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October 31, 2023

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Re: *Reliability and Resource Adequacy Study Review* – Avalon Supply (Transmission) Study

In correspondence dated May 5, 2023, the Board of Commissioners of Public Utilities ("Board") directed Newfoundland and Labrador Hydro ("Hydro") file a number of updates regarding the studies and analyses ongoing within the *Reliability and Resource Adequacy Study Review* ("*RRA Study Review*"). In particular:

1) Hydro shall file by May 19, 2023 a comprehensive list of all reports, studies and analyses it has currently underway or planned with respect to the reliability of the LIL, potential alternative generation resources, the load forecast, and any other issues raised in the 2022 RRAS Update and the May 1-2, 2023 technical conference. This list shall include a description of the scope of each study, report and analysis, the consultant or group undertaking the work and the schedule for completion.

2) Hydro shall file with the Board a copy of each report, study or analysis listed in response to number 1 above as it is completed.[1]

On May 25, 2023, Hydro provided the Board with a list of all reports, studies, and analyses currently underway or planned to support future filings in relation to the *RRA Study Review*.[2] Enclosed herein is an overview of the Avalon Supply (Transmission) Study, including an attachment containing the study, "Assessment of the BDE/SOP Transmission Constraints" performed by TransGrid Solutions Inc. ("TransGrid Study").[3]

The TransGrid Study contains commercially sensitive information. A version in which this information has been redacted is enclosed. The Board has been provided with a complete copy as well as a copy of the redacted version.

[1] "Newfoundland and Labrador Hydro - Reliability and Resource Adequacy Study Review - To Parties - Further Process," Board of Commissioners of Public Utilities, May 5, 2023, p. 2.
[2] "*Reliability and Resource Adequacy Study Review* – Listing of Planned Reports, Studies, and Analyses," Newfoundland and Labrador Hydro, May 25, 2023, Table 1 and att. 1.
[3] "Assessment of the BDE/SOP Transmission Constraints TN1817.01.05," TransGrid Solutions Inc., October 25, 2023.

Should you have any questions, please contact the undersigned.

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

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Avalon Supply (Transmission) Study

Overview

October 31, 2023

A report to the Board of Commissioners of Public Utilities

newfoundland labrador hydro

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Attachment 1: "Assessment of the BDE/SOP Transmission Constraints TB1817.01.05," TransGrid Solutions Inc., October 25, 2023.

1.0 Context within the RRA Study Review

Newfoundland and Labrador Hydro ("Hydro") filed the "Reliability and Resource Adequacy Study" ("2018 Filing") with the Board of Commissioners of Public Utilities ("Board") in November 2018.[1] Since the 2018 Filing, Hydro has filed regular updates to the Reliability and Resource Adequacy Study, numerous technical notes, additional studies, and third-party reports. Additionally, the *Reliability and Resource Adequacy Study Review* proceeding ("*RRA Study Review*") has included five rounds of requests for information and four technical conferences, providing for substantial discourse and exchange of information between Hydro, the Board, and the parties. Further, there are additional studies and reporting underway and upcoming throughout the next year.

The regulatory record for this proceeding is robust, with good reason. The provincial electrical grid is in the midst of unprecedented change—it is evolving from an isolated to an interconnected system, some of the assets the province has historically relied on most are aging and nearing retirement, there are significant new assets integrated into the electrical system and being proven reliable, and the province is facing a material increase in load driven by global transitions from fossil fuels to renewable energy sources.

In the coming years and decades, Hydro will have to make significant investments to maintain its legislative obligation of safely and reliably providing electrical service in an environmentally responsible manner to Newfoundlanders and Labradorians.[2] As such, through the *RRA Study Review*, Hydro is modelling its system expansion in consideration of various forecast scenarios and within the context of continuously evolving energy policy. The numerous studies that Hydro has completed and planned are all necessary to validate and justify the information that Hydro feeds into its models that produce critical information on which timely, prudent decisions are to be made.

While the enclosed study provides valuable, necessary information, it cannot and should not be considered independent of the rest of the studies and analyses ongoing through the *RRA Study Review*. Rather, the study is an input that will—along with other studies completed and ongoing—inform Hydro's broader system resource planning process now and into the future.

[1] "Reliability and Resource Adequacy Study," Newfoundland and Labrador Hydro, rev. September 6, 2019 (originally filed November 16, 2018).
[2] *Electrical Power Control Act*, *1994*, SNL 1994, c E-5.1, s 3(b)(iii).

2.0 Background

In its May 25, 2023 correspondence to the Board,[3] Hydro advised that it had engaged TransGrid Solutions ("TransGrid") to complete a study[4] to determine the Bay d'Espoir ("BDE") to Soldiers Pond ("SOP") transmission constraints in contingency scenarios, including a Labrador Island Link ("LIL") bipole outage.[5] The TransGrid Study also presented a series of potential capital transmission upgrade options that could alleviate these constraints to facilitate more new off-Avalon generation. A simplified diagram of the BDE-SOP 230 kV transmission system is provided in Figure 1, which includes reference to terminal stations in Sunnyside ("SSD"), Come By Chance ("CBC"), Western Avalon ("WAV"), and Long Harbour ("LHR").

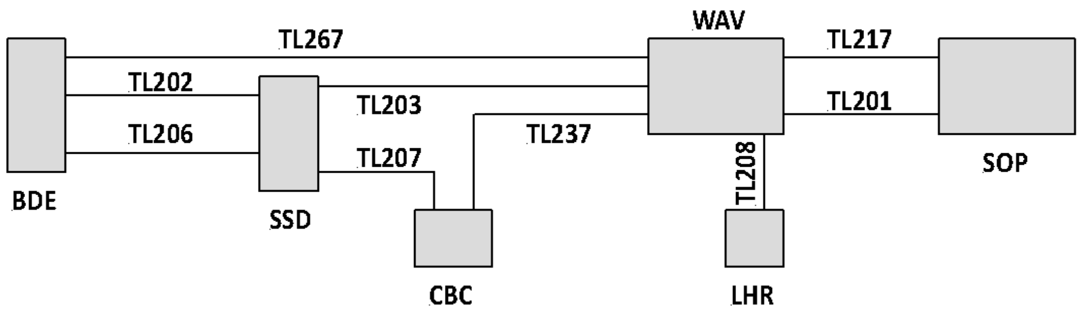

Figure 1: BDE-SOP 230 kV Transmission System

Following the transition from generation to synchronous condenser operations at the Holyrood Thermal Generating Station ("Holyrood TGS") and the Hardwoods Gas Turbine, the BDE-SOP transmission system must supply the majority of the Avalon Peninsula's demand during a LIL bipole outage, assuming no new generation sources are constructed on the Avalon. The existing BDE-SOP transmission constraints are defined based on further single contingency events, such as transmission line outages, that cause thermal overloads on lines remaining in service and/or low voltage conditions that must be avoided to ensure reliable operation.[6]

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[3] "*Reliability and Resource Adequacy Study Review* – Listing of Planned Reports, Studies, and Analyses," Newfoundland and Labrador Hydro, May 25, 2023.
[4] "Assessment of the BDE/SOP Transmission Constraints TB1817.01.05," TransGrid Solutions Inc., October 25, 2023, ("TransGrid Study"), included as Attachment 1 to this overview, serves as a refresh to the "Avalon Capacity Study – Solutions to Serve Island Demand during a LIL Bipole Outage" completed in May 2019. Since the completion of the original study, the Transmission Planning Criteria has been further defined as it relates to a LIL bipole outage.
[5] The transmission transfer capability west of Bay d'Espoir is less of a factor for the *RRA Study Review*, given the majority of the Island load is east of Bay d'Espoir and the long-term plan is to remove large generation sources on the Avalon Peninsula.
[6] For example, the sudden loss of transmission line TL217 during a LIL bipole outage when Island demand is greater than 1,285 MW will result in a thermal overload of TL201. A thermal overload occurs when power flow through a line exceeds its rated capacity. Rated capacity is a function of various environmental factors including ambient temperature.

Understanding the limitations of the BDE-SOP transmission system is an important component of the analysis required in support of a generation expansion plan. The addition of new generation sources will impact the flow of electricity in the transmission network. This is of particular importance in the event of a LIL bipole outage.

The TransGrid Study had two main objectives that were divided into two phases:[7]

- **Phase 1**: Determine all the existing 230 kV transmission constraints between Bay d'Espoir and Soldiers Pond with current Avalon thermal generation sources unavailable.[8] The required analysis involved assessing various 230 kV line contingencies between Bay d'Espoir and Soldiers Pond to determine transfer limits with and without the LIL online.
- **Phase 2**: Determine the increased transfer capacity to the Avalon Peninsula for various transmission reinforcement options provided by Hydro. This required analysis involved assessing various 230 kV line contingencies between Bay d'Espoir and Soldiers Pond for each option.[9]

It is important to note that the TransGrid Study is not intended to and does not make recommendations as to whether transmission reinforcements should be proposed. This determination will be made in consideration of all matters being contemplated within the *RRA Study Review*. Rather, the TransGrid Study provides valuable information that will serve as input to, and improve the quality of, Hydro's resource planning model. It is a prudent, necessary step to consider the BDE-SOP transmission constraints, as the solution to mitigate these constraints to enable particular generation expansion scenarios could come with a considerable cost and must be factored into the larger system supply decisions. A study of the options to mitigate these transmission constraints may also identify short-term options to alleviate supply constraints and provide reliability or financial benefits in advance of generation expansion.

The purpose of this overview is to provide a high-level summary of TransGrid's findings and recommendations, as well as Hydro's assessment of those findings and planned next steps.

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[7] A future third phase will eventually be performed to evaluate the feasibility of a Remedial Action Scheme to potentially reduce the scope of capital upgrades evaluated as part of Phase 2.

[8] Unit 3 at the Holyrood TGS and the Hardwoods Gas Turbine will continue to operate solely as synchronous condensers.

[9] A detailed description of each option is provided in Attachment 1 to this overview.

3.0 Summary of TransGrid's Findings

3.1 Phase 1

The primary objective of Phase 1 of the TransGrid Study was to determine all the 230 kV transmission "bottlenecks" between Bay d'Espoir and Soldiers Pond during a LIL bipole outage. As highlighted in Table 1, the most limiting (N-1) contingency is the loss of TL217, which overloads TL201 (both in the corridor of WAV to SOP). As noted herein, an outage to TL217 during a LIL bipole outage would result in a customer impact when Island demand exceeds 1,285 MW, which corresponds to Avalon gross load of 664 MW.

Table 1: LIL Bipole Outage – Transmission Bottlenecks (BDE-SOP)

Contingency	Power Transfer Limit (East) out of BDE (MW)	Island Demand that can be Served (MW)	Avalon Gross Load[10] that can be Served (MW)	Limiting Criteria
System Intact	980	1865	964	Voltage Levels at SSD
System Intact	912	1771	918	Voltage Levels at SSD
Steady-State N-1 (TL237)	921	1770	921	Voltage Levels at WAV
Steady-State N-1 (TL203)	916	1765	918	Voltage Levels at SSD
Steady-State N-1 (TL207)	901	1745	909	Voltage Levels at SSD
Steady-State N-1 (TL201 or TL217)	872	1700	885	Voltage Levels at SSD
Steady-State N-1 (TL203)	836	1630	853	Thermal Overload (TL207)
Steady-State N-1 (TL206 or TL202)	805	1595	832	Voltage Levels at SSD
Steady-State N-1 (TL201)	780	1550	810	Thermal Overload TL217
Steady-State N-1 (TL267)	773	1545	807	Voltage Levels at SSD
Three-Phase Fault at WAV (TL267)	760	1525	794	System Instability
Steady-State N-1 (TL267)	683	1410	733	Thermal Overload (TL202/ TL206/TL203)
Steady-State N-1 (TL237)	679	1400	730	Thermal Overload (TL203)
Steady-State N-1 (TL206 or TL202)	679	1400	730	Thermal Overload (TL202/TL206)
Steady-State N-1 (TL207)	659	1375	714	Thermal Overload (TL203)
Steady-State N-1 (TL217)	603	1285	664	Thermal Overload (TL201)

[10] Avalon Gross Load is the total load of the Avalon Peninsula including industrial customers. This would include any customers electrically downstream (east) of the Western Avalon Terminal Station as well as Vale Newfoundland and Labrador Limited.

The following are additional findings from Phase 1 of TransGrid's Study:

- Fault near WAV when LIL operating in bipole: The power flow eastward out of Bay d'Espoir must be limited to 680 MW when the LIL is online in bipole in order to meet transient under-voltage criteria[11] if there is a three-phase fault near the Western Avalon Terminal Station on TL267.[12]
- LIL bipole trip: Avalon generation is required to be in service during peak conditions when the LIL is online in bipole to prevent system instability from occurring should the LIL bipole trip.[13] This requirement can be reduced or eliminated as follows:
  - The implementation of a mechanism to quickly trip Avalon load when the LIL experiences a bipole trip; and/or
  - BDE-SOP transmission corridor upgrades, as evaluated in Phase 2.

3.2 Phase 2

The primary objective of Phase 2 of the TransGrid Study was to perform a technical evaluation of various options for BDE-SOP transmission upgrades to determine the opportunity for an incremental increase in power transfer capacity to the Avalon during a LIL bipole outage following the conversion of the Holyrood TGS and the Hardwoods Gas Turbine to synchronous condenser operation.[14] This would have the potential benefit of minimizing customer impact in such a scenario. The BDE-SOP transmission upgrade options considered in the TransGrid Study include:

- **Option 1**: Reconductor - TL201, TL203, TL202/TL206;
- **Option 2**: Option 1 + Dynamic Line Ratings ("DLR") - TL201/TL217, TL203, TL202/TL206;
- **Option 3**: A third line (Western Avalon Terminal Station to Soldiers Pond) + TL203/TL202/TL206 reconductor;

[11] Post-fault recovery voltages on the alternating current system shall be as follows:
- Transient under voltages following fault clearing should not drop below 70%; and
- The duration of the voltage below 80% following fault clearing should not exceed 20 cycles.

[12] For this limitation to have an impact and necessitate dispatch of the Holyrood Gas Turbine, the LIL bipole would have to be derated to approximately 300 MW during peak conditions.

[13] Please refer to Table 2-4 of Attachment 1 to this overview.

[14] A detailed description of the options considered is provided in Section 3.2 of Attachment 1 to this overview. Options 6 and 9 were removed from consideration during the study due to similarities to the other options considered.

- **Option 4**: A third line (Western Avalon Terminal Station to Soldiers Pond) + DLR (TL201, TL202, TL206, TL203);
- **Option 5**: Option 4 + TL203/TL202/TL206 reconductor;
- **Option 7**: A third line (Western Avalon Terminal Station to Soldiers Pond) + TL203/TL202/TL206 reconductor + terminate TL267 at Black River;[15]
- **Option 8f**: 3rd Line (Western Avalon Terminal Station to Soldiers Pond) + a new 230 kV line from Bay d'Espoir to Black River (tap off of TL204/TL231) + reconductor TL203, TL202/TL206 + terminate TL267 at Black River;
- **Option 10**: A new 230 kV circuit from Bay d'Espoir to Soldiers Pond; and
- **Option 10a**: Options 1–10 + reactive power support[16] in the Sunnyside/Come by Chance area.

Hydro may evaluate slight variations of the options listed if they are deemed more appropriate for specific generation expansion scenarios being considered during the *RRA Study Review*.

