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May 24, 2019

The 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 and Board Secretary

Dear Ms. Blundon:

Re: Reliability and Resource Adequacy Study – Avalon Capacity Study

Further to Newfoundland and Labrador Hydro's ("Hydro") Reliability and Resource Adequacy Study, filed with the Board of Commissioners of Public Utilities (the "Board") on November 16, 2018, please find attached an original and eight copies of the following report:

- TransGrid Solutions, "Avalon Capacity Study – Solutions to Serve Island Demand during a LIL Bipole outage," May 23, 2019.

In section 6.2 of the Reliability and Resource Adequacy Study, Hydro committed to working with the Board and stakeholders to further the understanding of Hydro's ability to supply customers in the unlikely event of the prolonged loss of the Labrador Island Link ("LIL") bipole. Hydro worked with TransGrid Solutions through 2019 to investigate solutions to serve the Island Interconnected System demand during a LIL bipole outage. The attached report assesses system performance and the impact of subsequent system events in this supply scenario.

Should you have any questions, please contact the undersigned.

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

Shirley A. Walsh
Senior Legal Counsel, Regulatory
SAW/ls

Encl.

cc: Gerard Hayes, Newfoundland Power
Paul Coxworthy, Stewart McKelvey
Dennis Brown, Q.C., Browne Fitzgerald Morgan & Avis
Danny Dumaresque
Larry Bartlett, Teck Resources Limited

ecc: Denis Fleming, Cox & Palmer
Roberta Frampton Benefiel, Grand Riverkeeper® Lab

Engineering Support Services for:

Avalon Capacity Study

Newfoundland and Labrador Hydro

Attention: Mr. Rob Collett

Solutions to Serve Island Demand during a LIL Bipole outage

Report number: R1529.01.02
Date of issue: May 23, 2019

Prepared By:
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Revisions

Project Name:	Avalon Capacity Study
Document Title:	Solutions to Serve Island Demand during a LIL Bipole outage
Document Type:	Report
Document No.:	R1529.01.02
Last Action Date:	May 23, 2019

Rev. No.	Status	Prepared By	Checked By	Date	Comments
00	DFC	R. Brandt, R. Ostash	C. Karawita	April 4, 2019	Draft Issued for review by Hydro
01	IFA			May 3, 2019	Issued for approval
02	ABC			May 23, 2019	Report updated based on comments received May 17
03					
04					
05					

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

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1. Executive Summary

With the introduction of Muskrat Falls, a large portion of the generation serving the Island load will be located in Labrador. Therefore, the reliability of the LIL is a key driver of NLIS reliability. To inform a risk-based analysis of such implications Hydro filed a Reliability and Resource Adequacy study with the Board in November, 2018. In addition, a set of operational studies is currently underway to identify system operating limits for various stages of new equipment coming in to service in the Newfoundland and Labrador Hydro (Hydro) Island Interconnected System (IIS). Stage 4 is the final stage of these studies, and includes the 900 MW LIL bipole, the Muskrat Falls (MFA) generators, the SOP synchronous condensers and the ML. The Holyrood thermal generators, the Stephenville Gas Turbine, and the Hardwoods Gas Turbine are no longer in-service, and Holyrood Unit 3 is operating as a synchronous condenser.

The analysis summarized in this report includes a review of power delivery to the Avalon Peninsula in the event of an outage to the LIL bipole. Transmission system constraints are examined in consideration of aspects such as voltage profiles, transmission line thermal limits, and transient stability.

Transmission Planning Criteria are not defined for a scenario where the LIL bipole is out of service. The objective of this study is therefore to assess system performance and the impact of subsequent system events. The results of the analysis include operational considerations that arise as a result of increased power transfer limits to the Avalon Peninsula without further reinforcement.

This report also presents transmission-oriented solutions that increase the power transfer capacity of the 230 kV transmission corridor between Bay d'Espoir and Soldiers Pond. This would mean that more power from supply located off the Avalon Peninsula could be delivered to the load centre and that capacity assistance from Corner Brook Pulp and Paper or supply from the Maritimes could also be used to assist if the situation were to occur.

Finally, the report presents alternative solutions involving the placement of new gas turbines (GT) on the Avalon peninsula.

1.1 Conclusions

The results of the analysis indicate that transmission capacity to the Avalon Peninsula is a function of how Transmission Planning Criteria are applied when the LIL bipole is out of service.

If criteria were relaxed as compared to normal operation, all existing sources of supply and over 650 MW of incremental off-Avalon generation could be supported without being constrained by the transmission system.[1]

This mode of operation during a LIL bipole outage scenario is defined by the following criteria:

- Transmission System voltages are held within emergency operating range of 0.90 to 1.10 pu.[2]

[1] Incremental sources of supply are defined in Table 2-2.

[2] If transmission system voltages are permitetd to fall to 0.90 pu, voltages at Come By Chance Terminal Station must be held to 0.923 pu due to customer voltage requriements.

- Transmission corridors may be loaded to the thermal limit without consideration of the next contingency.
- In this mode of operation, a line trip will result in a best case scenario of controlled load shed or potentially system instability.

To be capable of serving peak Island demand when the LIL is unavailable, the 230 kV transmission corridor between Bay d'Espoir and Soldiers Pond needs to have capacity to transfer approximately 950 MW[3]. In the mode of operation defined above, up to 930 MW may be transferred without transmission upgrades.

Consideration was also given to more conservative modes of operation during a LIL bipole outage. These modes are defined as follows:

1. **System intact** – all 230 kV lines between Bay d'Espoir and Soldiers Pond are in-service and voltages held to a minimum of 0.95 pu. In this mode of operation, a line trip will result in a best case scenario of controlled load shed or potentially system instability.
2. **Steady state N-1 outage** (no fault) of any of the 230 kV lines between Bay d'Espoir and Soldiers, such that there are no steady state thermal or voltage violations. In this mode of operation, a line trip may result in system instability.
3. **Relaxed consideration of 3PF at BDE**[4], such that next worst case fault location on any of the 230 kV lines between Bay d'Espoir and Soldiers Pond, does not result in transient undervoltage conditions or instability.
4. **3PF on any of the 230 kV lines between Bay d'Espoir and Soldiers,** (including a 3PF at BDE) such that it does not result in transient undervoltage conditions or instability.[5]

The resulting power transfer limits are listed in **red text** in Table 1-1, along with the maximum Island demand that can be served and the resulting violation that would occur if the limits were exceeded to serve peak Island demand.[6]

[3] As measured eastward out of Bay d'Espoir, assuming incremental generation is available, as per Table 2-2.
[4] This scenario includes cases where the 3PF at BDE is neglected, in accordance with Transmission Planning Criteria.
[5] Such a case would be an enhancement of Transmission Planning Criteria where faults at BDE are given the same consideration as all other faults.
[6] Peak Island demand in this study is based on a 2028 peak case. Island demand varies with generation dispatch and system topology since the demand calculation included losses.

