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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 ONLY

Technical Note: TN1205.50.05
Date of issue: November 10, 2017

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Revisions

Project Name:	RFI Studies
Document Title:	Operational Studies: Maritime Link ONLY
Document Type:	Technical Note
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Rev. No.	Status	Prepared By	Checked By	Date	Comments
00	DFC	H. Suriyaarachchi, R. Ostash	H. Suriyaarachchi	June 22, 2017	Issued for review by Hydro
01	IFA	H. Suriyaarachchi, R. Ostash		August 4, 2017	Issued for approval by Hydro after incorporating comments received from Hydro
02	IFA	H. Suriyaarachchi, R. Ostash		Aug 22, 2017	Issued for approval by Hydro after incorporating comments received from Hydro on Aug. 16, 2017
03	ABC	H. Suriyaarachchi, R. Ostash		Aug 30, 2017	Final approval by Hydro
04	ABC	R. Ostash		Sept. 8, 2017	Fixed text regarding ML frequency controller from 50 MW to 100 MW needed to prevent UFLS for loss of largest generator
05	ABC	R.Ostash		Nov. 10, 2017	Modified ML import/export plots to match Island demand

Legend of Document Status:

Approved by Client	ABC
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Approval not Required	ANR

Table of Contents

1. Summary

Operational studies were performed so that the system operating limits of the Newfoundland and Labrador Hydro (Hydro) power system can be determined for the period in time where the Maritime Link (ML) is in-service, but prior to the Labrador Island Link (LIL) coming in to service. The Soldiers Pond synchronous condensers are assumed not to be in service for the purposes of this analysis. Synchronous condenser impacts will be considered as a separate operational study to be completed immediately following the assessment of Maritime Link impacts.

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 Island system's steady state and dynamic response 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 avoid these violations.

1.1 System Intact Conditions

During system intact conditions, there are two main issues in the system that require system operating 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.

In order to avoid thermal overloads in this corridor, it must be ensured that 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) is not 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

2. **ML Import/Export Limits**

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 while importing must not cause the frequency to drop below 58 Hz (controlled UFLS is allowed). The blue and red lines in Figure 1-1 show the ML import limits plotted against the demand on the Island. These points were determined from a variety of operating conditions ranging from peak load to light load. In order 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.

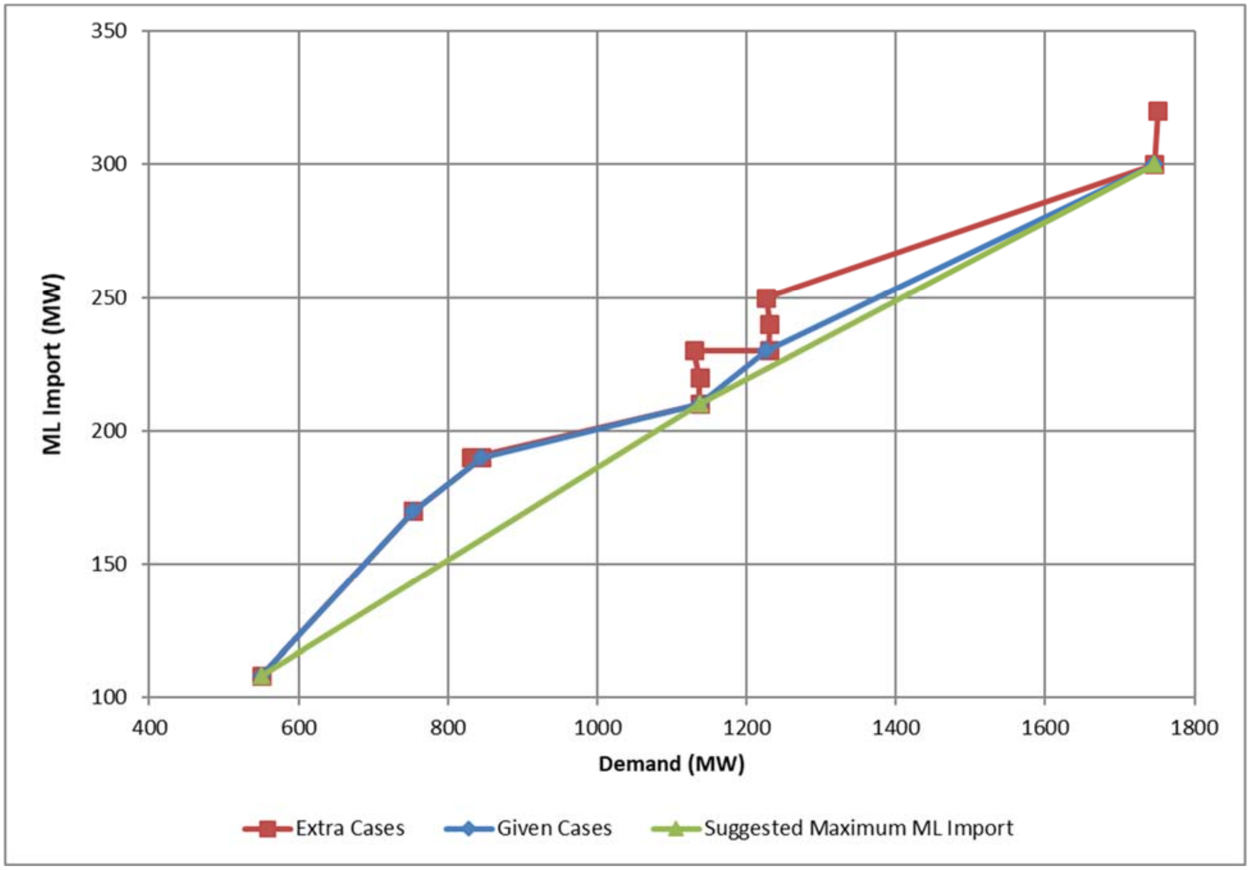

Figure 1-1. Maximum ML import level versus Island demand

b. ML Export Limit

Loss of the ML bipole while exporting results in an overfrequency on the Island. Prior to the ML, the only overfrequency on the Island would be due to loss of load, however now that the loss of the ML bipole can occur while exporting, the overfrequency can become significant. The study found that the Holyrood thermal generators were having a large response to this event, and were significantly reducing their output to compensate for the overfrequency. The large reduction in output was deemed to be unacceptable for the operation of these thermal units, and it was decided that the ML export level should be limited so as to ensure that loss of the ML bipole does not result in the Holyrood units settling to more than 15 MW[1] below their pre-contingency operating point.

Additionally, the frequency criterion states that loss of the ML must not cause the frequency to rise above 62 Hz. The 15 MW Holyrood generator criterion was found to be most limiting for cases when one or more Holyrood units were on-line as generators. If a Holyrood unit was on-line as a synchronous condenser and not a generator, then the 15 MW criteria no longer applied and the 62 Hz overfrequency became the limiting factor in determining the ML export limit.

Figure 1-2 shows the maximum ML export limits plotted against Island demand. 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.

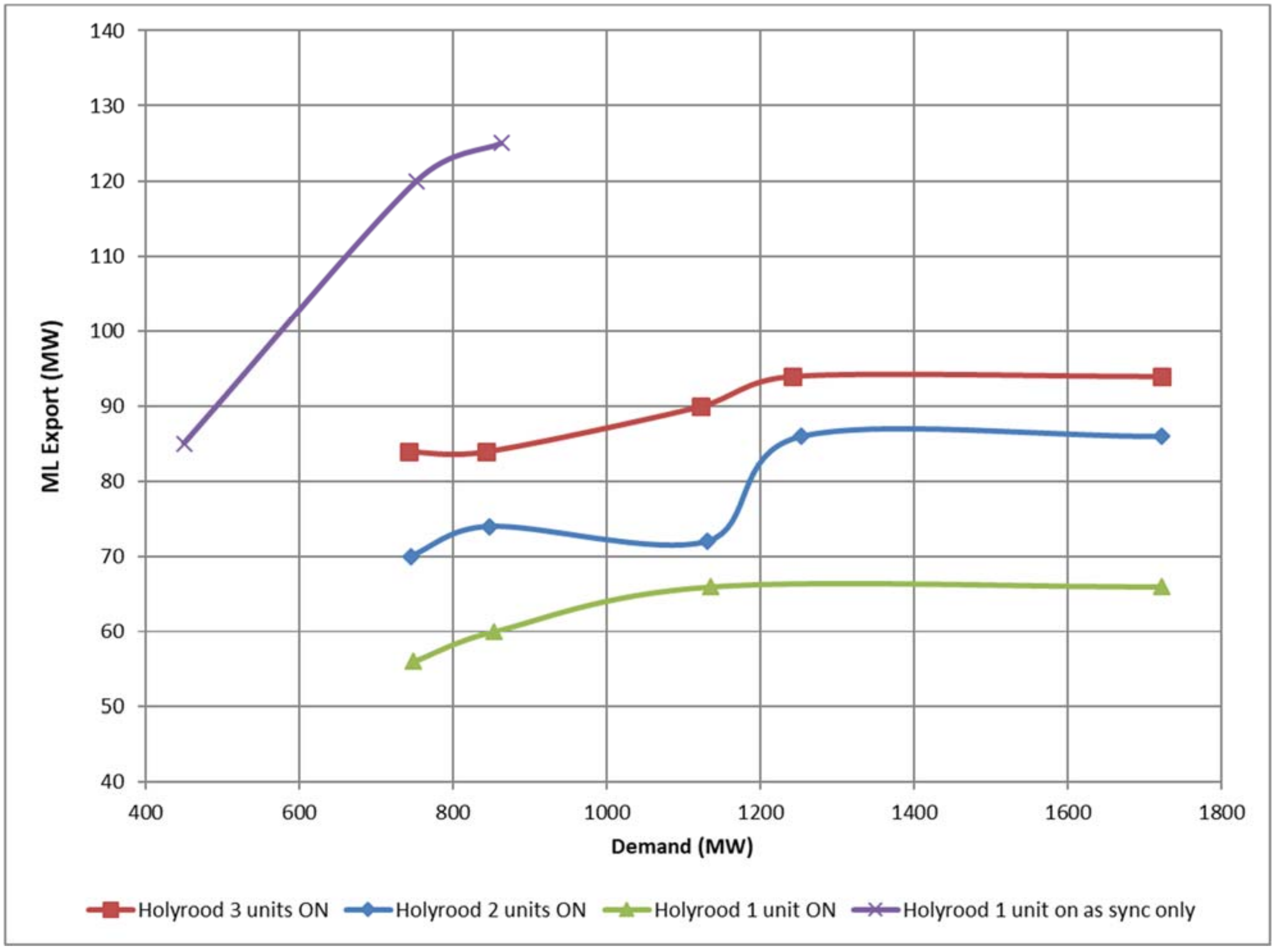

Figure 1-2. Maximum ML export level versus Island demand

The following recommendations are made regarding the ML export limits:

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

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 1-2 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 as listed in Table 1-2, 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 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)
3	85
2	70
1	55
1 as synchronous condenser	120

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 1-2, where one Holyrood unit is on-line as a synchronous condenser[2] (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.