The analysis also included an assessment of the impact of generation additions both on and off the Avalon Peninsula, allowing for an understanding of the reliability impacts of transmission upgrades in various expansion scenarios. The results of this analysis are presented in Table 2. The forecasted peak demand for the Island Interconnected System ("IIS") is approximately 1,900 MW by 2033.

Table 2: Overall Comparison of BDE-SOP Upgrade Options

Options	No New Avalon Generation					Additional 150 MW @ Holyrood TGS				
	No New Reactive Power		New Reactive Power Support in SSD/CBC Area[17]			No New Reactive Power		New Reactive Power Support in SSD/CBC Area[18]		
	IIS Demand (MW)	Capacity Increase to Avalon (MW)	IIS Demand (MW)	Capacity Increase to Avalon (MW)	STATCOM Required (MVAR)	IIS Demand (MW)	Capacity Increase to Avalon (MW)	IIS Demand (MW)	Capacity Increase to Avalon (MW)	STATCOM Required (MVAR)
1 to 5	1,560-1,680	130-200	1,750-1,815	200-275	200-225	1,835-1,880	285-325	1,945-2,025	360-415	100-125
7	1,675	205	1,864	245	300	1,938	350	2,060	415	225
8f	1,844	300	2,067	415	400	2,082	435	2,234	510	175
10	1,896	230	2,146	345	75	2,167	385	2,288	448	None
10a	2,096	300	*	*	*	2,293	420	*	*	*

* Not studied with additional reactive power since Island demand that can be met is already >= 2,100 MW

[15] A potential new terminal station east of Sunnyside Terminal Station known as the Black River Terminal Station ("BRV").
[16] The addition of reactive power would improve voltage levels following specific 230kV contingencies, thereby increasing power transfer capabilities.
[17] New 4x38 MVAr Cap + static synchronous compensator ("STATCOM").
[18] New 4x38 MVAr Cap + static synchronous compensator ("STATCOM").

4.0 Conclusion and Next Steps

As Hydro considers generation expansion alternatives as part of work related to the ongoing *RRA Study Review*, a review of transmission constraints and expansion options is ongoing and will iteratively build on the work described in this document and the attached TransGrid Study.

Transmission constraints are of particular importance in the case of a bipole outage following the transmission of thermal generation to synchronous condenser operation. In such an event, reliable supply to the Avalon Peninsula would be a function of transfer limits in BDE-SOP transmission line corridors that are set in consideration of possible contingencies.

The TransGrid Study has provided an indication of these transfer limits and the impacts of system upgrades under various generation expansion scenarios, including potential off-Avalon sources. Further, Hydro is exploring whether steps can be taken to maximize transfer capacity through existing assets, including modifications to protection schemes and implementation of dynamic transmission line ratings.

Hydro has identified the following next steps:

- Develop Class 5 cost estimates for select options evaluated during Phase 2 of the TransGrid Study;
- Perform an additional analysis to determine the technical feasibility of lower-cost solutions to partially alleviate the BDE-SOP transmission constraints (e.g., Remedial Action Scheme); and
- Explore options, such as DLR, to marginally increase BDE-SOP transfer limits to provide short-term reliability improvements and/or financial benefits in advance of the integration of new generation.

As Hydro confirms generation expansion plans, these next steps will allow for the determination of potential appropriate accompanying transmission expansion solutions to provide reliable service to customers and reduce the scope of future transmission upgrades.

Attachment 1

Assessment of the BDE/SOP Transmission Constraints TN1817.01.05

TransGrid Solutions Inc.

October 25, 2023

Report for:

Assessment of the BDE/SOP Transmission Constraints

NEWFOUNDLAND & LABRADOR HYDRO

Attention: Matthew Carter
Technical Note no.: TN1817.01.05
Date of issue: October 25, 2023

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Disclaimer

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Revisions

Project Name:	RFI Studies
Document Title:	Assessment of the BDE/SOP Transmission Constraints
Document Type:	Technical Note
Document No.:	TN1817.01.05
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01	DFC	R. Ostash		October 4, 2023	Updated draft for review.
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03	DFC	R. Ostash		October 11, 2023	Updated draft for review after incorporating NLH comments.
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1. Executive Summary

The Bay d'Espoir (BDE) to Soldiers Pond (SOP) 230 kV transmission system is critical to the Island Interconnected System (IIS) when the Labrador Island Link (LIL) is unavailable. Once the Holyrood (HRD) thermal generating station and Hardwoods (HRD) gas turbine are retired, the BDE-SOP transmission system must supply the majority of the Avalon Peninsula demand since there are no LIL imports delivered to SOP. Appreciable transmission constraints will limit the amount of BDE-SOP flow which are defined based on single contingency events causing thermal overloads or low voltage conditions. This will result in customer impact at higher Avalon loads when the LIL is unavailable.

This study has two main objectives that have been split into two phases:

- **Phase 1** - The primary objective was to determine all transmission constraints that currently exist during a LIL bipole outage when HRD and HWD are no longer available to supply real power or are completely offline. The required analysis involved assessing various 230 kV line contingences between BDE and SOP. BDE-SOP transfer limits were also determined for when the LIL bipole is in-service.
- **Phase 2** – The objective was to determine the increased transfer capacity to the Avalon Peninsula for various transmission reinforcement options provided by NLH. The required analysis involved assessing various 230 kV line contingences between BDE and SOP for each option.

The analyses for Phases 1 and 2 are summarized in this report. A future third phase will eventually be performed to evaluate the feasibility of a Remedial Action Scheme (RAS) to potentially reduce the scope of capital upgrades evaluated as part of Phase 2.

1.1 Phase 1 – Existing BDE-SOP Corridor

Phase 1 evaluated the power flow limitations on the existing 230 kV transmission corridor between BDE and SOP. It concluded that:

1) **With the LIL in-service:**
    a. **The power flow eastward of out BDE must be limited to 680 MW** in order to meet transient undervoltage criteria if there is a three-phase fault (3PF) near Western Avalon (WAV) on 230 kV line TL267.
    b. Earlier analysis indicated the need for further reduced BDE/SOP transfer limits (than listed in bullet a.above) when there were two or three SOP SCs in-service to avoid poorly and/or undamped oscillations that occurred along the 230 kV BDE/SOP corridor following a LIL bipole trip. **With the addition of the tuned PSSes on the Island system, this undamped response is no longer present, and the additional reduction in the BDE/SOP transfer limit is no longer required.**
    c. **Analysis confirmed that HRD generation is required to be in-service over peak** (amount of HRD generation depends on number of SOP SCs in-service and demand

level as shown in Table 2-4) in order to prevent system instability from occurring if the LIL bipole trips. The requirement can be reduced or eliminated as follows:

i. A mechanism to quickly trip Avalon load when the LIL bipole trips can reduce or eliminate the need for HRD generation to be in-service.

ii. BDE-SOP transmission corridor upgrades (evaluated in Phase 2 of this report) can also eliminate or reduce the need for HRD generation. In cases where it is not completely eliminated, it at least eliminates the need for new Avalon generation for any of the upgrade options as the Avalon generation requirements are all less than 123.5 MW and could be covered by the existing HRD CT.

2) **During a LIL bipole outage, a maximum Island demand of 1285 MW[1], and corresponding gross Avalon load of 664 MW, can be served[2]** to cater for the most limiting n-1 contingency, loss of TL217, which would otherwise overload TL201 if power flow along the corridor is higher. Table 2-1 provides a summary of all the existing transmission constraints between BDE-SOP for each n-1 contingency.

1.2 Phase 2 – BDE-SOP Corridor Upgrades

Phase 2 evaluated the system during an extended LIL bipole outage[2] to determine the improvement to power flow limitations on the 230 kV transmission corridor between BDE and SOP that could be gained from implementing various transmission upgrades to the BDE-SOP 230 kV corridor. The goal was to observe the increase in maximum Island demand and gross Avalon load that could be served during an extended LIL bipole outage.

In addition to base transmission upgrade options being considered, the following additional system upgrades were added to these options to observe any additional benefits that could be gained:

- 150 MW of additional generation at HRD
- 4x38 MVAR capacitor banks near Sunnyside (SSD) or new station Black River (BRV), plus STATCOM size needed to meet stability requirements.

The BDE-SOP upgrade options, along with the corresponding maximum Island demand and capacity increase to serve Avalon demand, are summarized in the tables listed below. Conclusions are drawn following the tables:

- Table 1-1 summarizes results for the base BDE-SOP upgrade options, without and with new 150 MW Avalon generation.
- Table 1-2 summarizes results for addition of reactive power support to the BDE-SOP upgrades options, without and with an additional 150 MW Avalon generation.
- Table 1-3 provides an overall summary comparing all options and upgrades analyzed in Phase 2.

---

[1] Including transmission losses
[2] Without supply from HRD thermal and HWD.

Table 1-1. Capacity Increase to Avalon for BDE-SOP Upgrade Options, with and without an additional 150 MW at HRD

	BDE-SOP Transmission Upgrade Options	No new Avalon generation				Addition of 150 MW at HRD				
		BDE East flow (MW)	Load Served (MW)		Capacity Increase to Avalon (MW)	BDE East flow (MW)	Load Served (MW)		Capacity Increase to Avalon (MW)	
			Max Island	Max Avalon Gross			Max Island	Max Avalon Gross	Compared to status quo	Compared to Option without new CT
-	Status Quo	603	1285	664	-	-	-	-	-	-
1	Reconductor - TL201/TL203/TL202/TL206	803	1583	827	163	843	1848	979	315	152
2	Option 1 + DLR[3] (TL201/ TL217/TL203/TL202/TL206)	816	1618	843	179	815	1836	968	304	125
3	3rd Line (WAV to SOP) + Reconductor (TL203/TL202/TL206)	814	1627	843	179	849	1883	991	327	148
4	3rd Line (WAV to SOP) + DLR (TL201/TL203/TL202/TL206)	746	1561	798	134	783	1819	949	285	151
5	Option 4 + Reconductor (TL203/TL202/TL206)	847	1679	868	204	842	1881	988	324	120
7	3rd Line (WAV to SOP) + Terminate TL267 in SSD Area + Reconductor TL203	885 857	1737 1675*	893 863*	229 205*	880	1938	1014	350	145
8f	3rd Line (WAV to SOP) + New 230 kV Line BDE to BRV (Tap off TL204/TL231) + Reconductor TL203, TL202/TL206 + Terminate TL267 at BRV	925	1844	961	297	912	2082	1100	436	139
10	New 230 kV Circuit from BDE to Piper's Hole (PHL) to SOP	869	1896	895	231	912	2167	1050	386	155
10a	Option 10 + 35% Series Comp on new BDE- PHL-SOP lines	925	2096	970	306	954	2293	1082	418	112

*limited by stability criteria – a 100 MVAR STATCOM can mitigate the violation, otherwise the maximum Island demand is reduced to the red number

[3] Dynamic Line Ratings

Table 1-2. Capacity Increase to Avalon for Upgrade Options, with / without an additional 150 MW at HRD + Reactive Power Support

	BDE-SOP Transmission Upgrade Options	No new Avalon generation					Addition of 150 MW at HRD					
		BDE East flow (MW)	Load Served (MW)		Capacity Increase to Avalon (MW)	STAT-COM (MVA)	BDE East flow (MW)	Load Served (MW)		Capacity Increase to Avalon (MW)		STAT-COM (MVA)
			Max Island	Max Avalon Gross				Max Island	Max Avalon Gross	Compared to status quo	Compared to Option without new CT	
-	Status Quo	603	1285	664	-	-	-	-	-	-		
+ 4x38 MVAR Capacitor Banks at SSD or BRV + STATCOM as listed												
1	Reconductor - TL201/TL203/TL202/TL206	896	1768	868	204	225	912	1973	1041	377	173	125
2	Option 1 + DLR (TL201/TL217/TL203/TL202/TL206)	895	1764	866	202	225	913	1973	1041	377	175	125
3	3rd Line (WAV to SOP) + Reconductor (TL203/TL202/TL206)	940	1804	938	274	225	933	2021	1058	394	120	125
4	3rd Line (WAV to SOP) + DLR (TL201/TL203/TL202/TL206)	905	1750	911	247	200	897	1947	1026	362	115	100
5	Option 4 + Reconductor (TL203/TL202/TL206)	944	1815	941	277	200	945	2024	1064	400	123	125
7	3rd Line (WAV to SOP) + Terminate TL267 in SSD Area + Reconductor TL203	977	1864	910	246	300	969	2060	1079	415	169	225
8f	3rd Line (WAV to SOP) + New 230 kV Line BDE to BRV (Tap off TL204/TL231) + Reconductor TL203, TL202/TL206 + Terminate TL267 at BRV	1068	2067	1080	416	400	1026	2234	1171	510	91	175
10	New 230 kV Circuit from BDE to Piper's Hole (PHL) to SOP	1011	2146	1008	344	75	993	2288	1112	448	104	none
10a	Option 10 + 35% Series Comp on new BDE-PHL-SOP lines	Not studied with additional reactive power since Island demand that can be met is already >= 2100 MW.										

Table 1-3. Overall Comparison of BDE-SOP Upgrade Options

Options	No New Avalon Generation					Additional 150 MW @ HRD				
	No New Reactive Power		New 4x38 MVAR caps + STATCOM			No New Reactive Power		New 4x38 MVAR caps + STATCOM		
	IIS demand (MW)	Capacity increase to Avalon (MW)	IIS demand (MW)	Capacity increase to Avalon (MW)	STATCOM (MVAR)	IIS demand (MW)	Capacity increase to Avalon (MW)	IIS demand (MW)	Capacity increase to Avalon (MW)	STATCOM (MVAR)
1-5	1560-1680	130-200	1750-1815	200-275	200-225	1835-1880	285-325	1945-2025	360-415	100-125
7	1675	205	1864	245	300	1938	350	2060	415	225
8f	1844	300	2067	415	400	2082	435	2234	510	175
10	1896	230	2146	345	75	2167	385	2288	448	None
10a	2096	300	*	*	*	2293	420	*	*	*

* Not studied with additional reactive power since the Island demand that can be met is already >= 2100 MW.

The following conclusions are drawn from Table 1-3::

- **The largest capacity increase to the Avalon is obtained via Options 8f, 10 and 10a, with the base version of these options seeing an increase of 230-300 MW.** These options have a new 230 kV line out of BDE, among other upgrades such as various line reconductorings and a new 230 kV line between WAV and SOP.
- **The remainder of the Options 1-7 provide capacity increases to the Avalon in the range of approximately 130-200 MW for the base version of these options**. These options focus on reconductoring various lines, adding series compensation to TL202 and TL206 and applying DLR. Some options also build a third 230 kV line between WAV and SOP, however, these options do not have new transmission out of BDE.
- **The addition of 150 MW of new generation at HRD** provides an additional increase in capacity to the Avalon ranging from approximately 100 MW to 160 MW compared to the base options. It also increases the total island demand that can be served by approximately 250 MW to 310 MW.
- **The addition of the reactive power support (4x38 MVAR capacitors plus STATCOM)** also increases the Island demand that can be served as well as the capacity to the Avalon.
    - **Options 1 through 8f require a STATCOM ranging from 200-400 MVAR** depending on the option. The STATCOM size requirements are smaller (around half) if the new 150 MW HRD generation is installed.
    - **Option 10 requires the smallest STATCOM size** of 75 MVAR, or no STATCOM if 150 MW of new Avalon generation is installed. Option 10 builds a new 230 kV line from BDE to a new station Piper's Hole (PHL) and PHL to SOP. In the other options, all new lines go through either BRV and/or SSD, and when there is a fault at BRV or SSD it affects the entire BDE-SOP corridor significantly. Whereas in Option 10, there is a new separate path that remains more intact, or less affected, when there is a fault near BRV or SSD, which improves the stability of the system for faults in this corridor.