Table 1-1. Power transfer limits without transmission upgrades

Contingency	Power transfer limit Eastward out of BDE (MW)	Island Demand that can be served (MW)[7,8]	Limiting Condition
System intact	**930**	1926	0.923 pu voltage at CBC[9]
System intact	**892**	1864	0.95 pu voltage at SSD
Steady state N-1 (TL267)	**701**	1568	0.90 pu volt at SSD
3PF BDE (TL267)	**568**	1273	Trans. undervoltage
3PF SSD (TL206)	**673**	1433	Trans. undervoltage

1.1.1 Transmission-Oriented Solutions

On the basis of the above, transmission system constraints can be avoided if the application of criteria is relaxed during a LIL bipole outage. Such a mode of operation would allow for the unconstrained accomodation of over 650 MW of incremental supply.[10]

For the purposes of this invesitgation, further analysis was performed to assess the transmission system upgrades that would be required to serve peak load in the event that incremental supply were installed. Table 1-2 summarizes transmission-oriented solutions for the scenarios listed in the previous section.

[7] In the event of a LIL bipole outage, the maximum generating capacity for the Island System is 1400 MW. Incremental capacity would need to be added in the form of interruptible agreements, import over the Maritime Link, or new generating sources.
[8] With the LIL out of service, transmission losses will increase as a function of dispatch and the location of incremental genration added to meet the capacity shortfall. Under peak load conditions, Island demand can exceed 1900 MW with the LIL out of service.
[9] If transmission system voltages are permitetd to fall to 0.90 pu, voltages at Come By Chance Terminal Station must be held to 0.923 pu due to customer voltage requriements.
[10] Please see Table 2-2.

Table 1-2. Transmission solutions to serve peak Island demand

System Condition	Transmission-oriented solutions		Why are the upgrades required?
	Option	Required upgrades	
System Intact	1	- 20 MVar of reactive power support (caps) at SSD	To meet 0.923 pu voltage at CBC
	2	- 100 MVAr of reactive power support (caps) at SSD	To meet 0.95 pu voltage at SSD
Steady state N-1 condition	1	- One new 230 kV BDE-WAV transmission line - 20 MVar of reactive power support (caps) at SSD - Thermal upgrades of TL203, TL201, TL217	To meet 0.9 pu voltage at SSD/WAV, and to avoid thermal overloading of transmission lines
	2	- 120 MVAr of reactive power support (caps) at SSD - 50% series compensation on TL267, TL202, TL206 - Thermal upgrades of TL207, TL237, TL203, TL201, TL217, TL206, TL202	
3PF (not including BDE)	1	- One new 230 kV BDE-WAV transmission line - 140 MVAr reactive power support (caps) at SSD - Thermal upgrades of TL203, TL201, TL217	To maintain system stability and meet transient undervoltage criteria, and to avoid thermal overloading of transmission lines
	2	- 120 MVAr of reactive power support (caps) at SSD - 50% series compensation on TL267, TL202, TL206 - Thermal upgrades of TL207, TL237, TL203, TL201, TL217, TL206, TL202	
3PF (including BDE)	1	- 2x230 kV BDE-WAV lines - 320 MVAR STATCOM at SSD - Thermal upgrades of TL201, TL217	
	2	- 2x500 kV BDE-WAV lines (plus 500/230 kV transformers) - Thermal upgrades of TL201, TL217	

Although this study shows series compensation as part of several technically feasible solutions, there are issues not considered in this study that could arise when installing series compensation, especially in a small and weak system. Sub-synchronous oscillations and interactions with generators, HVDC and wind farms are all possibilities that would require detailed study and mitigation. It is therefore recommended that solutions involving series compensation not be considered beyond this investigation without futher detailed technical studies.

An HVDC transmission solution could also be a feasible option to enhance transfer capacity between Bay d'Espoir and Soldiers Pond. However, due to cost and relatively short transmission distance, an HVDC option was not evaluated in this study. If this option were to be pursued, a technical assessment would be required to determine the HVDC rating, overload, monopole or bipole configuration, control/operating philosophy for operating HVDC in parallel with the AC transmission corridor, etc.

1.1.2 New Avalon Generation Solutions

The alternative of placing new GTs on the Avalon Peninsula was also explored. Table 1-3 summarizes possible solutions that are able to serve peak Island demand.

Table 1-3. Solutions involving new Avalon GTs to serve peak Island demand

System Condition	New Avalon Generation-oriented solutions		Why is the upgrade required?
	Option	Required upgrades	
System Intact	1	- 1 x 60 MW GT	To meet 0.95 pu voltage at SSD
Steady state N-1 condition	1	- 1 x 60 MW GT on Avalon - 250 MVAr of reactive power support (caps) at SSD - Thermal upgrades of TL202, TL206, TL203, TL201	To meet 0.9 pu voltage at SSD/WAV, and to avoid thermal overloading of transmission lines
	2	- 2 x 60 MW GTs - 100 MVAr of reactive power support (caps) at SSD - Thermal upgrades of TL202, TL206, TL203, TL201	
3PF (not including BDE)	1	- 2 x 60 MW GTs - HRD Units 1&2 as syncs at SSD - Thermal upgrades of TL202, TL206, TL203, TL201	To maintain system stability and meet transient undervoltage criteria, and to avoid thermal overloading of transmission lines
	2	- 3 x 60 MW GTs on Avalon - Thermal upgrades of TL202, TL206, TL203, TL201	
3PF (including BDE)	1	- 3 x 60 MW GTs on Avalon - HRD Units 1&2 as syncs at SSD - Thermal upgrades of TL202, TL206, TL203, TL201	
	2	- 4 x 60 MW GTs	

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. The area of interest is the 230 kV corridor between Bay d'Espoir and Soldiers Pond.

