	
TL269	230	Bottom Brook	Granite Canal	195205	5-1-30-14 (RESTORE)	5-1-30-3 (TRIP)	
				195218	5-1-29-16 (RESTORE)	5-1-29-3 (TRIP)	
TL222	138	Stony Brook	South Brook	No SPAR			
TL222	138	South Brook	Springdale	No SPAR			
TL223	138	Springdale	Indian River	No SPAR			
TL224	138	Indian River	Howley	No SPAR			
TL245	138	Howley	Deer Lake	No SPAR			

4.2.2 Criteria

The following criteria were used for the dynamic analysis:

- Post fault recovery voltages on the ac system shall be as follows:
    - Transient undervoltages following fault clearing should not drop below 70%
    - The duration of the voltage below 80% following fault clearing should not exceed 20 cycles
- Post fault system frequencies shall not drop below 58 Hz (this criteria is only valid before the LIL is fully in-service as a bipole) and shall not rise above 62 Hz
- For contingencies resulting in overfrequencies, the output of the Holyrood units shall be monitored to ensure that the post-fault output of these units does not change by more than 15 MW[10] compared to the pre-fault output
- Underfrequency load shedding shall be permitted, but controlled, for loss of generation or loss of the ML pole/bipole or loss of the LIL monopole (this criteria is only valid before the LIL is fully in-service as a bipole). The existing underfrequency load shedding scheme shall be assumed for operation of the Island Interconnected System in this study.

[10] Output of each HRD unit as measured at 20 seconds of simulation time.

5. System Intact Study Results

5.1 Island System - Steady State Analysis

5.1.1 Thermal Overloads

There were no overloads identified in the Island system in this study during N-1 system conditions.

The Island's major load centre is located on the east side of the Island on the Avalon Peninsula, however, the main hydro generation is located on the west side of the Island. This creates the potential for large power flows from west to east on the 230 kV lines between BDE and SOP. The most limiting segment of this corridor is the one between Western Avalon (WAV) and SOP. This transmission corridor is depicted in Figure 5-1.

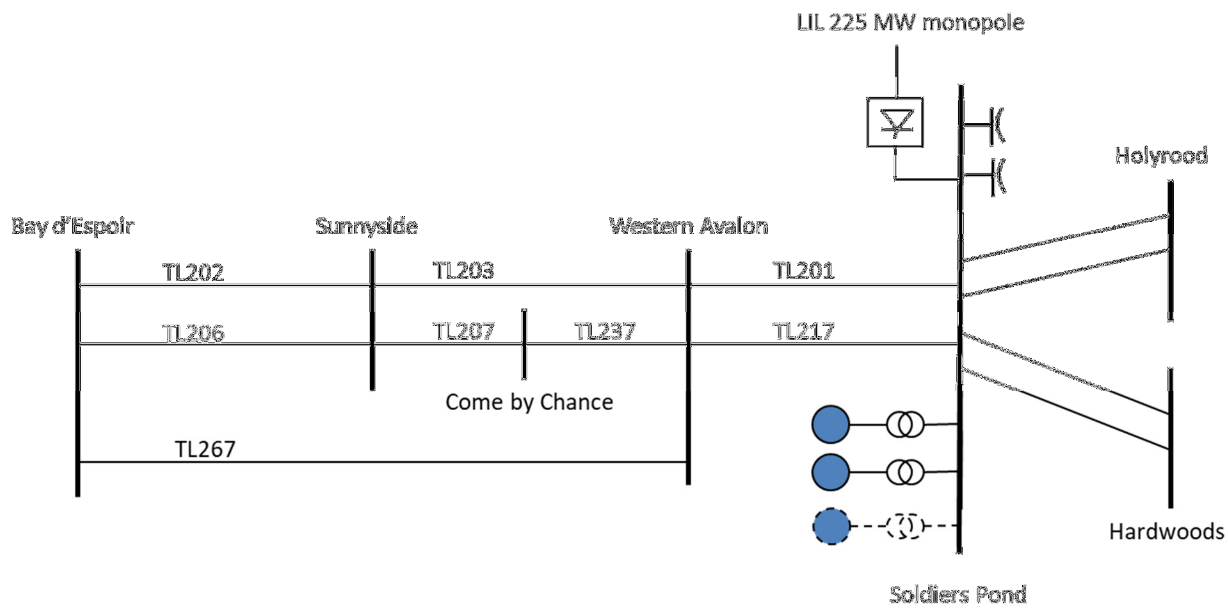

Figure 5-1. 230 kV transmission corridor from BDE to SOP

Previous operational studies indicated that in order to avoid thermal overloads in this corridor, the total pre-contingency power flow from WAV to SOP (i.e. the sum of power flow on TL217 and TL201, as measured at WAV) should not be greater than the thermal rating of line TL201. The MVA rating of line TL201 as given in the PSSE base cases is summarized in Table 1-1.

Table 5-1. Thermal rating of TL201

Season	Thermal Rating TL201 (MVA)
Winter	322.2
Spring/Fall	260.2
Summer	175.5

Generally speaking, this system operating limit still applies after the LIL is in-service because if the power flowing between WAV and SOP is greater than the thermal rating of TL201, and if T217 trips, then TL201 will be overloaded. However, once the LIL is in-service, the power infeed at Soldiers Pond from the LIL off-loads this corridor by supplying the load centre directly. In all of the power flow scenarios considered in this operational study with the LIL monopole in-service, no overloads were found during system intact conditions[11]. This means that the power flow along the 230 kV corridor between BDE and SOP was not high enough to surpass this system operating limit under these conditions.

5.1.2 Steady State Voltage

There were no steady state voltage violations identified in the Island system in this study during N-1 system conditions.

There were also no voltage violations that occurred for loss of a SOP filter. However, if a filter is lost at SOP, the LIL power transfer would have to be reduced to 112 MW according to the filter switching sequence at SOP.

5.2 Labrador System - Steady State Analysis

5.2.1 Thermal Overloads

There were no overloads identified in the Labrador system in this study during N-1 system conditions.

5.2.2 Steady State Voltage

Steady state voltage violations at MFA 315 kV bus were identified for the following contingencies:

1. Loss of one of the two 315 kV MFA-CHF lines (L3101 or L3102)
2. Loss of a 72 MVAR MFA filter
3. Loss of the MFA 150 MVAR reactor

5.2.2.1 Loss of L3101 or L3102

Loss of one of the two 315 kV MFA-CHF lines (L3101 or L3102) was the worst-case contingency, having the potential to result in voltage collapse under peak load conditions, and violating the 0.90 pu criteria under lighter load conditions. In order to ensure the MFA 315 kV voltage remains at or above 0.9 pu following the loss of L3101 or L3102, LIL transfer limits are identified in Table 5-2. The LIL transfer limits were assessed over the expected range of Labrador loading conditions at Happy Valley Terminal Station (35 MW to 100 MW) and CHF 735 kV bus voltages (0.975 pu to 1.005 pu).

LIL power flow should be limited in accordance with Table 5-2 to ensure compliance with Transmission Planning Criteria. The worst-case limitation for LIL is when power flow is restricted to 65 MW under peak load conditions with the CF 735 kV bus voltage at 0.975 pu. In all cases,the loss of a 315 kV transmission line will result in a bus voltage of 0.9 pu at MFATS2.

[11] Worst case loading in the BDE-SOP corridor was found during n-1 contingencies in the peak load case with import over the ML. No overloads were found in this case.

Table 5-2. LIL transfer limits to prevent steady state voltage violations at MFATS2

HVY Load (MW)	CHF Voltage (pu)			
	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

Hydro has expressed an interest in exploring the application of a Special Protection Scheme (SPS) to increase opportunities for power transfer over the LIL. This SPS will be explored in a separate study.

5.2.2.2 Loss of a MFA Filter

Loss of a filter is less onerous than loss of a 315 kV transmission line and operation in accordance with Table 5-2 will ensure compliance with Tranmission Planning Criteria. The worst-case voltage for loss of a filter would occur under maximum load conditions with the CF 735 kV bus voltage at 0.975 pu. With LIL transfer limited to 65 MW as per Table 5-2, loss of a filter results in a bus voltage of 0.945 pu at MFATS2.

However, it should be noted that for phased monopolar approach, if an MFA filter trips, the LIL (and other filter and the reactor) will also trip automatically since there are no redundant filters.

5.2.2.3 Loss of the MFA Reactor

The results for loss of the MFA reactor are summarized in Table 5-3.

Table 5-3. Voltage violations at MFATS2 for loss of MFA reactor

System condition	Bus Voltage at MFA (pu)			CHF 735 kV Bus Voltage (pu)	LIL Power Transfer (MW)
	N-0	Loss of MFA reactor	Loss of reactor and cross-trip an MFA filter		
Peak Load	1.007	1.113	1.060	0.975	45
	1.040	1.149	1.095	1.005	45
Light Load	1.025	1.130	1.077	0.975	45
	1.057	1.166	1.112	1.005	45

The worst case scenario for loss of the 150 MVAR reactor is during light load conditions with the LIL monopole operating at the minimum power transfer of 45 MW, and with the CHF generators operating at their maximum voltage setpoints of 1.005 pu. In this case, the MFA voltage reaches 1.166 pu when the reactor trips.

