Q. Reference PUB-NLH-523: Please provide the report on the need for additional reactive power compensation in the Bottom Brooke area.

A. Please see PUB-NLH-565, Attachment 1 Maritime Link VSC HVdc Run-Back Requirements PSS®E Dynamic Contingency Analysis, May 2016.

Approved for Release	May 03, 2016 Date

MARITIME LINK VSC HVDC RUN-BACK REQUIREMENTS
PSS®E DYNAMIC CONTINGENCY ANALYSIS

Newfoundland and Labrador Hydro

DATE: MAY 02, 2016

newfoundland labrador hydro
a nalcor energy company

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1 INTRODUCTION

On November 29, 2013, the Nova Scotia Utility and Review Board approved the Maritime Link Project. The Maritime Link (ML) requires the construction of a ± 200 kV, 500 MW HVdc transmission link between Bottom Brook Terminal Station (BBK) in western Newfoundland and Woodbine Substation in Cape Breton, Nova Scotia. In addition, Emera Newfoundland Limited (ENL), the owner of ML, will be constructing a new 230 kV transmission line (TL269) between Granite Canal Terminal Station (GCL) and BBK to ensure a minimum transfer capacity of 250 MW on the ML for single 230 kV transmission line contingencies in western Newfoundland.

As part of the Lower Churchill Project (LCP), the ML will be designed to connect the Island Interconnected System to Nova Scotia's grid. Through a contract with Emera, Nalcor Energy will deliver approximately 168 MW and 0.98 TWh (less losses) to customers in Nova Scotia from generation at Muskrat Falls in Labrador. Nalcor Energy will have access to approximately 80 MW of transfer capacity on the ML and through the Nova Scotia grid.

This report provides the results of a system planning study undertaken by Newfoundland and Labrador Hydro (NLH), ENL and Nova Scotia Power (NSPI). The objective of the study is to assess the interconnection of the ML to the Island Interconnected System and to determine high-level system reinforcements and/or control schemes to ensure that the Island Interconnected System remains stable following disturbances. Of particular interest is the minimum amount of curtailment of the ML for faults on the NL system and if additional reactive power (VAR) support in the form of shunt capacitor banks would improve the overall system response and reduce the amount of curtailment.

The scope of the study includes the modeling and analysis of the transmission systems in both NL and the Northeast Power Coordination Council (NPCC) footprint. The study includes an analysis of system stability during transient events with consideration of reactive power requirements for the ML.

The transient stability analysis was completed using Version 32 of PSS®E software from Siemens PTI.

2 EARLY NLH SYSTEM PLANNING INTERCONNECTION STUDIES

A number of system integration studies have been completed by the NLH System Planning Department to help understand the implications of connecting the Island Interconnected System to Labrador via the Labrador Island Link LCC HVdc transmission system (LIL) at Soldiers Pond (SOP) and the Maritime Link VSC HVdc transmission system (ML) at Bottom Brook (BBK). The studies include both power system steady state and dynamic analysis completed using Siemens PTI Power System Simulator for Engineers (PSS®E) Version 32. A copy of the reports has been included in Appendix A and B. The reports are summarized below.

2.1 TECHNICAL NOTE: BOTTOM BROOK VSC EXPORT LIMITS – MARITIME LINK RUNBACK SUMMARY (SEPTEMBER 25, 2013) – RELEASED NOVEMBER 19, 2013

The purpose of this load flow study was to analyze the impact of transferring up to 500 MW of export power over the Maritime Link under a number of system conditions following a single contingency outage (N-1) to transmission equipment. The approach would determine generation and transmission limitations and identify system upgrades to support the interconnection. A total of 19 PSS®E base case load flow scenarios, which were designed to simulate worst case operating configurations for the newly interconnected transmission system, were studied. The cases were intended to stress transmission corridors and determine system operating limits. The base cases varied import power orders on the LIL, export power orders on the ML, system load (light, intermediate, winter peak) and Island generation dispatch between economic, minimum and maximum.

The study assumed the following system configuration and upgrades:

1. Holyrood thermal units G1 and G2 are decommissioned
2. Holyrood thermal unit G3 has been converted to a synchronous condenser.
3. A new 60 MW/127 MVA aero-derivative combustion turbine is installed at Holyrood.
4. 230 kV transmission line TL201 between Western Avalon and Hardwoods has been routed through the new SOPTS and is divided into two transmission lines, TL201 (WAV-SOP) and TL266 (SOP-HWD).

5. 230 kV transmission line TL217 between Western Avalon and Holyrood has been routed through the new SOPTS and is divided into two transmission lines, TL217 (WAV-SOP) and TL265 (SOP-HRD).
6. 230 kV transmission line TL242 between Holyrood and Hardwoods has been routed through the new SOPTS and is divided into two transmission lines, TL242 (SOP-HWD) and TL268 (SOP-HRD).
7. 230 kV transmission line TL218 (Holyrood to Oxen Pond) is not routed through SOPTS.
8. A new 230 kV transmission line TL267 is in service connecting Bay d'Espoir to Western Avalon.
9. A new 230 kV transmission line TL269 is in service connecting Granite Canal to Bottom Brook.
10. TL201 (WAV-SOP) has been rebuilt to the NLH standard 3" ice load steel tower design supporting 804 kcmil AASCR/TW conductor. Line thermal capacity has been calculated at 80°C providing for RATEA/B/C[1] ratings of 355.8/411.5/459.6 MVA.
11. 230 kV transmission line TL228 between Buchans and Massey Drive has been uprated to a hot conductor temperature of 55°C.

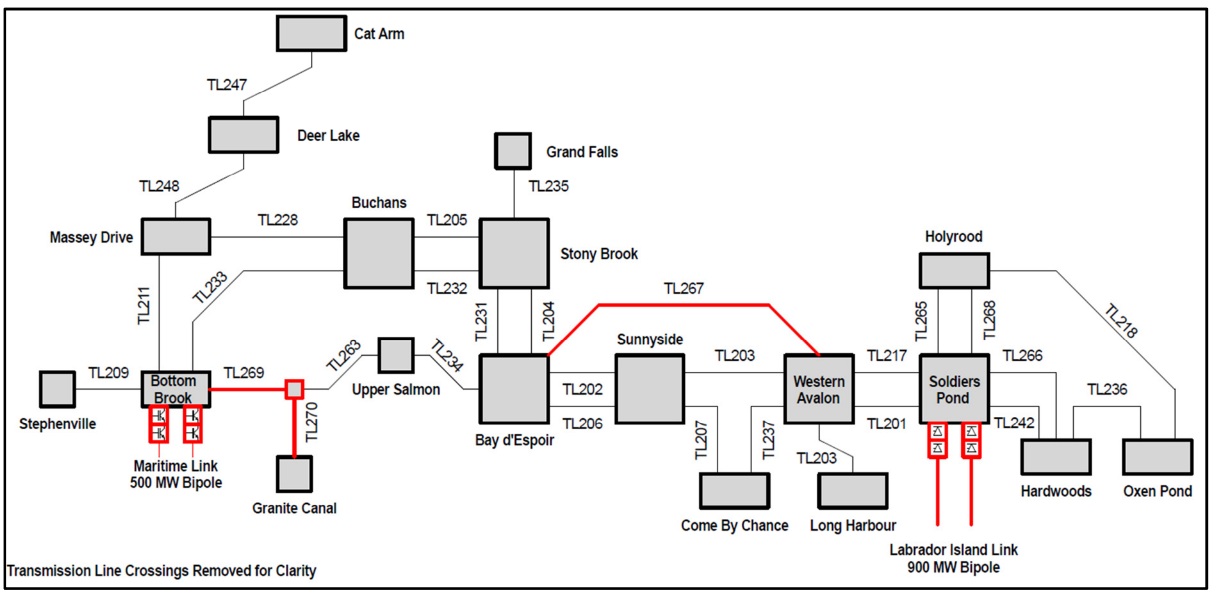

Figure 1: Island Interconnected 230 kV Transmission System with HVdc Interconnected

[1] Rate A/B/C refer to line ratings for ambient temperatures of 30°C/15°C/0°C.

2.1.1 LOAD FLOW ANALYSIS

For the purposes of the analysis, three base cases were studied in detail (BC7, BC10, BC13) to identify transmission element overloads and bus voltage violations with all elements in service and under single contingency outages (N-1). These cases were selected to cover all contingencies for spring/fall and summer operating conditions for Island loads ranging from 420 MW to 1100 MW. Earlier studies identified these as stress cases for the bulk transmission system connecting SOP to BBK, requiring adjustments in import power over the LIL and export power on the ML.

2.1.2 MARITIME LINK VSC RUNBACKS – SPS DESIGN

In the event of transmission line overloads or unacceptable bus voltages, the ML and LIL would be run back to maintain Island hydro dispatch while clearing the violation. This would provide the highest level of system stability following a transmission element outage as both converter stations can respond much quicker than the governors on the Island hydro units. The results from this load flow analysis forms the basis of the Special Protection System (SPS) design which is required to protect the bulk 230 kV transmission system in the event a transmission line element is out of service.

2.1.3 EMERA/NALCOR ENERGY CONTRACTUAL OBLIGATIONS – FIRM EXPORTS

Nalcor Energy has contractual obligations to Emera to provided approximately 168 MW and 0.98 TWh (less losses) measured at the MFA rectifier commutating bus, to customers in Nova Scotia. The remaining capacity will be used by Nalcor to export power into other markets. The Island Interconnected system has been designed to deliver 158 MW at the Bottom Brook ac commutating bus for all operating conditions and single contingency outages. Exceptions are major events on the Labrador Island Link (LIL). Complete curtailment of the Emera block of energy is required for the permanent loss of the LIL pole or bipole.

Following a permanent loss of the bipole, NLH plans to schedule import power from Nova Scotia over the ML to supply load shed due to operation of the Island UFLS protection scheme. A loss of a pole would force the healthy pole to ramp up to 2.0 p.u. current, importing 900 MW at the rectifier end for 10 minutes. This would give operators time to start up standby generation and prevent Island UFLS provided the ML has been curtailed.

After 10 minutes the healthy pole would ramp down to 1.5 p.u. current importing up to 675 MW at the rectifier.

2.1.4 ML EXPORT POWER LIMITATIONS

ML export power is limited by hydro generating capacity during the winter months, however under lighter systems loads during the spring, summer and fall operating periods additional power is available for export. In these cases, the system has been designed to deliver a firm capacity of 250 MW for a loss of any single transmission line element. This limit is established by the firm transfer capacity of transmission lines west of BDE for the loss of a single transmission element. Specifically, this worst case export occurs for loss of TL233 between Buchans and Bottom Brook during a summer day with flows limited by the thermal line rating of TL228 which connects Buchans with Massey Drive.

With all lines in service, the exports are limited to 470 MW in the summer due to the thermal rating of TL228. The VSC rated transfer capacity of 500 MW can be exported under spring/fall operating conditions with all lines in service.

2.1.5 SECONDARY ENERGY SALES

Export power orders above the firm export power limit of 250 MW will be curtailed in the event of a contingency outage on the Island's ac transmission system. An SPS or runback scheme will be designed to protect the bulk 230 kV transmission system when the Maritime Link is operating above 250 MW by automatically running back the ML and subsequently LIL following a transmission element outage. The system will monitor breaker status and power flows on each identified transmission line to determine the required runback power order.

2.1.6 MAXIMUM ML EXPORT RESULTS (N-1)

A comprehensive steady state analysis was completed to determine the maximum export limits for single contingency outages on the Island Interconnected system during off peak operating conditions. The results are found in section 2.1.6.1 to 2.1.6.3.

2.1.6.1 Spring/Fall Operating Conditions (Base Case 7 – BC7)

BC7 is a base case developed to simulate typical spring and fall (shoulder period) operating conditions on the Island Interconnected System with an intermediate load of 1100 MW and economic Island hydro dispatch. The results of the contingency analysis for this case also cover BC5 and BC6. Table 1 summarizes the maximum export power orders on the ML for each single contingency line outage.

Table 1: Spring/Fall Operating Conditions - Maximum Export

Operating Condition	Contingency	LIL Import (MW)	ML Export (MW)	Comments
Spring/Fall Intermediate (1100 MW)	TL211	828	443	Export Limited by TL233
	TL233	828	373	Export Limited by TL228
	TL228	828	470	Export limited by TL233
	TL232	828	407	Export Limited by TL205
	TL234	828	496	Export Limited by TL211
	TL263*	828	423	Export Limited by TL211
	TL269*	828	392	Minimal Acceptable Voltage at Buchans TS

Assumptions: TL228 is permitted to operate at 55°C, TL201/TL242 uprated to 80°C, +/-250 MVAR available at BBK

***System is VAR Limited - Potential Voltage Collapse**

2.1.6.2 Summer Day Operating Conditions (Base Case 10 – BC10)

BC10 is a base case developed to simulate a typical summer day operating conditions on the Island Interconnected System with a light load of 700 MW and economic Island hydro dispatch. The results of the contingency analysis for this case also cover BC8 and BC9. Table 2 summarizes the maximum export power orders on the ML for each single contingency line outage.

Table 2: Summer Day Operating Conditions - Maximum Export

Operating Conditions	Contingency	LIL Import (MW)	ML Export (MW)	Comments
Summer Day Light (700 MW)	N-0	825	470	Export Limited by TL228
	TL211	825	329	Export limited by TL233
	TL233	530	250	Export Limited by TL211
	TL228	624	305	Export Limited by TL233
	TL217	730	391	Export Limited by TL201 and BDE Gen. Dispatch
	TL201	718	383	Export Limited by TL217 and BDE Gen. Dispatch
	TL205	707	378	Export limited by TL232
	TL232	571	262	Export Limited TL205
	TL231	702	371	Export limited by TL204
	TL204	704	372	Export limited by TL231
	TL234	708	377	Export limited by TL233
	TL263*	633	310	Export Limited by TL228
	TL269*	607	284	Export limited by TL228
	TL237	794	446	Export Limited by TL203 and BDE Gen. Dispatch
	TL247	804	420	Export limited by TL228
	TL248	781	402	Export limited by TL228

Assumptions: TL228 is permitted to operate at 55°C, TL201/TL242 uprated to 80°C, +/-250 MVAR available at BBK
***System is VAR Limited - Potential Voltage Collapse**

2.1.6.3 Summer Night Operating Conditions (Base Case 13 – BC13)

BC13 is a base case developed to simulate a typical summer night operating conditions on the Island Interconnected System with an extreme light load of 420 MW and minimum Island hydro dispatch. The results of the contingency analysis for this case also cover BC11 and BC12. Table 3 summarizes the maximum export power orders on the ML for each single contingency line outage.

Table 3: Summer Night Operating Conditions - Maximum Export

Operating Conditions	Contingency	LIL Import (MW)	ML Export (MW)	Comments
Summer Night Extreme Light (420 MW)	TL233	435	288	Export Limited by TL211
	TL232	435	301	Export Limited TL205

Assumptions: TL228 is permitted to operate at 55°C, TL201/TL242 uprated to 80°C, +/-250 MVAR available at BBK
***System is VAR Limited - Potential Voltage Collapse**

2.1.7 ML RUNBACK SUMMARY

The results from the steady state load flow analysis determine the maximum export limits for single contingency outages on the Island Interconnected System during off peak operating conditions. These maximums will be used as a basis for the Maritime Link SPS or runback scheme design. Table 4 is a summary table which clearly identifies the bulk 230 kV transmission lines that must be monitored by the ML runback scheme with the shaded blocks indicating the time of the year in which the contingency of the specified line will require a runback of the VSC converter. The values in each block indicate the maximum export power order (MW) on the ML which will become the runback power order following the line outage.

A number of contingencies during the summer months require the runback of the Labrador Island Link (LIL) to clear transmission line thermal overloads. These runback values have been marked with a star in the table. Outages to TL201, TL217 and TL237 are found to overload transmission lines between SOP and BDE which can only be cleared by reducing the power order of the LIL. For the purposes of this analysis the system operating philosophy was maintained and both HVdc links ramped back to maintain Island hydro generation dispatch. The maximum power order listed for these contingencies assume Island hydro generation is maintained and not maximized. Therefore, the maximum export for these contingencies is dependent on the Island hydro dispatch. Further system dynamic studies are required to establish limits on the amount of load the hydro units can pick up and maintain stable operation. The results from these studies may impact the maximum export values shown in this table for these cases.

Table 4: ML Maximum Export Summary

Contingency	Required Runback Power Order (MW)			
	Winter	**Spring/Fall**	**Summer Day**	**Summer Night**
LIL Bipole	0			
LIL Pole	0			
TL201			383*	
TL204			372	
TL205			378	
TL211		443	329	
TL217			391*	
TL228		470	305	
TL231			371	
TL232		407	262	301
TL233		373	250	288
TL234		496	377	
TL237			446*	
TL247			420	
TL248			402	
TL263		423	310	
TL269		392	284	
Average		**429**	**334**	**295**

**Export is Dependent on Island Generation Dispatch*

A copy of the above referenced report can be found in Appendix A.

2.2 MARITIME LINK PRELIMINARY INTERCONNECTION STUDY (JULY 2014) – RELEASED AUGUEST 13, 2014

The purpose of this transient stability study was to determine potential high-level power system reinforcements and/or control schemes required for the interconnection of the ML to Island Interconnected System to maintain stable operation following power system disturbances. The scope of the study includes the detailed modelling of the Island Interconnected System and the Labrador Interconnected System. The transmission systems have been approximated using equivalent power system representations at the interface busses at Montagnais (Québec) and Woodbine (Nova Scotia).

This study builds on the steady state load flow analysis completed by NLH's System Planning Department: "Bottom Brook VSC Export Limits – Maritime Link Runback Summary", completed in 2013 which is summarized in section 2.1 and found in Appendix A of this report.

The transient stability analysis was completed using Version 32 of PSS®E software from Siemens PTI.

This study has assumed the same power system upgrades have been performed as the steady state load flow study in Section Technical Note: Bottom Brook VSC Export Limits – Maritime LInk Runback Summary (September 25, 2013) – Released November 19, 20132.1. The overall study assumptions of this report as it relates to power system operation are identical to those outlined in Section 3 of this report. System performance of this study is measured against the NLH System Planning Criteria as specified in Section 4.

2.2.1 BASE CASES

For the purposes of this study a set of 11 base case PSS®E models were developed for the LIL integration studies. These cases provide insight into system operating details including the location of spinning reserve, whether it will be on the Island Interconnected System, in Labrador or in Nova Scotia. Table 5 provides a list of the base case scenarios used for this dynamic stability study, which details the system conditions (seasonal), island load and generation dispatch, LIL mode of operation and power order, and the ML mode of operation and power order.

Table 5: Dynamic Study Base Case Scenarios

Case	System Condition	Island Load (MW)	LIL Mode	LIL Power (MW)	Island Generation	ML Mode	ML Power (MW)
BC1	Heavy Load	1757	Bipole	830	1085	Bipole	158
BC2	Heavy Load	1588	Bipole	830	915	Bipole	158
BC3	Heavy Load	1594	Bipole	676	1075	Bipole	158
BC4	Heavy Load	1471	Monopole	396	1258	Bipole	182
BC5[2]	Heavy Load	1500	Offline	0	1258	Bipole	-250
BC6	Heavy Load	1415	Bipole	830	1085	Bipole	500
BC7	Intermediate Load	1261	Bipole	830	931	Bipole	500
BC8	Intermediate Load	1261	Bipole	676	1085	Bipole	500
BC9	Light Load	700	Bipole	830	370	Bipole	500
BC10	Light Load	700	Monopole	550	650	Bipole	500
BC11	Extreme Light Load	400	Bipole	415	335	Bipole	350

[2] Base Case 5 represents an extreme condition where the LIL bipole is out of service. Transient stability analysis was not performed for this mode of operation.

2.2.2 RESULTS OF DYNAMIC ANALYSIS

The transient stability of a transmission system refers to its ability to maintain synchronism following a severe power system disturbance such as a fault. For the purposes of this investigation, base case scenario simulations were subjected a list of worst case disturbances as found in the report. The results indicated a subset of the contingencies resulted in undesirable system performance such as instability, underfrequency load shedding (UFLS), or other violations to System Planning Criteria. The results for each contingency are found in Sections 2.2.2.1 to 2.2.2.6.

2.2.2.1 Faults at Bay d'Espoir

In peak load cases with maximum generation online within the Island Interconnected System, faults at BDE result in system instability. The scenarios are summarized in Table 6.

Table 6: Notable System Conditions Following Faults at BDE

Base Case	Contingency	System Condition
BC1	3Φ Fault at BDE, trip of TL202	Instability
BC1	3Φ Fault at BDE, trip of TL204	Instability
BC1	3Φ Fault at BDE, trip of TL234	Instability
BC1	3Φ Fault at BDE, trip of Generator	Instability
BC3	3Φ Fault at BDE, trip of TL202	Instability
BC3	3Φ Fault at BDE, trip of TL204	Instability
BC3	3Φ Fault at BDE, trip of TL234	Instability
BC3	3Φ Fault at BDE, trip of Generator	Instability

2.2.2.2 AC Transmission Line Faults in Western Newfoundland

Transient analysis indicates that ac faults at selected terminals stations in western Newfoundland will cause the reactive power output of the VSC converter in BBK to exceed the specified limit of 125 MVAR per pole. This was found to be the case in load flow scenarios where the ML was operating at its rated output of 500 MW. A list of these scenarios is provided in

Table 7: Notable Contingencies that Resulted in VSC Exceeding Reactive Capability and illustrated in the figures below. A runback of 250 MW on the ML for each contingency reduces the reactive power requirement below the rating.

Table 7: Notable Contingencies that Resulted in VSC Exceeding Reactive Capability

Base Case	Contingency	System Condition	ML Runback Required (MW)
BC6	3Φ Fault at BUC, trip of TL233	ML VSC Reactive Power capability exceeded	250
BC7	3Φ Fault at STB, trip of TL204	ML VSC Reactive Power capability exceeded	250
BC7	3Φ Fault at USL, trip of TL263	ML VSC Reactive Power capability exceeded	250
BC8	3Φ Fault at GCL, trip of TL263	ML VSC Reactive Power capability exceeded	250
BC9	3Φ Fault at MDR, trip of TL228	ML VSC Reactive Power capability exceeded	250

2.2.2.3 Temporary Bipole Faults (LIL)

In the event of a temporary bipole fault (or a monopole fault), undesirable system conditions were found for the scenarios listed in Table 8.

Table 8: Notable System Conditions Resulting from Temporary Bipole Faults (LIL)

Base Case	Contingency	System Condition	ML Runback Required (MW)
BC4	Temp. Monopole Fault (300ms)	LIL Commutation Failures	0
BC6	Temp. Bipole Fault (300ms)	UFLS	250
BC7	Temp. Bipole Fault (300ms)	UFLS	250
BC9	Temp. Bipole Fault (300ms)	UFLS	N/A
BC10	Temp. Monopole Fault (300ms)	LIL Commutation Failures	0

2.2.2.4 Permanent Pole Faults (LIL)

Analysis indicated that underfrequency load shedding and instability can result from the permanent loss of a pole on the LIL if no remedial action is taken with respect to ML export. These results are listed in Table 9.

Table 9: Notable Contingencies Resulting from Permanent Pole Faults (LIL)

Base Case	Contingency	System Condition	Runback Required (MW)
BC1	Permanent Pole Fault	UFLS	0*
BC2	Permanent Pole Fault	UFLS	0*
BC3	Permanent Pole Fault	UFLS	0*
BC4	Permanent Pole Fault	f < 58 Hz	0*
BC6	Permanent Pole Fault	UFLS	250
BC7	Permanent Pole Fault	UFLS	250
BC8	Permanent Pole Fault	UFLS	250
BC9	Permanent Pole Fault	UFLS	250
BC10	Permanent Pole Fault	Instability	N/A[3]

* The ML export power will be curtailed for any LIL pole/bipole faults.

[3] A runback of the ML does not alleviate the power system instability that occurs due to a permanent trip of a LIL HVdc pole. The updated ABB VSC PSS®E model alleviates this issue in later studies.

2.2.2.5 Loss of Generation within the Island Interconnected System

When the LIL is operating at or near rated capacity, the loss of generation within the Island Interconnected System results in UFLS. This was found to be the case for contingencies involving the loss of generation at USL, BDE, or the isolation of Cat Arm (CAT) generation during the tripping of TL248 and cross-tripping of TL247. These cases are listed in Table 10.

Table 10: Notable Conditions Resulting from Loss of Island Generation

Base Case	Contingency	System Condition	Runback Required (MW)
BC1	3Φ Fault @USL, Trip G1	UFLS	0
BC1	3Φ Fault @MDR, Trip TL248+TL247+CAT G1/G2	UFLS	0
BC1	3Φ Fault @BDE, Trip G7[4]	Instability	N/A
BC2	3Φ Fault @MDR, Trip TL248+TL247+CAT G1/G2	UFLS	0
BC2	3Φ Fault @BDE, Trip G7	UFLS	0
BC3	3Φ Fault @BDE, Trip G7[5]	Instability	0
BC4	3Φ Fault @MDR, Trip TL248+TL247+CAT G1/G2 UFLS	UFLS	0
BC6	3Φ Fault @USL, Trip G1	UFLS	250
BC6	3Φ Fault @MDR, Trip TL248+TL247+CAT G1/G2	UFLS	250
BC6	3Φ Fault @BDE, Trip G7	UFLS	250
BC7	3Φ Fault @USL, Trip G1	UFLS	250
BC7	3Φ Fault @BDE, Trip G7	UFLS	250
BC8	3Φ Fault @BDE, Trip G7	UFLS	250
BC9	3Φ Fault @USL, Trip G1	UFLS	250
BC9	3Φ Fault @MDR, Trip TL248+TL247+CAT G1/G2	UFLS	250
BC9	3Φ Fault @BDE, Trip G7	UFLS	250

[4] Covered in Section 2.2.2.1

[5] Covered in Section 1.1.1.4

2.2.2.6 Loss of a Synchronous Condenser at Soldiers Pond

As per Table 11, it was found that a three-phase fault at SOP followed by the tripping of a synchronous condenser in BC9 results in commutation failure during post-fault recovery of the HVdc voltage.

Table 11: Notable System Conditions Resulting from Loss of HISC at SOP

Base Case	Contingency	System Condition	ML Runback Required (MW)
BC9	3Φ Fault @SOP, Trip SC1	LIL Commutation Failure	250

In this case, the LIL and ML are operating at capacity, while the generation on the Island Interconnected Transmission System is reduced to approximately 370 MW. The loss of a synchronous condenser at SOP results in a deficit of reactive power, particularly as the export of 500 MW over the ML is not interrupted by the fault. A runback of the ML to 250 MW eliminates the LIL commutation failure for a loss of SC1 following a three-phase fault at SOP. The design of operating instructions should be developed in lieu of a runback on the ML, as the Island generation should not be permitted to dispatch at a low level. Too much reliance on the HVdc systems at SOP and BBK would impact performance of the Island Interconnected System following a system disturbance due to the lack of inertia on the system, short circuit level and reactive power support.

2.2.3 CONCLUSIONS

A transient stability analysis was performed to identify unacceptable conditions arising from disturbances within the Island Interconnected System. Recommendations for these conditions are listed in Table 12.

Table 12: Transient Stability Analysis - Summary

Contingency	Remedial Action
Faults at BDE	No Action – Accepted as an "Exceptional Contingency"
Faults at BBK, BUC, GCL, MDR, STB and USL	Curtailment of ML export to 250 MW
LIL Temporary Bipole Faults (350 ms)	Curtailment of ML export to 250 MW
LIL Permanent Pole Faults	Curtailment of ML export to 250 MW or 0 MW[6]
LIL Faults (Monopole Operation)	Curtailment of ML export to 0 MW
Loss of Island Generation	Curtailment of ML export to 250 MW or 0 MW.[7]
Loss of synchronous condenser at SOP	Development of Operating Instruction to avoid unacceptable system condition[8]

A copy of the above referenced report can be found in Appendix B.

[6] ML export power orders >250 MW are curtailed to 250 MW while export power orders <250 MW are curtailed to 0 MW (soft block).

[7] ML export power orders >250 MW are curtailed to 250 MW while export power orders <250 MW are curtailed to 0 MW (soft block).

[8] Unacceptable conditions were only observed for BC9.

3 ASSUMPTIONS

The analysis was performed using the following assumptions:

1. The Labrador-Island HVdc Link (LIL) is in service, along with all prerequisite upgrades to the Island Interconnected System, including:
   - A new 230 kV transmission line (TL267) between Bay d'Espoir Terminal Station (BDE) and Western Avalon Terminal Station (WAV).
   - A new 230 kV transmission line (TL269) between GCL and BBK.
   - A new 60 MW gas turbine is available at Holyrood (HRD) and is in service as a synchronous condenser. The generator is equivalent to a Brush BDAX 8-445ER.
   - Three 175 MW high-inertia synchronous condensers (HISCs) are in service at Soldiers Pond (SOP). For the purposes of this investigation, it is assumed that one of the three units is offline for maintenance[9].

2. Reserve for the Island Interconnected System is available either on the Island or in Labrador. The full capacity of the LIL is available to respond to transient events. When operating as a bipole, each pole can be adjusted to provide a power flow in the range between 45 MW and 450 MW. When operating as a monopole, power flow over the pole can be adjusted to anywhere in the range between 45 MW and 900[10] MW.

3. During transient events involving the LIL, the ML may be tripped to avoid instability or underfrequency load shedding within the Island Interconnected System.

4. There shall be no underfrequency load shedding for loss of a pole on the LIL while operating as a bipole. Underfrequency load shedding within the Island System is acceptable for loss of a pole when the LIL is in a monopole configuration. This assumes that the ML export power has been curtailed. As specified in "Hydro Operating Instruction T-068 - Guideline for Unit Maximum Loading", the loss of supply should not result in the loss of load set to trip at 58.0 Hz.

5. Following a temporary pole fault on the LIL, full power on that pole can be restored within 300 ms.

6. The ML has a specified reactive power limit of 125 MVAR per pole at the BBK 230 kV bus.

[9] It is assumed that all three HISCs are in service when the LIL is in monopole operation or out of service.

[10] The LIL is rated for 900 MW for 10 min and 675 MW continuous during monopolar operation.

7. The ML can curtail export to Nova Scotia within 750 ms of fault inception for bulk 230 kV transmission lines west of BDE.

4 SYSTEM PLANNING CRITERIA

The following list is provided as summary of Hydro's Transmission Planning Practices as accepted by the Public Utilities Board:

- Hydro's bulk transmission system[11] is planned to be capable of sustaining the single contingency loss of any transmission element without loss of system stability;
- In the event a transmission element is out of service, power flow in all other elements of the power system should be at or below normal rating;
- The Hydro system is planned to be able to sustain a successful single pole reclose for a line to ground fault based on the premise that all system generation is available;
- Transformer additions at all major terminal stations (i.e. two or more transformers per voltage class) are planned on the basis of being able to withstand the loss of the largest unit;
- For single transformer stations there is a back-up plan in place which utilizes NLH's and/or Newfoundland Power's mobile equipment to restore service;
- For normal operations, the system is planned on the basis that all voltages be maintained between 95% and 105%;
- For contingency or emergency situations voltages between 90% and 110% is considered acceptable; and
- For new terminal stations connected to the bulk system, Hydro's preferred bus arrangement is a breaker-and-one-half scheme. Where there are a limited number of elements, a ring bus arrangement is acceptable.

[11] Hydro's bulk transmission system on the Island of Newfoundland is generally considered to be the 230 kV transmission system and the underlying 138 kV transmission loops between connection points on the 230 kV system including Western Avalon to Holyrood and Deer Lake-Stony Brook-Sunnyside.

4.1 STEADY STATE ANALYSIS CRITERIA

For analysis of the Island Interconnected System with the HVdc connection to Labrador included, the following criteria are used to assess the need for system reinforcements:

- With a transmission element (line, transformer, synchronous condenser, shunt or series compensation device) is out of service, power flow in all other elements of the power system should be at or below normal rating;
- Transformer additions at all major terminal stations (i.e. two or more transformers per voltage class) are planned on the basis of being able to withstand the loss of the largest unit;
- For normal operations all voltages be maintained between 95% and 105%;
- For contingency or emergency situations all voltages be maintained between 90% and 110%; and
- Analysis will be conducted with one high inertia synchronous condenser out of service at Soldiers Pond.

4.2 TRANSIENT ANALYSIS CRITERIA

- System response shall be stable and well damped following a disturbance;

- System disturbances include:
  - Successful single pole reclosing on line to ground faults;
  - Unsuccessful single pole reclosing on line to ground faults;
  - Three phase faults except a three phase fault on the Bay d'Espoir 230 kV bus with tripping of a 230 kV transmission line;
  - Loss of the largest generator on line on the Island System with and without fault;
  - Line to ground or three phase fault with tripping of a synchronous condenser;
  - Temporary pole fault;
  - Permanent pole fault; and
  - Temporary bipole fault.

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

- Post fault system frequencies shall not drop below 59 Hz;

- Under frequency load shedding:
  - shall not occur for loss of island generation with the HVdc link in service;
  - shall not occur for permanent loss of HVdc pole;
  - shall not occur for a temporary bipole outage; and
  - shall be controlled for a permanent bipole outage.

- There shall be no commutation failures of the HVdc link during post fault recovery.