2. Phase 1 – Existing BDE/SOP Corridor

Phase 1 of this report is evaluating the power flow limitations on the existing 230 kV transmission corridor between BDE and SOP.

Since the original analysis was performed, the IIS models have been updated, including the addition/tuning[4] of power system stabilizers ("PSS") on various IIS generators. Therefore, the following system issues are revisited in Phase 1 to determine if any of these conclusions need to be updated:

1) Revisit the BDE/SOP Corridor Limits with the LIL out of service, with relaxed criteria where the system response to a 3PF is allowed to violate the transient undervoltage criteria as long as the system remains stable (except for a 3PF near BDE in which case the system may go unstable). What Island Demand can this serve?

2) Revisit the BDE/SOP Corridor Limits with LIL in-service, such that the IIS meets Transmission Planning criteria, meaning the system response to all three-phase faults (3PF) is stable and meets transient undervoltage criteria (except for a 3PF near BDE which may go unstable). What Island Demand can this serve?

3) Revisit the analysis performed in determining the minimum Avalon Generation Requirements for MVAr support. Is the HRD gas turbine required to be on during peak conditions to avoid voltage collapse following a LIL bipole trip?

4) Revisit the analysis performed in determining the impact on the number of SOP units online and the BDE/SOP limits. Earlier analysis identified electromechanical oscillations following a LIL bipole trip when BDE/SOP flow was too high and was worst with three SOP synchronous condensers ("SC") in-service.

2.1 Assumptions

Please note the following key assumptions for Phase 1:

- HRD U3 available as only a SC. No MWs from HRD thermal units. The HRD CT is assumed available at maximum power of 123.5 MW. Note that HRD CT is set to 70 MW when LIL online with two SOP SCs in-service and Island demand is 1850 MW as per the minimum Avalon generation requirements defined in Section 2.3 in order to maintain system stability following the loss of the LIL bipole.
- HWD CT available as only a SC.
- All 230kV lines are in-service pre-contingency.
- Two SOP SCs are in-service
- ML is operating at 0 MW, with the ML frequency controller enabled.

[4] A future PSS tuning study is required to further optimize settings.

- Newfoundland Power Avalon Generation at 39 MW
- Fermeuse Wind output at 6 MW

2.2 BDE/SOP Corridor Transfer Limits

The worst contingency on the BDE/SOP corridor is a 3PF near BDE on TL267, TL202 or TL206, however, Transmission Planning Criteria allows for the possibility of instability if this fault occurs. The next worst disturbance is a 3PF at the other end of these same lines, i.e. at Western Avalon ("WAV") or Sunnyside ("SSD"). These limits are currently defined for the scenario when the LIL is in-service.

When the LIL is out-of-service for an extended period (emergency state), Transmission Planning Criteria is relaxed to allow a 3PF on any 230 kV line to violate transient undervoltage criteria as long as system stability is maintained (except for a 3PF at or near BDE which may result in instability). When the LIL is in-service, Transmission Planning criteria should be met for all n-1 contingencies, excluding a 3PF at or near BDE.

2.2.1 LIL Out-of-Service

Analysis was performed with the LIL out-of-service to determine the transfer limits on the BDE/SOP 230 kV corridor and the corresponding IIS demand that can be served. Please note that this analysis assumes that the HRD CT is on-line at rated capacity of 123.5 MW in all cases. BDE/SOP transfer limits and the corresponding Island demand that can be served are provided for various system conditions, ranging from system intact to loss of each 230 kV between BDE and SOP under various steady state and dynamic scenarios. Table 2-1 lists the limits, the maximum Island demand[5] that can be served and states the limiting criteria, which includes voltages reaching steady state criteria limits and transmission lines reaching their Rate C[6] thermal limit.

The most limiting (n-1) contingency is loss of TL217 (highlighted yellow), which overloads TL201. To avoid the overload of TL201 (Rate C), Island demand must be limited to 1285 MW, which corresponds to Avalon gross load of 664 MW.

Table 2-1. LIL out of service – BDE/SOP transfer limits and maximum Island demand

Contingency	Power transfer limit Eastward out of BDE (MW)	Island Demand that can be served (MW)	Avalon Gross Load (MW)[7]	Limiting Criteria (Rate C thermal & steady state voltage limits)
System intact	**980**	1865	964	0.90 pu voltage at SSD
System intact	**912**	1771	918	0.95 pu voltage at SSD

[5] Vale is assumed to be at 52.5 MW in the study cases.
[6] PSSE Rate A, B, C correspond to ambient temperatures of 30 deg C (summer), 15 deg C (spring/fall) and 0 deg C (winter), respectively. Transmission line thermal ratings are calculated in accordance with IEEE Standard 738-2012 – Calculating the Current-Temperature Relationship of Bare Overhead Conductors.
[7] The total Avalon load including Vale (TL208) and includes losses.

Contingency	Power transfer limit Eastward out of BDE (MW)	Island Demand that can be served (MW)	Avalon Gross Load (MW)[7]	Limiting Criteria (Rate C thermal & steady state voltage limits)
Steady state N-1 (TL237)	**921**	1770	921	0.90 pu voltage at WAV
Steady state N-1 (TL203)	**916**	1765	918	0.90 pu voltage at SSD
Steady state N-1 (TL207)	**901**	1745	909	0.90 pu voltage at SSD
Steady state N-1 (TL201 or TL217)	**872**	1700	885	0.90 pu voltage at SSD
Steady state N-1 (TL203)	**836**	1630	853	Rate C TL207
Steady state N-1 (TL206 or TL202)	**805**	1595	832	0.90 pu voltage at SSD
Steady state N-1 (TL201)	**780**	1550	810	Thermal overload (Rate C) TL217
Steady state N-1 (TL267)	**773**	1545	807	0.90 pu voltage at SSD
Steady state N-1 (TL267)	**683**	1410	733	Rate C TL202 & TL206 & TL203
Steady state N-1 (TL237)	**679**	1400	730	Rate C TL203
Steady state N-1 (TL206 or TL202)	**679**	1400	730	Rate C TL202 or TL206
Steady state N-1 (TL207)	**659**	1375	714	Rate C TL203
Steady state N-1 (TL217)	**603**	**1285**	**664**	**Thermal overload (Rate C) TL201**
3PF at WAV (TL267)	**760**	1525[8]	794	System Instability

Note: It is assumed there is enough generation off-Avalon to meet island demand requirements.

Table 2-2 lists the limits corresponding to Rate A and Rate B thermal limits. There are currently no concerns with the Rate A and B thermal limits because the temperature will not be greater than 15 Deg C when Island Demand is >1,000 MW, and Island demand at 30 Deg C would likely be less than 750 MW. However, the forecasted demand for light load conditions should be monitored.

[8] It is noted that this value is slightly affected by the number of SOP SCs that are in-service. If 3 SOP SCs are in-service, the voltage recovers faster at SOP after the fault clears, which then causes the power transfer into SOP to recover faster and to a higher value transiently, which then causes the voltage in the middle of the corridor at SSD to collapse faster. So, in fact, the transfer limit is slightly more limited with 3 SOP SCs in-service compared to 1 or 2. The value listed in the table is valid for 3 SOP SCs in-service. This will be investigated further in a future study.

Table 2-2. LIL out of service – BDE/SOP transfer limits and maximum Island demand

Contingency	Power transfer limit Eastward out of BDE (MW)	Island Demand that can be served (MW)	Avalon Gross Load (MW)	Limiting Criteria (Rate A/B thermal limits)
Steady state N-1 (TL237)	**625**	1320	683	Rate B TL203
Steady state N-1 (TL207)	**598**	1280	661	Rate B TL203
Steady state N-1 (TL267)	**598**	1280	661	Rate B TL202 & TL206 & TL203
Steady state N-1 (TL206 or TL202)	**565**	1225	630	Rate B TL202 or TL206
Steady state N-1 (TL217)	**519**	1150	589	Rate B TL201
Steady state N-1 (TL267)	**416**	1000	507	Rate A TL202 & TL206
Steady state N-1 (TL206 or TL202)	**390**	960	484	Rate A TL202 or TL206
Steady state N-1 (TL217)	**368**	935	471	Rate A TL201

2.2.2 LIL In-service

With the LIL in-service, the Transmission Planning Criteria states that the system response to any 3PF should meet the dynamic performance criteria (except for a 3PF near BDE which may go unstable).

Even though the system is not required to maintain stability following a 3PF near BDE, the worst case BDE 3PF was simulated (which is a 3PF at BDE on TL267) in order to determine the corresponding BDE/SOP transfer limit. A range of IIS demand and LIL infeed levels were tested to determine the BDE/SOP transfer limit to meet the transient undervoltage criteria[9] following a 3PF at BDE on TL267. The tests were performed with a varying number of SOP SCs in-service and with a varying number of CBC capacitors in-service. The acceptable transfer limit to maintain stability for a 3PF at BDE was determined to be in the range of 625 MW to 640 MW considering all of these variations. Since the range is relatively small, it is recommended to apply a fixed limit of 625 MW in all scenarios, if stability is to be maintained for a 3PF at or near BDE. It is also recommended when transferring high power eastward out of BDE to have as many CBC capacitors in-service as possible to help support the voltage along the corridor in case a fault occurs.

Figure 2-1 below shows an example of the transient voltage recovery at the SSD 230 kV bus when the BDE/SOP corridor is transferring 625 MW eastward out of BDE. In this example, Island demand was 1850 MW, LIL infeed set to 420 MW, two SOP SCs in-service and four CBC capacitors in-service. As detailed in upcoming Section 2.3, the HRD CT was in-service at 70 MW. Note the red circled area of the

[9] Post fault recovery voltages on the ac system should not drop below 0.7 pu and the duration of the voltage below 80% should not exceed 20 cycles.

SSD 230 kV voltage is the limiting portion of the response; this transient undervoltage increases to the point of voltage collapse as the BDE/SOP transfer increases beyond 625 MW.

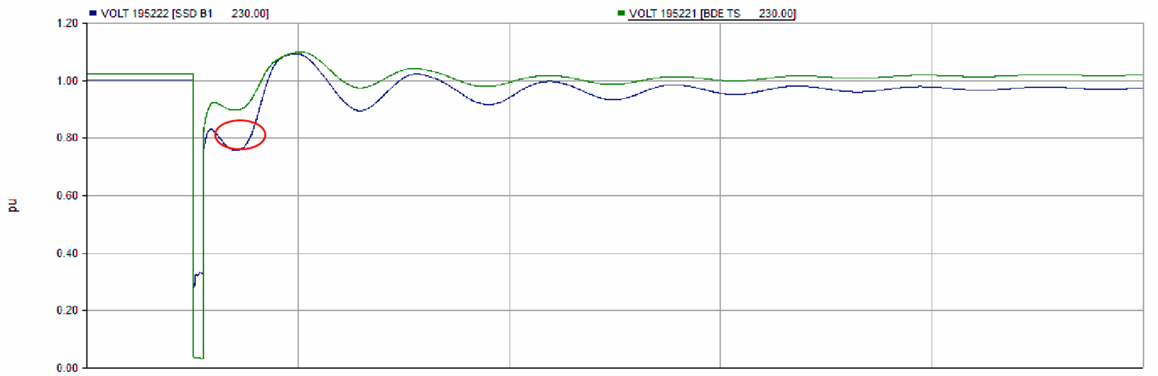

Figure 2-1. 3PF BDE on TL267, at BDE/SOP transfer limit of 625 MW

Since it is not required to meet criteria for a 3PF at BDE, the next worst contingency was tested, which is a 3PF is on TL267 at WAV. To meet transient undervoltage criteria for a fault at WAV on TL267, a BDE/SOP corridor limit of approximately 680 MW is required.

A seasonally dependent bottleneck also exists in the WAV-SOP portion of the 230 kV corridor (TL217/TL201). The TL201/TL217 loading should not exceed the thermal rating of TL201, otherwise TL201 will become overloaded if TL217 trips. The TL201 thermal ratings are [redacted] The NLSO has implemented a check in SCADA to detect a potential overload when the LIL is online or offline.

The BDE/SOP transfer limits when the LIL is in-service are summarized in Table 2-3.

Table 2-3. LIL in service – BDE/SOP transfer limits and maximum Island demand

Contingency	Power transfer limit Eastward out of BDE (MW)	Limiting Criteria
3PF at BDE (TL267)[10]	**625**	Transient undervoltage
3PF at WAV (TL267)	**680**	Transient undervoltage
Steady state N-1 (TL217)	**368 (Rate A TL201 Violation)** **519 (Rate B TL201 Violation)** **603 (Rate C TL201 Violation)** (Note that TL201 can also become overloaded if TL217 trips when power flow direction is westward from SOP to BDE, which would typically correspond to lighter demand, high LIL import and ML export conditions.)	WAV-SOP (TL217/TL201) should not exceed the seasonally-dependent thermal rating of TL201 (in case TL217 trips). [redacted]

[10] This fault is not required to maintain system stability, however, the power transfer limit to maintain stability is provided for information purposes.

2.3 Need for Avalon Generation Over Peak

The analysis in this study determined the updated Avalon generation requirements (for the HRD CT) to ensure that the system is not only stable, but also meets the transient voltage recovery criteria, following the loss of the LIL bipole under high Island demand conditions. The amount of Avalon generation needed depends on the Island demand and on the number of SOP SCs in-service, as summarized in Table 2-4.

Note the Avalon generation requirements were determined for 0 to 3 SOP SCs being in-service, assuming that HRD 3 SC is also in-service. Sensitivity analysis was performed to check the equivalency of an SOP SC being in-service to the HRD 3 SC being in-service. It was found that an SOP SC provides slightly better system response than the HRD 3 SC. For example, the system response is slightly better (or Avalon generation requirements are slightly reduced, or have more margin) if 3 SOP SCs are in-service compared to 2 SOP SCs and the HRD 3 SC. Therefore, it would be safe to use the 2 SOP SC+HRD 3 SC column if there were 3 SOP SCs in-service and HRD 3 was out-of-service.

The Avalon generation requirements are not significantly dependent on the pre-contingency BDE/SOP power transfer, i.e. the Avalon generation is required even if the BDE/SOP transfer is operating at a value lower than the limits identified in Section 2.1.

The values listed in Table 2-4 that are above 123.5 MW would require additional Avalon generation once HRD thermal generation is decommissioned, since the only Avalon generation would be the HRD CT. Therefore, it could be concluded that once Island demand exceeds 1,925 MW and HRD thermal generation is retired (assuming 2 SOP Syncs + HRD 3 SC) there would be a requirement for new Avalon generation if no BDE-SOP transmission upgrades are performed. In order to obtain additional generation at HRD during this study, the simulations were performed by changing HRD 3 from a synchronous condenser to a thermal unit and by turning on HRD thermal unit 1 as needed to obtain the Avalon generation values listed in Table 2-4. However, it is noted that once HRD thermal generation is retired, HRD 3 will continue to operate as a SC only.

