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April 15, 2020

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

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

Dear Ms. Blundon:

Re: Reliability and Resource Adequacy Study Review — Operational Studies — Stage 4

Further to Newfoundland and Labrador Hydro's ("Hydro") correspondence of August 4, 2017, please find attached the following documents:

- Attachment 1: Technical Note TN1205.71.06, "Stage 4D LIL Bipole: Transition to High Power Operation," TransGrid Solutions Inc., April 7, 2020; and
- Attachment 2: Technical Note TN1205.72.03, "Stage 4E LIL Bipole: High Power Operation" TransGrid Solutions Inc., April 7, 2020.

Technical Note TN1205.71.06 regarding transition to high power operation was previously submitted to the Board of Commissioners of Public Utilities ("Board") on September 30, 2019; however, it has been updated to include the following:

- New information on the alpha minimum issue;
- Updated philosophy on Maritime Link runbacks, frequency controller action, and under frequency load shedding; and
- Results of the analysis of the generic model against the new General Electric Labrador-Island Link ("LIL")model.

Technical Note TN1205.72.03 is provided as per Hydro's prior commitment and is the final Stage 4 study. The study investigates the Island Interconnected System under high power operation of the LIL bipole with full LIL control functionality.

In addition to the above reports, attached are:

- Attachment 3: Technical Note TN1205.74.01, "Operational Considerations with 0 and 1 SOP Synchronous Condensers" TransGrid Solutions Inc., April 7, 2020; and
- Attachment 4: Technical Note TN1205.73.01, "Updates to Alpha Minimum Issue and LIL Transfer Limits" TransGrid Solutions Inc., February 3, 2020.

Due to delays in the commissioning of the Soldiers Pond synchronous condensers ("SOP synchronous condensers"), the technical note regarding "Operational Considerations with 0 and 1 SOP Synchronous Condensers" was added to provide direction for operating the Island Interconnected System with the LIL in service prior to the SOP synchronous condensers coming into service or operating with one SOP synchronous condenser in service. TN1205.73.01 regarding "Updates to Alpha Minimum Issue and LIL Transfer Limits" was added to resolve firing angle concerns raised in the Liberty Consulting Group's Eighth Quarterly Monitoring Report on the Integration of Power Supply Facilities to the Island Interconnected System.

Should you have any questions, please contact the undersigned.

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

SWalsh

Shirley A. Walsh
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Encl.

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Reliability and Resource Adequacy Study – Operational Studies – Stage 4

Attachment 1

Engineering Support Services for:
RFI Studies

Newfoundland and Labrador Hydro

Attention: Mr. Rob Collett

Stage 4D LIL Bipole: Transition to High Power Operation

Technical Note: TN1205.71.07
Date of issue: April 7, 2020

Prepared By:
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Disclaimer

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

Revisions

Project Name:	RFI Studies
Document Title:	Stage 4D LIL Bipole: Transition to High Power Operation
Document Type:	Technical Note
Document No.:	TN1205.71.07
Last Action Date:	April 7, 2020

Rev. No.	Status	Prepared By	Checked By	Date	Comments
00	DFC	R. Ostash/ R. Brandt		January 14, 2020	Preliminary draft Issued for review by Hydro
01	IFC			August 13, 2019	Updated report based on comments received on August 7, 2019
02	IFC			September 17, 2019	Updated report based on comments received on September 10, 2019
03	IFA			September 20, 2019	Updated report based on comments received on September 20, 2019
04	ABC			September 25, 2019	Updated and approved report based on final comments received September 25, 2019
05	IFA			February 26, 2020	Updated report using simulations with GE's PSSE model of the LIL.
06	IFA			March 31, 2020	Updated report based on comments received on March 6, 2020.
07	IFA			April 7, 2020	Updated report based on comments received on April 7, 2020.

Legend of Document Status:

Approved by Client	ABC	Issued for Approval	IFA
Draft for Comments	DFC	Issued for Information	IFI
Issued for Comments	IFC	Returned for Correction	RFC

Table of Contents

1. Executive Summary

Operational studies are underway to determine the system operating limits of the Newfoundland and Labrador Hydro (“Hydro”) Island Interconnected System (“IIS”). To date, several stages of operational studies have been performed to identify Labrador Island link (“LIL”) and Maritime Link (“ML”) transfer limits for the phased monopolar approach, with the LIL monopole operating up to a maximum of 225 MW.

Stage 4 is the final stage of operational studies and includes the 900 MW LIL bipole, the Muskrat Falls (“MFA”) generators, the Soldiers Pond (“SOP”) synchronous condensers and the ML.

This report investigates the period in time where the system is transitioning from low to high power operation on the LIL. LIL and ML transfer limits are determined for this period in time as more equipment comes into service.

As equipment is being brought online, the following considerations/sensitivities are considered in this report:

- Operation of the Holyrood (“HRD”) Thermal Plant was considered
- Number of SOP synchronous condensers in-service (1 or 2)
- LIL operating as monopole or bipole
    - Without frequency control
    - Without 2 pu 10-minute overload capability for loss of a pole
- Number of SOP and MFA filters (needed to meet IEC harmonic distortion limits)

1.1 LIL Transfer Limits

The contingencies that define the LIL transfer limits are loss of the LIL bipole and loss of a LIL pole. LIL transfer limits for the transitional period are shown in Figure 1–1 (ML frequency controller in-service) and Figure 1–2 (ML frequency controller out-of-service).

Loss of the LIL Bipole
Ultimately, the UFLS scheme will be modified/re-designed during the final Stage 4 operational study to allow increased LIL transfer limits while ensuring that the system remains stable after shedding the 58 Hz block of load, as per Transmission Planning Criteria. However, during the period when the system is transitioning from low to high power operation, the existing UFLS scheme will remain in place, therefore LIL transfer limits are needed to ensure that the system remains stable following the loss of the LIL bipole. The frequency criteria used in this study allowed the 58 Hz block of load to be shed if the LIL bipole is lost, as long as the system recovered well and in a stable manner following the loss of LIL bipole. Note also that if the LIL bipole is lost, the ML (if exporting) will runback[1].

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[1] If the ML is exporting less 150 MW or importing less than 170 MW, the ML response would be limited to frequency controller action. If the ML is exporting and is runback, no further support is provided by the ML frequency controller.

Loss of the LIL Pole

Transmission Planning Criteria for loss of a LIL pole are defined to ensure that such an event will not cause the IIS frequency to drop below 59 Hz and will not result in UFLS. The LIL will ultimately have a 10-minute 2 pu overload rating; however, during the period when the system is transitioning from low to high power operation, this overload capability will not be available. Rather, the LIL's capacity for pole compensation will be limited to 1 pu DC current. It is noted that the ML is equipped with runbacks or frequency controller action to provide support in the event of the loss of a LIL pole.

With the use of ML runbacks or the operation of the ML frequency controller, the IIS frequency remained above 59 Hz for loss of a LIL pole under all operating scenarios, with the exception of peak load conditions. Under peak load conditions, except for the case with the ML exporting 500 MW, the loss of a LIL pole was more limiting than loss of the bipole. The LIL transfer limits were reduced accordingly for these peak load cases in order to ensure IIS frequency remains above 59 Hz if a LIL pole trips.

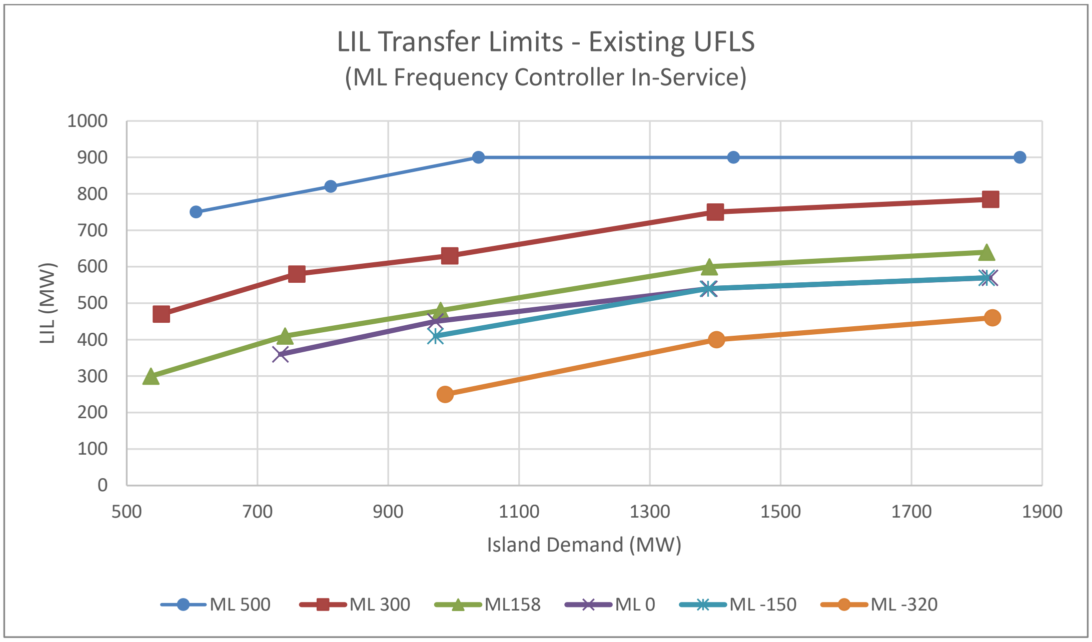

Figure 1–1. LIL Transfer Limits (ML Frequency Controller in-service)

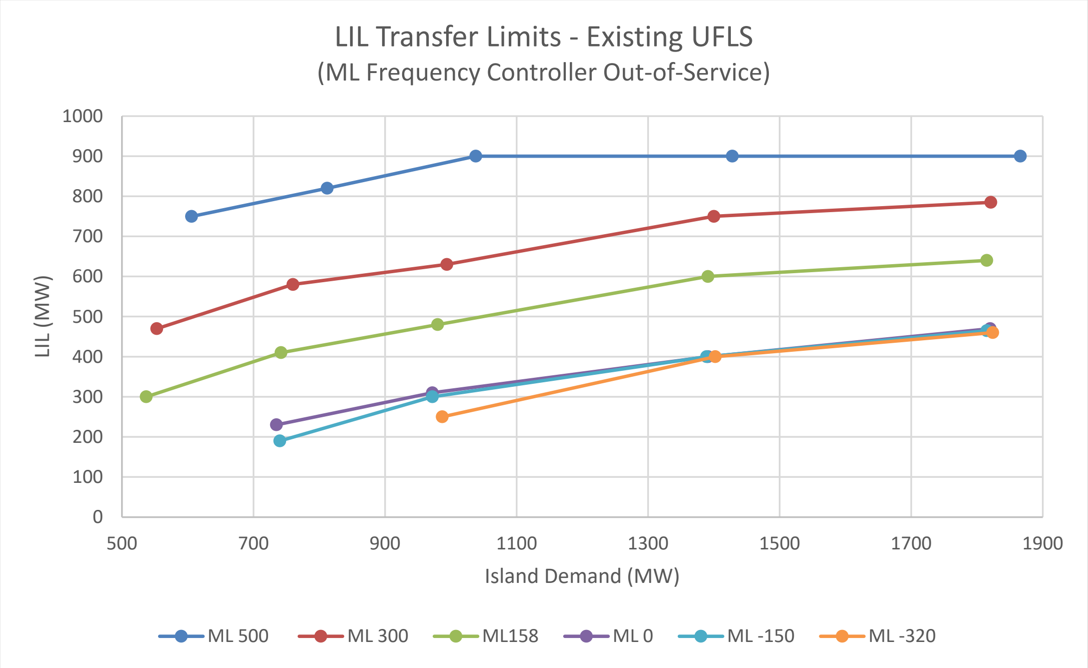

Figure 1–2. LIL Transfer Limits (ML Frequency Controller out-of-service)

1.2 ML Transfer Limits

As per Transmission Planning Criteria, loss of an ML pole (when importing) should not result in UFLS and frequency should remain above 59 Hz. UFLS is allowed for loss of the ML bipole; frequency is allowed to dip below 58 Hz as long as the system recovers well after the 58 Hz block of load is shed. If exporting, frequency should remain below 62 Hz for loss of an ML pole or bipole.

1.2.1 Without use of LIL Runbacks or Run-ups

ML transfer limits without the use of LIL runbacks or run-ups are show in Figure 1–3. This figure assumes that only HRD unit 3 is in-service as a synchronous condenser during ML export (no HRD units dispatched as generators). Figure 1–4 depicts the ML export limits[2] with 1, 2 and 3 HRD units in-service and dispatched as generators.

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[2] More restrictive ML export limits are needed when HRD units are in-service in order to limit the decrease in power output to 15 MW per HRD unit in response to the system overfrequency that occurs when the ML bipole is lost.

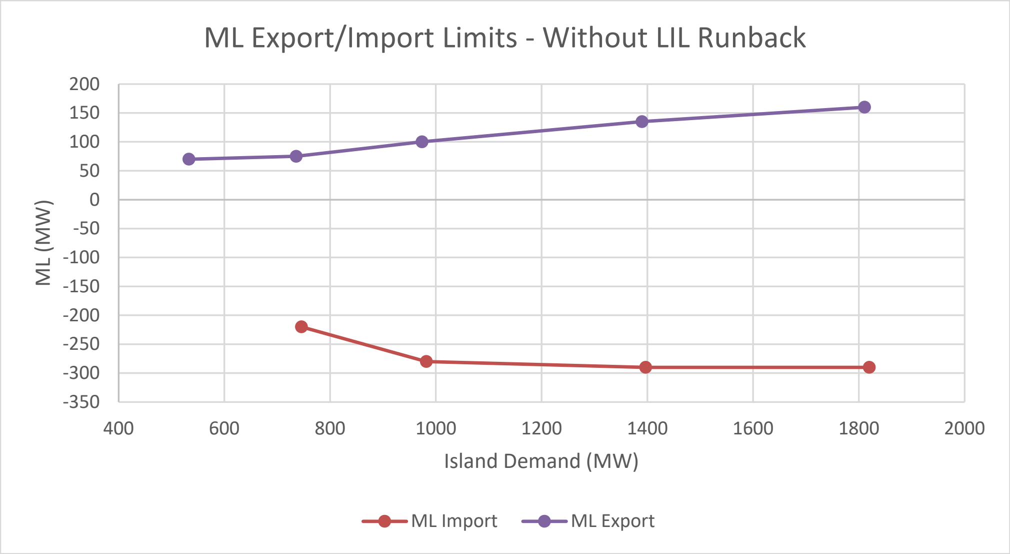

Figure 1–3. ML import/export limits, without LIL run-ups/runbacks or frequency control (no HRD units dispatched as generators).

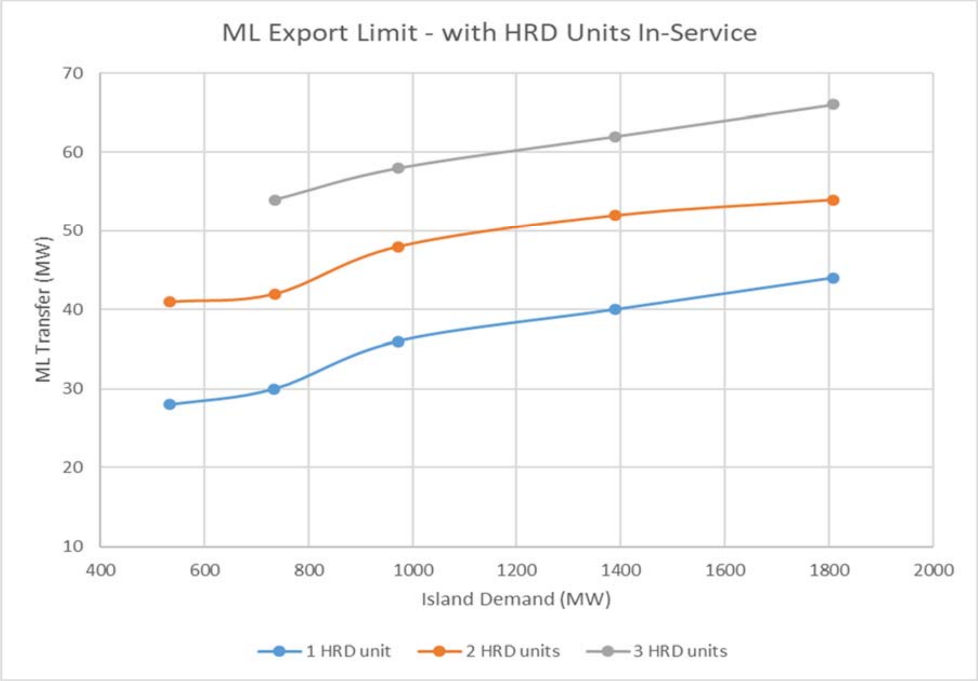

Figure 1–4. ML Export Limits with HRD Units In-service (without LIL runbacks)

1.2.2 With the use of LIL Runbacks and Run-ups

If LIL run-ups are initiated when there is loss of ML import, and LIL runbacks are initiated when there is loss of ML export, then ML power transfer is not limited, and the ML can operate over its full range from 320 MW import to 500 MW export. This assumes that there is sufficient room available on the LIL (up or down) to cover for loss of the ML bipole.

A simple approach to determine the amount of LIL runback or run-up that is required for a particular ML import or export level is to simply runback or run-up the LIL by the amount of ML export or import that was lost. Note that the LIL runback or run-up should be high enough at MFA to consider LIL losses such that the total LIL runback or run-up as measured at Soldiers Pond is equal to the amount of ML export or import that was lost. This method is applicable to all levels of ML import or export over all ranges of IIS demand.

1.3 Additional Conclusions

The following additional conclusions were made during the study.

1. **Need for Avalon Generation during High Island Demand**

To ensure stability and to avoid electromechanical oscillations for loss of the LIL bipole, there is a requirement to ensure that generation is online on the Avalon Peninsula over peak.

a) To avoid voltage collapse

The IIS can become unstable if the LIL bipole trips during high IIS demand. It was determined that a minimum amount of Avalon generation (as defined in Table 1-1) is required to be in-service during high IIS demand to prevent system instability if the LIL bipole is lost. The Come-By-Chance capacitor banks should also be in-service (as many as steady state voltage allows) when the power flow eastward from Bay d'Espoir ("BDE") towards Soldiers Pond ("SOP") is high to help support the voltage if the LIL bipole is lost.

Table 1-1. Minimum Avalon Thermal Generation Required to be in-service to prevent voltage collapse following LIL bipole trip

IIS Demand (MW)	Avalon Generation (MW)			
	0 SOP Syncs	1 SOP Sync	2 SOP Syncs	3 SOP Syncs
1750-1850	120	70	40	None*
1700-1750	70	15	None*	None*
1600-1700	30	None*	None*	None*

*unless required for MW dispatch to meet IIS demand and ML exports

b) To avoid electromechanical oscillations

Electromechanical oscillations were also observed following a trip of the LIL bipole. In this case, the oscillations were worst (least damped) with three SOP synchronous condensers in-service, and became more damped with fewer SOP synchronous condensers in-service. With one or no SOP synchronous condensers in-service, the oscillations are damped and no mitigation is required.

The following pre-contingency power flow limits should be followed to improve the damping of the oscillation and to avoid system instability:

- Two SOP synchronous condensers – limit power flow eastward out of BDE (on TL202, TL206, TL267) to 540 MW
- Three SOP synchronous condensers – limit power flow eastward out of BDE (on TL202, TL206, TL267) to 510 MW

Once properly tuned Power System Stabilizers (“PSSs”) are in-service, these power flow restrictions for the two and three SOP synchronous condenser scenarios can likely be eliminated and then only the limits in Table 1-1 would apply.

c) To avoid instability due to 3PF on TL267

Additionally, in line with previous operational studies[3], when power flow from BDE to SOP reaches levels around 650 MW (with or without the LIL in service), the IIS can also experience instability if there is a three phase fault (“3PF”) on line TL267. Therefore, power flow on this corridor should be limited to 650 MW.

2. Impact of SOP Synchronous Condensers on LIL Transfer Limits

The SOP synchronous condensers provide inertia to the Island, and they help the system by slowing down the rate of change of frequency immediately after infeed from the LIL is lost. It was found that although they slow down the initial rate of change of frequency, they do not impact the minimum frequency that occurs, and therefore the transfer limits defined in this study were the same whether one or two SOP synchronous condensers were in-service.

3. Concept of “Net DC”

The concept of “Net DC” to the IIS applies when the ML is exporting and can be runback to 0 MW if the LIL bipole is lost. For example, at a 1400 MW demand level, LIL power transfer is limited to 750 MW if ML is exporting 300 MW. At the same demand level, LIL power transfer is limited to 600 MW if ML is exporting 158 MW. In both cases, subtracting ML export from the LIL transfer limit results in a value of around 450 MW, which could be termed the “Net DC” limit. Figure 1–5 shows the approximate “Net DC” limits when the ML is exporting. Note that over peak, the Net DC is limited by loss of a LIL pole instead of loss of the LIL bipole. Also note that the “Net DC” limits are very similar for various ML export levels.

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[3] TGS report R1529.01.02 “Solutions to Serve Island Demand during a LIL Bipole Outage”, and TGS report TN1205.62.05 “Stage 4A LIL Bipole: Preliminary Assessment of High Power Operation”.

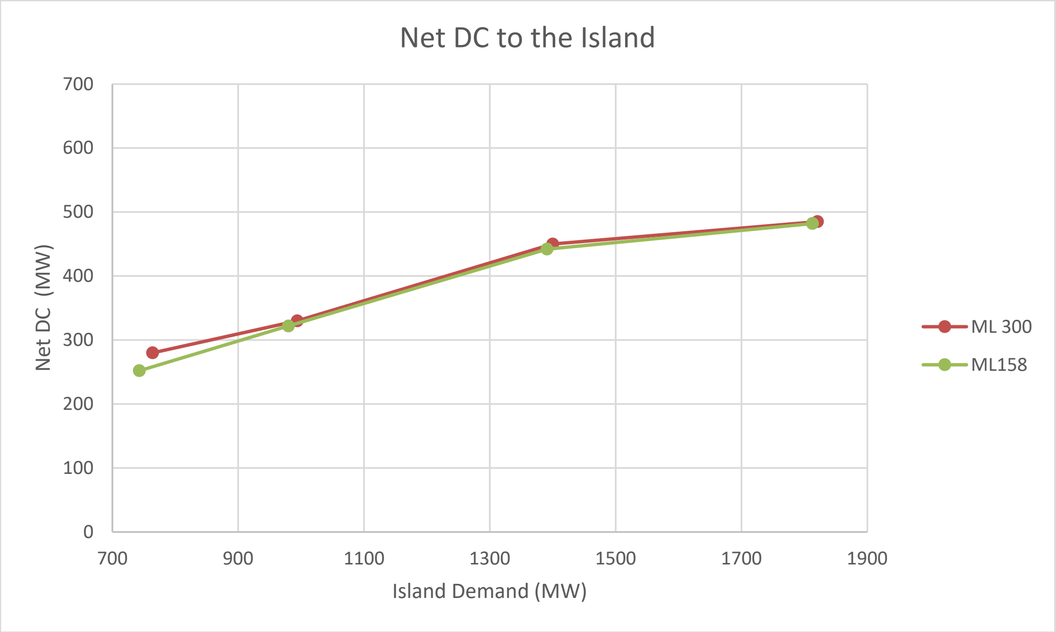

Figure 1–5. Maximum "Net DC" to the Island during ML export

1.4 Harmonic Analysis

In order to meet IEC harmonic limits, the analysis concluded that the LIL may be operated up to 675 MW in monopole operation and 900 MW in bipole operation with the filter configurations listed in Table 1-2.

Table 1-2. LIL limits and filter configurations to meet IEC harmonic limits[4]

Monopole Operation up to 675 MW		**Bipole Operation up to 900 MW**	
Muskrat Falls	**Soldiers Pond**	**Muskrat Falls**	**Soldier's Pond**
two A type	one A type, one B type	two A type filters**	one A type, one B type
two A type, one B type	one A type, two B type	two A type, one B type	one A type, two B type
two A type, two B type	two A type, two B type	two A type, two B type	two A type, two B type
three A type, one B type	two A type, three B type	three A type, one B type	two A type, three B type
	three A type, two B type		three A type, two B type

** except when only one or two MFA units are in service under light load conditions, or when only one MFA unit is in service under peak load conditions, in which case, operation is possible only up to 810 MW with two A type filters

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[4] The type A filter is a triple tuned filter, tuned to harmonics 3, 12, and 23. The type B filter is a high pass filter, tuned to the 11th harmonic.

2. Study Models and Criteria

The Interconnected Island System (IIS) is the area of focus for this study.

2.1 Interconnected Island System

The 230 kV network of the IIS is shown in Figure 2–1.

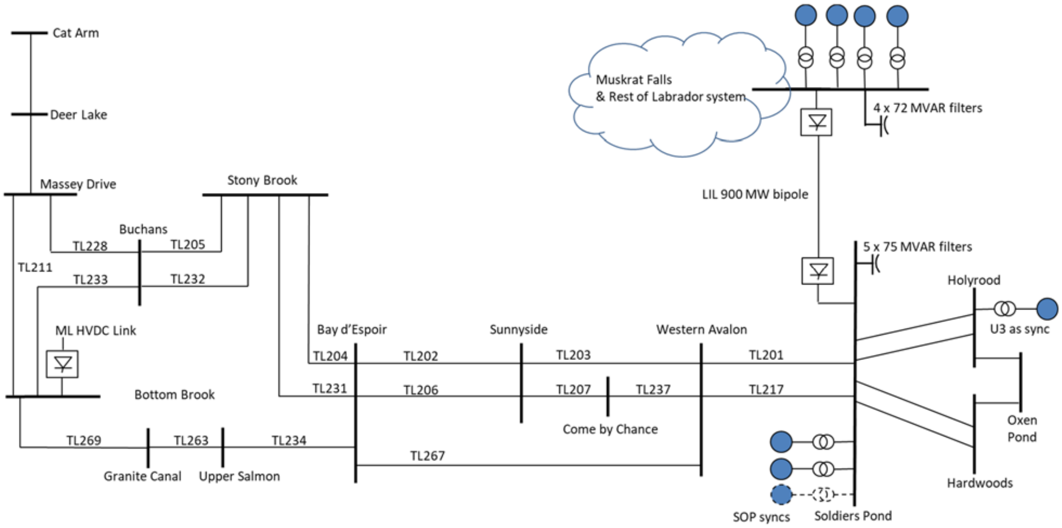

Figure 2–1. Interconnected Island System 230 kV grid

2.2 Study Assumptions

The following assumptions are made for this study:

- HRD units (1,2,3) are available as required, until the full LIL 900 MW bipole and all associated equipment and control functionality are in-service.[5] The final Stage 4 operational study will assume that the HRD units have been retired.
- LIL frequency controller is not in-service. The LIL frequency controller will be considered in-service in the final Stage 4 operational study.
- LIL 2 pu 10-minute overload is not available.
- The existing ULFS scheme will remain as is. The new UFLS scheme will be assumed in-service in the final Stage 4 operational study.
- ML can operate between 320 MW import and 500 MW export, if not limited by operational restrictions

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[5] Thermal generation is minimized in all base cases, but may be increased, as required, if transmission system violations are found.

- It is assumed that the ML (if exporting) will runback to 0 MW in the event of the loss of the LIL bipole or a pole. It is assumed that no additional support will be provided from the ML frequency controller if it has been runback.
- As long as import capacity is available, the ML frequency controller will provide up to 150 MW of frequency support if a LIL pole is lost or for other underfrequency events that cause the ML frequency controller to operate, as long as the ML has not been runback for the event.
- The ML frequency controller was enabled when ML flow ranged between -170MW (import) to 150 MW (export). Runbacks will occur whenever the LIL bipole is lost and the ML is exporting more than 150 MW. It is assumed that if a runback occurs, the ML frequency controller will not provide further support.

2.3 Study Criteria

The applicable Transmission Planning Criteria for this study is summarized below:

- Steady state voltage : 0.95 pu – 1.05 pu during n-0 conditions
- Steady state voltage : 0.90 pu – 1.1 pu during n-1 conditions
- 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 59 Hz and shall not rise above 62 Hz
- For a loss of the ML bipole and for loss of the LIL bipole, underfrequency load shedding shall be permitted, but controlled, and the system frequency is allowed to shed the 58 Hz block of load shed, as long as the system recovers in a stable manner.

2.4 Contingencies

Table 2-1 lists the contingencies that were considered in this study.

Table 2-1. Contingencies

Line/Generator	Description
Loss of LIL pole	Permanent loss of LIL pole. Assumes no 2pu overload functionality
Loss of LIL bipole	Permanent loss of LIL bipole
Loss of ML bipole	Permanent loss of ML bipole
Loss of ML pole	Permanent loss of ML pole

2.5 PSSE Base Cases

Table 2-2 lists the base cases that were used to analyze the IIS system in this study.

Table 2-2. Base cases

Load Condition	Island Demand (MW)[6]	LIL Power Transfer (at MFA) (MW)	Island Generation (MW)
Peak[7]	1825	810 (import)	1214
Intermediate Peak	1391	700 (import)	889
Intermediate	980	620 (import)	548
Light	743	520 (import)	402
Extreme Light	537	300 (import)	402

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[6] Island Demand includes load and losses. Variations in Island Demand for the same loading condition are attributed to incremental losses associated with variations in dispatch.
[7] Peak loading conditions are based on 2028 forecasted load.

3. LIL Transfer Limits

There are two contingencies that define the LIL transfer limits:

1. Loss of a LIL pole
2. Loss of the LIL bipole

Loss of the LIL Bipole

Loss of the LIL bipole is the contingency that defines the requirements of the UFLS scheme for the IIS. Ultimately, the UFLS scheme will be modified/re-designed during the final Stage 4 operational study to allow increased LIL transfer limits while still ensuring that the system remains stable after shedding the 58 Hz block of load, as per Transmission Planning Criteria.

This report is investigating the period in time where the system is transitioning from low to high power operation. During this time, the existing UFLS scheme will remain in place and LIL transfer limits will be enforced as required to ensure that the system remains stable following the loss of the LIL bipole. The frequency criteria used in this study allows the 58 Hz block of load to be shed if the LIL bipole is lost, as long as the system recovers well and in a stable manner following the loss of LIL bipole and the subsequent UFLS. Note also that if the LIL bipole is lost, the ML (if exporting greater than 150MW) will be runback to 0 MW[8].

Loss of the LIL bipole was simulated for IIS system conditions ranging from extreme light to peak demand, and for levels of ML power transfer ranging from 320 MW import to 500 MW export. There are two stability issues that were observed when the LIL bipole is lost:

1. Decline in IIS frequency and subsequent UFLS
2. Voltage collapse around the mid-point of the BDE-SOP 230 kV corridor (around Sunnyside) during high IIS demand conditions

LIL transfer limits required for reasons of underfrequency are described in Section 3.1. The voltage collapse issue is discussed further in Section 3.2.3.

Loss of the LIL Pole

The Transmission Planning Criteria for loss of a LIL pole are specified such that this event should not cause the IIS frequency to drop below 59 Hz, and it should not result in UFLS.

The LIL is ultimately being designed with a 10-minute 2 pu overload rating. If one of the LIL poles is lost, the remaining pole is rated to transmit 2 pu for 10 minutes, after which the continuous monopole rating drops down to 1.5 pu. The purpose of the 10-minute 2.0 pu overload rating is to allow operators time to quickly dispatch other resources to make up for the loss of infeed from the LIL pole that was lost.

During the transition from low to high power operation, this 2 pu overload capability will not yet be available. Rather, the LIL's capacity for pole compensation will be limited to 1 pu DC current. It is noted

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[8] If the ML is exporting less than 150MW or importing less than 170MW, the ML response would be limited to frequency controller action.

that the ML is equipped with runbacks or frequency controller action to provide support in the event of the loss of a LIL pole.

Since the last update of the report, GE's PSSE model of the LIL was received. The loss of a LIL pole was revisited for this study using the GE model of the LIL, as described below.

Simulations for loss of a LIL pole were re-run using GE's model of the LIL for the same IIS system conditions as the LIL bipole. The LIL transfer limits determined for loss of the LIL bipole were checked to ensure that loss of a LIL pole at these LIL power transfer limits would meet the 59 Hz criteria.

3.1 Study Results

With the use of ML runbacks or the operation of the ML frequency controller, the IIS frequency remains above 59 Hz for loss of a LIL pole under all operating scenarios, with the exception of peak load conditions. Under peak load conditions, except for the case with ML exporting 500 MW export, loss of a LIL pole was more limiting than loss of the LIL bipole, and the LIL transfer limits were reduced accordingly for these cases in order to ensure IIS frequency remains above 59 Hz if a LIL pole trips.

The LIL power transfer limits during the transitional period are listed in Table 3-1 and shown in Figure 3–1 (ML frequency controller in-service) and Figure 3–2 (ML frequency controller out-of-service).

Please note the following:

- In all peak demand cases, voltage considerations were found to be more limiting than underfrequency concerns. The results in the table below only reflect underfrequency limits, while Section 3.2.3 discusses the voltage collapse issue and prevention in more detail.

Table 3-1. Transitional Period Results – LIL Transfer Limits with and without ML Frequency Controller

				ML Frequency Controller IN					ML Frequency Controller OUT				
	Demand	Generation	ML	Loss LIL Bipole Transfer Limit (MW)	Minimum Frequency (Hz)	Loss LIL Pole Transfer Limit (MW)	ML Runback* (MW)	Minimum Frequency (Hz)	Loss LIL Bipole Transfer Limit (MW)	Minimum Frequency (Hz)	Loss LIL Pole Transfer Limit (MW)	ML Runback* (MW)	Minimum Frequency (Hz)
Peak	1866	1530**	500	900	58.08	900	400	59.6	900	58.08	900	400	59.6
Ipeak	1428	1094	500	900	57.97	900	400	59.2	900	57.97	900	400	59.2
Int	1038	703	500	900	57.81	900	400	59.2	900	57.81	900	400	59.2
Light	812	476	500	820	57.93	820	350	59.5	820	57.93	820	350	59.5
ExLight	606	401	500	750	58	750	260	59.4	750	58	750	260	59.4
Peak	1821	1285**	300	900	57.71	785	300	59.1	900	57.71	785	300	59.1
Ipeak	1400	915	300	750	57.79	750	300	59.3	750	57.79	750	300	59.3
Int	994	589	300	630	57.87	630	190	59.13	630	57.87	630	190	59.13
Light	760	452	300	580	57.87	580	130	59.4	580	57.87	580	130	59.4
ExLight	553	409	300	470	58.05	470	0	59.17	470	58.05	470	45	59.08
Peak	1815	1303**	158	720	57.73	640	158	59.15	720	57.73	640	158	59.15
Ipeak	1391	889	158	600	57.72	600	158	59.83	600	57.72	600	158	59.22
Int	980	548	158	480	57.86	480	0	59.17	480	57.86	480	40	59.15
Light	742	433	158	410	57.88	410	0	59.31	410	57.88	410	0	59.13
ExLight	537	402	158	300	58.02	300	0	59.45	300	58.02	300	0	59.45
Peak	1820	1330**	0	670	57.92	570	-	59.03	510	57.81	470	-	59.08
Ipeak	1391	906	0	540	57.87	540	-	59.01	400	57.85	400	-	59.5
Int	972	538	0	450	57.92	450	-	59.23	310	57.91	310	-	59.66
Light	735	403	0	340	57.99	360	-	59.31	230	57.93	230	-	59.83
ExLight	535	404	0	130	59.05	130	-	59.99	130	58.1	130	-	59.99
Peak	1815	1049**	-150	650	57.95	570	-	59.04	510	57.77	465	-	59.06
Ipeak	1389	757	-150	540	57.91	540	-	59.03	400	57.87	400	-	59.6
Int	972	424	-150	410	57.99	410	-	59.3	300	57.88	300	-	59.45
Light	740	402	-150	190	58.82	190	-	59.8	190	57.99	190	-	59.8
ExLight	536	400	-46	90	59.15	90	-	59.99	90	58.4	90	-	59.99
Peak	1824	998**	-320	500	57.85	460	-	59	500	57.85	460	-	59
Ipeak	1402	724	-320	400	57.83	400	-	59.46	400	57.83	400	-	59.46
Int	987	421	-320	250	57.98	250	-	59.8	250	57.98	250	-	59.8
Light	750	400	-260	90	58.6	90	-	59.99	90	58.6	90	-	59.99

Loss of Pole is more limiting that loss of LIL bipole

Not included in plot since not a limiting case

*In all cases, it is assumed that if ML runback is used, there is no additional support provided by the ML frequency controller.