5 BASE CASES

Analysis was performed using system models that were developed for LIL integration studies. These models reflect system conditions where the Island Interconnected System is connected to Labrador via the LIL and to Nova Scotia via the ML.

In the base cases, the LIL was modeled using the PSS®E CDC4T Line-Commutated Converter (LCC) model with a PAU1XT frequency controller. The ML was modeled as a Voltage Source Converter (VSC) system using Version 2.0.0 of the HVdc Light Detailed Model which was developed for ABB's Generation 4 VSC control system.

Eight base cases were considered for this analysis. The base cases were developed to assess the impacts of the following system variations:

- System loading conditions (i.e. heavy, intermediate, and extreme light)
- Island dispatch (i.e. maximum generation, economic dispatch, or minimum generation)
- Import to the Island Interconnected System over the LIL (i.e. 0 MW to 830 MW)
- Export over the ML (i.e. 0 MW to 500 MW)

The base cases are listed in Table 13. Positive power values for the LIL and ML indicate import from Labrador to the Island and Newfoundland to Nova Scotia respectively. Only base case 8004 studied reverse power on the ML in the event of a series of major outages to the LIL or permanent bipole outage. Load flow plots for the base cases are provided in Appendix C.

Table 14 provides the Hydro's Island Interconnected System generation capacities used in preparing the base cases.

Table 13 – Base Case Scenarios Studied

Case	System Condition	Island Load (MW)	LIL Operating Mode	LIL Power @ MFA (MW)	Island Generation (MW)	ML Operating Mode	ML Power @ BBK (MW)
8001	Peak Load	1757	Bipole	900	1085	Bipole	158
8002	Peak Load	1588	Bipole	677	915	Bipole	158
8003	Peak Load	1594	Bipole	900	1075	Bipole	350
8004[12]	Peak Load	1471	OFF	0	1258	Reverse Power	-310
8005	Intermediate Load	1261	Bipole	676	1085	Bipole	158
8006	Intermediate Load	1261	Bipole	900	1085	Bipole	500
8007	Extreme Light Load	400	Bipole	415	335	Bipole	337

[12] Base Case 8004 simulates an extreme case where the LIL has been forced out of service due to a permanent bipole fault during the winter peak heating load season. In this case NLH will import up to 310 MW of power at BBK from NS to supply the maximum amount of customer load. It should be noted that this case can be considered an N-2 contingency event prior to applying additional disturbances to the system.

Table 14 – NLH Hydro System Capacity

Source	Rated Capacity (MW)	Comments
Hydro		
Bay d'Espoir	604	Bay d'Espoir generation is calculated as (6 x 75MW) + (1 x 154 MW). Units 1 to 6 at Bay d'Espoir have a sustained capacity of 73 MW per unit and a peak capacity of75 MW. (6 x 73 + 154 = 592 MW)
Cat Arm	127	2 x 63.5 MW
Upper Salmon	84	
Hinds Lake	75	
Granite Canal	40	
Paradise River	8	
Snook's, Venam's, Roddickton	0	For load flow analysis, the value of generation is netted out with load that it supplies
Subtotal Hydro	**938**	
Non-Utility/PPA		
Star Lake	15	Nameplate rating
Exploits	90.8	Grand Falls + Bishop's Falls
Corner Brook Cogen	15	
Rattle Brook	4	
St. Lawrence	11	The wind farms are not considered in capacity planning due to the variability of wind but are included in this analysis to assess transient response of the wind farms to system contingencies. For the purposes of this investigation, wind farms are generating at approximately 40% of rated capacity.
Fermeuse	11	
Subtotal NUG/PPA	**146.8**	
Total capacity	**1084.8 (1085)**	
Standby Generation		
Holyrood CT	60	
Hardwoods CT	50	
Stephenville CT	50	
Hawke's Bay Diesel	5	
St. Anthony Diesel	9.7	
Total Standby capacity	**114.7**	
Island Spinning Reserve Requirement	**154**	**Largest unit on system with Holyrood offline**

6 RESULTS OF DYNAMIC ANALYSIS

The transient stability of a transmission system refers to its ability to maintain synchronism following a severe disturbance such as a fault. For the purposes of this investigation, base cases were subjected to the disturbances listed in Appendix C.

It was found that a subset of the contingencies resulted in undesirable system performance such as instability, underfrequency load shedding (UFLS), or other violations to System Planning Criteria. These contingencies are categorized as follows:

- Faults at Bay d'Espoir
- AC Transmission Line Faults in Western Newfoundland
- Temporary Bipole Faults
- Permanent Pole Faults
- Loss of Generation within the Island System
- Loss of a Synchronous Condenser at Soldiers Pond

These cases are described in the sections below.

6.1 FAULTS AT BAY D'ESPOIR

In peak load cases with maximum import over the LIL and high levels of Island generation, faults at Bay d'Espoir (BDE) result in underfrequency load shedding events or unsatisfactory post fault recovery voltages at Buchans Terminal Station (BUCTS). The scenarios are summarized in Table 15.

Table 15 – Notable System Conditions Following Faults at BDE

Base Case	Contingency	System Condition
8001	3Φ Fault at BDE, Trip of BDE Unit 7	UFLS[13]
8001	Trip of BDE Unit 7	UFLS[12]
8006	3Φ Fault at BDE, Trip of TL202	Angular Stability, Buchans Terminal Station (BUCTS) 230 kV bus voltage recovery <0.70 pu.
8006	3Φ Fault at BDE, Trip of TL204	Angular Stability, BUCTS 230 kV bus voltage recovery <0.70 pu.
8006	3Φ Fault at BDE, Trip of TL234	Angular Stability, BUCTS 230 kV bus voltage recovery <0.70 pu.
8006	3Φ Fault at BDE, Trip of Unit 7	UFLS[12]
8006	Trip of Unit 7	UFLS[12]

It should be noted that NLH has classified faults at Bay d'Espoir as "exceptional contingencies" and it has been accepted that their occurrence under heavy load conditions may lead to system instability or a violation of the NLH Transmission Planning Criteria. However, this study will identify if any transmission system additions will improve system response for faults at BDE. UFLS occurs for loss of BDE Unit 7 for base cases 8001 and 8006 as generation on the Island is at a maximum with zero spinning reserve and the LIL is importing its rated power. As a result, unless export is curtailed on the ML, the frequency on the Island will decay and activate NLH's existing UFLS scheme to maintain system frequency. The scenario demonstrates a requirement to carry reserve on the LIL for loss of generation on the Island Interconnected System.

[13] UFLS occurs for loss of BDE Unit G7 (154 MW) due to lack of spinning reserve on the Island and carried on the LIL. The LIL Power Frequency Controller (PFC) is not able to act on a reduction of system frequency due to loss of generation in base cases 8001 and 8006. These cases demonstrate the requirement to maintain reserve on the LIL for loss of generation on the Island Interconnected System.

For the majority of disturbances on the 230 kV transmission lines connecting BDE east to Sunnyside (SSD) and west to Stony Brook (STB) and Upper Salmon (USL), a runback of the ML to a specified amount would improve system performance and meet NLH's System Planning Criteria.

In previous dynamic studies, *Maritime Link Preliminary Interconnection Study – July 2014* (See Appendix B), using an earlier version of ABB's HVdc light VSC PSS®E model it was determined that three phase faults close in to BDE on 230 kV transmission lines would result in angular instability.

ABB's new Gen. 4 PSS®E model prevents the angular stability issues previously experienced for three phase faults close in to BDE; however voltage recovery issues are prevalent. The following sections will study the system response after a three phase fault at BDE and a trip of a 230 kV transmission circuit.

6.1.1 3-PHASE FAULT ON TL202/TL206

Three-phase faults close in to BDE which would trip one of the parallel circuits TL202 or TL206 between BDE and SSD would result in a stable ac system response as shown in Figure 2-Figure 5. However, it should be noted that the recovery voltage at BUC drops below 0.70 pu as shown in Figure 6. Without a shunt capacitor bank installed at BBK a 750ms runback of the ML would not prevent the <0.70 pu recovery voltage at BUC as shown in Figure 7. Figure 8 illustrates that a runback of 250 MW in 200ms will improve the voltage recovery at BUC to stay above 0.70 pu. Runback of the ML is not required with the installation of a 50 MVAR shunt capacitor bank at BBK as shown in Figure 9.

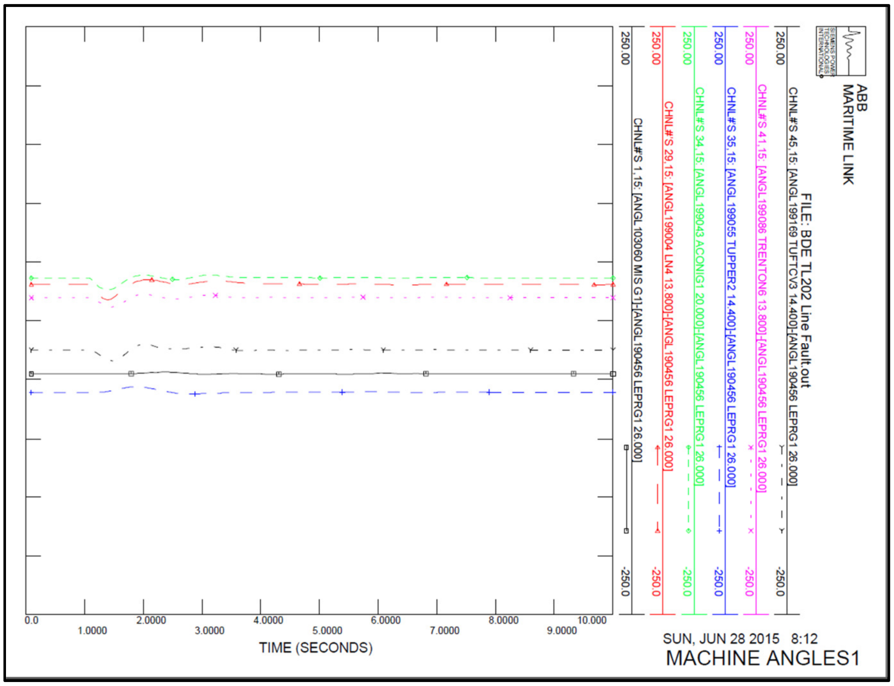

Figure 2: BC 8006 - BDE TL202 3-Phase Fault – No Runback

Nova Scotia Machine Relative Rotor Angles

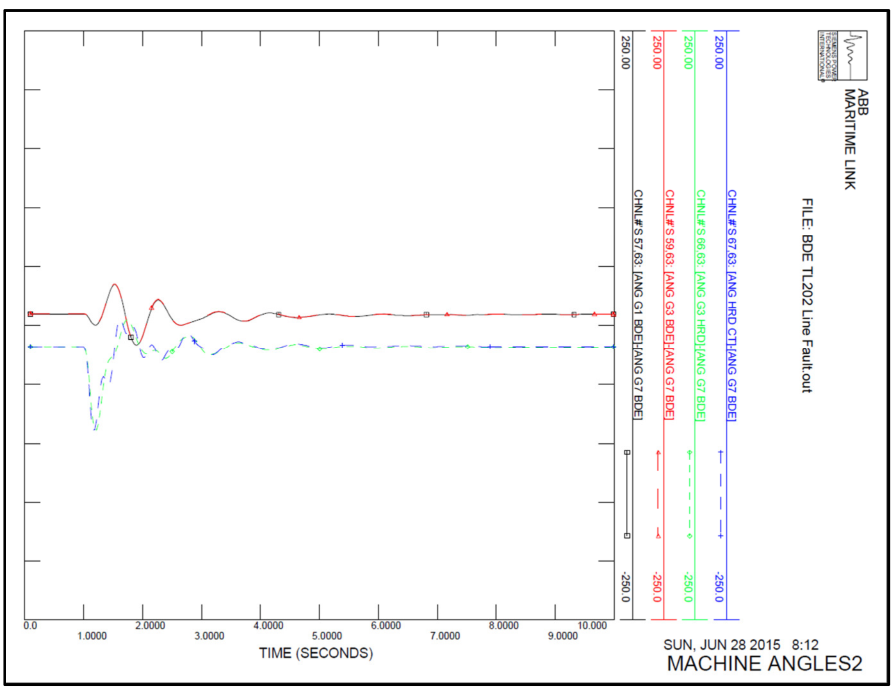

Figure 3: BC 8006 - BDE TL202 3-Phase Fault – No Runback

HRD and BDE Machine Relative Rotor Angles

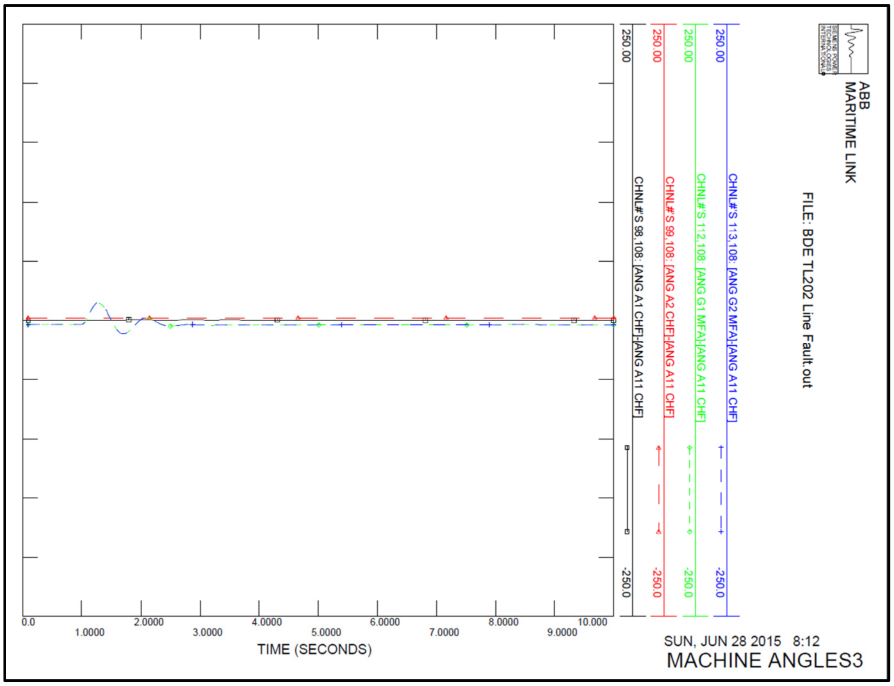

Figure 4: BC 8006 - BDE TL202 3-Phase Fault – No Runback CHF and MFA Machine Relative Rotor Angles

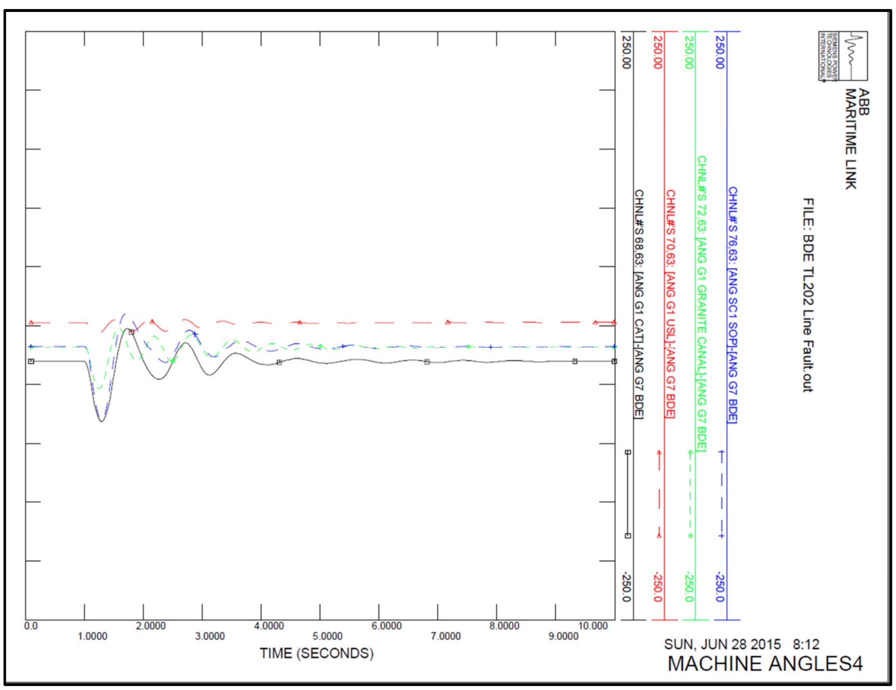

Figure 5: BC 8006 - BDE TL202 3-Phase Fault – No Runback SOP, GCL, USL and CAT Machine Relative Rotor Angles

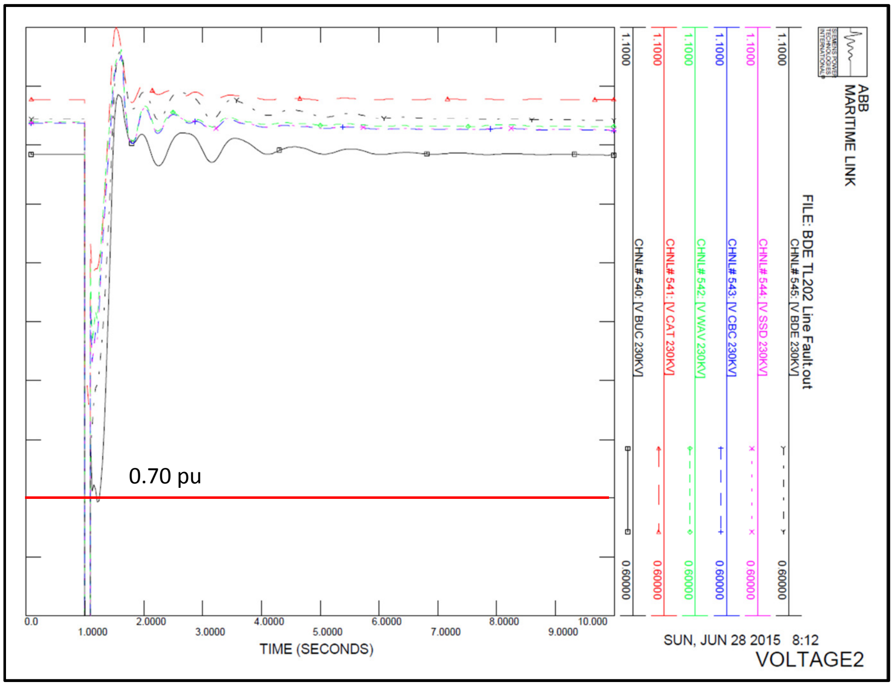

Figure 6: BC 8006 - BDE TL202 3-Phase Fault – No Runback SSD, CBC, WAV, CAT, BUC Bus Voltages

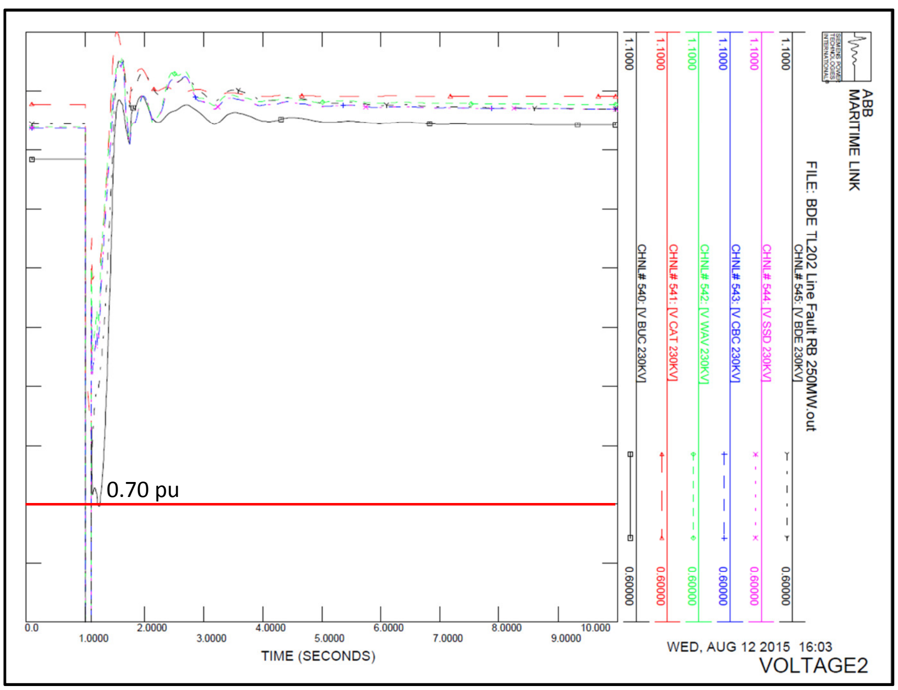

Figure 7: Base Case 8006 - BDE TL202 3-Phase Fault – 250 MW ML Runback in 750ms

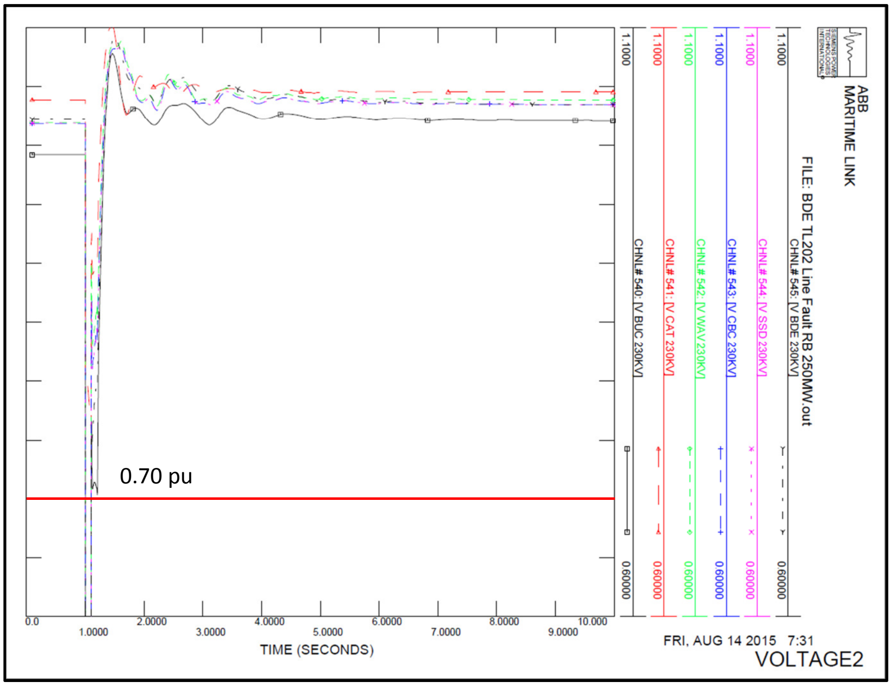

Figure 8 - Base Case 8006 - BDE TL202 3-Phase Fault – 250 MW ML Runback in 200ms

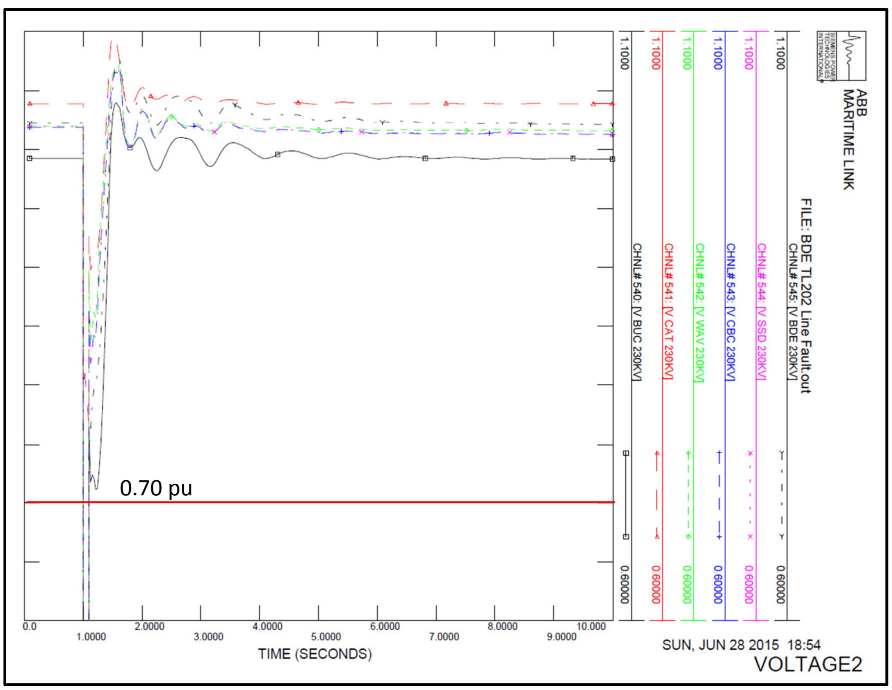

Figure 9: Base Case 8006 - BDE TL202 3-Phase Fault
50 MVAR Shunt Capacitor Bank Installed at BBK – No ML Runback

6.1.2 3-PHASE FAULT ON TL204/TL231

Three-phase faults close into BDE which would trip one of the parallel circuits TL204 or TL231 between BDE and STB would result in a stable ac system response as shown in Figure 10-Figure 13. Despite the stable system response, the recovery voltage at BUC drops below 0.70 pu as shown in Figure 14. Without a shunt capacitor bank installed at BBK a 750ms runback of the ML would not prevent the <0.70 pu recovery voltage at BUC as shown in Figure 15. Figure 16 illustrates a runback of 250 MW in 150ms which improves the voltage recovery at BUC to remain above 0.70 pu.

Runback of the ML is not required with the installation of 50 MVAR shunt capacitor bank at BBK. Figure 17 illustrates the system recovery voltages with a shunt capacitor bank installed at BBK.

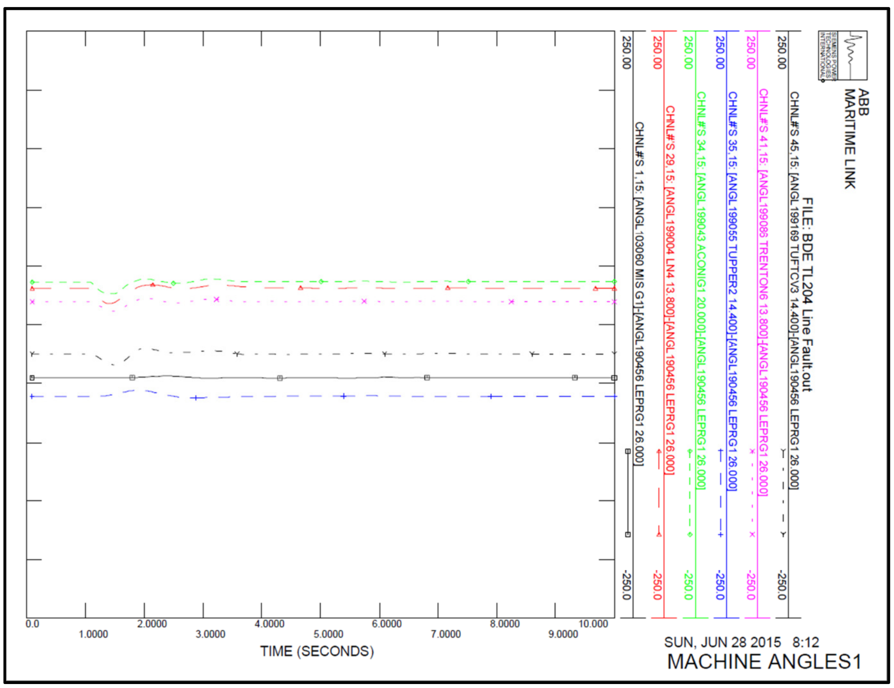

Figure 10: BC 8006 - BDE TL204 3-Phase Fault – No Runback
Nova Scotia Machine Relative Rotor Angles

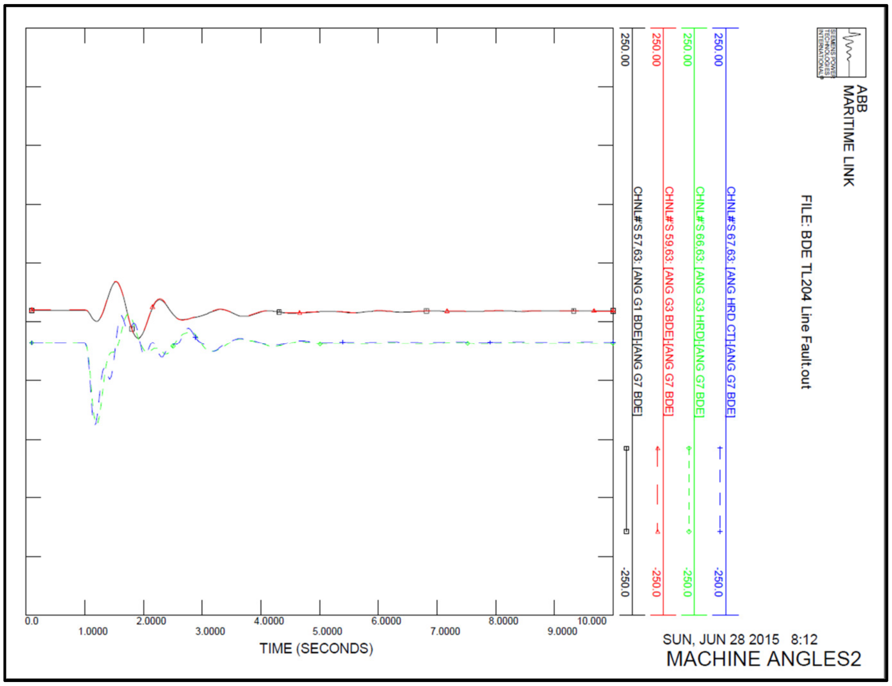

Figure 11: BC 8006 - BDE TL204 3-Phase Fault – No Runback
HRD and BDE Machine Relative Rotor Angles

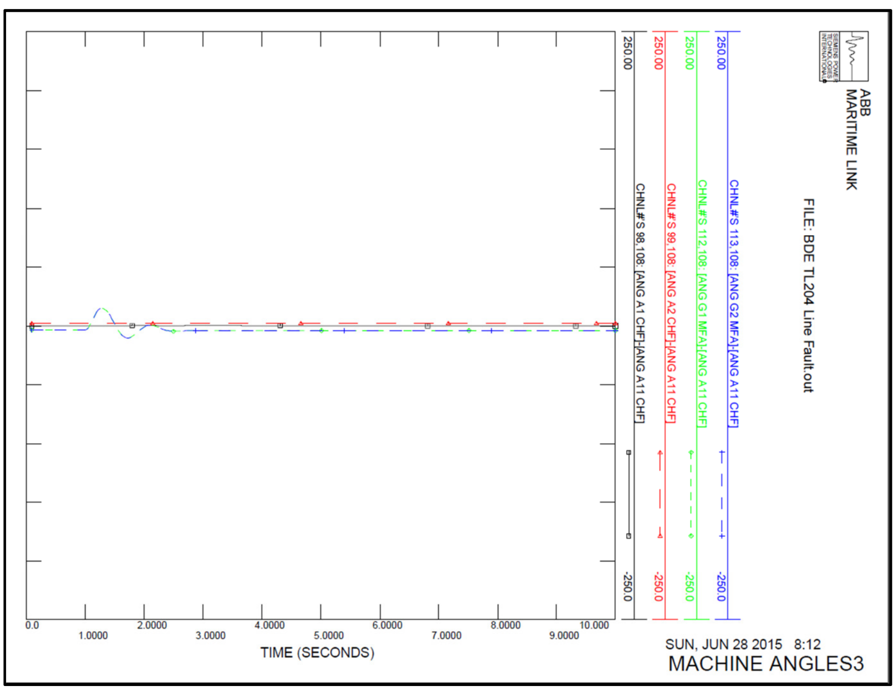

Figure 12: BC 8006 - BDE TL204 3-Phase Fault – No Runback
CHF and MFA Machine Relative Rotor Angles

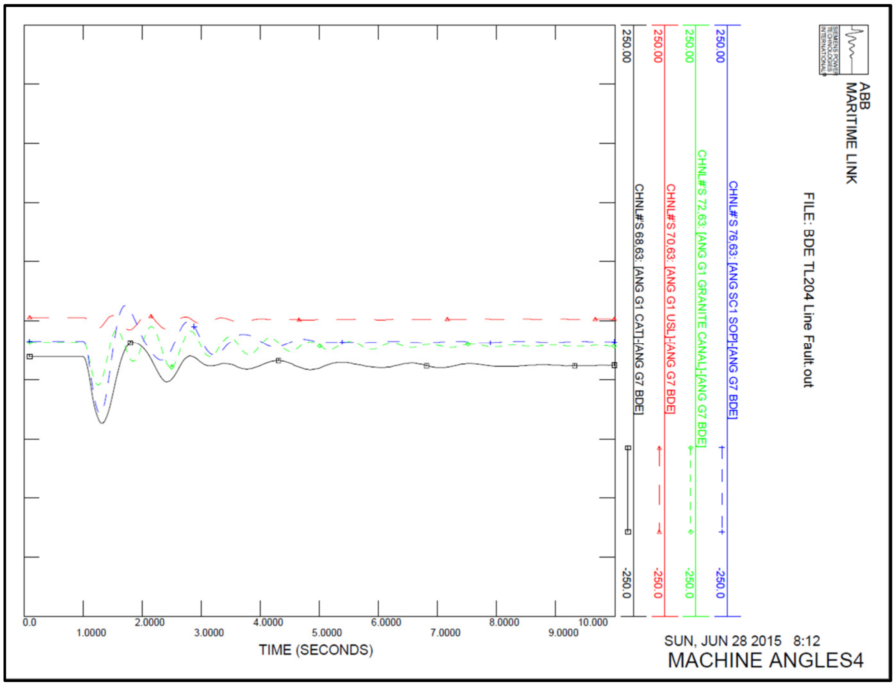

Figure 13: BC 8006 - BDE TL204 3-Phase Fault – No Runback
SOP, GCL, USL and CAT Machine Relative Rotor Angles