Table 2-4. Avalon generation requirements[11] to avoid voltage collapse following LIL bipole trip[12]

IIS Demand (MW)	Avalon Generation[13] (MW)			
	0 SOP Syncs + HRD 3 SC	1 SOP Sync + HRD 3 SC	2 SOP Syncs + HRD 3 SC	3 SOP Syncs + HRD 3 SC
2100	400	300	200	150
2000	370	260	175	123.5
1950	350	230	150	90
1925	335	215	123.5	75

[11] Assumes HRD3 is in-service as a SC (where generation requirements are less than 123.5 MW) and as a thermal unit when more Avalon generation is required.
[12] This study assumed the Avalon generation came from the HRD CT (and HRD thermal units when needed). It is assumed that other new Avalon Generation would provide similar results.
[13] This assumes there is already 40 MW of NP Avalon Generation and 6 MW of Wind Generation at Fermeuse.

IIS Demand (MW)	Avalon Generation[13] (MW)			
	0 SOP Syncs + HRD 3 SC	1 SOP Sync + HRD 3 SC	2 SOP Syncs + HRD 3 SC	3 SOP Syncs + HRD 3 SC
1850	300	120	70	40
1750	120	70	30	None*
1650	70	40	None*	None*
1550	None*	None*	None*	None*

*Unless otherwise required to serve demand

Figure 2-2 below shows an example of the transient voltage recovery at the SSD 230 kV bus following the loss of LIL bipole when the BDE/SOP corridor is transferring 625 MW eastward out of BDE. In this example, Island demand was 1850 MW, LIL infeed 420 MW, two SOP SCs in-service and four CBC capacitors in-service. As per Table 2-4, the HRD CT was in-service at 70 MW. Note the red circled area of the SSD 230 kV voltage is the limiting portion of the response; this transient undervoltage worsens to the point of voltage collapse as the MW output of the HRD CT is reduced.

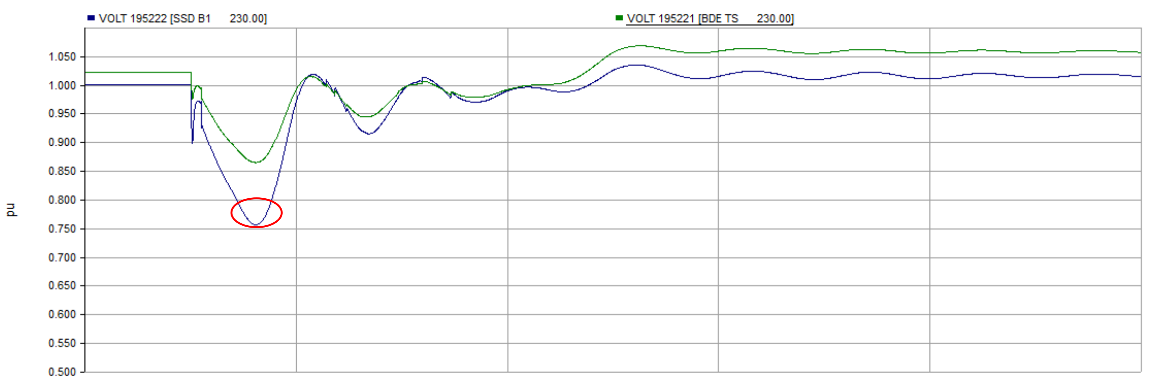

Figure 2-2. Loss of LIL Bipole at peak demand, 70 MW HRD CT

2.3.1 Impact of BDE-SOP Transmission Corridor Upgrades on Avalon Generation Requirements

Phase 2 of this report (Section 3) evaluates various options to upgrade the 230 kV transmission corridor between BDE and SOP in order to serve more Island demand, and more Avalon load, during a LIL bipole outage. These upgrades have additional benefit in that they reduce the Avalon generation requirements listed in Table 2-4.

Analysis was performed to assess the Avalon generation requirements over peak with the various BDE-SOP corridor upgrades[14] in place, assuming that two SOP SCs are in-service. For each BDE-SOP upgrade option, the LIL bipole was put into service at 700 MW, at Island demand levels of 1800 MW,

[14] Please refer to Section 3 of the report for details of the BDE-SOP corridor upgrade options considered in Phase 2 of this analysis.

1950 MW and 2100 MW to observe if the system is stable or unstable following a LIL bipole trip, and if unstable, how much Avalon generation needs to be in-service to prevent the instability. Table 2-5 below summarizes the results and includes the Avalon generation requirements to ensure that the transient undervoltage criteria is met following the loss of the LIL bipole, which is the same criteria used to defined the requirements listed in Table 2-4. It is evident that all the BDE-SOP upgrade options reduce the Avalon generation requirements compared to Table 2-4. Options 1, 2 and 4 need Avalon generation to be in-service at Island demand of 1950 MW. Options 3, 5 and 7 need Avalon generation somewhere between 1950 MW and 2100 MW. Options 8f and 10 do not require Avalon generation to be in-service up to demand levels of 2100 MW. There would be no requirement for new Avalon generation for any of the Options as they are all less than 123.5 MW.

Table 2-5. Avalon generation requirements - with BDE-SOP corridor upgrades

BDE-SOP Upgrade Option	Island Demand (MW), with 2 SOP SCs in-service		
	1800 MW	1950 MW	2100 MW
Base (no upgrades)	40	150	200
Option 1	none	40	100
Option 2	none	40	105
Option 3	none	none	70
Option 4	none	40	95
Option 5	none	none	70
Option 7	none	none	40
Option 8f	none	none	none
Option 10	none	none	none

2.3.2 Impact of Avalon UFLS on Avalon Generation Requirements

One way to reduce (or possibly eliminate) the requirement for Avalon generation to be in-service during high demand is to shed more load on the Avalon when the LIL bipole trips. Preliminary analysis has shown that if a sufficient amount of Avalon load can be tripped quickly enough, it eliminates/reduces the need for Avalon generation to be in-service (as per Table 1-4).

An 1850 MW Island demand example is discussed here. Normally, with two SOP SCs in-service, this demand level would require 70 MW of Avalon generation (HRD CT) to be in-service to prevent voltage collapse along the BDE-SOP corridor if the LIL bipole trips. Several simulations were run to assess the impact of shedding more load on the Avalon by shifting all of the Avalon blocks of under-frequency load shed to the higher UFLS frequency blocks. It was found that even shifting all Avalon load blocks to the

58.8 Hz block is not fast enough, because the voltage has already collapsed by the time the frequency reaches 58.8 Hz.

To assess if tripping the Avalon load quicker improved the voltage response (i.e. not by relying on UFLS), the same blocks of Avalon load were forced to trip shortly after the LIL bipole tripped. A significant improvement in the BDE-SOP voltage response was observed, and it can eliminate/reduce the need for Avalon generation to be in-service if the load can be tripped quickly enough.

The plot in Figure 1-3 below shows the IIS frequency and the SSD voltage for a LIL bipole trip:

- Green - the base response with 70 MW[15] of generation from HRD CT - total UFLS is 740 MW using the Interim UFLS (Avalon and off-Avalon)
- Blue - the impact of tripping the Avalon load blocks ~120 ms after the LIL bipole trip (no Avalon generation in-service) – total load shed is 460 MW (Avalon only)
- Red - the impact of tripping the Avalon load blocks ~370 ms after the LIL bipole trip (no Avalon generation in-service) – total load shed is 460 MW (Avalon only)

It is noted that less total load is shed and improved frequency response is observed in the Avalon load tripping options (blue and red plots) compared to the option of relying on UFLS (green plot).

[15] Without the 70 MW of generation from HRD CT, the voltage collapses and the system does not recover.

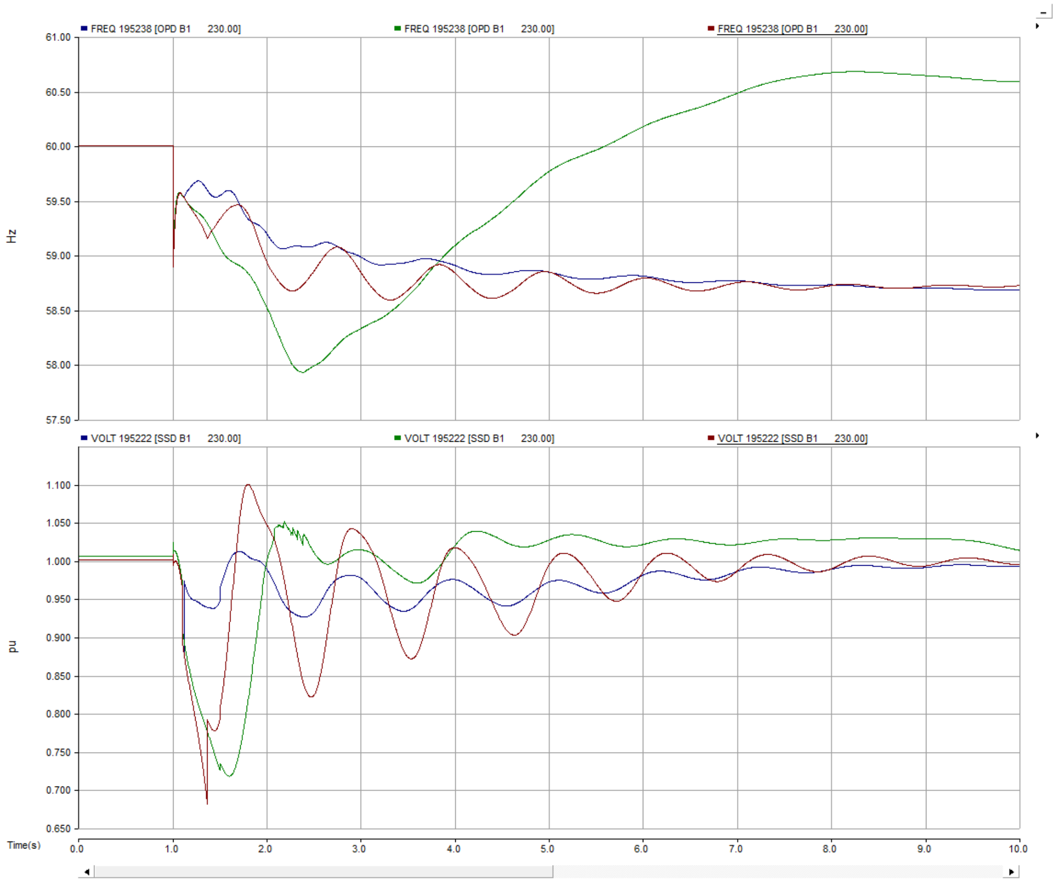

Figure 2-3. Impact of fast shedding of Avalon load after LIL bipole trip – 1850 MW demand, LIL 700 MW

If this option is deemed to be worth investigation, further evaluation would be needed over a wider range of high Island demand scenarios to determine a more accurate amount of Avalon load that would need to be shed and how quickly. Additionally, a method of ensuring the Avalon load can be tripped quickly enough (e.g. a special protection scheme or an under-voltage load shedding scheme) would also need to be determined, seeing as how the evaluation has shown that relying on the UFLS scheme is not fast enough.

This investigation could potentially be assessed as part of a Phase 3 study.

2.4 Electromechanical Oscillations Following LIL Bipole Trip

Earlier analysis indicated the need for further reduced BDE/SOP transfer limits when there were two or three SOP SCs in-service to avoid the poorly and/or undamped oscillations that occurred along the 230 kV BDE/SOP corridor following a LIL bipole trip, as shown in Figure 2-4. The green plot represents two SOP SCs in-service, and the blue plot represents three SOP SCs in-service. HRD 3 SC is also in-service in both cases.

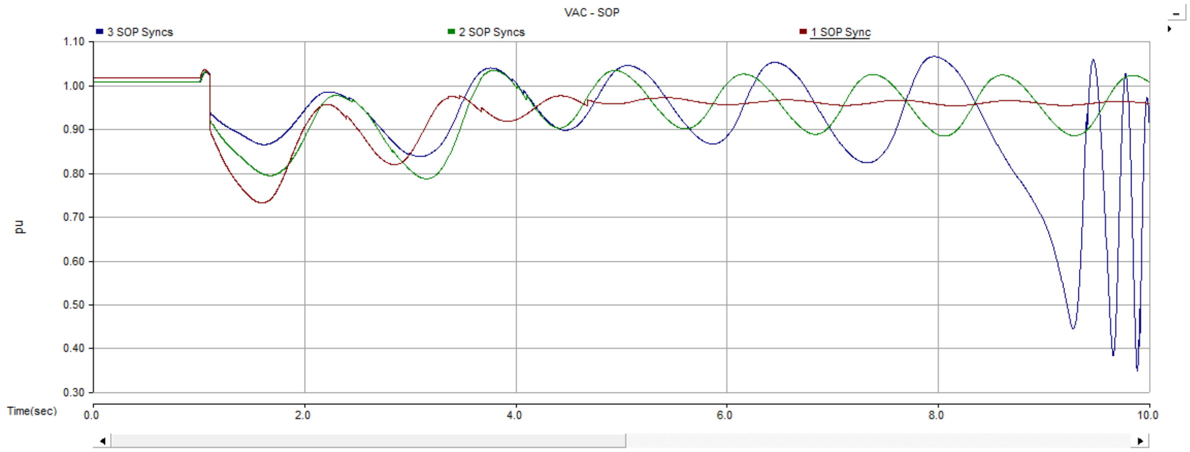

Figure 2-4. Earlier analysis showing undamped oscillations with 3 SOP SCs in-service

With the addition of the tuned PSSes on the Island system, this undamped response is no longer present, and the additional reduction in the BDE/SOP transfer limit is no longer required. The BDE/SOP transfer limits described in Section 2.3 apply regardless of the number of SOP SCs in-service. An example of the voltage response at SSD following a LIL bipole trip with the tuned PSSes is shown in Figure 2-5. This is at a BDE/SOP transfer of 625 MW and an Island demand of 1675 MW. The simulation was tested with 2 SOP SCs (red), with 3 SOP SCs (green) and with 3 SOP SCs in-service but with HRD 3 SC out-of-service (blue). Oscillations are observed but they are damped. A final PSS tuning study, taking into considering the IIS final configuration, is planned to be performed upon completion of the Final Operational Study report, which will take this contingency and scenario into consideration.