** HRD CT dispatched to avoid voltage collapse following loss of LIL bipole, and HRD units dispatched to provide sufficient generation for system conditions.

Minimum IIS Generation

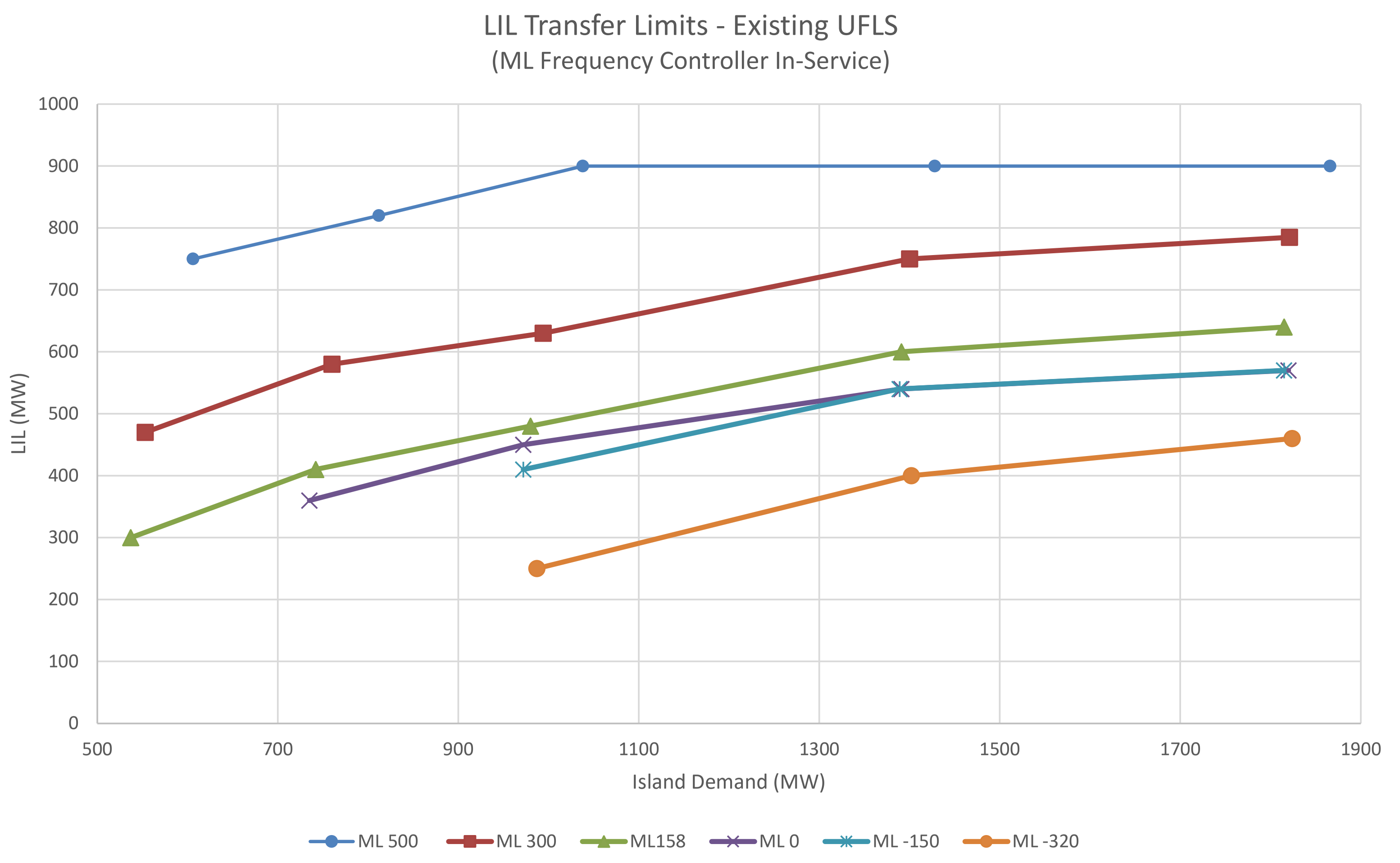

Figure 3–1. Transitional Period – LIL Transfer Limits – ML Frequency Controller In-Service

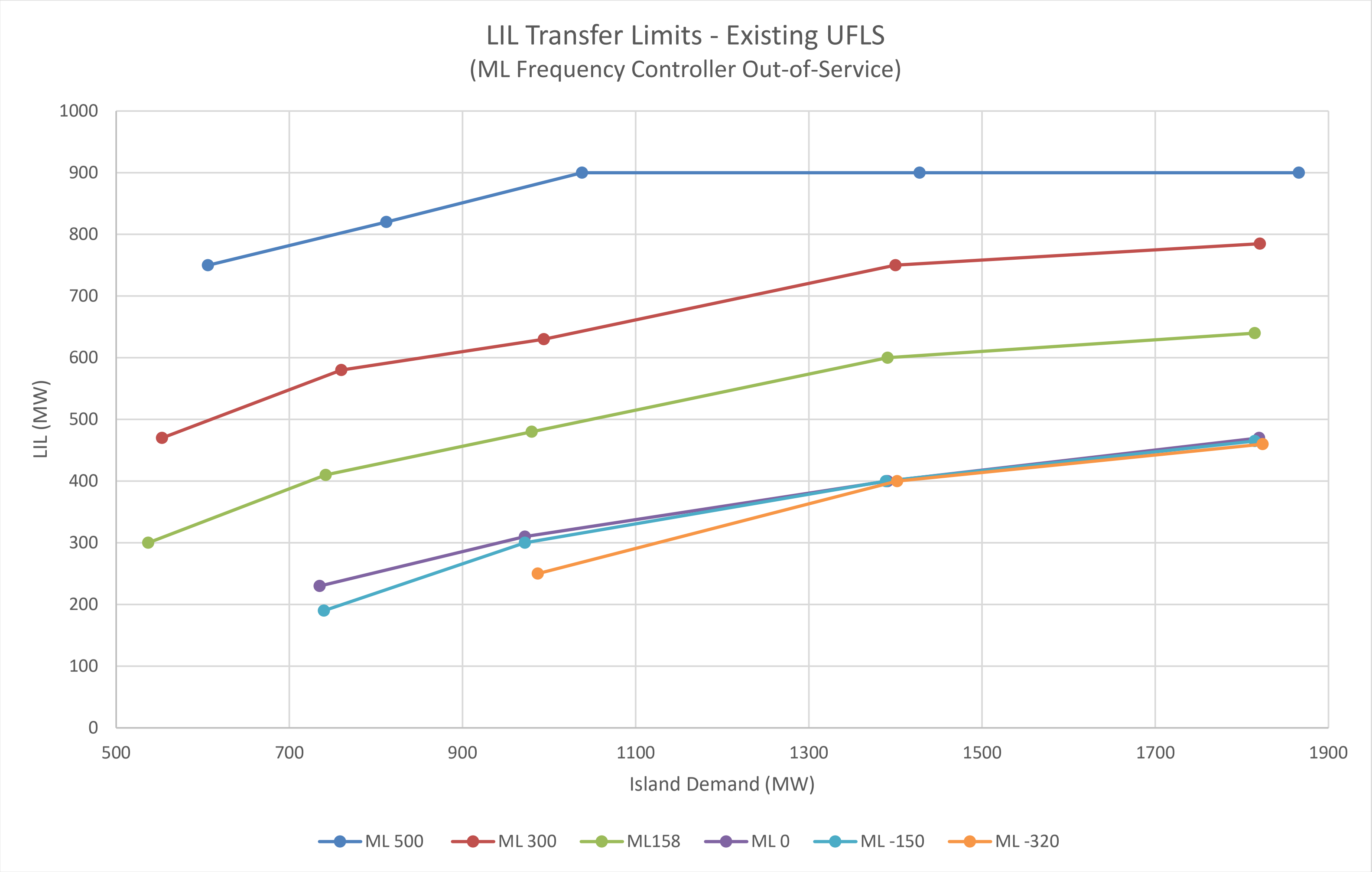

Figure 3–2. Transitional Period – LIL Transfer Limits – ML Frequency Controller Out-of-Service

3.2 Further Discussion on LIL Transfer Limits

This section discusses the following additional topics with regards to LIL transfer limits:

1. Concept of "Net DC" to the Island
2. Impact of 1 or 2 SOP synchronous condensers in-service
3. Need for Avalon Generation during high Island demand

3.2.1 Net DC to the Island

3.2.1.1 During ML Export

The concept of "Net DC" to the IIS applies when the ML is exporting and can be runback to 0 MW if the LIL is lost. For example, at a 1400 MW demand level, LIL power transfer is limited to750 MW if ML is exporting 300 MW. At the same demand level, LIL power transfer is limited to 600 MW if ML is exporting 158 MW. In these cases, subtracting ML export from the LIL transfer limit results in a value of around 450 MW, which could be termed the "Net DC" limit. Table 3-2 shows this example, indicating that for IIS demand around 1400 MW, the maximum "Net DC" to the IIS should be limited to 450 MW.

Table 3-2. Net DC to the Island

Demand (MW)	Generation (MW)	LIL Transfer Limit (MW)	ML Export (MW)	ML Runback or Frequency controller support	Maximum NET DC = LIL Limit -ML Runback or Frequency controller support (MW)
1821	1285	785	300	300	585
1400	915	750	300	300	450
994	589	630	300	300	330
764	404	580	300	300	280
1813	1214	640	158	158	482
1391	889	600	158	158	442
980	548	480	158	158	322
743	402	410	158	158	252

Figure 3–3 graphically depicts the maximum net DC to the Island from Table 3-2, with each line on the plot representing a different ML export level.

It is evident from Figure 3–3 that the net DC to the Island is approximately the same regardless of ML export level, as long as the ML export is runback to 0 MW when the LIL bipole is lost[9].

Note that over peak, the Net DC is limited by loss of a LIL pole instead of loss of the LIL bipole. Also note that the "Net DC" limits are very similar for various ML export levels.

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[9] Please note that if the ML export is runback to 0 MW, it is assumed that no additional support will be provided from the ML frequency controller. The ML 0 MW or ML import cases assume ML frequency controller action since runbacks are not available in those cases.

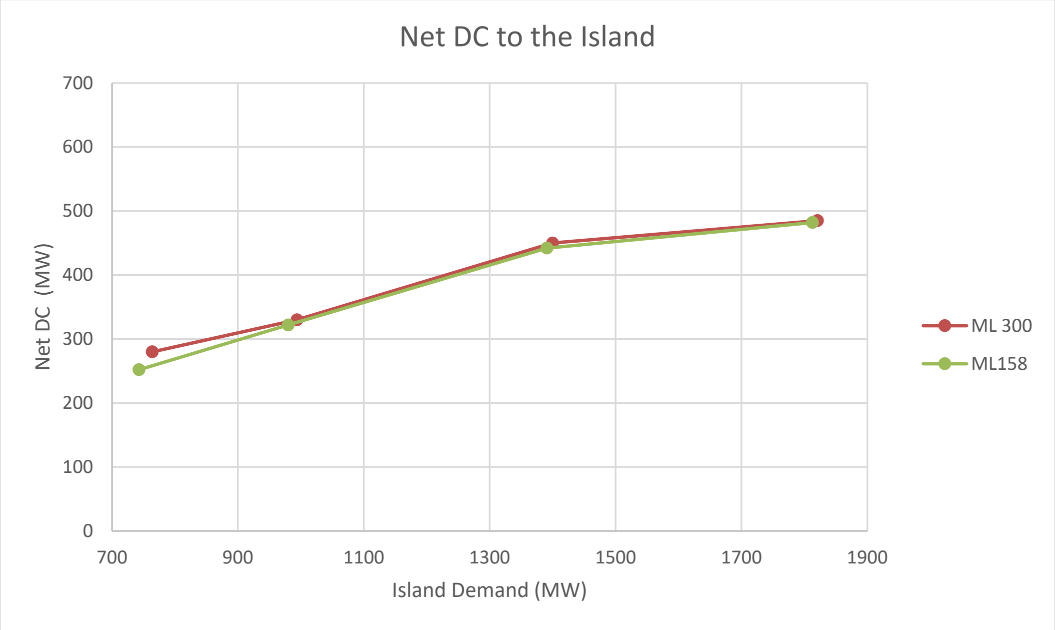

Figure 3–3. Maximum "Net DC" to the Island during ML export

3.2.1.2 During ML import

The "NET DC" concept does not apply in the same manner when the ML is operating at 0 MW or when importing because it cannot be runback to help the IIS frequency. However, as long as import capacity is available, the ML frequency controller will provide up to 150 MW of frequency support if a LIL pole or the bipole is lost.

The LIL transfer limits in Figure 3–1 corresponding to ML at 0 MW and ML importing 150 MW are nearly identical. This is because in both cases the ML provides a fast 150 MW response to loss of the LIL infeed, resulting in a similar frequency response in the IIS.

The LIL transfer limit corresponding to ML 320 MW import is approximately 150 MW lower than the ML 0 MW and ML 150 MW import cases, because in this case the ML is already operating at the import limit and does not provide any of the 150 MW support. In this case, the ML frequency controller capacity would be set to 0 MW to ensure that Maritime Area limits are not violated. Similarly, the LIL transfer limit corresponding to ML 250 MW import is approximately 80 MW lower than the ML 0 MW and ML 150 MW import cases, because there is only 70 MW of room for the frequency controller to assist. Therefore, in some sense the Net DC concept is also evident in the ML import cases, but from the perspective of support from the ML frequency controller, not from running back the ML export.

Therefore, if the ML is importing more than 170 MW (i.e. 320-170 MW=150 MW), the LIL transfer will be begin to be limited corresponding to how much room there is left for the ML frequency controller to respond, up until it reaches the maximum of 320 MW, at which point LIL transfer is most limited.

3.2.2 Impact of SOP Synchronous Condensers

The SOP synchronous condensers provide inertia to the Island, and help the system by slowing down the rate of change of frequency immediately after infeed from the LIL is lost.

Figure 3–4 shows an example of the IIS frequency response following a sustained loss of the LIL bipole, with one (blue) and two (green) synchronous condensers in-service. It is evident that the rate of change of initial frequency decline is slower with two synchronous condensers, but that the minimum frequency dip that occurs after ~3.4 seconds is very similar in both cases.[10] Therefore, this study found no significant difference in LIL power transfer limits whether there was one SOP synchronous condenser in-service or two SOP synchronous condensers in-service. This is explained by the fact that the minimum frequency of the system following the loss of supply is highly dependent on the resulting capacity deficit as opposed to total system inertia. On this basis, the loss of supply is most effectively counteracted by load shedding, runbacks, and frequency controller action. As mentioned above, the additional inertia serves to slow down the rate of frequency decay. However, the extra time for governor action is insufficient to make an appreciable difference in frequency recovery.

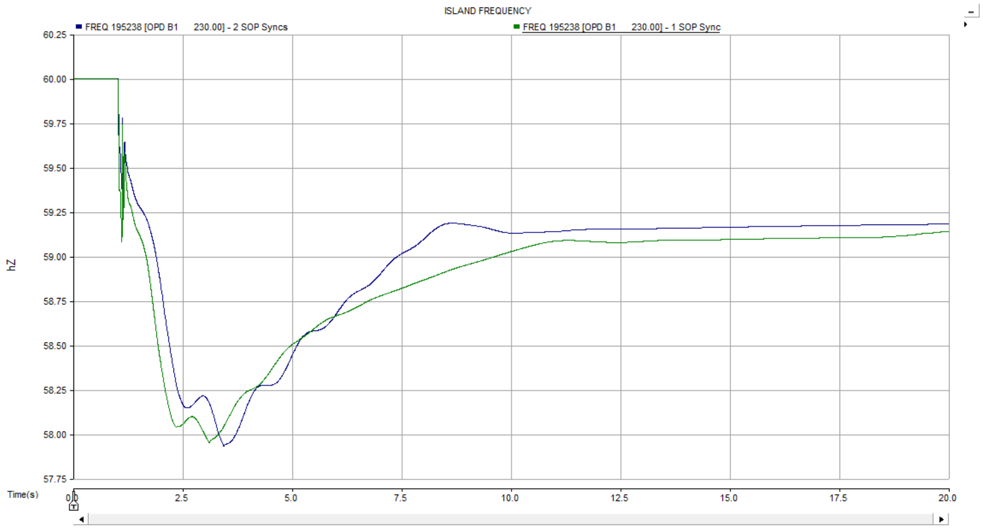

Figure 3–4. Loss of LIL bipole. Frequency response with 1 (blue) and 2 (green) SOP synchronous condensers.

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[10] Both cases have very similar minimum frequencies with slight differences being attributed to variations in the electromechanical oscillations that occur as the frequency approaches 58 Hz. These variations are due to the differences in inertia in the two cases.

3.2.3 High Island Demand – Need for Avalon Generation

To ensure stability and to avoid electromechanical oscillations for loss of the LIL bipole, there is a requirement to ensure that generation is online on the Avalon Peninsula over peak. This was introduced in the Stage 4A operational study and the Avalon Capacity study[11] .

The Avalon Capacity study observed voltage collapse for three-phase faults on the 230 kV AC lines between Bay d'Espoir and Sunnyside/Western Avalon, and the Stage 4A High Power study observed similar voltage collapse scenarios for 3PF on lines at BDE and following loss of the LIL bipole under peak demand. Previous studies have correlated the voltage collapse issue with high power transfer (i.e. greater than 650 MW) between BDE and SOP. In order to reduce this power flow during peak Island demand, there is a need for Avalon generation to be in-service.

The results of this analysis indicate the following:

1. Voltage Collapse

The voltage collapse occurs when the system becomes unstable on the first swing of transient undervoltage (worst near Sunnyside) after the LIL bipole trips. This issue is worst with no SOP synchronous condensers in-service and improves as more SOP synchronous condensers are brought into service since they provide reactive power support in the area. It is noted that the voltage collapse is not a function of the pre-event LIL power flow or the 230 kV power flow to the Avalon Peninsula, but rather it is a function of the total power flow over the 230 kV corridor following the LIL bipole trip. This is due to the lack of dynamic reactive support to withstand such significant power flows in the BDE-SOP corridor. The voltage collapse can be mitigated by ensuring sufficient Avalon generation is on-line pre-contingency during high demand as summarized in Table 3-3, for scenarios with 0, 1, 2 and 3 SOP synchronous condensers in-service.

Table 3-3. Minimum Avalon Thermal Generation Required to be in-service to prevent voltage collapse following LIL bipole trip

IIS Demand (MW)	Avalon Generation (MW)			
	0 SOP Syncs	1 SOP Sync	2 SOP Syncs	3 SOP Syncs
1750-1850	120	70	40	None*
1700-1750	70	15	None*	None*
1600-1700	30	None*	None*	None*

*unless required for MW dispatch to meet IIS demand and ML exports

2. Electromechanical Oscillations

Electromechanical oscillations were also observed following a trip of the LIL bipole. In this case, the oscillations were worst (least damped) with three SOP synchronous condensers in-service, and became

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[11] TGS report R1529.01.02 "Solutions to Serve Island Demand during a LIL Bipole Outage", and TGS report TN1205.62.05 "Stage 4A LIL Bipole: Preliminary Assessment of High Power Operation".

more damped with fewer SOP synchronous condensers in-service. With one or no SOP synchronous condensers in-service, the oscillations are damped and no mitigation is required.

The magnitude of the oscillations observed in the scenarios with two and three SOP synchronous condensers in-service can be reduced and the subsequent instability resulting from the undamped oscillations can be avoided by limiting the pre-contingency power flow eastward out of BDE during high demand. It should be noted that although the magnitude of the oscillations is significantly reduced (and instability avoided) by limiting this power flow, there are still lower magnitude oscillations observable in the AC system voltage. This issue will ultimately require mitigation using power system stabilizer tuning.

An example of the oscillations observed in AC voltage is given in Figure 3–5, which shows the SOP voltage response following a LIL bipole trip with one (red), two (green) and three (blue) SOP synchronous condensers in-service. It is observed that the first swing in AC undervoltage is worst with one SOP synchronous condenser in-service, but this response is most damped; whereas the case with three SOP synchronous condensers has the smallest first swing in AC undervoltage, but the oscillations are undamped, leading to system instability around 7 seconds after the LIL tripped.

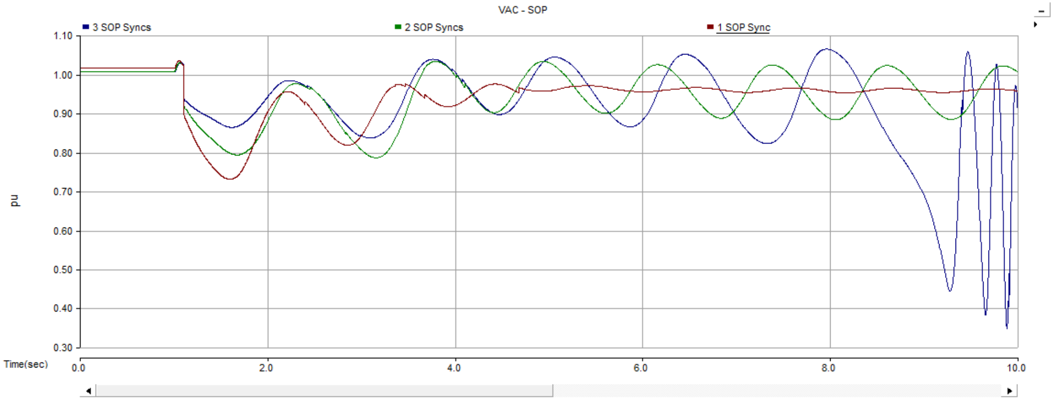

Figure 3–5. Example of SOP voltage response after loss of LIL bipole under high demand

The following pre-contingency power flow limits should be followed:

- Two SOP synchronous condensers – limit power flow eastward out of BDE (on TL202, TL206, TL267) to 540 MW
- Three SOP synchronous condensers – limit power flow eastward out of BDE (on TL202, TL206, TL267) to 510 MW

Once properly tuned PSS's are in-service, the minimum Avalon generation requirements for the 2 and 3 SOP synchronous condenser scenarios can likely be significantly reduced.

3. **Additional Items to Note**

- The Come-By-Chance capacitor banks should be in-service when the power flow eastward from BDE towards SOP is high to help support the voltage if the LIL bipole is lost. Keeping the pre-contingency voltage near Sunnyside as high as possible (within criteria) improves the system response to the worst case contingencies.

- In line with previous operational studies, when power flow from BDE to SOP reaches levels around 650 MW, the IIS can also experience instability if there is a 3PF on line TL267. Therefore, power flow on this corridor should be limited to 650 MW. The details of the operating guideline to limit power flow between BDE and SOP will be finalized during the final Stage 4 operational studies, taking into consideration all contingencies in the system including three-phase AC faults and loss of the LIL bipole.
- While it is targeted that system stability shall be maintained following the loss of the LIL bipole, this contingency is beyond the scope of Transmission Planning criteria. Results of the analysis indicate that the loss of the LIL bipole may result in transient undervoltages.

4. ML Transfer Limits

Loss of the ML bipole and ML pole are the contingencies that define the ML import and export limits.

If the ML bipole or pole is lost while exporting, the IIS will experience an overfrequency. Transmission Planning criteria states that this overfrequency should not go above 62 Hz.

If the ML bipole or pole is lost while importing, the IIS will experience an underfrequency. Transmission Planning criteria state that for loss of the bipole controlled UFLS is permitted, and the frequency is allowed to dip below 58 Hz, as long as the system recovers well after the 58 Hz block of load is shed. For loss of a pole, the frequency should remain above 59 Hz and UFLS is not permitted.

Note that if an ML pole is lost, it is assumed that the healthy ML pole will pick up the transfer that was lost on the other ML pole, up to its rating of 250 MW.

Ultimately, the LIL will have a frequency controller with a small deadband that will respond to assist IIS frequency if the ML bipole or pole trips. During the transition from low to high power operation, however, the LIL frequency controller will not yet be available.

This study determined ML export and import limits for two scenarios during the transition period:

1. Without the use of LIL runbacks or runups
2. With the use of LIL runbacks and runups

4.1 Without the use of LIL Runbacks/Run-ups

ML import and export limits were first determined without the use of LIL run-ups or runbacks to establish a baseline for the ML transfer limits. These limits were determined for scenarios when there are no Holyrood (HRD) units in-service as generators, and for scenarios where one or more HRD units are in-service. When there are no HRD units in-service as generators, the limiting criteria for loss of ML exports is keeping the system frequency below 62 Hz. When an HRD unit is in-service as a generator, the limiting criteria for ML exports becomes ensuring that the power on the HRD units does not decrease by more than 15 MW per unit as a result of the overfrequency following the loss of the ML bipole.

4.1.1 No HRD Units In-Service

These limits are listed in Table 4-1 for loss of the ML bipole and for loss of an ML pole. Red text depicts cases where loss of an ML pole is more limiting than loss of the ML bipole.

Table 4-1. ML import/export limits without LIL run-ups/runbacks – no HRD units

Import/ Export	Demand (MW)	Generation (MW)	Loss of ML Bipole		Loss of ML Pole	
			ML Transfer (MW)	Max/Min Frequency (Hz)	ML Transfer (MW)	Max/Min Frequency (Hz)
Export	1811	1213	160	62.0	160	~60.0
	1390	865	135	61.9	135	~60.0
	974	530	100	61.9	100	~60.0

Import/ Export	**Demand (MW)**	**Generation (MW)**	**Loss of ML Bipole**		**Loss of ML Pole**	
			ML Transfer (MW)	**Max/Min Frequency (Hz)**	**ML Transfer (MW)**	**Max/Min Frequency (Hz)**
	736	399	75	62.0	75	~60.0
	533	425	70	61.9	70	~60.0
Import	1835	1130	-320	58.07	-290	59.0
	1397	750	-320	57.98	-290	59.0
	982	537	-280	57.93	-280	59.16
	746	496	-220	57.93	-220	59.9

Since loss of an ML pole or bipole have the same 62 Hz frequency criteria, loss of an ML bipole defines the ML export limits.

The loss of supply (including the loss of a generator within the Island Interconnected System or the loss of a pole) must not result in UFLS. When importing, the loss of an ML pole is more restrictive than the loss of the ML bipole when defining the ML import limit in the peak demand case. In all other cases, limits are defined by the loss of the bipole. This is due to the fact that the ML is equipped with pole compensation where the healthy pole will run up to a maximum of 250 MW in the event of a pole trip. In the peak load case, there is a capacity shortfall, which results in a frequency drop to 59 Hz.

Figure 4–1 graphically depicts the most limiting ML import/export limits from Table 4-1. Note the data point for the extreme light demand case during ML import from Table 4-1 is not included because it is already at minimum generation, yet loss of the ML bipole does not result in a frequency dip to the limit of 58 Hz is the ML bipole is lost. This data point would falsely skew the results.

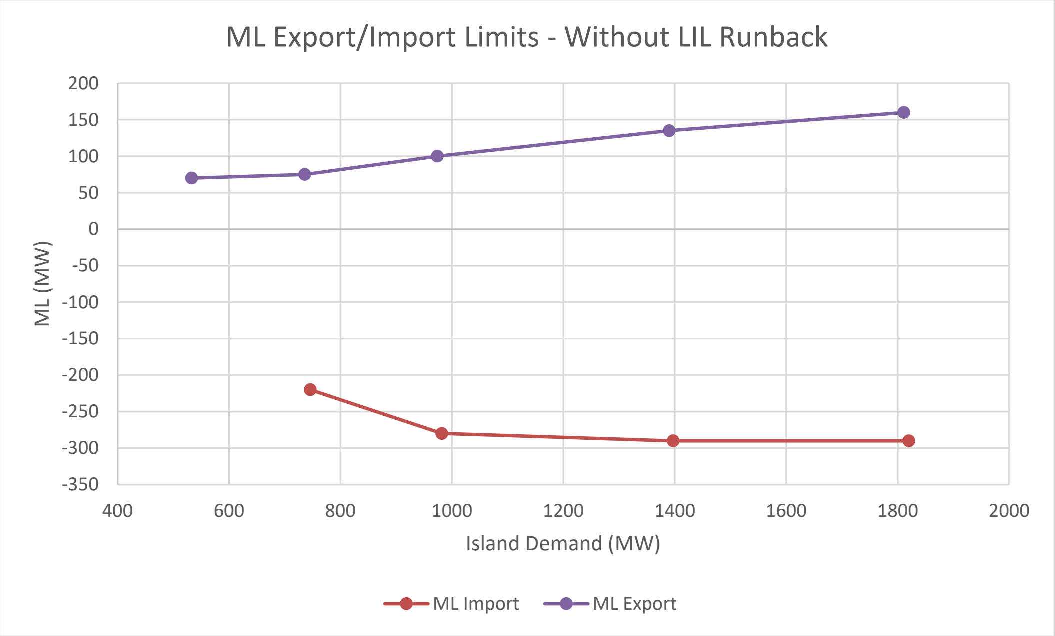

Figure 4–1. ML import/export[12] limits, without LIL run-ups/runbacks or frequency control

4.1.2 HRD Units In-Service

As previously mentioned, with HRD units in-service, ML exports must be limited such that loss of the ML bipole does not result in more than a 15 MW decrease in power output of an HRD unit in response to the system overfrequency. ML import levels shown in Figure 4–1 are not affected when HRD units are in-service.

Figure 4–2 depicts the ML export limits with 1, 2 and 3 HRD units in-service.

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[12] ML export limits in Figure 4-1 assume that no HRD units are in-service. Please see Figure 4-2 for ML export limits with HRD units in-service.

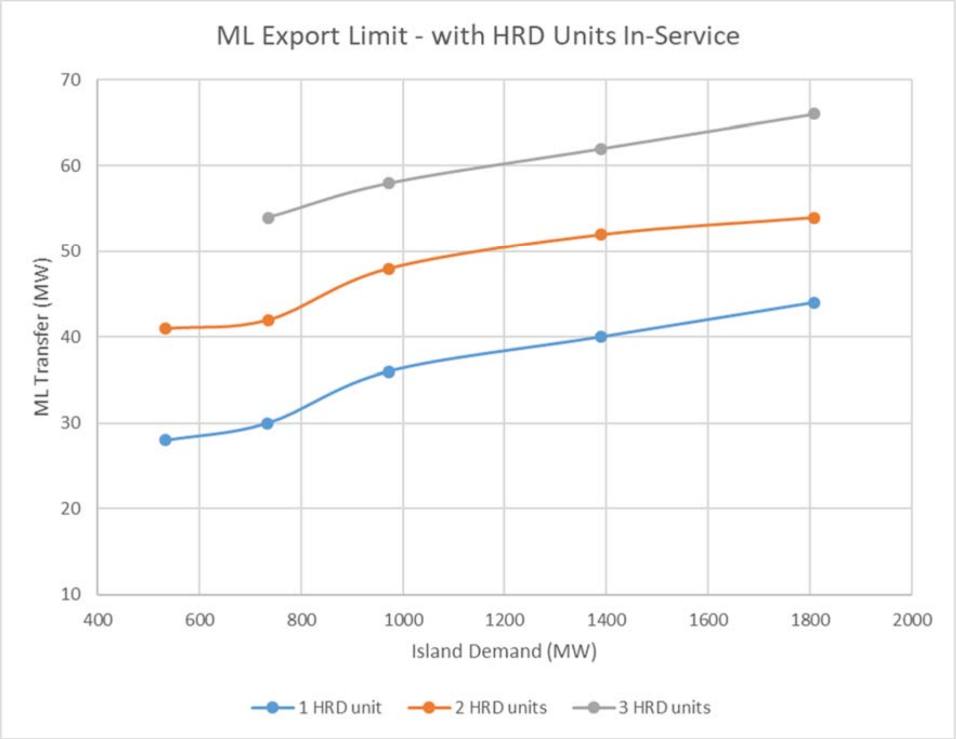

Figure 4–2. ML Export Limits with HRD units in-service

4.2 With LIL runbacks/run-ups

If LIL run-ups are used when there is loss of ML import, and LIL runbacks are used when there is loss of ML export, then the ML power transfer is not limited, and it can operate over its full range from 320 MW import to 500 MW export. This assumes that there is sufficient room available on the LIL (up or down) to cover for the loss of the ML bipole with the runbacks presented in this report.

4.2.1 ML Export Limits

Table 4-2 summarizes the minimum LIL runbacks needed to keep IIS frequency above 62 Hz following the loss of an ML pole or bipole at ML export at levels of 500 MW and 300 MW.

Table 4-2. Minimum LIL runbacks needed for loss of ML Export

Demand (MW)	Generation (MW)	ML Export (MW)	At MFA		At SOP		Maximum net loss of export on the IIS to meet 62 Hz (MW)
			LIL Transfer (MW)	Total Runback (MW)	LIL Transfer (MW)	Total Runback (MW)	
Loss of ML Bipole							
1428	1094	500	900 -> 500	400	832 -> 480	352	148
1038	703		900 -> 446	454	832 -> 432	400	100
812	476		900 -> 392	508	832 -> 380	452	48
606	402		750 -> 226	524	702 -> 222	480	20
1821	1285	300	900 ->744	156	832 -> 700	132	168
1400	915		840 -> 654	186	780 -> 618	162	138
994	589		710 -> 480	230	668 -> 464	204	96
764	404		640 -> 394	246	606 -> 380	226	74
553	400		470 -> 216	254	452 -> 212	240	60
Loss of ML Pole							
1428	1094	500	900 -> 712	188	832 -> 672	160	90
1038	703		900 -> 659	214	832 -> 626	206	44
812	476		900 -> 618	282	832 -> 588	244	6
606	402		750 -> 470	358	702 -> 452	250	0

However, rather than running back the LIL by the minimum amount needed to keep the IIS frequency below 62 Hz for each particular operating condition, a simpler approach that could be applied to all levels of ML export over all ranges of IIS demand would be to simply runback the LIL by the amount of ML export that was lost. Note that the LIL runback should be high enough at MFA to consider LIL losses, such that the total LIL runback as measured at Soldiers Pond is equal to the amount of ML export that was lost. Table 4-3 summarizes the maximum frequencies observed in the IIS using this approach for loss of the ML bipole at the maximum ML export of 500 MW.