Tripping one of the MFA filters reduces this worst case voltage to 1.11 pu, which represents a marginal violation of the 1.1 pu steady state voltage criteria. Criteria are met in all other cases if a filter is tripped.

However, it is not possible to trip one of the MFA filters, since loss of a filter will automatically cause the LIL to trip in the phase monopolar approach.Therefore, if the MFA reactor trips, the LIL (and both MFA filters) must also be tripped.

5.3 Island System - Dynamic Analysis

The results of the dynamic analysis are discussed in four sections:

1. Transmission line faults
2. Loss of generation
3. Loss of the LIL monopole
4. Loss of the ML bipole

5.3.1 Transmission Line Faults

The dynamic analysis did not identify any violations of the dynamic performance criteria for any of the three-phase faults or any of the SPAR faults (successful or unsuccessful reclose) that were tested.

5.3.2 Loss of Generation

Loss of the largest generator on the Island resulted in controlled underfrequency load shedding and the frequency remained above 58 Hz in all cases, which meets the present-day criteria.

5.3.3 Loss of the LIL Monopole

Loss of the LIL monopole was tested for the following conditions to ensure that the system frequency remained above 58 Hz:

1. Base assumption – two SOP synchronous condensers in-service
2. Sensitivity – no SOP synchronous condensers in-service
3. Sensitivity – ML frequency controller out-of-service
4. Sensitivity – ML out-of-service

Table 5-4 summarizes the minimum Island frequency observed for each system condition in which loss of the LIL monopole was tested.

Table 5-4. Minimum Island system frequency resulting from loss of LIL monopole

Case	Island Load	ML	Minimum Island System Frequency (Hz)		
			2 SOP syncs	3 SOP syncs	0 SOP syncs
MON1	Peak	Export	58.70	58.74	58.60
MON2		Import	58.65	58.66	58.60
MON3	Intermediate	Export	58.56	58.59	58.46
MON4		Import	58.57	58.58	58.53
MON5	Light	Export	58.46	58.52	58.34
MON6		Import	59.41	59.42	59.37
ML out-of-service					
MON15	Peak	-	58.31		
MON16	Intermediate	-	58.16		
MON17	Light	-	58.00*		
ML frequency controller out-of-service					
MON1	Peak	Export	58.32		
MON2		Import	58.28		
MON3	Intermediate	Export	58.09		
MON4		Import	58.15		
MON5	Light	Export	58.00*		
MON6		Import	59.05		

*Causes 58 Hz block of load to shed.

In all cases, loss of the LIL results in controlled UFLS.

Under light load conditions, if the ML frequency controller is out-of-service, or if the ML itself is out-of-service, loss of the LIL (when transferring 225 MW) causes the Island frequency to drop to 58 Hz, which triggers the 58 Hz block of loadshed. In order to avoid the 58 Hz block of load from being shed, LIL power transfer must be limited to 200 MW.

With the ML and its frequency controller in-service, controlled UFLS occurs, however, the Island frequency remains above the 58 Hz criteria in all of the cases that were studied, from light load to peak load conditions.

If it were desired to avoid UFLS altogether for loss of the LIL monopole, then LIL power transfer must be limited as shown in Figure 5-2, depending on how many SOP synchronous condensers are in-service.

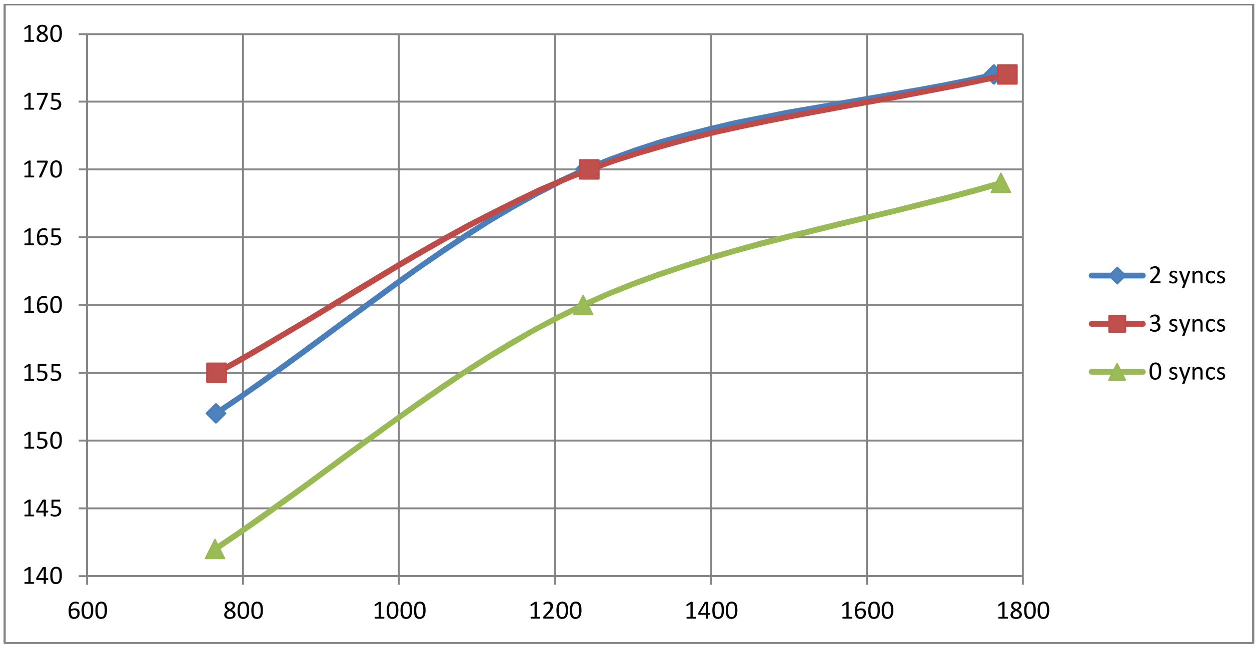

Figure 5-2. LIL Transfer Limit to avoid UFLS in the IIS

5.3.4 Loss of the Maritime Link

Loss of the ML bipole is the defining case for identifying the allowable import and export limits on the ML. The ML import and export limits as determined in the previous operational studies were re-visited with the LIL 225 MW monopole in-service.

Loss of the ML bipole was tested in order to determine the ML import and export limits for the following system conditions:

1. Base assumption – two SOP synchronous condensers in-service
2. Sensitivity – three SOP synchronous condensers in-service
3. Sensitivity – no SOP synchronous condensers in-service[12]

5.3.4.1 ML Import Limit

Loss of the ML while importing results in an underfrequency on the Island. The ML import levels were identified to ensure that loss of the ML bipole does not result in the Island frequency dropping below 58 Hz.

Figure 5-3, Figure 5-4 and Figure 5-5 show the ML import limits for two, three and zero SOP synchronous condensers in-service, respectively. In each of these figures:

- Blue line –ML import limits for the various study cases

[12] These operating limits will be followed when one SOP synchronous condenser is in service.

- Green line –the suggested ML import limit to be used, since it is at, or slightly below, the ML import limits that were defined for the study cases (blue line), giving a small amount of margin/conservatism regarding the maximum ML import limits