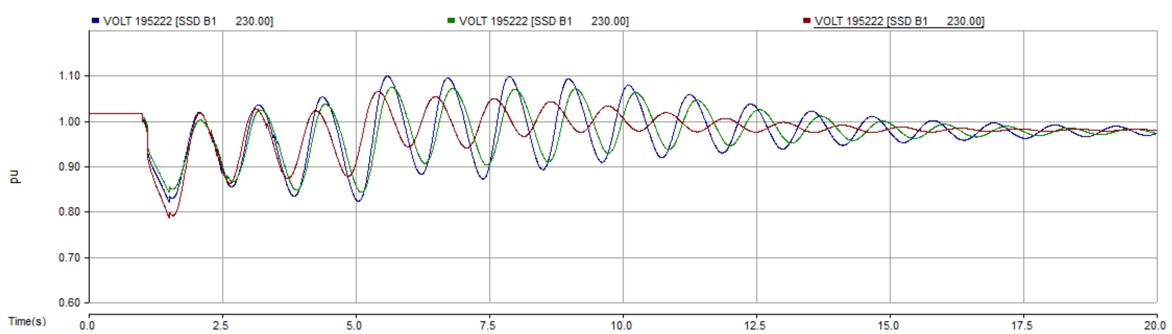

Figure 2-5. SSD voltage response with 2 SOP SCs, 3 SOP SCs and 3 SOP SCs with HRD 3 SC out-of-service using latest models and PSSes

2.5 Summary

Phase 1 evaluated the power flow limitations on the existing 230 kV transmission corridor between BDE and SOP. It concluded that:

1) **With the LIL in-service:**
    a. **The power flow eastward of out BDE must be limited to 680 MW** in order to meet transient undervoltage criteria if there is a three-phase fault (3PF) near Western Avalon (WAV) on 230 kV line TL267.
    b. Earlier analysis indicated the need for further reduced BDE/SOP transfer limits (than listed in bullet a.above) when there were two or three SOP SCs in-service to avoid poorly and/or undamped oscillations that occurred along the 230 kV BDE/SOP corridor following a LIL bipole trip. **With the addition of the tuned PSSes on the Island system, this undamped response is no longer present, and the additional reduction in the BDE/SOP transfer limit is no longer required.**
    c. **Analysis confirmed that HRD generation is required to be in-service over peak** (amount of HRD generation depends on number of SOP SCs in-service and demand level as shown in Table 2-4) in order to prevent system instability from occurring if the LIL bipole trips. The requirement can be reduced or eliminated as follows:
        i. A mechanism to quickly trip Avalon load when the LIL bipole trips can reduce or eliminate the need for HRD generation to be in-service.
        ii. BDE-SOP transmission corridor upgrades (evaluated in Phase 2 of this report) can also eliminate or reduce the need for HRD generation. In cases where it is not completely eliminated, it at least eliminates the need for new Avalon generation for any of the upgrade options as the Avalon generation requirements are all less than 123.5 MW and could be covered by the existing HRD CT.
2) **During a LIL bipole outage, a maximum Island demand of 1285 MW[16], and corresponding gross Avalon load of 664 MW, can be served[17]** to cater for the most limiting n-1 contingency, loss of TL217, which would otherwise overload TL201 if power flow along the corridor is higher. Table 2-1 provides a summary of all the existing transmission constraints between BDE-SOP for each n-1 contingency.

[16] Including transmission losses
[17] Without supply from HRD thermal and HWD.

3. Phase 2 – BDE/SOP Corridor Upgrades

Phase 2 of this report is evaluating the improvement to power flow limitations on the 230 kV transmission corridor between BDE and SOP that could be gained from implementing various upgrades to the corridor. A key assumption for Phase 2 is that the HRD thermal generation station and HWD gas turbine no longer supply real power.

Section 2.1.1 (Table 1-1) showed that a maximum Island demand of 1285 MW, and corresponding gross Avalon load of 664 MW, can be served during a LIL bipole outage in order to cater for the most limiting n-1 contingency, which is loss of TL217 which would otherwise overload TL201 if power flow along the corridor is higher. These limits are valid under the assumption that the HRD CT is generating 123.5 MW, its maximum output and HRD units are decommissioned or offline.

This section discusses additional analysis that was conducted to assess a variety of options to upgrade the 230 kV transmission corridor between BDE and SOP in order to be able to serve more Island demand, and specifically more Avalon demand, during a LIL bipole outage.

3.1 Assumptions

The following assumptions are applicable to the analysis:

- LIL bipole outage
- Maritime Link (ML) exports are set to 0MW (or import as needed) – ML Frequency Controller is enabled
- HRD CT operating at 123.5 MW
- Holyrood Thermal Generating Station is out of service with Unit 3 operating in synchronous condenser mode
- Unlimited generation off-Avalon. The location and size of new generation sources is currently unknown and to be determined by Resource Planning Team.
- CBC, HWD and OPD capacitors in-service to offload SOP SCs to ensure acceptable[18] SOP S.S. voltages.
- Steady State Voltage Criteria
    - Pre-contingency limits: For normal operations all bus voltages shall be maintained between 95% and 105%
    - Post-contingency limits: For contingency or emergency situations, bus voltages shall be maintained between 90% and 110%. Generator terminal voltages shall be maintained between 95% and 105% in contingency or emergency situations

[18] If during the analysis the SS voltages at SOP went above 1.05 pu, the 230 kV SOP voltage setpoint was reduced until the SS voltages were brought back to 1.05 pu maximum.

- For a three-phase fault (3PF) at BDE, the system is not required to maintain system stability. This fault location, when occurring on one of the 230 kV lines in the BDE-SOP corridor (TL202, TL206 or TL267), results in instability under heavy power flow from BDE towards SOP (i.e. starting at around 625 MW), which is an accepted risk given the low probability of the event occurring.

3.2 Options - BDE/SOP Corridor Upgrades

The BDE-SOP corridor upgrade options considered in this study are listed in Table 3-1. Note that Options 6 and 9 are not listed as they were removed from consideration prior to the analysis being performed.

Table 3-1. BDE-SOP Upgrade Options

Option 1: Reconductor - TL201, TL203, TL202/TL206
• Reconductor TL201 with GRACKLE • Reconductor TL203 with GRACKLE • Reconductor TL202/TL206 with DRAKE/ACCC/TW. Addition of series compensation (adjustments may be required). • New station east of SSD known as Black River (BRV)
Option 2: Option 1 + Dynamic Line Ratings (DLR) - TL201/TL217, TL203, TL202/TL206
• Reconductor TL201 with GRACKLE • Reconductor TL203 with GRACKLE • Reconductor TL202/TL206 with DRAKE/ACCC/TW. Addition of series compensation (adjustments may be required). • New station east of SSD known as Black River (BRV) • DLR is an additional: ○ 20% for Rate C (0ºC Ambient Rating)
Option 3: 3rd Line (WAV to SOP) + TL203/TL202/TL206 Reconductor
• 3rd line from WAV to SOP, TL272, is FALCON • Reconductor TL203 with GRACKLE • Reconductor TL202/TL206 with DRAKE/ACCC/TW. Addition of series compensation (adjustments may be required). • New station east of SSD known as Black River (BRV)
Option 4: 3rd Line (WAV to SOP) + DLR (TL201, T202, TL206, TL203)
• 3rd line from WAV to SOP, TL272, is FALCON • DLR is an additional:

○ 20% for Rate C (0ºC Ambient Rating)
Option 5: Option 4 + TL203/TL202/TL206 Reconductor
• 3rd line from WAV to SOP, TL272, is FALCON • Reconductor TL203 with GRACKLE • Reconductor TL202/TL206 with DRAKE/ACCC/TW. Addition of series compensation (adjustments may be required). • New station east of SSD known as Black River (BRV) • DLR is an additional: ○ 20% for Rate C (0ºC Ambient Rating)
Option 7: 3rd Line (WAV to SOP) + TL203/TL202/TL206 Reconductor + Terminate TL267 at BRV
• 3rd line from WAV to SOP, TL272, is FALCON • Reconductor TL203 with GRACKLE • Reconductor TL202/TL206 with DRAKE/ACCC/TW. Addition of series compensation (adjustments may be required). • New station east of SSD known as Black River (BRV) • Terminate TL267 at BRV
Option 8f: 3rd Line (WAV to SOP) + New 230 kV Line BDE to BRV (Tap off TL204TL231) + Reconductor TL203, TL202/TL206 + Terminate TL267 at BRV
• 3rd line from WAV to SOP, TL272, is FALCON • Reconductor TL203 with GRACKLE • New station east of SSD known as Black River (BRV) • New 230kV GRACKLE transmission line from a new tap station between BDE and STB and connects into BRV. Addition of series compensation (adjustments may be required). • Reconductor TL202/TL206 with DRAKE/ACCC/TW. Addition of series compensation • Terminate TL267 at BRV
Option 10: New 230 kV Circuit from BDE to SOP
• New station east of SSD known as Pipper's Hole (PHL) • 4th line from BDE to PHL, GRACKLE • 3rd line from PHL to SOP, GRACKLE • Two 230kV line reactors 15 MVAR at PHL

Options1-10 + Reactive Power Support in the SSD/CBC Area
• Goal is to determine optimal location, type and size of reactive power support to further increase transfer capacity from BDE to SOP. The objective should be to increase transfer capacity by at least 300 MW, since this would accommodate all potential off-Avalon generation projects.

3.3 Methodology

For each of the Options 1-10[19], steady state analysis was first performed to evaluate all single contingencies listed in Section 3.3.1. The maximum Island demand and gross Avalon load that can be served without causing a thermal overload or violating steady state voltage criteria was determined for each contingency. A table summarizing the most limiting contingencies and corresponding maximum Island demand was created to compare the options. The full set of results is provided in Appendix 1.

Transient stability analysis was then performed at the maximum Island demand identified for Options 1-10 during the steady state analysis. The aim was to evaluate a three-phase fault on each of the 230 kV line in the BDE-SOP corridor to see if stability would be a more limiting factor than steady state violations.

Options 1-10 were also evaluated with the addition of static reactive power support (4x38 MVAr capacitor banks) in the SSD/BRV area, for the most limiting contingency that resulted due a steady state voltage violation (<0.9pu). These options were then studied with the addition of dynamic reactive support (STATCOM).

Finally, the benefits of the installation of three additional 50 MW supply options (totalling 150 MW) at the existing HRD facility were evaluated by adding the new 150 MW to Options 1-10 and redoing the steady state and transient stability analysis.

3.3.1 Contingencies

The following steady state contingencies are considered in the analysis:

- Loss of each 230kV from BDE-SOP
- Loss of a SOPSC unit
- Loss of HRD3 SC
- Loss of CBC, HWD, OPD capacitor bank

The contingencies assessed as part of the transient analysis were 3PFs on each of the 230 kV lines between BDE and SOP, as well as loss of a SOP SC, HRD 3 SC and the HRD CT.

[19] Options 6 and 9 were eliminated prior to the analysis being performed as they were not practical or considered very similar to other options.

3.4 Phase 2 Results

3.4.1 BDE-SOP Upgrade Options

3.4.1.1 Steady state evaluation

The maximum Island demand, along with maximum Avalon gross demand, that can be served for the existing system and for the system with the various BDE-SOP corridor upgrade options are summarized in Table 3-2. These limits are based on steady state analysis and it must be understood that transient contingences may be more limiting and will be assessed in Section 3.4.1.2. The table lists the capacity increase to the Avalon for each upgrade option, as well as the limiting element and violation (thermal and/or steady state voltage) and the corresponding contingency that results in the violation.

3.4.1.2 Transient stability evaluation

Transient stability analysis was also performed for each option at the maximum allowable Island demand level defined by the steady state analysis. Violations of transient stability criteria are listed in the right-most column of Table 3-2. The following points apply to the transient stability analysis:

- Under emergency conditions (extended LIL bipole outage):
    - For all 3PF locations (with the exception of BDE), criteria is relaxed to allow the transient undervoltage criteria to be violated, but the system must maintain stability.
- 3PFs listed in Table 3-2 that result in undamped or critically damped oscillations may be able to be mitigated by proper tuning of power system stabilizers (PSS) and would not necessarily be the cause for further limiting the maximum Island demand. Additional analysis involving a PSS tuning study would be needed to verify if acceptable damping could be achieved.
- The remainder of the stability violations listed in the table do not fall under the categories described in the two bullet points above, and these violations are shown in red text and would therefore be more limiting than the limits determined from the steady state analysis. They would require the maximum Island demand to be reduced from the maximum determined in the steady state analysis in order to ensure system stability is maintained. The corresponding reduced maximum Island and Avalon demand to meet stability requirements is also shown in red text.

Several additional transient stability simulations[20] were performed with a STATCOM at BRV for Option 7 to assess the violation of transient stability criteria listed in red text to get an approximate idea of the size of STATCOM that would be needed to allow the system to maintain stability at the maximum Island demand determined from the steady state analysis, rather than reducing this maximum.

For Option 7, at the maximum allowable Island demand of 1737 MW, as determined from steady state violations, a 3PF at BRV on TL202 or TL206 results in system instability. This would require the maximum Island demand to be reduced to 1675 MW to mitigate the instability, unless a STATCOM (or some form of dynamic reactive support) is installed. A 3PF at BDE on TL267, TL202 or TL206 also results in instability

[20] Additional analysis with static and dynamic reactive support is performed in Section 3.4.2.

(which is an accepted risk), however, for information purposes a STATCOM was also sized to mitigate this instability.

Simulations with a STATCOM at BRV were performed. It was found that the following approximate STATCOM size would be required to maintain system stability:

- 100 MVAR to maintain stability for a 3PF at BRV on TL202 or TL206 (Figure 3-1)
- 475 MVAR to maintain stability for a 3PF at BDE on TL202, TL206 or TL267 (Figure 3-2)

Plots of the BDE-SOP corridor voltage response and the reactive power output of the STATCOM are shown in Figure 3-1 and Figure 3-2 for the BRV and BDE 3PFs listed above, respectively. Without the STATCOMs, the system response is unstable and the voltage collapses after the fault is cleared.