Table 4-3. LIL Runback @ SOP = Loss of ML Export

Demand (MW)	Generation (MW)	ML Export (MW)	At MFA		At SOP		Maximum frequency (Hz)
			LIL Transfer (MW)	Total Runback (MW)	LIL Transfer (MW)	Total Runback (MW)	
1428	1094	500	900 -> 342	558	832 -> 332	500	60.2
1038	703		900 -> 342	558	832 -> 332	500	60.3
812	476		900 -> 342	558	832 -> 332	500	60.8*
606	402		750 -> 204	546	702 -> 202	500	61.3*

*These cases show some small oscillatory behaviour that will be addressed in the next stage of the operational study.

Please note that if there are HRD units in-service, LIL runback should be high enough to ensure that the maximum difference between the LIL runback as measured at Soldiers Pond and the loss of ML export is not greater than the limits shown in Figure 4–2. This will limit the decrease in power at an HRD unit to a maximum of 15 MW per unit if the ML bipole is lost.

4.2.2 ML Import Limits

Table 4-4 summarizes the minimum LIL run-ups needed to meet the underfrequency criteria for loss of the ML bipole and pole during maximum import of 320 MW.

Table 4-4. Minimum LIL run-ups needed for loss of ML import

Demand (MW)	Generation (MW)	ML Import (MW)	At MFA		At SOP		Maximum net loss of import on the IIS to meet underfrequency criteria (MW)
			LIL Transfer (MW)	Total Run-up (MW)	LIL Transfer (MW)	Total Run-up (MW)	
Loss of ML Bipole							
1820	974	320	0	0	0	0	>320
1401	674		0	0	0	0	320
987	421		250->296	46	245->290	45	275
818	407	260*	90->154	64	89->152	63	197
Loss of ML Pole							
1824	998	320	500 -> 519	19	480 -> 498	18	52
1402	724		390 -> 418	28	378 -> 404	26	44
987	421		250 -> 279	29	245 -> 273	28	42
750	400	260*	90 -> 90	0	89 -> 89	0	0

*maximum ML import during 750 MW demand with LIL at 90 MW (minimum IIS generation)

Rather than running up the LIL by the minimum amount needed to meet underfrequency criteria for each particular operating conditions, a simpler approach that could be applied to all levels of ML import over all ranges of IIS demand would be to simply run-up the LIL by the amount of ML import that was lost. Note that the LIL run-up should be high enough at MFA to consider LIL losses, such that the total LIL run-up as measured at Soldiers Pond is equal to the amount of ML import that was lost. Table 4-5 summarizes the minimum frequencies observed in the IIS if using this approach for loss of the ML bipole at the maximum import level of 320 MW.

Table 4-5. LIL Run-up @ SOP = Loss of ML Import

Demand (MW)	Generation (MW)	ML Import (MW)	At MFA		At SOP		Minimum Frequency (Hz)
			LIL Transfer (MW)	Total Run-up (MW)	LIL Transfer (MW)	Total Ru-up (MW)	
1824	998	320	460 -> 820	360	442 -> 762	320	59.9
1402	724		400 -> 760	350	387 -> 707	320	59.9
987	421		250 -> 594	344	244 -> 564	320	59.75

Demand (MW)	Generation (MW)	ML Import (MW)	At MFA		At SOP		Minimum Frequency (Hz)
			LIL Transfer (MW)	Total Run-up (MW)	LIL Transfer (MW)	Total Ru-up (MW)	
750	400	260*	90 -> 360	270	89 -> 349	260	59.8

*maximum ML import during 750 MW demand with LIL at 90 MW (minimum IIS generation)

5. Harmonic Analysis

Harmonic analysis was performed to determine the maximum LIL transfer limits before the IEC performance limits are exceeded, as the system transitions from low power (225 MW monopole) to high power (900 MW bipole) operation.

In this study, the harmonic currents generated by the converter as given in the GE AC Filter Performance report [1] were used.

5.1 IEC Performance Limits

The performance limits according to IEC 61000-3-6 are given in Table 5-1.

Table 5-1. IEC performance limits

Odd harmonic (non-multiple of 3)		Odd harmonics (multiple of 3)		Even harmonics	
Harmonic	**Dh (%)**	**Harmonic**	**Dh (%)**	**Harmonic**	**Dh (%)**
5	2	3	2	2	1.4
7	2	9	1	4	0.8
11	1.5	15	0.3	6	0.4
13	1.5	21	0.2	8	0.4
17≤h≤49	1.2*17/h	21<h≤45	0.2	10≤h≤50	0.19*(10/h)+0.22
THD ≤ 3%					

5.2 Muskrat Falls

5.2.1 AC system harmonic impedance

Because this study was looking at operational limits, impedance sectors were not used to represent the ac system as was the case for the contract design. Rather, the analysis was performed using power flow cases created by Hydro, where calculated impedance points at each harmonic order were considered under various operating conditions. The power flow cases used to represent the Labrador system at peak and light load scenarios are shown in Table 5-2.

Table 5-2. Loadflows considered for MFA

Number	Load Condition	Island Demand (MW)	LIL Power Transfer (MW)	Island Generation
P90	Peak	1815	689	Maximum
P50	Light	740	196	Minimum generation

The system conditions that were considered for each power flow case were:

- 1, 2, 3 or 4 MFA units in-service
- Contingencies:
  - MFA unit
  - 315 kV transmission line between Churchill Falls (CHF) and MFA out of service
  - One 735 kV transmission line between CHF and Montagnais out of service
  - Two 735 kV transmission lines between CHF and Montagnais out of service

5.2.2 Background harmonics

The measured background harmonics at CHF were increased by a factor of two[13] and applied at the MFA converter bus. Table 5-3 shows the background harmonics included in the study. The values for harmonics not included in Table 5-3 were negligible.

Table 5-3. Background harmonics applied at MFA

Harmonic	2x measured background harmonics at CHF
2	0.24
3	0.84
4	0.12
5	0.5
6	0.08
7	0.32
8	0.04
9	0.08
10	0.06
11	0.12
12	0.04
13	0.18
14	0.04
15	0.02
16	0.02
17	0.08
18	0.04
19	0.06
20	0.02
21	0.02
22	0.04

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[13] Measurements were performed before the construction of Muskrat Falls Terminal Station 2. In addition, it is expected that the ac terminal station and HVdc converters will be in service before the Muskrat Falls generators. On this basis, background harmonics were doubled to provide a conservative representation of system conditions.

Harmonic	2x measured background harmonics at CHF
23	0.04
24	0.02
25	0.04
26	0.02
27	0.02
28	0.02
29	0.02
30	0.02
31	0.02
33	0.02
34	0.02
35	0.02
37	0.02
41	0.02
49	0.02

5.2.3 Results

In order to determine whether the IEC limits were met, the harmonic performance indices were calculated for four filter configurations:

- with 2A type filters in service
- with 2A type filters and 1B type filter in service
- with 2A type filters and 2B type filters in service
- with 3A type filters and 1B type filter in service

The type A filter is a triple tuned filter, tuned to harmonics 3, 12, and 23. The type B filter is a high pass filter, tuned to the 11th harmonic. The filter component data is shown in Figure 5–1 and Table 5-4.

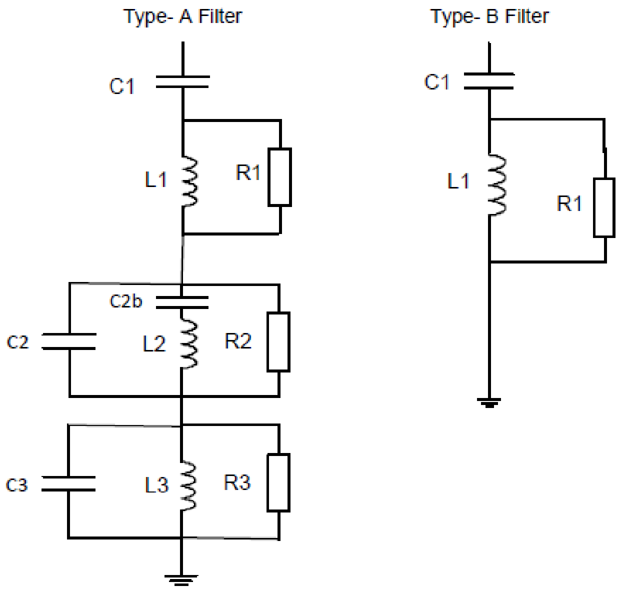

Figure 5–1. MFA filter circuit

Table 5-4. MFA filter parameters

Filter type	A	B
Nominal Mvar	72	72
system voltage (kVrms L-L)	315	315
C_1 (μF)	1.91	1.91
C_2 (μF)	13.58	-
C_3 (μF)	2.80	-
L_1 (mH)	21.03	30.5
L_2 (mH)	55.44	-
L_3 (mH)	6.98	-
R_1 (Ω)	369	388
R_2 (Ω)	443	-
R_3 (Ω)	1549	-
C_2b (μF)	126.9	-

The MFA study results are provided in Appendix 1 and 3, with values exceeding IEC limits shown in red. Note that these results are the maximum values for all cases studied, and the values for each harmonic order may not correspond to the same case.

The study results showed that the IEC limits were met in all cases for monopole operation. The LIL may therefore be operated up to 675 MW in monopole operation with:

- two A type filters in service
- two A type filters and one B type filter in service

- two A type filters and two B type filters in service
- three A type filters and one B type filter in service

In bipole operation, the LIL may be operated up to 810 MW:

- with two A type filters in service when one or two MFA units are in service under light load conditions
- one MFA unit in service under peak load conditions

For all other cases studied, the LIL may be operated up to 900 MW in bipole operation with:

- two A type filters and one B type filter in service
- two A type and two B type filters in service
- three A type and one B type filter in service

5.3 Soldiers Pond

5.3.1 AC system harmonic impedance

Similar to Muskrat Falls, at Soldiers Pond (SOP), the study considered the calculated impedance points at each harmonic order for the power flow cases listed in Table 5-5 and for the contingencies listed below. The power flow cases represented the Island system in the year 2028 ranging from peak to extreme light load conditions.

Table 5-5. Power flows considered for SOP

Load Condition	Island Demand (MW)	ML Export (MW)	LIL Power Transfer (MW)
Peak	1815	158	689
High Intermediate-	1390	158	606
Low Intermediate	980	158	525
Light	740	158	196
Extreme Light	530	158	196

The system conditions that were considered for each power flow case included:

- 1 or 2 SOP synchronous condensers in-service
- Contingencies:
    - HRD unit
    - SOP synchronous condenser
    - 230kV transmission line between SOP and WAV out of service
    - 230kV transmission line between SOP and HRD out of service

- 230kV transmission line between SOP and HWD out of service

5.3.2 Background harmonics

For SOP, background harmonics were set in accordance with the maximum of the measured background harmonics as measured at Hardwoods Terminal Station, Western Avalon Terminal Station, and Holyrood Terminal Station.

Table 5-6 below shows the background harmonics included in the study. The values for harmonics not included in Table 5-6 were negligible.

Table 5-6. Background harmonics applied at SOP

Harmonic	Maximum measured background harmonics at HWD/WAV/HRD
2	0.02
3	1.06
4	0.08
5	1.42
6	0.03
7	0.52
8	0.01
9	0.20
11	0.10
13	0.36
14	0.01
15	0.01
16	0.01
17	0.05
18	0.01
19	0.03
20	0.01
21	0.01
23	0.05
24	0.01
25	0.07
27	0.01
29	0.02
31	0.01
35	0.01
37	0.01
41	0.01

5.3.3 Results

In order to determine whether the IEC limits were met, the harmonic performance indices were calculated for five filter configurations:

- with 1A type and 1B type filter in service
- with 1A type and 2B type filters in service
- with 2A type and 2B type filters in service
- with 2A type and 3B type filters in service
- with 3A type and 2B type filters in service

The Type A filter is a triple tuned filter, tuned to harmonics 3, 12, and 23. The Type B filter is a triple tuned filter, tuned to harmonics 11, 24, and 36. The filter component data is shown in Figure 5–2 and Table 5-7.

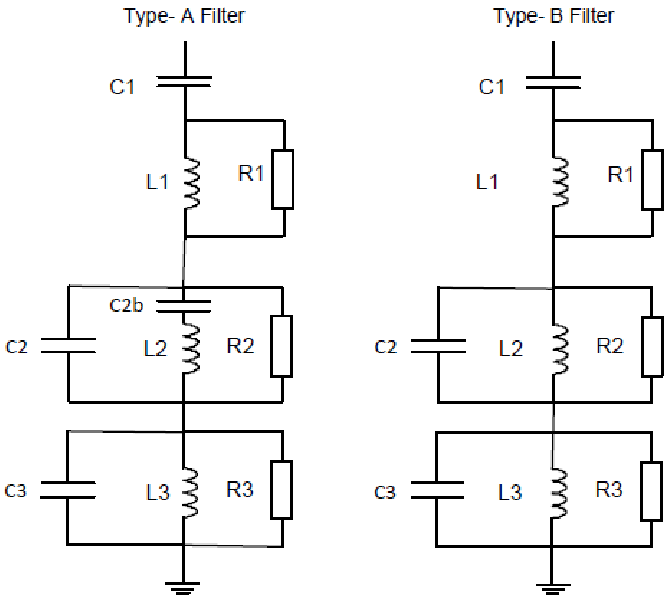

Figure 5–2. SOP filter circuits

Table 5-7. SOP filter parameters

Filter type	A	B
Nominal MVAr	75	75
system voltage (kVrms L-L)	230	230
C_1 (μF)	3.73	3.74
C_2 (μF)	17.34	4.50
C_3 (μF)	6.99	7.25
L_1 (mH)	10.72	5.15
L_2 (mH)	40.21	5.35
L_3 (mH)	2.88	1.12
R_1 (Ω)	141	170
R_2 (Ω)	514	175
R_3 (Ω)	2028	1491
C_2b (μF)	175	-

When the measured background harmonics are applied at Soldiers Pond, the IEC limits were met up to 675 MW in monopole operation and 900 MW in bipole operation.

The study results are provided in Appendix 2 and 4, with values exceeding IEC limits shown in red. Note that these results are the maximum values for all cases studied, and the values for each harmonic order may not correspond to the same case.

On the basis of the above, the LIL may be operated up to 675 MW in monopole operation or up to 900 MW in bipole operation with any of the following combinations of filters in-service:

- one A type filter and one B type filter in service
- one A type filter and two B type filters in service
- two A type filters and two B type filters in service
- two A type filters and three B type filters in service
- three A type filters and two B type filters in service

6. Conclusions

6.1 LIL Transfer Limits

The contingencies that define the LIL transfer limits are loss of the LIL bipole and loss of a LIL pole. LIL transfer limits for the transitional period are shown in Figure 6–1 (ML frequency controller in-service) and Figure 6–2 (ML frequency controller out-of-service).

Loss of the LIL Bipole

Ultimately, the UFLS scheme will be modified/re-designed during the final Stage 4 operational study to allow increased LIL transfer limits while ensuring that the system remains stable after shedding the 58 Hz block of load, as per Transmission Planning Criteria. However, during the period when the system is transitioning from low to high power operation, the existing UFLS scheme will remain in place, therefore LIL transfer limits are needed to ensure that the system remains stable following the loss of the LIL bipole. The frequency criteria used in this study allowed the 58 Hz block of load to be shed if the LIL bipole is lost, as long as the system recovered well and in a stable manner following the loss of LIL bipole. Note also that if the LIL bipole is lost, the ML (if exporting) will runback[14].

Loss of the LIL Pole

Transmission Planning Criteria for loss of a LIL pole are defined to ensure that such an event will not cause the IIS frequency to drop below 59 Hz and will not result in UFLS. The LIL will ultimately have a 10-minute 2 pu overload rating; however, during the period when the system is transitioning from low to high power operation, this overload capability will not be available. Rather, the LIL's capacity for pole compensation will be limited to 1 pu DC current. It is noted that the Maritime Link ("ML") is equipped with runbacks or frequency controller action to provide support in the event of the loss of a LIL pole.

With the use of ML runbacks or the operation of the ML frequency controller, the IIS frequency remained above 59 Hz for loss of a LIL pole under all operating scenarios, with the exception of peak load conditions. Under peak load conditions, except for the case with the ML exporting 500 MW, the loss of a LIL pole was more limiting than loss of the bipole. The LIL transfer limits were reduced accordingly for these peak load cases in order to ensure IIS frequency remains above 59 Hz if a LIL pole trips.

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[14] If the ML is not exporting, the ML response would be limited to frequency controller action. If the ML is exporting and is runback, no further support is provided by the ML frequency controller.

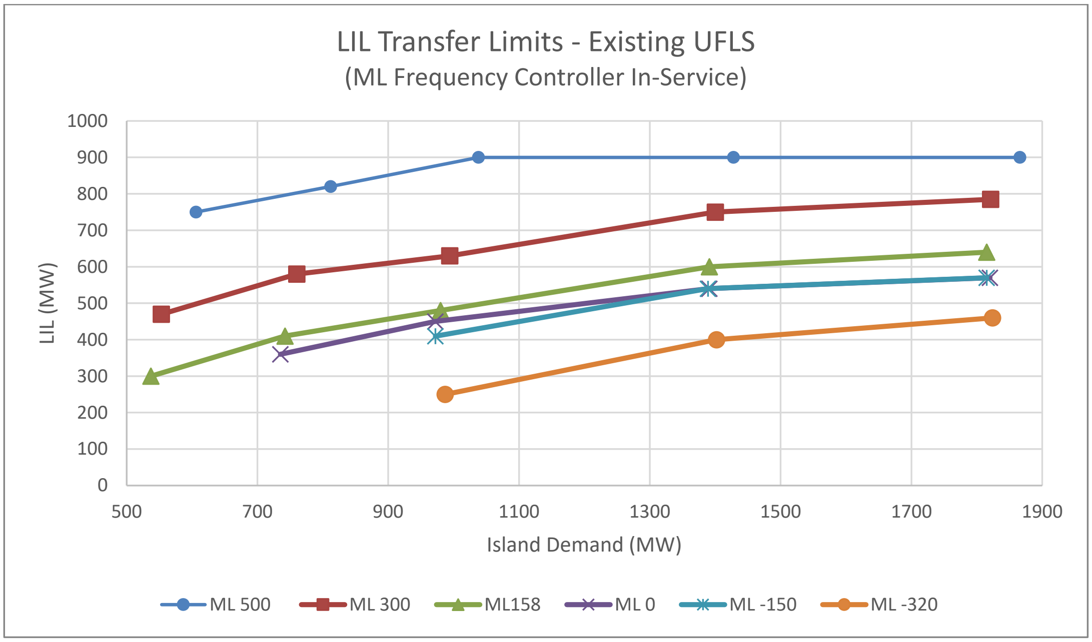

Figure 6–1. LIL Transfer Limits (ML Frequency Controller in-service)

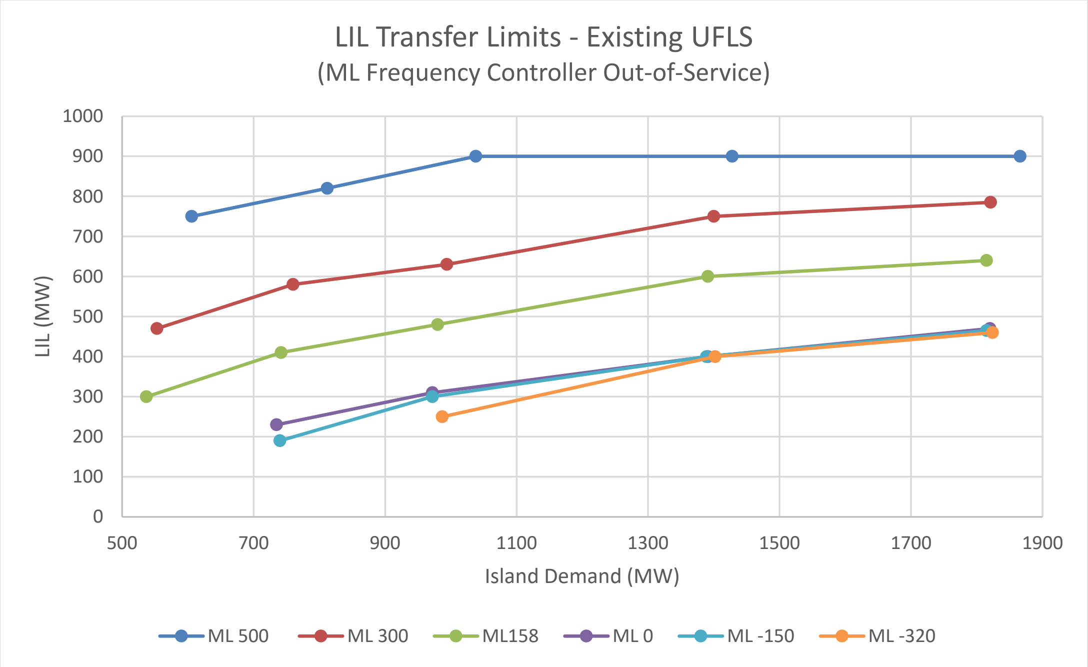

Figure 6–2. LIL Transfer Limits (ML Frequency Controller out-of-service)

6.2 ML Transfer Limits

As per Transmission Planning Criteria, loss of an ML pole (when importing) should not result in UFLS and frequency should remain above 59 Hz. UFLS is allowed for loss of the ML bipole; frequency is allowed to dip below 58 Hz as long as the system recovers well after the 58 Hz block of load is shed. If exporting, frequency should remain below 62 Hz for loss of an ML pole or bipole.

6.2.1 Without use of LIL Runbacks or Run-ups

ML transfer limits without the use of LIL runbacks or run-ups are show in Figure 6–3. This figure assumes that only HRD unit 3 is in-service as a synchronous condenser during ML export (no HRD units dispatched as generators). Figure 6–4 depicts the ML export limits[15] with 1, 2 and 3 HRD units in-service and dispatched as generators.

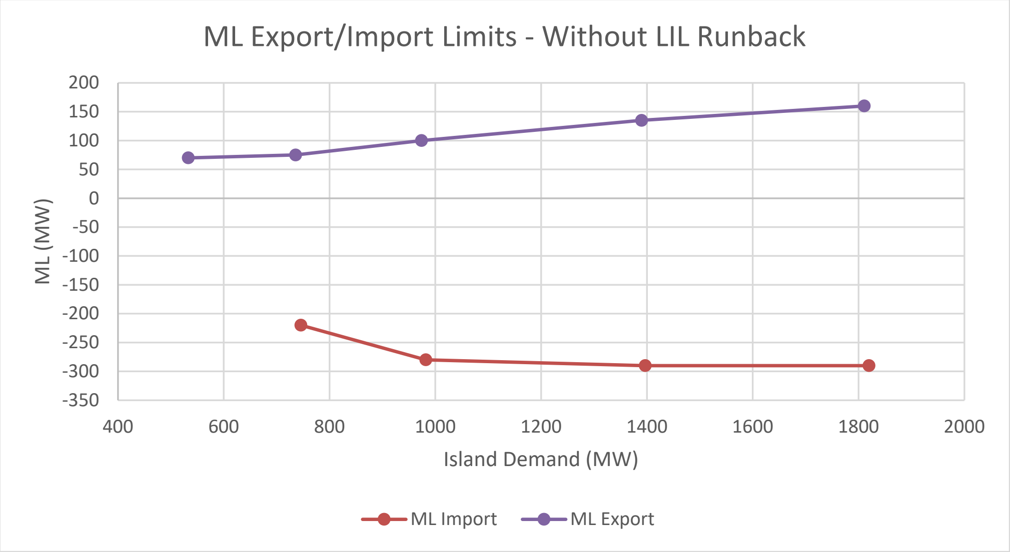

Figure 6–3. ML import/export limits, without LIL run-ups/runbacks or frequency control (no HRD units dispatched as generators)

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[15] More restrictive ML export limits are needed when HRD units are in-service in order to limit the decrease in power output to 15 MW per HRD unit in response to the system overfrequency that occurs when the ML bipole is lost.

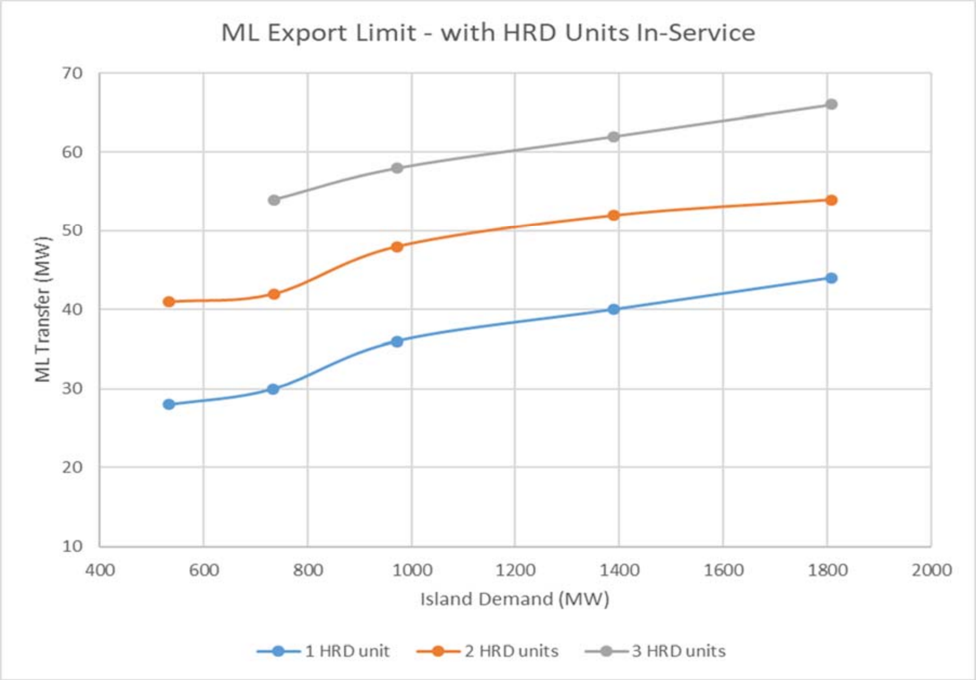

Figure 6–4. ML Export Limits with HRD Units In-service (without LIL runbacks)

6.2.2 With the use of LIL Runbacks and Run-ups

If LIL run-ups are initiated when there is loss of ML import, and LIL runbacks are initiated when there is loss of ML export, then ML power transfer is not limited, and the ML can operate over its full range from 320 MW import to 500 MW export. This assumes that there is sufficient room available on the LIL (up or down) to cover for loss of the ML bipole.

A simple approach to determine the amount of LIL runback or run-up that is required for a particular ML import or export level is to simply runback or run-up the LIL by the amount of ML export or import that was lost. Note that the LIL runback or run-up should be high enough at MFA to consider LIL losses such that the total LIL runback or run-up as measured at Soldiers Pond is equal to the amount of ML export or import that was lost. This method is applicable to all levels of ML import or export over all ranges of IIS demand.

6.3 Additional Conclusions

The following additional conclusions were made during the study.

1. **Need for Avalon Generation during High Island Demand**

To ensure stability and to avoid electromechanical oscillations for loss of the LIL bipole, there is a requirement to ensure that generation is online on the Avalon Peninsula over peak.

a) To avoid voltage collapse

The IIS can become unstable if the LIL bipole trips during high IIS demand. It was determined that a minimum amount of Avalon generation (as defined in Table 6-1) is required to be in-service when IIS demand is greater than 1600 MW to prevent system instability if the LIL bipole is lost. The Come-By-Chance capacitor banks should also be in-service (as many as steady state voltage allows) when the power flow eastward from Bay d'Espoir (BDE) towards SOP is high to help support the voltage if the LIL bipole is lost.

Table 6-1. Minimum Avalon Thermal Generation Required to be in-service

IIS Demand (MW)	Avalon Generation (MW)			
	0 SOP Syncs	1 SOP Sync	2 SOP Syncs	3 SOP Syncs
1750-1850	120	70	40	None*
1700-1750	70	15	None*	None*
1600-1700	30	None*	None*	None*

*unless required for MW dispatch to meet IIS demand and ML exports

b) To avoid electromechanical oscillations

Electromechanical oscillations were also observed following a trip of the LIL bipole. In this case, the oscillations were worst (least damped) with three SOP synchronous condensers in-service, and became more damped with fewer SOP synchronous condensers in-service. With one or no SOP synchronous condensers in-service, the oscillations are damped and no mitigation is required.

The following pre-contingency power flow limits should be followed to improve the damping of the oscillation and to avoid system instability:

- Two SOP synchronous condensers – limit power flow eastward out of BDE (on TL202, TL206, TL267) to 540 MW
- Three SOP synchronous condensers – limit power flow eastward out of BDE (on TL202, TL206, TL267) to 510 MW

Once properly tuned PSS's are in-service, these power flow restrictions for the two and three SOP synchronous condenser scenarios can likely be eliminated and then only the limits in Table 1-1 would apply.

c) To avoid instability due to 3PF on TL267

Additionally, in line with previous operational studies[16], when power flow from BDE to SOP reaches levels around 650 MW (with or without the LIL in service), the IIS can also experience instability if there is a three phase fault ("3PF") on line TL267. Therefore, power flow on this corridor should be limited to 650 MW.

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[16] TGS report R1529.01.02 "Solutions to Serve Island Demand during a LIL Bipole Outage", and TGS report TN1205.62.05 "Stage 4A LIL Bipole: Preliminary Assessment of High Power Operation".

2. Impact of SOP Synchronous Condensers on LIL Transfer Limits

The SOP synchronous condensers provide inertia to the Island, and they help the system by slowing down the rate of change of frequency immediately after infeed from the LIL is lost. It was found that although they slow down the initial rate of change of frequency, they do not impact the minimum frequency that occurs, and therefore the transfer limits defined in this study were the same whether one or two SOP synchronous condensers were in-service.

3. Concept of "Net DC"

The concept of "Net DC" to the IIS applies when the ML is exporting and can be runback to 0 MW if the LIL bipole is lost. For example, at a 1400 MW demand level, LIL power transfer is limited to 750 MW if ML is exporting 300 MW. At the same demand level, LIL power transfer is limited to 600 MW if ML is exporting 158 MW. In both cases, subtracting ML export from the LIL transfer limit results in a value of around 450 MW, which could be termed the "Net DC" limit. Figure 6–5 shows the approximate "Net DC" limits when the ML is exporting. Note that over peak, the Net DC is limited by loss of a LIL pole instead of loss of the LIL bipole. Also note that the "Net DC" limits are very similar for various ML export levels.

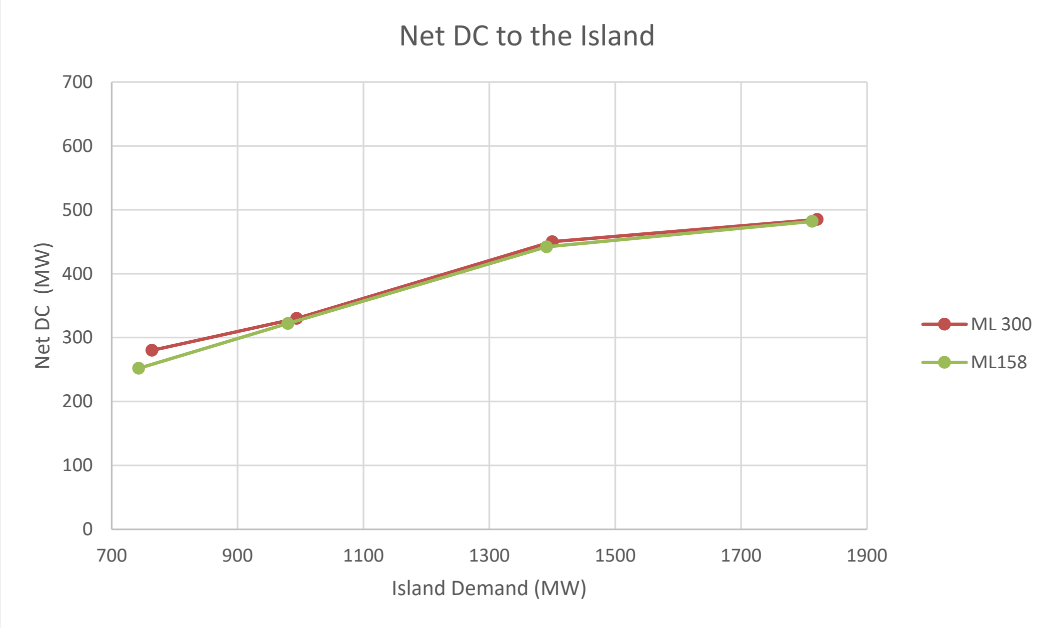

Figure 6–5. Maximum "Net DC" to the Island during ML export

6.4 Harmonic Analysis

In order to meet IEC harmonic limits, the analysis concluded that the LIL may be operated up to 675 MW in monopole operation and 900 MW in bipole operation with the filter configurations listed in Table 6-2.

Table 6-2. LIL limits and filter configurations to meet IEC harmonic limits[17]

Monopole Operation up to 675 MW		Bipole Operation up to 900 MW	
Muskrat Falls	**Soldiers Pond**	**Muskrat Falls**	**Soldier's Pond**
two A type	one A type, one B type	two A type filters**	one A type, one B type
two A type, one B type	one A type, two B type	two A type, one B type	one A type, two B type
two A type, two B type	two A type, two B type	two A type, two B type	two A type, two B type
three A type, one B type	two A type, three B type	three A type, one B type	two A type, three B type
	three A type, two B type		three A type, two B type

** except when only one or two MFA units are in service under light load conditions, or when only one MFA unit is in service under peak load conditions, in which case, operation is possible only up to 810 MW with two A type filters

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[17] The type A filter is a triple tuned filter, tuned to harmonics 3, 12, and 23. The type B filter is a high pass filter, tuned to the 11th harmonic.

Reliability and Resource Adequacy Study – Operational Studies – Stage 4

Attachment 2

newfoundland labrador
hydro
a nalcor energy company

Engineering Support Services for:

RFI Studies

Newfoundland and Labrador Hydro

Attention: Mr. Rob Collett

Stage 4E LIL Bipole: High Power Operation

Technical Note: TN1205.72.04
Date of issue: April 7, 2020

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Revisions

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Table of Contents

1. Executive Summary

The final stage of operational studies is underway to determine the system operating limits of the Newfoundland and Labrador Hydro ("Hydro") Island Interconnected System ("IIS"). To date, several stages of operational studies have been performed to identify Labrador Island link ("LIL") and Maritime Link ("ML") transfer limits for the phased monopolar approach. Additionally, several preliminary Stage 4 operational studies[1] have been performed, which looked at key issues at operation with all equipment and LIL bipole functionality in-service, as well as a transition study[2] to assess LIL and ML transfer limits as the system transitions from low to high power operation.