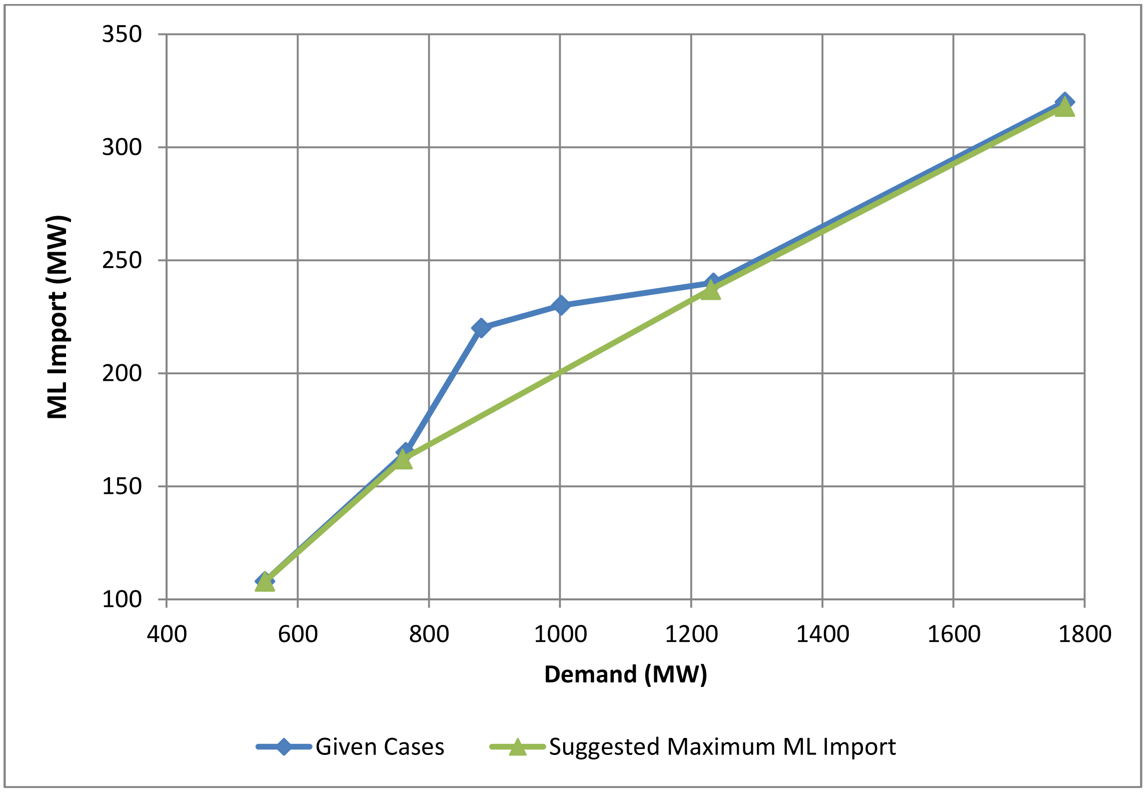

Figure 5-3. ML import limits, 2 SOP synchronous condensers in-service

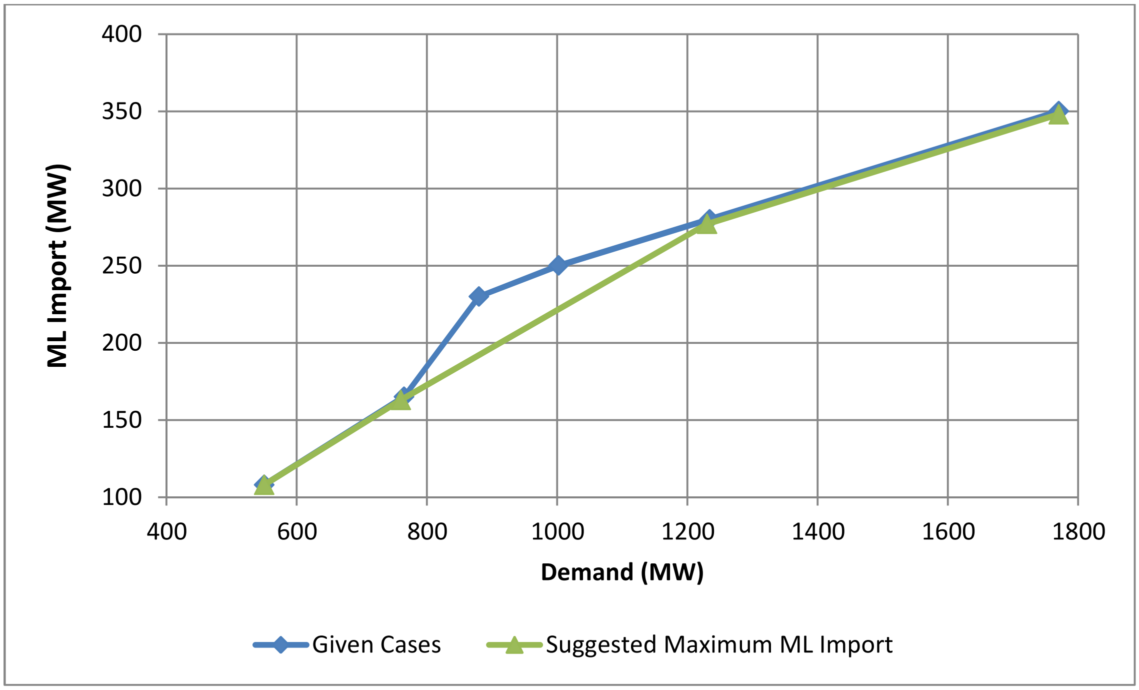

Figure 5-4. ML import limits, 3 SOP synchronous condensers in-service

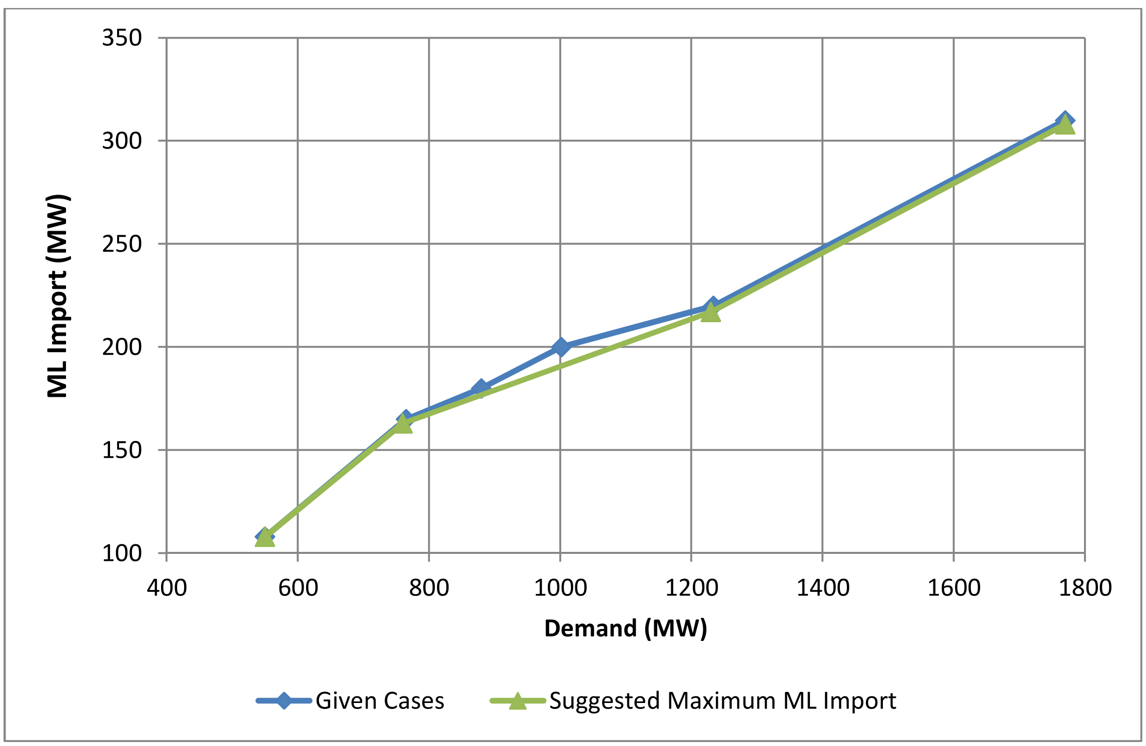

Figure 5-5. ML import limits, no synchronous condensers in-service

Figure 5-6 plots the suggested maximum ML import levels for all three scenarios on the same graph, with two (blue), three (green) and zero (red) SOP synchronous condensers in-service. It is recommended to limit the ML import level to remain at or below the values defined in this figure, depending on the Island demand level and how many SOP synchronous condensers are in-service.