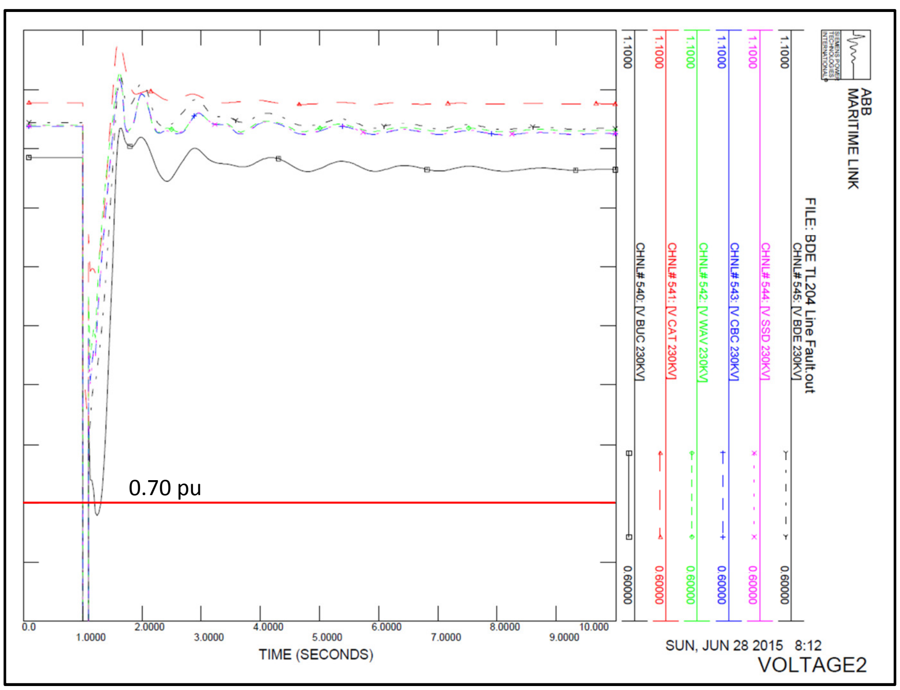

Figure 14: BC 8006 - BDE TL204 3-Phase Fault – No Runback
SSD, CBC, WAV, CAT, BUC Bus Voltages

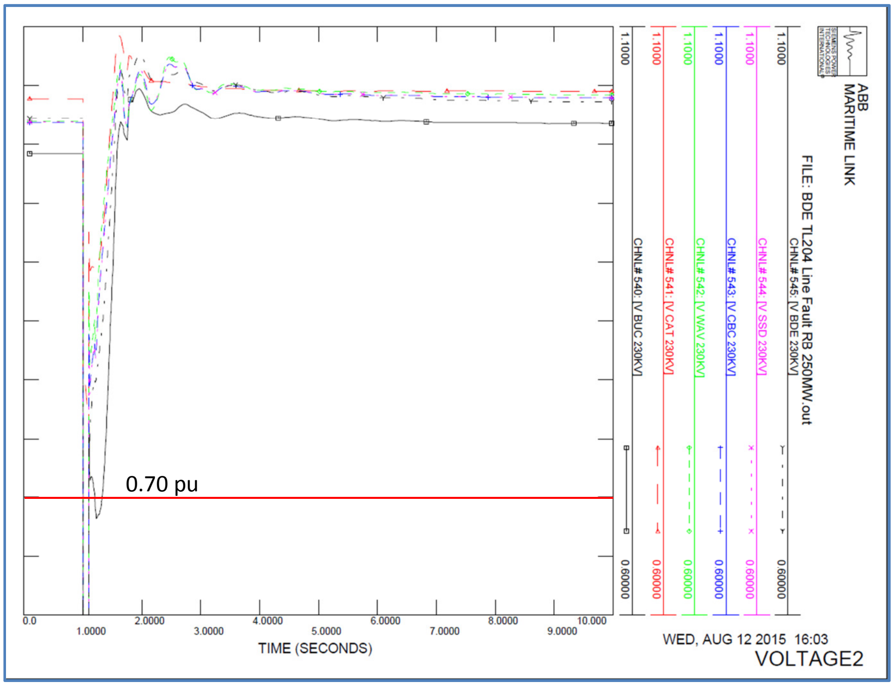

Figure 15: Base Case 8006 - BDE TL204 3-Phase Fault – 250 MW ML Runback in 750ms

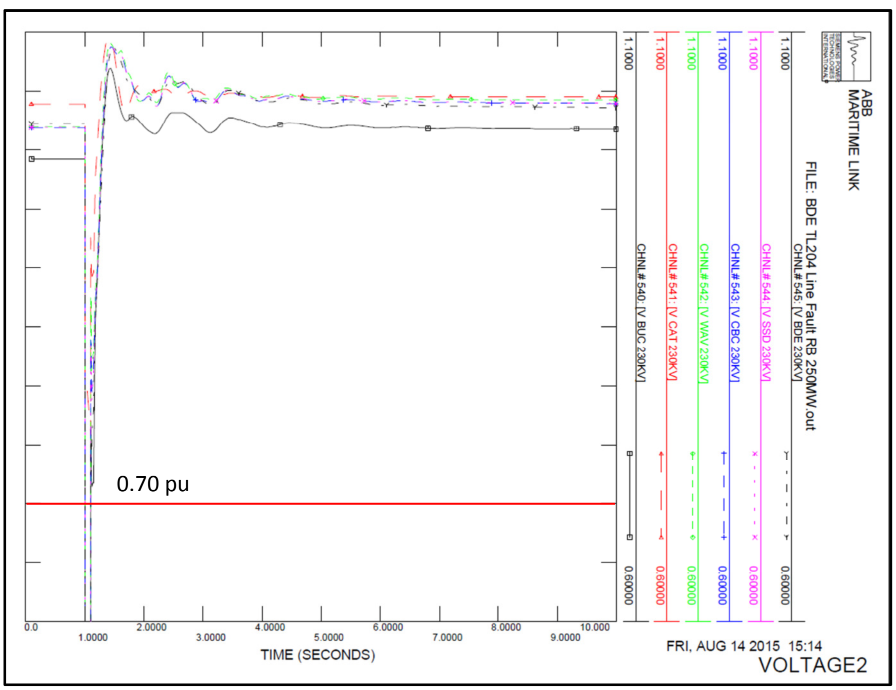

Figure 16: Base Case 8006 - BDE TL204 3-Phase Fault – 250 MW ML Runback in 150ms

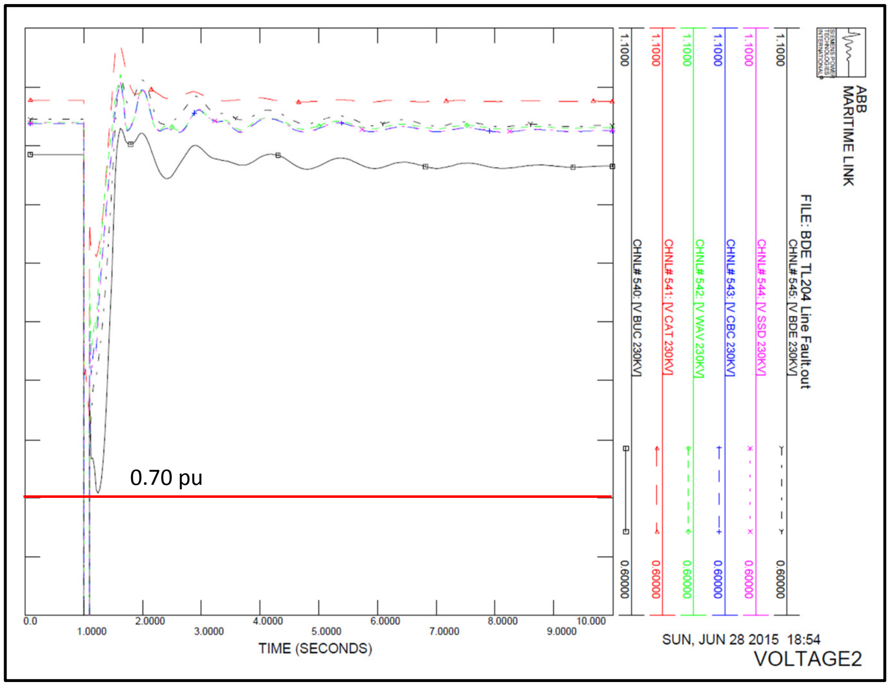

Figure 17: Base Case 8006 - BDE TL204 3-Phase Fault
50 MVAR Shunt Capacitor Bank Installed at BBK – No ML Runback

6.1.3 3-PHASE FAULT ON TL234

Three-phase faults close in to BDE which trip TL234 between BDE and USL will result in a stable machine response on the Island Interconnected System. As shown in Figure 18-Figure 21 the response results in many machine angle and voltage oscillations which become positively damped within 30 seconds. Runback of the ML is not required in this case to maintain system stability. However, further analysis was completed with the installation of a 50 MVAR shunt capacitor bank at BBK to investigate performance improvements (Figure 28). To improve system performance it was determined that a runback of 100 MW in 750ms (Figure 23-Figure 27) is required without a capacitor bank while the runback is reduced to 50 MW in 750ms (Figure 29) with a 50 MVAR shunt capacitor bank installed at BBK. This result demonstrates in this case that the magnitude of runback is reduced with the installation of a 50 MVAR shunt reactor at BBK.

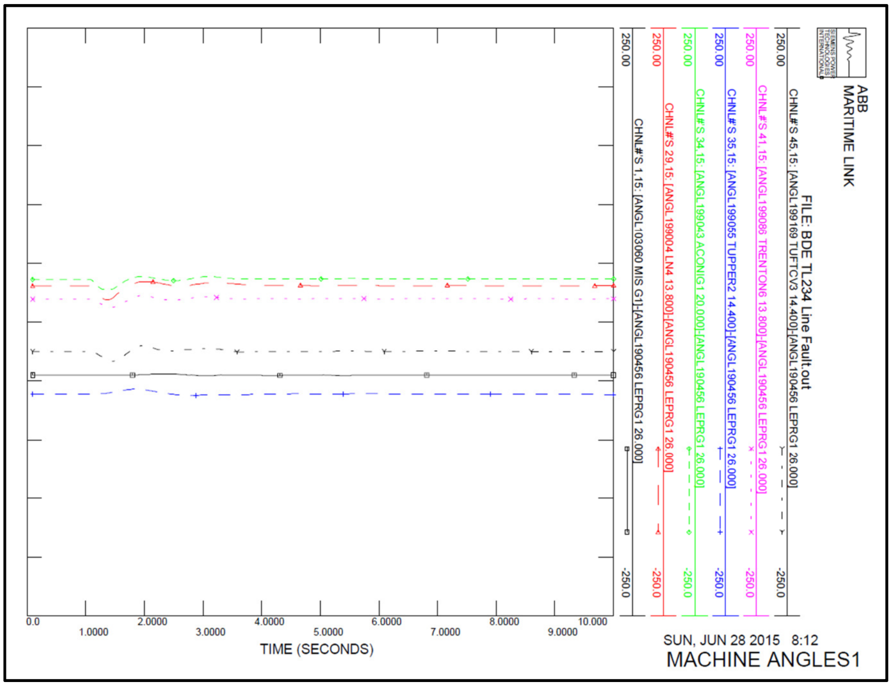

Figure 18: BC 8006 - BDE TL234 3-Phase Fault – No Runback

Nova Scotia Machine Relative Rotor Angles

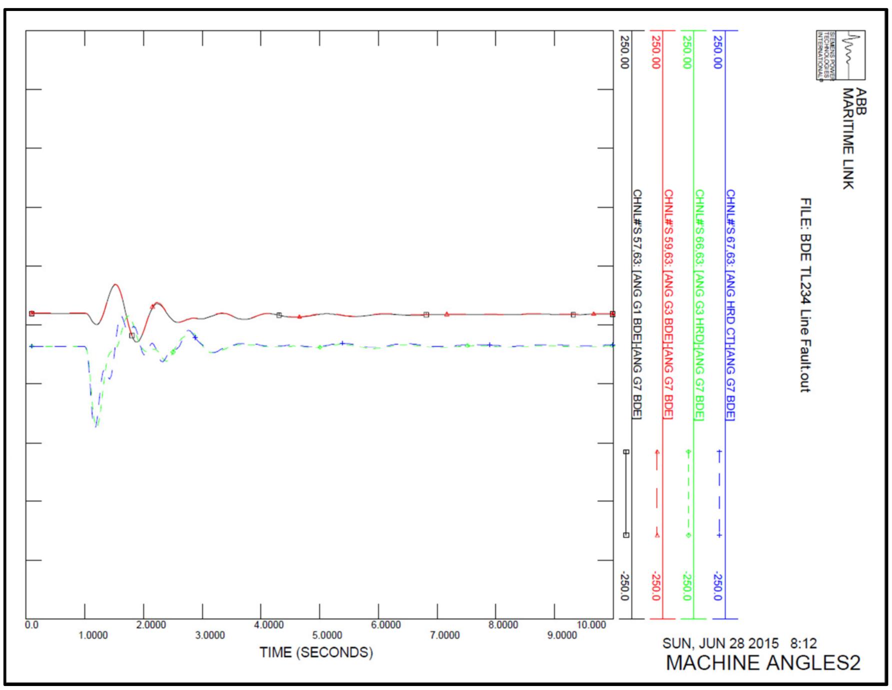

Figure 19: BC 8006 - BDE TL234 3-Phase Fault – No Runback

HRD and BDE Machine Relative Rotor Angles

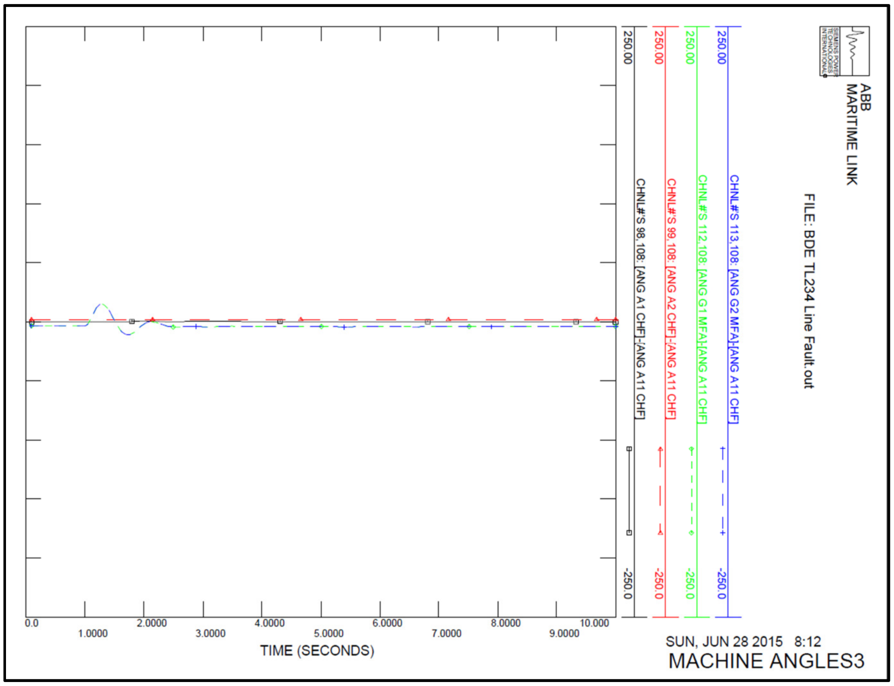

Figure 20: BC 8006 - BDE TL234 3-Phase Fault – No Runback CHF and MFA Machine Relative Rotor Angles

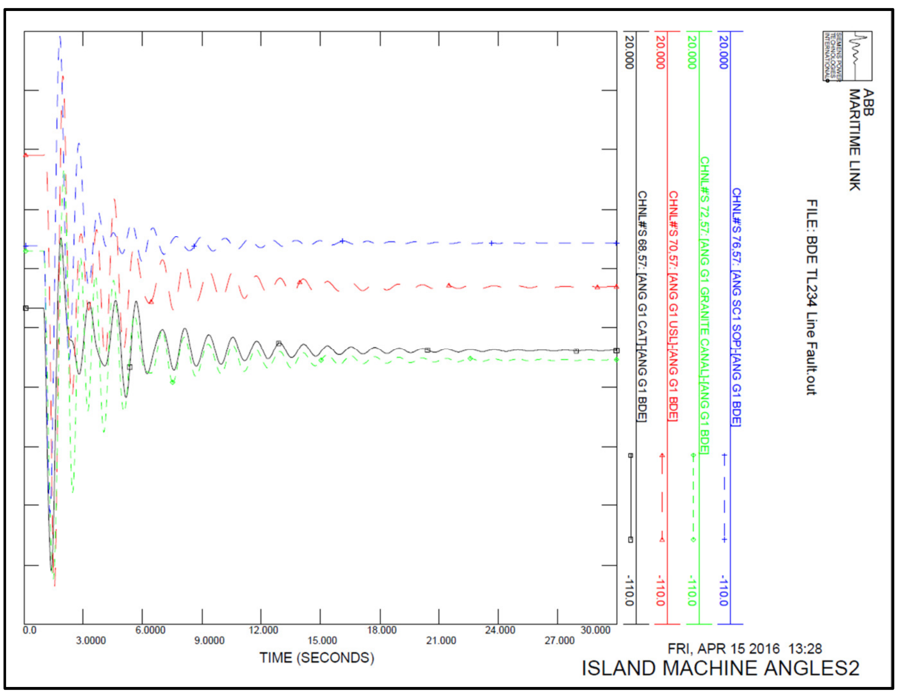

Figure 21: BC 8006 - BDE TL234 3-Phase Fault – No Runback SOP, GCL, USL and CAT Machine Relative Rotor Angles

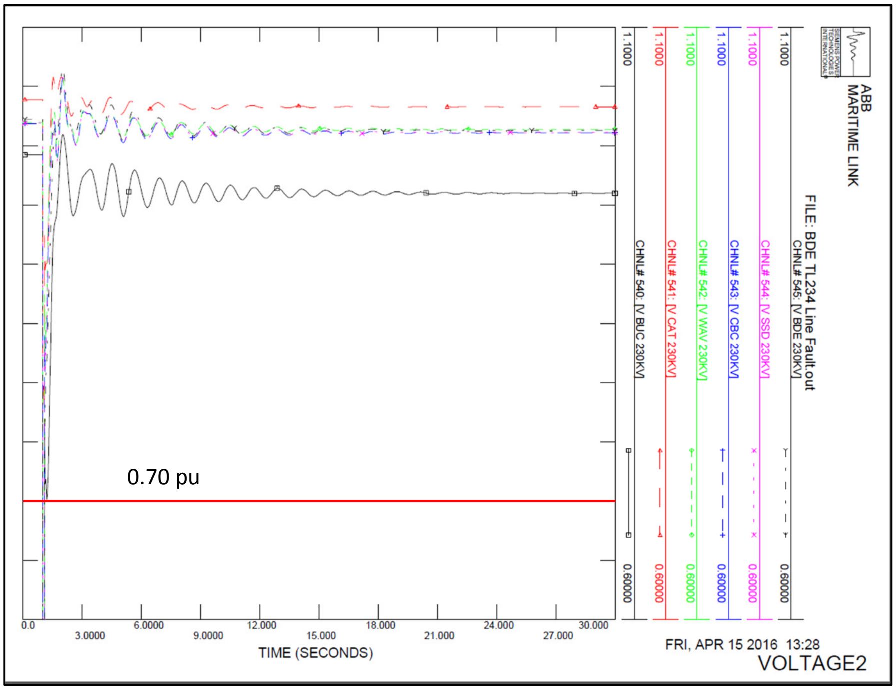

Figure 22: BC 8006 - BDE TL234 3-Phase Fault – No Runback SSD, CBC, WAV, CAT, BUC Bus Voltages

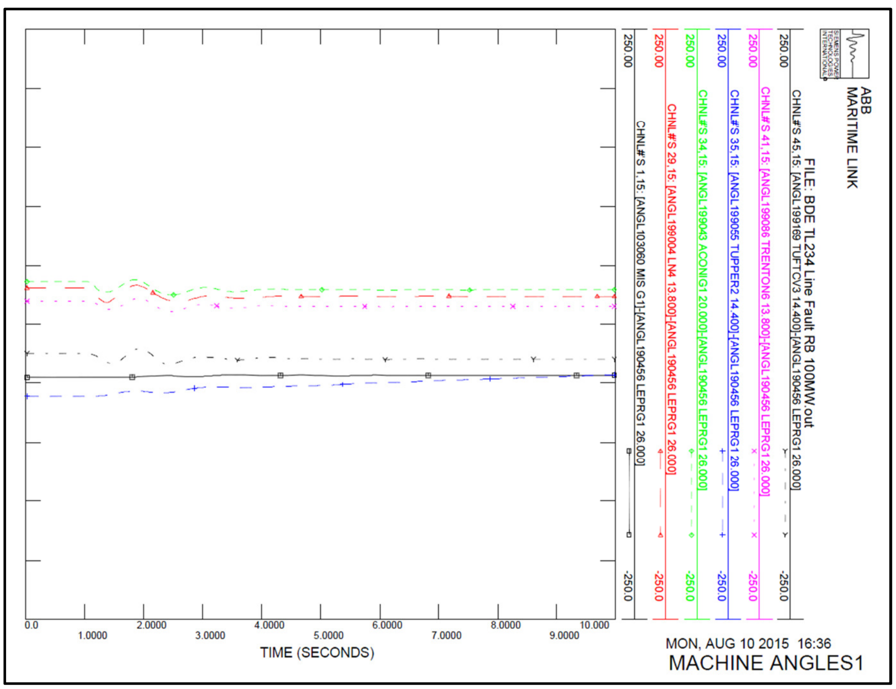

Figure 23: Base Case 8006 - BDE TL234 3-Phase Fault – 100 MW ML Runback in 750ms Nova Scotia Machine Relative Rotor Angles

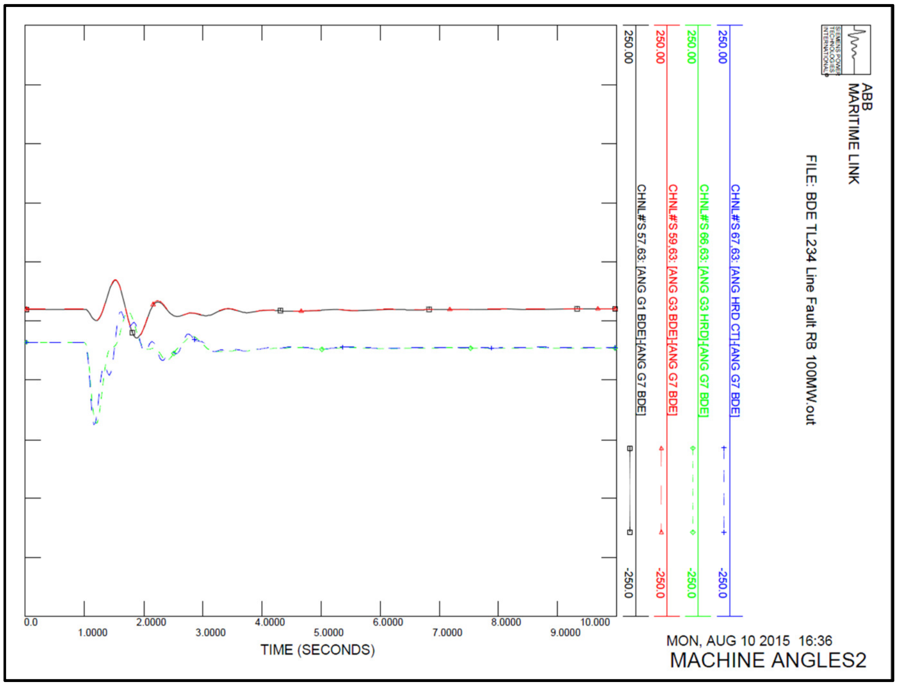

Figure 24: Base Case 8006 - BDE TL234 3-Phase Fault – 100 MW ML Runback in 750ms HRD and BDE Machine Relative Rotor Angles

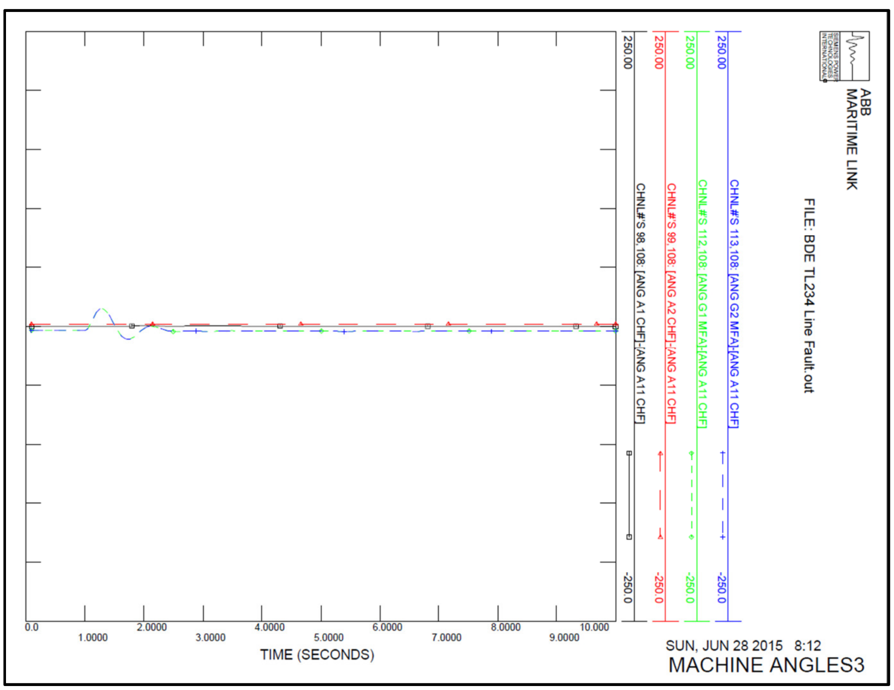

Figure 25: Base Case 8006 - BDE TL234 3-Phase Fault – 100 MW ML Runback in 750ms CHF and MFA Machine Relative Rotor Angles

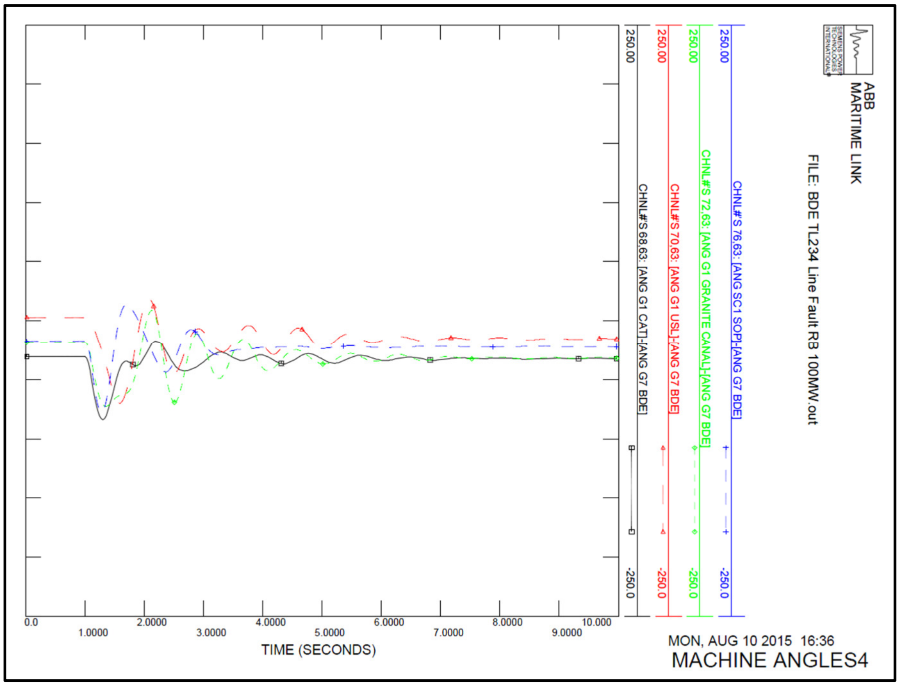

Figure 26: Base Case 8006 - BDE TL234 3-Phase Fault – 100 MW ML Runback in 750ms SOP, GCL, USL and CAT Machine Relative Rotor Angles

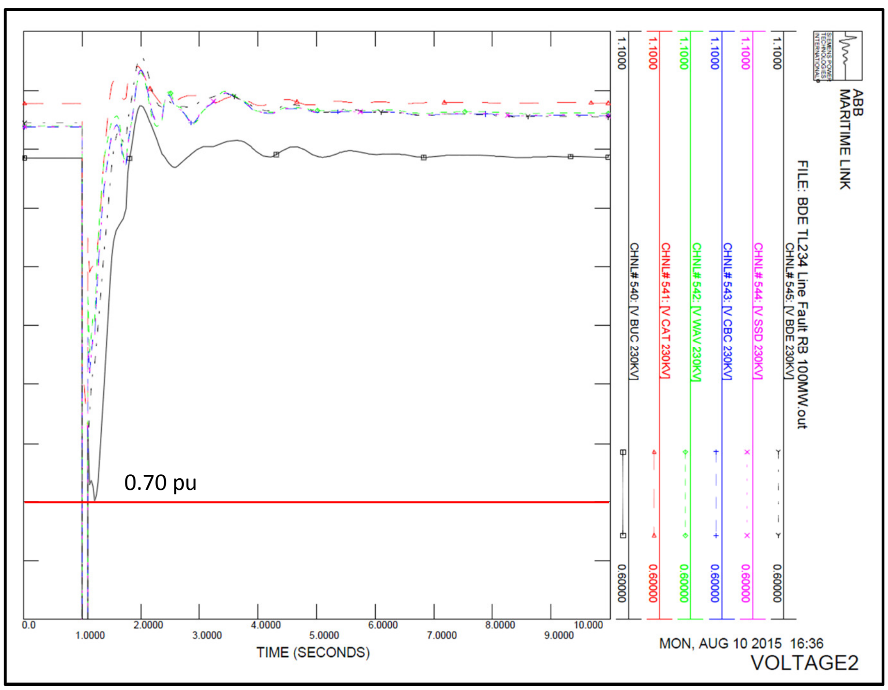

Figure 27: BC 8006 - BDE TL234 3-Phase Fault – 100 MW ML Runback in 750ms SSD, CBC, WAV, CAT, BUC Bus Voltages

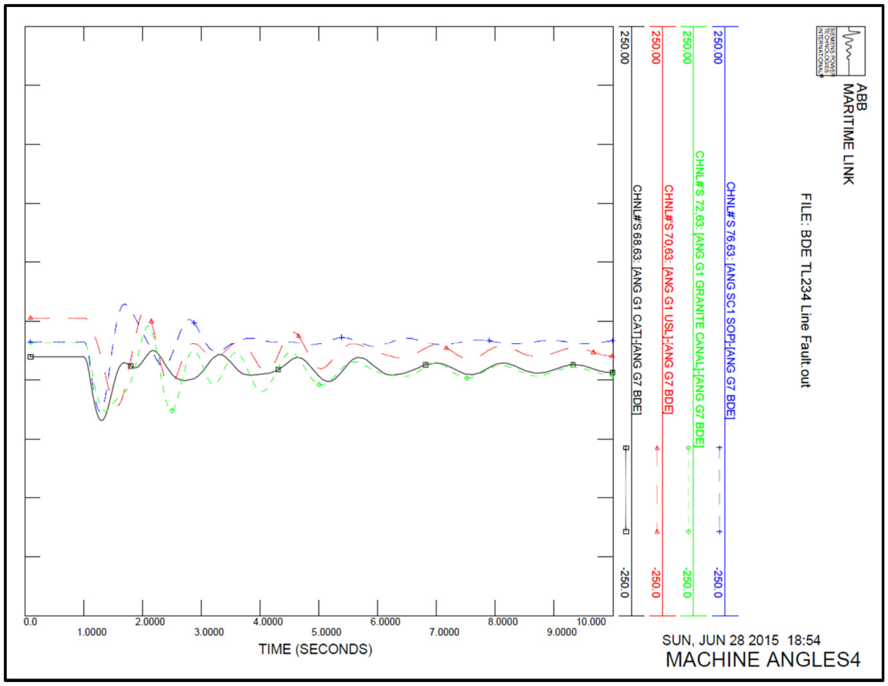

Figure 28: Base Case 8006 - BDE TL234 3-Phase Fault

50 MVAR Shunt Capacitor Bank Installed at BBK – No ML Runback

SOP, GCL, USL and CAT Machine Relative Rotor Angles

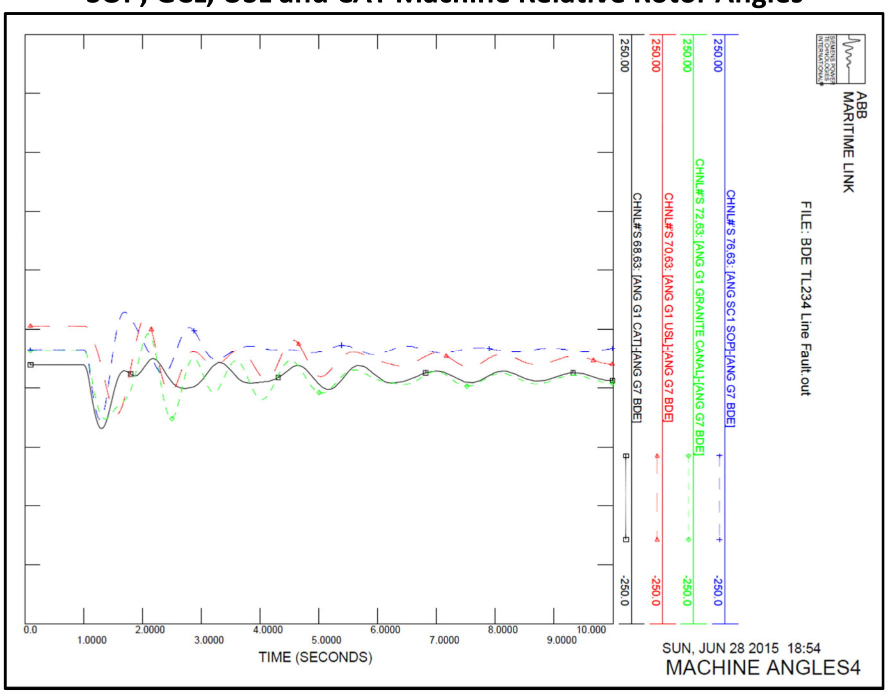

Figure 29: Base Case 8006 - BDE TL234 3-Phase Fault

50 MVAR Shunt Capacitor Bank Installed at BBK – 50 MW ML Runback in 750ms

SOP, GCL, USL and CAT Machine Relative Rotor Angles

6.2 AC TRANSMISSION LINE FAULTS IN WESTERN NEWFOUNDLAND

Results from the power system transient analysis indicate that faults located at three 230 kV terminal stations west of BDE result in system instability and/or low recovery voltages. Three phase faults on transmission lines TL269, TL263 and TL234 close in to BBKTS, GCLTS and USLTS which, result in the subsequent tripping of the circuit, can result in voltage instability throughout the system or the recovery voltages at BUCTS and BBKTS falling below the established minimum planning criteria value of 0.70 pu. A summary of the system conditions as a result of faults west of BDE can be found in Table 16.