1.2 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 1-3.

Table 1-3. Prior outages requiring system operating limits

Prior Outage	Next contingency	Issue	Mitigation
TL201/ TL217	TL217/ TL201	Thermal overloading of WAV-SOP underlying 138 kV system; System instability – peak load conditions	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 1100 MW or less If the load is higher than 1100 MW, even if the flow in the corridor is limited to 90 MVA, this scenario

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[2] 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.

Prior Outage	Next contingency	Issue	Mitigation
			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 to (as measured at BBK): 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/ 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)

Prior outages of 230 kV outlet lines at Bottom Brook were also tested (TL211, TL233 and TL269/TL263/TL234) because they significantly weaken the connection of the ML to the Island system. No issues were observed in this study[3] for these prior outages, although it must be noted that the ML import and export levels are being limited during this period in time (i.e. prior to the LIL being in-service) to below the ML's ultimate levels of 300 MW import and 500 MW export. It is anticipated that prior outages of outlet lines at Bottom Brook may require run-backs or operating guidelines once the ML is operating at its full import/export levels.

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[3] It should be noted that the PSSE ML model (ABB open source model) had to be put into the "Extreme Weak" mode of operation in order to avoid numerical convergence issues during prior outages of Bottom Brook outlet lines.

1.3 ML Frequency Controller

It is planned that the ML frequency controller will be placed in service when the link goes into operation. For the purposes of this investigation, operation both with and without the frequency controller was examined.

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 in time where the Maritime Link (ML) is in-service, but prior to the installation of the Labrador Island Link (LIL).

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 Island system's steady state and dynamic response met the system performance criteria as documented in Hydro's Transmission Planning Criteria. Where criteria violations were discovered, system operating limits were determined to mitigate these violations.

2.1 Scope of Study

The main focus of the study is on the bulk power transmission system on Hydro system. The bulk 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
- 230 kV, 315 kV and 735 kV systems in Labrador

Please note that since this study was performed on the system prior to the LIL being in-service, the LIL and the Labrador system were not monitored/analyzed in this study.

Additionally, 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.

3. Study Models

The assumptions for the base case setup are as follows:

- No LIL in-service
- No MFA generators in-service
- No SOP synchronous condensers in-service
- No frequency controller on the ML (for the majority of the study. A sensitivity analysis is performed at the end of the study to enable the frequency controller and observe its impact.)

3.1 PSSE Base Cases

Hydro created a set of PSSE version 32 base cases to represent the Island system 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

Case	Loading	ML power direction	ML transfer[1] (MW)
ML1	Peak (Winter)	Export	43
ML2		Import	-245
ML3	Shoulder (Spring/fall)	Export	306
ML4		Import	-252
ML5	Light (Summer)	Export	102
ML6		Import	-216
ML7	Medium Light	Export	147
ML9		Import	-188
ML8	Low Intermediate	Export	173
ML10		Import	-207
ML11	Extreme Light	Export	120
ML12		Export	145
ML13		Import	-100

1 ML transfer is the maximum transfer possible while maintaining the reserve in Newfoundland.

Please note that the original set of cases that was provided included cases ML1 through ML6. These cases were used to perform the full steady state and dynamic analysis.

Cases ML7 through ML13 were provided later on in the studies for the purpose of defining the ML import/export limits during the loss of the ML bipole, and therefore these cases were not used to study the full steady state and dynamic analyses, but rather focused solely on the loss of the ML bipole.

3.2 Dynamic Models

3.2.1 Island System

The 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.

3.2.2 Maritime Link

The ML is represented in dynamics using ABB's open source VSC model. This model includes a frequency controller. This model also includes a damping controller, but its application was beyond the scope of this investigation.

4. Study Methodology

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

First, the steady state analysis was performed to determine the system operating limits as needed to meet the steady state performance criteria. The base cases were modified accordingly.

Then, the dynamic analysis took these modified base cases and determined the system operating limits as needed to meet the dynamic criteria. The base cases were again modified accordingly.

Finally, the steady state analysis was repeated on the base cases as modified by the dynamic analysis to ensure 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. The bus voltages and the loading of the transmission lines in the bulk system were monitored. If a violation of criteria was found, the generation on the system was re-dispatched and/or the ML import/export level was adjusted, as appropriate, to mitigate the violation.

4.1.1 Contingencies

All single contingencies of the Island's bulk system 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 have been used in the steady state:

- Thermal Limits[4]:
    - 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

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

In cases where a thermal rating was not available, the available lower rating was used. For example, if Rate B was not available in the PSSE case, Rate A was used instead.

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 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)

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
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)	
				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	5-1-45-3	

Line Name	Volt. (kV)	Station 1	Station 2	Faulted Bus	SUCCESSFUL SPAR Clearing Time (cycles)*	UN-SUCCESSFUL SPAR Clearing Time (cycles)*	Notes
					(RESTORE)	(TRIP)	
TL209	230	Bottom Brook	Stephen-ville	195205	NA		
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)	
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	Deer Lake	195208	5-1-29-16	5-1-29-3	Cross-trip of TL247 between

Line Name	Volt. (kV)	Station 1	Station 2	Faulted Bus	SUCCESSFUL SPAR Clearing Time (cycles)*	UN-SUCCESSFUL SPAR Clearing Time (cycles)*	Notes
		Drive			(RESTORE)	(TRIP)	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
- Underfrequency load shedding shall be permitted, but controlled, for loss of generation or loss of the ML pole/bipole (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 with only the ML in service.

5. System Intact Study Results

5.1 Steady State Analysis

Table 5-1 summarizes the steady state violations that were observed. The only violations were transmission line thermal overloads in the 230 kV transmission corridor between Bay d'Espoir and Soldiers Pond. As such violations are not permitted, generation redispatch would be required in each case in order to prevent the overloads from occurring. The steady state voltages were within criteria.

Table 5-1. Thermal overloads

Case	Contingency	Violation
ML2	TL202 Trip	Overload TL206
	TL206 Trip	Overload TL202
	TL267 Trip	Overload TL202 & TL206
	TL207 Trip	Overload TL203
	TL217 Trip	Overload T 201
ML4	TL202 Trip	Overload TL206
	TL206 Trip	Overload TL202
	TL267 Trip	Overload TL202 & TL206
	TL207 Trip	Overload TL203
	TL217 Trip	Overload TL201
ML5	TL202 Trip	Overload TL206
	TL206 Trip	Overload TL202
	TL217 Trip	Overload TL201
ML6	TL217 Trip	Overload TL201

The Island's major load center is located on the Avalon Peninsula. The majority of the hydro generation that serves this load is located on the west side of the Island, starting at Bay d'Espoir (BDE) and beyond. There is thermal generation located on the Avalon peninsula (Holyrood and Hardwoods), however whenever possible the hydro generation is used first before the thermal generation. This can result in large power flow from west to east over the 230 kV transmission corridor between Bay d'Espoir and Soldiers Pond (SOP). This transmission corridor is depicted in Figure 5-1.

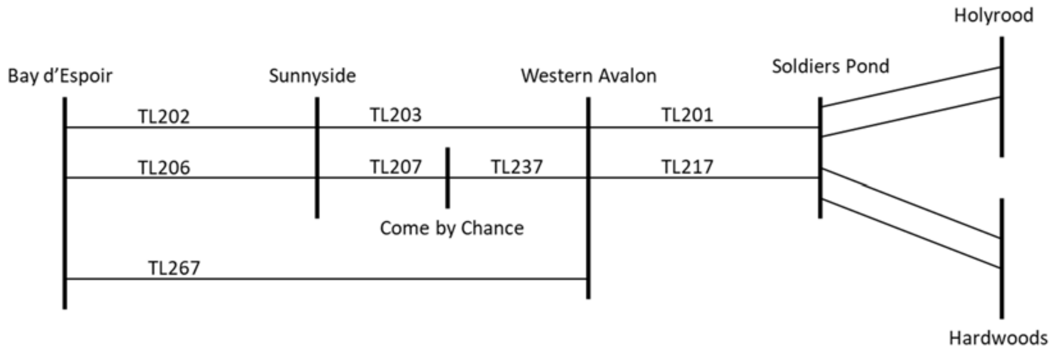

Figure 5-1. 230 kV transmission corridor from BDE to SOP

As shown in Table 5-1, the transmission lines between Bay d'Espoir and Soldiers Pond all have the potential to become overloaded for loss of a parallel line.

The most defining corridor is the one between Western Avalon and Soldiers Pond – TL201/TL217. This corridor will define the system operating limit for the entire 230 kV transmission corridor.

In order to avoid these thermal violations, the power transfer to the Avalon Peninsula through this 230 kV corridor needs to be restricted in order to respect the thermal rating of line TL201, as it has the most limiting MVA rating. In order to avoid overloading line TL201, the maximum pre-contingency MVA flows on lines TL217 and TL201 are listed in Table 5-2 for the specific base cases used in this study. In order to limit this power flow, generation on the Avalon peninsula (Holyrood or Hardwoods) must be increased and the generation on the west of the Island (for example, Bay d'Espoir or Cat Arm) must be decreased.

Table 5-2. Power flow limits in the study cases that required redispatch

Case	TL217 Flow (MVA)	TL201 Flow (MVA)
ML2	162.1	159.8
ML4	143.8	141.7
ML5	91.0	89.7
ML6	86.4	85.3

Generally, it must be ensured that the total pre-contingency loading between Western Avalon and Soldiers Pond is not greater than the thermal rating of line TL201. This will ensure that loss of TL217 would not result in line TL201 becoming overloaded. The goal is to define a system operating limit that can ensure that the loading on this transmission corridor between Western Avalon and Soldiers Pond remains at or below such a level. The MVA rating of line TL201 as given in the PSSE base cases is summarized in Table 5-3.

Table 5-3. Thermal rating of TL201

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

5.2 Dynamic Analysis

The results of the dynamic analysis are discussed in three sections: transmission line faults, loss of generation, and loss of the ML bipole.

5.2.1 Transmission Line Faults

The dynamic analysis did not undercover 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, with one minor exception shown in Figure 5-2.

Figure 5-2 shows the transient voltage response to a 3PF at Soldiers Pond on line TL201 (a similar response is seen for a 3PF on the parallel line TL217). The transient analysis criteria states that post fault voltages should be above 80% by 20 cycles (333 msec) after the fault has cleared. The 230 kV voltages at Oxen Pond and Hardwoods briefly dip to 0.79 pu at around 27 cycles after the fault has cleared, due to a damped but oscillatory voltage response.

This violation occurred only for case ML2, which is a peak load case in which the Island is importing from the ML. This case is deemed to be a marginal violation that is acceptable for short term operation. Operational studies in early 2018 will include the application of power system stabilizers that will allow for improved damping. Such improvements would eliminate this violation.