Stage 4 is the final stage of operational studies and includes the 900 MW LIL bipole, the Muskrat Falls ("MFA") generators, the Soldiers Pond ("SOP") synchronous condensers and the ML. The Holyrood thermal generators ("HRD"), the Stephenville Gas Turbine, and the Hardwoods Gas Turbine are no longer in-service[3]. Holyrood Unit 3 is operating as a synchronous condenser.

This report is the final Stage 4 study, and investigates the IIS under high power operation of the LIL bipole with full LIL control functionality, including LIL frequency controller and 2 pu 10-minute overload capability for loss of a LIL pole. This report addresses the following:

- Updated LIL transfer limits using a modified underfrequency load shedding ("UFLS") scheme such that the IIS can handle loss of a 900 MW LIL bipole sending end transfer with an export of 158 MW, resulting in a net IIS import from Labrador usage of approximately 675 MW.[4]
- Updated ML transfer limits with LIL frequency controller action and/or LIL runbacks/runups
- Steady state analysis (thermal, voltage) of the IIS under n-1 and n-1-1 conditions
- Preliminary[5] analysis of dynamic response of IIS under n-1 three-phase fault ("3PF") conditions
- ML transfer limits under n-1 and n-1-1 conditions (230 kV line prior outage at Bottom Brook terminal)
- Summary of ML emergency actions

1.1 LIL Transfer Limits with Modified UFLS Scheme

The existing UFLS was modified to allow the IIS to maintain stability following the loss of the 900 MW LIL bipole, under the assumption of ML export of 158 MW. LIL transfer limits were then determined under different ML transfer levels using this new UFLS scheme.

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[1] TGS report "Stage 4A LIL Bipole: Preliminary Assessment of High Power Operation", TN1205.62.05, November 21, 2018.

[2] TGS report "Stage 4D LIL Bipole: Transition to High Power Operation", TN1205.71.04, September 25, 2019.

[3] The Stephenville Gas Turbine and the Hardwoods Gas Turbine are scheduled to be retired in in the early 2020's. This study considers long term operation after these units are no longer in service.

[4] This case represents the maximum capacity shortfall for the Island System where exports to Nova Scotia are limited to 158 MW. This represents the minimum firm export at Bottom Brook Terminal Station over peak. Firm export transmission capacity at Bottom Brook Terminal station is 250 MW.

[5] Note final dynamic analysis to be done once IIS generator parameters are finalized and PSS tuning has been completed.

Analysis was performed with the GE model of the LIL to assess long term operation of the LIL with 2 pu overload capability and frequency controller functionality. LIL power transfer limits were determined to ensure criteria compliance for the loss of the LIL bipole and LIL pole. The redesigned UFLS scheme is assumed to be in place for long term operation.

The LIL power transfer limits with full LIL bipole functionality using the GE model of the LIL are shown in Figure 1–1 (ML frequency controller in-service) and Figure 1–2 Figure 9–2 (ML frequency controller out-of-service).

Loss of the LIL Bipole
As per Transmission Planning Criteria, loss of the LIL bipole is allowed to initiate the 58 Hz block of load shed, as long as the system recovers well and in a stable manner. Additionally, if the LIL bipole is lost, the ML (if exporting) will runback to 0 MW[6].

Loss of the LIL Pole
Transmission Planning Criteria for loss of a LIL pole states that this event should not cause the IIS frequency to drop below 59 Hz, and it should not result in UFLS. The LIL is designed with a 10-minute 2 pu overload rating to allow operators time to quickly dispatch other resources if a LIL pole is lost. However, when the LIL is operating at high pre-contingency power transfers, the 2pu 10-minute overload capability is not sufficient to avoid a capacity shortfall, which either requires ML frequency controller response, ML runback action and/or load limitation on the LIL to prevent underfrequency load shedding if a LIL pole trips at high LIL power transfer.

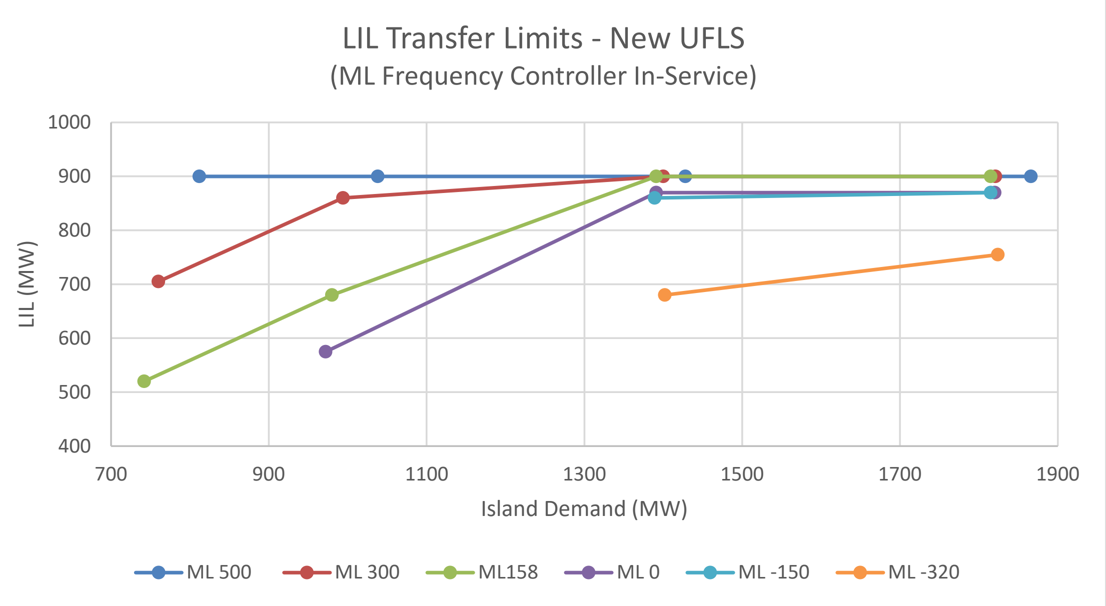

Figure 1–1. LIL Transfer Limits for varying ML import/export levels with modified UFLS Scheme (ML Frequency Controller in-service)

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[6] If the ML is exporting, the ML response would be limited to runback to 0 MW. If the ML is not exporting, the ML response would be limited to frequency controller action.

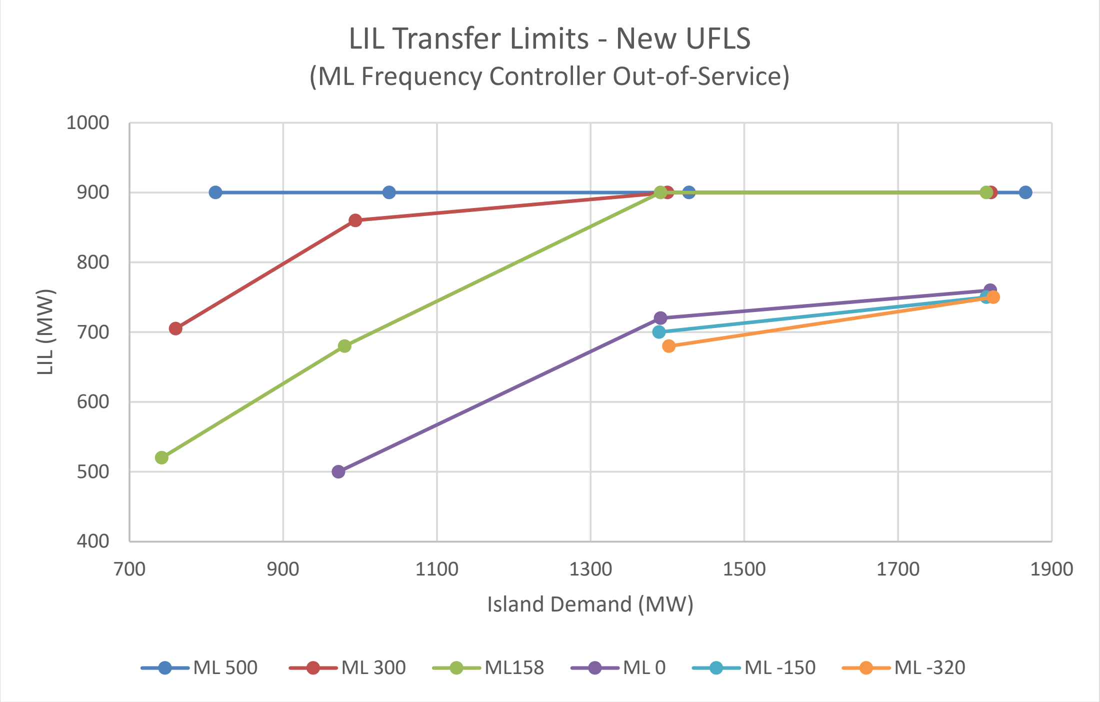

Figure 1–2. LIL Transfer Limits for varying ML import/export levels with new UFLS Scheme (ML Frequency Controller out-of-service)

1.2 ML Transfer Limits with LIL Frequency Controller In-service

As per Transmission Planning Criteria, loss of an ML pole (when importing) should not result in UFLS and frequency should remain above 59 Hz. Loss of the ML bipole is allowed to initiate the 58 Hz block of load shed, as long as the system recovers well and in a stable manner. If the ML is exporting, frequency should remain below 62 Hz for loss of an ML pole or bipole.

This study found that with the LIL frequency controller in-service, the ML can export its full rating of 500 MW without violating the 62 Hz criteria, and can import the full 320 MW transfer limit without violating the underfrequency criteria if the ML bipole trips or if the ML pole trips . No LIL runups or runbacks are required for loss of an ML pole or bipole as long as the LIL frequency controller is in-service.

1.3 Need for Avalon Generation during High Island Demand

As presented in the Stage 4D study[7], the IIS can become unstable if the LIL bipole trips during high IIS demand, and that a minimum amount of Avalon generation is required to be in-service when IIS demand is greater than 1600 MW.

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[7] Section 3.2.3 in TGS report TN1205.71.07 "Stage 4D LIL Bipole: Transition to High Power Operation", dated April 7, 2020.

1.4 "Net DC"

The concept of "Net DC"[8] to the IIS applies when the ML is exporting and can be runback to 0 MW if the LIL is lost. The modified UFLS scheme allows higher "Net DC" than previously reported in the Stage 4D study. Figure 1–3 graphically depicts the maximum "Net DC" to the IIS with the modified UFLS scheme in place, and the assumption that the ML export will runback to 0 MW if the LIL bipole trips, but that the ML frequency controller will not provide additional support in this scenario.

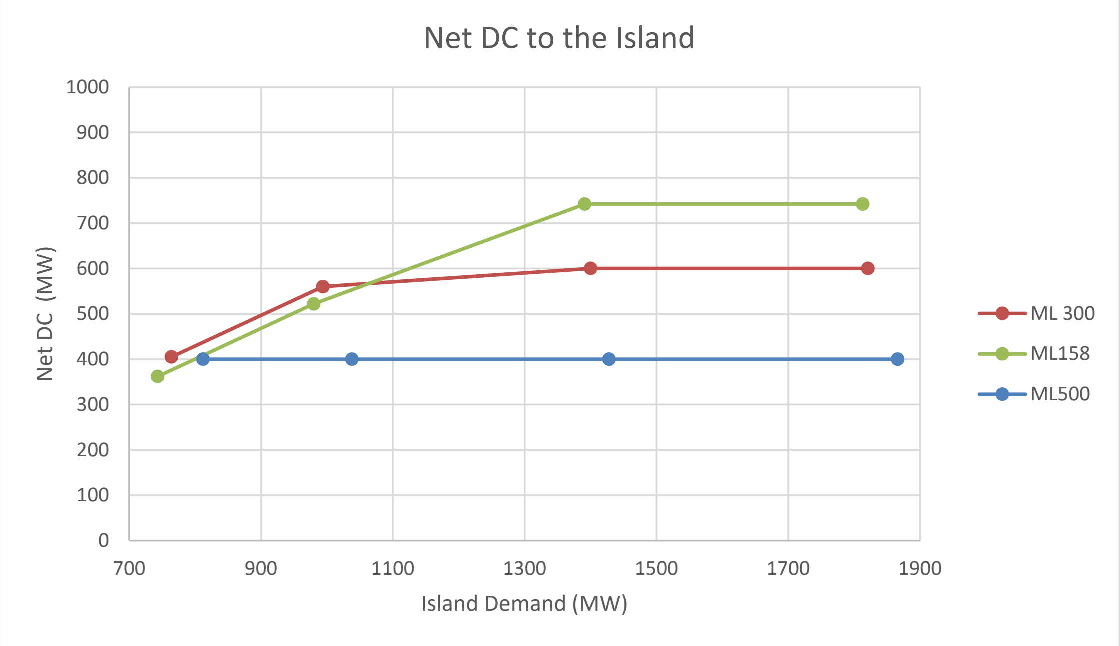

Figure 1–3. Maximum "Net DC" to the Island during ML export

1.5 Thermal Overloads

N-1 steady state contingency analysis of the IIS was performed during system intact (n-1) and prior outage (n-1-1) conditions. The set of results summarizing thermal overloads is included in Appendix 2.

1.6 Preliminary Dynamic Analysis

The ML is equipped with an Automatic Stability Runback[9], which is intended to bring the ML back within its PQ[10] capability if it becomes overloaded as reactive power demand from the system increases, since the ML is in AC voltage control at Bottom Brook.

Preliminary dynamic analysis was performed with the ML's Automatic Stability Runback in-service. No dynamic performance issues were observed in the IIS.

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[8] "Net DC" was export in previous report, please refer to this report for further explanation on the concept.

[9] The Automatic Stability Runback of the ML was simulated by running power back by 50%.

[10] PQ capability defines the operating limits of the ML as limited by its current rating. Priority can be given to P or Q or some combination thereof, such that the total current must be kept at or below the current rating.

1.7 ML Operation Under Weak Bottom Brook Conditions

The ML is connected to the IIS at Bottom Brook through three 230 kV lines, namely TL211, TL233 and TL269. Prior outages of 230 kV outlet lines at Bottom Brook, namely TL211, TL233 or TL269, in conjunction with a 3PF on one of the other in-service outlet lines (TL211, TL233, TL269) can leave the ML connected to the IIS at Bottom Brook via only one 230 kV line.

In such conditions, the short circuit levels at Bottom Brook are below the specified limits for the ML and power flow of the DC link must be limited. It is noted that the results presented in this section are based on PSSE results. In many cases, PSSE simulations of contingencies under low short circuit conditions resulted in numerical instability. The operating limits represent the maximum power flow that could be transmitted over the ML with stable results in PSSE.

These limits are currently in effect. However, the performance of the ML under low short circuit conditions is under review by Emera. Based on worst case n-1-1 conditions, Table 1-1 summarizes the ML transfer limits during prior outages of TL211, TL233 and TL269.

Table 1-1. ML Limits during N-1-1 at Bottom Brook

Prior Outage	ML Transfer Limits (MW)	
	Both ML poles in-service	One ML pole in-service
TL211	[11]	35 export / 50 import
TL233	Must be operated as monopole	60 export/ 50 import
TL269	150 export / 320 import	230 export / 250 import

1.8 Summary of ML Actions

Various ML actions are required to mitigate steady state and dynamic performance issues, as summarized in Section 8 of this report and as listed in Table 1-2.

Table 1-2. ML Actions

Control Features	Frequency controller	Provides 150 MW of support during IIS underfrequency events, including loss of generation and loss of LIL infeed. Under normal operation, the frequency controller would be in service when ML flow is between -170MW (import) and 150MW (export)
	Automatic Stability runback	Needed during high ML export conditions to prevent oscillations in AC voltage following a 3PF of various 230 kV lines. Under normal operation, runbacks would be active when ML flow exceeds 150MW (export)

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[11] These cases resulted in numerical instability in PSSE simulations. Hydro is working with Emera and ABB to perform PSCAD simulations to validate system limits in these cases.

Automatic Emergency Actions	ML export runback to 0 MW	Needed if the LIL bipole trips, in addition to UFLS, to keep system stable
	ML export – partial runback	Needed if a LIL pole trips (under certain IIS conditions) to avoid UFLS
Manual Emergency actions	Operator-initiated runbacks	Needed to mitigate certain thermal overloads during n-1 and n-1-1 events
Limitations for Line Outages	Limitations initiated by ML Operator	As summarized in the previous section, ML flow must be limited in the event of outages to TL211, TL233 and TL269 due to ML design limitations at low short circuit levels.

2. Study Models and Criteria

The Interconnected Island System (IIS) is the area of focus for this study.

2.1 Interconnected Island System

The 230 kV network of the IIS is shown in Figure 2–1.

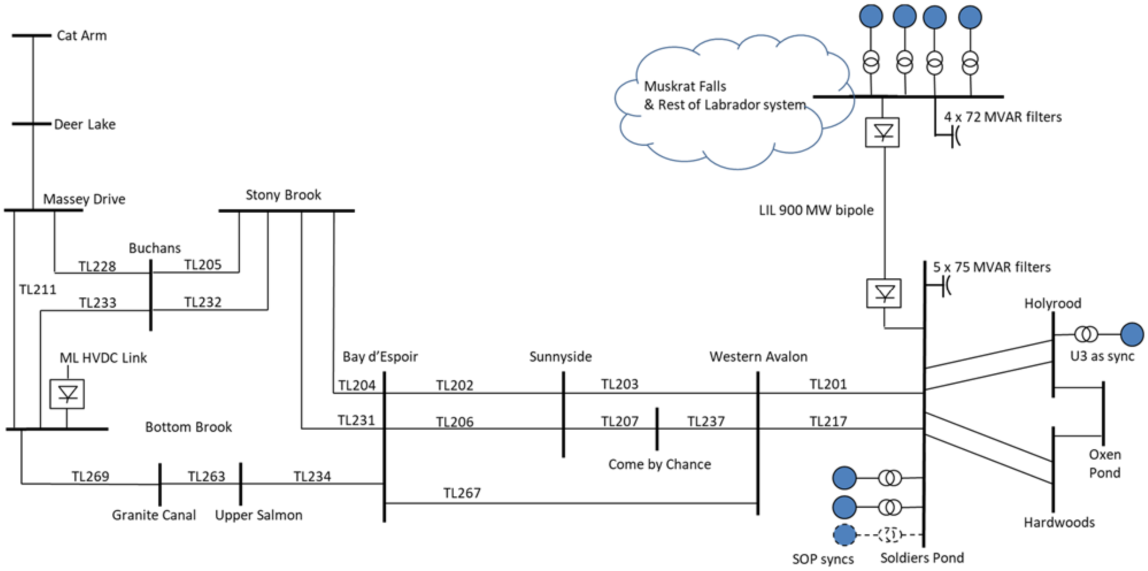

Figure 2–1. Interconnected Island System 230 kV grid

2.2 Study Assumptions

The following assumptions are made for this study:

- Thermal generation from HRD units (1,2,3) is decommissioned. HRD unit 3 is operating as a synchronous condenser.
- Two Soldiers Pond synchronous condensers are in-service.
- LIL frequency controller is in-service.
- LIL 2 pu 10-minute overload is available.
- A modified UFLS scheme is in-service, which allows the IIS to remain stable following loss of the 900 MW LIL bipole during ML export of 158 MW.
- ML can operate between 320 MW import and 500 MW export, if not limited by operational restrictions.
- As long as import capacity is available, the ML frequency controller may be activated to provide up to 150 MW of frequency support if a LIL pole or the bipole is lost or for other underfrequency

events. It is assumed that if a ML runback has taken place in response to loss of the LIL bipole, that further action by the ML frequency controller to the underfrequency will not occur in this situation.

- Under normal operation the frequency controller shall be enabled when ML flow is between -170MW (import) to 150 MW (export). Runbacks shall be enabled whenever the ML is exporting greater than 150 MW.

2.3 Study Criteria

The applicable Transmission Planning Criteria for this study is summarized below:

- Steady state voltage : 0.95 pu – 1.05 pu during n-0 conditions
- Steady state voltage : 0.90 pu – 1.1 pu during n-1 conditions
- 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 59 Hz and shall not rise above 62 Hz
- For a permanent loss of the ML bipole, underfrequency load shedding shall be permitted, but controlled, and the system frequency shall not drop below 58 Hz
- For a permanent loss of the LIL bipole, underfrequency load shedding is permitted, but controlled, and the system frequency is allowed to shed the 58 Hz block of load shed, as long as the system recovers in a stable manner.

2.4 Contingencies

Table 2-1 lists the 230 kV AC line contingencies that were considered in this study.

Three-phase faults were simulated at both ends of a transmission line, with a 6-cycle clearing time. In addition to AC system contingencies, the following HVDC contingencies were also simulated, including:

- Loss of LIL pole
- Loss of LIL bipole
- Loss of ML pole
- Loss of ML bipole

Table 2-1. AC contingencies

Line Name	Volt. (kV)	Station 1	Station 2	Faulted Bus
TL201	230	Soldiers Pond	Western Avalon	195249
				195229
TL202	230	Bay d'Espoir	Sunnyside	195221

Line Name	Volt. (kV)	Station 1	Station 2	Faulted Bus
				195222
TL203	230	Sunnyside	Western Avalon	195222
				195229
TL207	230	Sunnyside	Come-by-Chance	195222
				195227
TL211	230	Massey Drive	Bottom Brook	195208
				195205
TL218	230	Holyrood	Oxen Pond	195234
				195238
TL228	230	Buchans	Massey Drive	195215
				195208
TL231	230	Bay d'Espoir	Stony Brook	195221
				195216
TL232	230	Stony Brook	Buchans	195216
				195215
TL233	230	Bottom Brook	Buchans	195205
				195215
TL234	230	Bay d'Espoir	Upper Salmon	195221
				195220
TL236	230	Hardwoods	Oxen Pond	195236
				195238
TL237	230	Come-by-Chance	Western Avalon	195227
				195229
TL247	230	Cat Arm	Deer Lake	195210
				195209
TL248	230	Massey Drive	Deer Lake	195208
				195209
TL263	230	Upper Salmon	Granite Canal	195220
				195218
TL266	230	Soldier Pond	Hardwoods	195249
				195236
TL267	230	Bay d'Espoir	Western Avalon	195221
				195229
TL268	230	Soldier Pond	Holyrood	195249
				195234
TL269	230	Bottom Brook	Granite Canal	195205
				195218

2.5 PSSE Base Cases

Table 2-2 lists the base cases that were used to analyze the IIS system in this study. Base Cases reflect long term (ten year) load forecast conditions in accordance with Hydro's annual assessment process. For the purposes of operational analysis, generator dispatches were developed to reflect worst-case conditions in terms of transmission line power flows, reactive support, and system inertia.

Table 2-2. Base cases

Load Condition	Island Demand (MW)[12]	Island Generation (MW)	LIL Power Transfer (at MFA) (MW)	ML Power Transfer (at BBK) (MW)
Peak	n/a*			
Intermediate Peak	1428	1094	900	500
Intermediate	1038	703	900	500
Light	812	476	900	500
Extreme Light	606	402	750	500
Peak	1821	1285	900	300
Intermediate Peak	1401	866	900	300
Intermediate	1007	473	900	300
Light	764	404	700	300
Extreme Light	553	400	470	300
Peak	1811	1135	900	158
Intermediate Peak	1392	716	900	158
Intermediate	986	423	768	158
Light	743	402	520	158
Extreme Light	537	402	300	158
Peak	1803	968	900	0
Intermediate Peak	1384	671	760	0
Intermediate	972	423	576	0
Light	734	384	360	0
Extreme Light	535	404	130	0
Peak	1801	817	900	-150
Intermediate Peak	1382	527	750	-150
Intermediate	973	426	410	-150
Light	740	402	190	-150
Extreme Light	536	400	90	-46
Peak	1803	760	770	-320
Intermediate Peak	1387	516	600	-300
Intermediate	987	421	250	-320

---

[12] Island Demand includes load and losses. Variations in Island Demand for the same loading condition are attributed to incremental losses associated with variations in dispatch.

Load Condition	**Island Demand (MW)**[12]	**Island Generation (MW)**	**LIL Power Transfer (at MFA) (MW)**	**ML Power Transfer (at BBK) (MW)**
Light	750	400	90	-260
Extreme Light	n/a**			

*Not enough generation to export 500 MW on ML during peak load conditions.
** IIS generation is minimized in this case and there is insufficient load to import on the ML.

3. LIL Transfer Limits using Modified UFLS Scheme

There are two contingencies that define the LIL transfer limits:

1. Loss of a LIL pole
2. Loss of the LIL bipole

Loss of the LIL Bipole

Loss of the LIL bipole is the contingency that defines the requirements of the UFLS scheme for the IIS. During this study, the UFLS scheme was modified/re-designed to ensure that the system remains stable following the loss of the LIL bipole, and that the IIS frequency recovers well after initiating the 58 Hz block of loadshed. The modified ULFS used in this study is summarized in Table 3-1. The PSSE dynamic data file for the modified UFLS scheme is provided in Appendix 1.

Table 3-1. Modified[13] UFLS Scheme

Frequency (Hz)	Bus	Bus Name	Load Shed Block* (MW)
59.0	196565	KEN	54
59.0	195135	GLV	12
58.9	196546	BLK	37
58.9	196221	GRH	14
58.8	195624	MDR	89
58.8	196570	KBR	40
58.8	196561	CHA	54
58.6	195144	CLV	56
58.6	196568	SJM	50
58.6	196563	GDL	54
58.6	196574	PUL	40
58.4	195126	GFS	41
58.4	196572	RRD	38
58.4	195133	GAM	29
58.3	195132	GAN	24
58.3	196573	VIR	70
58.3	195655	HWD	52

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[13] Since this study was completed, the UFLS was modified further in order to move approximately 150 MW of load from the 58.8 Hz block and distribute it among the lower frequency blocks. This will help to minimize the amount of load that is shed for less serious events. The impact on the frequency response of the system following the loss of LIL bipole is minimal when compared to the frequency response observed and recorded in this study using the data in Table 3-1.

Frequency (Hz)	Bus	Bus Name	Load Shed Block* (MW)
58.3	195157	MSY	17
58.2	195130	COB	28
58.2	195165	BLK	11
58.2	195167	BRB	24
58.2	196562	BCV	27
58.2	196564	GOU	29
58.2	196560	KEL	24
58.2	196567	SLA	49

*based on peak load case

Modifications to the ULFS scheme were made under the base assumption that the ML was exporting 158 MW, with the aim of being able to transfer rated power of 900 MW on the LIL. This reflects the worst-case shortfall for Island system where imports are maximized, and exports are limited to firm commitment values. During other ML transfer levels between 320 MW import and 500 MW export, LIL transfer limits were determined, if necessary, with the modified ULFS scheme in place. As the ML frequency controller may occasionally be out of operation, operating restrictions will be in place such that the UFLS scheme will ensure stable operation.

Loss of the LIL bipole was simulated for IIS system conditions ranging from extreme light to peak demand, and for levels of ML power transfer ranging from 320 MW import to 500 MW export. There are two stability issues that were observed when the LIL bipole is lost:

1. Decline in IIS frequency and subsequent UFLS
2. Voltage collapse around the mid-point of the BDE-SOP 230 kV corridor (around Sunnyside) during high IIS demand conditions

LIL transfer limits required for reasons of underfrequency (bullet point 1 above) are described in Section 3.1 with the re-designed UFLS scheme in place.

The voltage collapse issue (bullet point 2 above) is summarized in the Stage 4D report[14] and can be mitigated by ensuring a minimum amount of Avalon generation is in-service under specified high levels of IIS demand.

Loss of the LIL Pole

The Transmission Planning Criteria for loss of a LIL pole are specified such that this event should not cause the IIS frequency to drop below 59 Hz, and it should not result in UFLS.

The LIL is designed with a 10-minute 2 pu overload rating. If one of the LIL poles is lost, the remaining pole is rated to transmit 2 pu at the sending end for 10 minutes, after which the continuous monopole rating drops down to 1.5 pu. The purpose of the 10-minute 2.0 pu overload rating is to allow operators time to quickly dispatch other resources to make up for the loss of infeed from the LIL pole that was lost.

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[14] TGS report "Stage 4D LIL Bipole: Transition to High Power Operation", TN1205.71.04, September 25, 2019, Section 3.3.3.

3.1 Study Results

Analysis was performed with the GE model of the LIL to assess long term operation of the LIL with 2 pu overload capability and frequency controller functionality. LIL power transfer limits were determined to ensure criteria compliance for the loss of the LIL bipole and LIL pole. The redesigned UFLS scheme is assumed to be in place for long term operation.

The LIL power transfer limits with full LIL bipole functionality using the GE model of the LIL are listed in Table 3-2 and shown in Figure 3–1(ML frequency controller in-service) and Figure 3-2 (ML frequency controller out-of-service). Note that the results for loss of the LIL bipole while the ML is exporting are the same with and without the ML frequency controller in-service since these cases rely on ML runback only when the LIL bipole trips (no ML frequency controller action).

Please note the following:

- **During ML Export**
  When the ML is exporting, the IIS frequency remains above 59 Hz for loss of a LIL pole under all operating scenarios with the use of ML runbacks or the operation of the ML frequency controller as detailed in Table 3-2. If the ML frequency controller is in-service, ML runbacks are required under some operating scenarios if the LIL is transferring greater than 870 MW. If the ML frequency controller is not in-service, ML runbacks are required if the LIL is transferring greater than approximately 700 MW.
- **During ML Import**
  When the ML is importing or operating at 0 MW, the IIS frequency remains above 59 Hz for loss of a LIL pole under all operating scenarios, with the exception of peak load conditions. Under peak load conditions, loss of a LIL pole requires a lower LIL transfer limit than loss of the LIL bipole. These cases are depicted in red highlighted cells in Table 3-2.
- In all peak demand cases, voltage considerations were found to be more limiting than underfrequency concerns. The results in the table below only reflect underfrequency limits, while the Stage 4D report[15] previously discussed the voltage collapse issue and prevention.

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[15] Section 3.2.3 in TGS report TN1205.71.07 “Stage 4D LIL Bipole: Transition to High Power Operation”, dated April 7, 2020.

Table 3-2. Long Term Operational Results – LIL Transfer Limits with and without ML Frequency Controller

				ML Frequency Controller IN					ML Frequency Controller OUT				
	Demand	Generation	ML	Loss LIL Bipole Transfer Limit (MW)	Minimum Frequency (Hz)	Loss LIL Pole Transfer Limit (MW)	ML Runback* (MW)	Minimum Frequency (Hz)	Loss LIL Bipole Transfer Limit (MW)	Minimum Frequency (Hz)	Loss LIL Pole Transfer Limit (MW)	ML Runback* (MW)	Minimum Frequency (Hz)
Peak	1866	1530	500	900	58.61	900	-	59.03	900	58.61	900	90	59.02
Ipeak	1428	1094	500	900	58.5	900	-	59.00	900	58.5	900	85	59.07
Int	1038	703	500	900	58.28	900	110	59.04	900	58.28	900	110	59.04
Light	812	476	500	900	58.18	900	100	59.04	900	58.18	900	100	59.04
ExLight	575	401	500	750	58.44	750	-	59.19	750	58.44	750	30	59.05
Peak	1821	1285	300	900	58.26	900	-	59.00	900	58.26	900	100	59.05
Ipeak	1400	915	300	900	58.15	900	110	59.02	900	58.15	900	110	59.02
Int	994	589	300	860	57.91	860	-	59.02	860	57.91	860	85	59.06
Light	760	452	300	705	58.06	705	-	59.26	705	58.06	705	10	59.01
ExLight	553	409	300	470	58.5	470	-	59.58	470	58.5	470	-	59.64
Peak	1815	1303	158	900	58.11	900	-	59.00	900	58.11	900	98	59.01
Ipeak	1391	889	158	900	57.84	900	118	59.01	900	57.84	900	118	59.01
Int	980	548	158	680	57.97	680	-	59.32	680	57.97	680	-	59.35
Light	742	433	158	520	58.09	520	-	59.51	520	58.09	520	-	59.56
ExLight	537	402	158	300	58.5	300	-	59.73	300	58.5	300	-	59.77
Peak	1820	1330	0	900	58.14	870	-	59.05	900	57.89	780	-	59.00
Ipeak	1391	906	0	870	57.88	870	-	59.00	720	57.87	720	-	59.40
Int	972	538	0	575	58.16	575	-	59.55	500	57.96	500	-	59.70
Light	734	403	0	340	58.51	340	-	59.67	340	58.09	340	-	59.70
ExLight	535	404	0	130	59.05	130	-	59.90	130	58.58	130	-	59.95
Peak	1815	1049	-150	900	58.14	870	-	59.03	900	57.8	755	-	59.06
Ipeak	1389	757	-150	860	57.92	860	-	59.03	700	57.8	700	-	59.45
Int	972	424	-150	410	58.5	410	-	59.66	410	58.18	410	-	59.72
Light	740	402	-150	190	58.89	190	-	59.75	190	58.5	190	-	59.95
ExLight	536	400	-46	90	59.15	90	-	59.95	90	58.68 Hz - MI	90	-	59.95
Peak	1824	998	-320	900	57.84	755	-	59.04	900	57.84	755	-	59.04
Ipeak	1402	422	-320	680	58.01	680	-	59.30	680	58.01	680	-	59.30
Int	987	421	-320	250	58.51	250	-	59.80	250	58.51	250	-	59.80
Light	750	400	-260	90	58.79	90	-	59.95	90	58.78 Hz	90	-	59.95

Loss of Pole is more limiting that loss of LIL bipole

Not included in plot since not a limiting case

*If ML runback is used, there is no additional support provided by the ML frequency controller.