As a result, a combination of ML curtailment strategies with varying VSC response times with or without shunt capacitor banks installed at BBK were studied to determine the minimum system upgrades required maintaining system stability for these contingencies.

Table 16 – Notable System Conditions Following Faults West of BDE

Base Case	Contingency	System Condition
8006	3Φ Fault at BBK, Trip of TL269	Angular stability, BBK voltage and frequency are unstable (VSC not damping), recovery voltages at BBK and BUC are below 0.70 pu.
8006	3Φ Fault at GCL, Trip of TL263	Angular stability, BBK voltage and frequency are unstable (VSC not damping).
8006	3Φ Fault at GCL, Trip of TL269	Angular stability, BBK voltage and frequency are unstable (VSC not damping), recovery voltages at BBK and BUC are below 0.70 pu.
8006	3Φ Fault at USL, Trip of TL263	Angular stability, BBK voltage and frequency are unstable (VSC not damping), recovery voltages at BBK and BUC are below 0.70 pu.
8006	3Φ Fault at USL, Trip of TL234	Angular stability, BBK voltage and frequency are unstable (VSC not damping), recovery voltages at BBK and BUC are below 0.70 pu.

6.2.1 3-PHASE FAULTS AT BBK (TL269)

Three-phase faults close in to BBK which would trip TL269 between BBK and GCL would result in system instability. Clearly from Figure 30, large generators on the Island do not lose synchronism, however the response at Cat Arm (CAT) is not well damped. Further analysis into the response of the VSC installed at BBK indicates that the reactive power controller does not maintain a stable voltage on the system. Figure 31 displays the ML's real and reactive power outputs measured at BBK. As a result, the Island's system frequencies and bus voltages west of BDE are relatively unstable, as shown in Figure 32-Figure 34. It would appear, as shown in Figure 35, that this system disturbance will have a noticeable impact on generation outside the NL and NS boundaries into the NPCC interconnected transmission system.

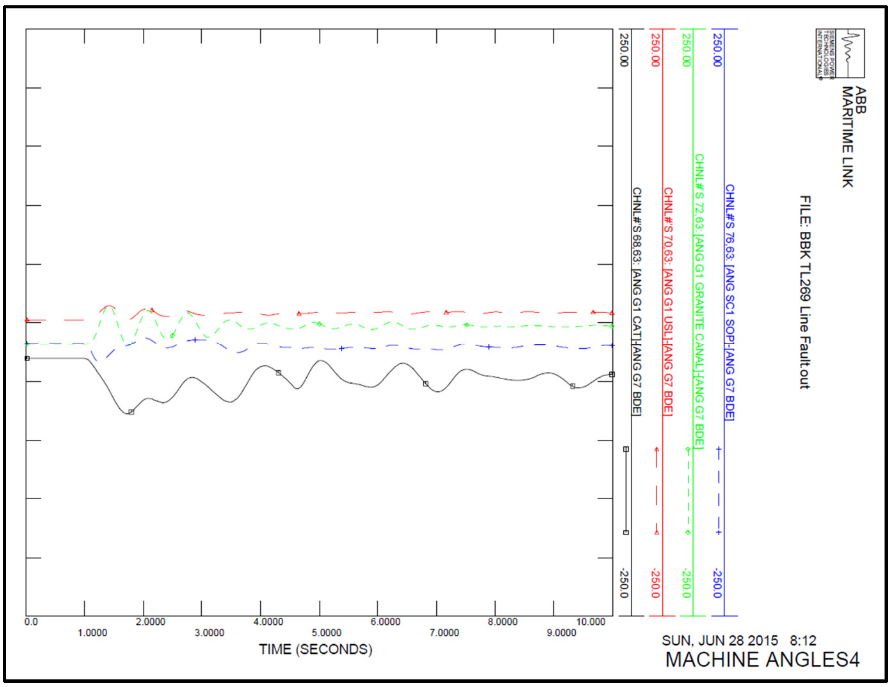

Figure 30: Base Case 8006 – BBK TL269 3-Phase Fault
SOP, GCL, USL and CAT Machine Relative Rotor Angles

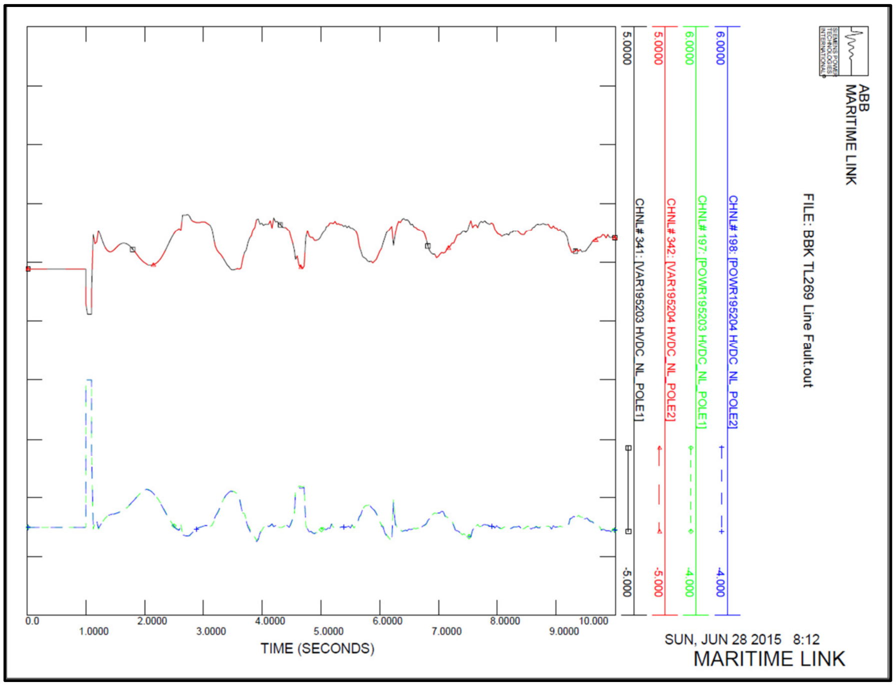

Figure 31: Base Case 8006 – BBK TL269 3-Phase Fault
Maritime Link Real and Reactive Power Outputs (per Pole)

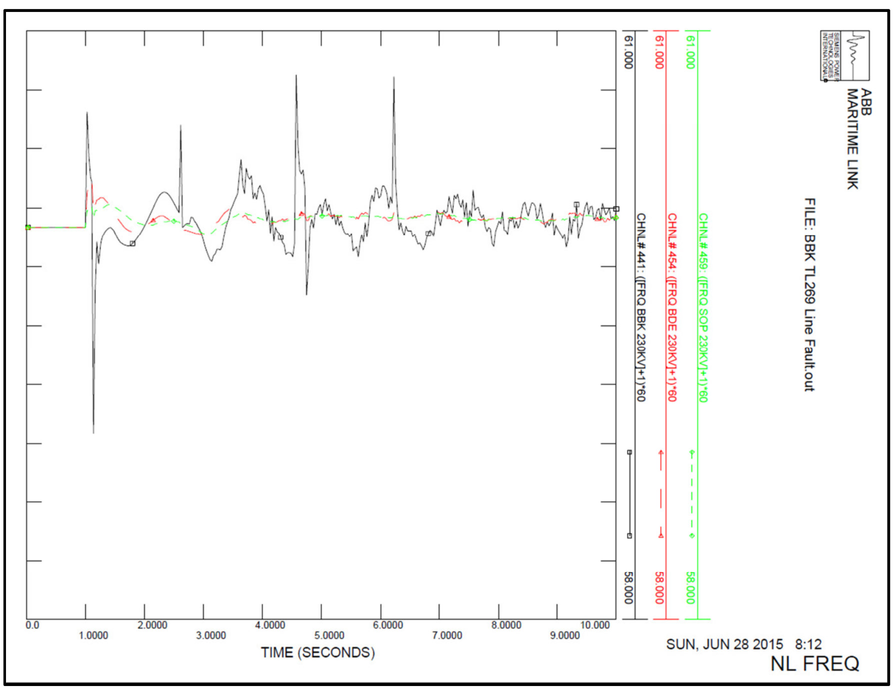

Figure 32: Base Case 8006 – BBK TL269 3-Phase Fault
NL Frequency at BBK, BDE and SOP

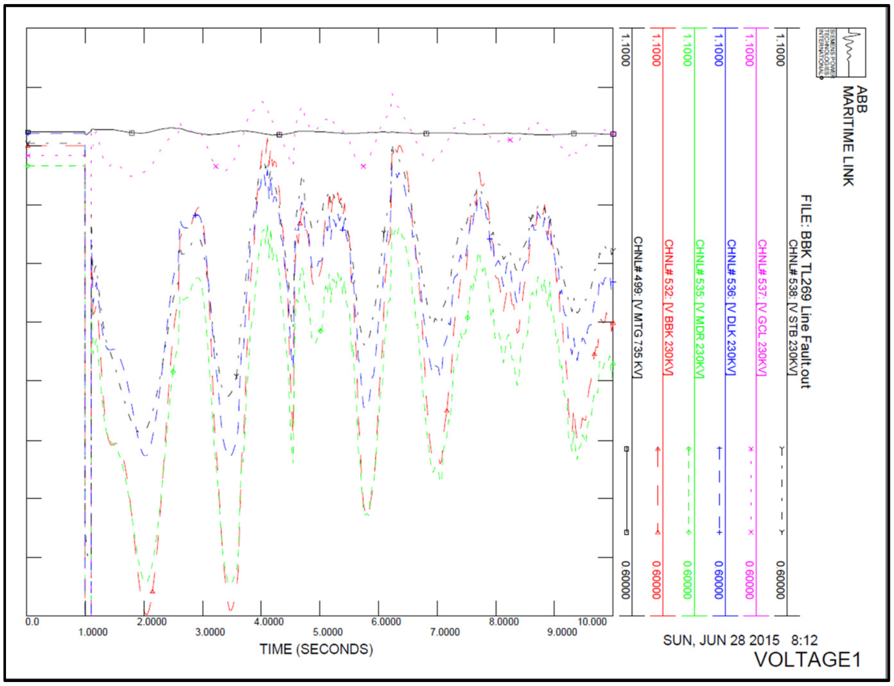

Figure 33: Base Case 8006 – BBK TL269 3-Phase Fault
230 kV Bus Voltages at MTG, BBK, MDR, DLK, GCL and STB

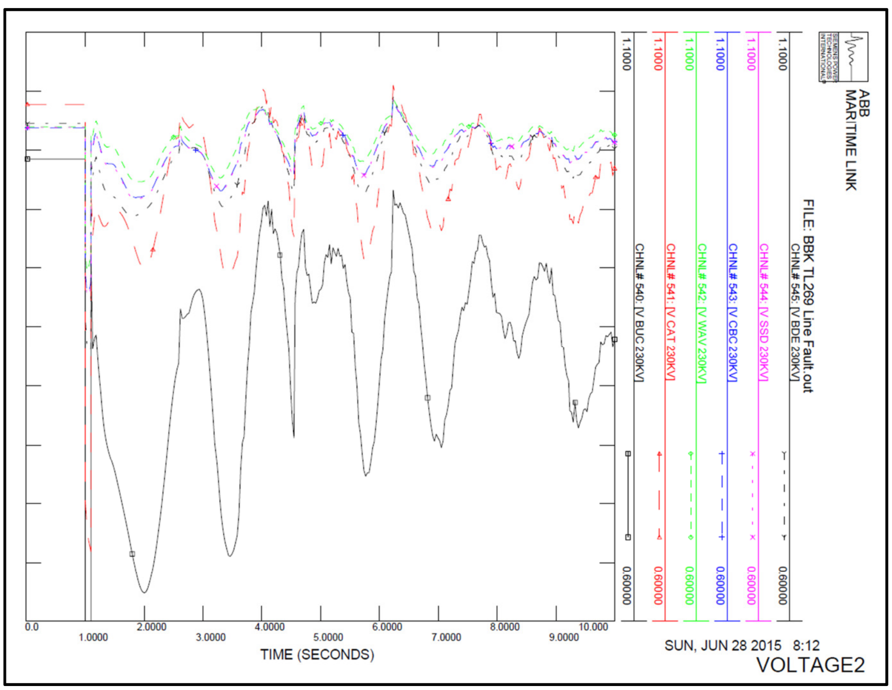

Figure 34: Base Case 8006 – BBK TL269 3-Phase Fault
230 kV Bus Voltages at BUC, CAT, WAV, CBC, SSD and BDE

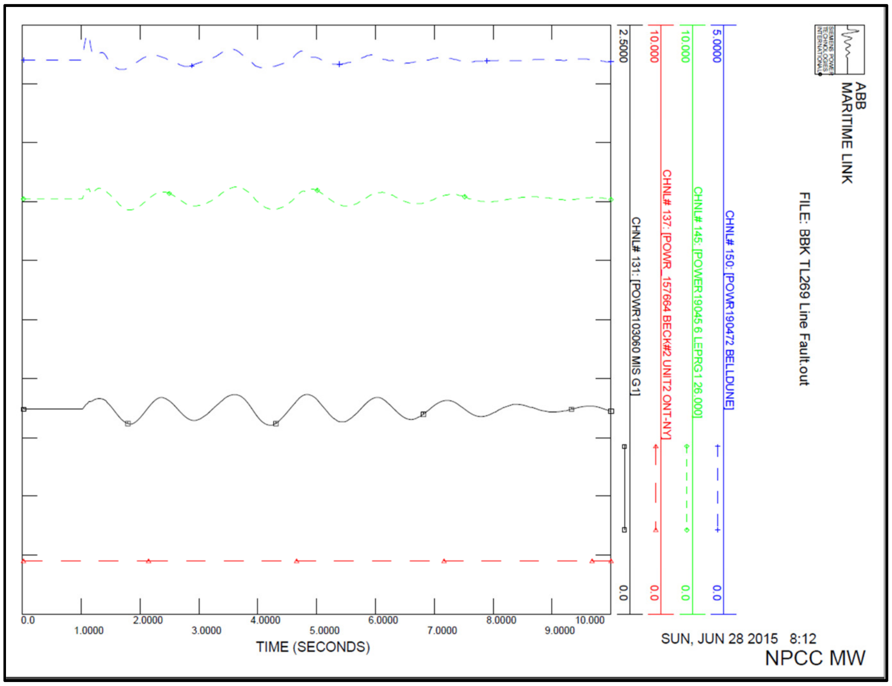

Figure 35: Base Case 8006 – BBK TL269 3-Phase Fault
NPCC Machine Real Power Output

Power system analysis has determined that a runback of the ML is required with or without the installation of a 50 MVAR shunt capacitor bank at BBK to mitigate the unstable system response for this contingency.

To achieve acceptable system response for this contingency, a 250 MW runback of the ML in 500ms is required without the installation of a 50 MVAR shunt capacitor bank at BBK as shown in Figure 36. A ML runback of 250 MW in 750ms will allow the 230 kV bus voltage at BUC to drop below 0.70 pu post recovery (Figure 37) while maintaining angular stability (Figure 38 & 39). The ML curtailment is reduced to 50 MW in 750ms with the installation of the capacitor bank at BBK as shown in Figure 40 to Figure 44. Once again, recovery voltage at BUC is an issue for this contingency.

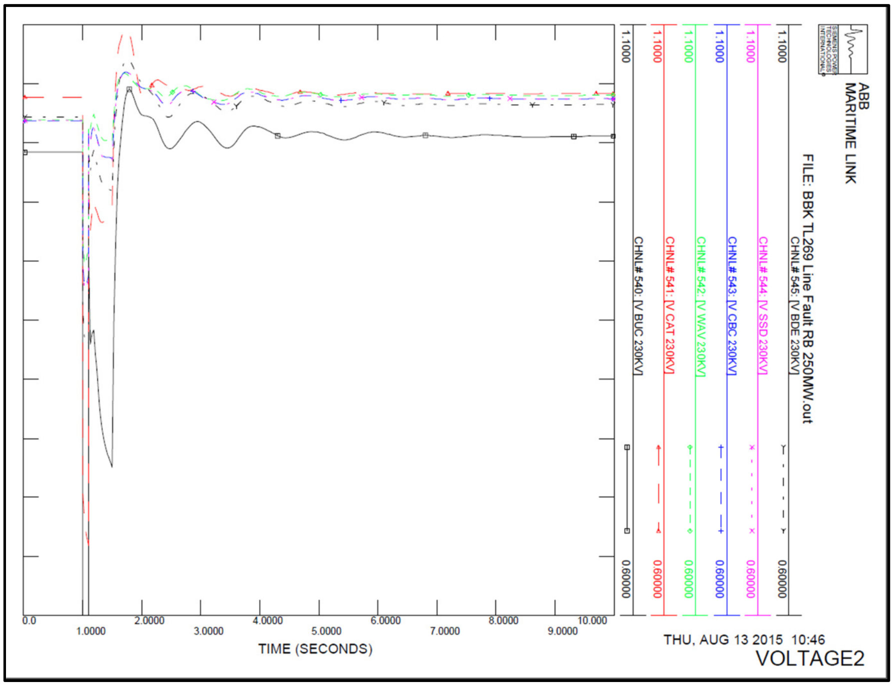

Figure 36: Base Case 8006 - BBK TL269 3-Phase Fault – 250 MW ML Runback in 500ms 230 kV Bus Voltages at BUC, CAT, WAV, CBC, SSD and BDE

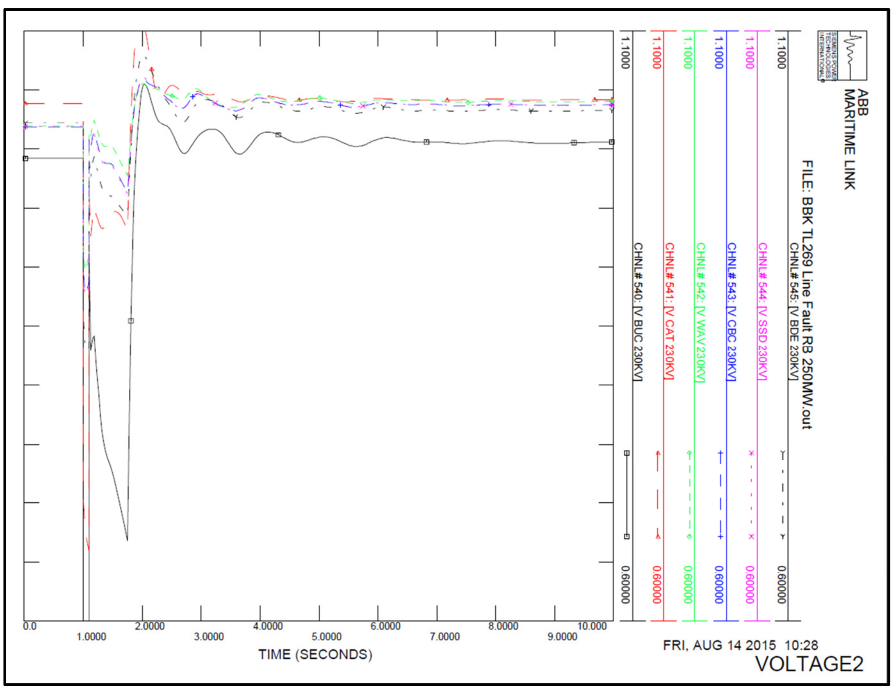

Figure 37: Base Case 8006 - BBK TL269 3-Phase Fault – 250 MW ML Runback in 750ms 230 kV Bus Voltages at BUC, CAT, WAV, CBC, SSD and BDE

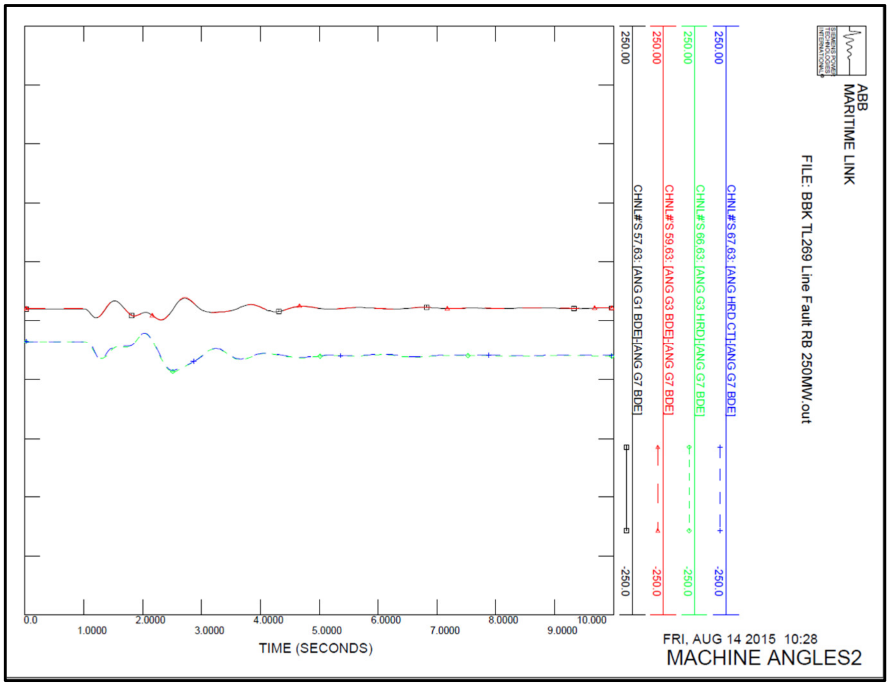

Figure 38: Base Case 8006 – BBK TL269 3-Phase Fault – 250 MW ML Runback in 750ms BDE and HRD Machine Relative Rotor Angles

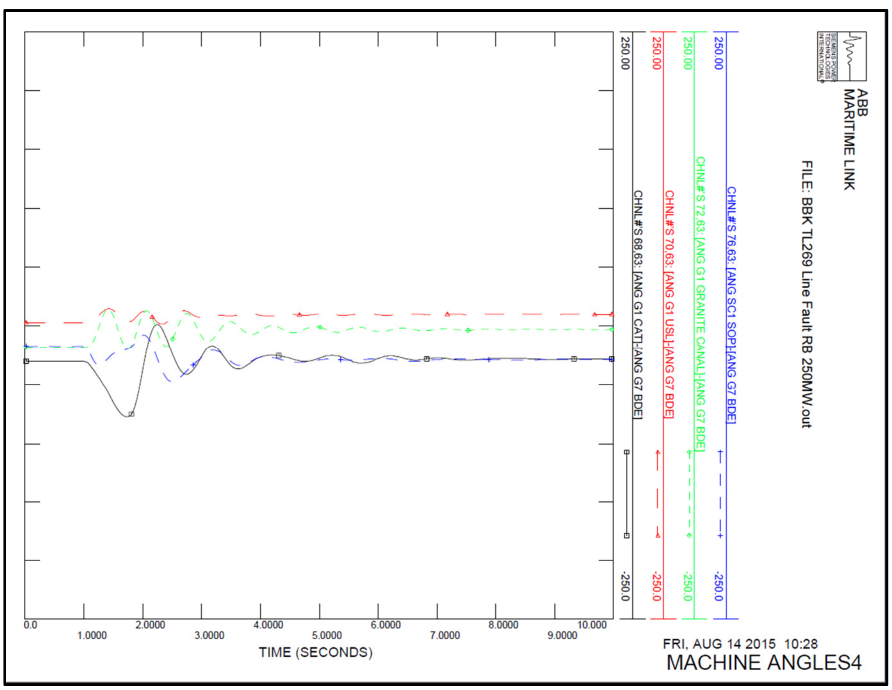

Figure 39: Base Case 8006 – BBK TL269 3-Phase Fault – 250 MW ML Runback in 750ms SOP, GCL, USL and CAT Machine Relative Rotor Angles

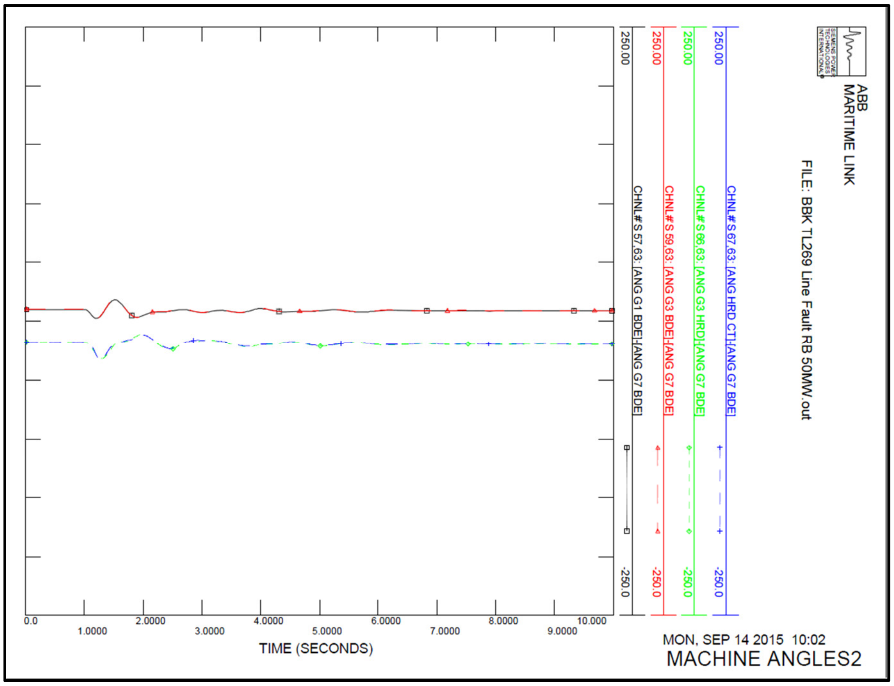

Figure 40: Base Case 8006 – BBK TL269 3-Phase Fault
50 MVAR Shunt Capacitor Bank Installed at BBK – 50 MW ML Runback in 750ms
BDE and HRD Machine Relative Rotor Angles

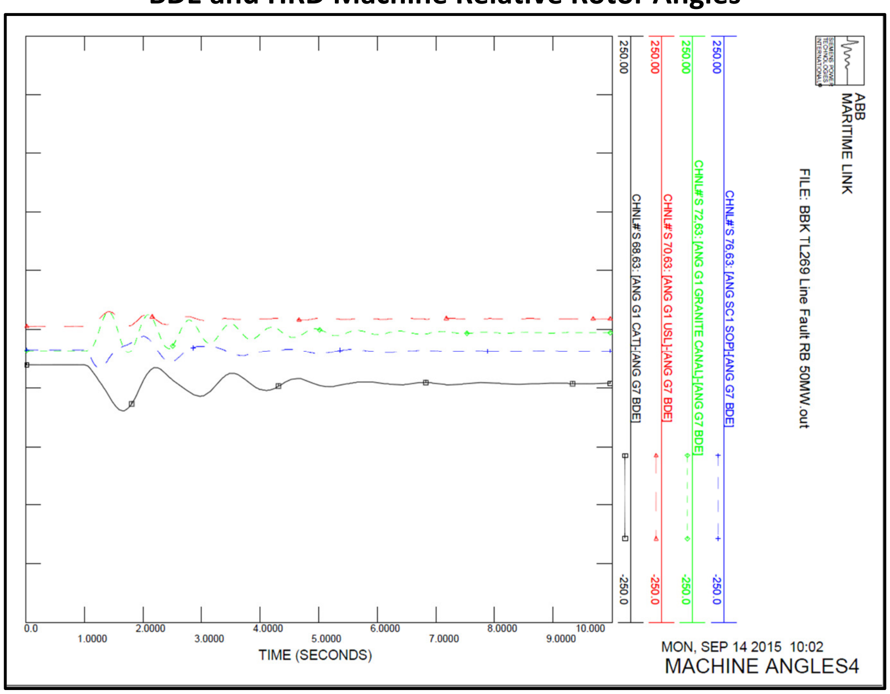

Figure 41: Base Case 8006 – BBK TL269 3-Phase Fault
50 MVAR Shunt Capacitor Bank Installed at BBK – 50 MW ML Runback in 750ms
CAT, USL, GCL and SOP Machine Relative Rotor Angles

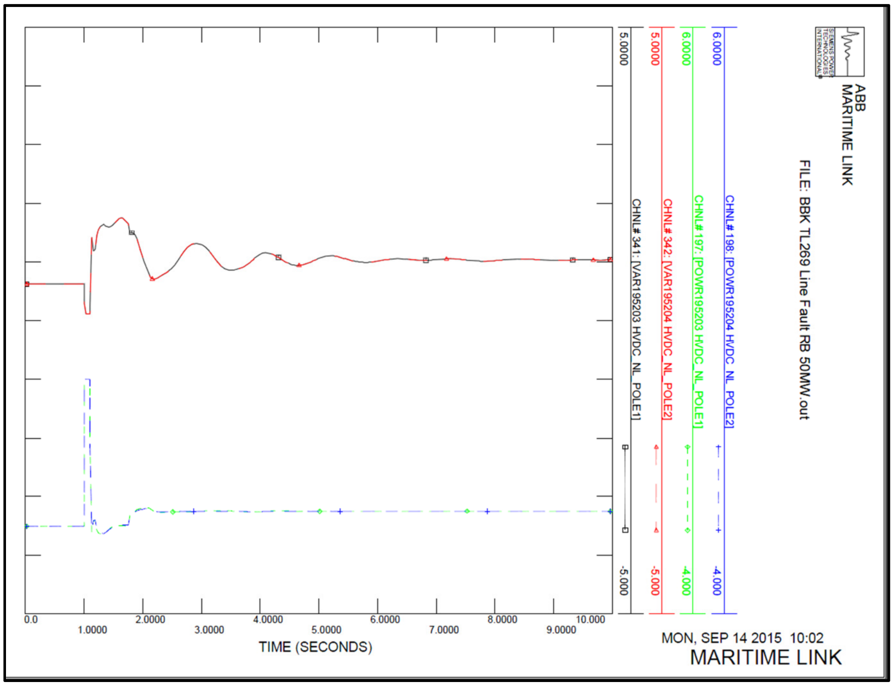

Figure 42: Base Case 8006 – BBK TL269 3-Phase Fault

50 MVAR Shunt Capacitor Bank Installed at BBK – 50 MW ML Runback in 750ms

ML Real and Reactive Power Output at BBK (per Pole)

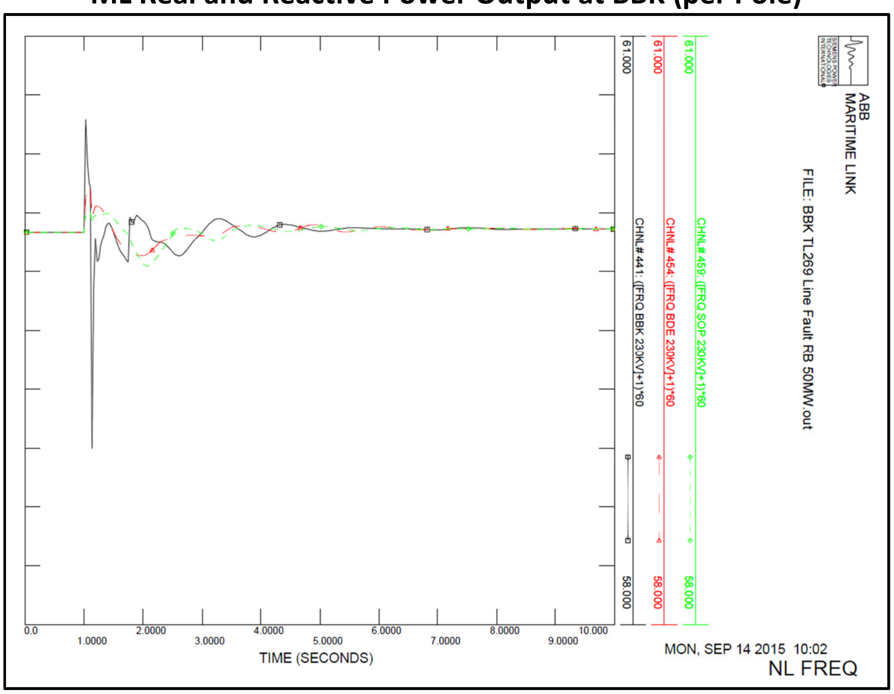

Figure 43: Base Case 8006 – BBK TL269 3-Phase Fault

50 MVAR Shunt Capacitor Bank Installed at BBK – 50 MW ML Runback in 750ms

NL Frequency Response at BBK, BDE and SOP

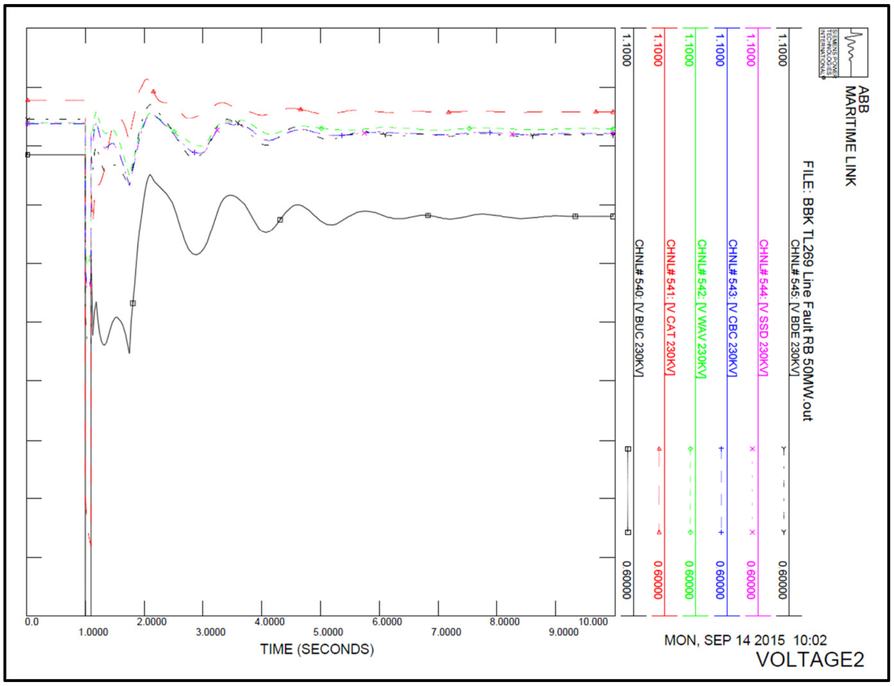

Figure 44: Base Case 8006 – BBK TL269 3-Phase Fault
50 MVAR Shunt Capacitor Bank Installed at BBK – 50 MW ML Runback in 750ms
230 kV Bus Voltages at BUC, CAT, WAV, CBC, SSD, BDE

6.2.2 3-PHASE FAULTS AT GCL (TL269/TL263)

For three phase faults close in to GCL on TL263, power system transient analysis has determined that a runback of the ML is required with or without the installation of a 50 MVAR shunt capacitor bank at BBK to mitigate the unstable system response for this contingency.