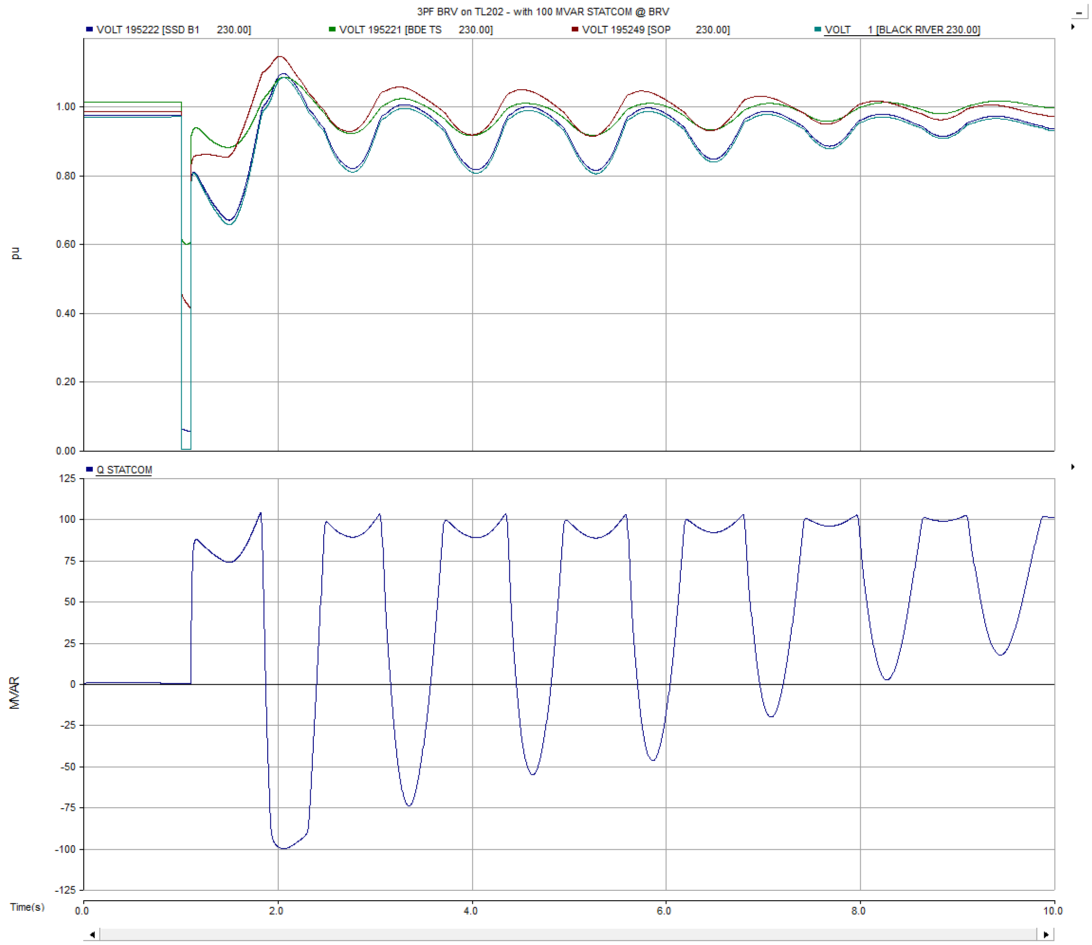

Figure 3-1. 3PF BRV on TL202 – with 100 MVAR STATCOM at BRV

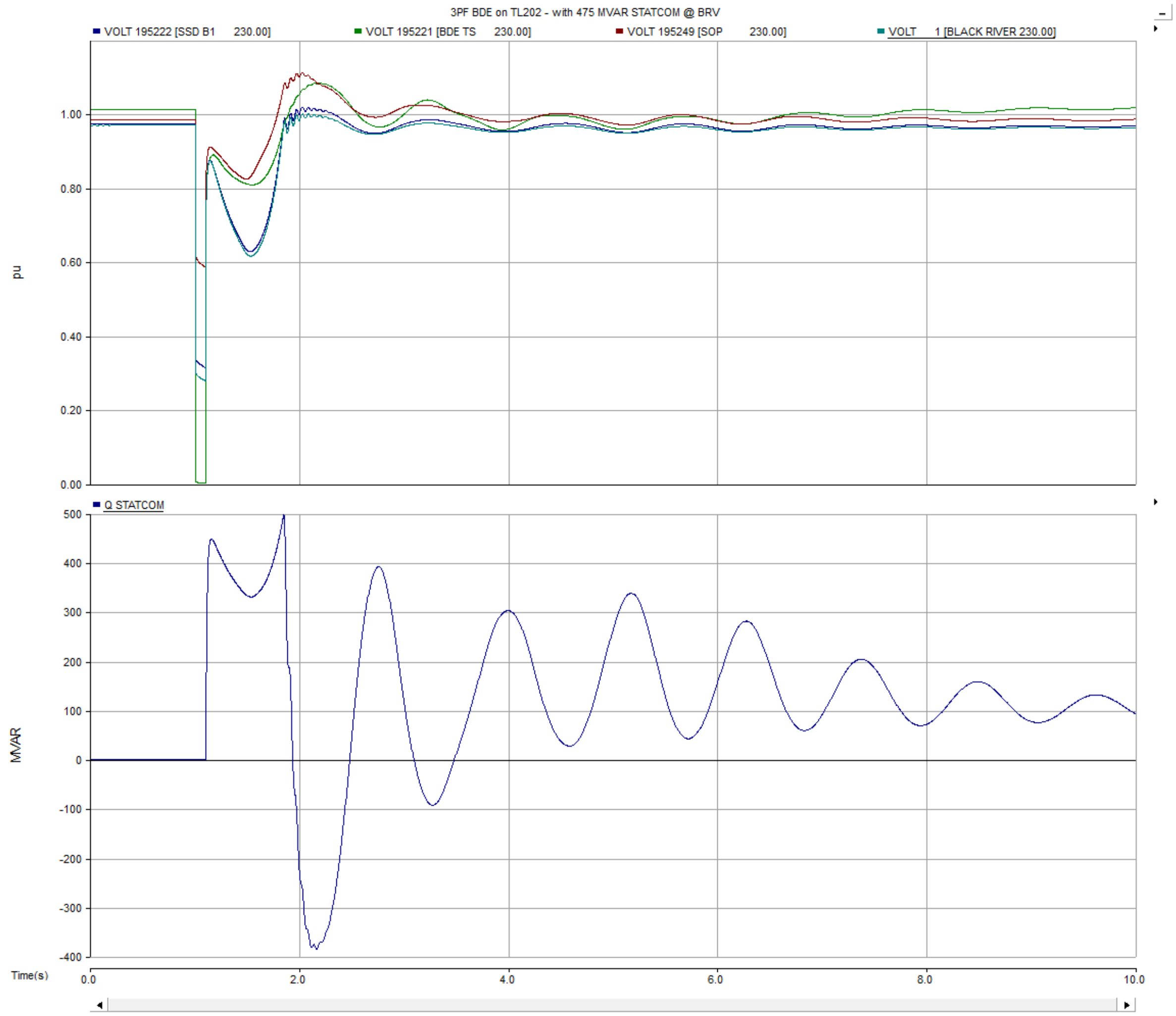

Figure 3-2. 3PF BDE on TL202 – with 475 MVAR STATCOM at BRV

Table 3-2. BDE-SOP Upgrade Options – Capacity Increase to Avalon – during LIL extended outage

	Option	BDE Flow East (MW)	Load Served (MW)		Capacity Increase to Avalon (MW)	Limiting Element (Contingency) Steady State	Transient Stability Results
			Max Island	Max Avalon Gross			
-	Status Quo	603	1285	664	-	TL201 thermal (TL217)	-
1	Reconductor - TL201/TL203/TL202/TL206	803	1583	827	163	TL217 thermal (TL201)	3PF BDE TL267, TL202/6 unstable
2	Option 1 + DLR (TL201/TL217/ TL203/TL202/TL206)	816	1618	843	179	TL207 thermal (TL203) + 0.90pu BRV (TL267)	3PF BDE TL267, TL202/6 unstable 3PF WAV TL267 transient UV 3PF SSD TL202/6 transient UV
3	3rd Line (WAV to SOP) + Reconductor (TL203/TL202/TL206)	814	1627	843	179	TL207 thermal (TL203)	3PF BDE TL267, TL202/6 unstable
	+ TL207 Reconductor[21]	856	1688	876	212	0.9 pu BRV (TL206)	3PF BDE TL267, TL202/6 unstable 3PF WAV TL267 undamped osc.* 3PF SSD TL202/6 undamped osc.*
4	3rd Line (WAV to SOP) + DLR (TL201/TL203/TL202/TL206)	746	1561	798	134	TL203 thermal (TL207)	3PF BDE TL267, TL202/6 unstable
	+ TL203 Reconductor[21]	793 789	1627 1600	833 827	169 163	TL202/6 thermal (TL206/2)	3PF BDE TL267, TL202/6 unstable 3PF WAV TL267 unstable 3PF SSD TL202/6 undamped osc.*
5	Option 4 + Reconductor (TL203/TL202/TL206)	847	1679	868	204	0.9 pu BRV (TL267)	3PF BDE TL267, TL202/6 unstable
7	3rd Line (WAV to SOP) + Terminate TL267 in SSD Area + Reconductor TL203	885 857	1737 1675	893 863	229 205	0.9 pu BRV + TL267 thermal (TL206)	3PF BDE TL267, TL202/6 unstable 3PF BRV TL202/6 unstable

[21] The additional reconductoring shown for Options 3, 4 8f and 10 were only analyzed for the base analysis here in Table 3-2 to get an idea of how much additional demand could be served by upgrading the next limiting element. These additional line reconductorings were not considered throughout the rest of the report when additional analysis involving 150 MW of HRD generation and new reactive power support was performed.

Option		BDE Flow East (MW)	Load Served (MW)		Capacity Increase to Avalon (MW)	Limiting Element (Contingency) Steady State	Transient Stability Results
			Max Island	Max Avalon Gross			
8f	3rd Line (WAV to SOP) + New 230 kV Line BDE to BRV (Tap off TL204/TL231) + Reconductor TL203, TL202/TL206 + Terminate TL267 at BRV	925	1844	961	297	TL207 thermal (TL203)	3PF BDE TL267-1, TL202/6-1 unstable 3PF BRV TL202/6-1 transient UV 3PF BRV STB-BRV transient UV
	+ TL207 Reconductor[21]	948	1880	981	317	TL202/6-2 thermal (TL206/2-2)	Same as above
10	New 230 kV Circuit from BDE to SOP	869	1896	895	231	TL203 thermal (TL207)	3PF BDE TL267, TL202/6, BDE-PHL unstable
	+ TL203 Reconductor[21]	908	1957	926	262	TL202/6 thermal (TL206/2)	Same as above
10a	+ 35% Series Comp on new BDE-PHL-SOP line	925	2096	970	306	0.9 pu SSD + TL202/6 thermal (BDE-PHL)	3PF BDE TL267, TL202/6 unstable 3PF BDE on BDE-PHL unstable 3PF PHL on BDE-PHL or PHL-SOP critically damped osc.*

*Undamped or critically damped oscillations may be able to be mitigated by proper tuning of power system stabilizers (PSS) and would not necessarily be cause for further limiting the maximum Island demand. Additional analysis involving a PSS tuning study would be needed to verify if acceptable damping could be achieved.

3.4.2 BDE-SOP Upgrade Options + Reactive Support

The next step was to analyze the options with additional reactive support installed near SSD or BRV to determine any further increase in capacity to the Avalon.

3.4.2.1 Static Reactive Support – Capacitor Banks near SSD/BRV

Static reactive support in the form of 4x38 MVAr capacitors was added at SSD or BRV depending on the option. The capacitor bank sizes were chosen to match those at CBC.

In some of the options shown in Table 3-2, thermal overloads are more limiting than the 0.9 pu (n-1) steady state voltage criteria. When evaluating the addition of capacitor banks at SSD or BRV, it was assumed that any thermal overloads more limiting than the steady state voltage criteria were mitigated, and therefore, the most limiting contingency in terms of 0.9 pu steady state voltage was assessed with the addition of the 4x38 MVAr capacitor banks to observe the increase in IIS demand that could be served.

The results of the addition of static reactive support near SSD/BRV are summarized in Table 3-3.

3.4.2.2 Dynamic Reactive Support – STATCOM at BRV

Transient stability simulations were performed at these increased IIS demand levels with the 4x38 MVAr capacitors in-service to see if there were any stability violations, and if so, what size of STATCOM would be needed to mitigate these violations.

The resulting worst case transient stability violation (not including a 3PF at BDE which may go unstable) and the corresponding STATCOM sizing required to allow the system to meet transient stability criteria at the maximum Island demand listed are summarized in the right-most columns in Table 3-3.

Table 3-3. BDE-SOP Upgrade Options – Capacity Increase to Avalon – with Addition of Reactive Power Support in SSD/BRV area

		4x38 MVAR Capacitors near SSD/BRV + STATCOM						
Option		BDE Flow East (MW)	Load Served (MW)		Capacity Increase to Avalon (MW)	Limiting Element (Contingency) Steady State	Limiting Transient Stability Violation*	STATCOM to fix Transient Stability violations
			Max Island	Max Avalon Gross				
1	Reconductor - TL201/TL203/TL202/TL206	896	1768	868	204	0.9 pu BRV (TL267) (assumes TL217, TL207 thermal overloads mitigated)	3PF SSD TL202	225 MVAR
2	Option 1 + DLR (TL201/ TL217/TL203/TL202/TL206)	895	1764	866	202	0.9 pu BRV (TL267) (assumes TL217, TL207 thermal overloads mitigated)	3PF SSD TL202	225 MVAR
3	3rd Line (WAV to SOP) + Reconductor (TL203/TL202/TL206)	940	1804	938	274	0.9 pu BRV (TL267) (assumes TL201, TL207 thermal overloads mitigated)	3PF SSD TL202	225 MVAR
4	3rd Line (WAV to SOP) + DLR (TL201/TL203/TL202/TL206)	905	1750	911	247	0.9 pu SSD (TL267) (assumes TL203, TL207, TL202, TL206 thermal overloads mitigated)	3PF SSD TL202	200 MVAR
5	Option 4 + Reconductor (TL203/TL202/TL206)	944	1815	941	277	0.9 pu BRV (TL267) (assumes TL207 thermal overload mitigated)	3PF SSD TL202	200 MVAR
7	3rd Line (WAV to SOP) + Terminate TL267 in SSD Area + Reconductor TL203	977	1864	910	246	0.9 pu BRV (TL206) (assumes TL207, TL267 thermal overloads mitigated)	3PF BRV TL202	300 MVAR
8f	3rd Line (WAV to SOP) + New 230 kV Line BDE to BRV (Tap off TL204/TL231) + Reconductor TL203, TL202/TL206 + Terminate TL267 at BRV	1068	2067	1080	416	0.9 pu BRV (TL206) (assumes TL207, TL202, TL206, BRV-WAV thermal overloads mitigated)	3PF BRV TL202-1	400 MVAR
10	New 230 kV Circuit from BDE to SOP	1011	2146	1008	344	0.9 pu WAV (PHL-SOP)	3PF SSD TL202,	75 MVAR

Option		4x38 MVAR Capacitors near SSD/BRV + STATCOM						
		BDE Flow East (MW)	Load Served (MW)		Capacity Increase to Avalon (MW)	Limiting Element (Contingency) Steady State	Limiting Transient Stability Violation*	STATCOM to fix Transient Stability violations
			Max Island	Max Avalon Gross				
						(assumes TL203, TL201, TL207, TL202, TL206 thermal overloads mitigated)	3PF WAV TL267	
10a	Not studied with additional reactive power since Island demand that can be met is already 2100 MW.							

*3PF at BDE are not listed since this fault is unstable for all options and is deemed to be acceptable.

3.4.3 BDE-SOP Upgrade Options + 150 MW New Avalon Generation

The most limiting contingencies[22] for each upgrade option were re-assessed to observe the impact of installing an additional 150 MW of generation at HRD[23]. Island demand was scaled up to determine the new maximum Island demand and corresponding maximum gross Avalon demand that can be served for each upgrade option with the additional 150 MW at HRD. The results are summarized in Table 3-4.

It is observed that additional generation at HRD directly reduces the amount of power flow on the BDE-SOP corridor, and consequently allows approximately 110-155 MW of additional Avalon gross demand to be served, depending on the upgrade option. It also increases the total island demand that can be served by approximately 250 MW to 310 MW.

Transient stability simulations were performed at the new maximum Island demand levels for the system with the additional 150 MW at HRD. Please refer to the explanations surrounding transient stability criteria in Section 3.4.1.2.

The main stability issues observed were instability for a 3PF at BDE, which is deemed acceptable. Option 8f also showed instability for a 3PF at STB on the new STB-BRV line (shown in red text in the right-most column of Table 3-4) , which would require the maximum Island demand to be reduced to 1890 MW, or a 125 MVAR STATCOM can also mitigate the violation if the maximum demand is not reduced from 2082 MW.

3.4.3.1 Additional Reactive Power Support

The same 4x38 MVAR capacitor banks as studied in Section 3.4.2.1 were added to Options 1-10 in addition to the new 150 MW of Avalon generation to observe the increase in demand that can be served. It was assumed for purposes of analyzing reactive power that all thermal loading issues are mitigated.

Transient stability simulations were performed at these increased IIS demand levels to see if there were any stability violations, and if so, what size of STATCOM would be needed to mitigate these violations.

The results are summarized in Table 3-5.

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[22] Analysis was only performed for the most limiting contingency listed in Table 2-2, as it is assumed that the most limiting contingency will be the same, whether or not the new 150 MW is added at HRD.
[23] NLH Technical Note TP-TN-233 "Preliminary Stability Model – Holyrood 50 MW Gas Turbine", September 9, 2023.