Minimum IIS Generation

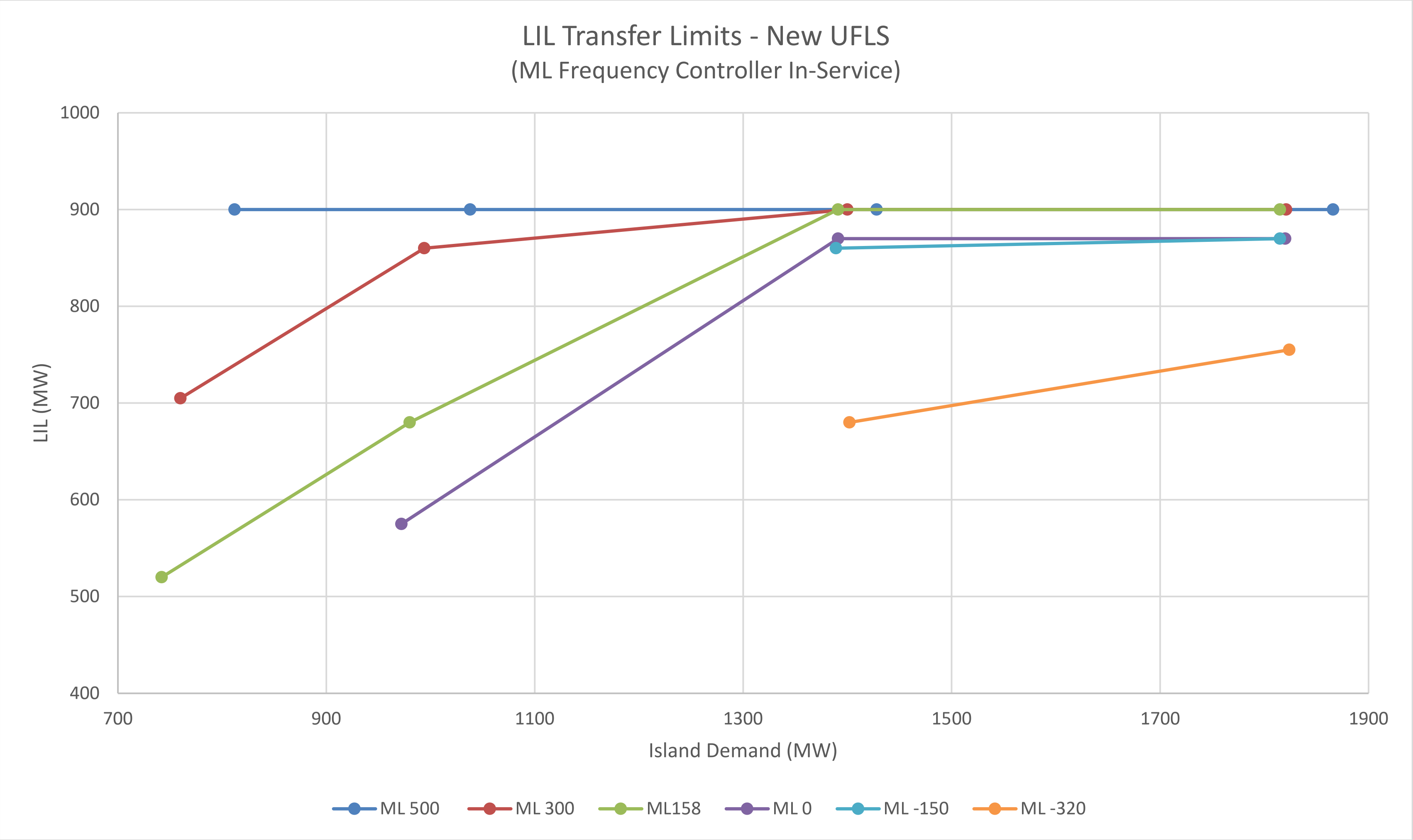

Figure 3–1. Long Term Operation– LIL Transfer Limits – ML Frequency Controller In-Service

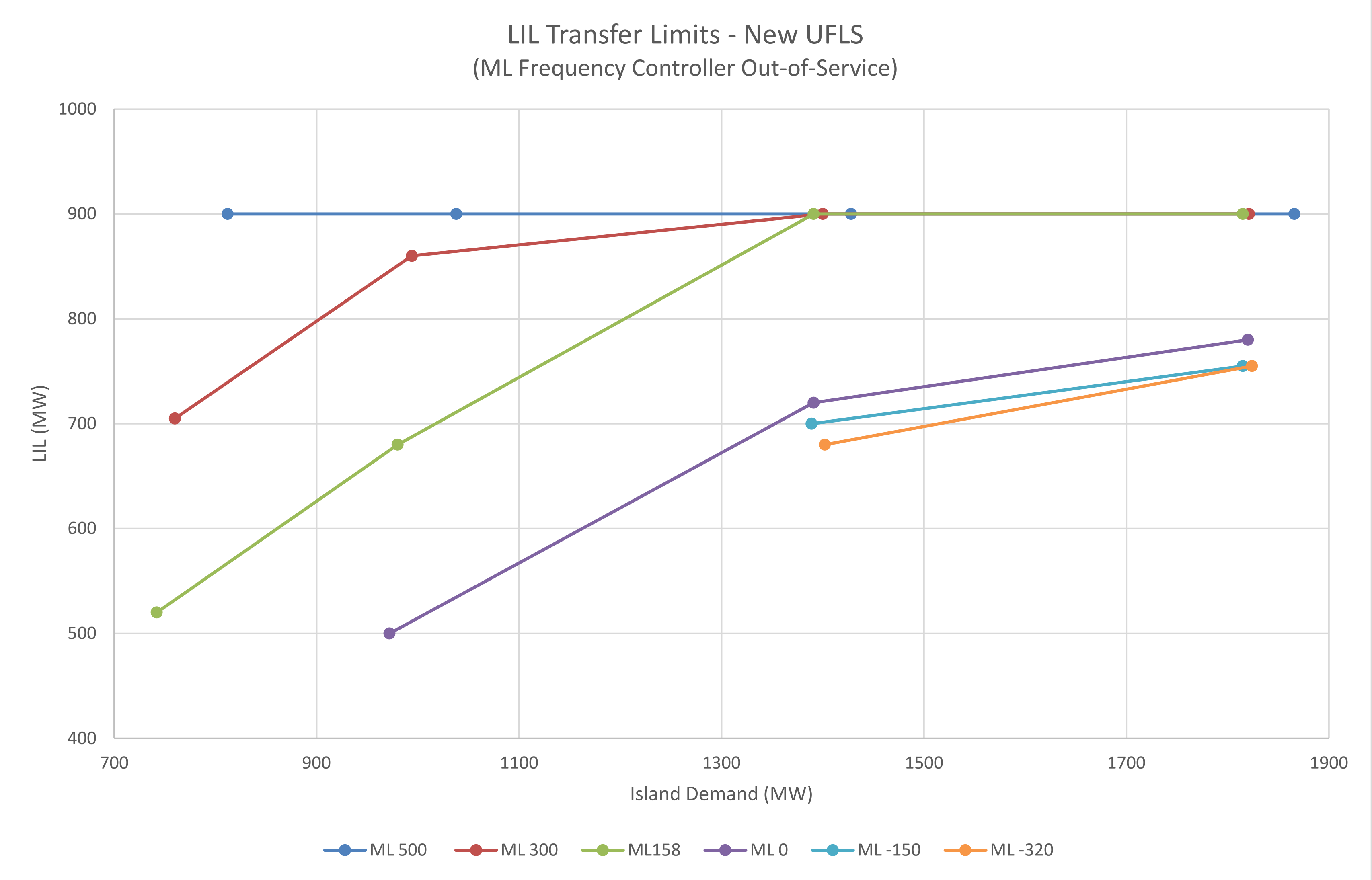

Figure 3–2. Long Term Operation– LIL Transfer Limits – ML Frequency Controller Out-of-Service

Table 3-2. Long Term Operational Results – LIL Transfer Limits with and without ML Frequency Controller

				ML Frequency Controller IN					ML Frequency Controller OUT				
	Demand	Generation	ML	Loss LIL Bipole Transfer Limit (MW)	Minimum Frequency (Hz)	Loss LIL Pole Transfer Limit (MW)	ML Runback* (MW)	Minimum Frequency (Hz)	Loss LIL Bipole Transfer Limit (MW)	Minimum Frequency (Hz)	Loss LIL Pole Transfer Limit (MW)	ML Runback* (MW)	Minimum Frequency (Hz)
Peak	1866	1530	500	900	58.61	900	-	59.03	900	58.61	900	90	59.02
Ipeak	1428	1094	500	900	58.5	900	-	59.00	900	58.5	900	85	59.07
Int	1038	703	500	900	58.28	900	110	59.04	900	58.28	900	110	59.04
Light	812	476	500	900	58.18	900	100	59.04	900	58.18	900	100	59.04
ExLight	575	401	500	750	58.44	750	-	59.19	750	58.44	750	30	59.05
Peak	1821	1285	300	900	58.26	900	-	59.00	900	58.26	900	100	59.05
Ipeak	1400	915	300	900	58.15	900	110	59.02	900	58.15	900	110	59.02
Int	994	589	300	860	57.91	860	-	59.02	860	57.91	860	85	59.06
Light	760	452	300	705	58.06	705	-	59.26	705	58.06	705	10	59.01
ExLight	553	409	300	470	58.5	470	-	59.58	470	58.5	470	-	59.64
Peak	1815	1303	158	900	58.11	900	-	59.00	900	58.11	900	98	59.01
Ipeak	1391	889	158	900	57.84	900	118	59.01	900	57.84	900	118	59.01
Int	980	548	158	680	57.97	680	-	59.32	680	57.97	680	-	59.35
Light	742	433	158	520	58.09	520	-	59.51	520	58.09	520	-	59.56
ExLight	537	402	158	300	58.5	300	-	59.73	300	58.5	300	-	59.77
Peak	1820	1330	0	900	58.14	870	-	59.05	900	57.89	780	-	59.00
Ipeak	1391	906	0	870	57.88	870	-	59.00	720	57.87	720	-	59.40
Int	972	538	0	575	58.16	575	-	59.55	500	57.96	500	-	59.70
Light	734	403	0	340	58.51	340	-	59.67	340	58.09	340	-	59.70
ExLight	535	404	0	130	59.05	130	-	59.90	130	58.58	130	-	59.95
Peak	1815	1049	-150	900	58.14	870	-	59.03	900	57.8	755	-	59.06
Ipeak	1389	757	-150	860	57.92	860	-	59.03	700	57.8	700	-	59.45
Int	972	424	-150	410	58.5	410	-	59.66	410	58.18	410	-	59.72
Light	740	402	-150	190	58.89	190	-	59.75	190	58.5	190	-	59.95
ExLight	536	400	-46	90	59.15	90	-	59.95	90	58.68 Hz - MI	90	-	59.95
Peak	1824	998	-320	900	57.84	755	-	59.04	900	57.84	755	-	59.04
Ipeak	1402	422	-320	680	58.01	680	-	59.30	680	58.01	680	-	59.30
Int	987	421	-320	250	58.51	250	-	59.80	250	58.51	250	-	59.80
Light	750	400	-260	90	58.79	90	-	59.95	90	58.78 Hz	90	-	59.95

🟥 Loss of Pole is more limiting that loss of LIL bipole

▨ Not included in plot since not a limiting case

*If ML runback is used, there is no additional support provided by the ML frequency controller.

Minimum IIS Generation

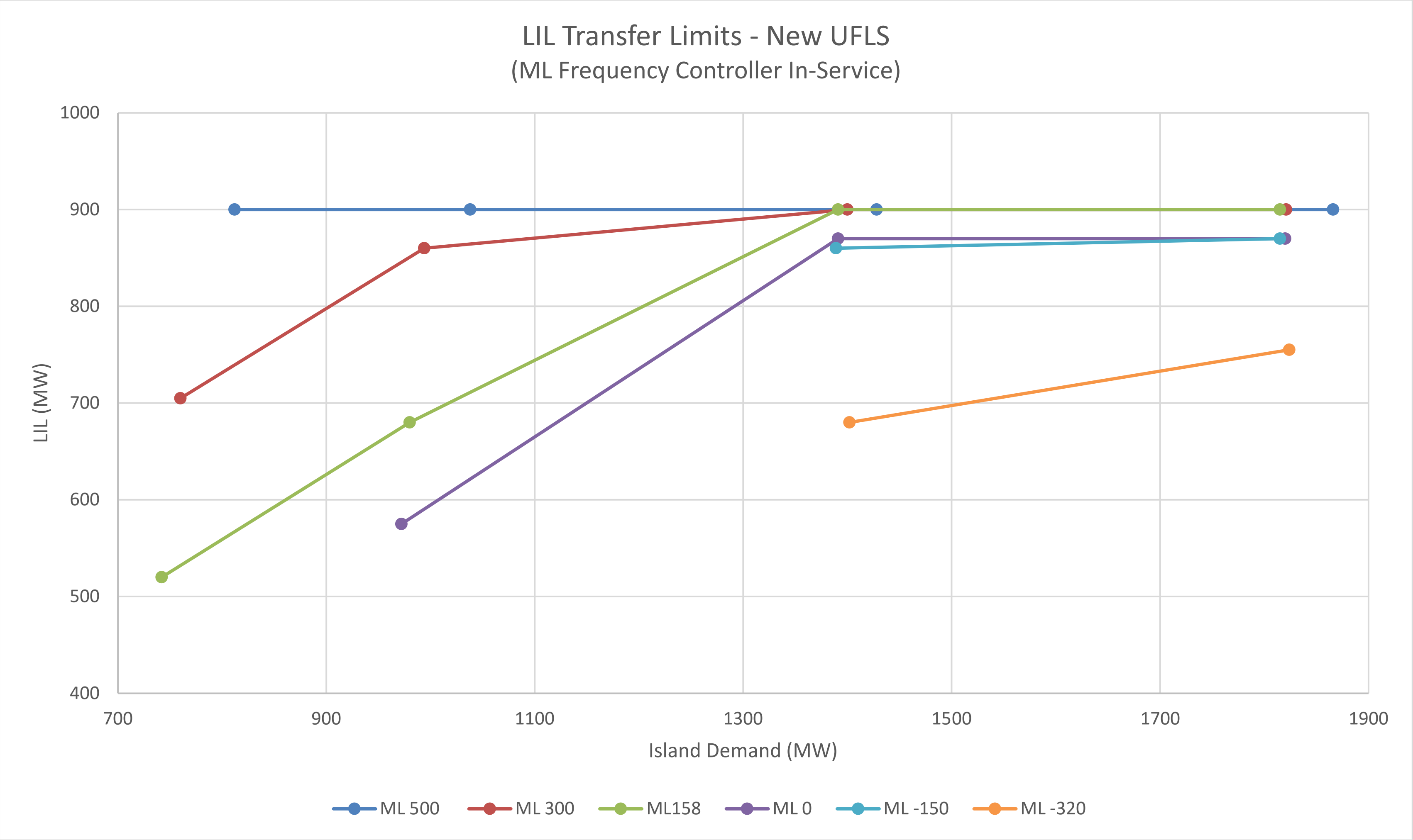

Figure 3–1. Long Term Operation– LIL Transfer Limits – ML Frequency Controller In-Service

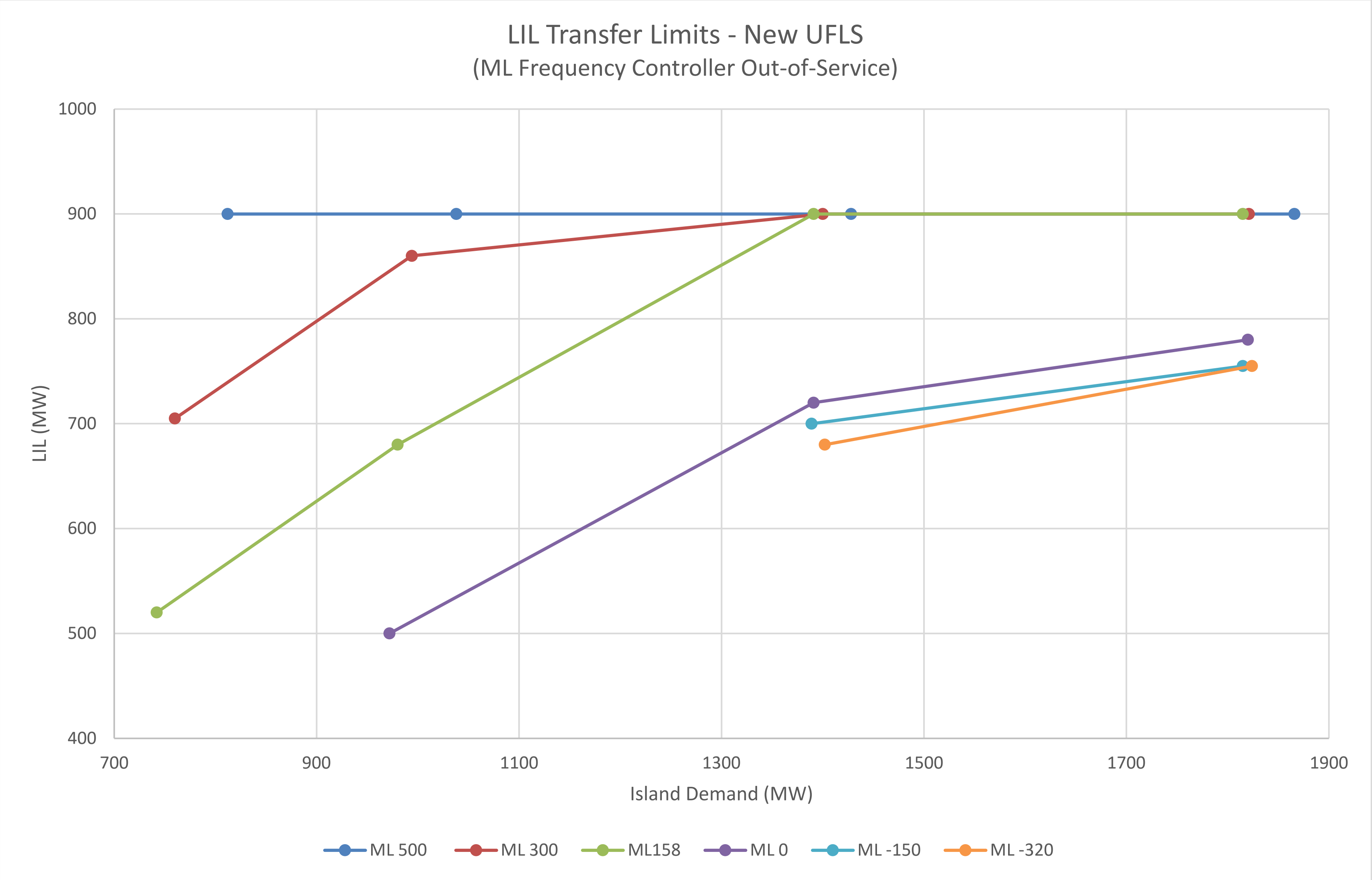

Figure 3–2. Long Term Operation– LIL Transfer Limits – ML Frequency Controller Out-of-Service

3.2 "Net DC" to the Island

The concept of "Net DC" to the IIS applies when the ML is exporting and can be runback to 0 MW if the LIL is lost. For example, at an approximate 1000 MW demand level, LIL power transfer is limited to 680 MW if ML is exporting 158 MW. At the same demand level, LIL power transfer is limited to 860 MW if ML is exporting 300 MW. In both cases, subtracting ML export from the LIL transfer limit results in a value of between 520 and 560 MW, which could be termed the "Net DC" limit. Table 3-3 shows this example, indicating that for IIS demand around 1000 MW, the maximum "Net DC" to the IIS should be limited to 600 MW.

Table 3-3. Net DC to the Island

Demand (MW)	Generation (MW)	LIL Transfer Limit (MW)	ML Export (MW)	Maximum NET DC = LIL Limit -ML Export (MW)
1866	1530	900	500	400*
1428	1094	900	500	400*
1038	703	900	500	400*
812	476	900	500	400*
1821	1285	900	300	600*
1400	915	900	300	600*
994	589	860	300	560
764	404	705	300	405
1813	1214	900	158	742
1391	889	900	158	742
980	548	680	158	522
743	402	520	158	362

*maximum Net DC available, not at a frequency limit

Figure 3–3 graphically depicts the maximum net DC to the Island from Table 3-3. Each line on the plot represents a different ML export level.

It is evident from Figure 3–3 that the net DC to the Island is similar regardless of ML export level, as long as the ML export is runback to 0 MW when the LIL bipole is lost. It is noted that the ML 500 MW export scenario shows a maximum net DC of 400 MW, however, this is not an actual limit to due underfrequency but rather the maximum available when using a 500 MW runback for loss of 900 MW LIL infeed. The same statement also applies to the higher demand cases with ML exporting 300 MW; a runback of 300 MW for loss of 900 MW LIL infeed results in a maximum net DC of 600 MW, which corresponds to the maximum available net DC but is not a limit due to underfrequency.

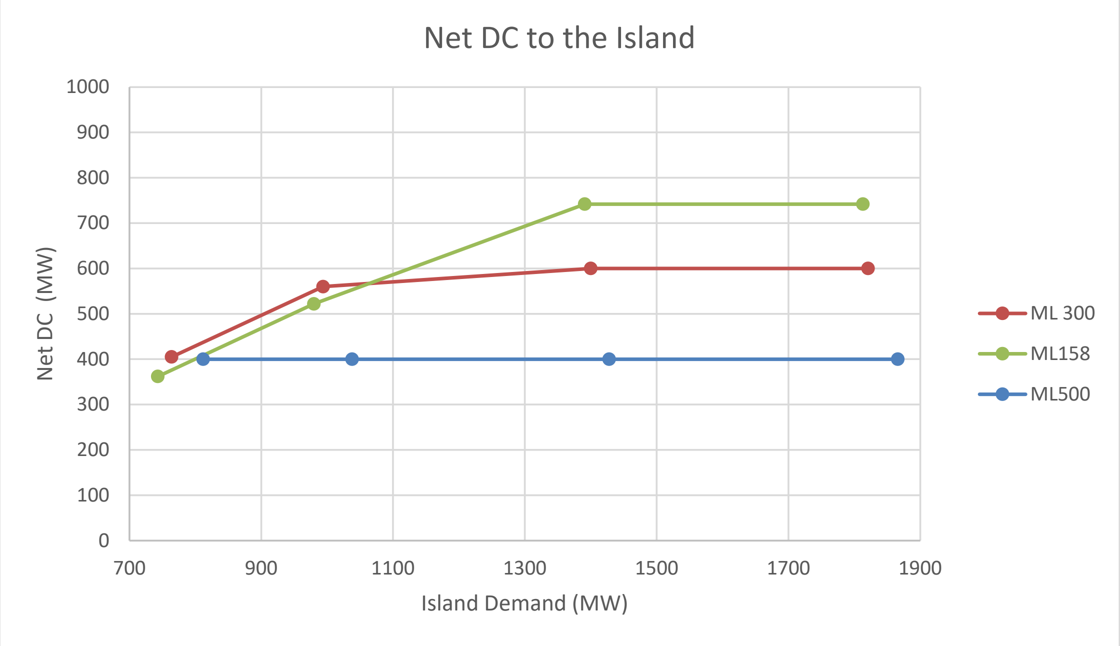

Figure 3–3. Maximum "Net DC" to the Island during ML export

4. ML Transfer Limits

Loss of the ML bipole and ML pole are the contingencies that define the ML import and export limits.

If the ML bipole or pole is lost while exporting, the Island frequency will increase. Transmission Planning criteria state that this overfrequency should not go above 62 Hz.

If the ML bipole or pole is lost while importing, the Island frequency will decrease. Transmission Planning criteria state that for loss of the bipole frequency can dip below 58 Hz, as long as the system recovers well after the 58 Hz block of load is shed. For loss of a pole, the frequency should remain above 59 Hz.

Note that if an ML pole is lost, it is assumed that the healthy ML pole will pick up the transfer that was lost on the other ML pole, up to its rating of 250 MW at the rectifier.

4.1 With LIL Frequency Controller In-Service

The LIL is equipped with runback/runup functionality and frequency controller functionality to assist IIS frequency if the ML bipole or pole trips. This study determined that if the LIL frequency controller is in-service, there are no requirements for runback or runup on the LIL if the ML bipole trips.

ML import of 320 MW and 150 MW and maximum ML export of 500 MW were simulated with the LIL frequency controller in-service. The resulting minimum and maximum IIS frequency excursions are summarized in Table 4-1 for loss of the ML bipole.

It is concluded that, if the LIL bipole and its frequency controller are in-service, the ML can export its full rating of 500 MW without violating the 62 Hz criteria, and can import the full 320 MW transfer limit without violating the underfrequency criteria if an ML pole is lost or the ML bipole is lost.

Table 4-1. Frequency Excursions due to loss of ML bipole (LIL frequency controller in-service)

ML Import/ Export	LIL (MW)	Demand (MW)	Generation (MW)	Loss of ML Bipole	
				ML Transfer (MW)	Max/Min Frequency (Hz)
Export	900	1860	1525	500	60.94
	900	1428	1094		60.94
	900	1038	703		60.97
	900	812	476		60.98
	750	606	402		61.00
Import	870	1801	842	-150	58.57
	860	1382	432		58.47
	410	973	426		59.45
Import	755	1804	774	-320	58.31
	680	1386	423		58.39
	250	987	421		58.8*

4.2 With LIL Frequency Controller Out-of-Service

Please refer to the Stage 4D report[16] for ML transfer limits when the LIL frequency controller is out-of-service.

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[16] TGS report "Stage 4D LIL Bipole: Transition to High Power Operation", TN1205.71.04, September 25, 2019, Section 3.3.3.

5. Preliminary Dynamic Analysis of the IIS

Three-phase faults on all bulk system 230 kV lines in the IIS were simulated for the light, intermediate and peak load cases, for ML transfers of 320 MW import, and for 158 MW, 300 MW and 500 MW export, with LIL at corresponding maximum transfer limit (as per Figure 3–1) for each case.[17]

The ML is equipped with an Automatic Stability Runback, which is intended to bring the ML back within its PQ capability if it becomes overloaded as reactive power demand from the system increases, since the ML is in AC voltage control at Bottom Brook. The logic for this controller is summarized as follows:

```
IF V > 0.70 pu (i.e. voltage is within normal range)
    AND P > 0.35 pu (i.e. P >175 MW)
    AND Q > 0.5 pu (i.e. Q (including filter) > 250 MVAR)

    (AND 150 ms timer expires)

    THEN S is outside capability curve - > Runback 50%
```

The PSSE model of the ML does not include this Automatic Stability Runback[18]. Therefore, to assess its applicability to the 3PFs that were tested, the post-fault simulation quantities of the ML were analyzed to see if the criteria of the control logic for the Automatic Stability Runback was met. If so, the ML was runback 50% after a delay of 150 ms.

With the ML's Automatic Stability Runback in-service, there were no dynamic performance issues observed in the IIS.

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[17] As stated in Section 2.5, worst-case dispatches were developed for the purposes of this analysis to identify operational limits. Operating procedures including the application of operating restrictions or re-dispatching generation recommendations will be developed to address any violations to Transmission Planning Criteria.

[18] It is recommended that a future version of the ML PSSE model include the Automatic Stability Runback so that it can be more accurately assessed during the final stage of dynamic analysis.

6. Steady State Analysis of the IIS

Steady state contingency analysis was performed on the following subset of base cases:

- Light, intermediate, peak load conditions
- ML 320 MW import, ML 158 MW export, ML, 250 MW export, ML 500 MW export
- At the maximum allowable LIL transfer limit for the corresponding case

N-1 analysis was performed for system intact (n-1) and prior outage (n-1-1) conditions of all 230 kV lines in the IIS. The analysis did not find any issues related to steady state voltage. However, thermal overloads were identified for various contingencies during system intact and prior outage conditions.

Results of the worst-case thermal overloads for the system intact (N-1) analysis are summarized in Table 6-1.

Table 6-1. N-1 Thermal Overloads in the IIS

Monitored Element	**Contingency**	**Overloads (% of Thermal Rating)**											
		Light Demand				**Intermediate Demand**				**Peak Demand**			
		ML -260	**ML 158**	**ML 250**	**ML 500**	**ML -320**	**ML 158**	**ML 250**	**ML 500**	**ML -320**	**ML 158**	**ML 250**	**ML 300**
Stony Brook T1	Stony Brook T2									158.5	150.3	134.2	134.3
Stony Brook T2	Stony Brook T1									111.0	129.3	130.3	125.7
TL217	TL201				141.1								
TL231	TL204				112.8								
TL232	TL205				124.8								
TL233	TL211				161.8				106.9				
TL201*	TL217		120.6	169.0	274.0		115.2	144.1	148.8				
TL222a	TL228				103.0								
TL222b					110.5								
TL223					117.9								
TL224					102.4								
TL204	TL231				112.7								
TL205	TL232				177.2				125.0				
TL211	TL233				181.1				120.4				
TL228					177.4				134.8				
TL263					120.0								
TL203	TL237				136.6								
Deer Lake T2	TL248										180.6	137.6	180.9

*Overloads avoided if system is re-dispatched to reduce LIL infeed and increase generation on west side of island or reduce ML exports.

Operational protocols will be developed by Hydro for the overload conditions described above where mitigating actions would be defined on the basis of the ambient temperature.

Appendix 2 contains tables summarizing the thermal overloads that result from n-1 contingencies during system intact and during prior outages of 230 kV lines in the IIS.

7. ML Operation Under Weak Bottom Brook Conditions

Performance of the ML was studied under weak Bottom Brook conditions. The ML is connected to the IIS at Bottom Brook through three 230 kV lines, namely TL211, TL233 and TL269. Prior outages of these lines were considered, in conjunction with a 3PF on each of the remaining in-service outlet lines leaving the ML connected to the IIS at Bottom Brook via only one 230 kV line.

In such conditions, the short circuit levels at Bottom Brook are below the limits specified by Emera for the ML and power flow of the dc link must be limited due to this design restriction.[19,20] It is noted that the results presented in this section are based on PSSE results. In many cases, PSSE simulations of contingencies under low short circuit conditions resulted in numerical instability. The operating limits represent the maximum power flow that could be transmitted over the ML with stable results in PSSE.

These limits are currently in effect. However, the performance of the ML under low short circuit conditions is under review by Emera.

7.1 TL211 / TL233

The weakest system conditions at Bottom Brook occur when there is a simultaneous outage of TL211 and TL233, leaving the ML connected via TL269. Depending on system conditions (loading, generation dispatch), the short circuit level (“SCL”) at Bottom Brook during an outage of TL211 and TL233 ranges from 335 MVA to 404 MVA.

Table 7-1 summarizes the dynamic results of a prior outage of TL211 followed by a 3PF on TL233 (Rows shaded red represent unstable conditions. Rows shaded blue represent cases with numerical convergence issues in the PSSE software), and the resulting SCL at Bottom Brook.

Table 7-1. TL233 Outage with Prior Outage of TL211

Case	ML (MW)	Outage 1	Outage 2	SCL (MVA)
Light-LIL-ML-260	-260	TL211	TL233	335
Light-LIL-ML-150	-150	TL211	TL233	339
Light-LIL-ML0	0	TL211	TL233	343
Light-LIL-ML158	158	TL211	TL233	348
Light-LIL-ML300	300	TL211	TL233	355
Peak-LIL-ML-300	-300	TL211	TL233	364
Peak-LIL-ML-320	-320	TL211	TL233	364
Light-LIL-ML500	500	TL211	TL233	387
Peak-LIL-ML-150	-150	TL211	TL233	394
Peak-LIL-ML0	0	TL211	TL233	397
Peak-LIL-ML158	158	TL211	TL233	401

---

[19] This ML design limitation is understood and accepted by Emera.

[20] Curtailment of ML flow would be initiated by the ML Operator.

Case	ML (MW)	Outage 1	Outage 2	SCL (MVA)
Peak-LIL-ML300	300	TL211	TL233	404

If both ML poles are in-service, it appears that the system may be too weak for the ML to operate, as the results are numerically unstable in PSSE.

If only one ML pole is in-service, it was determined that between 35-60 MW of export and 50 MW of import are acceptable. Hydro is working with Emera and ABB to assess system performance in these cases by performing further analysis in PSCAD.

7.2 TL211 / TL269

A simultaneous outage of TL211 and TL269 leaves the ML connected via TL233. Depending on system conditions (loading, generation dispatch), the SCL at Bottom Brook during an outage of TL211 and TL269 ranges from 534 MVA to 578 MVA.

Table 7-2 summarizes the dynamic results of a prior outage of TL211 followed by a 3PF on TL269 (Rows shaded red represent unstable conditions. Rows shaded yellow represent cases with criteria violations., Rows shaded green represent acceptable cases), and the resulting SCL at Bottom Brook.

Table 7-2. TL211 Outage with Prior Outage of TL269

Case	ML (MW)	Outage 1	Outage 2	SCL (MVA)
Light-LIL-ML-260	-260	TL269	TL211	534
Light-LIL-ML-150	-150	TL269	TL211	539
Light-LIL-ML0	0	TL269	TL211	544
Peak-LIL-ML-150	-150	TL269	TL211	549
Peak-LIL-ML0	0	TL269	TL211	549
Light-LIL-ML158	158	TL269	TL211	550
Peak-LIL-ML-300	-300	TL269	TL211	550
Peak-LIL-ML-320	-320	TL269	TL211	550
Peak-LIL-ML158	158	TL269	TL211	553
Light-LIL-ML300	300	TL269	TL211	556
Peak-LIL-ML300	300	TL269	TL211	563
Light-LIL-ML500	500	TL269	TL211	578

If both ML poles are in-service, it was determined that the ML can operate anywhere between 320 MW import up to 150 MW export. If ML export is increased beyond 150 MW, oscillations begin to appear in the system after fault recovery, and if export is further increased, the system eventually cannot recover.

If only one ML pole is in-service, the allowable ML export increases to 230 MW.

7.3 TL269 / TL233

A simultaneous outage of TL233 and TL269 leaves the ML connected via TL211. Depending on system conditions (loading, generation dispatch), the SCL at Bottom Brook during an outage of TL269 and TL2323 ranges from 777 MVA to 815 MVA.

Table 7-3 summarizes the dynamic results of a prior outage of TL269 followed by a 3PF on TL233 (Rows shaded red represent unstable conditions. Rows shaded green represent acceptable cases.), and the resulting SCL at Bottom Brook.

Table 7-3. TL233 Outage with Prior Outage of TL269

Case	ML (MW)	Outage 1	Outage 2	SCL (MVA)
Light-LIL-ML-260	-260	TL269	TL233	777
Light-LIL-ML-150	-150	TL269	TL233	781
Peak-LIL-ML0	0	TL269	TL233	782
Light-LIL-ML0	0	TL269	TL233	784
Peak-LIL-ML158	158	TL269	TL233	785
Light-LIL-ML158	158	TL269	TL233	787
Light-LIL-ML300	300	TL269	TL233	789
Peak-LIL-ML-150	-150	TL269	TL233	804
Light-LIL-ML500	500	TL269	TL233	808
Peak-LIL-ML-300	-300	TL269	TL233	811
Peak-LIL-ML-320	-320	TL269	TL233	811
Peak-LIL-ML300	300	TL269	TL233	815

If both ML poles are in-service, it was determined that the ML can operate anywhere between 320 MW of import up to 300 MW of export. The allowable ML export can be increased to 400 MW, if the ML is runback by 50% following the 3PF and trip of TL269.

If only one ML pole is in-service, the allowable ML export is 250 MW, which is not a stability limit, but the limit of the ML pole rating.

7.4 Summary – ML Limits during Prior Outage

Based on worst case n-1-1 conditions, Table 7-4 summarizes the ML transfer limits for prior outages of TL211, TL233 and TL269.

Table 7-4. ML Limits during N-1-1 at Bottom Brook

Prior Outage	ML Transfer Limits (MW)	
	Both ML poles in-service	One ML pole in-service
TL211	0*	35 export / 50 import
TL233	Must be operated as monopole *	60 export/ 50 import
TL269	150 export / 320 import	230 export / 250 import

*These cases resulted in numerical instability in PSSE simulations. Hydro is working with Emera and ABB to perform PSCAD simulations to validate system limits in these cases.