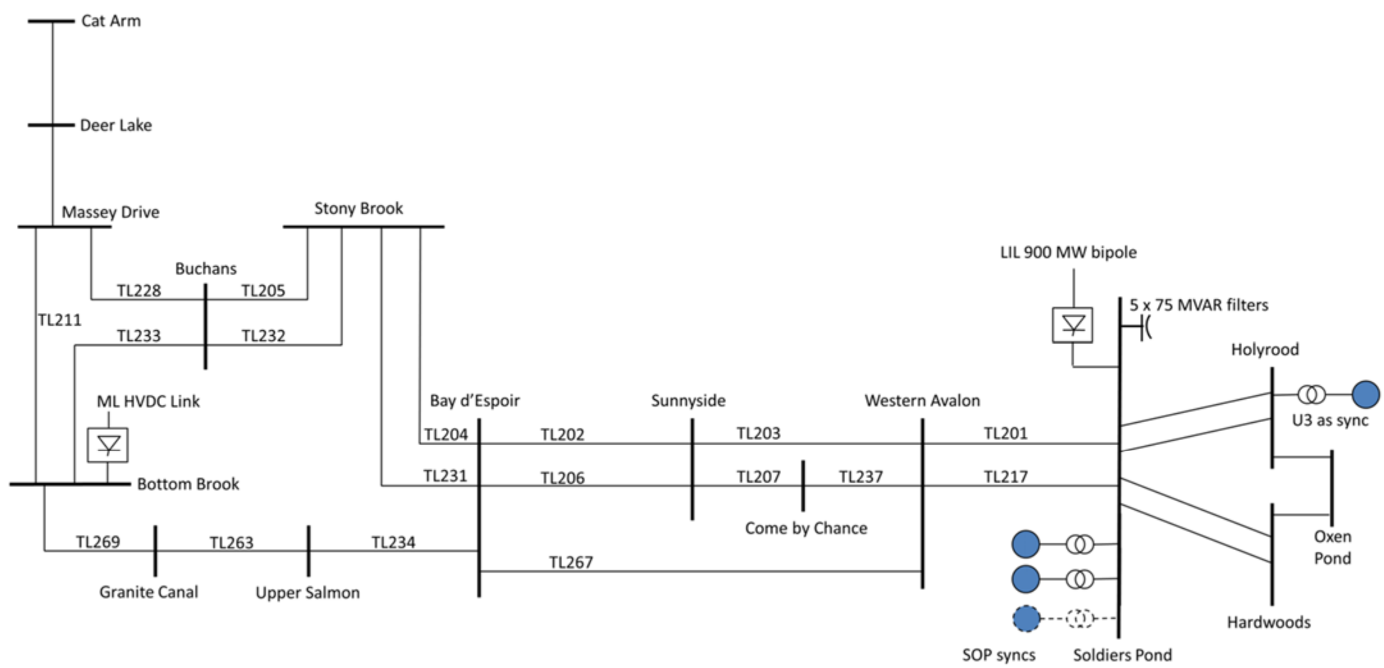

Figure 2-1. Interconnected Island System 230 kV grid

2.2 Base Case Assumptions

The base case for this study was a 2028 peak load case with the LIL out of service. The P90 customer load forecast for the Island Interconnected System is 1762 MW in this case. Under normal operation with the LIL bipole in service, Island Demand is approximately 1815 MW, including station service loads and 38.4 MW of transmission losses.[11]

The system was setup as follows:

- The Holyrood thermal generators are no longer available
- The Hardwoods and Stephenville Gas Turbines are no longer available
- Holyrood Unit 3 is operating as a synchronous condenser

[11] With the LIL out of service, transmission losses increase as a function of dispatch and the location of incremental genration added to meet the capacity shortfall. Under peak load conditions, Island demand can exceed 1900 MW with the LIL out of service.

- LIL bipole is unavailable
- Two of three 175 MVA SOP synchronous condensers are in-service[12]
- ML is available with no export commitments (i.e. NL Block curtailed)
- ML frequency controller available as import capacity permits
- A minimum operating reserve of 70 MW is maintained on the Island Interconnected System[13]

Unit Generation in Table 2-1 was assumed available.

Table 2-1. Unit Generation

Island Generation Capacity	Firm Capacity @ Test Year
Unit	**MW**
Bay D'Espoir - Unit 1	76.5
Bay D'Espoir - Unit 2	76.5
Bay D'Espoir - Unit 3	76.5
Bay D'Espoir - Unit 4	76.5
Bay D'Espoir - Unit 5	76.5
Bay D'Espoir - Unit 6	76.5
Bay D'Espoir - Unit 7	154.4
Cat Arm - Unit 1	67
Cat Arm - Unit 2	67
Granite Canal	40
Hinds Lake	75
Paradise River	8
Upper Salmon	84
Holyrood Thermal - Unit 1	-
Holyrood Thermal - Unit 2	-
Holyrood Thermal - Unit 3	-
Newfoundland Power - Avalon Hydro	43.9
Newfoundland Power - Off-Avalon Hydro	27.6
Newfoundland Power - Thermal	39
Hardwoods CT	-
Hawkes Bay Diesels	5
Holyrood CT	123.5
Holyrood Diesels	8.5
St. Anthony Diesels	9.7
Stephenville CT	-
Deer Lake - Units	105

[12] In accordance with Transmission Planning Criteria.
[13] Operating reserve requirements in the event of a bipole outage are under review.

Island Generation Capacity	Firm Capacity @ Test Year
Unit	**MW**
Bishop's Falls - Unit 1-6	9.6
Bishop's Falls - Unit 7	1.7
Grand Falls - Beeton	20.7
Grand Falls - Unit 4	19.7
Grand Falls - Unit 5/6	5.8
Grand Falls - Unit 7	2.6
Grand Falls - Unit 8	2.9
Corner Brook CoGen	-
Fermeuse Wind	6
Rattle Brook	-
St. Lawrence Wind	6
Star Lake	18
Vale Diesels	-
Total Island Generation Capacity	**1408.6**

Incremental generation listed in Table 2-2 was added as required to meet Island demand. The Island demand level[14] at which incremental generation was required is also listed.

Table 2-2. Incremental Generation[15]

Island Generation Capacity	Island Demand that can be served without Incremental Supply	Firm Capacity Addition	Island Demand that can be served with Incremental Supply
Unit	**MW**	**MW**	**MW**
CBPP Capacity Assistance[16]	1320	105	1400
ML Import	1400	300 (at BBK)	1690
Bay D'Espoir - Unit 8	1690	154	1830
Island Pond	1830	36	1865
Round Pond	1865	18	1885
Portland Creek	1885	23	1905
Cat Arm – Unit 3	1905	67	1950
Total Incremental Island Generation Capacity		**703**	

[14] This Island demand level at which the new generation is required is based on the system transmission at it is, i.e. no new transmission between BDE and SOP. If new transmission were built between BDE and SOP, losses would decrease and the Island demand level at which the new generation would be required would be slightly higher than listed in Table 2-2.
[15] Island Demand includes load and losses and equates to capacity minus operating reserve requirements.
[16] When capacity assistance is enacted with this customer, the customer's generation is diverted to increase the amount of utility load served.

2.3 Study Criteria

Hydro's Transmission Planning Criteria for normal operation are summarized below. It should be noted that criteria for operation during an outage to the LIL bipole are not defined. The results of this analysis will provide an indication of transmission system performance for varying levels of Avalon power transfer during such an event. These results will be used to determine appropriate criteria and allow for the identification of any capital upgrade requirements.

- 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

2.4 Contingencies

Three-phase faults (cleared in 100 ms), and trips of the following transmission lines were considered in this study:

- TL217
- TL201
- TL203
- TL237
- TL206
- TL202
- TL267

Contingencies on these lines reflect the worst case conditions for delivery to the Avalon Peninsula.

3. Study Methodology

The Stage 4A High Power operational study found that unacceptable performance could occur for a 3PF located anywhere on one of the three 230 kV lines running eastward of BDE, namely TL267, TL202 and TL206. Analysis also indicated that the system response is a function of power flow in this corridor. The worst case 3PF location is at Bay d'Espoir (BDE) on line TL267, and the next worst case 3PF location is at Sunnyside on line TL202 or TL206. Note that a 3PF at BDE is excluded from Transmission Planning Criteria.[17] A 3PF at Sunnyside (SSD) or Western Avalon (WAV), even if on TL267, TL202 or TL206 must meet all Transmission Planning Criteria under normal operation.

With the LIL out of service, the power transfer required through this corridor to serve peak Island demand exceeds the limits required to maintain system stability under these 3PF scenarios, as well as the limits required to respect steady state voltage limits and thermal ratings of lines in this corridor.

This study includes analysis to determine the BDE to SOP corridor power flow limits and associated maximum Island demand that can be served under the following scenarios when the LIL is unavailable:

1. **System intact** – all 230 kV lines between Bay d'Espoir and Soldiers Pond are in-service
2. **Steady state N-1 outage** (no fault) of any 230 kV line between Bay d'Espoir and Soldiers Pond, such that there are no steady state thermal or voltage violations.
3. **Relaxed consideration of 3PF at BDE**[18], such that next worst case fault location on any of the 230 kV lines between Bay d'Espoir and Soldiers Pond, does not result in transient undervoltage conditions or instability.
4. **3PF on any of the 230 kV lines between Bay d'Espoir and Soldiers**, (including a 3PF at BDE) such that it does not result in transient undervoltage conditions or instability.[19]

This study also evaluates various transmission-oriented solutions focused at increasing the power flow limits on this corridor, with the goal of serving peak Island demand. Alternative solutions involving the installation of new GTs on the Avalon Peninsula are also explored.