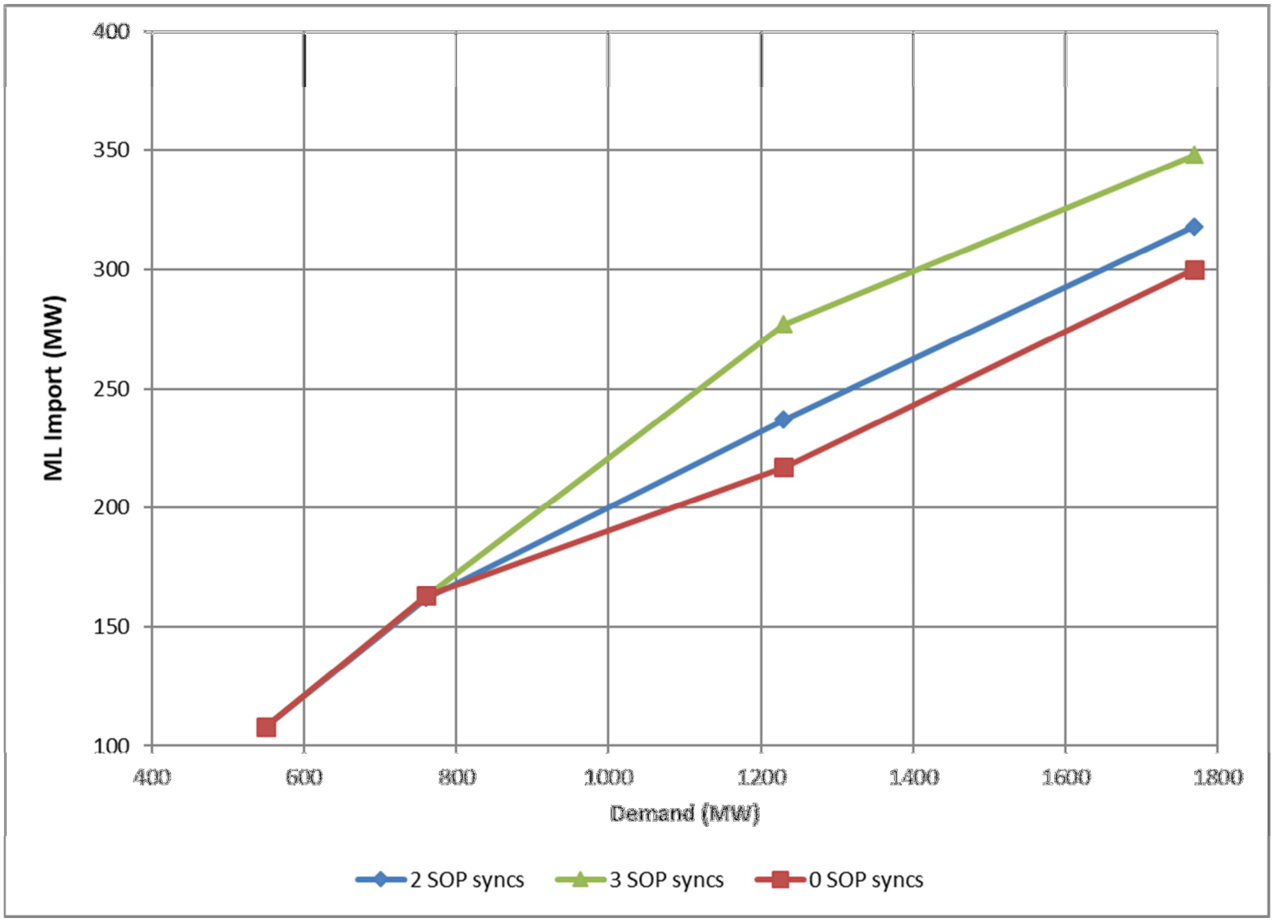

Figure 5-6. Maximum ML import levels – 2 (blue), 3 (green) and 0 (red) SOP synchronous condensers in-service

5.3.4.2 ML Export Limit

Loss of the ML while exporting results in an overfrequency on the Island. The ML export limits were identified to ensure that loss of the ML bipole does not result in the Island frequency rising above 62 Hz, and to ensure that the output of the Holyrood generators does not drop by more than 15 MW[13] from their pre-fault operating points in response to the overfrequency.

Previous operational studies found that the number of Holyrood units that are on-line has an impact on the maximum allowable ML export level, regardless of Island demand level. Even though the Holyrood units were monitored and the ML export level was limited to ensure the power output of the Holyrood

[13] As measured at 20 seconds of simulation time.

generators did not decrease more than 15 MW, the Holyrood generators still transiently contributed a significant amount to the overfrequency compared to other generators, which is why they directly impact the ML export limit. Whereas during underfrequency events (such as loss of the ML bipole while importing), the gate limits on the Holyrood governors are set such that the Holyrood units are very limited in increasing their power output, even transiently. Because of this, the significant impact of the Holyrood units was not observed for loss of the ML bipole while importing, and that is why the ML import limit was found to have a more linear relationship with the Island demand level compared to the ML export limit.

Additionally, it was found that when the Holyrood units are off-line or when one Holyrood unit is on-line as a synchronous condenser, the ML export limit is actually higher because in these cases the 62 Hz frequency limit is the defining criteria since the 15 MW Holyrood generator criteria is no longer applicable when they Holyrood units are not on-line and operating as generators.

Figure 5-7, Figure 5-8 and Figure 5-9 show the ML export limits (MW) in four separate lines – each line depicting either 1 Holyrood unit on-line as a synchronous condenser (purple), or 1 (green), 2 (blue) or 3 (red) Holyrood units on-line as generators.