Table 3-4. BDE-SOP Upgrade Options + 150 MW HRD Generation – Capacity Increase to Avalon – during LIL extended outage

Option		Steady state limitations	BDE Flow East (MW)	Load Served (MW)		Capacity Increase to Avalon (MW)	Transient Stability Violations
				Max Island	Max Avalon Gross		
-	Status Quo	TL201 thermal (TL217)	603	1285	664	-	-
Existing HRD CT + Additional 150 MW at HRD							
1	Reconductor - TL201/TL203/TL202/TL206	TL217 thermal (TL201)	843	1848	979	315	3PF BDE TL267, TL202/6 unstable
2	Option 1 + DLR (TL201/ TL217/TL203/TL202/TL206)	TL207 thermal (TL203) + 0.90pu BRV (TL267)	815	1836	968	304	3PF BDE TL267, TL202/6 unstable
3	3rd Line (WAV to SOP) + Reconductor (TL203/TL202/TL206)	TL207 thermal (TL203)	849	1883	991	327	3PF BDE TL267, TL202/6 unstable
4	3rd Line (WAV to SOP) + DLR (TL201/TL203/TL202/TL206)	TL203 thermal (TL207)	783	1819	949	285	3PF BDE TL267 unstable 3PF BDE TL202/6 transient UV
5	Option 4 + Reconductor (TL203/TL202/TL206)	0.9 pu BRV (TL267)	842	1881	988	324	3PF BDE TL267, TL202/6 unstable
7	3rd Line (WAV to SOP) + Terminate TL267 in SSD Area + Reconductor TL203	0.9 pu BRV + TL267 thermal (TL206)	880	1938	1014	350	3PF BDE TL267, TL202/6 unstable 3PF BRV TL202/6 undamped osc.*
8f	3rd Line (WAV to SOP) + New 230 kV Line BDE to BRV (Tap off TL204/TL231) + Reconductor TL203, TL202/TL206 + Terminate TL267 at BRV	TL207 thermal (TL203)	912 819	2082 1890	1100 996	436 332	3PF BDE TL267-1, TL202/6-1 unstable 3PF STB-BRV unstable
10	New 230 kV Circuit from BDE to SOP	TL203 thermal (TL207)	912	2167	1050	386	3PF BDE TL267, TL202/6 unstable 3PF BDE on BDE-PHL unstable
10a	+ 35% Series Comp on new BDE-PHL-SOP line	0.9 pu SSD + TL202/6 thermal (BDE-PHL)	954	2293	1082	418	3PF BDE TL267, TL202/6, BDE-PHL unstable

*It may be possible to mitigate the oscillations via PSS tuning. A separate study would be needed to verify.

Table 3-5. BDE-SOP Upgrade Options + 150 MW HRD Generation + Reactive Power Support – Capacity Increase to Avalon – during LIL extended outage

Option		Additional 150 MW at HRD + 4x38 MVAR Capacitors near SSD/BRV + STATCOM						
		BDE Flow East (MW)	Load Served (MW)		Capacity Increase to Avalon (MW)	Limiting Element (Contingency) Steady State	Limiting Transient Stability Violation*	STATCOM to fix Transient Stability violations
			Max Island	Max Avalon Gross				
1	Reconductor - TL201/TL203/TL202/TL206	912	1973	1041	377	0.9 pu BRV (TL267) (assumes TL217, TL207 thermal overloads mitigated)	3PF SSD TL202	125 MVAR
2	Option 1 + DLR (TL201/TL217/TL203/TL202/TL206)	913	1973	1041	377	0.9 pu BRV (TL267) (assumes TL217, TL207 thermal overloads mitigated)	3PF SSD TL202	125 MVAR
3	3rd Line (WAV to SOP) + Reconductor (TL203/TL202/TL206)	933	2021	1058	394	0.9 pu BRV (TL267) (assumes TL201, TL207 thermal overloads mitigated)	3PF SSD TL202	100 MVAR
4	3rd Line (WAV to SOP) + DLR (TL201/TL203/TL202/TL206)	897	1947	1026	362	0.9 pu SSD (TL267) (assumes TL203, TL207, TL202, TL206 thermal overloads mitigated)	3PF SSD TL202	125 MVAR
5	Option 4 + Reconductor (TL203/TL202/TL206)	945	2024	1064	400	0.9 pu BRV (TL267) (assumes TL207 thermal overload mitigated)	3PF SSD TL202	125 MVAR
7	3rd Line (WAV to SOP) + Terminate TL267 in SSD Area + Reconductor TL203	969	2060	1079	415	0.9 pu BRV (TL206) (assumes TL207, TL267 thermal overloads mitigated)	3PF BRV TL202	225 MVAR
8f	3rd Line (WAV to SOP) + New 230 kV Line BDE to BRV (Tap off TL204/TL231) + Reconductor TL203, TL202/TL206 + Terminate TL267 at BRV	1026	2234	1171	507	0.9 pu BRV (TL206) (assumes TL207, TL202, TL206, BRV-WAV thermal overloads mitigated)	3PF BRV TL202-1	175 MVAR
10	New 230 kV Circuit from BDE to SOP	993	2288	1112	448	0.9 pu WAV (PHL-SOP)	none	none

Option		Additional 150 MW at HRD + 4x38 MVAR Capacitors near SSD/BRV + STATCOM						
		BDE Flow East (MW)	Load Served (MW)		Capacity Increase to Avalon (MW)	Limiting Element (Contingency) Steady State	Limiting Transient Stability Violation*	STATCOM to fix Transient Stability violations
			Max Island	Max Avalon Gross				
						(assumes TL203, TL201, TL207, TL202, TL206 thermal overloads mitigated)		
10a	Not studied with additional reactive power since Island demand that can be met is already > 2100 MW.							

*3PF at BDE are not listed since this fault is unstable for all options and is deemed to be acceptable.

3.5 Summary

Table 3-6 summarizes the Phase 2 results, comparing the BDE-SOP upgrade options, with / without an additional 150 MW of generation at HRD, and with / without additional reactive power support, in terms of the IIS demand that can be served and the capacity increase to the Avalon.

Table 3-6. Overall Comparison of BDE-SOP Upgrade Options

Options	No New Avalon Generation					Additional 150 MW @ HRD				
	No New Reactive Power		New 4x38 MVAR caps + STATCOM			No New Reactive Power		New 4x38 MVAR caps + STATCOM		
	IIS demand (MW)	Capacity increase to Avalon (MW)	IIS demand (MW)	Capacity increase to Avalon (MW)	STATCOM (MVAR)	IIS demand (MW)	Capacity increase to Avalon (MW)	IIS demand (MW)	Capacity increase to Avalon (MW)	STATCOM (MVAR)
1-5	1560-1680	130-200	1750-1815	200-275	200-225	1835-1880	285-325	1945-2025	360-415	100-125
7	1675	205	1864	245	300	1938	350	2060	415	225
8f	1844	300	2067	415	400	2082	435	2234	510	175
10	1896	230	2146	345	75	2167	385	2288	448	None
10a	2096	300	*	*	*	2293	420	*	*	*

* Not studied with additional reactive power since Island demand that can be met is already >= 2100 MW

The following conclusions are drawn from Phase 2:

- **The largest capacity increase to the Avalon is obtained via Options 8f, 10 and 10a, with the base version of these options seeing an increase of 230-300 MW.** These options have a new 230 kV line out of BDE, among other upgrades such as various line reconductorings and a new 230 kV line between WAV and SOP.
- **The remainder of the Options 1-7 provide capacity increases to the Avalon in the range of approximately 130-200 MW for the base version of these options**. These options focus on reconductoring various lines, adding series compensation to TL202 and TL206 and applying DLR. Some options also build a third 230 kV line between WAV and SOP, however, these options do not have new transmission out of BDE.
- **The addition of 150 MW of new generation at HRD** provides an additional increase in capacity to the Avalon ranging from approximately 100 MW to 160 MW compared to the base options. It also increases the total island demand that can be served by approximately 250 MW to 310 MW.
- **The addition of reactive power support** also increases the Island demand that can be served as well as the capacity to the Avalon, however, it should be noted that Options 1 through 8f require a STATCOM ranging from 200-400 MVAR depending on the option. The STATCOM size requirements are smaller (around half) if the new 150 MW HRD generation is installed.

  Option 10 requires the smallest STATCOM size of 75 MVAR, or no STATCOM if 150 MW of new Avalon generation is installed. Option 10 builds a new 230 kV line from BDE to a new station Piper's Hole (PHL) and PHL to SOP. In the other options, all new lines go through either BRV and/or SSD, and when there is a fault at BRV or SSD it affects the entire BDE-SOP corridor significantly. Whereas in Option 10, there is a new separate path that remains more intact, or less affected, when there is a fault near BRV or SSD, which improves the stability of the system for faults in this corridor.

APPENDIX 1

STUDY RESULTS

OPTION 1 - Reconductor - TL201/TL203/TL202/TL206

Contingency	Power transfer Eastward out of BDE	Power transfer TL201+TL217	Island Demand that can be served (MW)	Avalon Load (MW)	Limiting Criteria (Rate C)	Limiting Voltage
System intact	927	541	1756	917	none	0.95 pu BRV
System intact*	**957**	**570**	**1827**	**949**	**none**	**0.95 pu BRV**
SOP SC	957	570	1827	949	none	0.933 BRV
HRD SC	957	570	1827	949	none	0.93 BRV
CBC cap	957	570	1827	949	none	0.931 BRV
HWD cap	957	570	1827	949	none	0.948 BRV
TL217	**921**	**540**	**1749**	**914**	**none**	**0.90 pu WAV / 0.916 pu CBC**
TL201	**803**	**472**	**1583**	**827**	**100% TL217**	**none**
TL201	**843**	**460**	**1848**	**979**	**100% TL217**	**none**
TL203	**820**	**486**	**1622**	**846**	**99.5% TL207**	**none**
TL237	957	570	1827	949	none	0.923 BRV
TL207	**947**	**563**	**1814**	**943**	**none**	**0.905 pu SSD / BRV**
TL206	**857**	**509**	**1689**	**877**	**none**	**0.90 pu SSD / 0.908 pu CBC**
TL267	**824**	**490**	**1640**	**851**	**none**	**0.903 pu SSD / 0.911 pu CBC**

Most limiting steady state n-1 contingency

Worst case steady state re-assessed with additional HRD 150 MW generation added

* HRD, HWD generator voltage setpoints increased to 1.05 pu, SOP 230 kV voltage setpoint of SOP SCs adjusted in all cases to ensure tertiary voltages below 1.05 pu

Worst contingency + 4x38 MVAR Caps (ignoring thermal OL of other contingencies)

TL267	**896**	**538**	**1768**	**868**	**none**	**0.903 pu SSD / 0.911 pu CBC**

Worst contingency + 4x38 MVAR Caps + 225 MVAR STATCOM (ignoring thermal OL of other contingencies)

3PF SSD TL202	**896**	**538**	**1768**	**868**	**stability**

OPTION 2 - Option 1 + DLR (TL201/ TL217/TL203/TL202/TL206)

Contingency	Power transfer Eastward out of BDE	Power transfer TL201+TL217	Island Demand that can be served (MW)	Avalon Load (MW)	Limiting Criteria (Rate C)	Limiting Voltage
System intact	927	541	1756	917	none	0.95 pu WAV
System intact*	**978**	**574**	**1830**	**955**	**none**	**0.95 pu BRV**
SOP SC	978	574	1830	955	none	0.931 BRV
HRD SC	978	574	1830	955	none	0.930 BRV
CBC cap	978	574	1830	955	none	0.930 BRV
HWD cap	978	574	1830	955	none	0.943 BRV
TL217	**903**	**536**	**1855**	**909**	**none**	**0.90 pu WAV / 0.916 pu CBC**
TL201	**887**	**522**	**1715**	**894**	**99.3% TL217**	**none**
TL203	**820**	**486**	**1618**	**843**	**99.7% TL207**	**none**
TL237	978	574	1830	955	none	0.912 BRV
TL207	**943**	**561**	**1812**	**942**	**none**	**0.90 pu SSD**
TL206	**836**	**498**	**1659**	**861**	**none**	**0.90 SSD comp**
TL267	**816**	**485**	**1618**	**845**	**none**	**0.90 BRV**
TL267	**815**	**451**	**1836**	**968**	**none**	**0.90 BRV**

Most limiting steady state n-1 contingency

Worst case steady state re-assessed with additional HRD 150 MW generation added

DLR applied to TL217

* HRD, HWD generator voltage setpoints increased to 1.05 pu, SOP 230 kV voltage setpoint of SOP SCs adjusted in all cases to ensure tertiary voltages below 1.05 pu

Worst contingency + 4x38 MVAR Caps (ignoring thermal OL of other contingencies)

TL267	**895**	**545**	**1764**	**866**	**none**	**0.903 pu SSD / 0.911 pu CBC**

Worst contingency + 4x38 MVAR Caps + 225 MVAR STATCOM (ignoring thermal OL of other contingencies)

3PF SSD TL202	**895**	**545**	**1764**	**866**	**stability**

OPTION 3 - 3rd Line (WAV to SOP) + Reconductor (TL203/TL202/TL206)

Contingency	Power transfer Eastward out of BDE	Power transfer TL201+TL217	Island Demand that can be served (MW)	Avalon Load (MW)	Limiting Criteria (Rate C)	Limiting Voltage
System intact	964	590	1831	953	none	0.955 pu WAV
System intact*	**1009**	**619**	**1901**	**986**	**none**	**0.95 pu SSD**
SOP SC	1009	619	1901	986	none	0.922 SSD
HRD SC	1009	619	1901	986	none	0.921 SSD
CBC cap	1009	619	1901	986	none	0.932 SSD
HWD cap	1009	619	1901	986	none	0.946 SSD
TL217	**976**	**597**	**1857**	**963**	**99.6% TL201**	**0.931 SSD**
TL272	**981**	**601**	**1867**	**967**	**99.9% TL201**	**0.934 SSD**
TL201	1009	619	1901	986	none	0.912 SSD
TL203	**814**	**501**	**1627**	**843**	**99.6% TL207**	**0.931 SSD**
TL203	**849**	**487**	**1883**	**991**	**99.8% TL207**	**0.97 BRV**
TL237	1009	619	1901	986	none	0.918 SSD
TL207	**989**	**606**	**1875**	**973**	**none**	**0.90 SSD**
TL206	**898**	**551**	**1749**	**907**	**none**	**0.90 SSD**
TL267	**856**	**525**	**1688**	**876**	**none**	**0.90 pu SSD / 0.909 pu CBC**

Most limiting steady state n-1 contingency

Worst case steady state re-assessed with additional HRD 150 MW generation added

* HRD, HWD generator voltage setpoints increased to 1.05 pu, SOP 230 kV voltage setpoint of SOP SCs adjusted in all cases to ensure tertiary voltages below 1.05 pu

OPTION 3 + Reconductor TL207 (Worst contingencies)

Contingency	Power transfer Eastward out of BDE	Power transfer TL201+TL217	Island Demand that can be served (MW)	Avalon Load (MW)	Limiting Criteria (Rate C)	Limiting Voltage
TL203	**875**	**540**	**1715**	**890**	**99.7% TL237**	**none**
TL267	**856**	**525**	**1688**	**876**	**none**	**0.90 pu SSD / 0.909 pu CBC**

Worst contingency + 4x38 MVAR Caps (ignoring thermal OL of other contingencies)

TL267	**940**	**577**	**1804**	**938**	**none**	**0.903 pu SSD / 0.911 pu CBC**

Worst contingency + 4x38 MVAR Caps + 225 MVAR STATCOM (ignoring thermal OL of other contingencies)