Steady state analysis is used to evaluate voltages and voltage stability along the 230 kV BDE to SOP corridor using PV curves, and to evaluate thermal loading of transmission lines in this corridor.

Transient stability analysis is used to evaluate the dynamic performance of the system for three-phase faults along this corridor.

[17] 3PF at BDE were assessed in the Stage IVA Operational Study. Results of that study determined the conditions under which such a fault would result in system instability.
[18] This scenario includes cases where the 3PF at BDE is neglected, in accordance with Transmission Planning Criteria. It is also includes consideration of enhanced Transmission Planning Criteria where stability must be maintained for a 3PF at BDE, but transient undervoltage violations would be permitted.
[19] Such a case would be an enhancement of Transmission Planning Criteria where faults at BDE are given the same consideration as all other faults.

3.1 Transmission-Oriented Solutions

The following transmission-oriented solutions (and combinations thereof) were evaluted to determine the resulting maximum allowable power flow in the BDE to SOP corridor, and the corresponding amount of Island demand that could be served.

- Units 1 and 2 at Holyrood converted to synchronous condensers.
- Additional AC transmission line(s) from BDE to SOP.
- Addition of DC transmission line from BDE to SOP.
- Addition of static reactive power support (capacitors) in Sunnyside area.
- Addition of dynamic reactive support (FACTS device) in Sunnyside area.
- Addition of synchronous condenser in Sunnyside area (e.g. relocation of Holyrood Units 1 & 2 generators)
- Thermal upgrades of 230 kV transmission lines
- Series compensation[20] on TL267, TL202 and TL206

3.2 Avalon Generation Solutions

The option of adding new Gas Turbines (GTs) on the Avalon Peninsula (60 MW units[21]) is also explored to determine how many GTs would be required to allow for minimal or no transmission reinforcements in order to serve peak Island demand under a LIL outage scenario.

[20] Although this study assess series compensation as part of several technically feasible solutions, there are issues not considered in this study that could arise when installing series compensation, especially in a small and weak system. Sub-synchronous oscillations and interactions with generators, HVDC and wind farms are all possibilities that would require detailed study and mitigation. It is therefore recommended that solutions involving series compensation not be considered beyond this investigation without futher detailed technical studies.

[21] Assumed to be equivalent to 60 MW Brush BDAX units

4. AC Transmission Solutions

As presented in Section 2.2, in the event of a LIL bipole outage, the maximum generating capacity for the Island System is 1400 MW. For the results presented in this section, any remaining capacity shortfall would need to be added in the form of interruptible agreements, import over the Maritime Link, or new generating sources.

4.1 System Intact

Steady state voltage and thermal loading of transmission lines between Bay d'Espoir and Soldiers Pond were analyzed under peak Island demand with the LIL out of service. In this mode of operation, a line trip will result in a best case scenario of controlled load shed or potentially system instability.

There were no thermal overloads if all 230 kV lines between BDE and SOP are in-service.

PV curves plotting the voltage of 230 kV buses between Bay d'Espoir and Soldiers Pond against power flow out of BDE are shown in Figure 4-1. Note that approximately 950 MW power flow eastward out of Bay d'Espoir corresponds to peak Island demand.

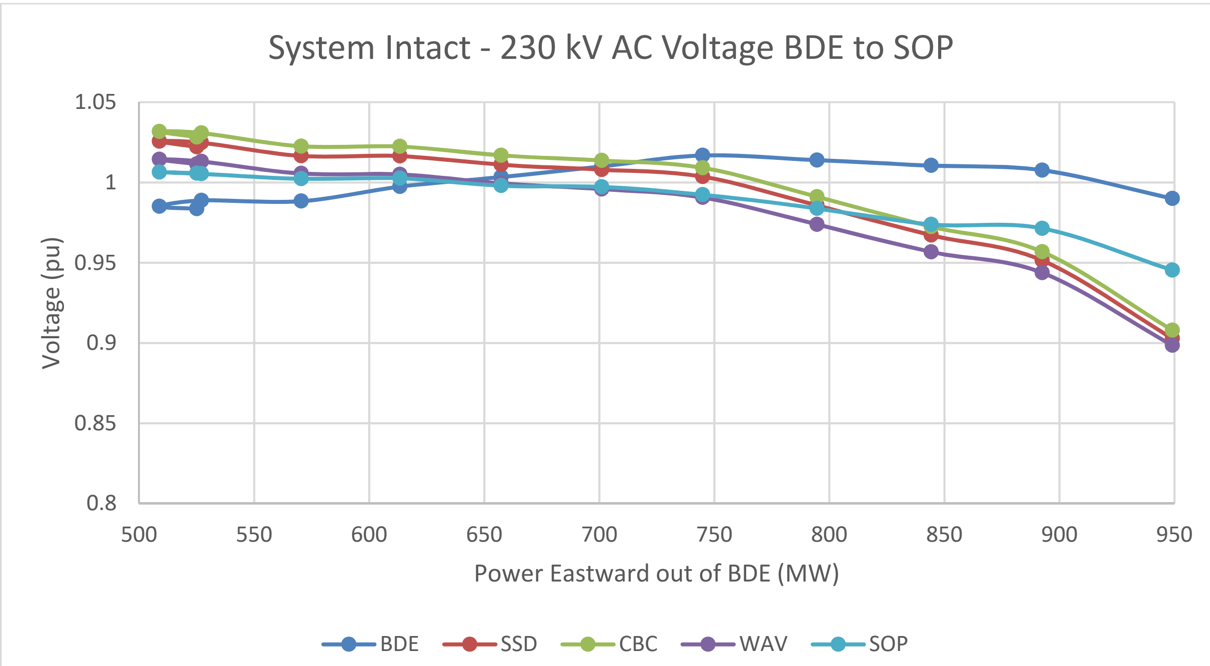

Figure 4-1. PV curves from BDE to SOP (system intact)

As per Section 2.3, voltages must be remain above 0.95 per unit under normal operation. If this criterion were applied in the event of a bipole outage, voltages at Sunnyside (SSD) and Western Avalon (WAV) would be in violation when serving peak Island demand. In order to bring the voltage up to 0.95 pu under peak Island demand, additional reactive power support of 100 MVAr is required at the Sunnyside bus.

Without the 100 MVAr additional reactive power support at Sunnyside, the maximum Island demand that can be served is 1864 MW, which is approximately 90 MW short of peak demand under these power flow conditions.

If voltages were to permitted to fall to 0.90 per unit, a maximum island capacity of 1926 MW could be supplied. It is noted that the 230 kV bus voltage at CBC must be held to a minimum of 0.923 pu to ensure acceptable voltages for an industrial customers in the area.

To meet peak island demand while ensuring all system voltages are above 0.90 pu (and 0.923 pu at CBC), required sysem reinforcements would include the addition of 20 MVAr of reactive power support at Sunnyside.

4.2 Steady State N-1 Conditions

Next, the system was analyzed under steady state conditions with a single contingency outage of each of the 230 kV lines between Bay d'Espoir and Soldiers Pond, with the goal of determing at what power flow levels along this corridor steady state voltages begin to violate the 0.9 pu steady state voltage criteria[22] and at what power flow levels thermal overloads begin to occur. In this mode of operation, a line trip may result in system instability. The results are listed in Table 4-1.