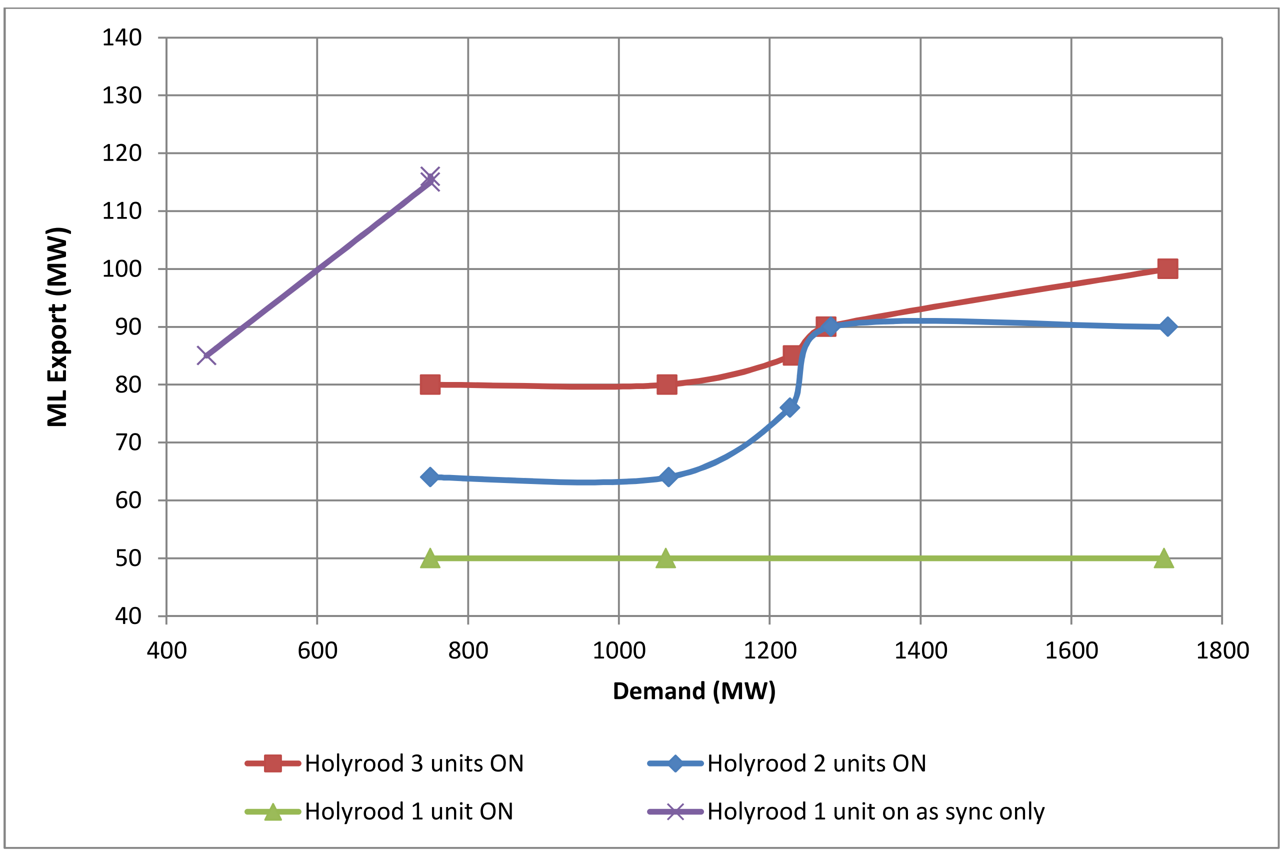

Figure 5-7. ML export limits, 2 SOP synchronous condensers in-service

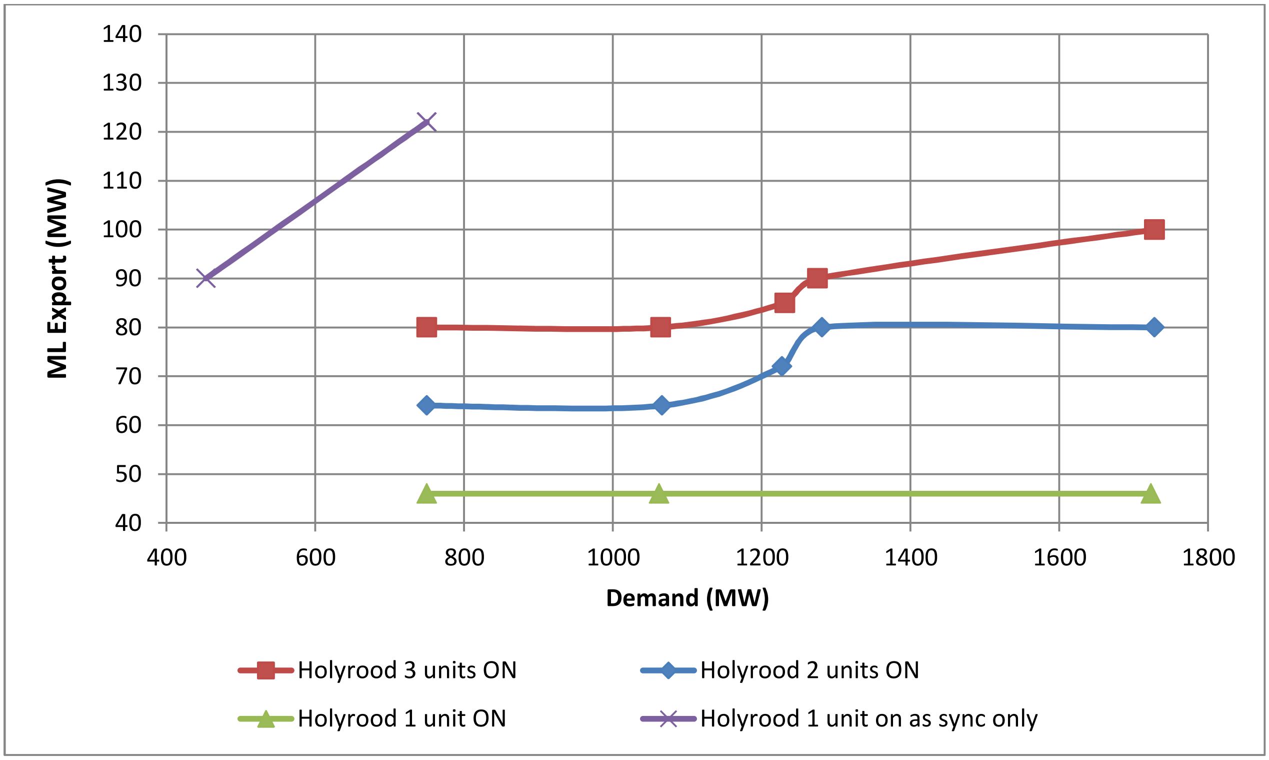

Figure 5-8. ML export limits, 3 SOP synchronous condensers in-service

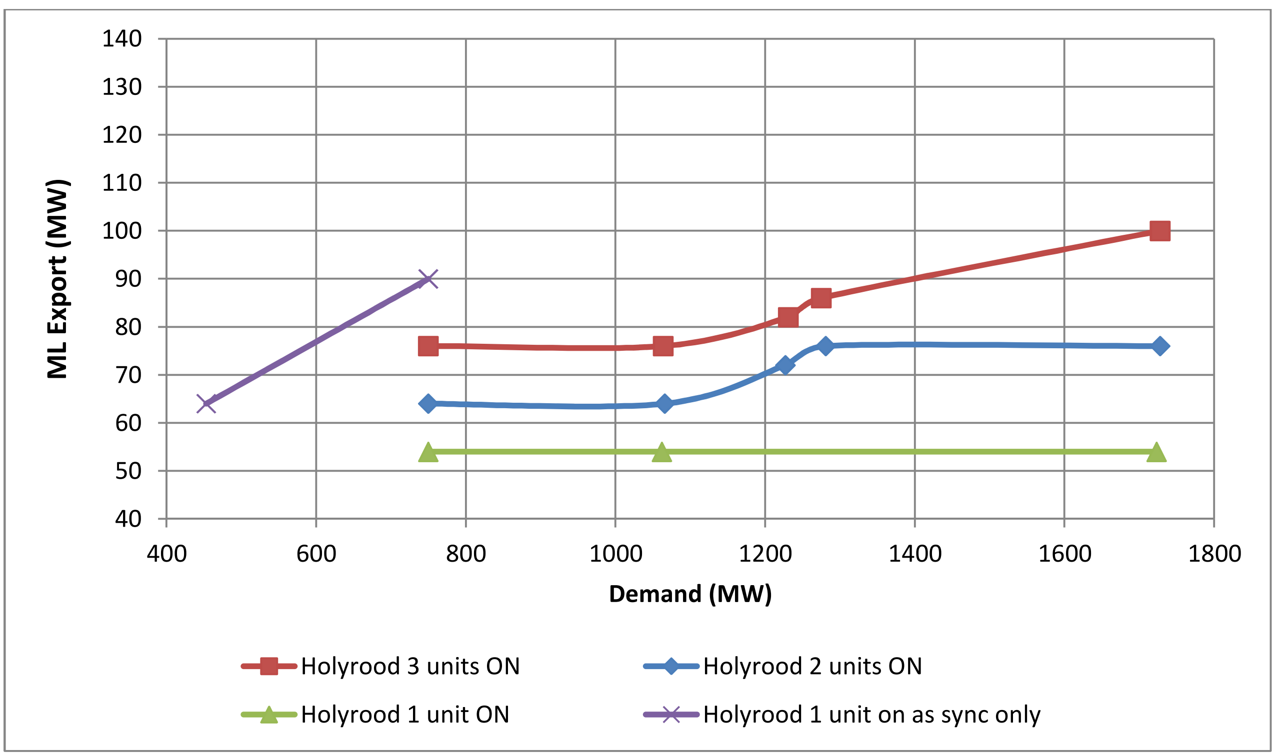

Figure 5-9. ML export limits, 0 SOP synchronous condensers in-service

Based on these findings, the following recommendations are made regarding the ML export limits:

1) **Island Demand > 750 MW**

If the Island demand is approximately 750 MW or greater and if 1 or more Holyrood units are on-line as a generator(s), the ML export limits do not vary greatly across the range of demand for the three lines representing 1, 2 or 3 Holyrood units on-line. 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 (for demand >= 750 MW), then the ML export limits could be defined as listed in Table 5-5, assuming the Island demand is greater than 750 MW. These limits ensure that the Holyrood generators will not drop by more than 15 MW from their pre-contingency output following the loss of the ML bipole while exporting.

Table 5-5. 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)		
	2 SOP Syncs in-service	3 SOP Syncs in-service	0 SOP Syncs in-service
3	80	80	75
2	65	65	65
1	45	45	45
1 as synchronous condenser	115	120	90

2) **Island Demand < 750 MW**

When Island demand is less than 750 MW, the Holyrood units are either off-line or one Holyrood unit is on-line as a synchronous condenser. In these cases, the ML export limit is higher because the 62 Hz frequency limit is the defining criteria (since the 15 MW Holyrood generator criteria is no longer applicable).

If the Island demand is less than 750 MW, it is recommended to limit ML export based on the straight line approximations in Figure 5-7 (2 SOP syncs in-service), Figure 5-8 (3 SOP syncs in-service) and Figure 5-9 (0 SOP syncs in-service), where one Holyrood unit is on-line as a synchronous condenser (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.

5.4 Labrador System – Dynamic Analysis

The LIL power transfers were limited as per Table 5-2, based on steady state voltage requirements at MFATS2. At these transfer levels, there were no dynamic issues identified in the Labrador system.

6. Prior Outage Study Results

It is important to study the system with prior outages of the major 230 kV bulk system elements in order to know what impact these outages will have on the system operating limits.

Table 6-1 lists the 230 kV prior outages and contingencies that were considered in the N-1-1 analysis. In order to limit the scope of work to a reasonable timeframe, only select contingencies with the potential for an appreciable system impact near to the prior outage were studied in conjunction with the prior outage.

Table 6-1. N-1-1 scenarios

Prior Outage	Contingency
TL268	TL265
	TL218
	TL266
	TL236
TL266	TL268
	TL218
	TL266
	TL236
TL218	TL268
	TL236
	TL266
TL236	TL218
	TL268
	TL266
TL217	TL201
	TL203
	TL202
	TL267
TL203	TL207
	TL237
	TL217
	TL202
	TL267
TL202	TL206
	TL267
	TL203
	TL217
TL267	TL202
	TL203
	TL217

Prior Outage	Contingency
TL231	TL204
	TL234
TL232	TL205
TL211	TL233
	TL269
	TL228
TL233	TL211
	TL269
	TL228
TL269	TL233
	TL211
	TL228
TL228	TL233
	TL269
	TL211
TL263	TL233
	TL211
TL234	TL231
	TL233
	TL211

The following sections define the N-1-1 scenarios that require system operating limits.

In all cases, the system operating limits determined in this study are compared with the system operational limits determined in the previous studies. Although the system operating limits were found to be quite similar for the most part between the current and previous studies, it was found that with the LIL in-service and operating at 225 MW that the study cases hit these system operating limits less frequently. The reason is that a large number of the system operating limits are there to prevent thermal overloads on the 230 kV corridor between Bay d'Espoir and Soldiers Pond. With the LIL injecting power directly at Soldiers Pond and to the BDE-SOP corridor is off-loaded.

Note that all prior outage system operating limits that are identified in this study are required to prevent steady state thermal overloads. With these system operating limits applied, the resulting dynamic simulations showed no issues with the LIL monopole in-service at 225 MW, with one minor exception discussed in Section 6.1.2.