Figure 45 and Figure 46 show that post fault, large generators on the Island do not lose synchronism; however the response at Cat Arm (CAT) is not well damped. Further analysis into the response of the VSC installed at BBK indicates that the reactive power controller cannot maintain a stable voltage on the system. Figure 47 displays the ML's real and reactive power outputs measured at BBK. As a result, the Island's system frequencies west of BDE and bus voltages are relatively unstable, as shown in Figure 48-Figure 50.

To maintain system stability and provide recovery voltages above 0.70 pu for this contingency a 100 MW runback of the ML in 750ms is required with or without the installation of a 50 MVAR shunt capacitor bank at BBK as shown in Figure 51-Figure 56.

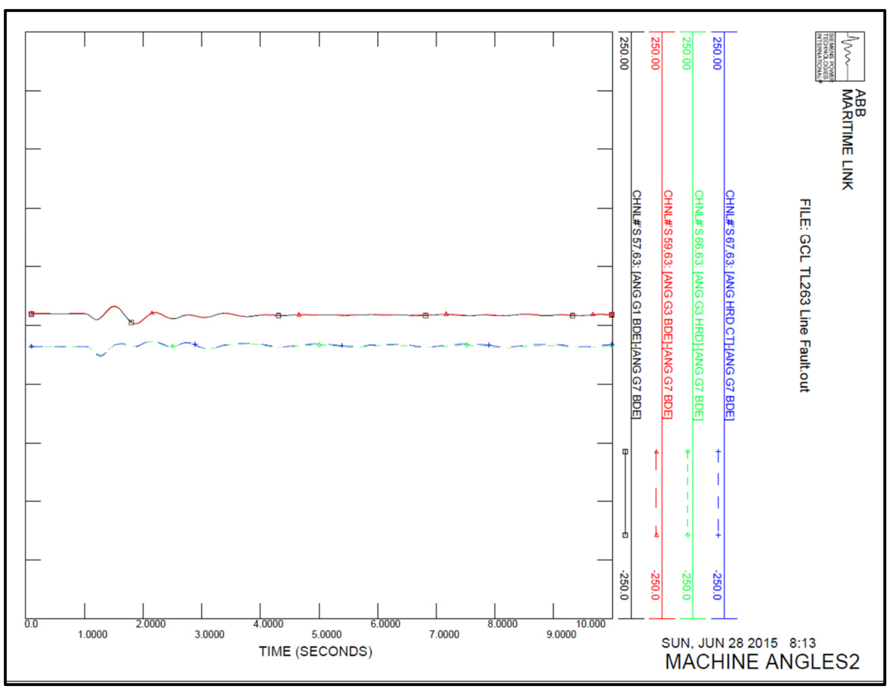

Figure 45: Base Case 8006 – GCL TL263 3-Phase Fault
BDE and HRD Machine Relative Rotor Angles

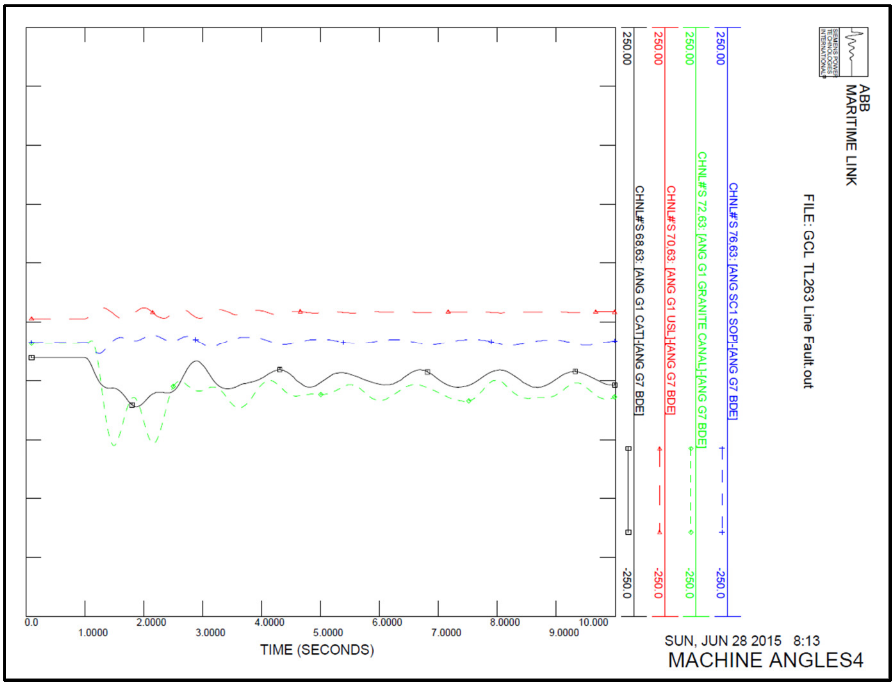

Figure 46: Base Case 8006 – GCL TL263 3-Phase Fault
CAT, USL, GCL and SOP Machine Relative Rotor Angles

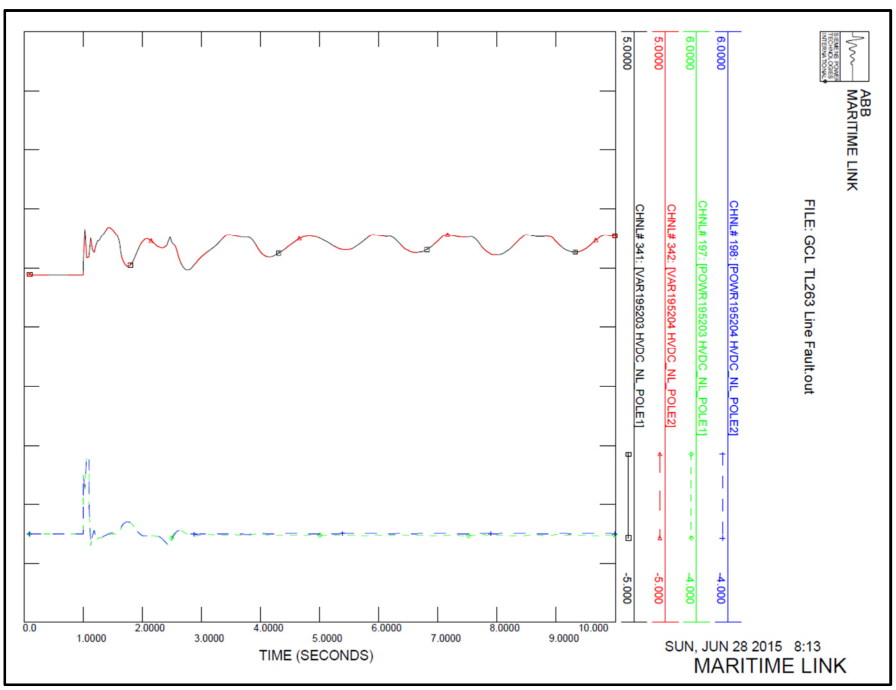

Figure 47: Base Case 8006 – GCL TL263 3-Phase Fault
ML Real and Reactive Power Output at BBK (per Pole)

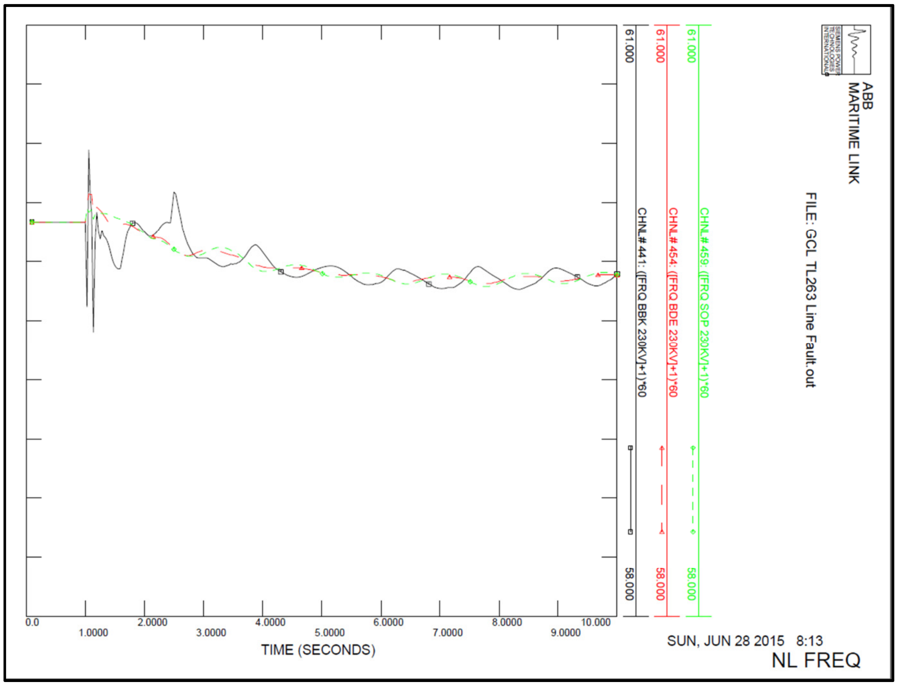

Figure 48: Base Case 8006 – GCL TL263 3-Phase Fault

NL Frequency Response at BBK, BDE and SOP

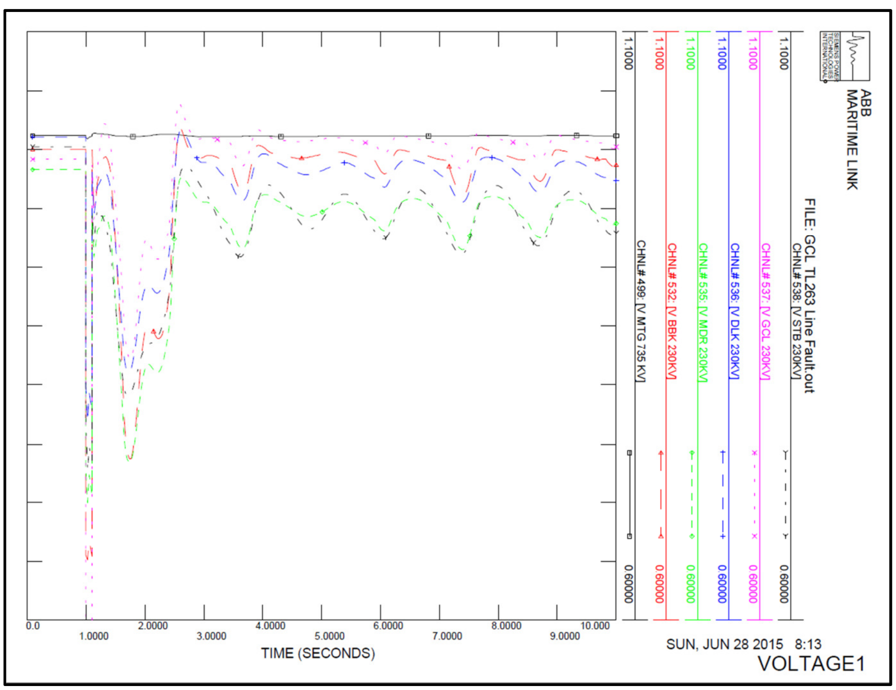

Figure 49: Base Case 8006 – GCL TL263 3-Phase Fault

Bus Voltages at MTG, BBK, MDR, DLK, GCL, STB

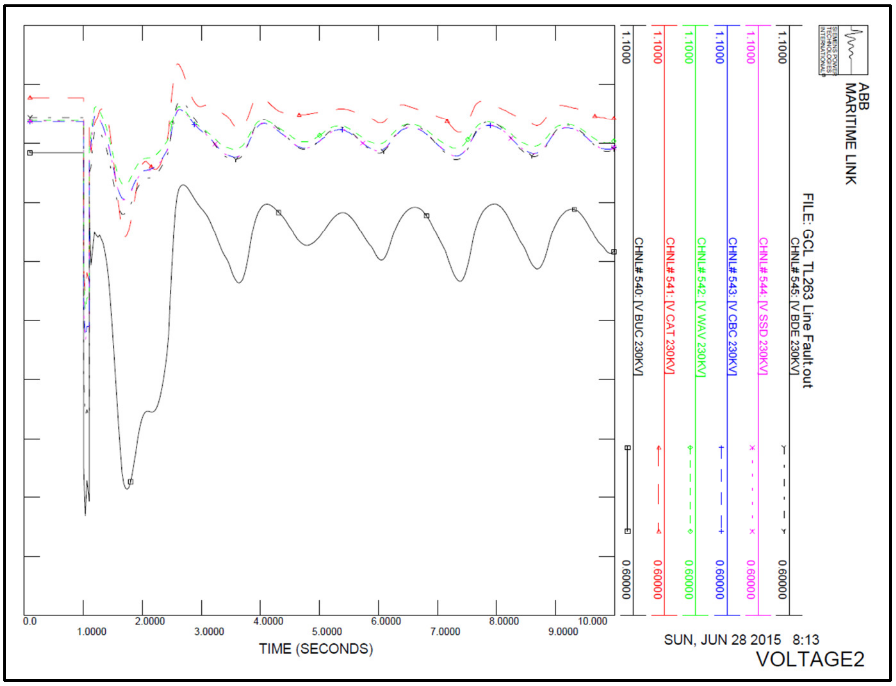

Figure 50: Base Case 8006 – GCL TL263 3-Phase Fault

230 kV Bus Voltages at BUC, CAT, WAV, CBC, SSD, BDE

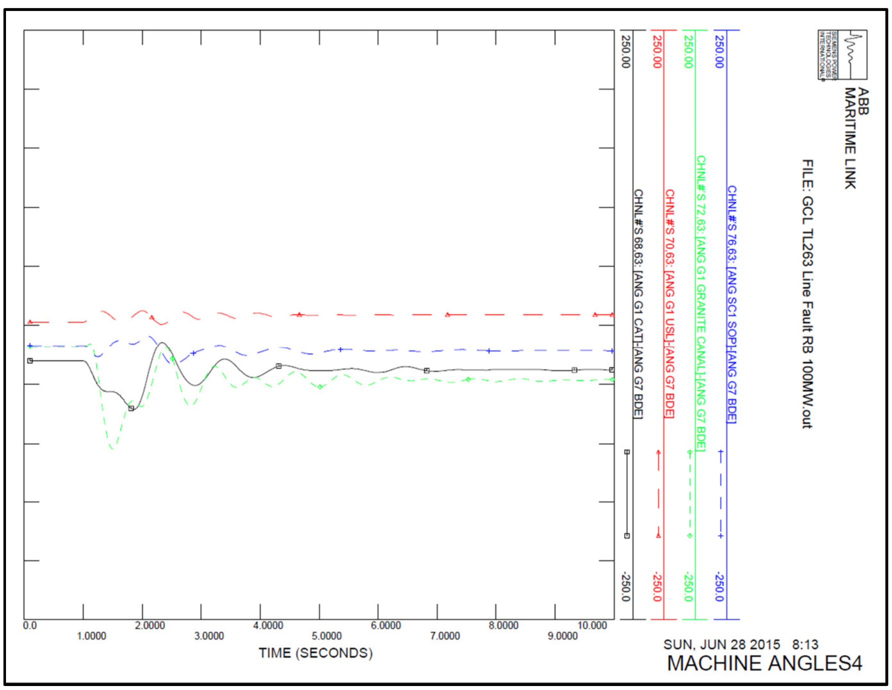

Figure 51: Base Case 8006 – GCL TL263 3-Phase Fault

100 MW ML Runback in 750ms

CAT, USL, GCL and SOP Machine Relative Rotor Angles

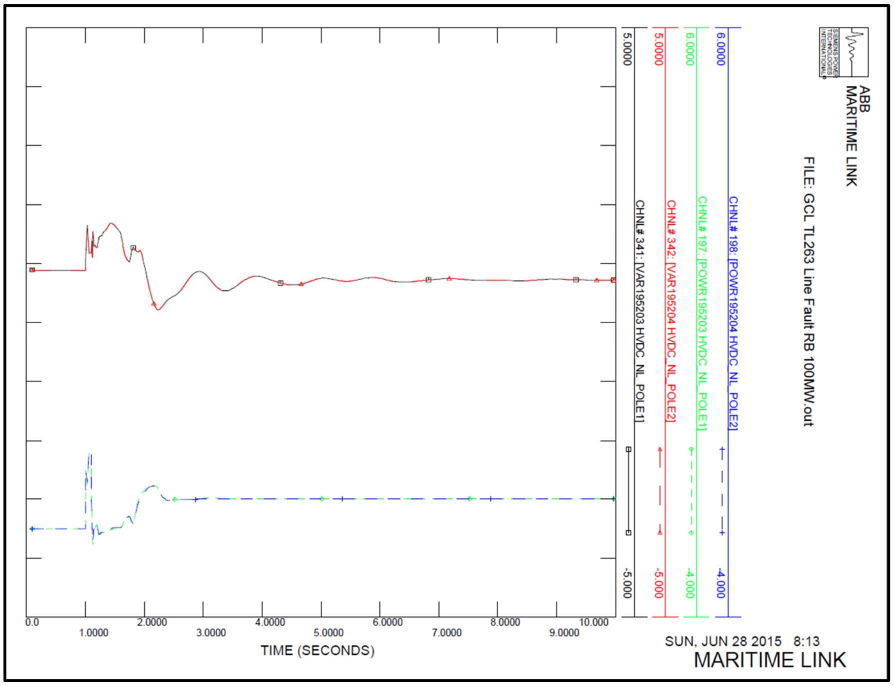

Figure 52: Base Case 8006 – GCL TL263 3-Phase Fault

100 MW ML Runback in 750ms

ML Real and Reactive Power Output at BBK (per Pole)

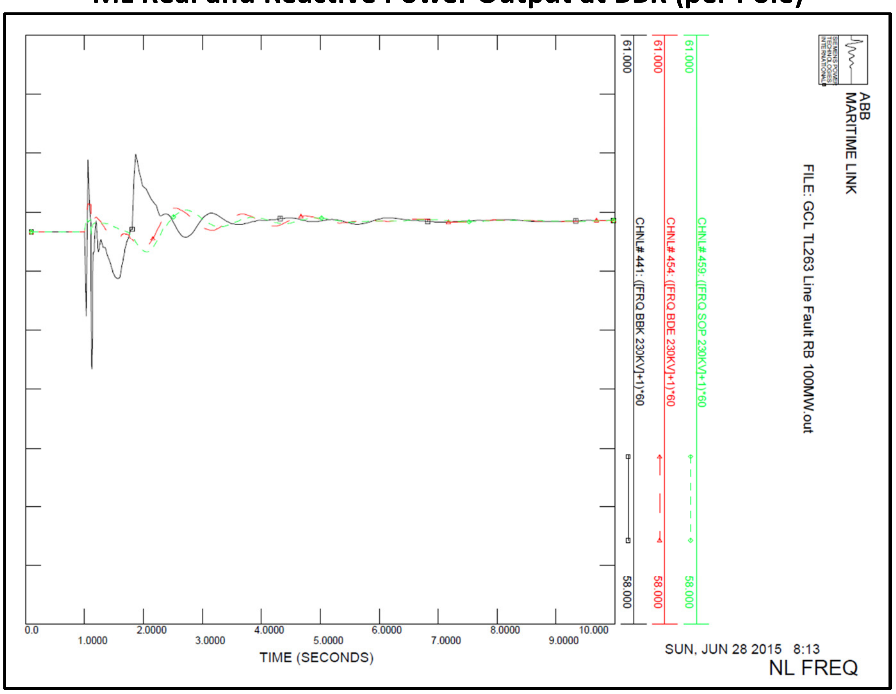

Figure 53: Base Case 8006 – GCL TL263 3-Phase Fault

100 MW ML Runback in 750ms

NL Frequency Response at BBK, BDE and SOP

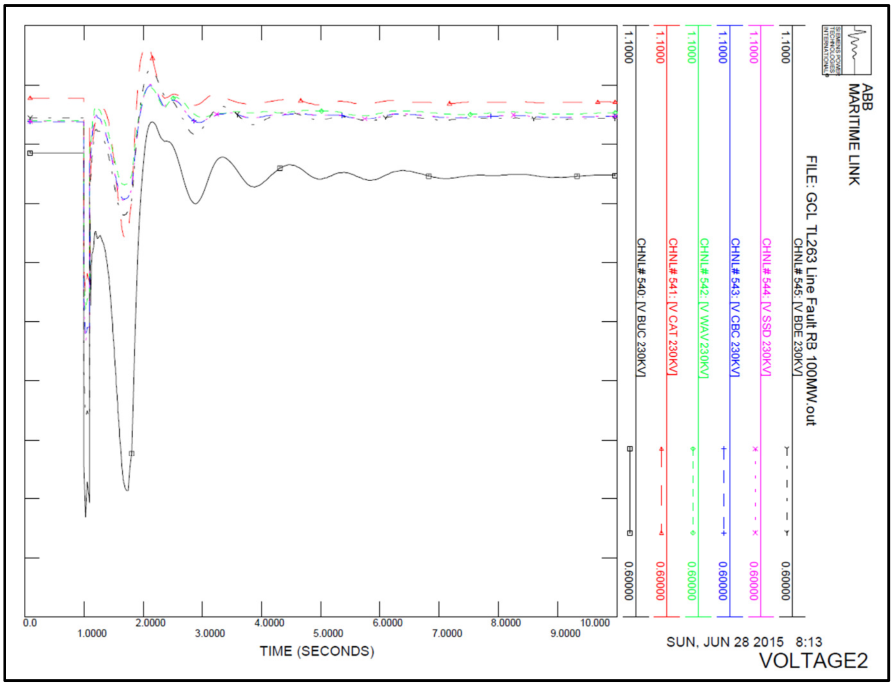

Figure 54: Base Case 8006 – GCL TL263 3-Phase Fault

100 MW ML Runback in 750ms

230 kV Bus Voltages at BUC, CAT, WAV, CBC, SSD, BDE

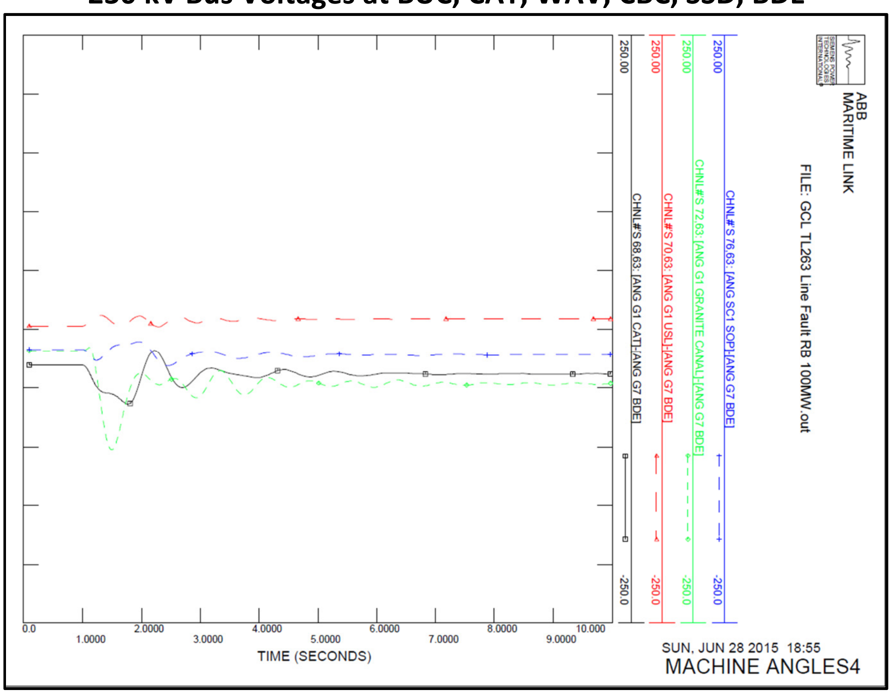

Figure 55: Base Case 8006 – GCL TL263 3-Phase Fault

50 MVAR Shunt Capacitor Bank Installed at BBK – 100 MW ML Runback in 750ms

CAT, USL, GCL and SOP Machine Relative Rotor Angles

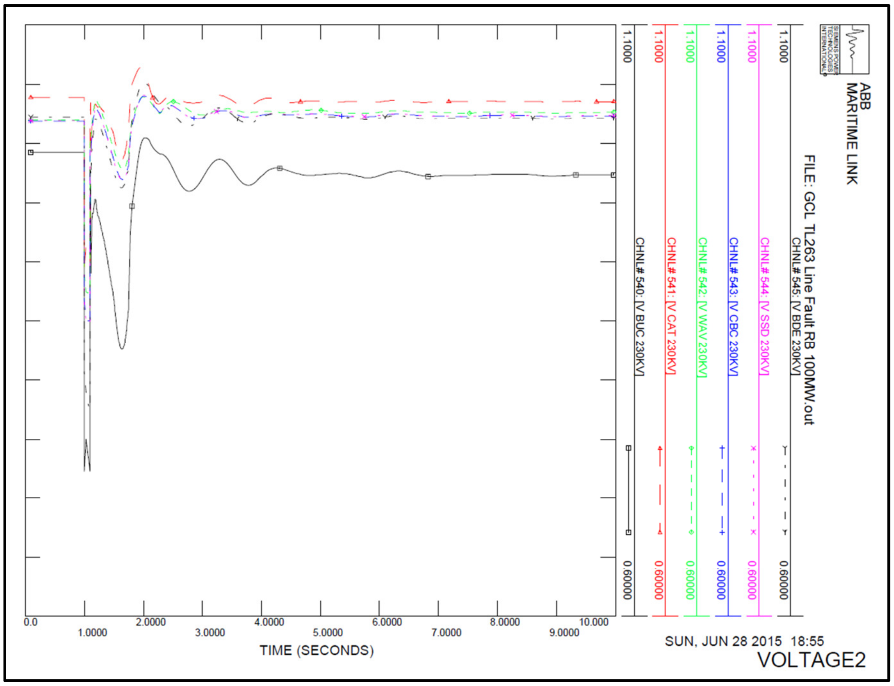

Figure 56: Base Case 8006 – GCL TL263 3-Phase Fault
50 MVAR Shunt Capacitor Bank Installed at BBK – 100 MW ML Runback in 750ms
230 kV Bus Voltages at BUC, CAT, WAV, CBC, SSD, BDE

For three phase faults close in to GCL on TL269, power system transient analysis has determined that a runback of the ML is required with or without the installation of a 50 MVAR shunt capacitor bank at BBK to mitigate the unstable system response for this contingency. Figure 57 indicates that post fault large generators on the Island do not lose synchronism; however the response at Cat Arm (CAT) is not well damped. Further analysis into the response of the VSC installed at BBK indicates that the reactive power controller does not maintain a stable voltage on the system. Figure 58 displays the ML's real and reactive power outputs measured at BBK. As a result, the Island's system frequencies west of BDE and bus voltages are relatively unstable, as shown in Figure 59-Figure 61.

To maintain system stability and provide recovery voltages above 0.70 pu for this contingency a 250 MW runback of the ML in 300ms is required without the installation of a 50 MVAR shunt capacitor bank at BBK as shown in Figure 62 -Figure 63. With a 50 MVAR capacitor bank installed at BBK, a 250 MW runback of the ML in 400ms is required to maintain acceptable bus recovery voltages as shown in Figure 64-Figure 67.