8. Summary of ML Emergency Actions

The ML actions that help mitigate steady state and dynamic performance issues can be summarized into the following three categories:

1. Control features
    a. Frequency controller
    The ML frequency controller provides up to 150 MW of support to the IIS during loss of a LIL pole or bipole. If the frequency controller is not in-service, LIL transfer limits are used to ensure Transmission Planning criteria are met.

    b. Automatic stability runback
    The automatic stability runback was shown to be needed during times of high ML export and low IIS demand conditions to maintain stability in the IIS following 3PF on various 230 kV transmission lines.

2. Emergency actions
    a. Loss of LIL bipole
    If the ML is exporting when the LIL bipole is lost, ML export will be runback to 0 MW.

    b. Loss of LIL pole
    When a LIL pole trips, the healthy LIL pole is designed to be capable of transmitting 2 pu for 10 minutes. Due to increased losses associated with monopolar operation, however, when the LIL is operating at high transfers pre-contingency this 2pu 10-minute overload capability is not always sufficient to avoid a capacity shortfall, which either requires ML frequency controller response, ML runback action and/or load limitation on the LIL to prevent underfrequency load shedding.

Table 3-2. Long Term Operational Results – LIL Transfer Limits with and without ML Frequency Controller

				ML Frequency Controller IN					ML Frequency Controller OUT				
	Demand	Generation	ML	Loss LIL Bipole Transfer Limit (MW)	Minimum Frequency (Hz)	Loss LIL Pole Transfer Limit (MW)	ML Runback* (MW)	Minimum Frequency (Hz)	Loss LIL Bipole Transfer Limit (MW)	Minimum Frequency (Hz)	Loss LIL Pole Transfer Limit (MW)	ML Runback* (MW)	Minimum Frequency (Hz)
Peak	1866	1530	500	900	58.61	900	-	59.03	900	58.61	900	90	59.02
Ipeak	1428	1094	500	900	58.5	900	-	59.00	900	58.5	900	85	59.07
Int	1038	703	500	900	58.28	900	110	59.04	900	58.28	900	110	59.04
Light	812	476	500	900	58.18	900	100	59.04	900	58.18	900	100	59.04
ExLight	575	401	500	750	58.44	750	-	59.19	750	58.44	750	30	59.05
Peak	1821	1285	300	900	58.26	900	-	59.00	900	58.26	900	100	59.05
Ipeak	1400	915	300	900	58.15	900	110	59.02	900	58.15	900	110	59.02
Int	994	589	300	860	57.91	860	-	59.02	860	57.91	860	85	59.06
Light	760	452	300	705	58.06	705	-	59.26	705	58.06	705	10	59.01
ExLight	553	409	300	470	58.5	470	-	59.58	470	58.5	470	-	59.64
Peak	1815	1303	158	900	58.11	900	-	59.00	900	58.11	900	98	59.01
Ipeak	1391	889	158	900	57.84	900	118	59.01	900	57.84	900	118	59.01
Int	980	548	158	680	57.97	680	-	59.32	680	57.97	680	-	59.35
Light	742	433	158	520	58.09	520	-	59.51	520	58.09	520	-	59.56
ExLight	537	402	158	300	58.5	300	-	59.73	300	58.5	300	-	59.77
Peak	1820	1330	0	900	58.14	870	-	59.05	900	57.89	780	-	59.00
Ipeak	1391	906	0	870	57.88	870	-	59.00	720	57.87	720	-	59.40
Int	972	538	0	575	58.16	575	-	59.55	500	57.96	500	-	59.70
Light	734	403	0	340	58.51	340	-	59.67	340	58.09	340	-	59.70
ExLight	535	404	0	130	59.05	130	-	59.90	130	58.58	130	-	59.95
Peak	1815	1049	-150	900	58.14	870	-	59.03	900	57.8	755	-	59.06
Ipeak	1389	757	-150	860	57.92	860	-	59.03	700	57.8	700	-	59.45
Int	972	424	-150	410	58.5	410	-	59.66	410	58.18	410	-	59.72
Light	740	402	-150	190	58.89	190	-	59.75	190	58.5	190	-	59.95
ExLight	536	400	-46	90	59.15	90	-	59.95	90	58.68 Hz - MI	90	-	59.95
Peak	1824	998	-320	900	57.84	755	-	59.04	900	57.84	755	-	59.04
Ipeak	1402	422	-320	680	58.01	680	-	59.30	680	58.01	680	-	59.30
Int	987	421	-320	250	58.51	250	-	59.80	250	58.51	250	-	59.80
Light	750	400	-260	90	58.79	90	-	59.95	90	58.78 Hz	90	-	59.95

🟥 Loss of Pole is more limiting that loss of LIL bipole

Not included in plot since not a limiting case

*If ML runback is used, there is no additional support provided by the ML frequency controller.

Minimum IIS Generation

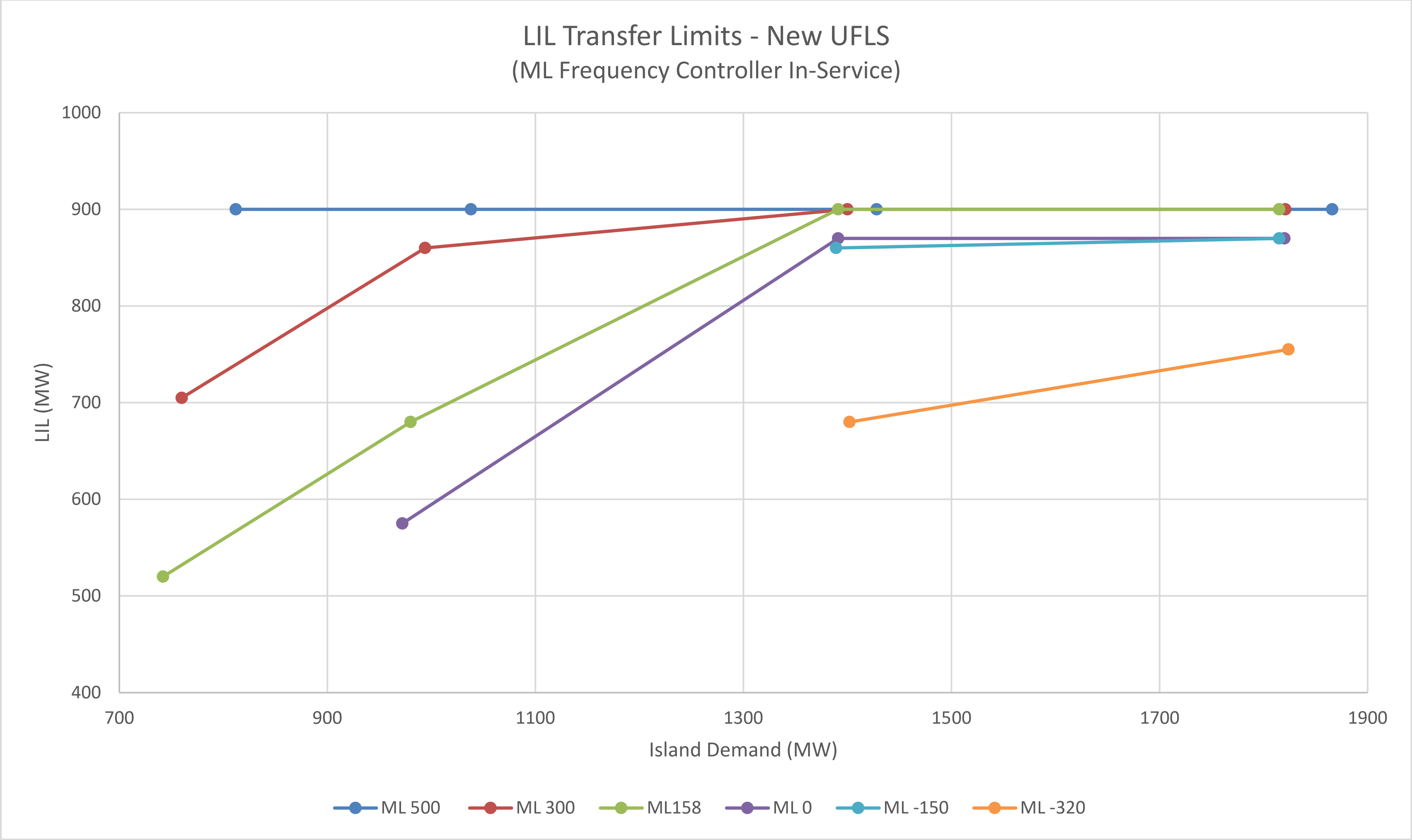

Figure 3–1. Long Term Operation– LIL Transfer Limits – ML Frequency Controller In-Service

Figure 3–2. Long Term Operation– LIL Transfer Limits – ML Frequency Controller Out-of-Service

   Table 3-2 lists the minimum required ML runback for loss of a LIL pole under various dispatches and IIS demand levels.

3. Manual EPC operations by operator to prevent thermal overloads
   a. Some of the thermal overloads in Appendix 2 are sensitive to ML transfer levels, and by reducing ML transfer levels these overloads can be mitigated. [21]
4. Limitations in the event of TL11, TL233, or TL269
   a. As presented in Section 7, power flow over the ML must be limited in the event of outages to 230 kV transmission lines at BBK.

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[21] It is noted that the requirement for manual EPC operation to prevent thermal overloads is not required in cases where the ML export is less than the firm transmission capacity of 250 MW.

9. Conclusions

9.1 LIL Transfer Limits with Modified UFLS Scheme

The existing UFLS was modified to allow the IIS to maintain stability following the loss of the 900 MW LIL bipole, under the assumption of ML export of 158 MW. LIL transfer limits were then determined under different ML transfer levels using this new ULFS scheme.

Analysis was performed with the GE model of the LIL to assess long term operation of the LIL with 2 pu overload capability and frequency controller functionality. LIL power transfer limits were determined to ensure criteria compliance for the loss of the LIL bipole and LIL pole. The redesigned UFLS scheme is assumed to be in place for long term operation.

The LIL power transfer limits with full LIL bipole functionality using the GE model of the LIL are shown in Figure 9–1 (ML frequency controller in-service) and Figure 9–2 (ML frequency controller out-of-service). Note that the results for loss of the LIL bipole while the ML is exporting are the same with and without the ML frequency controller in-service since these cases rely on ML runback only when the LIL bipole trips (no ML frequency controller action).

Loss of the LIL Bipole
As per Transmission Planning Criteria, loss of the LIL bipiole is allowed to initiate the 58 Hz block of loadshed, as long as the system recovers well and in a stable manner. Additionally, if the LIL bipole is lost, the ML (if exporting) will runback to 0 MW[22].

Loss of the LIL Pole
Transmission Planning Criteria for loss of a LIL pole states that this event should not cause the IIS frequency to drop below 59 Hz, and it should not result in UFLS. The LIL is designed with a 10-minute 2 pu overload rating to allow operators time to quickly dispatch other resources if a LIL pole is lost. However, when the LIL is operating at high pre-contingency power transfers, the 2pu 10-minute overload capability is not sufficient to avoid a capacity shortfall, which either requires ML frequency controller response, ML runback action and/or load limitation on the LIL to prevent underfrequency load shedding. The capacity shortfall is due to the increased losses when the LIL is suddenly switched to monopole mode.

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[22] If the ML is exporting, the ML response would be limited to runback to 0 MW. If the ML is not exporting, the ML response would be limited to frequency controller action.

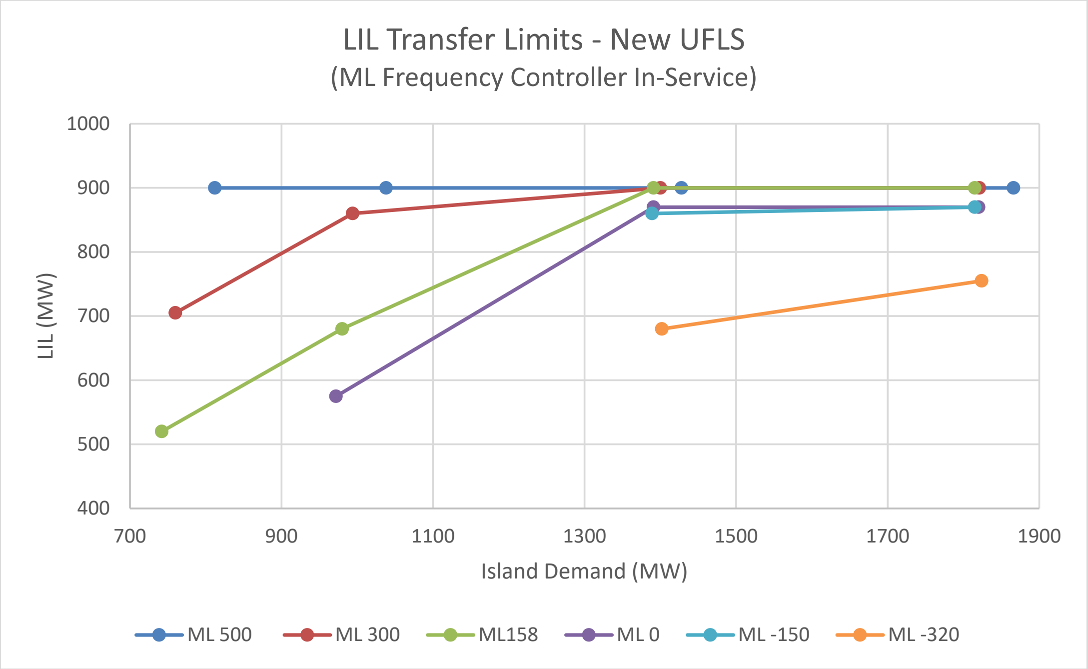

Figure 9–1. LIL Transfer Limits for varying ML import/export levels with modified UFLS Scheme (ML Frequency Controller in-service)

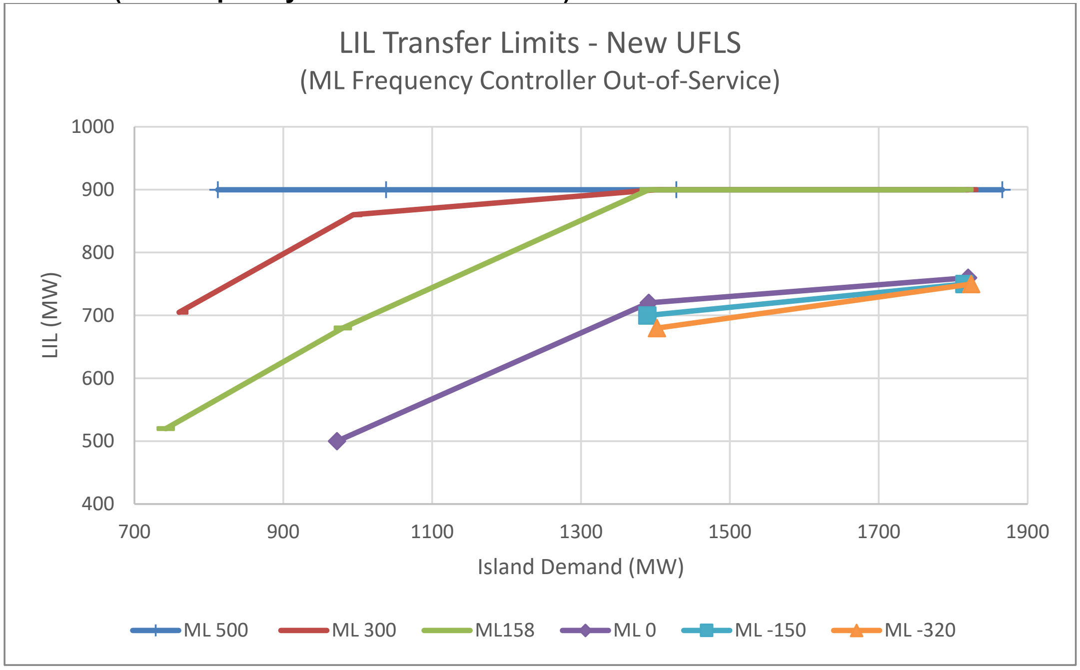

Figure 9–2. LIL Transfer Limits for varying ML import/export levels with new UFLS Scheme (ML Frequency Controller out-of-service)

9.2 ML Transfer Limits with LIL Frequency Controller In-service

As per Transmission Planning Criteria, loss of an ML pole (when importing) should not result in UFLS and frequency should remain above 59 Hz. UFLS is allowed for loss of the ML bipole, and the frequency is allowed to dip below 58 Hz as long as the system recovers well after the 58 Hz block of load is shed. If exporting, frequency should remain below 62 Hz for loss of an ML pole or bipole.

As its operation is coordinated with the LIL, the ML can export its full rating of 500 MW without violating the 62 Hz criteria. When there is a ML bipole trip when importing 320 MW from Nova Scotia, the LIL will provide frequency control support up to its rated capacity. When LIL capacity is limited, load shedding will occur. Even when there is no LIL capacity available, load shedding in response to the loss of the 320 MW of supply will not result in the violation of the 58 Hz criteria and without violating the 59 Hz criteria if an ML pole trips.

9.3 Need for Avalon Generation during High Island Demand

As presented in the Stage 4D study[23], the IIS can become unstable if the LIL bipole trips during high IIS demand, and a minimum amount of Avalon generation is required to be in-service when IIS demand is greater than 1600 MW.

9.4 "Net DC"

The concept of "Net DC"[24] to the IIS applies when the ML is exporting and can be runback to 0 MW if the LIL is lost. The modified UFLS scheme allows higher "Net DC" than previously reported in the Stage 4D study. Figure 9–3 graphically depicts the maximum "Net DC" to the IIS with the modified UFLS scheme in place, and the assumption that the ML export will runback to 0 MW will if the LIL bipole trips, but that the ML frequency controller will not provide additional support in this scenario.

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[23] Section 3.2.3 in TGS report TN1205.71.07 "Stage 4D LIL Bipole: Transition to High Power Operation", dated April 7, 2020.

[24] "Net DC" was export in previous report, please refer to this report for further explanation on the concept.

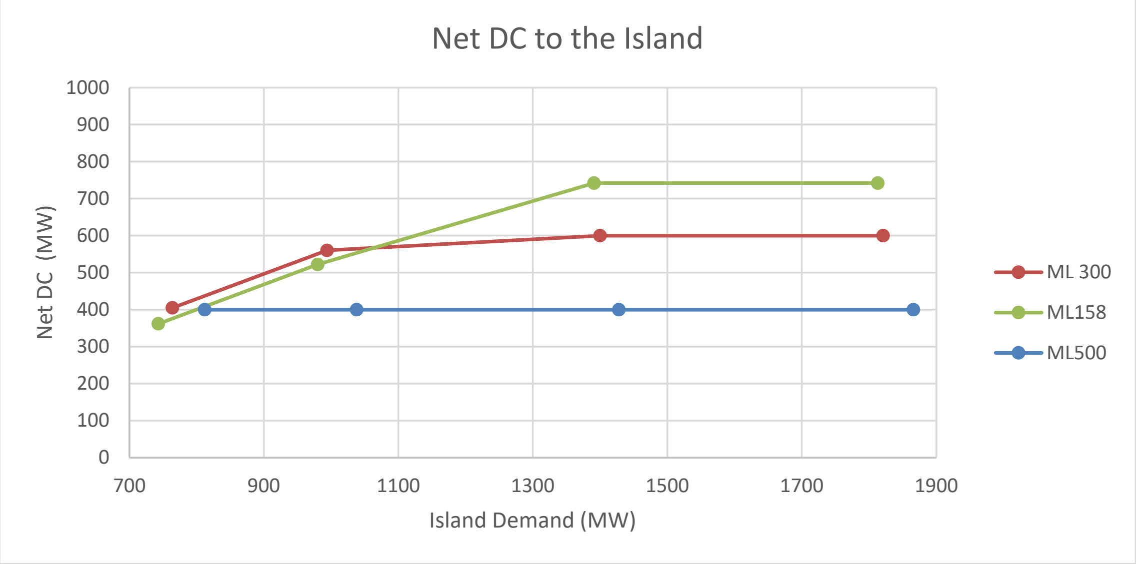

Figure 9–3. Maximum "Net DC" to the Island during ML export

9.5 Thermal Overloads

N-1 steady state contingency analysis of the IIS was performed during system intact (n-1) and prior outage (n-1-1) conditions. The set of results summarizing thermal overloads is included in Appendix 2.

9.6 Preliminary Dynamic Analysis

The ML is equipped with an Automatic Stability Runback[25], which is intended to bring the ML back within its PQ capability if it becomes overloaded as reactive power demand from the system increases, since the ML is in AC voltage control at Bottom Brook.

With the ML's Automatic Stability Runback in-service, no dynamic performance issues were observed in the IIS during the preliminary dynamic analysis.

9.7 ML Operation Under Weak Bottom Brook Conditions

The ML is connected to the IIS at Bottom Brook through three 230 kV lines, namely TL211, TL233 and TL236. Prior outages of 230 kV outlet lines at Bottom Brook, namely TL211, TL233 or TL269, in conjunction with a 3PF one of the other in-service outlet lines (TL211, TL233, TL269) can leave the ML connected to the IIS at Bottom Brook via only one 230 kV line.

Based on worst case n-1-1 conditions, Table 9-1 summarizes the ML transfer limits during prior outages of TL211, TL233 and TL269.

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[25] The Automatic Stability Runback of the ML was simulated by running power back by 50%.

Table 9-1. ML Limits during N-1-1 at Bottom Brook

Prior Outage	ML Transfer Limits (MW)	
	Both ML poles in-service	One ML pole in-service
TL211	0[26]	35 export / 50 import
TL233	Must be operated as monopole	60 export/ 50 import
TL269	150 export / 320 import	230 export / 250 import

9.8 Summary of ML Actions

Various ML actions are required to mitigate steady state and dynamic performance issues, as summarized in Section 8 of this report and as listed in Table 9-2.

Table 9-2. ML Actions

Control Features	Frequency controller	Provides 150 MW of support during IIS underfrequency events, including loss of generation and loss of LIL infeed.
	Automatic Stability runback	Needed during high ML export conditions to prevent oscillations in AC voltage following a 3PF of various 230 kV lines.
Automatic Emergency Actions	ML export runback to 0 MW	Needed if the LIL bipole trips, in addition to UFLS, to keep system stable
	ML export – partial runback	Needed if a LIL pole trips (under certain IIS conditions) to avoid UFLS
Manual Emergency actions	Operator-initiated runbacks	Needed to mitigate certain thermal overloads during n-1 and n-1-1 events

---

[26] These cases resulted in numerical instability in PSSE simulations. Hydro is working with Emera and ABB to perform PSCAD simulations to validate system limits in these cases.

Appendix 1

Modified UFLS Scheme – DYR data entry

PSSE Dynamic Data Entry (DYR) for Modified UFLS Scheme

```
/**********************************************************************
/           NLH Underfrequency Load Shedding
/           Burgeo load shed at 58.8 Hz
/           St. Albans load shed at 58.6 Hz
/           TL226 loads shed at 58.2 Hz
/           TL220 loads shed at 58.1 Hz
/
/**********************************************************************
 195178,'LDSHBL',1,58.400,0.0167,1.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0833/
 195432,'LDSHBL',1,58.600,0.0167,1.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0833/
 195409,'LDSHBL',1,58.200,0.0167,1.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0833/
 195407,'LDSHBL',1,58.200,0.0167,1.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0833/
 195408,'LDSHBL',1,58.200,0.0167,1.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0833/
 195435,'LDSHBL',1,58.100,0.0167,1.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0833/
 195436,'LDSHBL',1,58.100,0.0167,1.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0833/
 195437,'LDSHBL',1,58.100,0.0167,1.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0833/


/**********************************************************************
/           NP Underfrequency Load Shedding
/**********************************************************************
/ 59.0 Hz 15 sec time delay block - KEN,GLV - 54 + 12 = 66 MW
 196565,'LDSHBL',1,59.0,15.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/
 195135,'LDSHBL',1,59.0,15.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/

/ 58.9 Hz block - BLK,GRH - 37 + 14 = 51 MW
 196546,'LDSHBL',1,58.9,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/
 196221,'LDSHBL',1,58.9,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/

/ 58.8 Hz block - MDR,KBR,CHA - 89 + 40 + 54 = 183 MW
 195624,'LDSHBL',1,58.8,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/
 196570,'LDSHBL',1,58.8,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/
 196561,'LDSHBL',1,58.8,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/

/ 58.6 Hz block - CLV,SJM,GDL,PUL - 56 + 50 + 54 + 40 = 200 MW
 195144,'LDSHBL',1,58.6,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/
 196568,'LDSHBL',1,58.6,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/
 196563,'LDSHBL',1,58.6,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/
 196574,'LDSHBL',1,58.6,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/

/ 58.4 Hz block - GFS,RRD,GAM - 41 + 38 + 29 = 108 MW
 195126,'LDSHBL',1,58.4,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/
 196572,'LDSHBL',1,58.4,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/
 195133,'LDSHBL',1,58.4,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/
```

```
/ 58.3 Hz block - GAN,VIR,HWD,MSY - 24 + 70 + 52 + 17 = 163 MW
  195132,'LDSHBL',1,58.3,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/
  196573,'LDSHBL',1,58.3,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/
  195655,'LDSHBL',1,58.3,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/
  195157,'LDSHBL',1,58.3,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/

/ 58.2 Hz block - COB,BLK,BRB,BCV,GOU,KEL,SLA - 28 + 11 + 24 + 27 + 29 + 24 + 49 = 192 MW
  195130,'LDSHBL',1,58.2,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/
  195165,'LDSHBL',1,58.2,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/
  195167,'LDSHBL',1,58.2,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/
  196562,'LDSHBL',1,58.2,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/
  196564,'LDSHBL',1,58.2,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/
  196560,'LDSHBL',1,58.2,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/
  196567,'LDSHBL',1,58.2,0.0167,1.000,0.0,0.0,0.0,0.0,0.0,0.0,0.1/
```

Appendix 2

Steady State Thermal Overloads – Tables of Results

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Table A-0. System Intact N-1

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
195216 195806 1	195124 195805 1									158.52	150.30	133.95	134.26
195216 195805 1	195124 195806 1									158.79	150.56	134.18	134.50
195222 195809 1	195222 195808 1									111.04	129.33	130.26	125.70
195222 195808 1	195222 195809 1									110.97	129.33	130.16	125.61
TL217	TL201				141.09								
TL231	TL204				112.78								
TL232	TL205				124.75								
TL233	TL211				161.83				106.90				
TL201	TL217		120.59	169.02	273.98		115.20	144.10	148.82				
TL222a	TL228				102.99								
TL222b	TL228				110.50								
TL223	TL228				117.88								
TL224	TL228				102.41								
TL204	TL231				112.70								
TL205	TL232				177.18				125.01				
TL211	TL233				181.06				120.35				
TL228	TL233				177.43				134.84				
TL263	TL233				120.00								
TL203	TL237				136.63								
195209 195803 1	TL248										180.61	137.63	180.87
-	TL263				blown-up								
-	TL269				blown-up				blown-up				

Table A-1. Prior Outage TL201

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
TL217	195173 195175 1				178.37		125.18						
TL217	195173 195175 1			110.77				121.31					
195234 195815 6	195234 195817 8				129.12		115.76	111.04					
195234 195816 7	195234 195817 8				128.32		115.03	110.34					
-	TL217			blow up	blow up				blow up				
195163 195165 1	TL217	123.81	141.16										
195165 195167 1	TL217	122.54	152.57										
195167 195169 1	TL217	115.84	178.55										
195169 195171 1	TL217	113.48	181.74										
195171 195173 1	TL217	112.29	186.67										
195173 195175 1	TL217	110.82	193.57										
195229 195811 1	TL217		103.17										
195229 195812 1	TL217		102.61										
195229 195813 1	TL217		100.32										
195234 195815 6	TL217		134.58								103.68	116.04	116.03
195234 195816 7	TL217		133.72								103.02	115.30	115.29
195234 195817 8	TL217		130.31								100.39	112.36	112.35
-	TL234								blow up				

Table A-2. Prior Outage TL202

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
195216 195806 1	195124 195805 1									168.01	157.09	142.21	140.00
195216 195805 1	195124 195806 1									168.29	157.35	142.44	140.23

Table A-3. Prior Outage TL203

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
-	TL207				blow up								
-	TL237				blow up								
TL207	TL267				124.38								
TL237	TL267				139.27								

Table A-4. Prior Outage TL205

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
TL232	TL222b				140.73								
TL222a	TL228				116.46								
TL222b	TL228				124.89								
TL223	TL228				134.15								
TL224	TL228				118.80								
-	TL232				blow up				blow up				
195111 195112 1	TL232	111.42		110.54									
TL222a	TL232			133.67				108.30					
TL222b	TL232			143.94				118.79					
TL223	TL232	112.90		154.77				123.81					
TL224	TL232	129.77		139.50		104.32		108.00					
TL263	TL232			118.08									
-	TL233								blow up				
TL263	TL233				129.17								
-	TL234				blow up				blow up				
TL232	TL234			105.32									
-	TL263				blow up				blow up				

Table A-5. Prior Outage TL211*

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
195216 195806 1	195124 195805 1									165.69	148.15	131.64	128.12
195216 195805 1	195124 195806 1									165.97	148.39	131.84	128.32
TL233	195218 195224 1								111.06				
-	TL228									blow up			
TL263	TL232				130.16								
-	TL233				blow up				blow up			blow up	blow up
TL234	TL233			129.62									
TL263	TL233	114.20		152.06				108.40					
-	TL234				blow up				blow up				
TL233	TL234			144.24									
TL224	TL248												104.56
-	TL263				blow up				blow up				
TL233	TL263	119.54											
TL233	TL269												113.12

***Prior outage of TL211 requires ML to be limited to 0-35 MW export and 50 MW import, therefore thermal issues related these cases may not be valid.**

Table A-6. Prior Outage TL217

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
TL201	195173 195175 1		156.24		347.21		149.29		193.44				
195234 195815 6	195175 195817 8				130.44			112.60					
195234 195816 7	195175 195817 8				129.63			111.89					
195234 195815 6	195234 195817 8								117.48				
195234 195816 7	195234 195817 8								116.74				
195163 195165 1	TL201	123.81	141.16										
195165 195167 1	TL201	122.54	152.57										
195167 195169 1	TL201	115.84	178.55										
195169 195171 1	TL201	113.48	181.74										
195171 195173 1	TL201	112.29	186.67										
195173 195175 1	TL201	110.82	193.57										
195229 195811 1	TL201		103.17										
195229 195812 1	TL201		102.61										
195229 195813 1	TL201		100.32										
195234 195815 6	TL201		134.58								103.68	116.04	116.03
195234 195816 7	TL201		133.72								103.02	115.30	115.29
195234 195817 8	TL201		130.31								100.39	112.36	112.35
-	TL201			blow up	blow up		blow up		blow up				
-	TL234				blow up				blow up				
-	TL263								blow up				

Table A-7. Prior Outage TL218

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
-	TL236									blow up	blow up	blow up	blow up
TL242	TL266									140.82	140.78	140.68	140.69

Table A-8. Prior Outage TL228

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
195216 195806 1	195124 195805 1									157.28	157.65	144.47	142.48
195216 195805 1	195124 195806 1									157.54	157.92	144.73	142.73
-	195209 195210 1				blow up				blow up				
-	TL211									blow up			
-	TL222a								blow up				
-	TL222b								blow up				
TL233	TL222b				173.41								
TL263	TL222b				125.16								
TL233	TL223								119.44				
TL222a	TL232				118.60								
TL222b	TL232				127.26								
TL223	TL232				136.72				103.26				
TL224	TL232				121.41								
-	TL233				blow up				blow up				
195111 195112 1	TL233	102.47		120.76									101.95
TL222a	TL233			143.22				115.84					
TL222b	TL233		101.04	154.64				128.29					
TL223	TL233	102.20	106.50	166.28				132.58					

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
TL224	TL233	118.97		151.19				116.61					
TL234	TL233			101.17									
TL263	TL233			122.47									
-	TL234				blow up				blow up				
TL233	TL234			133.18									
-	TL263				blow up				blow up				

Table A-9. Prior Outage TL231

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
TL231	195140 195144 1				139.45				106.81				
195222 195808 1	195152 195809 1								105.58	113.53			
195216 195806 1	195216 195805 1									157.22			
195216 195805 1	195216 195806 1									157.47			
195222 195809 1	195222 195808 1								106.25	113.64	140.42	143.46	139.41
195222 195808 1	195222 195809 1										140.33	143.36	139.31
-	TL231				blow up				blow up			blow up	blow up
-	TL233								blow up				
-	TL234				blow up				blow up				
-	TL263				blow up				blow up				

Table A-10. Prior Outage TL232

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
-	TL205				blow up				blow up				
195111 195112 1	TL205	111.42		110.54									
TL222a	TL205			133.67				108.30					
TL222b	TL205			143.94				118.79					
TL223	TL205	112.90		154.77				123.81					
TL224	TL205	129.77		139.50		104.32		108.00					
TL263	TL205			118.08									
TL263	TL211				130.29								
TL205	TL222b				201.24				142.76				
TL228	TL222b				104.31								
TL222a	TL228				118.73								
TL222b	TL228				127.43								
TL223	TL228				136.86				103.27				
TL224	TL228				121.54								
-	TL233				blow up				blow up				
-	TL234				blow up				blow up				
TL205	TL234			150.94				114.40					
-	TL263				blow up				blow up				
TL205	TL269	110.78											107.92

Table A-11. Prior Outage TL233*

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
-	195209 195210 1				blow up				blow up				
-	195218 195224 1								blow up				
-	TL204								blow up				
-	TL205								blow up				
TL222b	TL205				106.70								
TL223	TL205				113.61								
-	TL211				blow up				blow up			blow up	blow up
TL234	TL211			129.68									
TL263	TL211	114.20		152.14				108.40					
-	TL222a								blow up				
-	TL222b								blow up				
TL228	TL222b				201.59								
-	TL223								blow up				
TL228	TL224								146.54				
-	TL228				blow up				blow up				
195111 195112 1	TL228	102.47		120.73									101.95
TL222a	TL228			143.19				115.84					
TL222b	TL228		101.04	154.61				128.29					
TL223	TL228	102.20	106.50	166.25				132.58					
TL224	TL228	118.97		151.15				116.61					
-	TL231								blow up				
TL263	TL231				130.91								

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
-	TL232				blow up				blow up				
-	TL234				blow up				blow up				
TL211	TL234		106.37	165.03				119.24					
TL228	TL234		109.23	162.09				131.98					
-	TL235								blow up				
-	TL248				blow up				blow up				
-	TL263				blow up				blow up				
TL211	TL263	135.99				109.97							117.18
TL228	TL263	102.19											111.75
-	TL269				blow up				blow up				blow up
TL211	TL269											114.77	
TL228	TL269											118.27	