6.1 Prior outage TL217 or TL201

The 230 kV corridor between Western Avalon and Soldiers Pond (TL201/TL217) is the most limiting from a thermal loading perspective and also from a stability perspective.

6.1.1 Steady State

If either line TL201 or line TL217 is out-of-service and the other line trips, there will be thermal overloads in the underlying 138 kV system if the pre-contingency power flow through that corridor is not limited.

Table 6-2 summarizes the maximum MVA flow that the corridor to avoid overloads to the underlying 138 kV system if the parallel line trips. In order to limit this flow, generation or LIL import on the Avalon peninsula must be increased.

Table 6-2. Prior outage TL217/TL201 and loss of the parallel line. Steady state limits.

Case	MON1	MON2	MON3	MON4	MON5	MON6
Flow Limit – Current Study (MVA)	97	108	141	140	104	102
Flow Limit - Previous Studies (MVA)	100	105	91	90	106	106

It is recommended to keep the flow between Western Avalon and Soldiers Pond limited to a maximum of 90 MVA if there is a prior outage of TL217 or TL201, since it is the most limiting, as per the system operating limits determined in the previous study.

6.1.2 Dynamic Stability

As determined in the previous operational studies, from a dynamics perspective, the peak load case with ML importing is the worst case scenario for the prior outage of TL201/TL217 and loss of the parallel line (3PF at Soldiers Pond). This case caused instability or violated transient voltage criteria (worst for peak load) in the ML-only study if the Island demand was greater than 1100 MW.

Therefore, case MON2 (peak load, ML importing, LIL in-service) was simulated in dynamics with the power flow from WAV to SOP limited to 90 MVA, with a prior outage of TL217. A 3PF at Soldiers Pond on line TL201 was simulated for the scenario with two SOP synchronous condensers in-service and for the scenario with no SOP synchronous condensers in-service. The 230 kV voltage at SOP is shown in Figure 6-1 for these two cases.

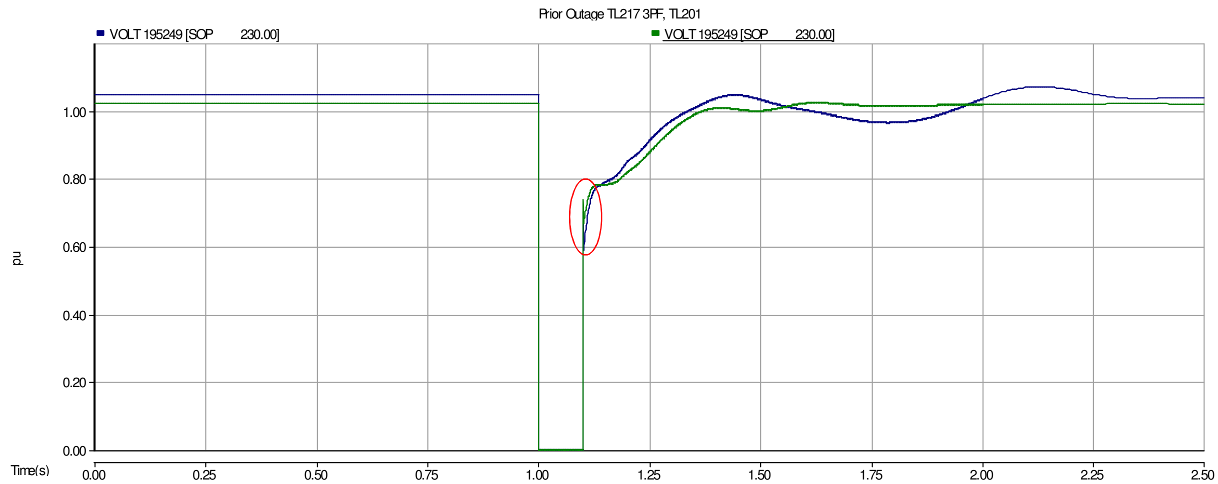

Figure 6-1. Prior outage TL217. 3PF at SOP on TL201. With 2 SOP syncs (green), and with 0 SOP syncs (blue).

The SOP voltage initially jumps to 0.7 pu after the fault is cleared in the case with two SOP synchronous condensers, and to 0.665 pu in the case with no SOP synchronous condensers in-service. The criteria states that the voltage after fault clearing should not be below 0.7 pu, and therefore the case without any SOP synchronous condensers in-service slightly violates this criteria. However, the system response is stable and well-damped in both cases (2 SOP syncs and 0 SOP syncs). The case with no SOP synchronous condensers is deemed to be a marginal violation that is acceptable for short term operation.

6.2 Prior outage TL203 or TL207/TL237

The 230 kV corridor between Sunnyside and Western Avalon (TL203/TL207/TL237) requires a system operating limit to restrict flow through this corridor if one of these lines is out-of-service.

If either line TL203 or one of lines TL207/TL237 is out-of-service and the other line trips, there can be thermal overloads on 230 kV line TL267 between Bay d'Espoir and Western Avalon if the pre-contingency power flow through that corridor is not limited.

Table 6-3 summarizes the maximum MVA flow that the corridor can handle without causing overloads to line TL267 if the parallel line trips. In order to limit this flow, generation on the Avalon peninsula must be increased.

Table 6-3. Prior outage TL207/TL237 or TL203 and loss of the parallel line. Steady state limits.

Case	MON1	MON2	MON3	MON4	MON5	MON6
Flow Limit – Current Study (MVA)	200	238	190	199	176	183
Flow Limit - Previous Studies (MVA)	199	247	212	226	183	186

It is recommended to limit the flow between Sunnyside and Western Avalon (as measured at Sunnyside) to a maximum of 175 MVA in spring/summer/fall and 200 MVA in winter if there is a prior outage of TL203, TL207 or TL237.

6.3 Prior outage TL202 or TL206 or TL267

The 230 kV corridor between Bay d'Espoir and Sunnyside/ Western Avalon (TL202/TL206/TL267) requires a system operating limit to restrict flow through this corridor if one of these lines is out-of-service.

The worst combination of outages in this corridor is TL267 and one of either TL202 or TL206. In this scenario, there can be thermal overloads on 230 kV line TL202 or TL206 (whichever is still in-service) between Bay d'Espoir and Sunnyside if the pre-contingency power flow through that corridor is not limited.

Table 6-4 summarizes the maximum MVA flow that the corridor can handle without causing overloads to line TL202 or TL206 (whichever remains in-service after the N-1-1 scenario) if the parallel lines trip. In order to limit this flow, generation on the Avalon peninsula must be increased.

Table 6-4. Prior outage TL202/TL206 or TL267 and loss of parallel line. Steady state limits.

Case	MON1	MON2	MON3	MON4	MON5	MON6
Flow Limit – Current Study (MVA)	376	397	310	312	215	213
Flow Limit - Previous Studies (MVA)	378	397	317	322	220	233

It is recommended to limit the flow between Bay d'Espoir and Sunnyside/Western Avalon (as measured at Bay d'Espoir) to a maximum of 375 MVA in winter, 310 MVA in spring/fall and 210 MVA in summer if there is a prior outage of TL202, TL206 or TL267.

6.4 Prior outage TL232 or TL205

There are two 230 kV lines connecting Buchans to Stony Brook (TL232, TL205). If one of these lines is out-of-service and the other line trips, it is possible to overload 138 kV line TL224 between Howley and Indian River, if the ML is importing power to the Island.

This overload can be avoided if the ML import levels and the power output are the Hinds Lake generator are limited as per Table 6-5.

Table 6-5. Prior outage TL232 or TL205 and loss of the parallel line. Steady state limits

Case	MON1	MON2	MON3	MON4	MON5	MON6
Mitigation – Current Study	-	Reduce ML import from 320 MW to 240 MW, and limit HLK gen to 40 MW	-	Reduce ML import from 240 MW to 200 MW, limit HLK gen to 40 MW	-	Reduce ML import from 165 MW to 120 MW

Case	MON1	MON2	MON3	MON4	MON5	MON6
Mitigation – Previous Study	-	Reduce ML import from 300 MW to 278 MW	-	Reduce ML import from 230 MW to 188 MW	-	Reduce ML import from 170 MW to 165 MW

It is recommended to limit ML import (as measured at BBK) to a maximum of 240 MW in winter, 200 MW in spring/fall, and 120 MW in summer if there is a prior outage of TL232 or TL205. If on-line, the output of Hinds Lake generator should also be limited to 40 MW.

6.5 Prior outage TL211/TL228

If there is a prior outage of 230 kV line TL211 or line TL228 and the other line trips, it is possible to overload 138 kV lines TL224 and TL223 between Howley, Indian River and Springdale. This was observed in case MON3 only, and it can be avoided by limiting Hinds Lake generation to 40 MW as shown in Table 6-6.