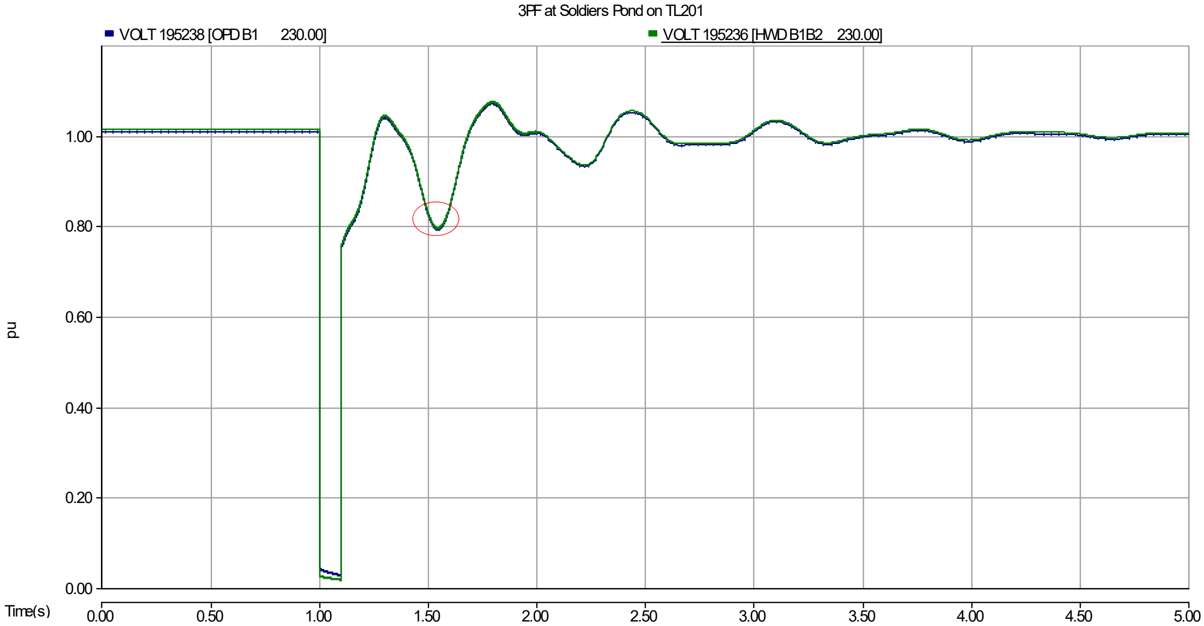

Figure 5-2. 230 kV voltage at Oxen Pond and Hardwoods for 3PF TL201 at Soldiers Pond.

5.2.2 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.

Just for information, once the LIL bipole is in-service at full power, the criteria will change to disallow underfrequency load shedding for loss of a generator, and the frequency will have to remain above 59 Hz.

5.2.3 Loss of the Maritime Link

Loss of the ML bipole was the defining case for identifying the allowable import and export limits on the ML.

5.2.3.1 ML Import Limit

The first run through the ML import cases produced the results shown in Table 5-4 for loss of the ML bipole. These cases result in underfrequency.

Table 5-4. Loss of ML bipole – base cases (import)

Case	System Load	ML Import (MW)	Minimum Frequency (Hz)	Maximum ML Import to maintain frequency above 58 Hz (MW)
ML2	Peak	245	58.09	> 245
ML4	Intermediate	252	57.98	230
ML6	Light	216	57.86	170

Cases ML4 (intermediate load) and ML6 (light load) violated the lower frequency limit of 58 Hz when the ML bipole was lost. In order to mitigate the violation, the pre-contingency power transfer on the ML must be limited to a lower import level, as given in Table 5-4.

The maximum ML import level is dependent on the system operating conditions, particularly the generation (inertia) that is on-line. In an attempt to define a general system operating limit regarding the maximum ML import for any given system condition, three additional base cases were provided (ML9 – medium light load, ML10 – low intermediate load, ML13 – extreme light load), totaling six base cases in which the ML was importing . If not already at an ML import limit, these cases were modified in 5-10 MW increments to reduce generation and increase ML import (while keeping the dispatch as similar to the base case as possible) until loss of the ML bipole resulted in the frequency dipping to 58 Hz. The total inertia on the Island system was recorded for each of these cases when the ML reached its import limit. The goal was to create a graph of ML import limit versus on-line inertia.

To obtain more points for the graph, other dispatches were created by forcing one Holyrood unit on at a time and reducing other generation, simply to get a feel for how this would impact the ML import limits even though these dispatches would not be likely to occur in reality.

Table 5-5 summarizes the ML import findings. Rows highlighted in yellow depict the base cases that were provided by Hydro (with minor dispatch adjustments to find the ML import limit for each case). The rest of the rows depict the extra cases that were created to test the ML import limits.

Table 5-5. Summary of ML Import Limits

Case	Load	ML Import (MW)	Inertia Online (MWs)	Island Demand (MW)
ML2a	Peak	320	7321	1750.4
ML2b	Peak	300	7434	1746.1
ML4	Int.	250	6208	1225.8

Case	Load	ML Import (MW)	Inertia Online (MWs)	Island Demand (MW)
ML4b	Int.	240	6154	1230.5
ML4c	Int.	230	6096.7	1229.8
ML10a	Low Int.	230	5632	1129.5
ML10b	Low Int.	220	5577.8	1137.2
ML10c	Low Int.	210	5520.8	1136.9
ML9b	Med. Light	190	4523.7	830.5
ML9c	Med. Light	190	4466.7	835.5
ML9d	Med. Light	190	4910.3	844.6
ML6c	Light	170	4154.9	753.3
ML6	Light	170	4326.5	753.5
ML13	Extreme Light	108*	3881.0	550.2

*This case is not at the 58 Hz limit, but the Island is already at minimum generation and therefore cannot import more from the ML at this demand level.

Figure 5-3 shows a graph of the ML import limit (MW) versus on-line inertia (MWs). The blue line shows a graph of the ML import limits obtained from small adjustments to the bases cases ML2, ML4, ML6, ML9, ML10 and ML13 (i.e. the realistic dispatches shown in the yellow rows in Table 5-5). This blue line provides a relatively linear relationship between on-line inertia and the ML import limit. The red line shows the additional other dispatch cases that were tested but not likely realistic (i.e. the other rows in Table 5-5).

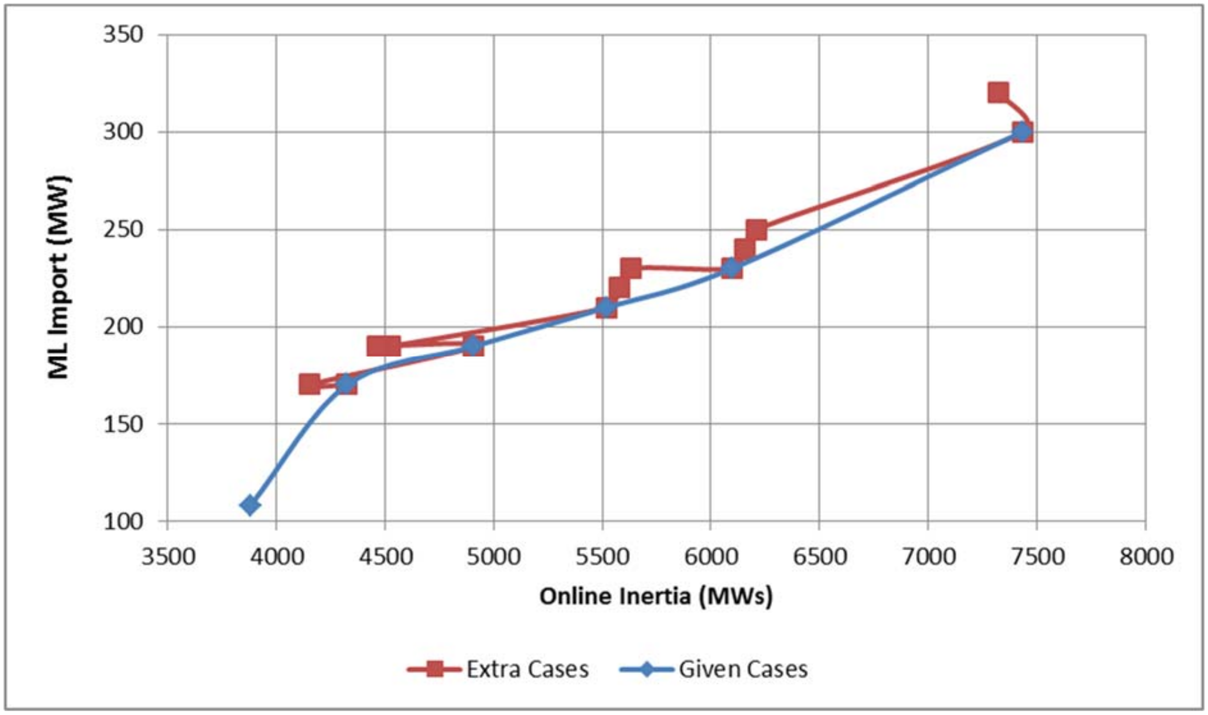

Figure 5-3. ML import limit as a function of inertia on-line

Rather than using inertia, it is easier to use Island demand as a guideline for defining the maximum ML import level for a given operating point. Figure 5-4 depicts a graph of the maximum allowable ML import as a function of Island demand (again based on Table 5-5).