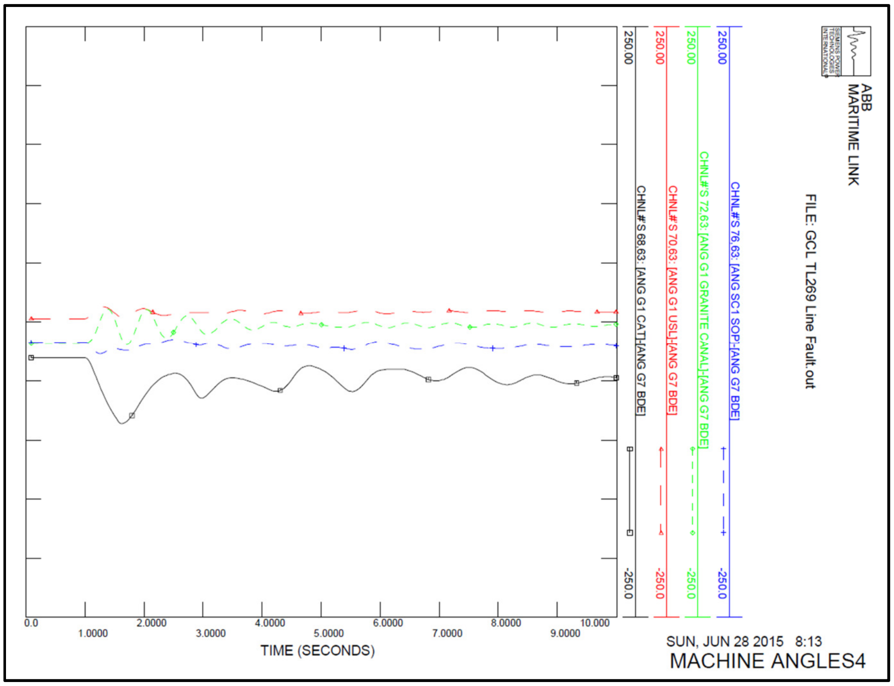

Figure 57: Base Case 8006 – GCL TL269 3-Phase Fault
CAT, USL, GCL and SOP Machine Relative Rotor Angles

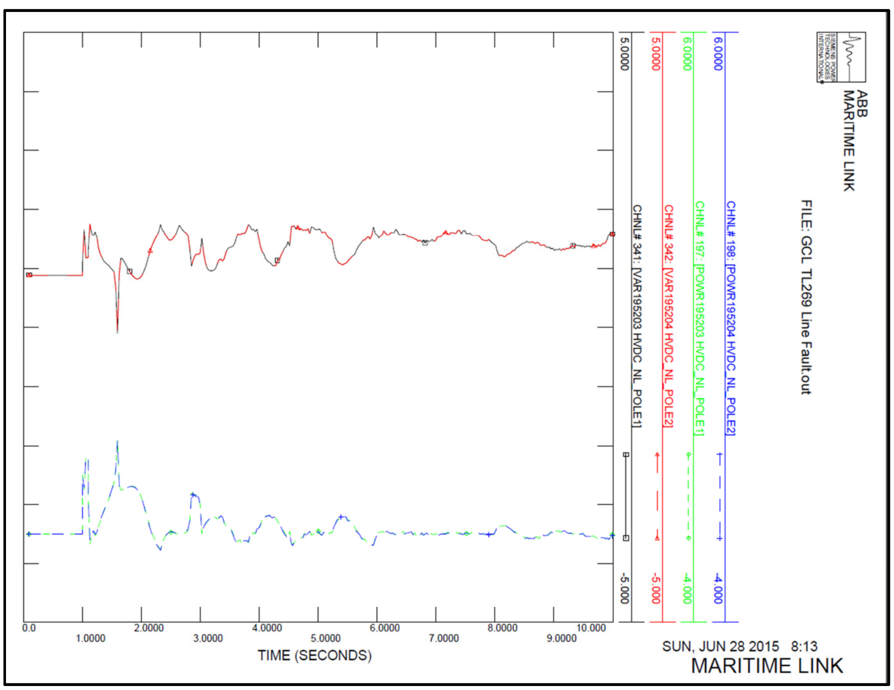

Figure 58: Base Case 8006 – GCL TL269 3-Phase Fault
ML Real and Reactive Power Output at BBK (per Pole)

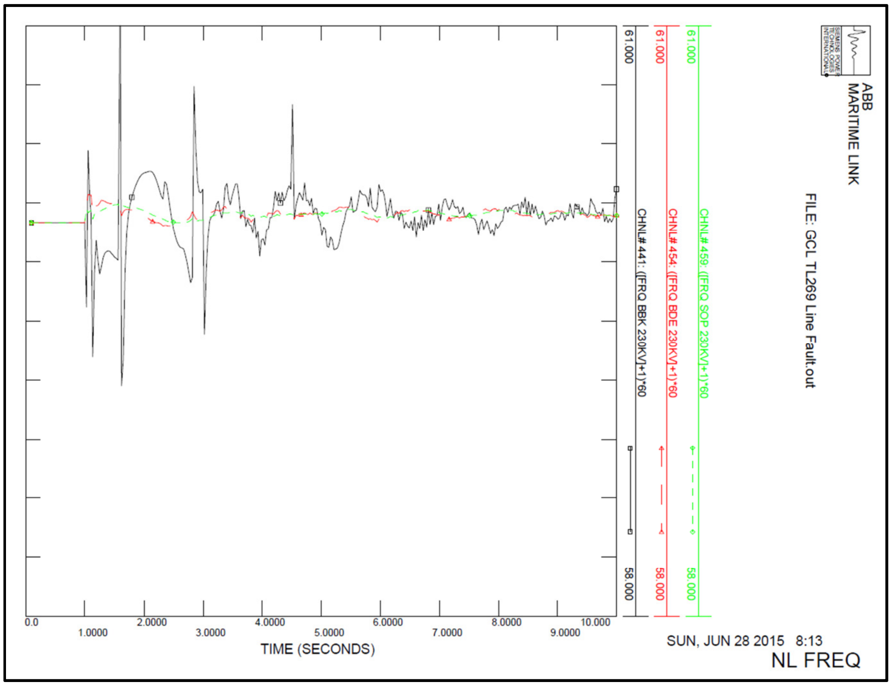

Figure 59: Base Case 8006 – GCL TL269 3-Phase Fault

NL Frequency Response at BBK, BDE and SOP

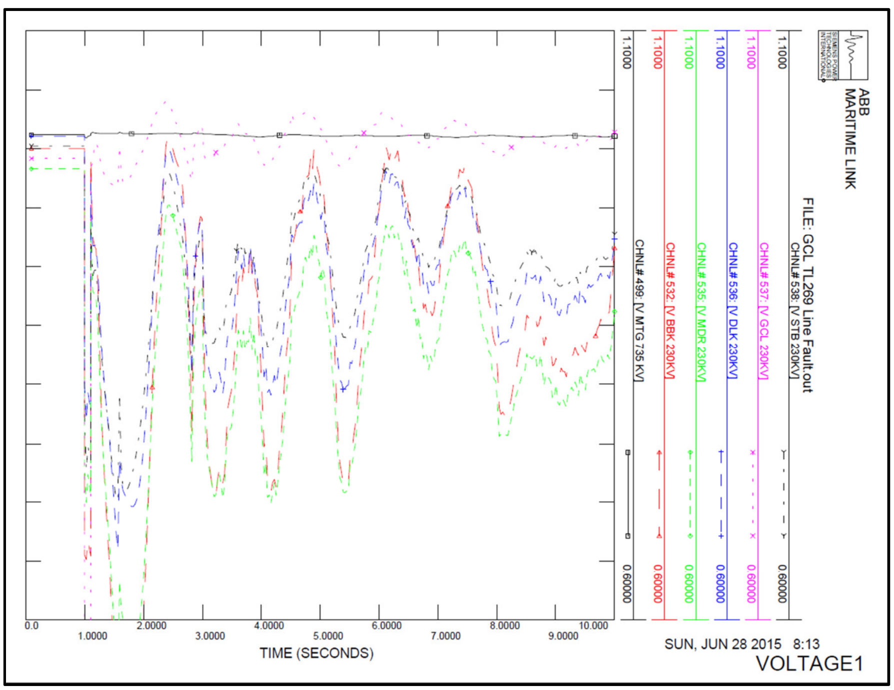

Figure 60: Base Case 8006 – GCL TL269 3-Phase Fault

Bus Voltages at MTG, BBK, MDR, DLK, GCL, STB

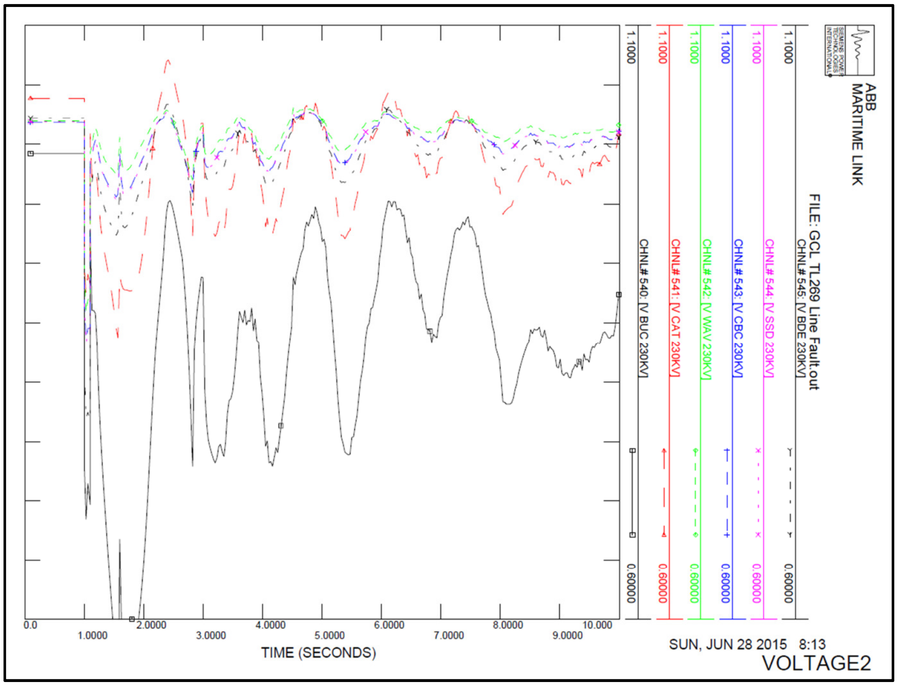

Figure 61: Base Case 8006 – GCL TL269 3-Phase Fault

230 kV Bus Voltages at BUC, CAT, WAV, CBC, SSD, BDE

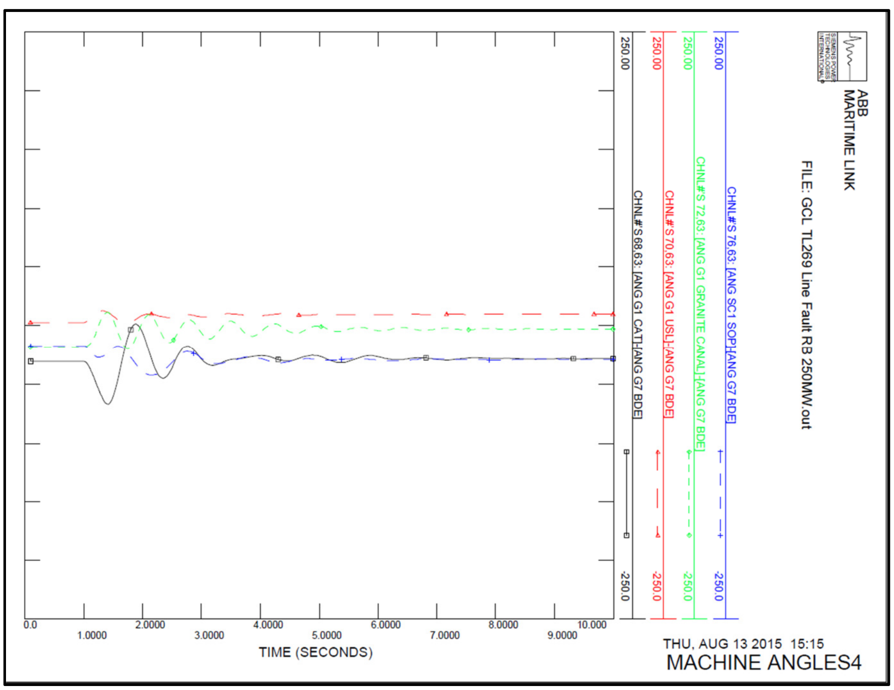

Figure 62: Base Case 8006 – GCL TL269 3-Phase Fault

250 MW ML Runback in 300ms

CAT, USL, GCL and SOP Machine Relative Rotor Angles

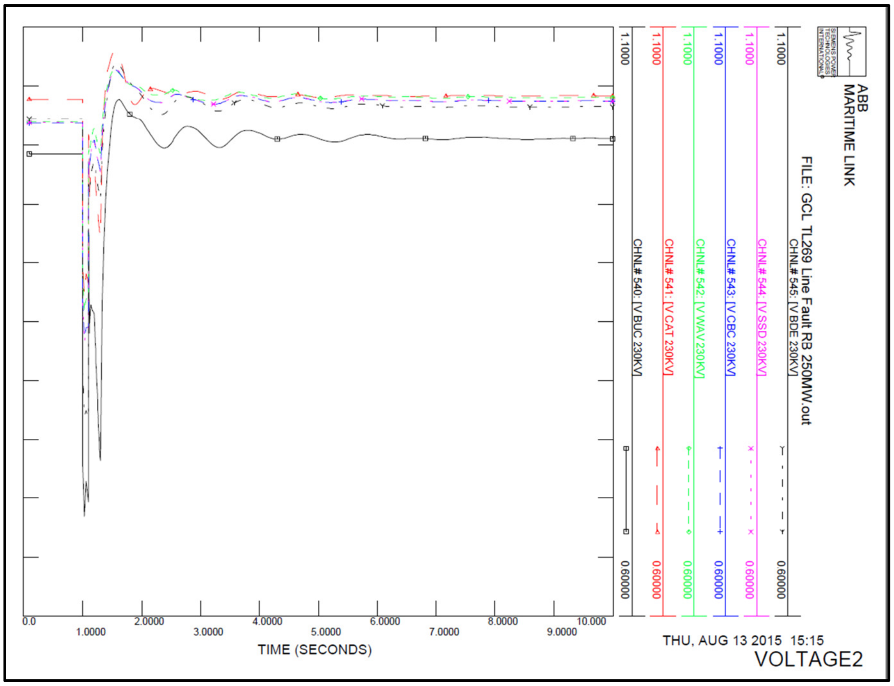

Figure 63: Base Case 8006 – GCL TL269 3-Phase Fault

250 MW ML Runback in 300ms

230 kV Bus Voltages at BUC, CAT, WAV, CBC, SSD, BDE

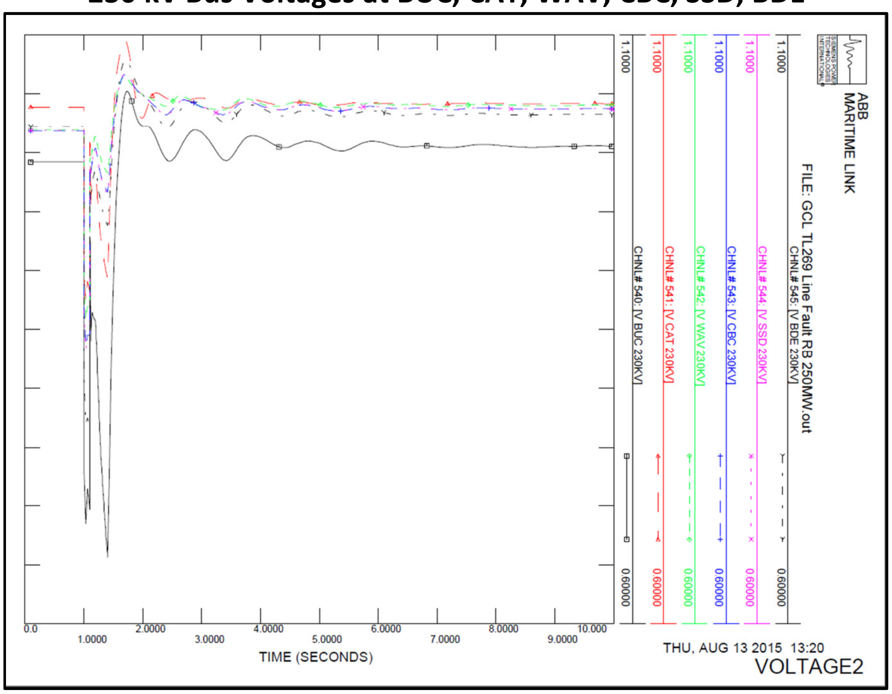

Figure 64: Base Case 8006 – GCL TL269 3-Phase Fault

250 MW ML Runback in 400ms

230 kV Bus Voltages at BUC, CAT, WAV, CBC, SSD, BDE

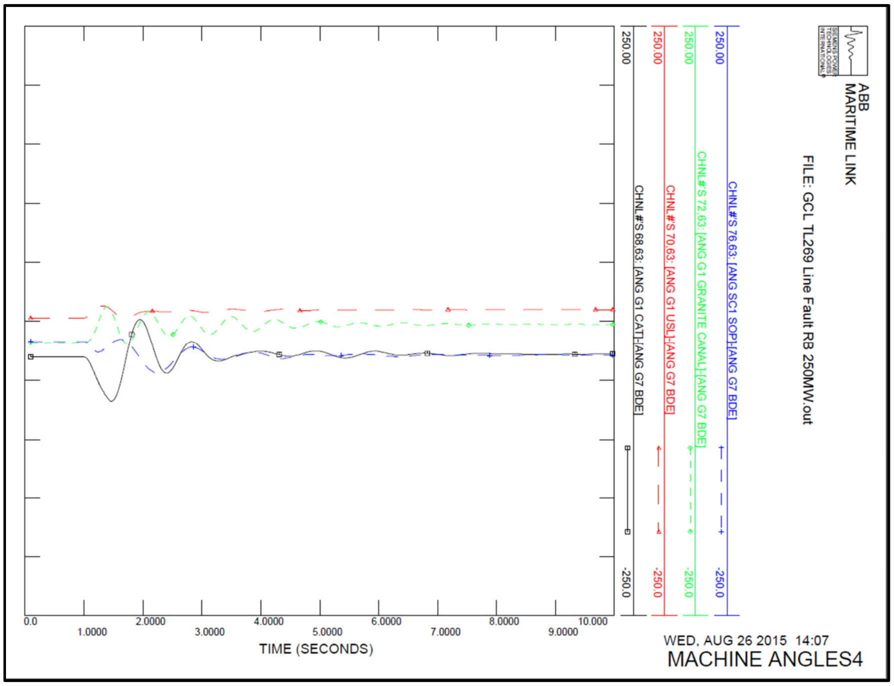

Figure 65: Base Case 8006 – GCL TL269 3-Phase Fault
50 MVAR Capacitor Bank at BBK - 250 MW ML Runback in 400ms
CAT, USL, GCL and SOP Machine Relative Rotor Angles

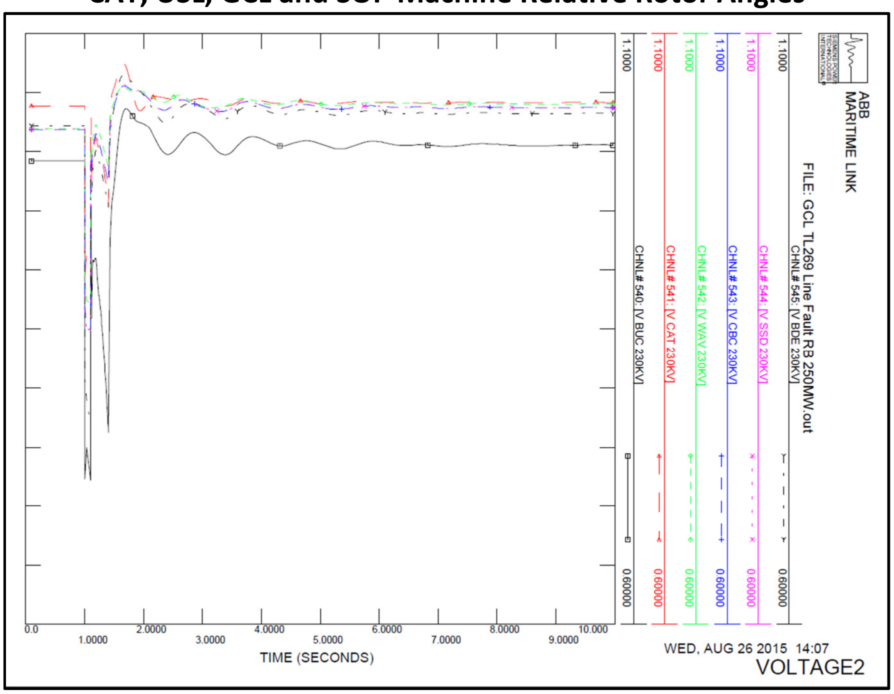

Figure 66: Base Case 8006 – GCL TL269 3-Phase Fault
50 MVAR Capacitor Bank at BBK - 250 MW ML Runback in 400ms
230 kV Bus Voltages at BUC, CAT, WAV, CBC, SSD, BDE

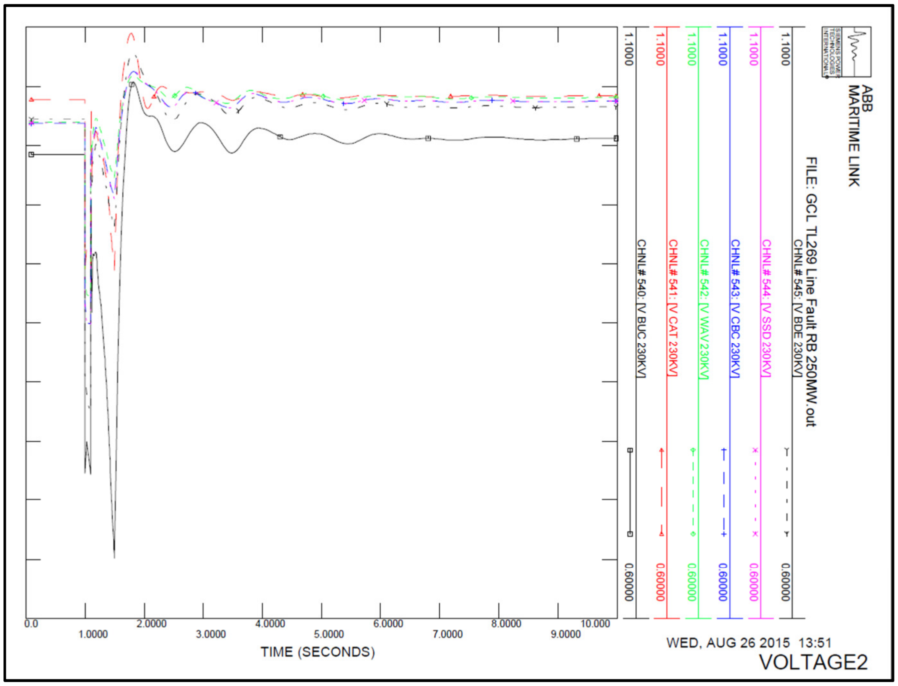

Figure 67: Base Case 8006 – GCL TL269 3-Phase Fault
50 MVAR Capacitor Bank at BBK - 250 MW ML Runback in 500ms
230 kV Bus Voltages at BUC, CAT, WAV, CBC, SSD, BDE

6.2.3 3-PHASE FAULTS AT USL (TL263/TL234)

For faults close in to USL on TL263, power system analysis has determined that a runback of the ML is not required with the installation of a 50 MVAR shunt capacitor bank at BBK to mitigate the unstable system response for this contingency.

Figure 68 and Figure 69 indicate that post fault large generators on the Island do not lose synchronism; however the responses at Cat Arm (CAT) and Granite Canal (GCL) are not well damped. Further analysis into the response of the VSC installed at BBK indicates that the reactive power controller does not maintain a stable voltage on the system. Figure 70 displays the ML's real and reactive power outputs measured at BBK. As a result, the Island's system frequencies west of BDE and bus voltages are relatively unstable, as shown in Figure 71-Figure 73.

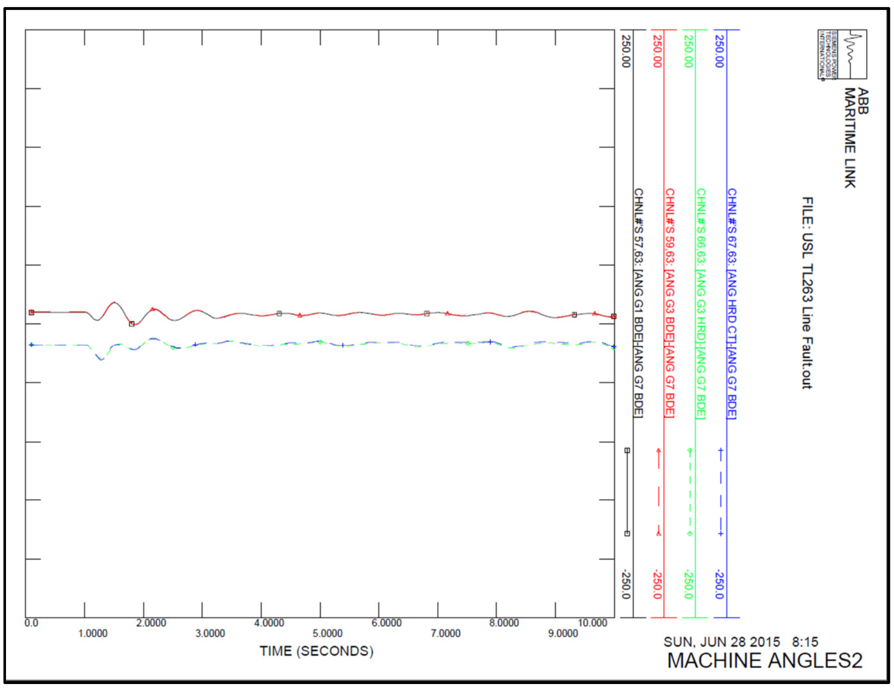

Figure 68: Base Case 8006 – USL TL263 3-Phase Fault BDE and HRD Machine Relative Rotor Angles

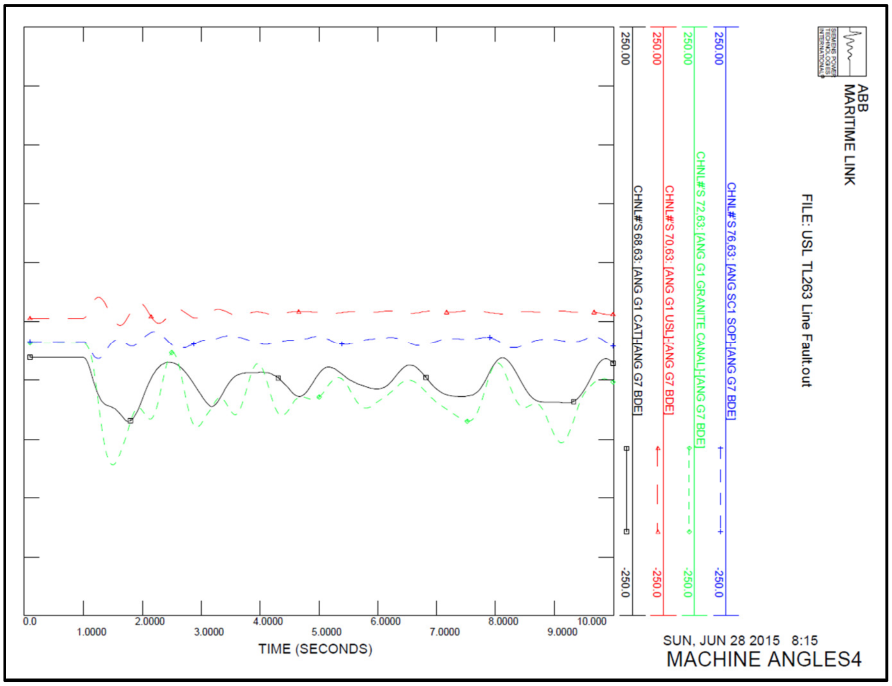

Figure 69: Base Case 8006 – USL TL263 3-Phase Fault

CAT, USL, GCL and SOP Machine Relative Rotor Angles

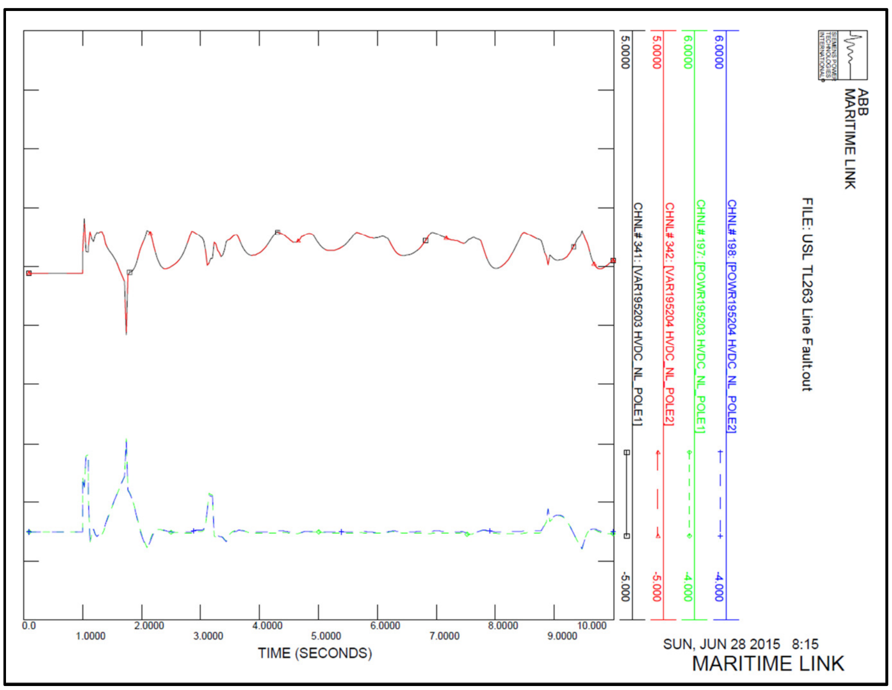

Figure 70: Base Case 8006 – USL TL263 3-Phase Fault

ML Real and Reactive Power Output at BBK (per Pole)

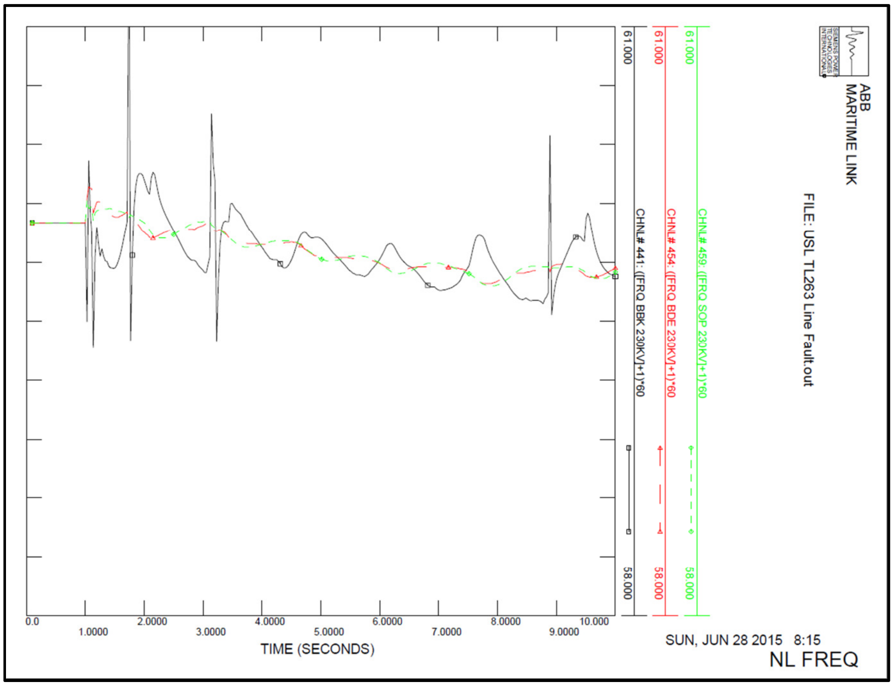

Figure 71: Base Case 8006 – USL TL263 3-Phase Fault
NL Frequency Response at BBK, BDE and SOP

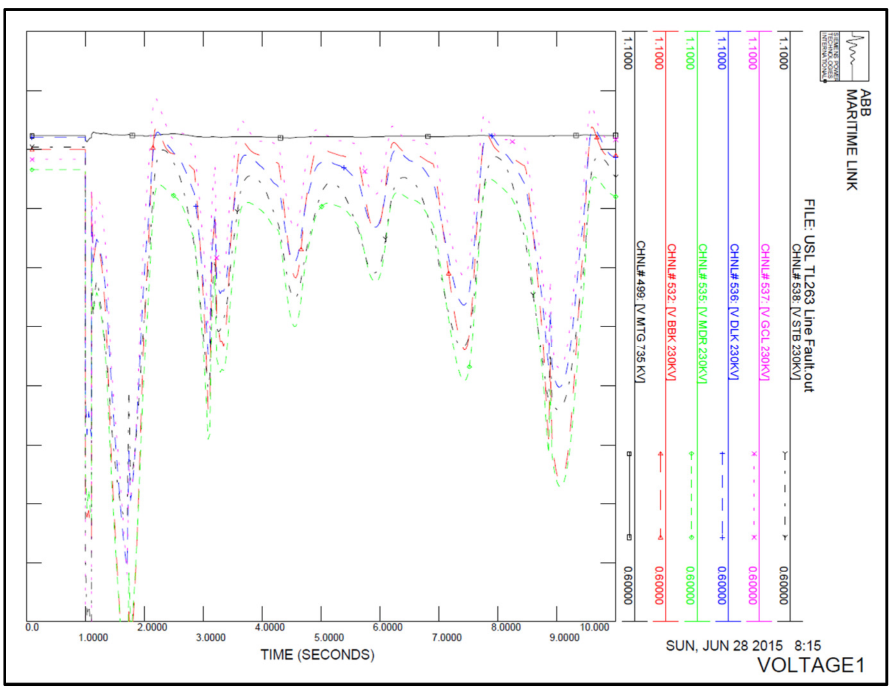

Figure 72: Base Case 8006 – USL TL263 3-Phase Fault
Bus Voltages at MTG, BBK, MDR, DLK, GCL, STB

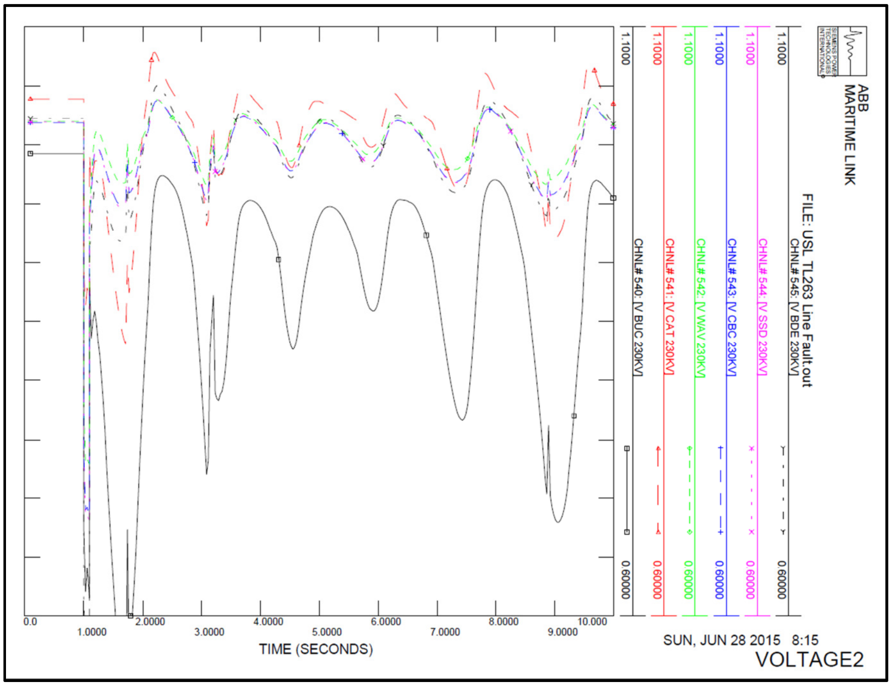

Figure 73: Base Case 8006 – USL TL263 3-Phase Fault

230 kV Bus Voltages at BUC, CAT, WAV, CBC, SSD, BDE

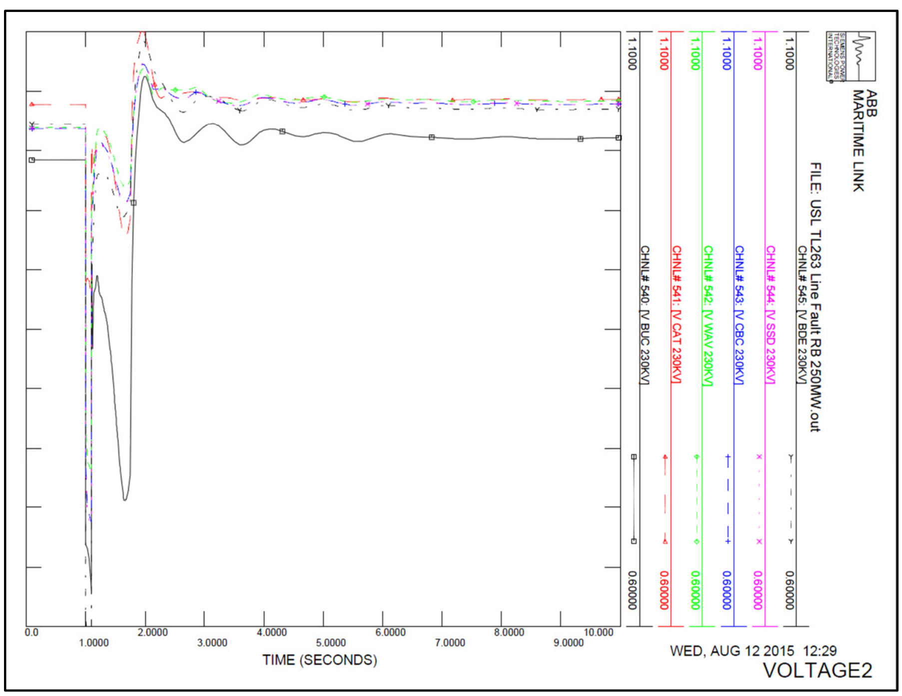

Figure 74: Base Case 8006 – USL TL263 3-Phase Fault

250 MW ML Runback in 300ms

230 kV Bus Voltages at BUC, CAT, WAV, CBC, SSD, BDE

To maintain system stability and provide recovery voltages above 0.70 pu for this contingency a 250 MW runback of the ML in 300 ms is required without the installation of a 50 MVAR shunt capacitor bank at BBK as shown in Figure 75.