Table 4-1. Island demand and power flow at which steady state criteria is violated

Contingency	0.9 pu Voltage Limit			Thermal Limit		
	Island Demand (MW)	BDE Flow (MW)	Bus with 0.9 pu voltage	Island Demand (MW)	BDE Flow (MW)	Overloaded Line
TL267	1596	749	CBC*	1584	749	TL203
TL202	1644	776	CBC*	1491	693	TL206
TL217	1707	862	WAV	1298	586	TL201
TL201	1706	870	WAV	1667	842	TL217
TL203	1752	902	WAV	1692	863	TL207
TL207	1759	906	SSD	1347	623	TL203
TL237	1777	918	WAV	1423	675	TL203

*CBC voltage limited by 0.923 pu criteria before other buses reach 0.9 pu

4.2.1 Steady State Voltage Violations

PV analysis performed along this corridor under N-1 conditions determined that the worst case 230 kV voltage profiles are at Sunnyside (Figure 4-2) and Western Avalon (Figure 4-3). The worst case contingencies are those involving loss of a Bay d'Espoir line, namely TL267, TL202 or TL206.

[22] As discussed in Section 4.1, the 230 kV bus voltage at CBC must be held to a minimum of 0.923 pu.

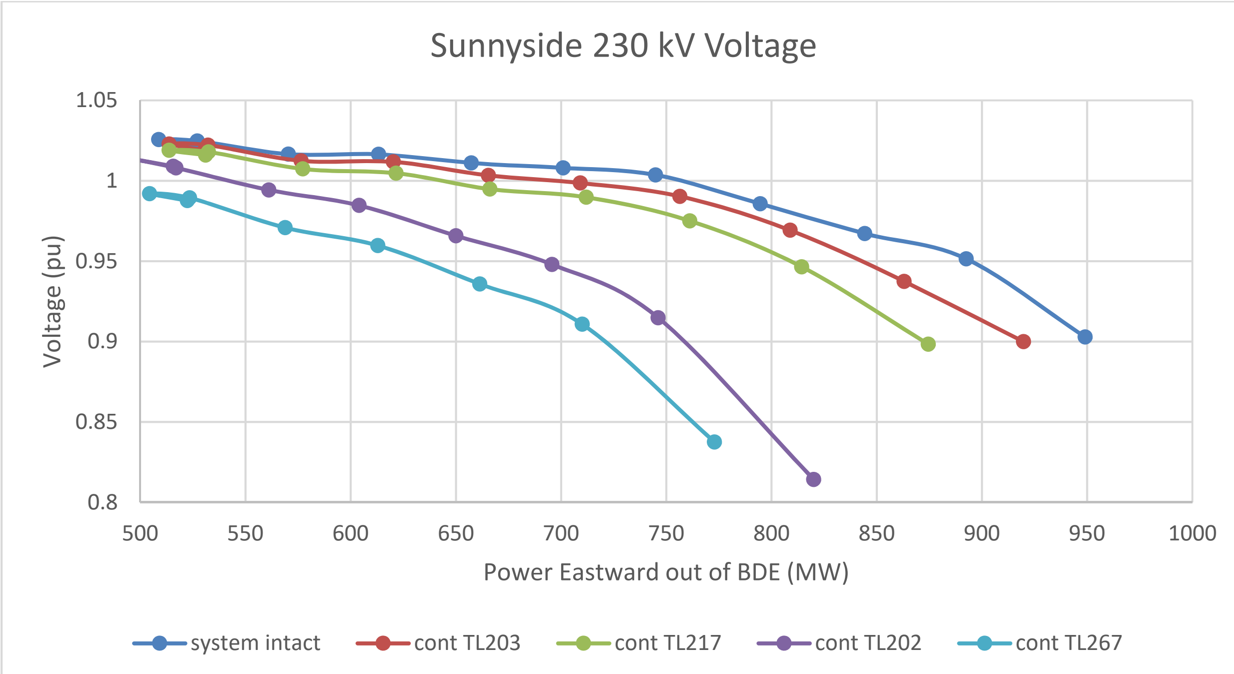

Figure 4-2. Sunnyside – PV curves – system intact and N-1

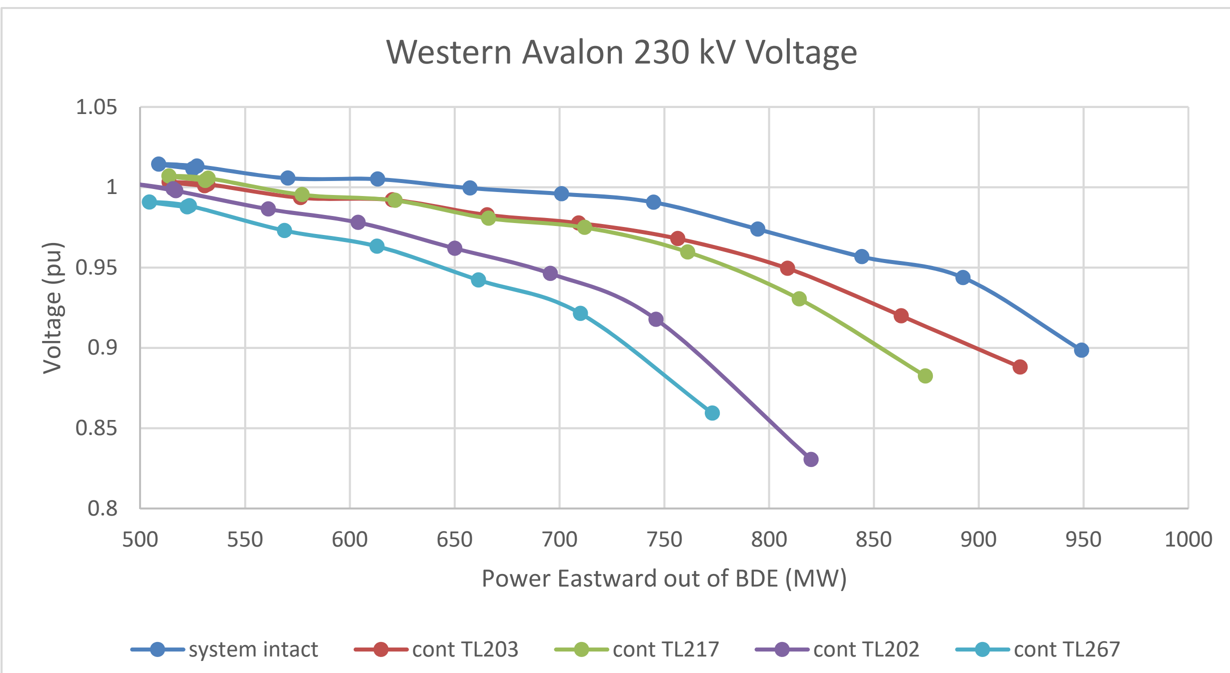

Figure 4-3. Western Avalon – PV curves – system intact and N-1

Various transmission solutions were evaluated to determine what would be required to maintain 0.9 pu voltage at Sunnyside and Western Avalon for an outage of a line in this corridor while serving peak Island demand:

- For an N-1 outage anywhere between Sunnyside, Western Avalon and Soldiers Pond, reactive power support of 180 MVAr at Sunnyside is sufficient to maintain 0.9 pu steady state voltage
- For an outage of a Bay d'Espoir line (TL267, TL202 or TL206), the addition of reactive power support alone is not sufficient to maintain 0.9 pu voltage. Two possible solutions include:
    - **Solution 1:** a new 230 kV transmission line between BDE and WAV, or
    - **Solution 2:** 50% series compensation on the three existing Bay d'Espoir lines (TL267, TL202, TL206) plus 120 MVAr of reactive power support at Sunnyside

4.2.2 Thermal Overloads

If peak Island demand were to be served under N-1 conditions with the LIL unavailable, the 230 kV lines in this corridor would require thermal upgrades. Table 4-2 lists the thermal ratings[23] required for each of these 230 kV lines under N-1 conditions to serve peak Island demand when the LIL is unavailable. If these thermal upgrades are not implemented, the maximum Island demand that can be served without violating thermal ratings is 1426 MW.