Similar to Figure 5-3, Figure 5-4 shows:

- Blue line –ML import limits for the base cases that were provided
- Red line –extra cases that were set up with unlikely dispatches (i.e. increasing thermal generation, reducing hydro generation) to observe the impact on the ML import limits
- 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 base cases that were provided (blue line), giving a small amount of margin/conservatism regarding the maximum ML import limits

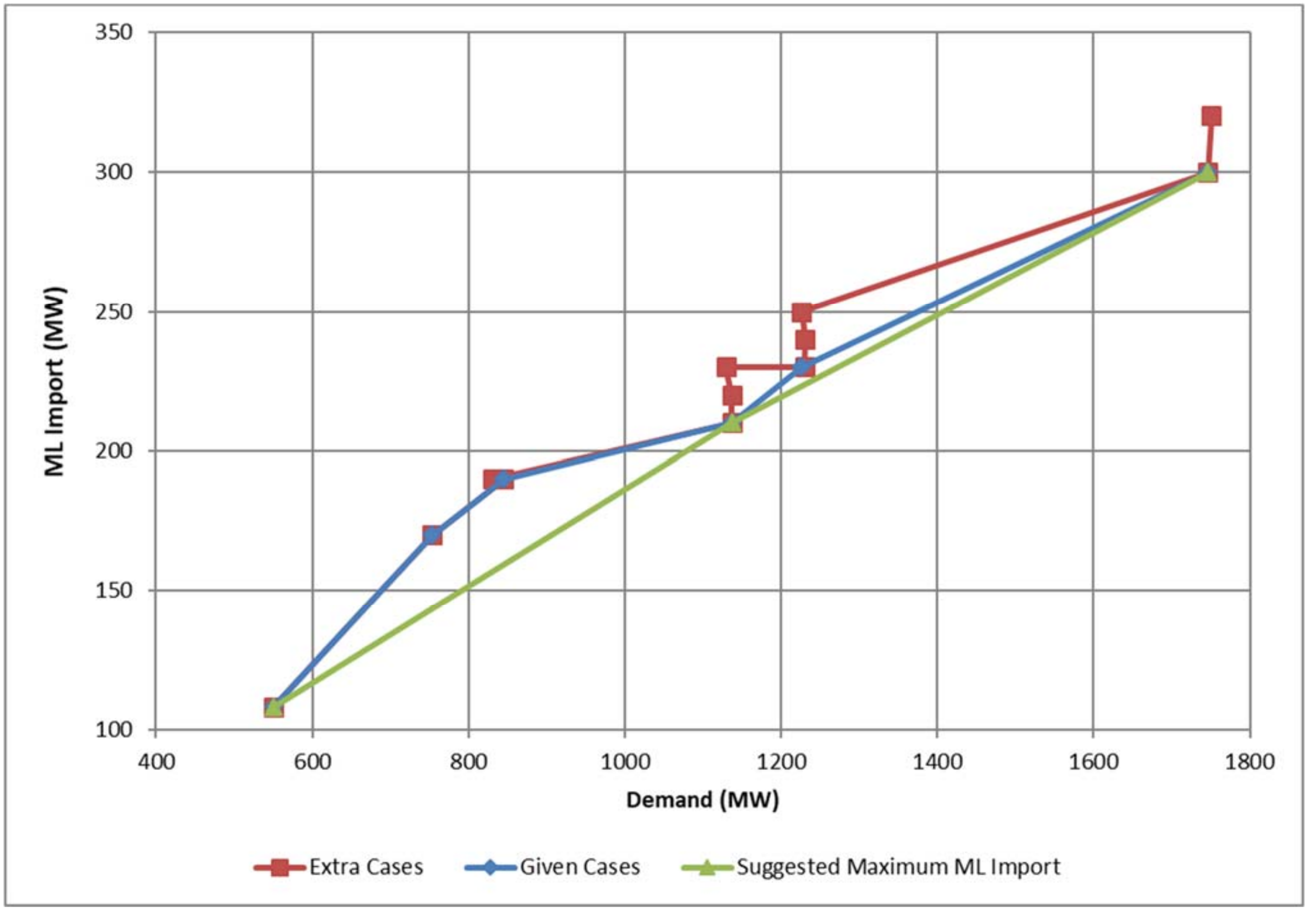

Figure 5-4. Maximum ML import level versus Island demand

It is therefore recommended to limit the ML import level to remain at or below the values defined by the green line in Figure 5-4, depending on the Island demand level.

5.2.3.2 ML Export Limit

The first run through the ML export cases produced the results shown in Table 5-4 for loss of the ML bipole. These cases result in overfrequency. Case ML3 (intermediate load) violated the upper frequency limit of 62 Hz when the ML bipole was lost.

Table 5-6. Loss of ML bipole – base cases (export)

Case	System Load	ML Export (MW)	Maximum Frequency (Hz)
ML1	Peak	43	60.22
ML3	Intermediate	306	62.77
ML5	Light	102	61.76

Cases involving significant overfrequency on the Island system, such as loss of the ML bipole, are new to the Island system. Prior to the installation of the ML, the only contingency that could result in an overfrequency on the Island was loss of load. Loss of the ML bipole, depending on how much power it is exporting, can be much more severe in terms of overfrequency compared to loss of load.

It was noticed during these large overfrequency events that the Holyrood generators were reacting to the overfrequency more than other generators, and were significantly lowering their power output in response to the overfrequency. An example of the Holyrood generator power output is shown below in Figure 5-5 for loss of the ML bipole while exporting 195 MW. The power output of the generators transiently drops by around 45 MW and settles around 30 MW lower than the pre-contingency operating point at around 20 seconds after the loss of the ML.

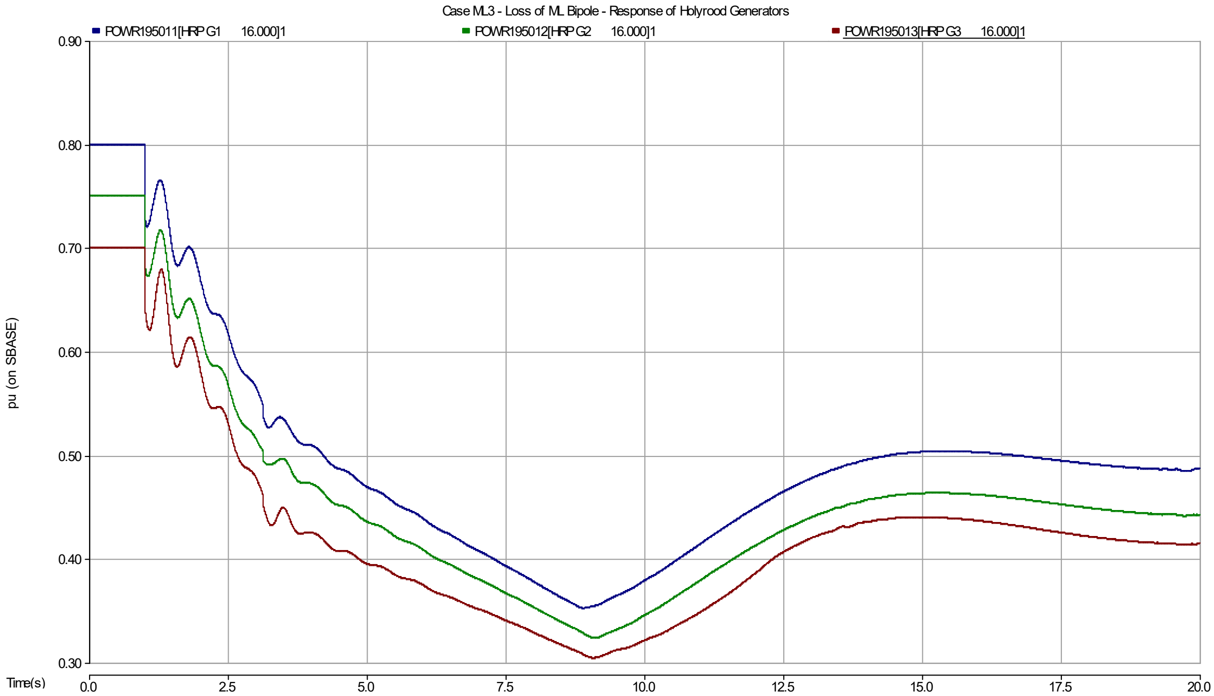

Figure 5-5. Case ML3. Holyrood generator power output in response to loss of ML bipole while exporting.

Hydro deemed that such a large reduction in power output of the Holyrood generators would be problematic for these thermal units, and they advised to determine the ML export limits such that loss of the ML bipole while exporting would not result in more than a 15 MW[5] reduction in power output of the Holyrood generators. As a result, the overfrequency that occurred following the loss of the ML bipole would be less than 62 Hz because the 15 MW Holyrood generator criteria is more limiting.

In order to develop a graph of maximum ML export limit versus Island demand (similar to the graph developed for the maximum ML import limit), four additional base cases were provided by Hydro (ML7 – medium light load, ML8 – low intermediate load, ML11/ML12 – extreme light load), totaling seven base cases in which the ML was exporting power to Nova Scotia.

These cases were used to find the ML export level at which the Holyrood generator(s) power output is reduced by 15 MW when the ML bipole is lost. The resulting ML export level was deemed to be the limit for that case.

To obtain more points for the graph, other dispatches were created by forcing one Holyrood unit on/off at a time and re-dispatching the generation accordingly, to get a feel for how this would impact the ML export limits (even though these dispatches would not be likely to occur in reality).

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[5] After discussions with Hydro, it was decided to use the following criteria in the study: by 20 seconds of simulation time the Holyrood generator(s) output should to be back to within 15 MW of the pre-contingency operating point. Transiently (before 20 seconds), the output of the Holyrood generators reduced more than 15 MW, which was deemed acceptable.

Table 5-7 summarizes the ML export findings. Rows highlighted in yellow depict the base cases that were provided by Hydro (with dispatch adjustments to find the ML export limit for each case). The rest of the rows depict the extra cases that were created.

Table 5-7. Summary of ML Export Limits

Case	Load	ML Export (MW)	Inertia Online (MWs)	Island Demand (MW)	Number of Holyrood units on-line
ML1	Peak	43*	7581	1723.1	3
ML3	Int.	94	7766	1242.1	3
ML3	Int.	86	7434	1253.2	2
ML8	Low Int.	90	6745	1122.5	3
ML8	Low Int.	72	7136	1131.3	2
ML8	Low Int.	66	6801	1136.0	1
ML7	Med. Light	84	6875	843.4	3
ML7	Med. Light	74	6821	847.4	2
ML7	Med. Light	60	6764	853.0	1
ML7	Med. Light	125	6658	862.8	1 as synch.
ML5	Light	84	5880	742.4	3
ML5	Light	70	5826	745.1	2
ML5	Light	56	6214	748.8	1
ML5	Light	120	6108	753.0	1 as synch.
ML12	Extreme Light	86**	4155	449.3	1
ML11	Extreme Light	85	4327	450.3	1 as synch.

*Case ML1 is already at maximum generation and cannot export more than 43 MW. This point is not included in the graph in Figure 5-6.

**Case ML12 is not included in the graph Figure 5-6. Case ML12 cannot export less than 86 MW on the ML because with one Holyrood unit on at minimum power (70MW) there is not enough other generation on-line to turn off in order to reduce the ML export any further. At an ML export level of 86 MW in Case ML12, the Holyrood 15 MW criteria is violated. Hence, during extreme light load scenarios, the Holyrood units should be off, or running as synchronous condenser.

Figure 5-6 depicts a graph of the ML export limit (MW) versus Island demand (MW) that was created from the data in Table 5-7. The ML export limit is shown in four separate lines – each line depicting either 1 Holyrood unit on-line as a synchronous condenser, or 1, 2 or 3 Holyrood units on-line as generators.