***Prior outage of TL233 requires ML to be limited to 0 MW or out-of-service, therefore many of these thermal issues are not valid.**

Table A-12. Prior Outage TL234*

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
-	195111 195112 1								blow up				
-	195111 195803 1								blow up				
-	195132 195133 1								blow up				
-	195133 195135 1								blow up				
-	195135 195136 1								blow up				
-	195136 195140 1								blow up				
-	195140 195144 1								blow up				
TL204	195140 195144 1				104.63								
TL231	195140 195144 1				104.93								
195222 195809 1	195152 195808 1								103.92				
195222 195808 1	195152 195809 1								103.26				
-	195209 195210 1				blow up				blow up				
-	195209 195803 1								blow up				
-	195218 195224 1								blow up				
-	TL201								blow up				
-	TL204				blow up				blow up				
-	TL205				blow up				blow up				
TL232	TL205			105.33									
-	TL211				blow up				blow up				
TL233	TL211	119.50		144.25									

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
-	TL217								blow up				
-	TL222a								blow up				
-	TL222b								blow up				
TL205	TL222b				142.72								
TL228	TL222b				149.76								
TL232	TL222b				106.83								
TL233	TL222b				133.04								
-	TL223								blow up				
-	TL224								blow up				
-	TL228				blow up				blow up				
-	TL231				blow up				blow up				
-	TL232				blow up				blow up				
TL205	TL232	110.68		150.95				114.42					
-	TL233				blow up				blow up				
TL211	TL233	135.94	106.37	165.03		109.94		119.22					
TL228	TL233	102.11	109.23	162.09				131.89					
-	TL235								blow up				
TL211	TL235				138.12								
TL223	TL235				100.73								
-	TL248								blow up				
-	TL267								blow up				

***Prior outage of TL269, of which TL234 is an extension, requires ML to be limited to 150 MW export-230 MW export therefore thermal issues related to the ML 300 MW and 500 MW export cases may not be valid.**

Table A-13. Prior Outage TL236

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
-	TL218									blow up	blow up	blow up	blow up

Table A-14. Prior Outage TL237

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
-	TL203				blow up								
TL203	TL267			103.80	190.19			113.97	119.79				

Table A-15. Prior Outage TL263*

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
-	195106 195108 1								blow up				
-	195111 195112 1								blow up				
-	195111 195803 1								blow up				
-	195132 195133 1								blow up				
-	195133 195135 1								blow up				
-	195135 195136 1								blow up				
-	195136 195140 1								blow up				
-	195140 195144 1								blow up				
195222 195809 1	195152 195808 1								103.58				
195222 195808 1	195152 195809 1								102.95				
-	195209 195210 1								blow up				
-	195209 195803 1								blow up				
195216 195806 1	195216 195805 1												136.36
195216 195805 1	195216 195806 1												136.59
-	195218 195224 1								blow up				
195222 195809 1	195222 195808 1									109.21	134.56		133.63
195222 195808 1	195222 195809 1									109.13	134.46		133.53
-	n-1				blow up								
-	TL201								blow up				
-	TL202								blow up				

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
-	TL204								blow up				
-	TL205								blow up				
TL232	TL205			105.267									
-	TL206								blow up				
-	TL211								blow up				
TL233	TL211	119.505		144.191									
-	TL217								blow up				
-	TL222a								blow up				
-	TL222b								blow up				
-	TL223								blow up				
-	TL224								blow up				
-	TL228								blow up				
-	TL231								blow up				
-	TL232								blow up				
TL205	TL232	110.789		150.846				114.311					
-	TL233								blow up				
TL211	TL233	135.987	106.27	164.866		109.969		119.096					117.184
TL228	TL233	102.184	109.159	161.974				131.729				103.562	111.75
-	TL235								blow up				
-	TL248								blow up				

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
-	TL267								blow up				

***Prior outage of TL269, of which TL236 is an extension, requires ML to be limited to 150 MW export-230 MW export therefore thermal issues related to the ML 300 MW and 500 MW export cases may not be valid.**

Table A-16. Prior Outage TL266

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
TL242	TL218									140.82	140.74	140.66	140.67
TL218	TL242									169.07	169.06	169.06	169.03

Table A-17. Prior Outage TL267

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
195216 195806 1	195124 195805 1									164.94	154.26	139.50	137.45
195216 195805 1	195124 195806 1									165.18	154.50	139.73	137.67
195222 195809 1	195152 195808 1									105.95	126.49	126.95	122.50
195222 195808 1	195152 195809 1									105.85	126.38	126.85	122.40
TL206	TL202	135.66			148.84								
TL207	TL203				124.28								
TL237	TL203				139.14								
TL202	TL206	135.64			148.81								
TL203	TL207	107.04											
-	TL234								blow up				
TL203	TL237			103.80	190.17			113.85	119.77				
-	TL263				blow up				blow up				

Table A-18. Prior Outage TL268

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
no additional issues caused by prior outage													

Table A-19. Prior Outage TL269*

Monitored Element	Contingency	Light ML-260	Light ML158	Light ML250	Light ML500	Int ML-320	Int ML158	Int ML250	Int ML500	Peak ML-320	Peak ML158	Peak ML250	Peak ML300
195222 195809 1	195152 195808 1												137.63
195222 195808 1	195152 195809 1												137.51
195216 195806 1	195216 195805 1												138.08
195216 195805 1	195216 195806 1												138.29
-	n-1				blow up				blow up				
TL232	TL205			105.273									
TL233	TL211	119.503		144.196									113.129
TL205	TL232	110.787		150.859				114.329					107.923
-	TL233												blow up
TL211	TL233	135.983	106.282	164.891		109.966		119.147				114.747	
TL228	TL233	102.16	109.166	161.99				131.824				118.224	

***Prior outage of TL269 requires ML to be limited to 150 MW export-230 MW export therefore thermal issues related to the ML 300 MW and 500 MW export cases may not be valid.**

Reliability and Resource Adequacy Study – Operational Studies – Stage 4

Attachment 3

newfoundland labrador
hydro
a nalcor energy company

Engineering Support Services for:
RFI Studies

Newfoundland and Labrador Hydro

Attention: Mr. Rob Collett

Operational Considerations With 0 and 1 SOP Synchronous Condensers

Technical Note: TN1205.74.02
Date of issue: April 7, 2020

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Revisions

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Table of Contents

1. Summary

This technical note provides a summary of considerations for operating the Interconnected Island System ("IIS") with the Labrador Island Link ("LIL") bipole in-service prior to the Soldiers Pond ("SOP") synchronous condensers coming into service, and with one SOP synchronous condenser in-service.

The following issues were evaluated and are summarized below.

1.1 Harmonics

Harmonic analysis from a previous study[1] indicated that with no SOP synchronous condensers in service, the LIL can be deblocked and run in bipolar mode up to 225 MW with one B type filter in service at SOP and still meet IEC performance limits. Beyond 225 MW, two SOP filters are required to operate up to its full steady state rating of 675 MW (1.5 pu) monopole or 900 MW bipole.

1.2 Short Circuit Levels

The short circuit level ("SCL") at SOP was determined with 0 and 1 SOP synchronous condensers in-service during a light load, minimum IIS generation scenario with varying number of Holyrood units in-service. According to the LIL specification, the short circuit level at SOP must be at least 2833 MVA for full power operation. Operation of the LIL at reduced short circuit levels is subject to GE approval and PSCAD analysis must be performed to validate acceptable transfer limits.

1.3 Step Change in Voltage

Table 1-1 lists the minimum number of Holyrood ("HRD") units[2] that need to be in-service when switching a SOP filter to ensure the resulting step change in voltage (delta V) is less than 5% if there are no SOP synchronous condensers in-service. With one SOP synchronous condenser in-service, the delta V from SOP filter switching is less than 5%, even with no HRD units on-line.

Table 1-1. Minimum number of HRD units to meet 5% Delta V for filter switching if there are no SOP synchronous condensers in-service

Minimum Number HRD Units	SOP Filters	Corresponding LIL Transfer (MW)
0	Cannot switch a filter (delta V > 10%)	
1	1st, 2nd, 3rd	Deblock up to 549 MW
2	4th, 5th	504 MW up 900 MW

1.4 Steady State Voltage: Deblock to Maximum LIL Transfer

The results of the steady state analysis indicate that the LIL cannot be deblocked when Island Demand is less than 500 MW. When Island demand is less than 750 MW, the LIL can only be deblocked with a single filter. Operation (and deblocking) with fewer than 2 filters is subject to GE approval. As demand

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[1] Please refer to Section 2 of this report.
[2] Holyrood Unit 3 may be in service as generator or as a synchronous condenser.

levels increase above 1000 MW, low voltage issues begin to arise, and it is better to deblock the LIL with two SOP filters in-service.

At peak demand, prior to the LIL being deblocked, all three HRD units must be dispatched to provide enough generation to meet demand and to support the IIS voltage and either a SOP synchronous condenser or the HRD CT must also be in-service, otherwise the voltage can collapse prior to the SOP filters being switched in and the LIL being deblocked.

1.5 Dynamic Performance

Dynamic performance of the IIS without SOP synchronous condensers was checked for a sampling of operating scenarios that are at the boundaries defined by acceptable steady state voltage.

Without the SOP synchronous condensers in-service, loss of an HRD unit results in the weakest conditions at the SOP bus. It also results in loss of reactive power support from that unit. In all cases that were tested, the IIS recovered in a stable manner from the fault. However, the LIL experienced commutation failure(s) during the fault recovery period in some instances, which is not usually considered to be acceptable. Most of the cases with subsequent commutation failures were high LIL transfer cases during low IIS demand, and could be mitigated by reducing the LIL transfer.

The one exception was the peak load case, which also experienced commutation failures during the fault recovery period. Reducing LIL transfer and/or placing the SOP synchronous condensers back into service did not eliminate these commutation failures.

It should be noted that PSSE is not an accurate tool for assessing commutation performance of the LIL. It is recommended that these cases be assessed with the PSCAD model of the LIL.

It should also be reiterated that the additional commutation failures during fault recovery did not prevent the IIS from recovering in a stable manner.

1.6 High Power Summer Tests

Please refer to Section 7 of this report for a summary of operation guidelines for performing the high-power summer tests, with LIL transferring 900 MW and the ML exporting 500 MW.

1.7 Summary of Results

The results described above have been consolidated into an operation plot that is provided in Section 8.

2. Harmonics

Harmonic analysis previously performed as part of the Stage 4D operational study, when the system is transitioning from low power operation to high power operation, identified LIL transfer limits required to meet the IEC performance limits with varying number of SOP filters in-service, including a scenario with no synchronous condensers in-service at Soldiers Pond. Table 2-1 summarizes the results with no SOP synchronous condensers.

Table 2-1. LIL Transfer Limits to meet IEC Limits – no SOP synchronous condensers

SOP filters in service	Maximum LIL Transfer to meet IEC limits	
	Monopole	Bipole
A type	Up to 135MW	Exceeded at deblock
B type	Up to 315MW	Up to 225MW
A+B type	Up to 675MW	Up to 900MW
A+2B type	Up to 675MW	Up to 900MW

In summary, the first pole of the LIL can be deblocked with one filter (A or B type) at SOP. However, if operating as a bipole with only one filter, it must be a B type filter, and LIL transfer is limited to 225 MW under this scenario.

When only considering the harmonic performance of the system[3], the LIL can operate up to its full steady state rating of 675 MW (1.5 pu) monopole or 900 MW bipole with two filters in service (either one A and one B type, or one A and one 2B type).

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[3] Other considerations such as reactive support requirements are addressed in other sections.

3. Short Circuit Level

The short circuit level (SCL) at Soldiers Pond was determined with 0 and 1 SOP synchronous condensers in-service during a light load, minimum IIS generation scenario[4] with varying number of Holyrood units in-service. The results are summarized in Table 3-1.

Table 3-1. SCL at SOP with 0 and 1 SOP synchronous condensers in-service

HRD units in-service	Short Circuit Level at SOP (MVA)	
	0 SOP Synchronous Condensers	1 SOP Synchronous Condenser
0	1170	1976
1	1639	2444
2	2141	2944
3	2644	3444

According to the LIL specification, the short circuit level at SOP must be at least 2833 MVA for full power operation. Operation of the LIL at reduced short circuit levels is subject to GE approval and PSCAD analysis must be performed to validate acceptable transfer limits.

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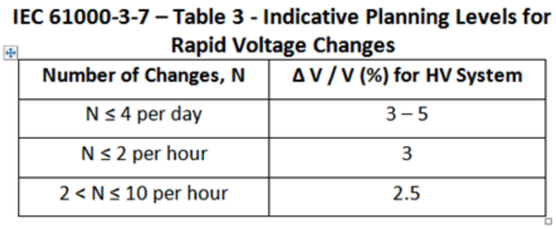
[4] The minimum IIS generation scenario is based on Hydro's minimum short circuit level case where Hydro units are at a minimum dispatch, gas turbines are offline, wind generators are offline, customer generation is online at firm supply levels, and non-utility generators are offline. Such a generating scenario may occur at various loading conditions depending on the number of Holyrood units online and the dispatch of the LIL and ML.

4. Delta V due to Filter Switching

An assessment of the step change in voltage (delta V) that occurs when switching a Soldiers Pond filter into service was performed. The delta V was recorded for the scenario with the SOP synchronous condensers out-of-service and for the scenario with one SOP synchronous condenser in-service. The assessment was performed with 0, 1, 2 and 3 Holyrood units in-service at the LIL filter switch-in and switch-out points.

The delta V is worst if the SOP synchronous condensers are not in-service.

The IEC guideline for maximum allowable step changes in voltage indicates that a delta V up to 5% can be acceptable if the occurrence is limited as per Figure 4–1.



IEC 61000-3-7 – Table 3 - Indicative Planning Levels for Rapid Voltage Changes

Number of Changes, N	Δ V / V (%) for HV System
N ≤ 4 per day	3 – 5
N ≤ 2 per hour	3
2 < N ≤ 10 per hour	2.5

Figure 4–1. IEC 6100-3-7 Table 3

4.1 No SOP Synchronous Condensers In-Service

Various cases were tested from prior to deblocking the LIL (1st and 2nd filter switch-in points) up to the point of the 5th filter switch-in to observe the delta V that occurs from switching a 75 MVAR filter into service at Soldiers Pond. Although the operating scenario (e.g. demand, dispatch) has a slight impact on delta V, the largest impact on delta V is the number of HRD units that are in-service and the number of SOP filters that are already in service. The largest delta V occurs when switching the last filter into service. The delta V results are summarized in Table 4-1 for the scenario with no SOP synchronous condensers in-service.

Table 4-1. Delta V from SOP Filter Switching – 0 SOP Synchronous Condensers

SOP Filter	Step Change in Voltage at SOP (%)				LIL filter switch in point (MW)	LIL filter switch out point (MW)
	0 HRD	1 HRD	2 HRD	3 HRD		
1st	>10	4.1 – 4.5	2.7 – 3.0	2.1 – 2.3	Deblock	Deblock
2nd	>10	4.6 – 4.9	2.9 – 3.1	2.1 – 2.2	Deblock	Deblock
3rd	>10	4.9 – 5.2	3.1 – 3.2	2.2 – 2.5	324	279
4th	>10	6.0 – 6.1	3.3 – 3.4	2.4 – 2.7	504	549
5th	>10	7.1 – 8.0	3.9 – 4.2	2.6 – 2.8	765	720

Table 4-2 lists the minimum number of Holyrood units that are required to be in-service when switching a SOP filter in order to keep the delta V to a maximum of 5% when there are no SOP synchronous condensers in-service.

Table 4-2. Minimum number of HRD units to switch specific SOP filters

Minimum Number HRD Units	SOP Filters	Corresponding LIL Transfer (MW)
0	Cannot switch a filter	
1	1st, 2nd, 3rd	Deblock up to 549 MW
2	4th, 5th	504 MW up 900 MW

On the basis of the above, if the LIL filters are switched at specified design levels, the LIL cannot be loaded in excess of 550 MW with no SOP synchronous condensers and fewer than two HRD units in service.

4.1.1 One SOP Synchronous Condenser In-Service

The delta V values were also calculated for the scenario with one SOP synchronous condenser in-service and the results are summarized in Table 4-3. Having a synchronous condenser at the SOP bus significantly improves the delta V that occurs at the SOP bus when switching a 75 MVAr filter. With one SOP synchronous condenser in-service, all step changes in voltage were observed to be less than 5%, even if there are no Holyrood units in-service.

Table 4-3. Delta V from SOP Filter Switching – 1 SOP Synchronous Condenser

SOP Filter	Step Change in Voltage at SOP (%)		LIL filter switch in point (MW)	LIL filter switch out point (MW)
	0 HRD	1 HRD		
1st	3.0 – 3.8	2.0 – 2.5	Deblock	Deblock
2nd	3.0 – 3.8	2.0 – 2.5	Deblock	Deblock
3rd	3.3 – 4.2	2.2 – 2.7	324	279
4th	3.4 – 4.2	2.3 – 2.7	504	549
5th	3.9 – 4.6	2.6 – 2.8	765	720

Please note that prior to switching a filter, it is recommended to adjust the voltage at SOP to a value that will ensure the voltage remains below 1.05 pu after the filter is switched in. For example, if a delta V of 4% is expected (based on Table 4-1 or Table 4-3), it is recommended to adjust the SOP voltage to be at a maximum of 1.01 pu prior to switching the filter so that the voltage remains at or below 1.05 pu after the filter is switched in.

5. Steady State Voltage

An assessment of the steady state voltage at Soldiers Pond was performed at the LIL filter switch-in and switch-out points over the full range of LIL operation; from prior to deblocking the LIL up to maximum LIL power transfer.

GE's filter switching scheme at Soldiers Pond is summarized in Table 5-1.

Table 5-1. GE Filter Switching Scheme at SOP

SOP Filters	LIL Power Transfer (MW)	
	Switch In	Switch Out
2	Deblock	Deblock
3	324	279
4	549	504
5	765	720

The steady state voltage at SOP was recorded over the full range of LIL power transfer; from prior to deblocking the LIL up to maximum LIL power transfer at each of the filter switch-out and switch-in points to observe any issues with overvoltage or undervoltage. The voltage at SOP was recorded with 0, 1, 2 and 3 HRD units in-service, for the scenario with no SOP synchronous condensers in-service (Table 5-2) and for the scenario with one SOP synchronous condenser in-service (Table 5-3).

Please note the following with regards to Table 5-1 and Table 5-3:

- Cells highlighted in red represent high voltage violations (>1.05 pu)
- Cells highlighted in purple represent low voltage violations (<0.95 pu or voltage collapse)

A discussion on the results is provided following the tables.

Table 5-2. SOP Voltage – Deblock to 900 MW LIL Transfer – 0, 1, 2, 3 HRD Units – 0 SOP synchronous condensers in-service

Demand (MW)	LIL Power (MW)	SOP Filters	SOP Voltage (pu)				Voltage setpoints[5] (pu)				Capacitors In-service[3]		
			0 HRD	1 HRD	2 HRD	3 HRD	BDE1-6	BDE7	HRD3	HRD1,2	CBC	OXP	HRD
500	0	0	1.004	1.011	1.031	1.037	0.96	0.93	0.97	0.995	0	0	0
	45	1	1.10	1.052	1.055	1.052	0.96	0.93	0.97	0.995	0	0	0
	225		1.063	1.031	1.034	1.035	0.96	0.93	0.97	0.995			
	45	2	>1.2	1.187	1.132	1.102	0.96	0.93	0.97	0.995	0	0	0
	225		1.121	1.063	1.055	1.051	0.96	0.93	0.97	0.995			
	324		1.087	1.043	1.041	1.04	0.96	0.93	0.97	0.995			
	279	3	>1.2	1.157	1.087	1.072	0.96	0.93	0.97	0.995	0	0	0
	549		0.956	1.007	1.012	1.013	0.96	0.93	0.97	0.995			
	504	4	>1.2	1.094	1.063	1.049	0.96	0.93	0.97	0.995	0	0	0
	650		1.082*	1.03	n/a	n/a	0.96	0.93	0.97	0.995	0	0	0
750	0	0	0.931	1.031	1.04	1.05	1.04	1.04	1.04	1.04	0	0	0
	45	1	0.97	1.008	1.032	1.042	0.98	0.98	0.97	0.995	0	0	0
	225		0.944	0.991	1.019	1.027	0.98	0.98	0.97	0.995	0	0	0
	45	2	1.056	1.036	1.048	1.055	0.96	0.93	0.97	0.995	0	0	0
	225		1.044	1.027	1.039	1.042	0.96	0.93	0.97	0.995	0	0	0
	324		0.999	1.012	1.025	1.031	0.96	0.93	0.97	0.995	0	0	0
	279	3	1.137	1.065	1.062	1.061	0.96	0.93	0.97	0.995	0	0	0
	549		0.975	1.022	1.027	1.027	0.99	0.99	0.99	0.995	0	0	0
	504	4	1.186	1.066	1.052	1.046	0.96	0.93	0.97	0.995	0	0	0
	765		collapse	1.042	1.043	1.046	1.043	1.043	1.03	1.03	0	0	0
	720	5	1.055	1.02	1.036	1.035	0.97	0.97	0.97	0.995	0	0	0

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[5] Please note that the voltage setpoints and in-service capacitors correspond to the case with zero (0) and one (1) HRD unit in-service since these are the most limiting cases. The cases with two and three HRD units may have adjusted voltage setpoints and/or in-service capacitors as required.

Demand (MW)	LIL Power (MW)	SOP Filters	SOP Voltage (pu)				Voltage setpoints[5] (pu)				Capacitors In-service[3]		
			0 HRD	1 HRD	2 HRD	3 HRD	BDE1-6	BDE7	HRD3	HRD1,2	CBC	OXP	HRD
	900		collapse	1.025	1.038	1.041	1.04	1.04	1.04	1.04	0	0	0
1000	0	0	0.959	1.02	1.04	1.05	1.043	1.043	1.02	1.02	2	2	2
	45	1	0.976	1.038	1.029	1.046	1.02	1.02	1.02	1.02	0	2	2
	225		1.006	1.034	1.044	1.048	1.02	1.02	1.0	1.0	0	2	2
	45	2	0.940	1.021	1.046	1.050	1.02	1.02	1.0	1.0	0	0	1
	225		0.987	1.027	1.041	1.050	1.02	1.02	1.0	1.0	0	0	1
	324		0.948	1.024	1.038	1.042	1.02	1.02	1.0	1.0	0	0	1
	279	3	1.034	1.025	1.041	1.047	1.0	1.0	0.97	0.995	0	0	0
	549		0.941	1.033	1.038	1.039	1.02	1.02	1.0	1.0	0	0	1
	504	4	1.099	1.034	1.038	1.041	0.98	0.98	0.97	0.995	0	0	0
	765		collapse	1.041	1.046	1.048	1.02	1.02	1.02	1.02	0	1	1
	720	5	1.036	1.023	1.027	1.028	1.0	1.0	0.97	0.995	0	0	0
	900		collapse	1.049	1.035	1.032	0.99	0.99	0.99	0.995	2	2	2
1250	0	0	collapse	collapse	1.035		1.043	1.043	1.05	1.05	4	2	2
	45	1	collapse	0.975	1.036	1.049**	1.043	1.043	1.05	1.05	4	2	2
	225		collapse	1.009	1.037	1.05	1.043	1.43	1.02	1.02	3	2	2
	45	2	0.964*	1.043	1.025	1.046	1.04	1.04	1.0	1.0	4	2	2
	225		0.966	1.032	1.041	1.051	1.0	1.0	1.0	1.0	3	2	2
	324		0.995	1.032	1.04	1.047	1.0	1.0	1.0	1.0	3	2	2
	279	3	1.003	1.025	1.042	1.048	1.0	1.0	0.99	0.995	1	1	2
	549		1.007	1.041	1.047	1.048	1.01	1.01	1.0	1.0	1	2	2
	504	4	1.049	1.034	1.044	1.046	0.99	0.99	0.98	0.995	1	1	1
	765		collapse	1.046	1.045	1.044	1.0	1.0	1.0	1.0	2	2	2
	720	5	1.036	1.023	1.027	1.028	0.99	0.99	0.99	0.99	1	1	1

Demand (MW)	LIL Power (MW)	SOP Filters	SOP Voltage (pu)				Voltage setpoints[5] (pu)				Capacitors In-service[3]		
			0 HRD	1 HRD	2 HRD	3 HRD	BDE1-6	BDE7	HRD3	HRD1,2	CBC	OXP	HRD
	900		collapse	1.049	1.035	1.032	1.0	1.0	1.0	1.0	2	2	2
1500	0	0	collapse	collapse	collapse	1.005	1.043	1.043	1.05	1.05	4	2	2
	45	1	collapse	collapse	collapse	1.038	1.043	1.043	1.05	1.05	4	2	2
	45	2	collapse	collapse	1.026	1.046	1.043	1.043	1.05	1.05	4	2	2
	225		collapse	0.975	1.047	1.048	1.043	1.043	1.05	1.05	4	2	2
	324		collapse	1.008	1.005	1.036	1.043	1.043	1.05	1.05	4	2	2
	279	3	collapse	1.032	1.018	1.04	1.03	1.03	1.03	1.03	4	2	2
	549		collapse	1.023	1.014	1.03	1.03	1.03	1.03	1.03	3	2	2
	504	4	collapse	1.038	1.042	1.05	1.0	1.0	1.0	1.0	3	2	2
	765		collapse	1.012	1.031	1.044	1.01	1.01	1.02	1.02	3	2	2
	720	5	collapse	1.039	1.039	1.045	1.0	1.0	1.0	1.0	2	2	2
	900		collapse	1.039	1.038	1.047	1.02	1.02	1.05	1.05	2	2	2
1800	0	0	collapse	collapse	collapse	collapse****	1.043	1.043	1.05	1.05	4	2	2
	45	2	collapse	collapse	collapse	1.032	1.043	1.043	1.05	1.05	4	2	2
	324		collapse	collapse	collapse	1.02	1.043	1.043	1.05	1.05	4	2	2
	279	3	collapse	collapse	0.987	1.042	1.043	1.043	1.05	1.05	4	2	2
	549		collapse	collapse	1.011	1.035**	1.043	1.043	1.05	1.05	4	2	2
	504	4	collapse	collapse	1.047	1.038**	1.043	1.043	1.05	1.05	4	2	2
	765		collapse	collapse	1.02	1.034	1.02	1.02	1.05	1.05	4	2	2
	720	5	collapse	collapse	1.02	1.045	1.02	1.02	1.04	1.02	4	2	2
	900		collapse	collapse	1.009	1.042	1.02	1.02	1.04	1.04	3	2	2

Table 5-3. SOP Voltage – Deblock to 900 MW LIL Transfer – 0, 1, 2, 3 HRD Units – 1 SOP synchronous condenser in-service

Demand (MW)	LIL Power (MW)	SOP Filters	SOP Voltage (pu)				Voltage setpoints[6] (pu)				Capacitors In-service[3]		
			0 HRD	1 HRD	2 HRD	3 HRD	BDE1-6	BDE7	HRD3	HRD1,2	CBC	OXP	HRD
500	0	0	0.998	1.004	1.015	1.026	0.96	0.93	0.97	0.995	0	0	0
	45	1	1.024	1.022	1.031	1.036	0.96	0.93	0.97	0.995	0	0	0
	225		1.013	1.014	1.023	1.025	0.96	0.93	0.97	0.995	0	0	0
	45	2	1.133	1.088	1.079	1.074	0.96	0.93	0.97	0.995	0	0	0
	225		1.037	1.031	1.033	1.034	0.96	0.93	0.97	0.995	0	0	0
	324		1.022	1.02	1.023	1.025	0.96	0.93	0.97	0.995	0	0	0
	279	3	1.101	1.049	1.046	1.044	0.96	0.93	0.97	0.995	0	0	0
	549		0.997	1.004	1.009	1.01	0.96	0.93	0.97	0.995	0	0	0
	504	4	1.046	1.037	1.034	1.034	0.96	0.93	0.97	0.995	0	0	0
	650		0.995	1.004	n/a	n/a	0.96	0.93	0.97	0.995	0	0	0
750	0	0	0.984	1.017	1.036	1.048	1.04	1.04	1.04	1.04	0	0	0
	45	1	0.994	1.002	1.016	1.026	0.98	0.98	0.97	0.995	0	0	0
	225		0.988	0.997	1.01	1.021	0.98	0.98	0.97	0.995	0	0	0
	45	2	1.016	1.016	1.027	1.039	0.96	0.93	0.97	0.995	0	0	0
	225		1.011	1.013	1.023	1.031	0.96	0.93	0.97	0.995	0	0	0
	324		1	1.005	1.014	1.02	0.96	0.93	0.97	0.995	0	0	0
	279	3	1.036	1.031	1.035	1.039	0.96	0.93	0.97	0.995	0	0	0
	549		0.999	1.012	1.016	1.018	0.99	0.99	0.99	0.995	0	0	0
	504	4	1.034	1.029	1.03	1.03	0.96	0.93	0.97	0.995	0	0	0
	765		0.981	1.018	1.023	1.029	1.043	1.043	1.03	1.03	0	0	0

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[6] Please note that the voltage setpoints and in-service capacitors correspond to the case with zero (0) and one (1) HRD unit in-service since these are the most limiting cases. The cases with two and three HRD units may have adjusted voltage setpoints and/or in-service capacitors as required.

Demand (MW)	LIL Power (MW)	SOP Filters	SOP Voltage (pu)				Voltage setpoints[6] (pu)				Capacitors In-service[3]		
			0 HRD	1 HRD	2 HRD	3 HRD	BDE1-6	BDE7	HRD3	HRD1,2	CBC	OXP	HRD
	720	5	1.006	1.02	1.019	1.013	0.97	0.97	0.97	0.995	0	0	0
	900		0.95	1.02	1.031	1.032	1.04	1.04	1.05	1.05	0	0	0
1000	0	0	0.981	1.01	1.03	1.038	1.02	1.02	1.02	1.02	2	2	2
	45	1	0.96	1.004	1.03	1.046	1.04	1.04	1.04	1.04	1	2	2
	225		1.002	1.016	1.028	1.036	1.02	1.02	1	1	0	2	2
	45	2	0.986	1.006	1.023	1.034	0.98	0.98	1	1	0	1	1
	225		1	1.016	1.028	1.034	1.02	1.02	1	1	0	0	1
	324		0.995	1.012	1.023	1.028	1.02	1.02	1	1	0	0	1
	279	3	1.012	1.013	1.024	1.031	1	1	0.97	0.995	0	0	0
	549		0.993	1.01	1.021	1.027	1.02	1.02	1	1	0	0	1
	504	4	1.013	1.015	1.023	1.027	0.98	0.98	0.97	0.995	0	0	0
	765		0.984	1.016	1.025	1.031	1.02	1.02	1.02	1.02	0	1	1
	720	5	1.002	1.009	1.014	1.018	1	1	0.97	0.995	0	0	0
	900		1.011	1.022	1.021	1.019	0.99	0.99	0.99	0.995	2	2	2
1250	0	0	0.905	0.977	1.02	1.044	1.043	1.043	1.05	1.05	4	2	2
	45	1	0.93	0.992	1.03	1.51	1.043	1.043	1.05	1.05	2	2	2
	225		0.977	1.008	1.03	1.042	1.043	1.43	1.02	1.02	3	2	2
	45	2	0.998	1.017	1.036	1.046	1.04	1.04	1	1	4	2	2
	225		0.983	1.006	1.023	1.033	1	1	1	1	2	2	2
	324		0.986	1.008	1.023	1.035	1	1	1	1	2	2	2
	279	3	0.995	1.01	1.026	1.033	1	1	0.99	0.995	1	1	2
	549		0.998	1.017	1.025	1.031	1.01	1.01	1	1	1	2	2
	504	4	1.006	1.014	1.023	1.03	0.99	0.99	0.98	0.995	1	1	1
	765		0.998	1.018	1.024	1.027	1	1	1	1	2	2	2

Demand (MW)	LIL Power (MW)	SOP Filters	SOP Voltage (pu)				Voltage setpoints[6] (pu)				Capacitors In-service[3]		
			0 HRD	1 HRD	2 HRD	3 HRD	BDE1-6	BDE7	HRD3	HRD1,2	CBC	OXP	HRD
	720	5	1.005	1.018	1.022	1.025	0.99	0.99	0.99	0.99	1	1	1
	900		0.995	1.017	1.02	1.021	1	1	1	1	2	2	2
1500	0	0	collapse	collapse	0.923	1.008	1.043	1.043	1.05	1.05	4	2	2
	45	1	collapse	collapse	0.986	1.028	1.043	1.043	1.05	1.05	4	2	2
	45	2	collapse	collapse	1.011	1.044	1.043	1.043	1.05	1.05	4	2	2
	225		0.927	0.99	1.028	1.048	1.043	1.043	1.05	1.05	4	2	2
	324		0.942	0.998	1.03	1.048	1.043	1.043	1.04	1.04	4	2	2
	279	3	0.966	1.007	1.036	1.05	1.03	1.03	1.02	1.02	4	2	2
	549		0.951	0.999	1.024	1.03	1.03	1.03	1.03	1.03	2	2	2
	504	4	0.994	1.015	1.029	1.038	1	1	1	1	3	2	2
	765		0.952	0.999	1.018	1.029	1.02	1.02	1.02	1.02	2	2	2
	720	5	0.994	1.016	1.027	1.033	1	1	1	1	2	2	2
	900		0.952	1.014	1.036	1.049	1.02	1.02	1.05	1.05	2	2	2
1800	0	0	collapse	collapse	collapse	0.971	1.043	1.043	1.05	1.05	4	2	2
	45	2	collapse	collapse	collapse	1.02	1.043	1.043	1.05	1.05	4	2	2
	324		collapse	collapse	0.952	1.013	1.043	1.043	1.05	1.05	4	2	2
	279	3	collapse	collapse	0.995	1.032	1.043	1.043	1.05	1.05	4	2	2
	549		collapse	0.945	1.005	1.032	1.043	1.043	1.05	1.05	4	2	2
	504	4	collapse	0.98	1.025	1.048	1.043	1.043	1.05	1.05	4	2	2
	765		collapse	0.962	1.008	1.031	1.02	1.02	1.05	1.05	4	2	2
	720	5	0.922	0.997	1.032	1.046	1.02	1.02	1.04	1.04	4	2	2
	900		collapse	0.977	1.016	1.037	1.043	1.043	1.05	1.05	3	2	2

The results in Table 5-2 and Table 5-3 indicate that high voltage concerns are present at low demand levels. On this basis, the LIL cannot be deblocked when Island Demand is less than 500 MW. When Island demand is less than 750 MW, the LIL can only be deblocked with a single filter. Operation (and deblocking) with fewer than 2 filters is subject to GE approval.

As demand levels increase above 1000 MW, low voltage issues begin to arise, and it is better to deblock the LIL with two SOP filters in-service.

At peak demand, prior to the LIL being deblocked, all three HRD units must be dispatched to provide enough generation to meet demand and to support the IIS voltage and either a SOP synchronous condenser or the HRD CT must also be in-service, otherwise the voltage can collapse prior to the SOP filters being switched in and the LIL being deblocked.