Table 4-2. Thermal Ratings to meet Peak Island Demand

Line	Worst Contingency	Today's Thermal Rating (MVA)	Thermal Rating Required to serve Peak Island Demand (MVA)	Island Demand that can be served after implementing the thermal upgrade (MW)
TL201	TL217	322.2	510	1459
TL203	TL207	347	550	1528
TL206	TL202	369.5	525	1528
TL202	TL206	369.5	525	1760
TL217	TL201	453.7	510	1782
TL237	TL203	459.6	515	1907
TL207	TL203	459.6	550	1957

4.3 3PF along Bay d'Espoir-Soldiers Pond Corridor

Next, the dynamic performance of the system was evaluated for three phase faults at locations along the BDE to SOP corridor. Various transmission reinforcement options were tested to determine the amount of Island demand that could served while maintaining system stability and meeting transient undervoltage criteria when the LIL is unavailable. Each solution was also tested at peak Island demand to determine the violations that occur if the contingency happened at peak demand. Table 4-3 summarizes the study results for the worst case three-phase faults (3PF BDE on TL267 and next worst case of 3PF SSD on TL206), as well as the study results of the system intact analysis (Section 4.1) and the worst steady state N-1 contingency TL267 (Section 4.2). For each transmission reinforcement option, the amount of Island demand that can be served under system intact conditions and under the worst

[23] These thermal rating requirements assume that no new AC transmission is built in the Bay d'Espoir to Soldiers Pond corridor, which would reduce the thermal rating requirements of some of the lines.

contingencies is listed. The table also states the criteria that is violated if the scenario/contingency were to occur while serving peak demand.

Table 4-3. Transmission-oriented solutions and Maximum Island demand

Transmission Reinforcement	Contingency	Maximum flow Eastward (MW)		Maximum Island Demand (MW)	Limiting Condition	Condition at Peak Island Demand
		Out of BDE	WAV-SOP			
None (base case)	System intact	929	531	1926	0.923 pu CBC	0.88pu voltage
	System intact	892	513	1864	0.95pu volt.	0.88pu voltage
	S.S. N-1: TL267	701	401	1568	0.90pu volt.	unstable
	3PF BDE TL267	568	326	1273	Trans. voltage	unstable
	3PF SSD TL206	673	392	1433	Trans. voltage	unstable
HRD units 1 & 2 as syncs	System intact	929	531	1926	0.923 pu CBC	0.88pu voltage
	System intact	892	513	1862	0.95pu volt.	0.88pu voltage
	S.S. N-1: TL267	701	401	1582	0.90pu volt.	unstable
	3PF BDE TL267	568	326	1273	Trans. voltage	unstable
	3PF SSD TL206	673	392	1433	Trans. voltage	unstable
250 MVAR cap SSD	System intact	940	541	1940	-	OK
	S.S. N-1: TL267	805	456	1778	Thermal limit	unstable
	3PF BDE TL267	555	324	1300	Trans. voltage	unstable
	3PF SSD TL206	669	394	1470	Trans. voltage	unstable
SSD Sync (175 MVAR)	System intact	864	503	1719	0.95pu volt.	0.88pu volt.
	S.S. N-1: TL267	716	412	1528	Thermal limit	unstable
	3PF BDE TL267	618	358	1349	Trans. voltage	unstable
	3PF SSD TL206	717	418	1500	Trans. voltage	unstable
SSD SVC (250 MVAR)	System intact	948	550	1950	-	OK
	S.S. N-1: TL267	806	471	1678	Thermal limit	unstable
	3PF BDE TL267	673	391	1428	Trans. voltage	unstable
	3PF SSD TL206	807	477	1648	Trans. voltage	unstable
SSD SVC (400 MVAR)	System intact	948	550	1950	-	OK
	S.S. N-1: TL267	864	511	1780	Thermal limit	unstable
	3PF BDE TL267	695	406	1463	Trans. voltage	unstable
	3PF SSD TL206	862	511	1733	Trans. voltage	unstable
SSD STATCOM (320 MVAR)	System intact	948	551	1950	-	OK
	S.S. N-1: TL267	805	492	1555	Thermal limit	unstable
	3PF BDE TL267	673	392	1433	Trans. voltage	unstable
	3PF SSD TL206	783	449	1686	Trans. voltage	unstable

Transmission Reinforcement	Contingency	Maximum flow Eastward (MW)		Maximum Island	Limiting Condition	Condition at Peak Island Demand
50% series compensation TL267, TL202, TL206	System intact	995	562	1868	0.95pu volt.	0.93pu volt.
	S.S. N-1: TL267	807	450	1623	Thermal limit	Voltage collapse
	3PF BDE TL267	694	392	1427	Trans. voltage	unstable
	3PF SSD TL206	856	491	1679	Trans. voltage	0.7pu trans. volt
50% series compensation TL267, TL202, TL206 + 120 MVAR cap SSD	System intact	964	546	1923	-	OK
	S.S. N-1: TL267	801	444	1709	Thermal limit	Thermal overload
	3PF BDE TL267	740	420	1495	Trans. voltage	unstable
	3PF SSD TL206	964	546	1923	-	OK
ONE new 230 kV line BDE-WAV	System intact	942	549	1927	-	OK
	S.S. N-1: TL267	892	513	1864	0.90pu volt.	0.88 pu volt.
	3PF BDE TL267	685	407	1459	Trans. voltage	unstable
	3PF SSD TL206	833	497	1678	Trans. voltage	0.6pu trans. volt.
ONE new 230 kV line BDE-WAV + 140 MVAR cap SSD	System intact	936	553	1917	-	OK
	S.S. N-1: TL267	948	551	1950	-	OK
	3PF BDE TL267	685	407	1459	Trans. voltage	unstable
	3PF SSD TL206	936	553	1917	-	OK
TWO new 230 kV lines BDE-WAV + 320 MVAR STATCOM SSD	System intact	934	550	1908	-	OK
	S.S. N-1: TL267	940	552	1923	-	OK
	3PF BDE TL267	951	569	1837	Trans. voltage	0.7 pu trans. volt
	3PF SSD TL206	997	599	1911	-	OK
TWO new 500 kV lines BDE-WAV	System intact	916	553	1875	-	OK
	S.S. N-1: TL267	914	554	1876	-	OK
	3PF BDE TL267	916	553	1875	-	OK
	3PF SSD TL206	916	553	1875	-	OK

4.3.1 3PF at BDE

In order for the system to recover from a 3PF at BDE on line TL267, with the LIL unavailable, and while serving peak Island demand, a significant amount of new AC transmission is required. This study found two possible solutions:

1) **Solution 1:** Two new 230 kV AC transmission lines between BDE and WAV, plus a 320 MVAR STATCOM at Sunnyside
2) **Solution 2:** Two new 500 kV AC transmission lines between BDE and WAV