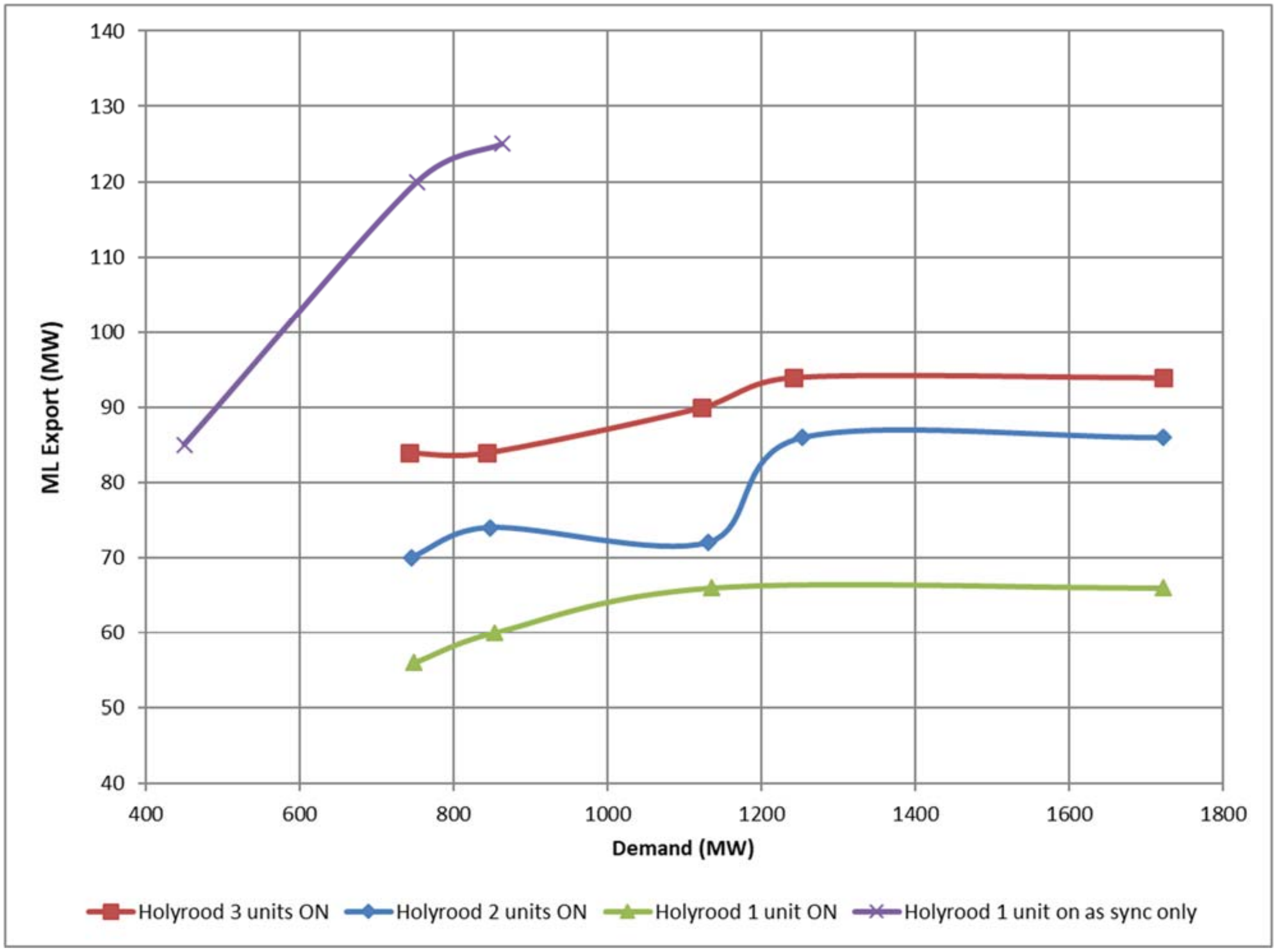

Figure 5-6. ML export limit as a function of Island demand and number of Holyrood units

It became evident 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 generators did not decrease more than 15 MW, the Holyrood generators still transiently contributed a significant amount to the overfrequency compared to other generators. 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, this same impact of the Holyrood units was not observed for loss of the ML bipole while importing, and that is why the ML import level was found to have a more linear relationship with the Island demand level compared to the ML export level, which depended more greatly on how many Holyrood units were on-line as generators rather than the Island demand level.

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 higher because in these cases the 62 Hz frequency limit is the defining criteria because the 15 MW Holyrood generator criteria is no longer applicable.

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 shown in Figure 5-6 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 5-8, 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 5-8. 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	120

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 5-6, 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.

Please note that during extreme light load scenarios, when the Island load is less than 750 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.

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.

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 severe 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 can handle without causing overloads to the underlying 138 kV system if the parallel line trips. In order to limit this flow, generation on the Avalon peninsula must be increased.

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

Case	ML1	ML2	ML3	ML4	ML5	ML6
Flow Limit (MVA)	100	105	91	90	106	106

It is recommended to limit the flow between Western Avalon and Soldiers Pond to a maximum of 90 MVA if there is a prior outage of TL217 or TL201.

6.1.2 Dynamic Stability

Cases ML1 through ML6 were modified to limit the power flow as per Table 6-2, with a prior outage of TL217. A 3PF on TL201 was tested for fault locations at both ends of the line, namely Soldiers Pond and Western Avalon.

A 3PF at Western Avalon on TL201 was stable and met the dynamic performance criteria in all cases.

A 3PF at Soldiers Pond, however, did not meet criteria in all cases. Table 6-3 summarizes these results and the corresponding mitigation.

Table 6-3. 3PF at SOP on TL201 during a prior outage of TL217

Case	**ML1**	**ML2**	**ML3**	**ML4**	**ML5**	**ML6**
Results	Unstable	Unstable	Stable but violates transient undervoltage criteria	Stable but violates transient undervoltage criteria	OK	OK

Cases ML1 and ML2 are peak load cases. Even if all Avalon peninsula generation is fully turned on, the pre-contingency flow on TL201 is limited to 65 MVA, however the system still becomes unstable if there is a 3PF at Soldiers Pond on TL201. Therefore, unless load is curtailed on the Avalon peninsula to further limit the power flow, the system can become unstable if the parallel line trips during peak load conditions.

Cases ML3 and ML4 are intermediate load cases. Reducing the power flow through the WAV-SOP corridor was also not enough to mitigate the transient undervoltage violations.

Cases ML5 and ML6 are light load cases, which are stable and meet criteria if the pre-contingency TL201 flow is limited as per Table 6-2.

It was found that if the Island load is 1100 MW or less, and if the Western Avalon-Soldiers Pond flow is limited to 90 MVA (west to east), then the system performance is acceptable for a prior outage of TL201 or TL217. Therefore, it is recommended that if an outage is planned for TL201 or TL217, that is done so when the load is no greater than 1100 MW, and that the corridor flow is limited to 90 MVA (as measured at Western Avalon).

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.

6.2.1 Steady State

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 6-4 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 6-4. Prior outage TL207/TL237 or TL203 and loss of the parallel line. Steady state limits.

Case	ML1	ML2	ML3	ML4	ML5	ML6
Flow Limit (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 180 MVA in summer and 200 MVA in winter if there is a prior outage of TL203, TL207 or TL237.

6.2.2 Dynamic Stability

No stability issues were observed when the pre-contingency power flow through TL203 or TL207/TL237 was limited as per Table 6-4.

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.

6.3.1 Steady State

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 6-5 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 6-5. Prior outage TL202/TL206 or TL267 and loss of the parallel line. Steady state limits.

Case	ML1	ML2	ML3	ML4	ML5	ML6
Flow Limit (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, 315 MVA in spring/fall and 220 MVA in summer if there is a prior outage of TL202, TL206 or TL267.

6.3.2 Dynamic Stability

If the pre-contingency power flow through the corridor between Bay d'Espoir and Sunnyside/Western Avalon is limited as per Table 6-5, no stability issues were observed.

6.4 Prior outage TL232 or TL205

6.4.1 Steady State

There are two 230 kV lines connecting Buchans to Stony Brook. 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 are reduced as per Table 6-6.

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

Case	ML1	ML2	ML3	ML4	ML5	ML6
Mitigation	-	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 275 MW in winter, 185 MW in spring/fall, and 165 MW in summer if there is a prior outage of TL232 or TL205.

6.4.2 Dynamic Stability

There were no stability issues observed for a prior outage of line TL205 or line TL232.

6.5 Prior outage TL211/TL228

6.5.1 Steady State

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 ML3 only, and it can be avoided by reducing Hinds Lake generation to 40 MW as shown in Table 6-7.

Table 6-7. Prior outage TL211 or TL228 and loss of parallel line. Steady state limits

Case	ML1	ML2	ML3	ML4	ML5	ML6
Mitigation	-	-	Limit Hinds Lake generation to 40 MW	-	-	-

6.5.2 Dynamic Stability

This scenario was also observed to result in an oscillatory system response that took approximately 60 seconds to damp out, particularly on the 138 kV network between Deer Lake and Stony Brook. The simultaneous outages of TL211 and TL228 cause the generation from Cat Arm and Hinds Lake to oscillate against the generation in the rest of the system. The oscillations are not as evident in AC voltage, but are particularly evident in the power flow through the 138 kV system between Deer Lake and Stony Brook.

Figure 6-1 shows the system response for this scenario for peak load case ML1, for a simulation time of 60 seconds. It is expected that the power system stabilizer (PSS) study that will be performed in the near future would be able to improve the damping for this scenario.