6. Dynamic Performance

Dynamic performance of the IIS without SOP synchronous condensers was checked for a sampling of operating scenarios.[7] The tested cases are listed in Table 6-1, along with the results. For each case a three-phase fault ("3PF") on a Holyrood unit was tested. Where violations were found, the case was re-run with one SOP synchronous condenser in-service.

A discussion of results is provided following Table 6-1.

Table 6-1. Dynamic performance tests without SOP synchronous condensers

Demand (MW)	# HRD units in-service	LIL (MW)	ML (MW)	# SOP Filters in-service	Disturbance	Results with 0 SOP synchronous condensers	Re-test violations with 1 SOP synchronous condenser
500	1	225	158	1	3PF HRD 3	Stable	
750	1	324	0	2	3PF HRD 1	Stable	
1000	1	480	158	3	3PF HRD3	Stable	
	2	900	500	5	3PF HRD1	Stable	
					3PF HRD 3	Additional commutation failures during fault recovery. Mitigated if LIL transfer limit reduced to 760 MW.	OK at the 900 MW LIL transfer (note only HRD unit 3 in-service, in addition to SOP sync.).
1250	1	549	158	3	3PF HRD1	Stable	
	2	900	500	5	3PF HRD1	Stable	
					3PF HRD3	Stable	
1430	2	900	500	5	3PF HRD1	Stable	
					3PF HRD3	Stable	
1750	3	900	500	5	3PF HRD3	Stable	
1850	3	900	500	5	3PF HRD1	Stable	
					3PF HRD 3	With HRD CT in service, the commutation failures during recovery are reduced to one. If two SOP synchronous condensers and the HRD CT are in-service, then there are no commutation failures during the fault recovery.	

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[7] The Stage 4D operational study includes LIL transfer limits as a function of Island Demand and ML power flow. The limits from the Stage 4D study include frequency considerations for LIL contingencies and must be observed in concert with the limits presented in this document to ensure compliance with Transmission Planning Criteria.

6.1 3PF on a Holyrood Unit

A three-phase fault on the high side of a Holyrood unit transformer, and subsequent tripping of the transformer and the Holyrood unit, was tested for each case. Without the SOP synchronous condensers in-service, loss of an HRD unit results in the weakest conditions at the SOP bus and in loss of reactive power support from that unit.

In all cases, the IIS recovered in a stable manner. However, it was noted in some cases that the LIL experienced commutation failure(s) during the fault recovery period. The LIL is expected to fail commutation during the fault, however, additional commutation failures during fault recovery is not usually considered to be acceptable.

The cases experiencing commutation failures during fault recovery are highlighted in red in Table 6-1. Most of these cases occur during higher LIL transfer at lower IIS demand. The additional commutation failures did not occur if the LIL transfer was reduced as mentioned in the results in Table 6-1.

One exception was the peak load case. In this case, reducing LIL transfer and/or placing the SOP synchronous condensers into service did not eliminate the additional commutation failures observed during the fault recovery.

It should be noted that PSSE is not an accurate tool for assessing commutation performance of the LIL. It is recommended that these cases be assessed with the PSCAD model of the LIL.

It should be reiterated that the additional commutation failures during recovery from the fault did not prevent the IIS from recovering in a stable manner.

7. High Power Summer Tests

The high power tests are intended to test the LIL at 900 MW transfer while the IIS is exporting 500 MW on the ML.

In order to ensure operation is within the acceptable bounds defined by the Stage 4 operating studies, the following guidelines should be followed:

- The LIL transfer limits defined for Stage 4D should be followed. When ML is exporting 500 MW, the LIL is allowed to transfer 900 MW for IIS demand levels of 1250 MW or above. It is assumed that the ML will runback will be in place to quickly reduce ML export to 0 MW if the LIL bipole trips.
- The appropriate number of HRD units should be in-service, according to IIS demand level and whether 0 or 1 SOP synchronous condenser is in-service, as defined in this report.

8. Summary of Results

On the basis of the study results presented above, considerations for operation for the LIL with fewer than two SOP synchronous condensers. Operational considerations in this mode of operation are summarized as follows:

- According to the LIL specification, the short circuit level at SOP must be at least 2833 MVA for full power operation. Operation of the LIL at reduced short circuit levels is subject to GE approval and PSCAD analysis must be performed to validate acceptable transfer limits.
- The LIL cannot be deblocked when Island Demand is less than 500 MW. When Island demand is less than 750 MW, the LIL can only be deblocked with a single filter in-service. Operation (and deblocking) with fewer than 2 filters is subject to GE approval.
- The Stage 4D operational study includes LIL limits as a function of Island Demand and ML power flow. These limits must be observed to ensure compliance with Transmission Planning Criteria.

The LIL may otherwise be operated up to rated capacity when one SOP unit is in service. When no SOP synchronous condensers are in service, the following restrictions must also be applied:

- A minimum of one Holyrood unit must be in service as either a generator or as a synchronous condenser for LIL operation.
- To avoid overvoltage conditions, the third SOP filter bank can only be placed in service when Island Demand exceeds 1000 MW.
- Two HRD units must be online for the fourth SOP filter bank to be placed in service due to unacceptable voltage deviations. In accordance with GE's filter switching scheme, LIL capacity is limited to 550 MW with less than four filters in service.
- It was found in PSSE simulations that multiple commutation failures may occur during recovery following a 3PF near the inverter. PSCAD analysis will be performed to verify if system restrictions are required to avoid this.
- LIL limits with no SOP synchronous condensers in service are presented in Figure 8–1.

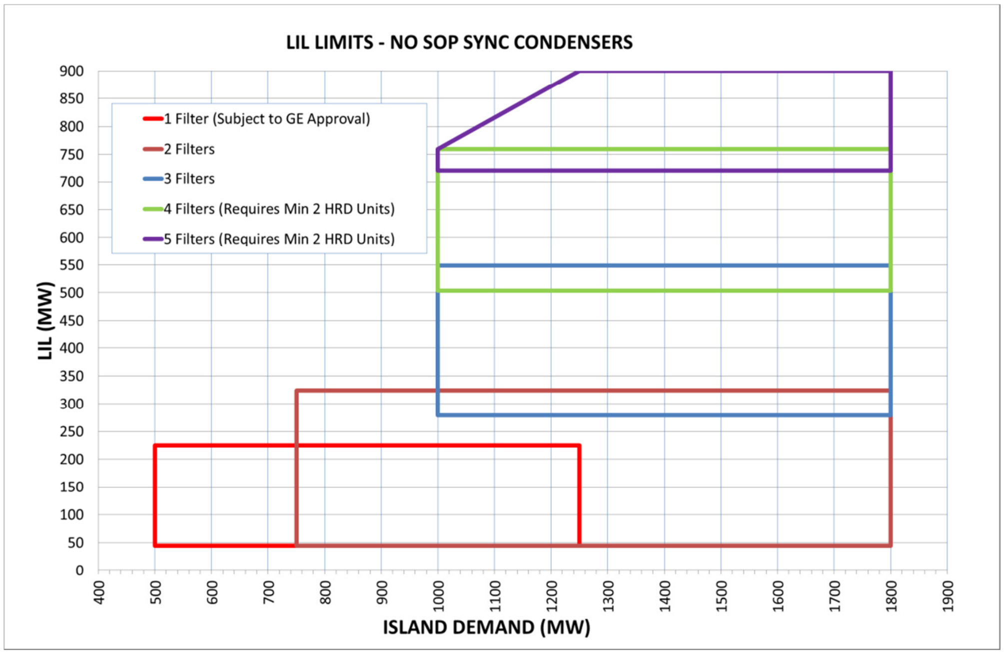

Figure 8–1. LIL Operating range[8] with no SOP synchronous condensers in service

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[8] Please note this plot does not consider Island frequency limitations. Limits presented in the Stage 4D report must also be observed.

Reliability and Resource Adequacy Study – Operational Studies – Stage 4

Attachment 4

Engineering Support Services for:
RFI Studies

Newfoundland and Labrador Hydro

Attention: Mr. Rob Collett

Updates to Alpha Minimum Issue and LIL Transfer Limits

Technical Note: TN1205.73.01
Date of issue: February 3, 2020

Prepared By:
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Revisions

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Table of Contents

1. Alpha Minimum Issue

Earlier Stage 4 operational studies used the generic PSSE model CDC7 to represent the Labrador Island Link (“LIL”). These studies had indicated that the pole compensation function of the LIL was limited in some cases due to the rectifier reaching minimum firing angle and needing the converter transformers to change taps (note that tap-changer action was not included in the generic model of the LIL).

After receiving GE’s PSSE model of the LIL, this same issue was not observed with the pole compensation function, and the LIL was able to reach the full 2 pu DC current overload capability. The PSSE generic model CDC7 was revisited and a modeling error was noted in the fault file that had been used to simulate the loss of a LIL pole. Upon correcting the fault file, the PSSE generic model of the LIL is able to reach the full 2 pu DC current overload on the healthy pole. Therefore, the minimum alpha issue at the rectifier was determined to be a modeling issue and has been resolved.

The loss of a LIL pole was revisited for the Stage 4D and Stage 4E operational studies using the GE model of the LIL, as described below.

2. Updated LIL Transfer Limits

The contingencies that define the LIL transfer limits are loss of the LIL bipole and loss of a LIL pole.

Loss of the LIL Bipole
As discussed in the Stage 4D operational study[1], the Underfrequency Load Shed (UFLS) scheme will be re-designed to ensure that the system remains stable and that the IIS frequency remains above 58 Hz following the loss of the LIL bipole[2], as per Transmission Planning Criteria. However, during the period when the system is transitioning from low to high power operation, the existing UFLS scheme will remain in place. During this period LIL transfer limits shall be specified to ensure that all criteria are met.

Loss of the LIL Pole
Transmission Planning Criteria for loss of a LIL pole are defined to ensure that such an event will not cause the IIS frequency to drop below 59 Hz and will not result in UFLS. The LIL will ultimately have a 10-minute 2 pu overload rating; however, during the period when the system is transitioning from low to high power operation, this overload capability will not be available. Rather, the LIL's capacity for pole compensation will be limited to 1 pu DC current. It is noted that the Maritime Link ("ML") is equipped with runbacks or frequency controller action to provide support in the event of the loss of a LIL pole.

2.1 Study Results – Transitional Period

As stated above, the overload capability and frequency controller capability of the LIL will not be immediately available.

With the use of ML runbacks or the operation of the ML frequency controller, the IIS frequency remains above 59 Hz for loss of a LIL pole under all operating scenarios, with the exception of peak load conditions. Under peak load conditions, except for the case with ML exporting 500 MW export, the loss of a LIL pole was more limiting than loss of the bipole, and the LIL transfer limits were reduced accordingly for these cases in order to ensure IIS frequency remains above 59 Hz if a LIL pole trips.

The updated LIL power transfer limits during the transitional period are listed in Table 1 and shown in Figure 1 (ML frequency controller in-service) and Figure 2 (ML frequency controller out-of-service).

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[1] TGS report "Stage 4D LIL Bipole: Transition to High Power Operation", TN1205.71.04, September 25, 2019, Section 3.3.3.

[2] If the ML is exporting and the LIL bipole trips, the ML is assumed to runback to 0 MW.

Table 1. Transitional Period Results – LIL Transfer Limits with and without ML Frequency Controller

				ML Frequency Controller IN					ML Frequency Controller OUT				
	Demand	Generation	ML	Loss LIL Bipole Transfer Limit (MW)	Minimum Frequency (Hz)	Loss LIL Pole Transfer Limit (MW)	ML Runback* (MW)	Minimum Frequency (Hz)	Loss LIL Bipole Transfer Limit (MW)	Minimum Frequency (Hz)	Loss LIL Pole Transfer Limit (MW)	ML Runback* (MW)	Minimum Frequency (Hz)
Peak	1866	1530**	500	900	58.08	900	400	59.6	900	58.08	900	400	59.6
Ipeak	1428	1094	500	900	57.97	900	400	59.2	900	57.97	900	400	59.2
Int	1038	703	500	900	57.81	900	400	59.2	900	57.81	900	400	59.2
Light	812	476	500	820	57.93	820	350	59.5	820	57.93	820	350	59.5
ExLight	606	401	500	750	58	750	260	59.4	750	58	750	260	59.4
Peak	1821	1285**	300	900	57.71	785	300	59.1	900	57.71	785	300	59.1
Ipeak	1400	915	300	750	57.79	750	300	59.3	750	57.79	750	300	59.3
Int	994	589	300	630	57.87	630	190	59.13	630	57.87	630	190	59.13
Light	760	452	300	580	57.87	580	130	59.4	580	57.87	580	130	59.4
ExLight	553	409	300	470	58.05	470	0	59.17	470	58.05	470	45	59.08
Peak	1815	1303**	158	720	57.73	640	158	59.15	720	57.73	640	158	59.15
Ipeak	1391	889	158	600	57.72	600	158	59.83	600	57.72	600	158	59.22
Int	980	548	158	480	57.86	480	0	59.17	480	57.86	480	40	59.15
Light	742	433	158	410	57.88	410	0	59.31	410	57.88	410	0	59.13
ExLight	537	402	158	300	58.02	300	0	59.45	300	58.02	300	0	59.45
Peak	1820	1330**	0	670	57.92	570	-	59.03	510	57.81	470	-	59.08
Ipeak	1391	906	0	540	57.87	540	-	59.01	400	57.85	400	-	59.5
Int	972	538	0	450	57.92	450	-	59.23	310	57.91	310	-	59.66
Light	735	403	0	340	57.99	360	-	59.31	230	57.93	230	-	59.83
ExLight	535	404	0	130	59.05	130	-	59.99	130	58.1	130	-	59.99
Peak	1815	1049**	-150	650	57.95	570	-	59.04	510	57.77	465	-	59.06
Ipeak	1389	757	-150	540	57.91	540	-	59.03	400	57.87	400	-	59.6
Int	972	424	-150	410	57.99	410	-	59.3	300	57.88	300	-	59.45
Light	740	402	-150	190	58.82	190	-	59.8	190	57.99	190	-	59.8
ExLight	536	400	-46	90	59.15	90	-	59.99	90	58.4	90	-	59.99
Peak	1824	998**	-320	500	57.85	460	-	59	500	57.85	460	-	59
Ipeak	1402	724	-320	400	57.83	400	-	59.46	400	57.83	400	-	59.46
Int	987	421	-320	250	57.98	250	-	59.8	250	57.98	250	-	59.8
Light	750	400	-260	90	58.6	90	-	59.99	90	58.6	90	-	59.99

Loss of Pole is more limiting that loss of LIL bipole

Not included in plot since not a limiting case

*In all cases, it is assumed that if ML runback is used, there is no additional support provided by the ML frequency controller.

** HRD CT dispatched to avoid voltage collapse following loss of LIL bipole, and HRD units dispatched to provide sufficient generation for system conditions.

Minimum IIS Generation

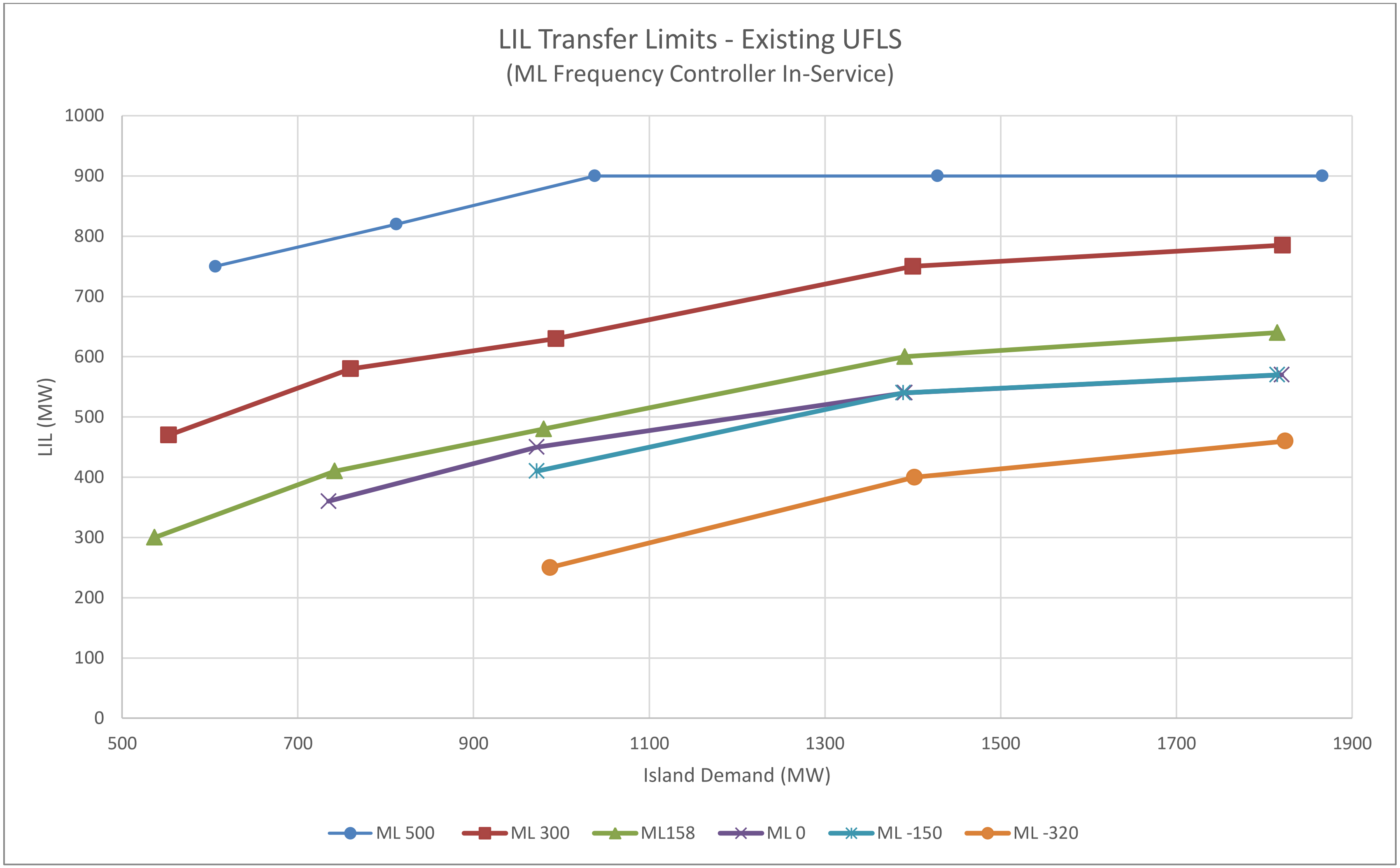

Figure 1. Transitional Period – LIL Transfer Limits – ML Frequency Controller In-Service

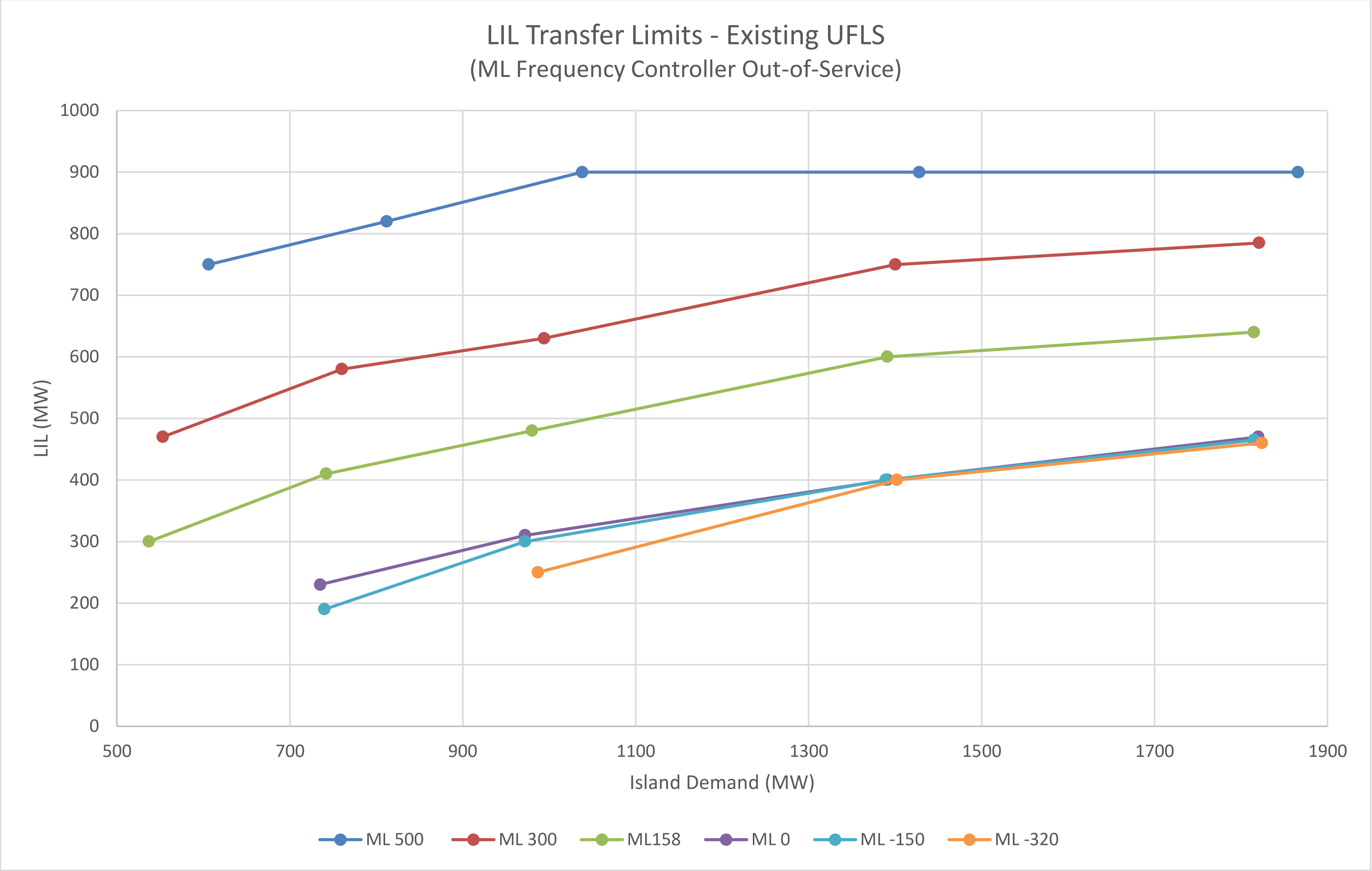

Figure 2. Transitional Period – LIL Transfer Limits – ML Frequency Controller Out-of-Service

2.2 Study Results – Full LIL Bipole Functionality

Analysis was performed to assess long term operation of the LIL when 2 pu overload capability and frequency controller functionality are available. LIL power transfer limits were determined to ensure criteria compliance for the loss of the LIL bipole and LIL pole. As stated above, the redesigned UFLS scheme is assumed to be in place for long term operation.

During ML Export

When the ML is exporting, the IIS frequency remains above 59 Hz for loss of a LIL pole under all operating scenarios with the use of ML runbacks or the operation of the ML frequency controller. If the ML frequency controller is in-service, ML runbacks are required under some operating scenarios if the LIL is transferring greater than 870 MW. If the ML frequency controller is not in-service, ML runbacks are required if the LIL is transferring greater than approximately 700 MW.

During ML Import

When the ML is importing or operating at 0 MW, the IIS frequency remains above 59 Hz for loss of a LIL pole under all operating scenarios, with the exception of peak load conditions. Under peak load conditions, loss of a LIL pole requires a lower LIL transfer limit than loss of the LIL bipole.

The updated LIL power transfer limits with full LIL bipole functionality are listed in Table 2 and shown in Figure 3 (ML frequency controller in-service) and Figure 4 (ML frequency controller out-of-service).

Table 2. Long Term Operational Results – LIL Transfer Limits with and without ML Frequency Controller

				ML Frequency Controller IN					ML Frequency Controller OUT				
	Demand	Generation	ML	Loss LIL Bipole Transfer Limit (MW)	Minimum Frequency (Hz)	Loss LIL Pole Transfer Limit (MW)	ML Runback* (MW)	Minimum Frequency (Hz)	Loss LIL Bipole Transfer Limit (MW)	Minimum Frequency (Hz)	Loss LIL Pole Transfer Limit (MW)	ML Runback* (MW)	Minimum Frequency (Hz)
Peak	1866	1530	500	900	58.61	900	-	59.03	900	58.61	900	90	59.02
Ipeak	1428	1094	500	900	58.5	900	-	59.00	900	58.5	900	85	59.07
Int	1038	703	500	900	58.28	900	110	59.04	900	58.28	900	110	59.04
Light	812	476	500	900	58.18	900	100	59.04	900	58.18	900	100	59.04
ExLight	575	401	500	750	58.44	750	-	59.19	750	58.44	750	30	59.05
Peak	1821	1285	300	900	58.26	900	-	59.00	900	58.26	900	100	59.05
Ipeak	1400	915	300	900	58.15	900	110	59.02	900	58.15	900	110	59.02
Int	994	589	300	860	57.91	860	-	59.02	860	57.91	860	85	59.06
Light	760	452	300	705	58.06	705	-	59.26	705	58.06	705	10	59.01
ExLight	553	409	300	470	58.5	470	-	59.58	470	58.5	470	-	59.64
Peak	1815	1303	158	900	58.11	900	-	59.00	900	58.11	900	98	59.01
Ipeak	1391	889	158	900	57.84	900	118	59.01	900	57.84	900	118	59.01
Int	980	548	158	680	57.97	680	-	59.32	680	57.97	680	-	59.35
Light	742	433	158	520	58.09	520	-	59.51	520	58.09	520	-	59.56
ExLight	537	402	158	300	58.5	300	-	59.73	300	58.5	300	-	59.77
Peak	1820	1330	0	900	58.14	870	-	59.05	900	57.89	780	-	59.00
Ipeak	1391	906	0	870	57.88	870	-	59.00	720	57.87	720	-	59.40
Int	972	538	0	575	58.16	575	-	59.55	500	57.96	500	-	59.70
Light	734	403	0	340	58.51	340	-	59.67	340	58.09	340	-	59.70
ExLight	535	404	0	130	59.05	130	-	59.90	130	58.58	130	-	59.95
Peak	1815	1049	-150	900	58.14	870	-	59.03	900	57.8	755	-	59.06
Ipeak	1389	757	-150	860	57.92	860	-	59.03	700	57.8	700	-	59.45
Int	972	424	-150	410	58.5	410	-	59.66	410	58.18	410	-	59.72
Light	740	402	-150	190	58.89	190	-	59.75	190	58.5	190	-	59.95
ExLight	536	400	-46	90	59.15	90	-	59.95	90	58.68 Hz - MI	90	-	59.95
Peak	1824	998	-320	900	57.84	755	-	59.04	900	57.84	755	-	59.04
Ipeak	1402	422	-320	680	58.01	680	-	59.30	680	58.01	680	-	59.30
Int	987	421	-320	250	58.51	250	-	59.80	250	58.51	250	-	59.80
Light	750	400	-260	90	58.79	90	-	59.95	90	58.78 Hz	90	-	59.95

Loss of Pole is more limiting that loss of LIL bipole

Not included in plot since not a limiting case

*If ML runback is used, there is no additional support provided by the ML frequency controller.

Minimum IIS Generation

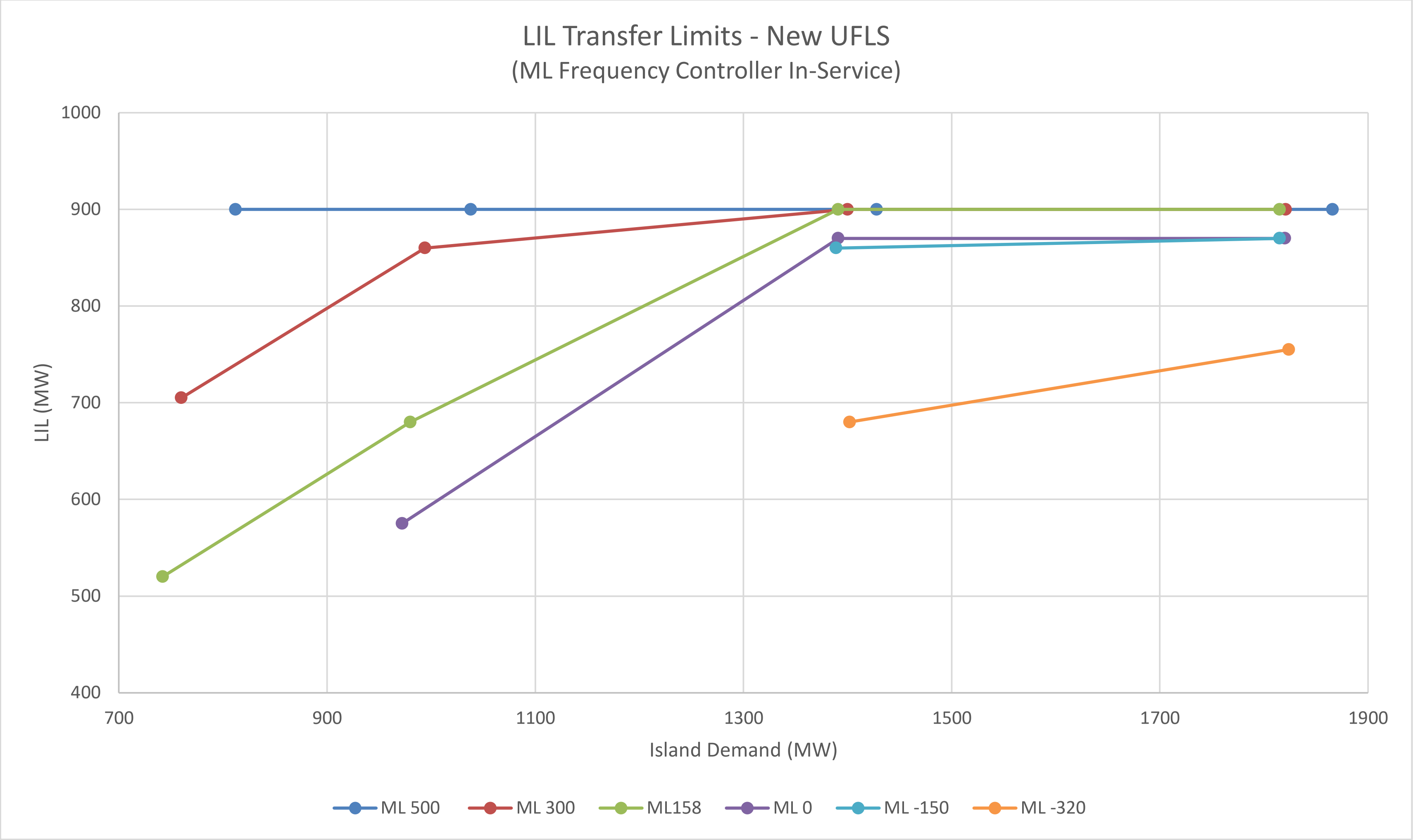

Figure 3. Long Term Operation– LIL Transfer Limits – ML Frequency Controller In-Service

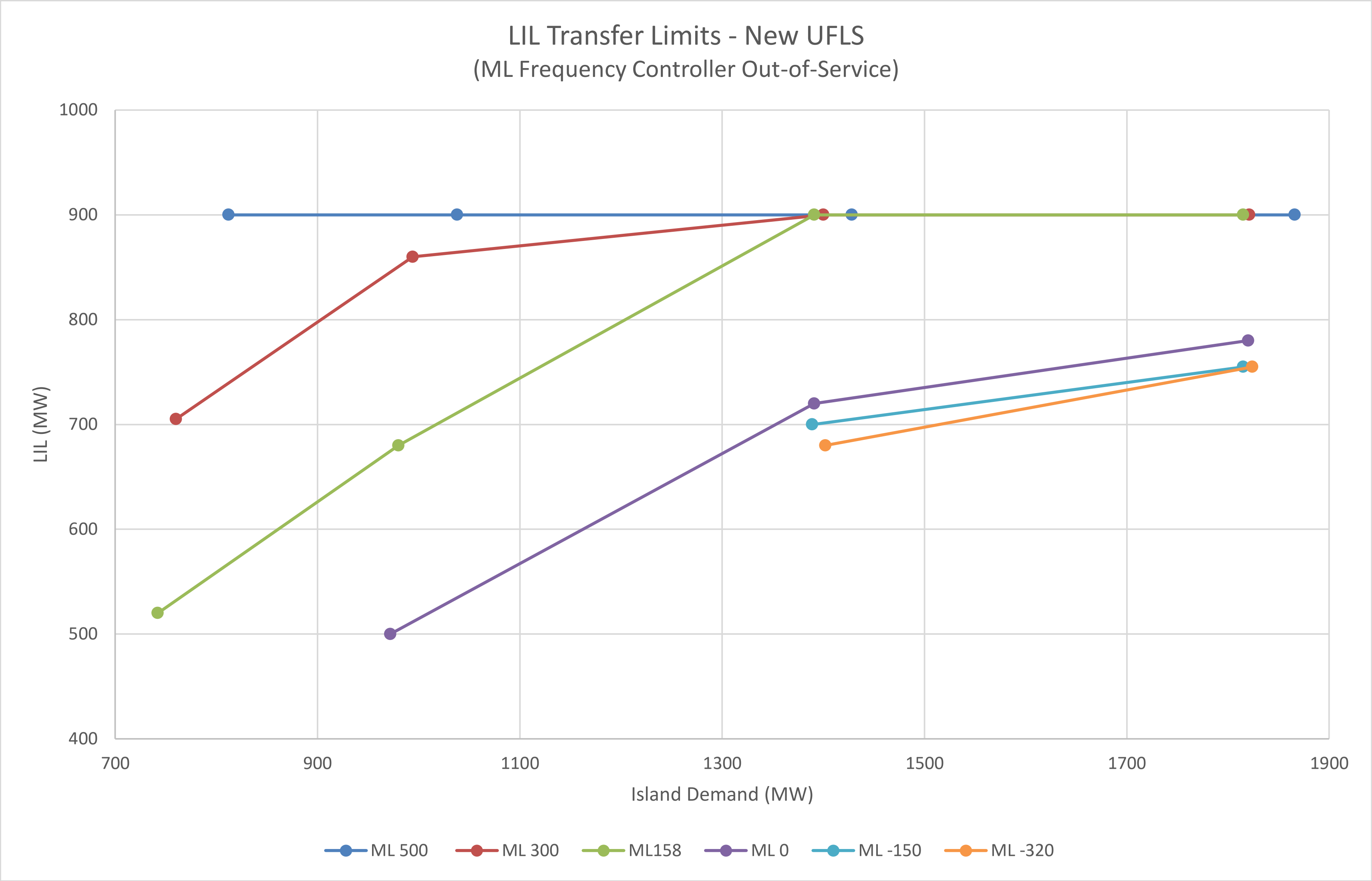

Figure 4. Long Term Operation– LIL Transfer Limits – ML Frequency Controller Out-of-Service