4.3.2 No Consideration of 3PF at BDE

If, in accordance with Transmission Planning criteria for normal operation, the 3PF at BDE is ignored, then the next worst fault is a 3PF at SSD on line TL202 or TL206. In order for the system to recover from this fault, with the LIL unavailable, and while serving peak Island demand, this study found the following two possible solutions:

1) **Solution 1:** 50% series compensation on TL202, TL206 and TL267, plus 120 MVAR reactive power support (caps) at SSD
2) **Solution 2:** One new 230 kV AC transmission line between BDE and WAV, plus 140 MVAR reactive power support (caps) at SSD

5. HVDC Transmission Solution

If operational consideration is given to subsequent transmission system contingencies following a bipole outage, the capacity of the existing transmission corridor between Bay d'Espoir and Soldiers Pond is limited to approximately 565 MW (Table 4-3, base case, 3PF BDE TL267). This equates to approximately 1270 MW of Island demand. In order to be able to serve peak demand (~1800-1900 MW) when the LIL is unavailable, this corridor needs to be capable of transferring at least 950 MW eastward out of Bay d'Espoir, which is approximately 400 MW of additional power transfer.

As an alternative to the AC transmission-oriented solutions evaluated in Section 4, it is also possible to consider an HVDC solution to enhance the transmission capacity between Bay d'Espoir and Soldiers Pond. Based on the simplistic calculations in the previous paragraph, it could be assumed that the required rating of the HVDC link would be in the approximate range of 400 MW.

Due to the high cost of an HVDC solution, especially given the relatively short transmission distance, detailed technical analysis was not performed for an HVDC solution at this time. If an HVDC solution were to be pursued, there are many details that would need to be studied and determined, such as:

- HVDC rating
- Overload rating
- Bipole or monopole configuration
- Operation of HVDC in parallel with AC lines, under system intact conditions and considering loss of an AC line or the HVDC link
- Other factors

6. New Avalon Generation

Due to the magnitude of new AC transmission that would be required to meet all system performance criteria under three-phase faults and during steady state N-1 contingencies, while serving peak load when the LIL is unavailable, the option of installing GTs on the Avalon Peninsula was also explored. This option was tested by adding 60 MW Brush BDAX units near Holyrood. As presented in Section 2.2, in the event of a LIL bipole outage, the maximum generating capacity for the Island System is 1400 MW. Incremental capacity would also be supplied by new GTS. Any remaining capacity shortfall would need to be added in the form of interruptible agreements, import over the Maritime Link, or new generating sources.

Table 6-1 summarizes the results.

Table 6-1. Avalon Generation solutions and Maximum Island demand

Transmission Reinforcement + Avalon Generation	Contingency	Maximum flow Eastward (MW)		Maximum Island Demand (MW)	Limiting Condition	Condition at Peak Island Demand
		Out of BDE	WAV-SOP			
1x60 MW GT on Avalon	System intact	869	486	1913	-	OK
	S.S. N-1: TL267	797	426	1784	Thermal limit	unstable
	3PF BDE TL267	632	352	1524	Trans. volt	unstable
	3PF SSD TL206	753	421	1697	Trans. volt	unstable
2x60 MW GTs on Avalon + 320 MVAR STATCOM at SSD	System intact	832	460	1916	-	OK
	S.S. N-1: TL267	807	438	1950	Thermal limit	Thermal overload
	3PF BDE TL267	723	394	1760	Trans. Volt.	Unstable
	3PF SSD TL206	832	460	1908	-	OK
2x60 MW GTs on Avalon	System intact	806	439	1914	-	OK
	S.S. N-1: TL267	807	434	1915	Thermal limit	Thermal overload
	3PF BDE TL267	594	315	1565	Trans. Volt.	Unstable
	3PF SSD TL206	758	415	1802	Trans. Volt.	Unstable
2x60 MW GTs on Avalon + HRD 1 & 2 moved to SSD as syncs	System intact	797	432	1894	-	OK
	S.S. N-1: TL267	810	430	1944	Thermal limit	Thermal overload
	3PF BDE TL267	754	407	1842	Trans. Volt.	Unstable
	3PF SSD TL206	797	432	1894	-	OK
3x60 MW GTs on Avalon + HRD 1 & 2 moved to SSD as syncs	System intact	797	432	1894	-	OK
	S.S. N-1: TL267	810	430	1944	-	OK
	3PF BDE TL267	754	407	1894	-	OK
	3PF SSD TL206	797	432	1894	-	OK

Transmission Reinforcement +	Contingency	Maximum flow Eastward (MW)		Maximum Island	Limiting Condition	Condition at Peak Island Demand
4x60 MW GTs on Avalon	System intact	673	328	1868	-	OK
	S.S. N-1: TL267	680	327	1902	-	OK
	3PF BDE TL267	612	292	1868	-	OK
	3PF SSD TL206	673	328	1868	-	OK

Impacts to thermal limits and requirements for thermal upgrades were discussed in Section 4.2.2 for the system without additional Avalon generation. The addition of generation on the Avalon peninsula would approximately reduce the requirement for thermal upgrades by the amount of Avalon generation that is added.

6.1.1 3PF at BDE

In order for the system to recover from a 3PF at BDE on line TL267, with the LIL unavailable, and while serving peak Island demand, the study found two possible solutions involving new GTs on the Avalon Peninsula:

1) **Solution 1:** Three 60 MW GTs on the Avalon Peninsula, plus Holyrood units 1 & 2 moved to Sunnyside and operated as synchronous condensers, plus the thermal upgrades listed in Table 6-2.

Table 6-2. Thermal upgrades if 3x60 MW GTs added to Avalon

Line	Worst Contingency	Today's Thermal Rating (MVA)	Thermal Rating Required to serve Peak Demand (MVA)
TL203	TL207	347	360
TL201	TL217	322.2	350
TL206	TL202	369.5	400
TL202	TL206	369.5	400

2) **Solution 2:** Four 60 MW GTs on the Avalon Peninsula

6.1.2 No Consideration of 3PF at BDE

If, in accordance with Transmission Planning Criteria for normal operation, the 3PF at BDE is not considered, then the next worst fault is a 3PF at SSD on line TL202 or TL206. In order for the system to recover from this fault, with the LIL unavailable, and while serving peak Island demand, this study found the following two possible solutions involving new GTs on the Avalon Peninsula::

1) **Solution 1:** Two 60 MW GTs on the Avalon Peninsula, plus Holyrood units 1 & 2 moved to Sunnyside and operated as synchronous condensers, or
2) **Solution 2:** Two 60 MW GTs on the Avalon Peninsula, plus a 320 MVAR STATCOM at Sunnyside

Both of the above solutions would require thermal upgrades as listed in Table 6-3.

Table 6-3. Thermal upgrades if 2x60 MW GTs added to Avalon

Line	Worst Contingency	Today's Thermal Rating (MVA)	Thermal Rating Required to serve Peak Demand (MVA)
TL203	TL207	347	405
TL201	TL217	322.2	400
TL206	TL202	369.5	440
TL202	TL206	369.5	440

7. Conclusions

The results of the analysis indicate that transmission capacity to the Avalon Peninsula is a function of how Transmission Planning Criteria are applied when the LIL bipole is out of service.