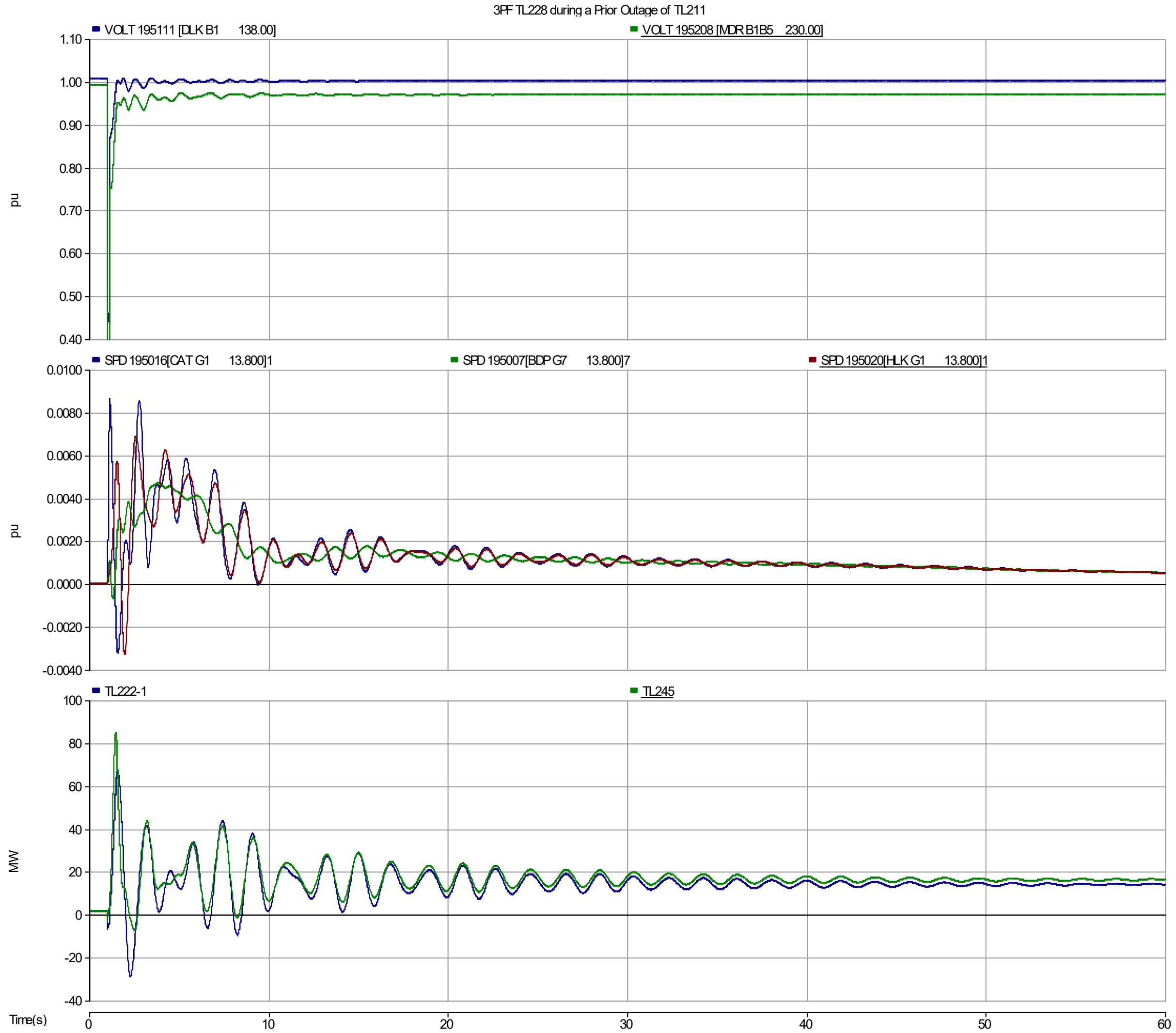

Figure 6-1. Case ML1. 3PF on TL228 for during a prior outage of TL211

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. This is true if the ML is importing power to the Island. Table 6-8 summarizes the ML import limits to avoid overloading line TL211.

Table 6-8. Prior outage of TL233 or TL234 and loss of parallel line. Steady state limits

Case	**ML1**	**ML2**	**ML3**	**ML4**	**ML5**	**ML6**
Mitigation	-	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, 220 MW in spring/fall, and 100 MW in summer if there is a prior outage of TL233 or TL234.

6.6.2 Dynamic Stability

As previously mentioned, an outage of an outlet line at Bottom Brook weakens the interconnection point of the ML. The ML model was observed to have numerical convergence issues during an outage of one of these lines, followed by a 3PF and tripping of another of these lines, leaving the ML connected to the Island system via only one 230 kV line.

The ABB open source model was being used to represent the ML in this study. The model was modified to enable the "Extreme Weak" mode of operation if there was a prior outage of TL211, TL233, TL269, TL263 or TL234. Enabling this mode eliminated the model convergence issues, and no stability issues were observed, other than some oscillations in the system. However, these oscillations were always damped.

Figure 6-2 shows an example of one of these oscillatory system responses. This example occurs during case ML3 when there is a 3PF on TL233 during a prior outage of TL211. This scenario causes the majority of the ML power to flow on line TL269 and results in oscillations in the AC voltage along this line. Despite the fact that the response is somewhat oscillatory, it is damped and meets the dynamic performance criteria.

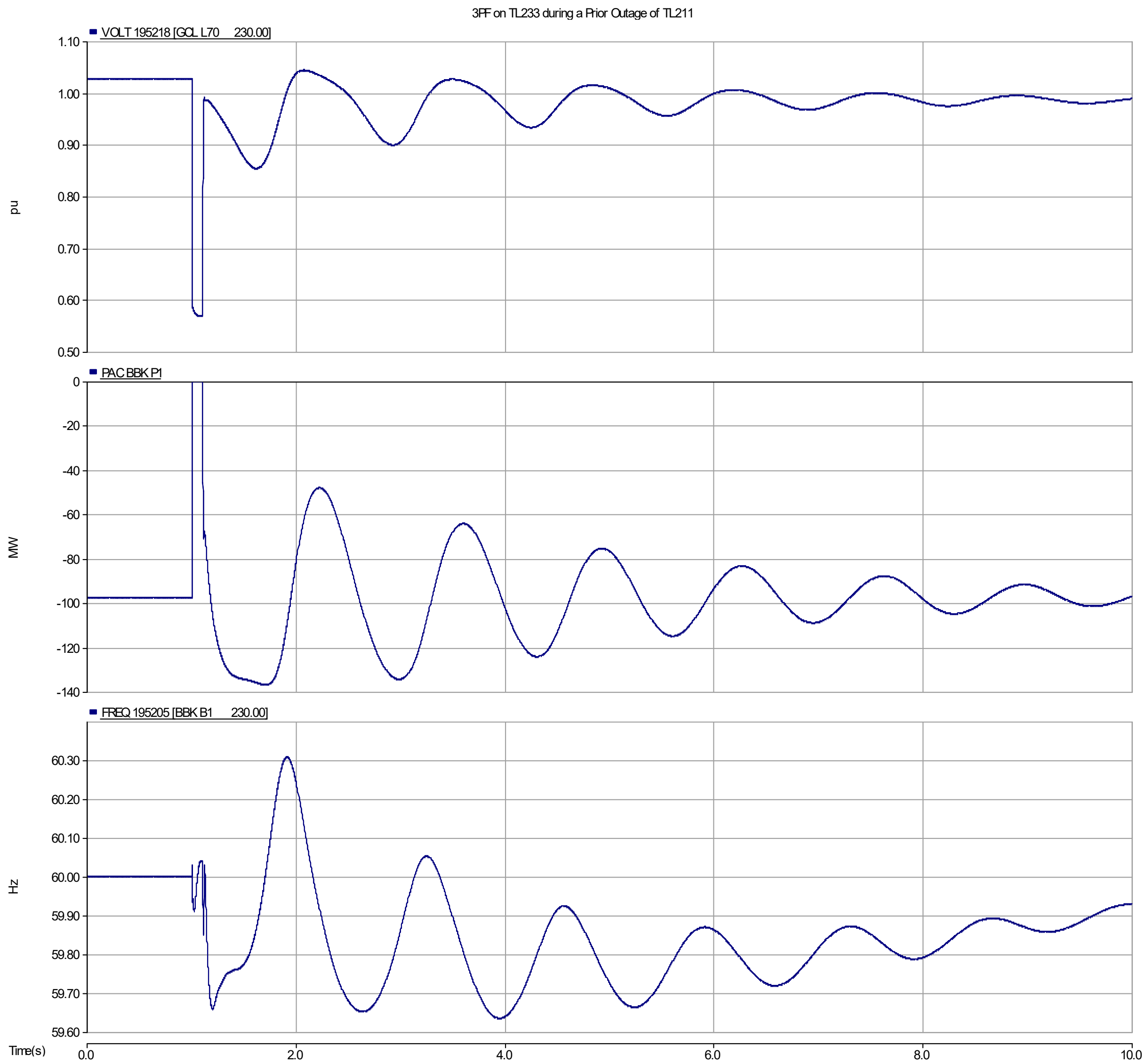

Figure 6-2. Case ML3. 3PF on TL233 during a prior outage of TL211

Please note that the cases being studied for this period of time (i.e. before the LIL is in-service) require the ML import and export to be limited to lower values than the ultimate levels of 500 MW export and the 300 MW import. At these lower ML import and export limits, the system's response met the dynamic performance criteria for prior outages at Bottom Brook. However, it can be expected that when operating at the full ML export and import limits, that runbacks and/or operating limits may be required if there is a prior outage of an outlet line at Bottom Brook. Damping controllers will also be activated for full power operation.

Additionally, please note that part-way through the study, an updated PSSE model of the ML was provided, "Abb_Hvdc_Light_Maritime_V_2.2.0_MTM_1.dll". Using this model with the "Extreme Weak" mode selected for prior outages near the Bottom Brook terminal, a significant improvement was observed in the system damping. Figure 6-3 shows the improved performance compared to Figure 6-2.

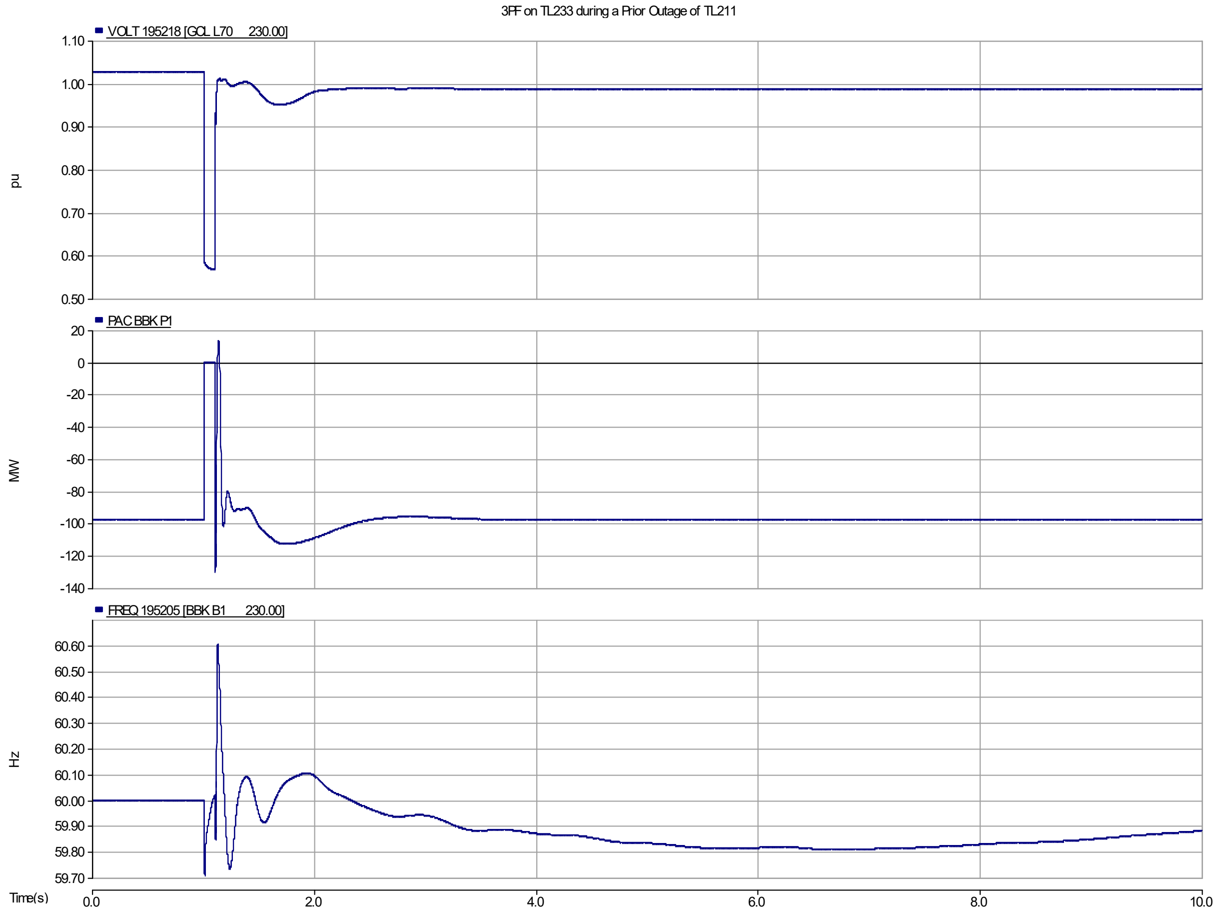

Figure 6-3. Case ML3. 3PF on TL233 during a prior outage of TL211, with updated PSSE ML model

7. ML Frequency Controller Results

The study up to this point was performed with the ML frequency controller disabled. Next, a study was performed to determine the limits of the frequency controller. Then, select contingencies were simulated with the ML frequency controller enabled in order observe its impact on the study results.