Table 6-6. Prior outage TL211 or TL228 and loss of parallel line. Steady state limits

Case	MON1	MON2	MON3	MON4	MON5	MON6
Mitigation – Current Study	-	-	Limit Hinds Lake generation to 40 MW	-	-	-
Mitigation – Previous Study	-	-	Limit Hinds Lake generation to 40 MW	-	-	-

6.6 Prior outage TL211/TL233/TL269/TL234/TL263

Lines TL211, TL233 and TL269 are the 230 kV outlet lines at Bottom Brook, which is the point of interconnection between the Island and the ML. An outage of an outlet line at Bottom Brook results in a weaker connection of the ML to the Island system.

Similarly, lines TL234 and TL263 are extensions of line TL269, which connect Bottom Brook to Bay d'Espoir. An outage of one of these lines also weakens the connection of the ML, and it forces the generation at Upper Salmon and/or Granite Canal to flow through Bottom Brook, increasing power flow in the area near the ML.

6.6.1 Steady State

If there is a prior outage of line TL233 or TL234 and the other lines trips, it is possible to overload line TL211 if the ML is importing power to the Island. Table 6-7 summarizes the ML import limits to avoid overloading line TL211.

Table 6-7. Prior outage of TL233 or TL234 and loss of parallel line. Steady state limits

Case	MON1	MON2	MON3	MON4	MON5	MON6
Mitigation – Current Study	-	Reduce ML import from 320 MW to 270 MW	-	Reduce ML import from 240 MW to 230 MW	-	Reduce ML import from 165 MW to 120 MW
Mitigation – Previous Study	-	Reduce ML import from 300 MW to 270 MW	-	Reduce ML import from 230 MW to 220 MW	-	Reduce ML import from 170 MW to 100 MW

It is recommended to limit ML import (as measured at BBK) to a maximum of 270 MW in winter, 230 MW in spring/fall, and 120 MW in summer if there is a prior outage of TL233 or TL234.

If there is a prior outage of line TL234 or TL211 and the other lines trips, it is possible to overload line TL269 during summer conditions if the ML is importing power to the Island. Table 6-8 summarizes the ML import limits to avoid overloading line TL269.

Table 6-8. Prior outage of TL211 and loss of TL234. Steady state limits

Case	MON1	MON2	MON3	MON4	MON5	MON6
Mitigation – Current Study	-	-	-	-	-	Reduce ML import from 165 MW to 145 MW
Mitigation – Previous Study	-	-	-	-	-	-

It is recommended to limit ML import (as measured at BBK) to a maximum of 145 MW in summer if there is a prior outage of TL211. As indicated in Table 6-7, a prior outage of TL234 already requires the ML import to be limited to 120 MW, which is more restrictive and will mitigate this overload as well.

6.6.2 Dynamic Stability

Prior outages of 230 kV outlet lines at Bottom Brook (TL211, TL233 and TL269/TL263/TL234) significantly weaken the connection of the ML to the Island system. No system stability issues were observed in this study for these prior outages, however, results suggested numerical convergence issues. It is therefore recommended that further analysis be performed in PSCAD to confirm results.

7. ML Frequency Controller Limits

7.1 Providing Frequency Support to Nova Scotia

In order to determine how much power the Island system could suddenly provide to Nova Scotia without experiencing underfrequency load shedding (UFLS), simulations were performed to step-change the power flow on the ML to mimic Nova Scotia suddenly taking "X" amount of power from the Island.

Table 7-1 summarizes the results of these simulations.

Table 7-1. Amount of power the Island can give to NS without UFLS

Case	Maximum Power to NS without UFLS (MW)	Minimum Frequency (Hz)
MON1	80	58.88
MON2	90	58.80
MON3	60	58.91
MON4	80	58.88
MON5	60	58.90
MON6	60	58.96

Under worst case system conditions, the Island can provide 60 MW to Nova Scotia without experiencing UFLS. This is the same amount of power that was determined in the previous operational studies without the LIL monopole in-service.

7.2 Receiving Frequency Support from Nova Scotia

Next, loss of the largest generator on the Island was tested with and without the ML frequency controller in-service. Previous operational studies determined the need to receive 100 MW from Nova Scotia under worst case system conditions in order to avoid UFLS for loss of the largest generator.

Table 7-2 summarizes these results.

Table 7-2. Impact of ML frequency controller on loss of largest generator

Case	Amount of UFLS (MW)	Min Frequency (HZ)
MON1 with freq. cont.	0	59.24
MON1 without freq. cont.	81.53	58.55
MON2 with freq. cont.	0	59.12
MON2 without freq. cont.	81.38	58.53
MON3 with freq. cont.	0	58.90
MON3 without freq. cont.	87.62	58.35

Case	Amount of UFLS (MW)	Min Frequency (HZ)
MON4 with freq. cont.	0	59.72
MON4 without freq. cont.	26.03	58.80
MON5 with freq. cont.	0	59.75
MON5 without freq. cont.	13.98	58.72
MON6 with freq. cont.	0	59.75
MON6 without freq. cont.	14.05	58.79

With the ML frequency controller in-service, UFLS is avoided for all cases if the MW limits on the frequency controller are set to +/- 100 MW. If the MW limits are reduced to +/- 90 MW, then loss of BDE Unit 7 results in UFLS in case MON3.

Therefore, it is concluded that in order to prevent UFLS for the worst case scenario involving loss of the largest generator, 100 MW of frequency support would be required from Nova Scotia. This is the same amount of power that was determined in the previous operational studies without the LIL monopole in-service.

8. Conclusions

The following system operating limits/guidelines are recommended for the period in time when the ML is in-service, and the LIL is in-service as a monopole operating at a maximum of 225 MW.

8.1 Interconnected Island System

8.1.1 System Intact Conditions

System operating limits for system intact conditions in the IIS are summarized in Table 8-1.

Table 8-1. System Intact Operating Limits/Guidelines - IIS

<table>
<tr><th>Contingency</th><th>Issue</th><th>Mitigation</th></tr>
<tr><td>TL217</td><td>Thermal overloading of TL201[14]</td><td>Limit WAV-SOP flow to (west to east, as measured at Western Avalon):
320 MVA (winter)
260 MVA (spring/fall)
175 MVA (summer)</td></tr>
<tr><td>Loss of LIL Monopole</td><td>Trigger 58 Hz block of loadshed if ML or its frequency controller are out-of-servce</td><td>If ML or its frequency controller are out-of-service, limit LIL power transfer to 200 MW.</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 8-1.</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[15] 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 rowspan="2">Number of Holyrood Units on – line</th><th colspan="3">ML Export Limit (MW)</th></tr>
<tr><th>2 SOP Syncs in-service</th><th>3 SOP Syncs in-service</th><th>0 SOP Syncs in-service</th></tr>
<tr><td>3</td><td>80</td><td>80</td><td>75</td></tr>
<tr><td>2</td><td>65</td><td>65</td><td>65</td></tr>
<tr><td>1</td><td>45</td><td>45</td><td>45</td></tr>
<tr><td>1 as sync. condenser</td><td>115</td><td>120</td><td>90</td></tr>
</table>
If Island demand < 750 MW, limit ML export (as measured at BBK) as defined in Figure 8-2.</td></tr>
</table>

[14] This overload was not observed in the cases studied, however, if the LIL is out-of-service or operating at lower power, it may be possible that this overload occurs, therefore the system operating limit still remains valid.
[15] As measured at simulation time of 20 seconds during the study.