If criteria were relaxed as compared to normal operation, all existing sources of supply and over 650 MW of incremental off-Avalon generation could be supported without being constrained by the transmission system.[24]

This mode of operation during a LIL bipole outage scenario is defined by the following criteria:

- Transmission System voltages are held within emergency operating range of 0.90 to 1.10 pu.[25]
- Transmission corridors may be loaded to the thermal limit without consideration of the next contingency.
- In this mode of operation, a line trip will result in a best case scenario of controlled load shed or potentially system instability.

To be capable of serving peak Island demand when the LIL is unavailable, the 230 kV transmission corridor between Bay d'Espoir and Soldiers Pond needs to have capacity to transfer approximately 950 MW[26]. In the mode of operation defined above, up to 930 MW may be transferred without transmission upgrades.

Consideration was also given to more conservative modes of operation during a LIL bipole outage.These modes are defined as follows: se

1. **System intact** – all 230 kV lines between Bay d'Espoir and Soldiers Pond are in-service and voltages held to a minimum of 0.95 pu. In this mode of operation, a line trip will result in a best case scenario of controlled load shed or potentially system instability.
2. **Steady state N-1 outage** (no fault) of any of the 230 kV lines between Bay d'Espoir and Soldiers, such that there are no steady state thermal or voltage violations. In this mode of operation, a line trip may result in system instability.
3. **Relaxed consideration of 3PF at BDE**[27], such that next worst case fault location on any of the 230 kV lines between Bay d'Espoir and Soldiers Pond, does not result in transient undervoltage conditions or instability.
4. **3PF on any of the 230 kV lines between Bay d'Espoir and Soldiers,** (including a 3PF at BDE) such that it does not result in transient undervoltage conditions or instability.[28]

[24] Incremental sources of supply are defined in Table 2-2.
[25] If transmission system voltages are permitetd to fall to 0.90 pu, voltages at Come By Chance Terminal Station must be held to 0.923 pu due to customer voltage requriements.
[26] As measured eastward out of Bay d'Espoir, assuming incremental generation is available, as per Table 2-2.
[27] This scenario includes cases where the 3PF at BDE is neglected, in accordance with Transmission Planning Criteria.

The resulting power transfer limits are listed in **red text** in Table 1-1, along with the maximum Island demand that can be served and the resulting violation that would occur if the limits were exceeded to serve peak Island demand.[29]

Table 7-1. Power transfer limits without transmission upgrades

Contingency	Power transfer limit Eastward out of BDE (MW)	Island Demand that can be served (MW)	Limiting Condition	Condition at Peak Island Demand
System intact	**930**	1926	0.923 pu voltage at CBC	0.88 pu steady state voltage
System intact	**892**	1864	0.95 pu volt.	0.88 pu steady state voltage
Steady state N-1 (TL267)	**701**	1568	0.90 pu volt.	Voltage collapse
3PF BDE (TL267)	**568**	1273	Trans. undervoltage	System instability
3PF SSD (TL206)	**673**	1433	Trans. undervoltage	System instability

7.1.1 Transmission-Oriented Solutions

On the basis of the above, transmission system constraints can be avoided if the application of criteria is relaxed during a LIL bipole outage. Such a mode of operation would allow for the unconstrained accomodation of over 650 MW of incremental supply.[30]

For the purposes of this invesitgation, further analysis was performed to assess the transmission system upgrades that would be required to serve peak load in the event that incremental supply were installed. Table 7-2 summarizes transmission-oriented solutions for the system conditions described in the previous section.

Table 7-2. Transmission solutions to serve peak Island demand

System Condition	Transmission-oriented solutions		Why are the upgrades required?
	Option	Required upgrades	
System Intact	1	- 20 MVAr of reactive power support (caps) at SSD	To meet 0.923 pu voltage at CBC
	2	- 100 MVAr of reactive power support (caps) at SSD	To meet 0.95 pu voltage at SSD

[28] Such a case would be an enhancement of Transmission Planning Criteria where faults at BDE are given the same consideration as all other faults.
[29] Peak Island demand in this study is based on a 2028 peak case. Island demand varies with the generation dispatch and system topology since the demand calculation included losses.
[30] Please see Table 2-2.

System Condition	Transmission-oriented solutions		Why are the upgrades required?
	Option	Required upgrades	
Steady state N-1 condition	1	- One new 230 kV BDE-WAV transmission line - Thermal upgrades of TL203, TL201, TL217 - 20 MVAr of reactive power support at SSD to meet CBC 0.923 pu voltage	To meet 0.9 pu voltage at SSD/WAV, and to avoid thermal overloading of transmission lines
	2	- 120 MVAr of reactive power support (caps) at SSD - 50% series compensation on TL267, TL202, TL206 - Thermal upgrades of TL207, TL237, TL203, TL201, TL217, TL206, TL202	
3PF (not including BDE)	1	- One new 230 kV BDE-WAV transmission line - 140 MVAr reactive power support (caps) at SSD - Thermal upgrades of TL203, TL201, TL217	To maintain system stability and meet transient undervoltage criteria, and to avoid thermal overloading of transmission lines
	2	- 120 MVAr of reactive power support (caps) at SSD - 50% series compensation on TL267, TL202, TL206 - Thermal upgrades of TL207, TL237, TL203, TL201, TL217, TL206, TL202	
3PF (including BDE)	1	- 2x230 kV BDE-WAV lines - 320 MVAR STATCOM at SSD - Thermal upgrades of TL201, TL217	
	2	- 2x500 kV BDE-WAV lines (plus 500/230 kV transformers) - Thermal upgrades of TL201, TL217	

An HVDC transmission solution could also be a feasible option to enhance transfer capacity between Bay d'Espoir and Soldiers Pond. However, due to cost and relatively short transmission distance, an HVDC option was not evaluated in this study. If this option were to be pursued, a technical assessment would be required to determine the HVDC rating, overload, monopole or bipole configuration, control/operating philosophy for operating HVDC in parallel with the AC transmission corridor, and other considerations.

7.1.2 New Avalon Generation Solutions

The alternative of placing new GTs on the Avalon Peninsula was also explored. Table 7-3 summarizes possible solutions that are able to serve peak Island demand.

Table 7-3. Solutions involving new Avalon GTs to serve peak Island demand

System Condition	New Avalon Generation-oriented solutions		Why is the upgrade required?
	Option	Required upgrades	
System Intact	1	- 1 x 60 MW GT	To meet 0.95 pu voltage at SSD
Steady state N-1 condition	1	- 1 x 60 MW GT on Avalon - 250 MVAr of reactive power support (caps) at SSD - Thermal upgrades of TL202, TL206, TL203, TL201	To meet 0.9 pu voltage at SSD/WAV, and to avoid thermal overloading of transmission lines
	2	- 2 x 60 MW GTs - 100 MVar of reactive power support (caps) at SSD - Thermal upgrades of TL202, TL206, TL203, TL201	
3PF (not including BDE)	1	- 2 x 60 MW GTs - HRD Units 1&2 as syncs at SSD - Thermal upgrades of TL202, TL206, TL203, TL201	To maintain system stability and meet transient undervoltage criteria, and to avoid thermal overloading of transmission lines
	2	- 3 x 60 MW GTs on Avalon - Thermal upgrades of TL202, TL206, TL203, TL201	
3PF (including BDE)	1	- 3 x 60 MW GTs on Avalon - HRD Units 1&2 as syncs at SSD - Thermal upgrades of TL202, TL206, TL203, TL201	
	2	- 4 x 60 MW GTs	