7.1 Providing Frequency Support to Nova Scotia

First, it was determined how much power the Island system could suddenly provide to Nova Scotia without experiencing underfrequency load shedding (UFLS).

In order to find this limit, simulations were run in which the power flow on the ML was step-changed to mimic Nova Scotia suddenly taking "X" amount of power from the Island. The simulations tested a range of power ramp rates associated with this step change in power, from a nearly instantaneous step to a slower 10-second ramp, to see if more power could be sent (while still avoiding UFLS) if the ramp rate was slower.

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)	Power ramp rate (sec)	Minimum Frequency (Hz)
ML1	90	0.05	58.90
	90	1	58.90
	90	2	58.90
	100	5	58.81
	100	10	58.88
ML2	80	0.05	58.91
	80	1	58.92
	80	2	58.93
	90	5	58.85
	100	10	58.88
ML3	60	0.05	59.00
	60	1	59.00
	60	2	59.00
	60	5	59.05
	70	10	58.86
ML4	70	0.05	58.88
	70	1	58.89
	70	2	58.90
	70	5	58.95
	80	10	58.93

Case	Maximum Power to NS without UFLS (MW)	Power ramp rate (sec)	Minimum Frequency (Hz)
ML5	70	0.05	58.82
	70	1	58.82
	70	2	58.83
	70	5	58.86
	80	10	58.83
ML6	60	0.05	58.95
	60	1	58.95
	60	2	58.95
	60	5	58.97
	70	10	58.86

It is clear from Table 7-1 that unless the power ramp rate is quite slow, for example 5 or 10 seconds or more, having the power sent suddenly or having the power ramped over several seconds made little or no difference in the total amount of power that could be sent from the Island to Nova Scotia without shedding any load on the Island.

Based on the results in Table 7-1, the Island can provide 60 MW to Nova Scotia without experiencing UFLS.

7.2 Impact of ML Frequency Controller on Study Results

The next step was to see what impact the ML frequency controller would have on the study results.

7.2.1 System Intact Conditions

Because the ML import/export limits are defined by the underfrequency/overfrequency that occurs following the loss of the ML bipole, it is obvious that the ML frequency controller will not affect those limits.

Additionally, there were no significant frequency deviations observed for any of the 3PF faults on the transmission lines in the system, and therefore the ML frequency controller would also not significantly impact those study results.

Therefore, only the major outages affecting frequency were tested with and without the ML frequency controller enabled to observe its impact. These outages included loss of the largest generator and loss of the largest load. Loss of an ML pole will automatically load the other ML pole (at maximum up to its rating), and so there is no need to test the frequency controller for this contingency.

Table 7-2 summarizes these results.

Table 7-2. Impact of ML frequency controller on select contingencies

Case	Amount of UFLS (MW)	Min/Max Frequency (Hz)	
	Gen	Gen	Load
ML1 with freq. cont.	0	59.39	60.23
ML1 without freq. cont.	81.42	58.60	60.66
ML2 with freq. cont.	0	59.48	60.26
ML2 without freq. cont.	81.5	58.56	60.87
ML3 with freq. cont.	0	59.33	60.19
ML3 without freq. cont.	88.06	58.37	60.55
ML4 with	52.06*	59.66	60.20
ML4 without freq. cont.	93.08	58.60	60.74
ML5 with freq. cont.	0	59.69	60.13
ML5 without freq. cont.	14.01	58.74	60.50
ML6 with	0	59.70	60.14
ML6 without freq. cont.	14.04	58.72	60.63

*due to undervoltage load shedding (UVLS)

Enabling the ML frequency controller allows the system to avoid UFLS 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 ML3.

Please note that one exception occurs for Case ML4, in which undervoltage load shedding (UVLS) occurs following the loss of one of the Holyrood generators.

There are no overfrequency issues with loss of the largest load.

According to SCADA data, the steady state frequency on the Island can vary around +/- 0.2 Hz. Therefore, a sensitivity analysis was also run to observe the impact of increasing the deadband on the ML frequency controller to +/- 0.5 Hz. A deadband of +/- 0.5 Hz was still sufficient avoid UFLS for loss of the largest generator in all cases that were tested with MW limits of +/- 100 MW.

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.

7.2.2 Prior Outage Conditions

There are two stability issues that occurred during prior outage conditions for which the ML frequency controller could be tested to observe its impact:

1. Prior outage TL217 or TL201, followed by loss of the parallel line
2. General observations of oscillatory system responses

7.2.2.1 Prior outage TL217 or TL201, followed by loss of the parallel line

This case resulted in instability during peak loading conditions, and violated the transient undervoltage limits during intermediate loading conditions

For peak load cases ML1 and ML2, there is improvement in the system response with the ML frequency controller enabled, but not enough to meet the dynamic performance criteria. Even if the MW limits on the frequency controller are increased to +/- 200 MW, the response is still not acceptable. Figure 7-1 shows the response of the system with and without the ML frequency controller enabled (with a +/-200 MW limit).

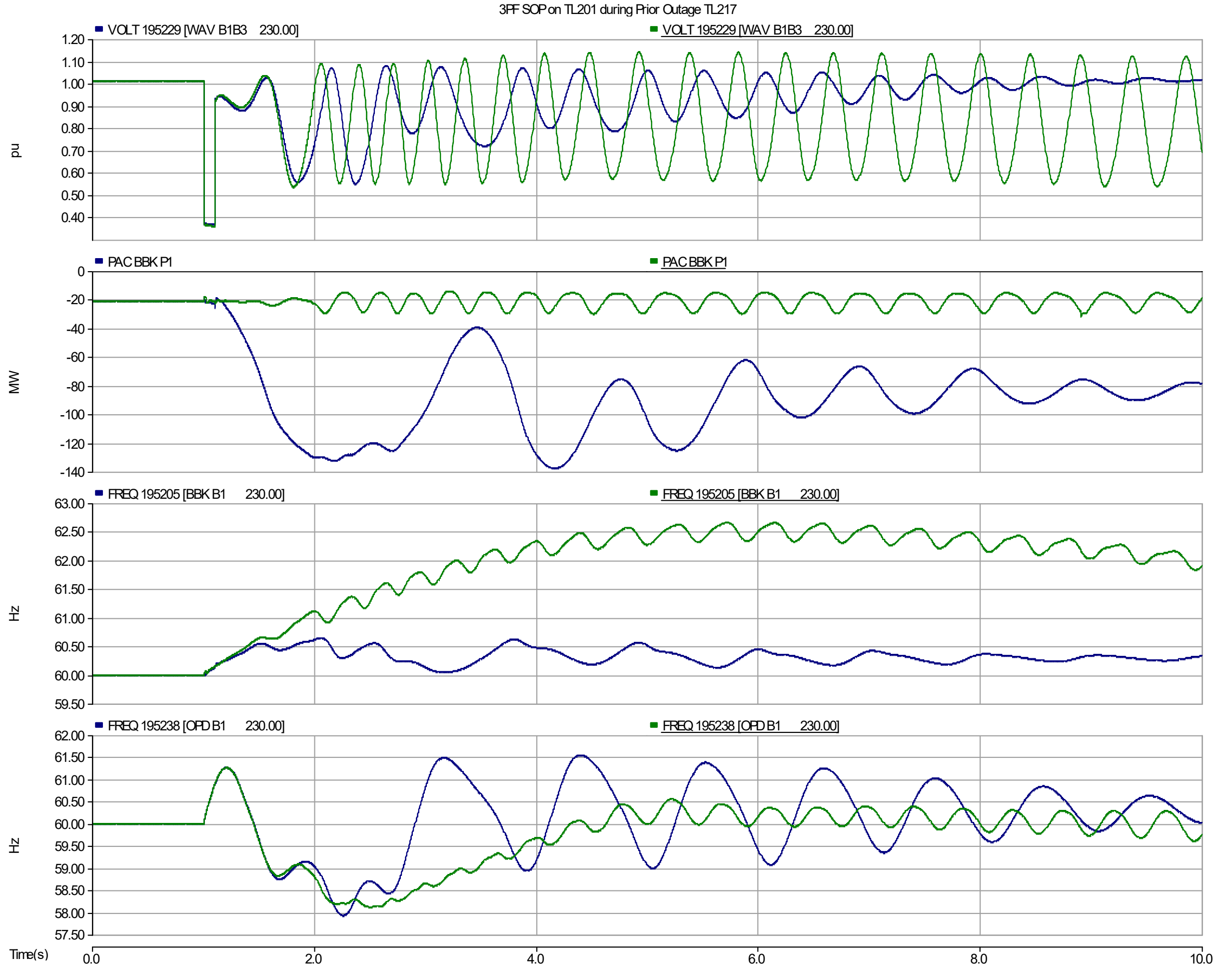

Figure 7-1. Case ML1. 3PF TL201 during prior outage of TL217, with and without ML frequency controller
Blue: with ML frequency controller. Green: without ML frequency controller

A system operating limit was defined for a prior outage of TL217 or TL201 in that a planned outage of one of these lines should only be taken when the Island load is less than 1000 MW load case, with the WAV-SOP corridor limited to 90 MVA flow. This limiting case was tested with the ML frequency controller enabled, but there was little to no impact on the system's dynamic performance. This is because there was only a small frequency excursion that occurred at the Bottom Brook bus for this fault, which was not significant enough for the ML frequency controller to produce much of an impact.