For faults close in to USL on TL234, analysis has determined that a runback of the ML is required with or without the installation of a 50 MVAR shunt capacitor bank at BBK.

To maintain recovery voltages above 0.70 pu for this contingency a 100 MW runback of the ML in 750ms is required regardless if 50 MVAR of shunt capacitors are installed at BBK as shown in Figure 75-Figure 82.

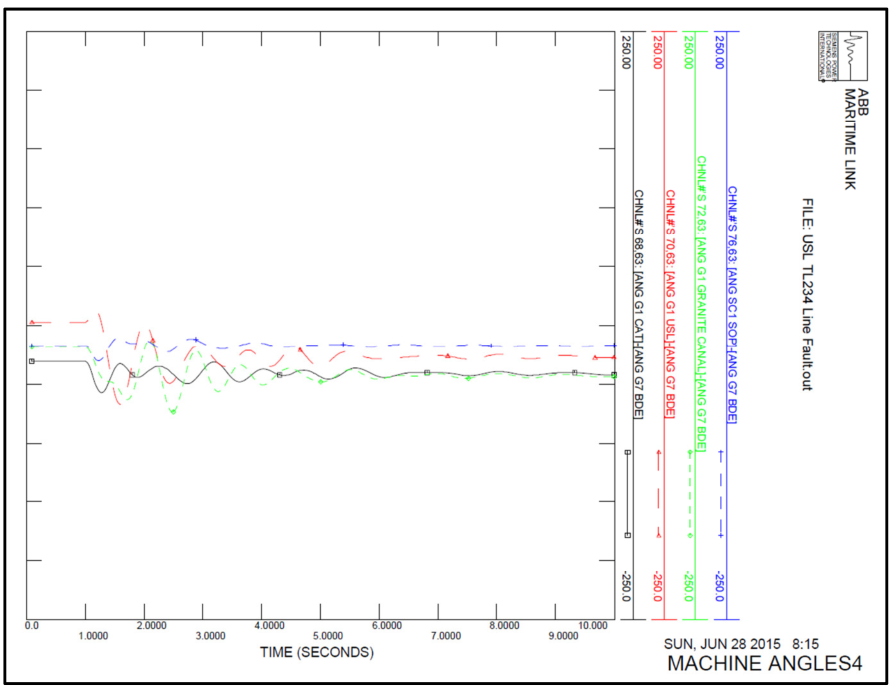

Figure 75: Base Case 8006 – USL TL234 3-Phase Fault
CAT, USL, GCL and SOP Machine Relative Rotor Angles

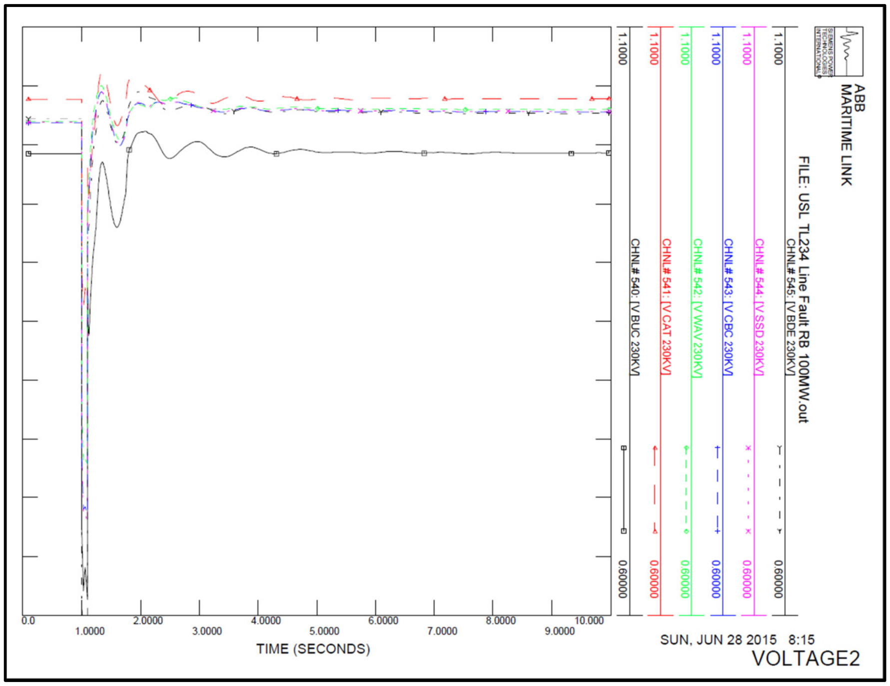

Figure 76: Base Case 8006 – USL TL234 3-Phase Fault

230 kV Bus Voltages at BUC, CAT, WAV, CBC, SSD, BDE

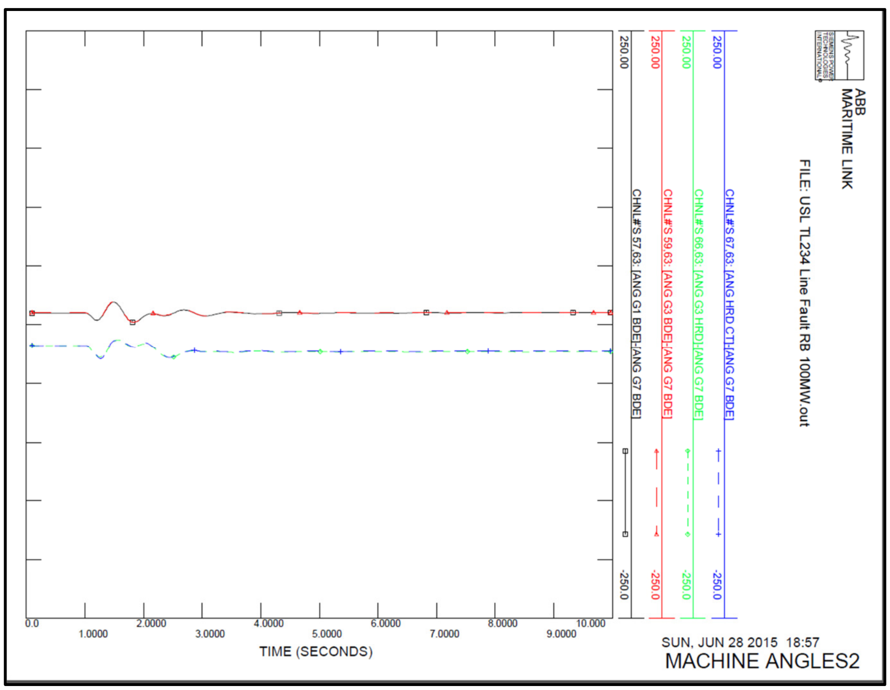

Figure 77: Base Case 8006 – USL TL234 3-Phase Fault

50 MVAR Capacitor Bank at BBK - 100 MW ML Runback in 750ms

BDE and HRD Machine Relative Rotor Angles

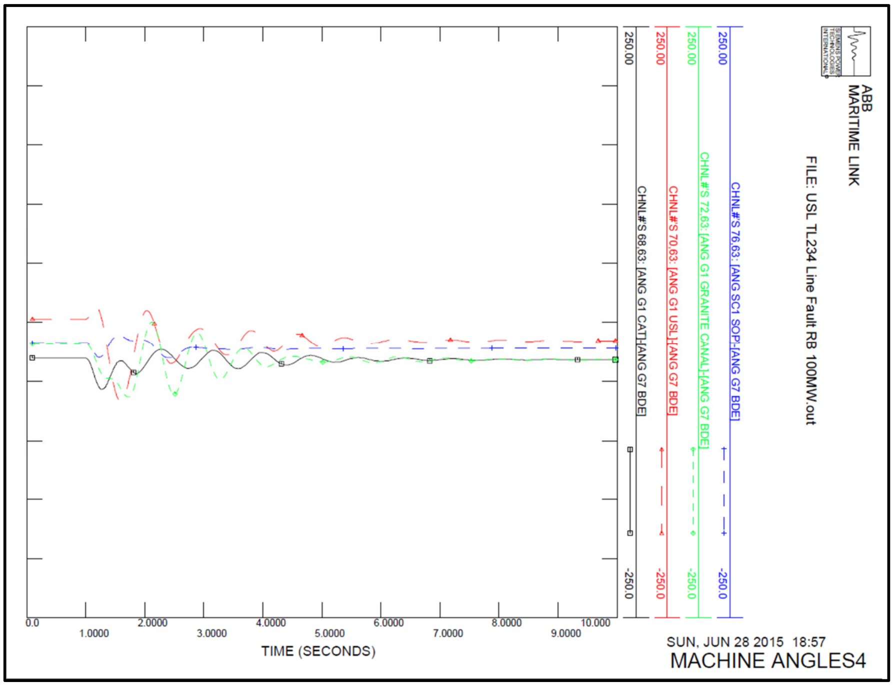

Figure 78: Base Case 8006 – USL TL234 3-Phase Fault
50 MVAR Capacitor Bank at BBK - 100 MW ML Runback in 750ms
CAT, USL, GCL and SOP Machine Relative Rotor Angles

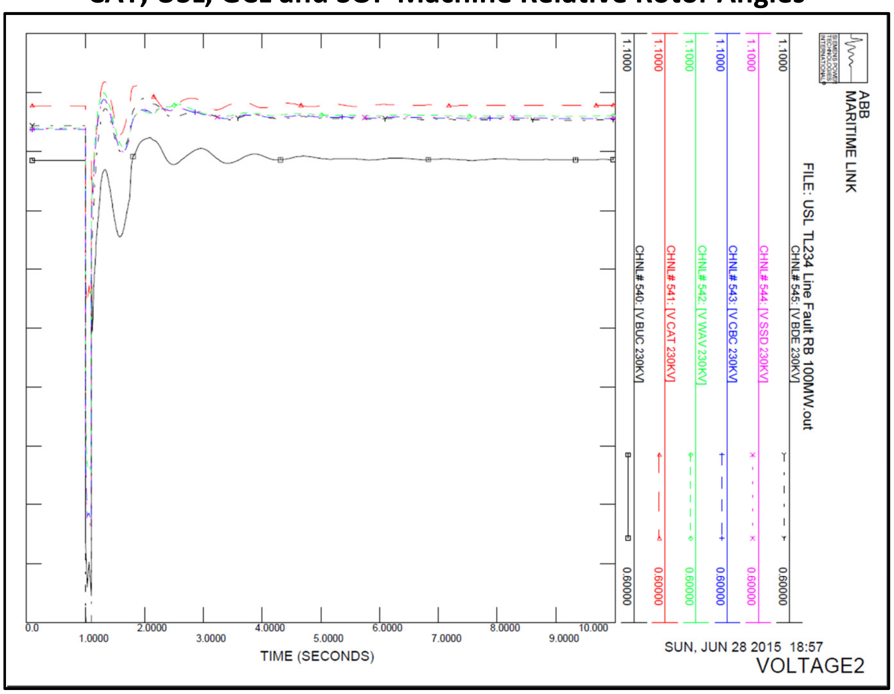

Figure 79: Base Case 8006 – USL TL234 3-Phase Fault
50 MVAR Capacitor Bank at BBK - 100 MW ML Runback in 750ms
230 kV Bus Voltages at BUC, CAT, WAV, CBC, SSD, BDE

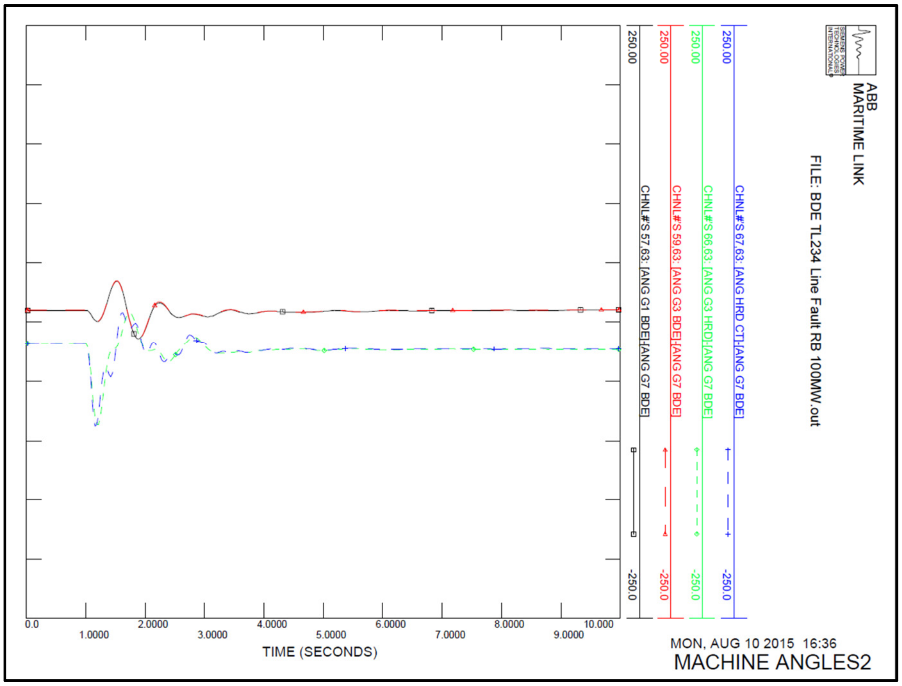

Figure 80: Base Case 8006 – USL TL234 3-Phase Fault

100 MW ML Runback in 750ms

BDE and HRD Machine Relative Rotor Angles

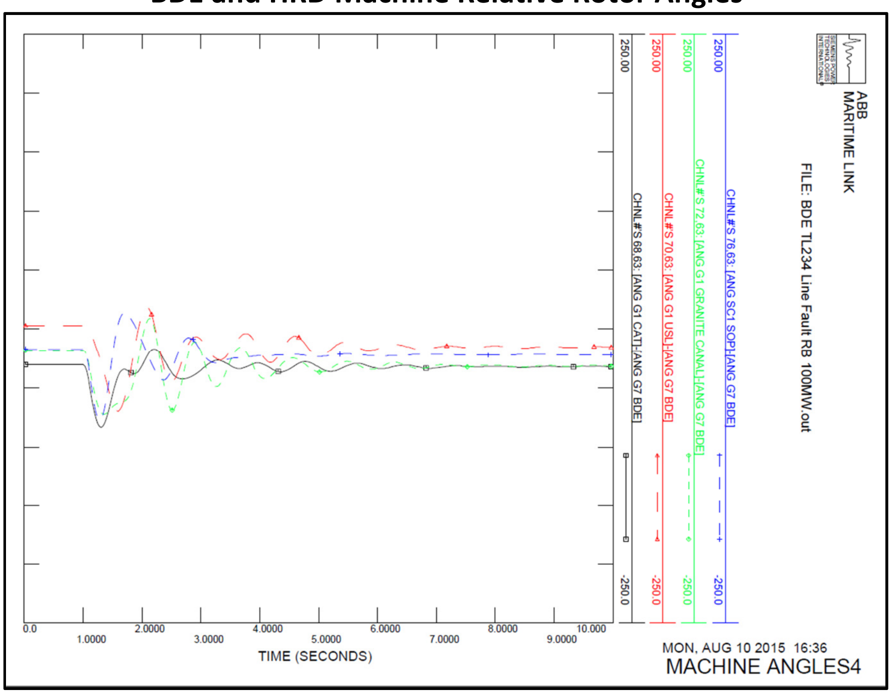

Figure 81: Base Case 8006 – USL TL234 3-Phase Fault

100 MW ML Runback in 750ms

CAT, USL, GCL and SOP Machine Relative Rotor Angles

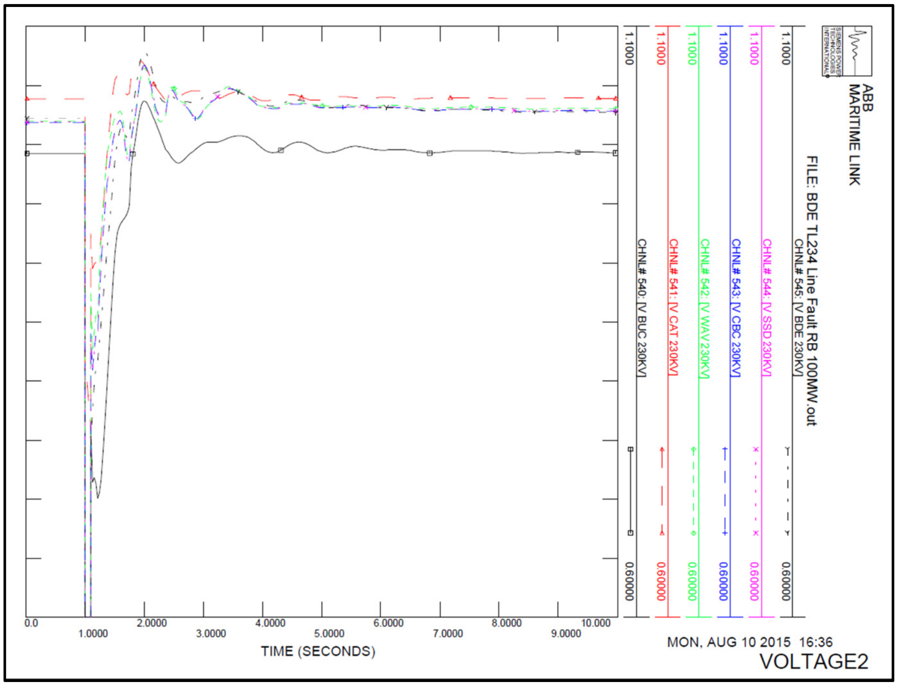

Figure 82: Base Case 8006 – USL TL234 3-Phase Fault
100 MW ML Runback in 750ms
230 kV Bus Voltages at BUC, CAT, WAV, CBC, SSD, BDE

6.3 TEMPORARY BIPOLE FAULTS

The Island Interconnected System has been designed to withstand temporary bipole faults by providing the required inertia in the form of high inertia synchronous condensers at Soldiers Pond. The number and size of the units have been selected such that a temporary loss of 900 MW does not result in an extremely large rate of change of system frequency which avoids activation of the Island's underfrequency load shedding protection system.

The system response for temporary bipole faults was stable with performance meeting the NLH System Planning Criteria. It should be noted that the ML export does not require curtailment to meet the performance criteria using the CDC4T dynamics model of the LIL[14]. Figure 83-Figure 85 show the relative angles of the major machines in the NLH system, while Figure 86 and Figure 87 display the response of each HVdc system following a 300ms trip of the LIL bipole operating at rated 900 MW. The system frequency response following loss of 900 MW is shown in Figure 88 which decays quickly but recovers without activation of the UFLS protection system. The major terminal station 230 kV bus voltages following the fault are shown in Figure 89.

[14] Temporary and permanent bipole faults will be analyzed by the vendor in detail using the updated GE Grid PSS®E LIL model which includes all the tuned HVdc control parameters. Results from later studies may indicate a need for high speed protection grade signals from the LIL control system to the ML VSC control system for a curtailment of exports to NS.

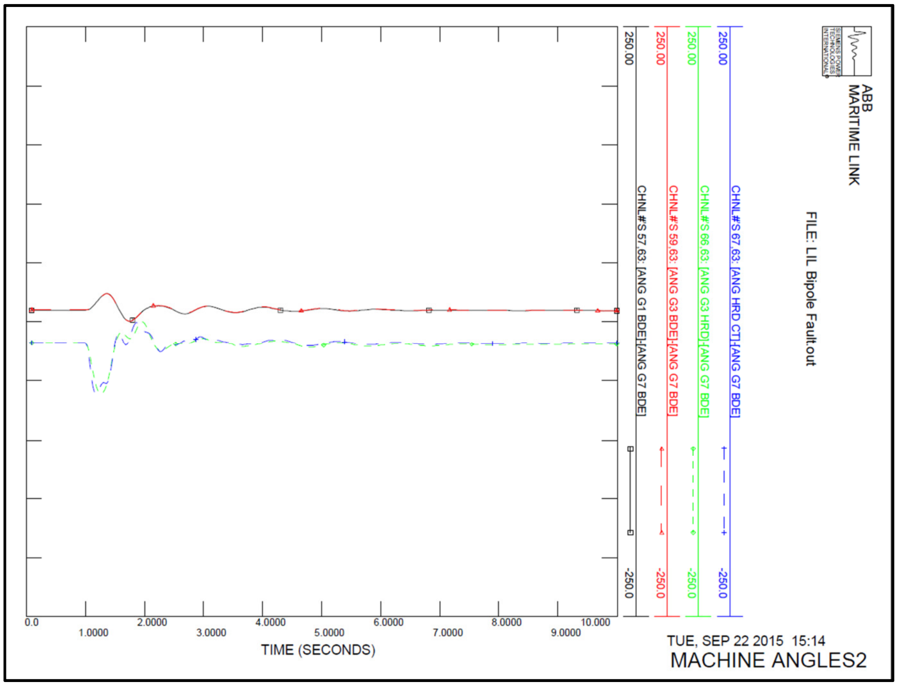

Figure 83: Base Case 8006 – LIL Temporary Bipole Fault

Fault Cleared in 300ms

BDE and HRD Machine Relative Rotor Angles

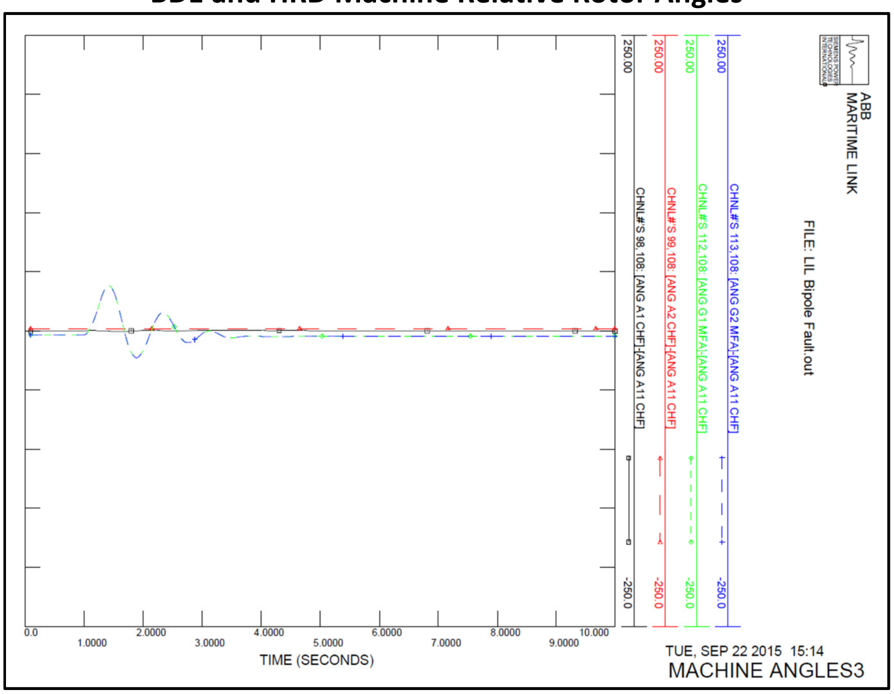

Figure 84: Base Case 8006 – LIL Temporary Bipole Fault

Fault Cleared in 300ms

CHF and MFA Machine Relative Rotor Angles

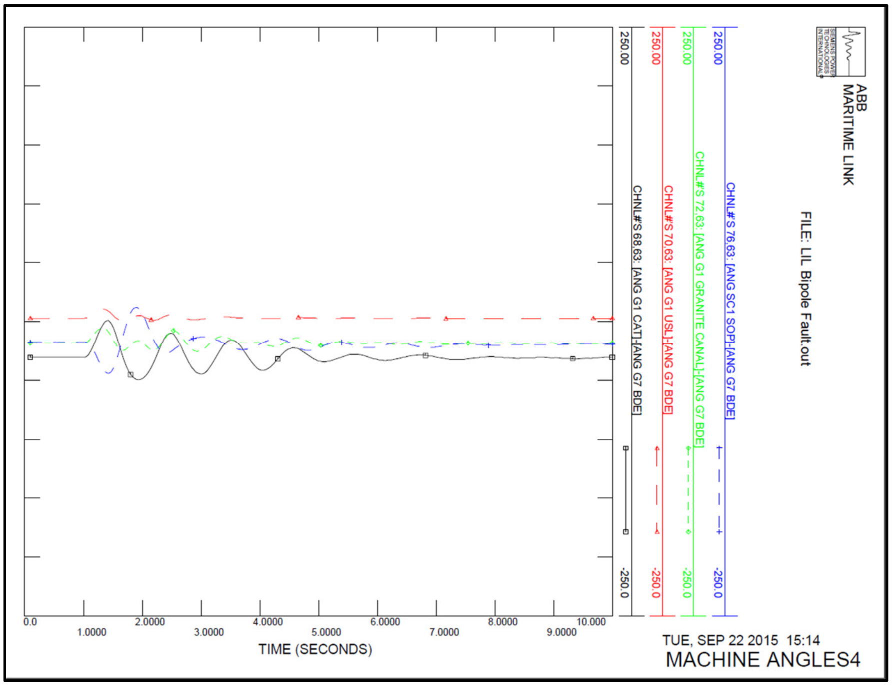

Figure 85: Base Case 8006 – LIL Temporary Bipole Fault

Fault Cleared in 300ms

CAT, USL, GCL and SOP Machine Relative Rotor Angles

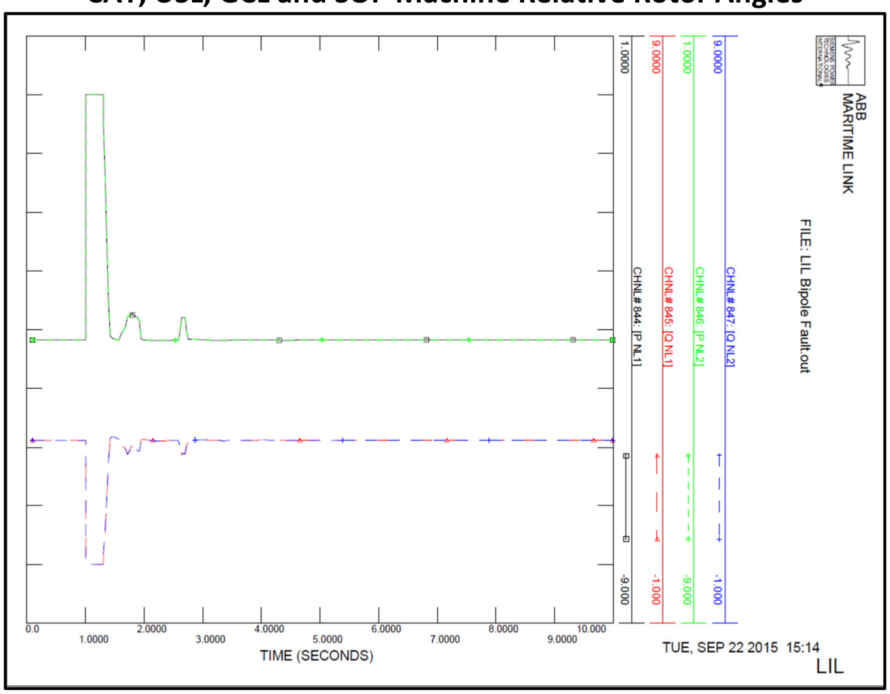

Figure 86: Base Case 8006 – LIL Temporary Bipole Fault

Fault Cleared in 300ms

LIL Real and Reactive Power Output at SOP (per Pole)

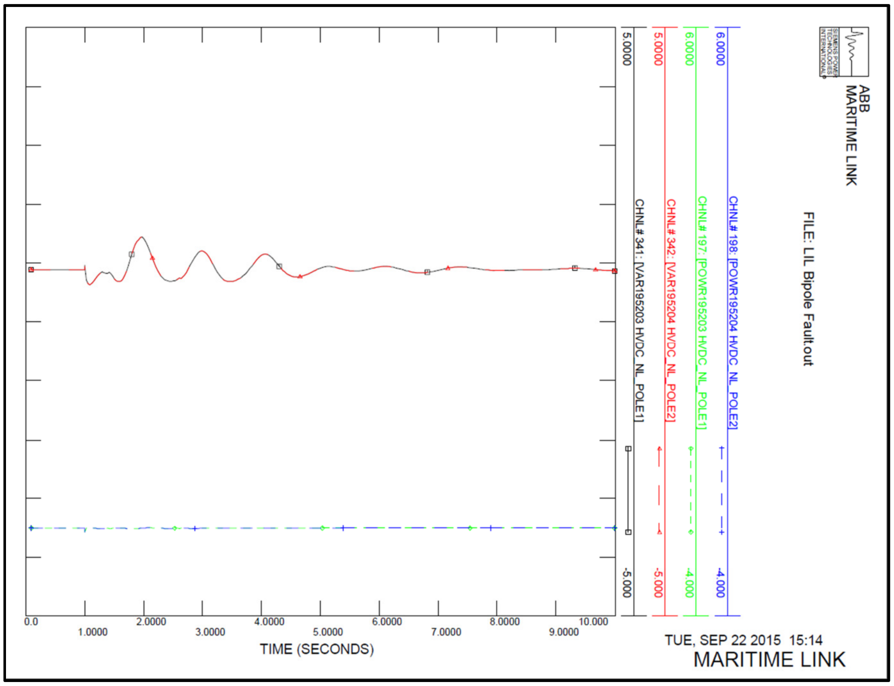

Figure 87: Base Case 8006 – LIL Temporary Bipole Fault

Fault Cleared in 300ms

ML Real and Reactive Power Output at BBK (per Pole)