3PF SSD TL202	**940**	**577**	**1804**	**938**	**stability**

OPTION 4 - 3rd Line (WAV to SOP) + DLR (TL201/TL203/TL202/TL206)

Contingency	Power transfer Eastward out of BDE	Power transfer TL201+TL217	Island Demand that can be served (MW)	Avalon Load (MW)	Limiting Criteria (Rate C)	Limiting Voltage
System intact	964	590	1810	941	none	0.955 pu WAV
System intact*	**971**	**599**	**1880**	**965**	**none**	**0.95 pu SSD**
SOP SC	971	599	1880	965	none	0.91 SSD/WAV
HRD SC	971	599	1880	965	none	0.915 SSD/WAV
CBC cap	971	599	1880	965	none	0.93 SSD
HWD cap	971	599	1880	965	none	0.945 SSD
TL217	971	599	1880	965	none	0.901 SSD
TL272	971	599	1880	965	none	0.905 SSD
TL201	971	599	1880	965	none	0.902 SSD
TL203	**818**	**508**	**1662**	**852**	**99.8% TL207**	**none**
TL237	**799**	**497**	**1637**	**838**	**99.9% TL203**	**none**
TL207	**746**	**464**	**1561**	**798**	**100% TL203**	**none**
TL207	**783**	**452**	**1819**	**949**	**100% TL203**	**none**
TL206	**8100010925613**	**493**	**1627**	**833**	**99.7% TL206**	**none**
TL267	**812**	**495**	**1617**	**838**	**100% TL203, 98% TL202/TL206**	**0.913 SSD**

Most limiting steady state n-1 contingency

Worst case steady state re-assessed with additional HRD 150 MW generation added

* HRD, HWD generator voltage setpoints increased to 1.05 pu, SOP 230 kV voltage setpoint of SOP SCs adjusted in all cases to ensure tertiary voltages below 1.05 pu

OPTION 4 + Reconductor TL203

Contingency	Power transfer Eastward out of BDE	Power transfer TL201+TL217	Island Demand that can be served (MW)	Avalon Load (MW)	Limiting Criteria (Rate C)	Limiting Voltage
TL207	**940**	**583**	**1837**	**945**	**99.7% TL237**	**0.90 SSD**
TL267	**823**	**504**	**1634**	**849**	**100% TL202, TL206**	**0.903 SSD**
TL206	**793**	**493**	**1627**	**833**	**99.7% TL202**	**none**
TL203	**818**	**508**	**1662**	**852**	**99.8% TL207**	**none**
TL237	**940**	**583**	**1837**	**945**	**none**	**0.90 SSD**

OPTION 4 + Reconductor TL207

Contingency	Power transfer Eastward out of BDE	Power transfer TL201+TL217	Island Demand that can be served (MW)	Avalon Load (MW)	Limiting Criteria (Rate C)	Limiting Voltage
TL203	**879**	**546**	**1750**	**899**	**99.7% TL237**	**none**

Worst contingency + 4x38 MVAR Caps (ignoring thermal OL of other contingencies)

TL267	**905**	**556**	**1750**	**911**	**none**	**0.903 pu SSD / 0.911 pu CBC**

Worst contingency + 4x38 MVAR Caps + 200 MVAR STATCOM (ignoring thermal OL of other contingencies)

3PF SSD TL202	**905**	**556**	**1750**	**911**	**stability**

OPTION 5 - Option 4 + Reconductor (TL203/TL202/TL206)

Contingency	Power transfer Eastward out of BDE	Power transfer TL201+TL217	Island Demand that can be served (MW)	Avalon Load (MW)	Limiting Criteria (Rate C)	Limiting Voltage
System intact	978	592	1831	954	none	0.955 pu WAV
System intact*	**1005**	**617**	**1902**	**984**	**none**	**0.95 pu SSD**
SOP SC	1005	617	1902	984	none	0.923 SSD
HRD SC	1005	617	1902	984	none	0.923 SSD
CBC cap	1005	617	1902	984	none	0.931 SSD
HWD cap	1005	617	1902	984	none	0.945 SSD
TL217	1005	617	1902	984	none	0.911 SSD
TL272	1005	617	1902	984	none	0.915 SSD
TL201	1005	617	1902	984	none	0.912 SSD
TL203	**876**	**540**	**1720**	**890**	**99.7% TL207**	**none**
TL237	1005	617	1902	984	none	0.918 SSD
TL207	**986**	**604**	**1877**	**971**	**none**	**0.90 SSD**
TL206	**903**	**554**	**1758**	**857**	**none**	**0.90 SSD / BRV**
TL267	**847**	**521**	**1679**	**868**	**none**	**0.90 BRV**
TL267	**842**	**483**	**1881**	**988**	**none**	**0.90 BRV**

Most limiting steady state n-1 contingency

Worst case steady state re-assessed with additional HRD 150 MW generation added

* HRD, HWD generator voltage setpoints increased to 1.05 pu, SOP 230 kV voltage setpoint of SOP SCs adjusted in all cases to ensure tertiary voltages below 1.05 pu

Worst contingency + 4x38 MVAR Caps (ignoring thermal OL of other contingencies)

TL267	**944**	**582**	**1815**	**941**	**none**	**0.903 pu SSD / 0.911 pu CBC**

Worst contingency + 4x38 MVAR Caps + 200 MVAR STATCOM (ignoring thermal OL of other contingencies)

3PF SSD TL202	**944**	**582**	**1815**	**941**	**stability**

OPTION 7 - 3rd Line (WAV to SOP) + Terminate TL267 in SSD Area + Reconductor TL203

Contingency	Power transfer Eastward out of BDE	Power transfer TL201+TL217	Island Demand that can be served (MW)	Avalon Load (MW)	Limiting Criteria (Rate C)	Limiting Voltage
System intact	971	589	1813	944	none	0.95 pu BRV
System intact*	**982**	**605**	**1871**	**963**	**none**	**0.95 pu BRV**
SOP SC	982	605	1871	963	none	0.936 BRV
HRD SC	982	605	1871	963	none	0.936 BRV
CBC cap	982	605	1871	963	none	0.936 BRV
HWD cap	982	605	1871	963	none	0.945 BRV
TL217	982	605	1871	963	none	0.919 BRV
TL272	982	605	1871	963	none	0.923 BRV
TL201	982	605	1871	963	none	0.920 BRV
TL203	**924**	**569**	**1790**	**922**	**99.9% TL207**	none
TL237	982	605	1871	963	none	0.925 BRV
TL207	982	605	1871	963	96.9% BRV-WAV	0.905 BRV
TL206	**885**	**546**	**1737**	**893**	96% TL267	**0.90 BRV**
TL206	**880**	**509**	**1938**	**1014**	96% TL267	**0.90 BRV**
TL267	**911**	**563**	**1773**	**912**	**none**	**0.90 BRV**
TL267-2	**963**	**593**	**1847**	**951**	**99.8% TL207**	**0.914 BRV**
TL206-2	982	605	1871	963	100.2% TL202-2	0.93 BRV

Most limiting steady state n-1 contingency

Worst case steady state re-assessed with additional HRD 150 MW generation added

* HRD, HWD generator voltage setpoints increased to 1.05 pu, SOP 230 kV voltage setpoint of SOP SCs adjusted in all cases to ensure tertiary voltages below 1.05 pu

Worst contingency + 4x38 MVAR Caps (ignoring thermal OL of other contingencies)

TL206	**977**	**605**	**1864**	**910**	**none**	**0.903 pu SSD / 0.911 pu CBC**

Worst contingency + 4x38 MVAR Caps + 300 MVAR STATCOM (ignoring thermal OL of other contingencies)

3PF BRV TL202	**977**	**605**	**1864**	**910**	**stability**

OPTION 8f - 3rd Line (WAV to SOP) + New 230 kV Line BDE to BRV (Tap off TL204/TL231) + Reconductor TL203, TL202/TL206 + Terminate TL267 at BRV

Contingency	Eastward Into BRV	Power transfer TL201+TL217	Island Demand that can be served (MW)	Avalon Load (MW)	Limiting Criteria (Rate C)	Limiting Voltage
System intact	999	636	1920	1010	none	0.957 pu BRV
System intact*	**1036**	**672**	**2015**	**1052**	**none**	**0.95 pu BRV**
SOP SC	1036	672	2015	1052	none	0.93 BRV
HRD SC	1036	672	2015	1052	none	0.93 BRV
CBC cap	1036	672	2015	1052	none	0.936 BRV
HWD cap	1036	672	2015	1052	none	0.945 BRV
TL217	1036	672	2015	1052	none	0.917 BRV
TL272	1036	672	2015	1052	none	0.917 BRV
TL201	1036	672	2015	1052	none	0.919 BRV
TL203	**925**	**588**	**1844**	**961**	**99.9% TL207**	none
TL203	**912**	**578**	**2082**	**1100**	**99.6% TL207**	none
TL237	**1022**	**741**	**1998**	**1042**	**99.8% BRV-WAV**	**0.929 BRV**
TL207	**1000**	**633**	**1959**	**1022**	**100% BRV-WAV**	**0.927 BRV**
TL206	**978**	**642**	**1955**	**1020**	none	**0.90 BRV**
TL267	**1012**	**654**	**1981**	**1033**	**none**	**0.90 BRV**
TL267-2	**968**	**628**	**1910**	**997**	**99.9% TL207**	**none**
TL206-2	**948**	**616**	**1880**	**981**	**99.8% TL202-2**	**none**
STB-BRV	**1008**	**654**	**1977**	**1031**	**none**	**0.9 BRV**

Most limiting steady state n-1 contingency
Worst case steady state re-assessed with additional HRD 150 MW generation added
* HRD, HWD generator voltage setpoints increased to 1.05 pu, SOP 230 kV voltage setpoint of SOP SCs adjusted in all cases to ensure tertiary voltages below 1.05 pu

OPTION 8f + Reconductor TL207

Contingency	Eastward Into BRV	Power transfer TL201+TL217	Island Demand that can be served (MW)	Avalon Load (MW)	Limiting Criteria (Rate C)	Limiting Voltage
TL203	**968**	**627**	**1910**	**997**	**99.8% BRV-WAV 96.9% TL237**	**none**
TL206-2	**948**	**616**	**1880**	**981**	**99.8% TL202-2**	**none**

Worst contingency + 4x38 MVAR Caps (ignoring thermal OL of other contingencies)

TL206	**1068**	**677**	**2067**	**1080**	**none**	**0.9 pu BRV**

Worst contingency + 4x38 MVAR Caps + 450 MVAR STATCOM (ignoring thermal OL of other contingencies)

3PF BRV TL202-1	**1068**	**677**	**2067**	**1080**	**stability**

OPTION 10 - New 230 kV Circuit from BDE to Piper's Hole (PHL) to SOP

Contingency	Power transfer Eastward out of BDE	Into SOP	Island Demand that can be served (MW)	Avalon Load (MW)	Limiting Criteria (Rate C)	Limiting Voltage
System intact	955	585	1955	948	none	0.95 pu PHL
System intact*	**1013**	**623**	**2124**	**1005**	**none**	**0.95 pu PHL**
SOP SC	1013	623	2124	1005	none	0.937 PHL
HRD SC	1013	623	2124	1005	none	0.937 PHL
CBC cap	1013	623	2124	1005	none	0.942 PHL
HWD cap	1013	623	2124	1005	none	0.945 PHL
TL217	**980**	**602**	**2070**	**980**	**100% TL201**	**0.934 PHL**
TL201	1013	623	2124	1005	none	0.923 PHL
TL203	1013	623	2124	1005	none	0.933 PHL
TL237	**935**	**771**	**1996**	**945**	**99.8% TL203**	**none**
TL207	**869**	**528**	**1896**	**895**	**99.9% TL203**	**none**
TL207	**912**	**529**	**2167**	**1050**	**99.7% TL203**	**none**
TL206	**908**	**560**	**1957**	**926**	**99.7% TL202**	**none**
TL267	**955**	**585**	**2031**	**961**	**100% TL202,TL206, 96% TL207**	**0.90 PHL**
PHL-SOP	**960**	**588**	**2039**	**965**	95.5% TL202, TL206	**0.902 SSD**
BDE-PHL	**960**	**588**	**2039**	**965**	95.3% TL202, TL206	**0.905 SSD**

Most limiting steady state n-1 contingency

Worst case steady state re-assessed with additional HRD 150 MW generation added

* HRD, HWD generator voltage setpoints increased to 1.05 pu, SOP 230 kV voltage setpoint of SOP SCs adjusted in all cases to ensure tertiary voltages below 1.05 pu

OPTION 10 + Reconductor TL203

Contingency	Power transfer Eastward out of BDE	Power transfer TL201+TL217	Island Demand that can be served (MW)	Avalon Load (MW)	Limiting Criteria (Rate C)	Limiting Voltage
TL207	1013	623	2124	1005	none	0.940 PHL
TL237	1013	623	2124	1005	none	0.945 PHL
TL206	**908**	**560**	**1957**	**926**	**99.7% TL202**	**none**

Worst contingency + 4x38 MVAR Caps (ignoring thermal OL of other contingencies)

TL267	**1045**	**641**	**2171**	**1030**	**none**	**0.9 pu PHL**
PHL-SOP	**1011**	**622**	**2146**	**1008**	none	**0.902 WAV**

Worst contingency + 4x38 MVAR Caps + 75 MVAR STATCOM (ignoring thermal OL of other contingencies)

3PF SSD TL202	**1011**	**622**	**2146**	**1008**	**stability**

OPTION 10a - Option 10 + 35% Series Compensation on new BDE-PHL-SOP lines

Contingency	Power transfer Eastward out of	Into SOP	Island Demand that can be served (MW)	Avalon Load (MW)	Limiting Criteria (Rate C)	Limiting Voltage
System intact*	**1147**	**709**	**2415**	**1100**	**none**	**0.95 pu PHL**
SOP SC	**1097**	**677**	**2351**	**1066**	**none**	**Run out of VARS**
HRD SC	1097	677	2351	1066	none	Run out of VARS
CBC cap	1097	677	2351	1066	none	none
HWD cap	1097	677	2351	1066	none	none
TL217	**1110**	**687**	**2430**	**1088**	**99.1% TL201**	**0.926 PHL**
TL201	1128	695	2407	1090	none	0.915 SSD
TL237	1128	695	2407	1090	none	0.931 PHL
TL203	1128	695	2407	1090	none	0.927 PHL
TL207	1128	695	2407	1090	none	0.915 SSD
TL202	**1012**	**628**	**2182**	**1001**	**99.7% TL206**	**0.937 PHL**
TL267	**1049**	**647**	**2241**	**1027**	**96.9% TL202,TL206**	**0.905 PHL**
PHL-SOP	**967**	**601**	**2109**	**967**	95.5% TL202, TL206	**0.902 SSD**
BDE-PHL	**959**	**596**	**2095**	**961**	95.3% TL202, TL206	**0.905 SSD**
BDE-PHL	**954**	**561**	**2293**	**1082**	94% TL202, TL206	**0.905 SSD**

Most limiting steady state n-1 contingency

Worst case steady state re-assessed with additional HRD 150 MW generation added

* HRD, HWD generator voltage setpoints increased to 1.05 pu, SOP 230 kV voltage setpoint of SOP SCs adjusted in all cases to ensure tertiary voltages below 1.05 pu