7.2.2.2 General observation of oscillatory system responses

1. Prior outage TL211, with a 3PF on TL228

The scenario that showed some of the worst damping was a prior outage of line TL211, followed by a 3PF on TL228. This scenario causes the generation at Cat Arm and Hinds Lake to oscillate against the generation in the rest of the system. Figure 7-2 shows the system response with and without the ML frequency controller, for a simulation time of 60 seconds. The third plot on the graph is the power flow on 138 kV line TL222, which is one of the quantities that takes the longest to damp out.

Although the ML frequency controller does make a small improvement in damping, it is not very effective. This case will be investigated further in the power system stabilizer (PSS) study that is planned for the near future.

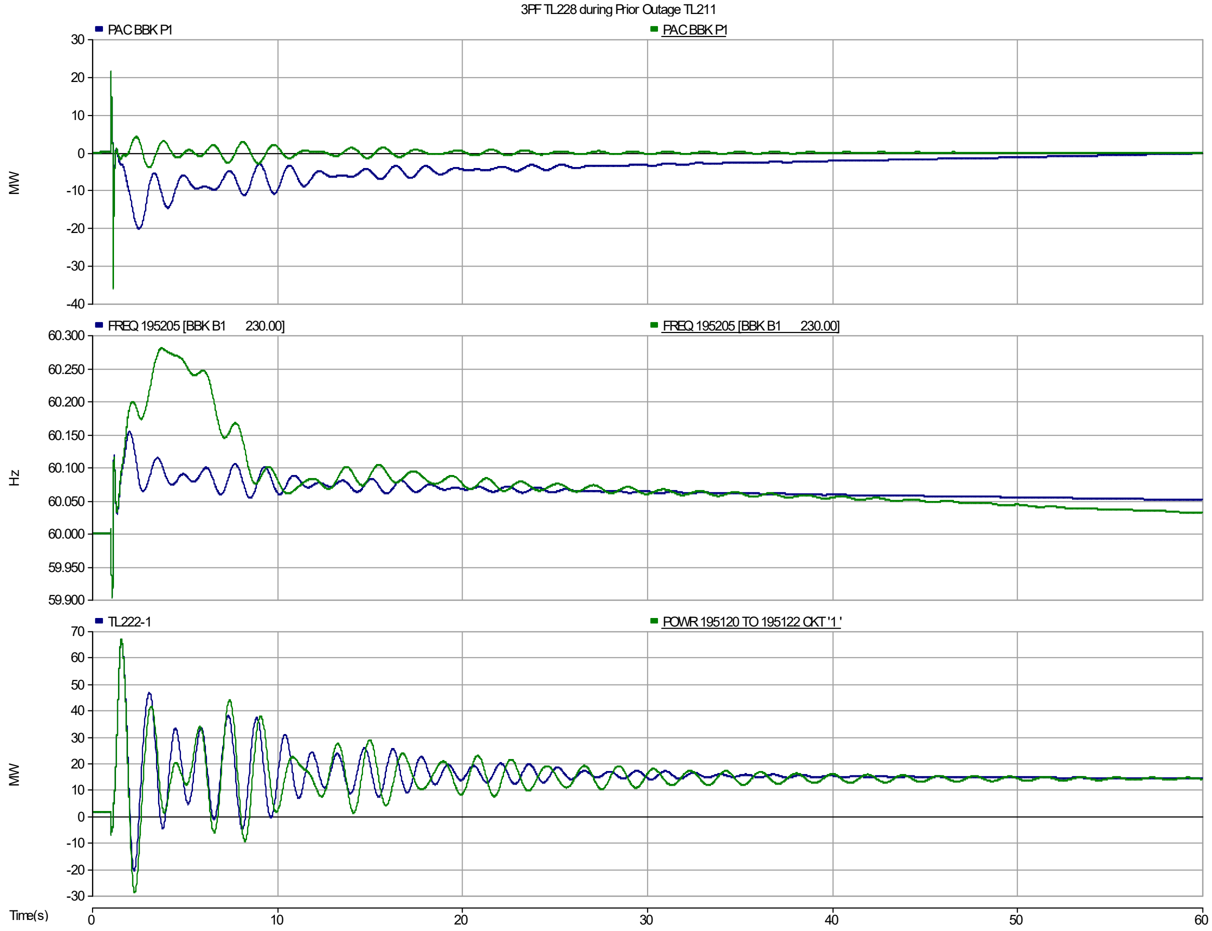

Figure 7-2. Case ML1. 3PF on TL228 during a prior outage of TL211, with and without the ML frequency controller

Blue: with ML frequency controller. Green: without ML frequency controller

8. Conclusions

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

8.1 System Intact

There are several contingencies that require system operating limits. These contingencies and their limits/mitigation are summarized in Table 8-1.

Table 8-1. System Intact Operating Limits/Guidelines

<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 Western Avalon):
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 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[6] 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>120</td></tr>
</table>
If Island demand < 750 MW, limit ML export (as measured at BBK) as defined in Figure 8-2.</td></tr>
</table>

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

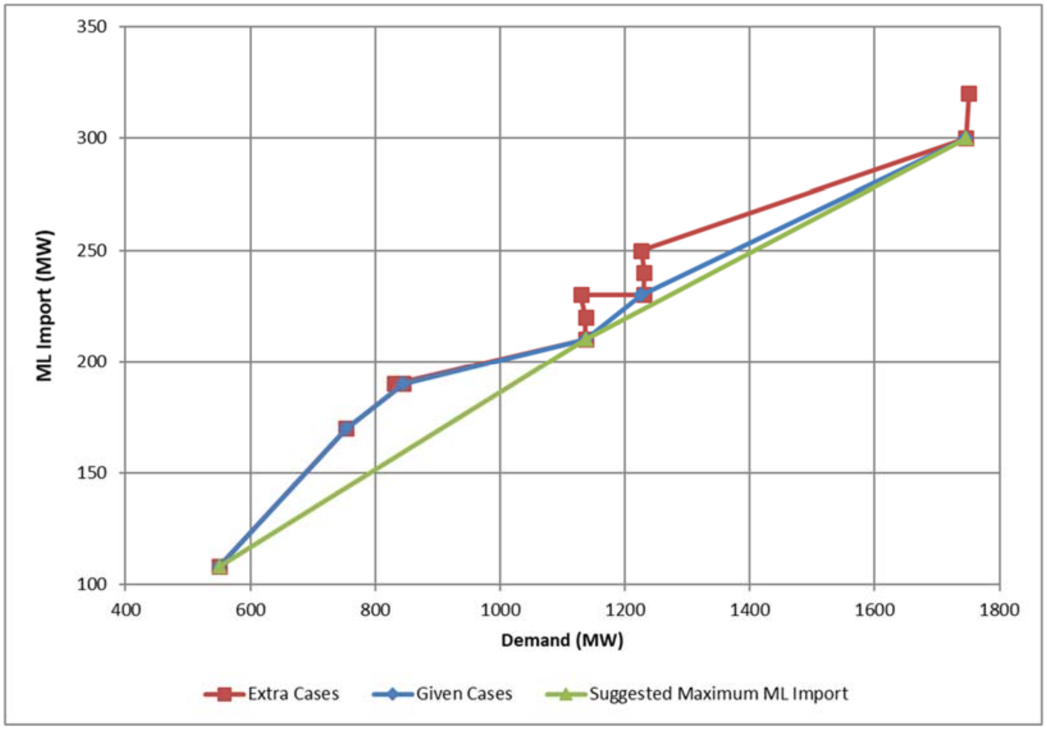

Figure 8-1. Maximum ML import level versus Island demand

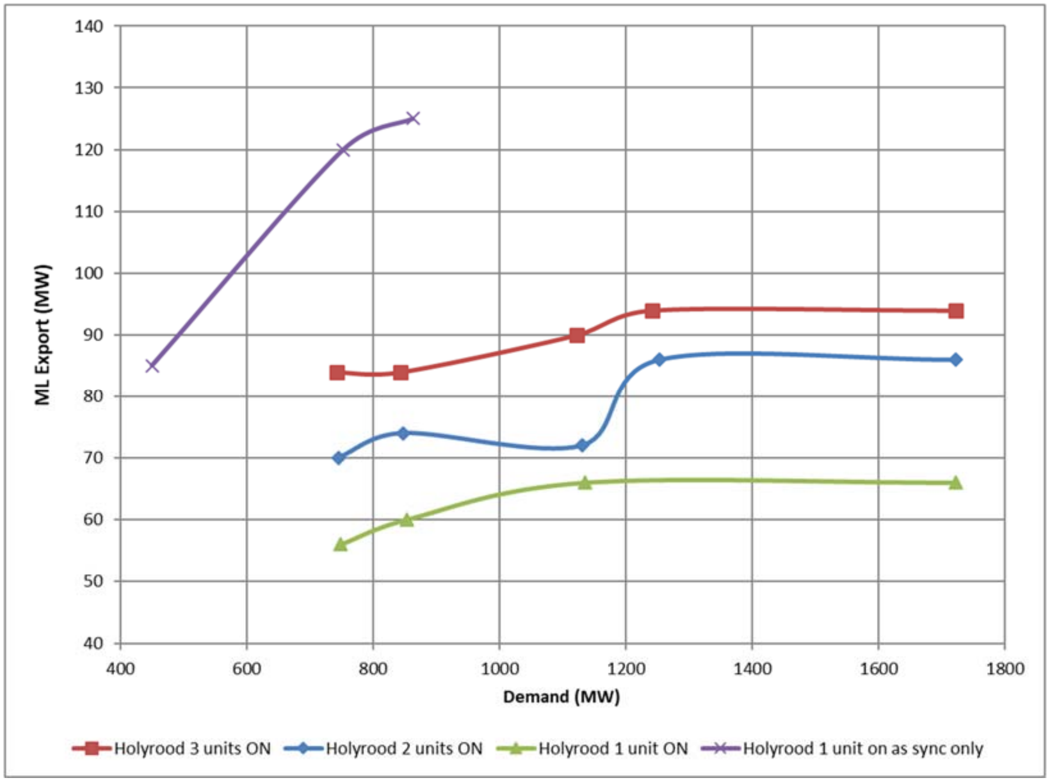

Figure 8-2. Maximum ML export level versus Island demand

8.2 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 8-2.

Table 8-2. Prior Outage Operating Limits/Guidelines

Prior Outage	Next contingency	Issue	Mitigation
TL201/ TL217	TL217/ TL201	Thermal overloading of WAV-SOP underlying 138 kV system; System instability – peak load conditions	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 1100 MW or less If the load is higher than 1100 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 to (as measured at BBK): 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/ 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)

6.3 Steady State Voltage Control at Soldiers Pond

The study determined that 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.

Using a 1.025 tap setting on the high side of the SOP synchronous condenser transformers keeps the SOP low side voltages nearer to 1.0 pu, and allows 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.

The SOP station service transformers can use a tap setting of 1.0.