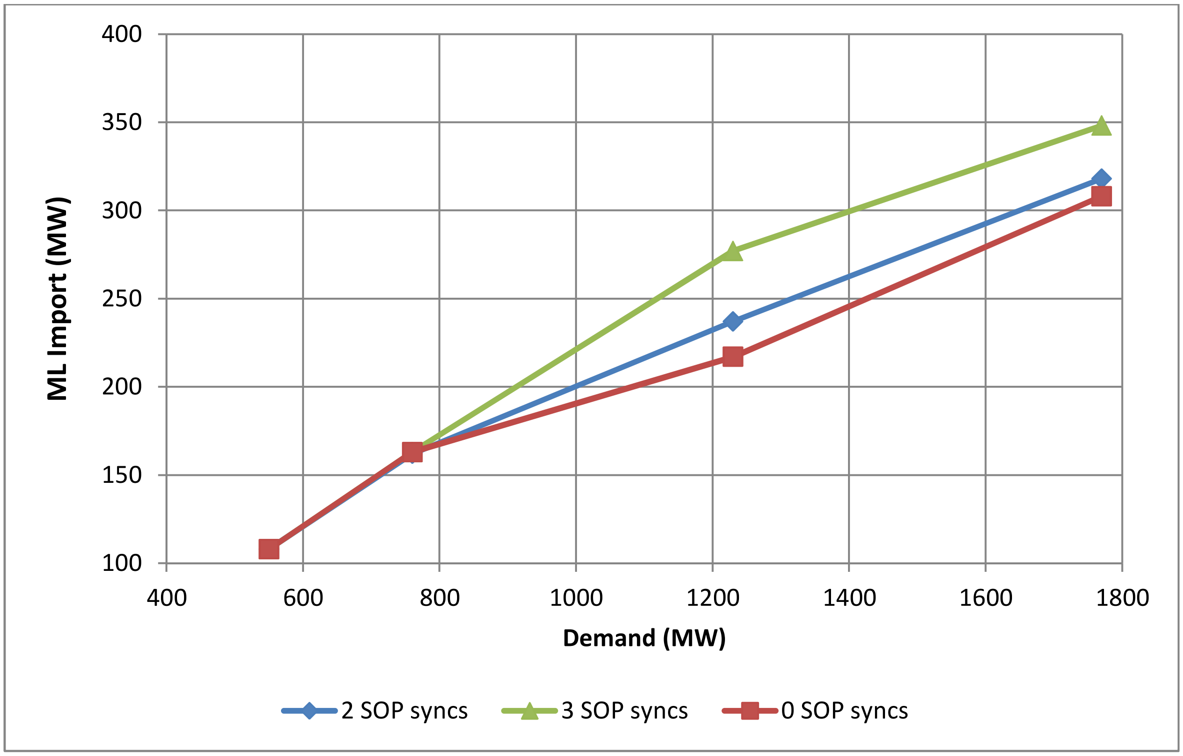

Figure 8-1. Maximum ML import levels – 2 (blue), 3 (green) and 0 (red) SOP synchronous

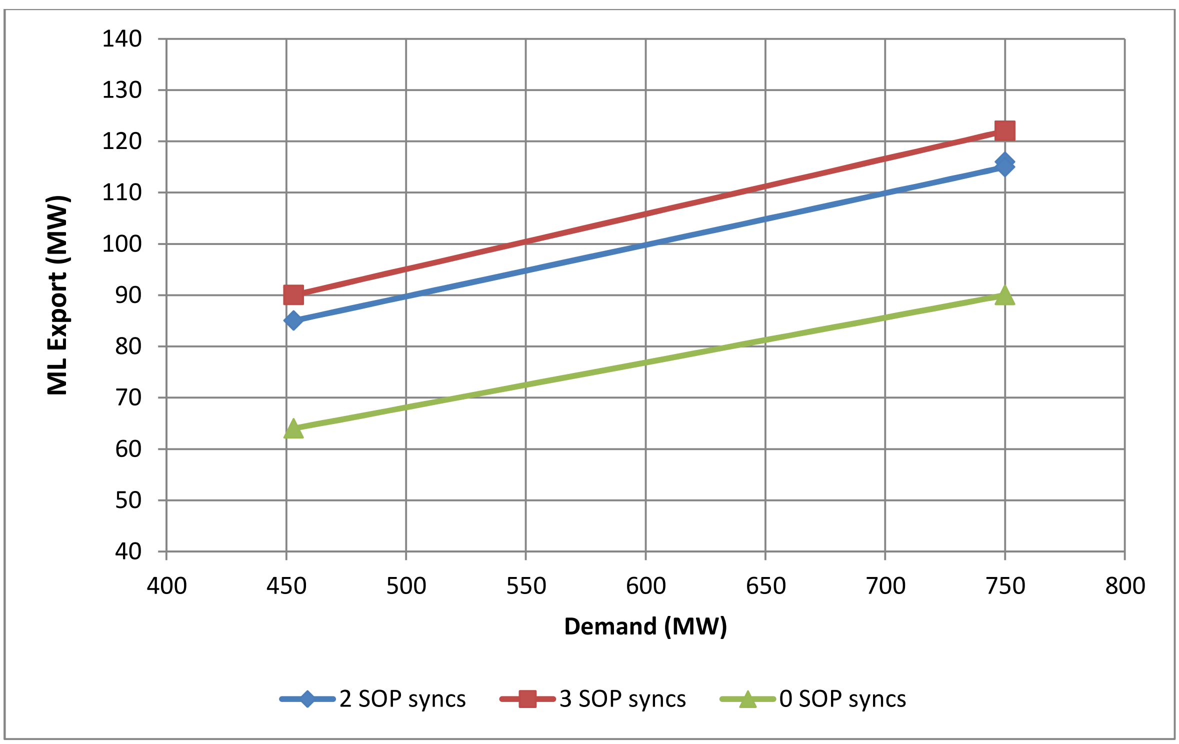

Figure 8-2. Island demand < 750 MW. Maximum ML export levels – 2 (blue), 3 (red) and 0 (green) SOP synchronous

8.1.2 Prior Outage Conditions

System operating limits for prior outage conditions in the IIS are summarized in Table 8-2.

Table 8-2. Prior Outage Operating Limits/Guidelines - IIS

Prior Outage	Next contingency	Issue	Mitigation
TL201/ TL217	TL217/ TL201	Thermal overloading of WAV-SOP underlying 138 kV system	Limit WAV-SOP flow to 90 MVA (as measured at the sending end) *Please note that if the LIL and SOP synchronous condensers are out-of-service, the outage of TL217 or TL201 should only be planned during times when the Island system load is 1100 MW or less in order to avoid potential for system instability
TL203/ TL207 or TL237	TL207 or TL237/ TL203	Thermal overloading of 230 kV line TL267	Limit SSD-WAV flow (as measured at the sending end): 200 MVA (winter) 175 MVA (summer/spring/fall)
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 the sending end) to: 375 MVA (winter) 310 MVA (spring/fall) 210 MVA (summer)
TL232/ TL205	TL205/ TL232	Thermal overloading of 138 kV line TL224	Limit ML import to (as measured at BBK): 240 MW (winter) 200 MW (spring/fall) 120 MW (summer) Limit output of HLK generator to 40 MW.
TL211/ TL228	TL228/ TL211	Thermal overload of 138 kV lines TL223 and TL224	The overload was only observed for Case MON3 (intermediate loading, with ML exporting). Limiting Hinds Lake generation to 40 MW mitigated the overload.
TL233/ TL234	TL234/ TL233	Thermal overload of 230 kV line TL211	Limit ML import to (as measured at BBK): 270 MW (winter) 230 MW (spring/fall) 120 MW (summer)
TL211	TL234	Thermal overload of 230 kV line TL269	Limit ML import to (as measured at BBK): 145 MW (summer)

8.2 Labrador System

8.2.1 System Intact Conditions

System operating limits for system intact conditions in Labrador are summarized in Table 8-3.

Table 8-3. Labrador system operating limits

<table>
<tr><th>Contingency</th><th>Issue</th><th>Mitigation</th></tr>
<tr><td>Loss of L3101 or L3102</td><td>Potential for voltage collapse</td><td>Limit LIL transfer as per table:
<table>
<tr><td></td><td colspan="4">CHF Voltage (pu)</td></tr>
<tr><td rowspan="2">HVY Load (MW)</td><td>0.975</td><td>0.985</td><td>0.995</td><td>1.005</td></tr>
<tr><td colspan="4">LIL Transfer (MW)</td></tr>
<tr><td>35</td><td>145</td><td>160</td><td>175</td><td>185</td></tr>
<tr><td>45</td><td>135</td><td>150</td><td>160</td><td>175</td></tr>
<tr><td>55</td><td>125</td><td>140</td><td>150</td><td>165</td></tr>
<tr><td>65</td><td>115</td><td>128</td><td>140</td><td>155</td></tr>
<tr><td>75</td><td>100</td><td>115</td><td>125</td><td>135</td></tr>
<tr><td>80</td><td>95</td><td>108</td><td>120</td><td>130</td></tr>
<tr><td>90</td><td>80</td><td>93</td><td>105</td><td>118</td></tr>
<tr><td>100</td><td>65</td><td>75</td><td>86</td><td>103</td></tr>
</table></td></tr>
<tr><td>Loss of MFA filter</td><td>Voltage at MFA as low as 0.89 pu depending on system conditions</td><td>If LIL transfer limits are applied as per table above, then no issues for loss of MFA filter.
However, it should be noted that for phased monopolar approach, if an MFA filter trips, the LIL will also trip automatically since there are no redundant filters.</td></tr>
<tr><td>Loss of MFA reactor</td><td>Voltage at MFA as high as 1.166 pu depending on system conditions</td><td>Tripping an MFA filter helps to mitigate the issue, however, not possible to trip one of the MFA filters. Loss of a filter will automatically trip the LIL in phased monopolar approach.
Therefore, if the MFA reactor trips, the LIL must also be tripped.</td></tr>
</table>

8.2.2 Prior Outage Conditions

System operating limits for under prior outage conditions in Labrador are summarized Table 8-4.

Table 8-4. Prior outages requiring system operating limits in the Labrador system

Prior Outage	Next contingency	Issue	Mitigation
L3101 / L3012	L3102 / L3011	LIL already out of service as per Table 8-3 for loss of L3101 or L3102	n/a