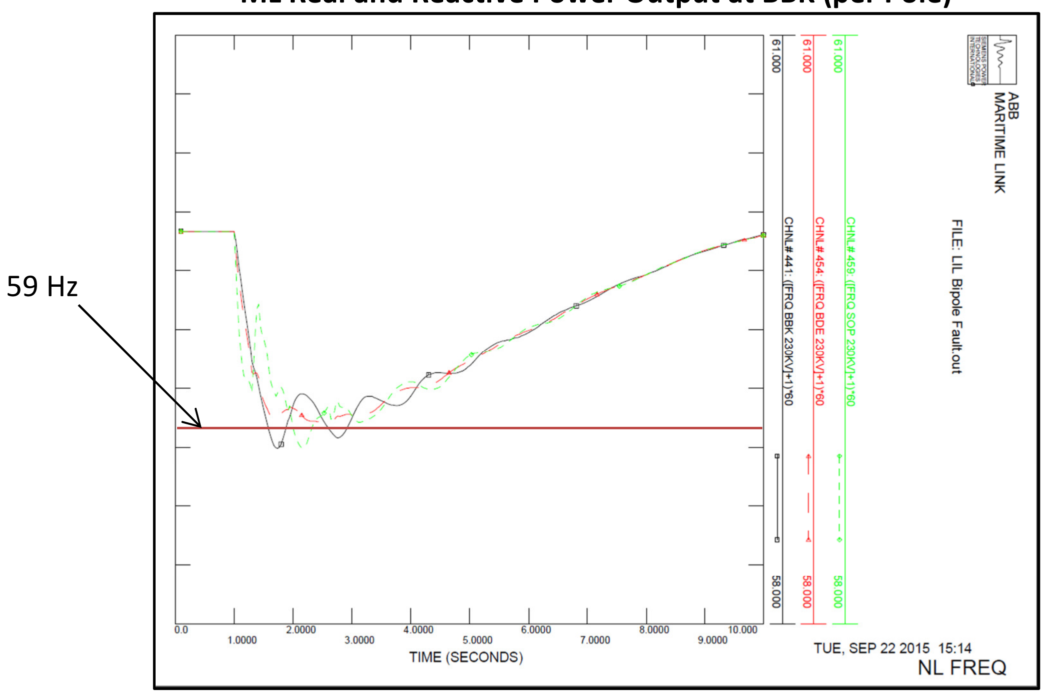

Figure 88: Base Case 8006 – LIL Temporary Bipole Fault

Fault Cleared in 300ms

NL Frequency Response at BBK, BDE and SOP

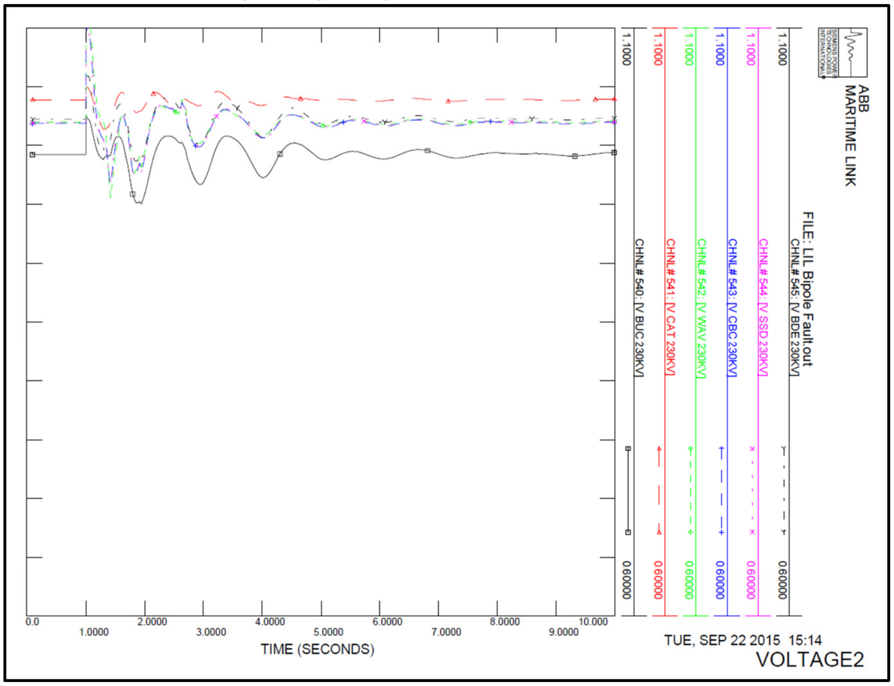

Figure 89: Base Case 8006 – LIL Temporary Bipole Fault

Fault Cleared in 300ms

230 kV Bus Voltages at BUC, CAT, WAV, CBC, SSD, BDE

6.4 PERMANENT POLE FAULTS

Permanent pole and bipole faults on the LIL may result in the curtailment of customer loads through activation of the UFLS protection system on the Island Interconnected System. To mitigate risk of underfrequency load shedding from pole fault, the design of the LIL controls and equipment have allowed for a 10 minute 2.0 pu and continuous 1.5 pu current overload on the healthy pole for the permanent loss of a pole. However, due to the increased losses on the transmission circuit for operation in monopolar configuration there is a system shortfall of approximately 225 MW which must be considered.

If the ML export power is not curtailed for the permanent loss of a pole, the generation deficit will activate the UFLS protection system to maintain system stability by disconnecting customer load as the system frequency falls. The amount and speed of the UFLS protection system is determined mainly by the rate of change of system frequency. As the frequency reaches 58 Hz the system begins shedding all remaining available load.

Therefore, the system design methodology involves the curtailment of the ML for all pole/bipole events. There will be high speed communications between the links to curtail ML exports in the event of a pole/bipole outage.

Despite the curtailment of the ML, for the permanent loss of the bipole, the generation deficit will activate the UFLS protection system to maintain system stability by disconnecting customer load as the system frequency falls. For the permanent loss of the LIL bipole, adjustments to the UFLS on the Island Interconnected System will be required to ensure a controlled recovery. Table 17 outlines the results of the permanent pole and bipole outages on the Labrador Island Link utilizing the existing UFLS scheme.

In base case 8001 there is no spinning reserve carried on either the LIL or the Island Interconnected System. Therefore, a permanent pole or bipole fault will result in UFLS. However, if the ML is curtailed for a permanent pole fault there will be no UFLS on the Island. This result is found in each base case where the LIL is at rated output and the ML is not curtailed.

All permanent bipole faults resulted in UFLS for the cases studied and demonstrates a requirement to adjust the existing UFLS scheme to rebalance supply and load. Analysis to date indicates that curtailment of the ML for a LIL bipole fault must be part of the adjusted Island UFLS scheme. The design of the post-interconnection UFLS scheme will be the subject of the operational studies to be completed in 2016.

Base case 8006 was selected first for study as both HVdc links are transferring their rated power. Figure 90 displays angular stability of the Island Interconnected System assuming systematic shedding of customer load for the pole fault. The Labrador Island Link (LIL) following the loss of a single pole activates the 2.0 pu current overload on the remaining healthy pole which is operating in monopole ground return configuration as shown in Figure 91. Figure 92 clearly shows the Maritime Link (ML) riding through the disturbance without altering its export power while Figure 93 displays power system frequency decay and recovery following customer load shedding.

To maintain supply for Island customers following a permanent pole fault the ML export must be curtailed. For base case 8006 a runback of 500 MW at the BBK converter maintained stable system operation following a permanent pole fault and the UFLS protection system was not triggered. Figure 94 and Figure 95 display the monopole 2.0 pu current overload on the LIL and the curtailment of 500 MW over the ML respectively. The curtailment of ML export results in an Island stable system response as shown in Figure 96-Figure 97. The frequency of the Island Interconnected System does not decay with the ML curtailment, while the results indicate an increase in overall system frequency. The spike in frequency at BBK can be attributed directly to the instantaneous curtailment of 500 MW of export.

Table 17 – Notable System Conditions Following Permanent Pole/Bipole Faults

<table>
<tr><th>Base Case</th><th>Contingency</th><th colspan="2">System Condition</th><th>ML Curtailment (MW)</th><th>Load Shed (MW)</th></tr>
<tr><td rowspan="3">8001</td><td rowspan="2">LIL Permanent Pole Fault</td><td rowspan="2">Stable System</td><td>UFLS</td><td>0</td><td>87</td></tr>
<tr><td>No UFLS</td><td>158</td><td>0</td></tr>
<tr><td>LIL Permanent Bipole Fault</td><td colspan="2">UFLS is Activated, System Collapse</td><td>158</td><td>519</td></tr>
<tr><td rowspan="3">8002</td><td rowspan="2">LIL Permanent Pole Fault</td><td rowspan="2">Stable System</td><td>No UFLS</td><td>0</td><td>0</td></tr>
<tr><td>No UFLS</td><td>158</td><td>0</td></tr>
<tr><td>LIL Permanent Bipole Fault</td><td colspan="2">UFLS is Activated, System Collapse</td><td>158</td><td>516</td></tr>
<tr><td rowspan="3">8003</td><td rowspan="2">LIL Permanent Pole Fault</td><td rowspan="2">Stable System</td><td>UFLS</td><td>0</td><td>132</td></tr>
<tr><td>No UFLS</td><td>350</td><td>0</td></tr>
<tr><td>LIL Permanent Bipole Fault</td><td colspan="2">UFLS is Activated, System Collapse</td><td>350</td><td>336</td></tr>
<tr><td rowspan="3">8005</td><td rowspan="2">LIL Permanent Pole Fault</td><td rowspan="2">Stable System</td><td>No UFLS</td><td>0</td><td>0</td></tr>
<tr><td>No UFLS</td><td>158</td><td>0</td></tr>
<tr><td>LIL Permanent Bipole Fault</td><td colspan="2">UFLS is Activated, System Collapse</td><td>158</td><td>395</td></tr>
<tr><td rowspan="3">8006</td><td rowspan="2">LIL Permanent Pole Fault</td><td rowspan="2">Stable System</td><td>UFLS</td><td>0</td><td>66</td></tr>
<tr><td>No UFLS</td><td>500</td><td>0</td></tr>
<tr><td>LIL Permanent Bipole Fault</td><td colspan="2">UFLS is Activated, System Stable</td><td>500</td><td>240</td></tr>
<tr><td rowspan="4">8007</td><td rowspan="2">LIL Permanent Pole Fault</td><td rowspan="2">UFLS is Activated, System Collapse</td><td>No UFLS</td><td>0</td><td>0</td></tr>
<tr><td>No UFLS</td><td>337</td><td>0</td></tr>
<tr><td rowspan="2">LIL Permanent Bipole Fault</td><td colspan="2">UFLS is Activated, System Collapse</td><td>0</td><td>103</td></tr>
<tr><td colspan="2">UFLS is Activated, System Collapse</td><td>337</td><td>0</td></tr>
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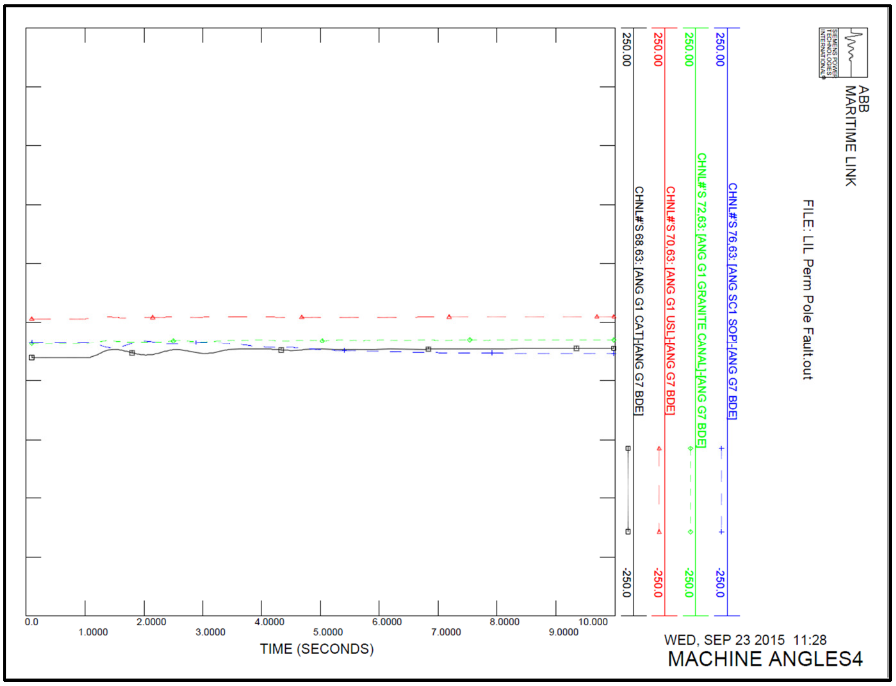

Figure 90: Base Case 8006 – LIL Permanent Pole Fault
No Curtailment of ML Export Power
CAT, USL, GCL and SOP Machine Relative Rotor Angles

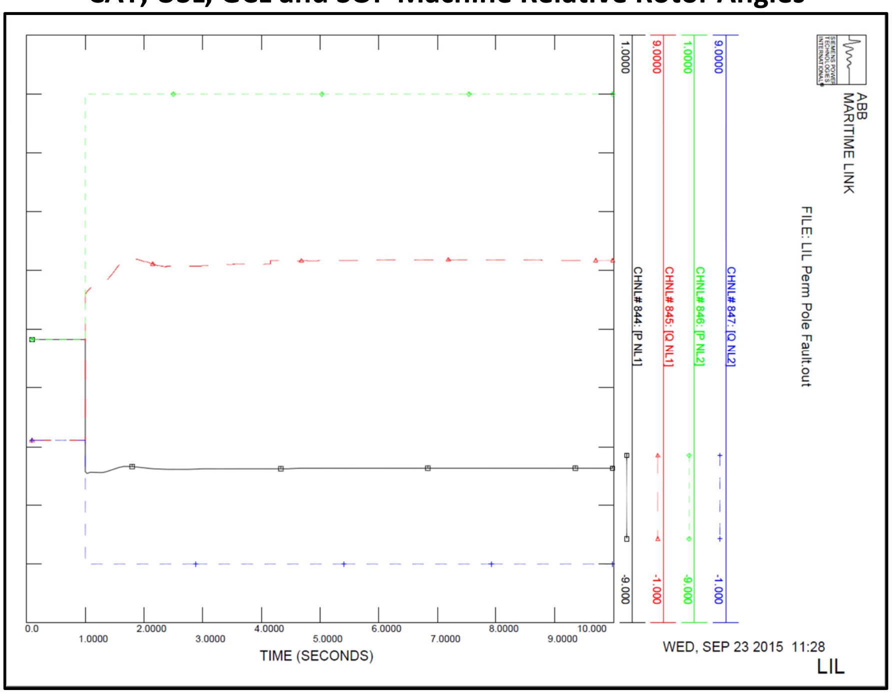

Figure 91: Base Case 8006 – LIL Permanent Pole Fault
No Curtailment of ML Export Power
LIL Real and Reactive Power Output at SOP (per Pole)

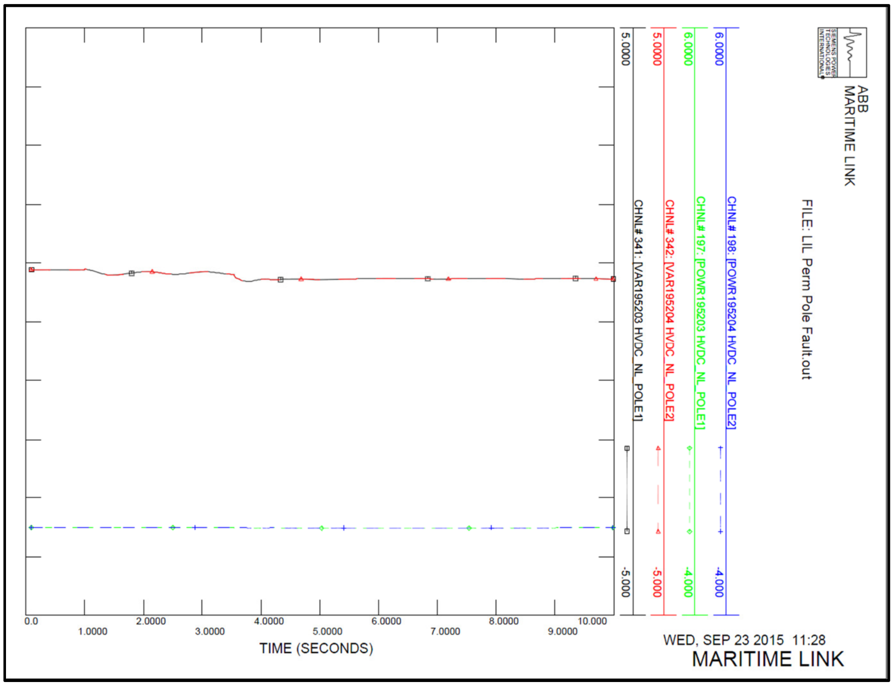

Figure 92: Base Case 8006 – LIL Permanent Pole Fault

No Curtailment of ML Export Power

ML Real and Reactive Power Output at BBK (per Pole)

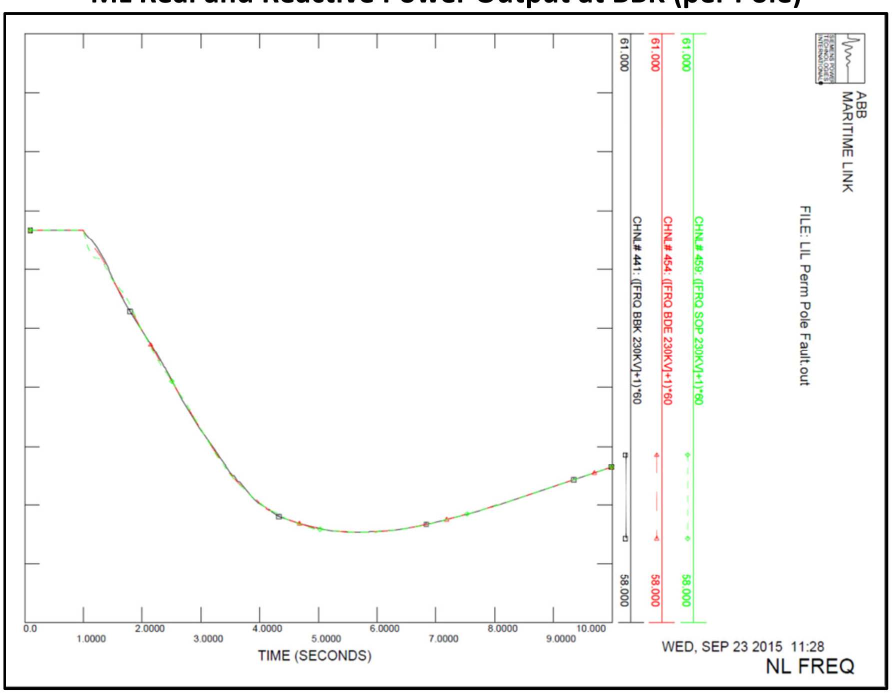

Figure 93: Base Case 8006 – LIL Permanent Pole Fault

No Curtailment of ML Export Power

NL Frequency Response at BBK, BDE and SOP

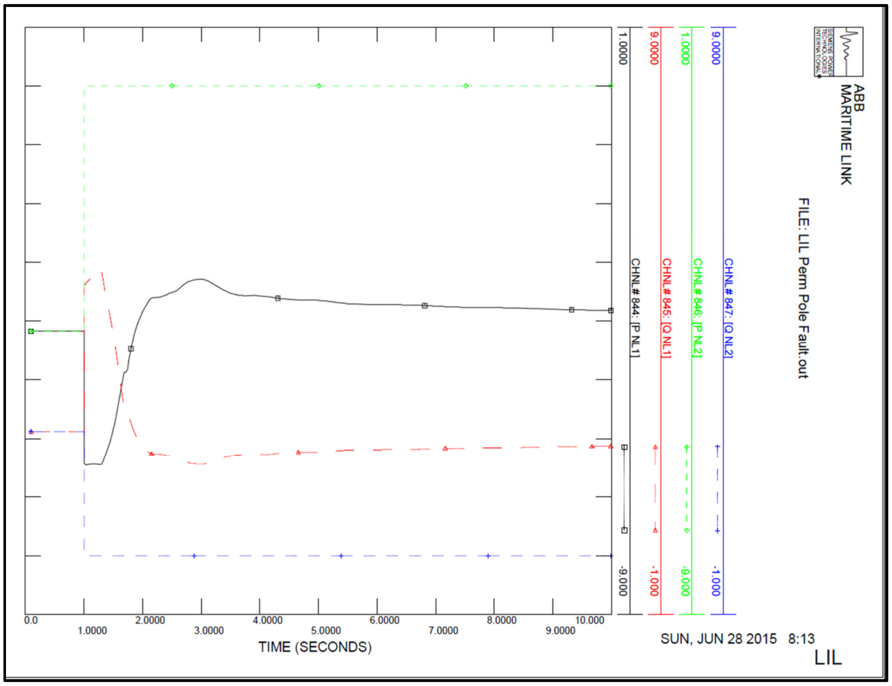

Figure 94: Base Case 8006 – LIL Permanent Pole Fault
Maritime Link 500 MW Curtailment
LIL Real and Reactive Power Output at SOP (per Pole)

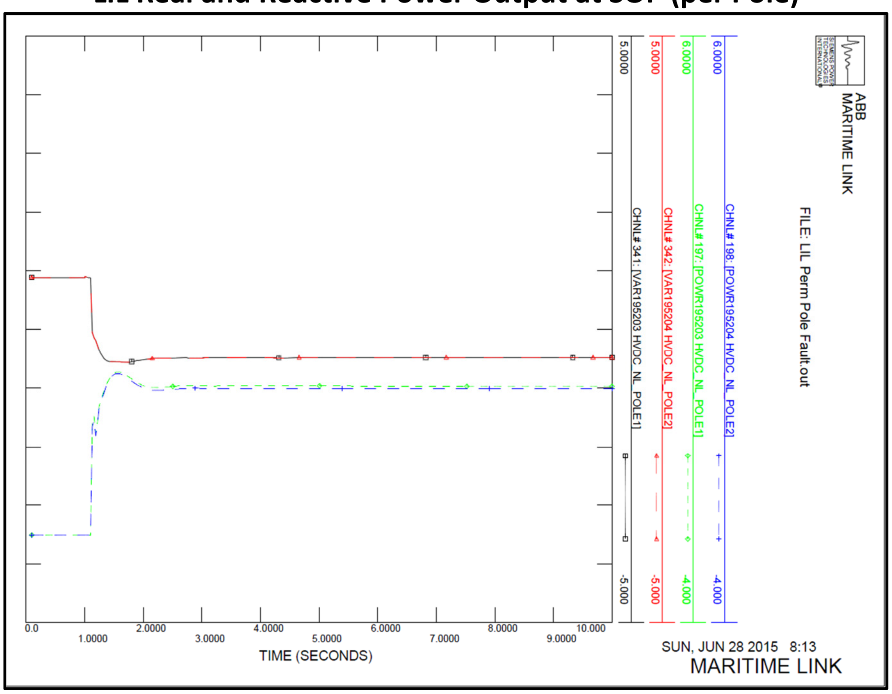

Figure 95: Base Case 8006 – LIL Permanent Pole Fault
Maritime Link 500 MW Curtailment
ML Real and Reactive Power Output at BBK (per Pole)

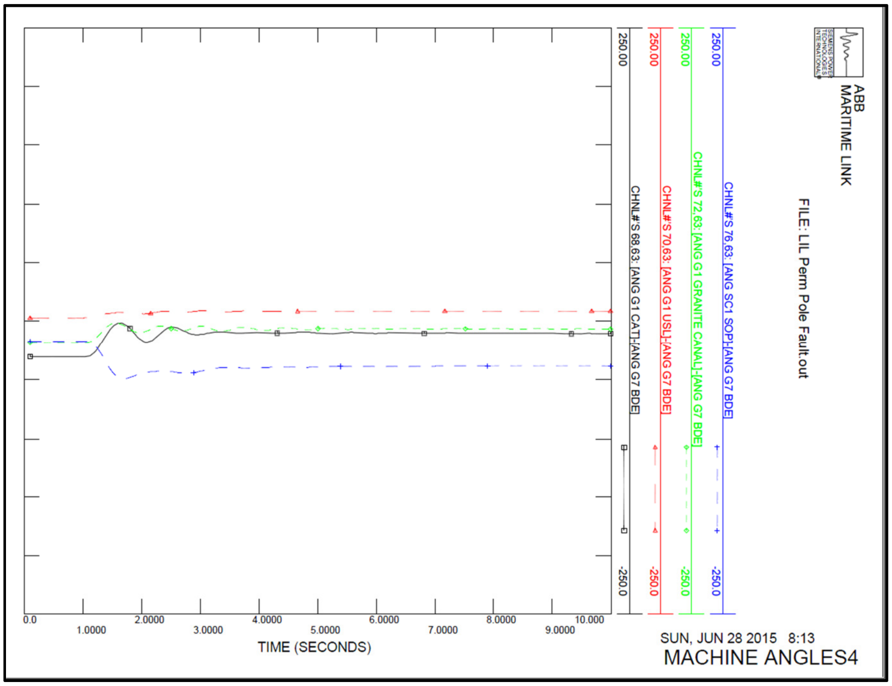

Figure 96: Base Case 8006 – LIL Permanent Pole Fault
Maritime Link 500 MW Curtailment
CAT, USL, GCL and SOP Machine Relative Rotor Angles

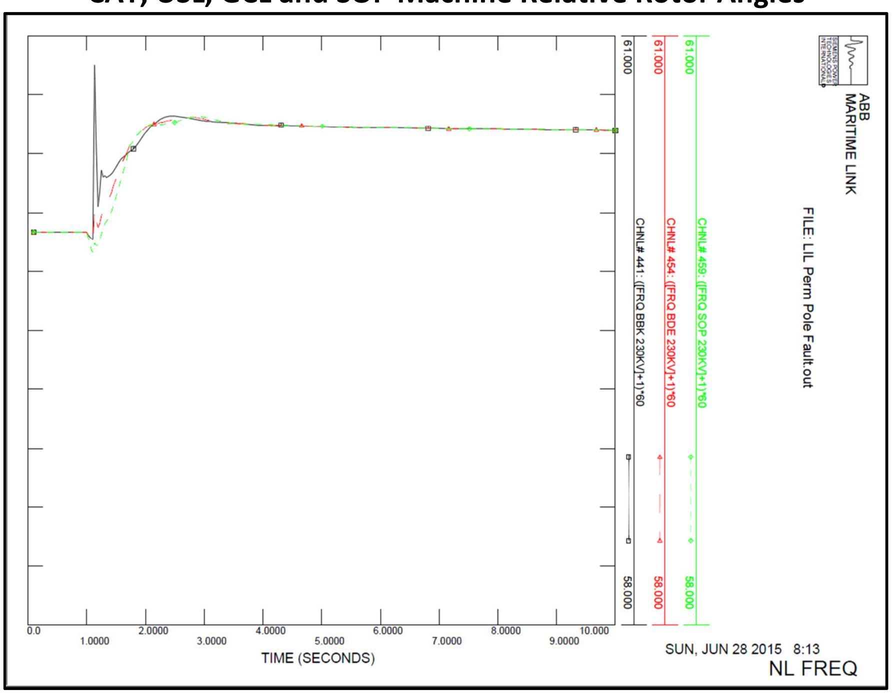

Figure 97: Base Case 8006 – LIL Permanent Pole Fault
Maritime Link 500 MW Curtailment
NL Frequency Response at BBK, BDE and SOP

For a permanent bipole fault, a loss of supply of the rated capacity of the LIL (900MW) will result in a rapid decay of frequency on the Island forcing the Island Interconnected System to shed customer load via the UFLS protection system despite the curtailment of exports over the ML. NLH will determine if the existing UFLS protection system is sufficient to shed load in a controlled manner while maintain generation on the Island for the permanent loss of the bipole.

For base case 8006, without curtailment of the ML, the loss of the LIL bipole with 833 MW landed in SOP results in the collapse of the Island Interconnected System as shown in Figure 98: Base Case 8006 – LIL Permanent Bipole Fault-Figure 100. The instantaneous curtailment of export power over the ML VSC at BBK allows the converter to remain online and provide voltage and angular support to the system following the trip of the LIL bipole. In this case the existing NLH UFLS protection system is activated and disconnects 240 MW of customer load. The analysis demonstrates that system frequency is restored following the UFLS event due to spinning reserve on the Island. Figure 101-Figure 103 show how a combination of the ML curtailment and UFLS protection system maintained a stable power system. Base case 8006 was the only case which was able to survive the permanent loss of the LIL bipole. Adjustments made to the UFLS protection system may be able to prevent other bipole trips from collapsing the Island Interconnected Transmission System, which is outside the scope of this study.

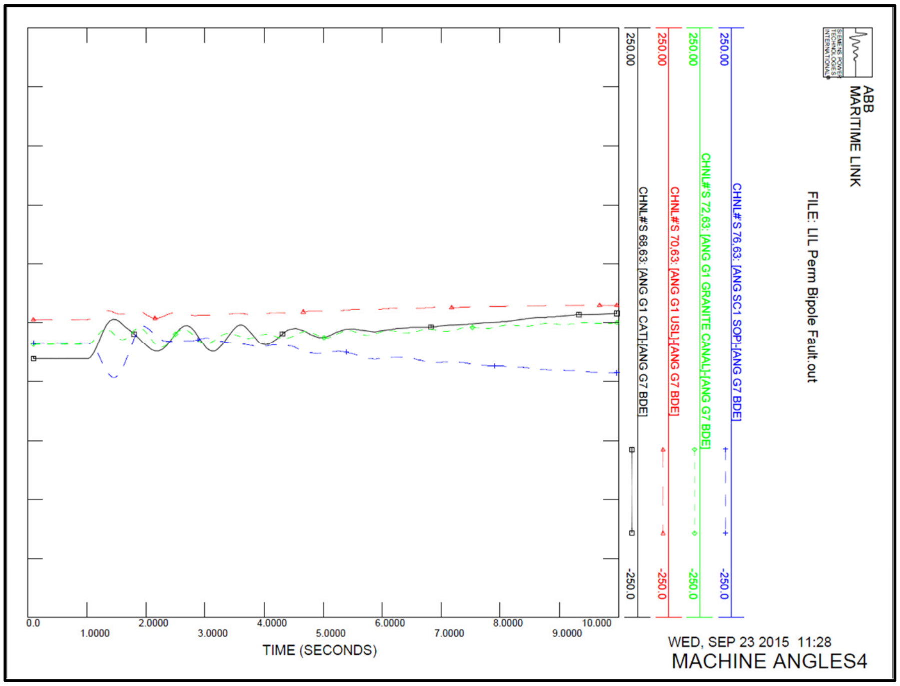

Figure 98: Base Case 8006 – LIL Permanent Bipole Fault

No Curtailment of ML Export Power

CAT, USL, GCL and SOP Machine Relative Rotor Angles

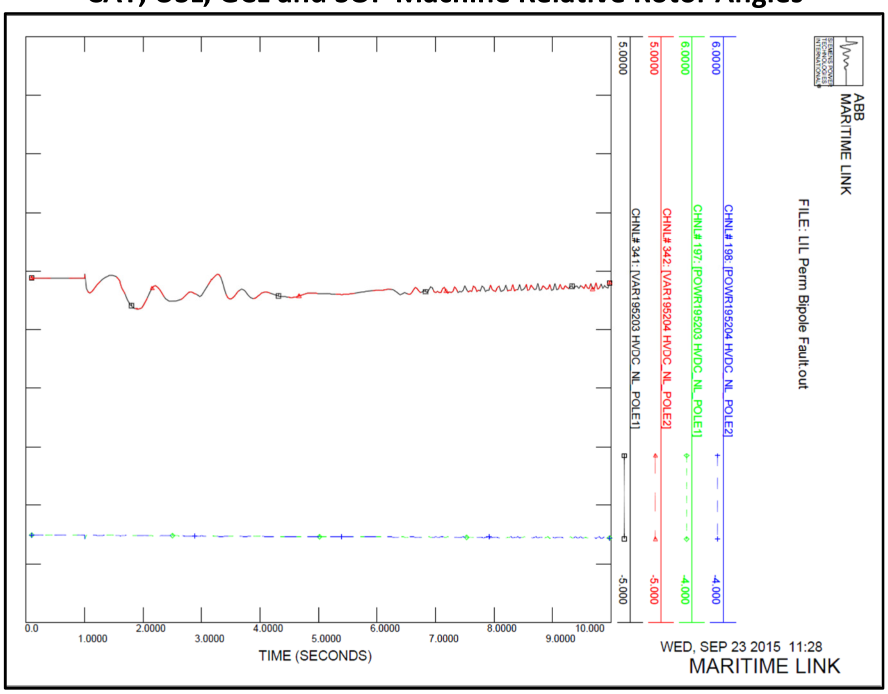

Figure 99: Base Case 8006 – LIL Permanent Pole Fault

No Curtailment of ML Export Power

ML Real and Reactive Power Output at BBK (per Pole)

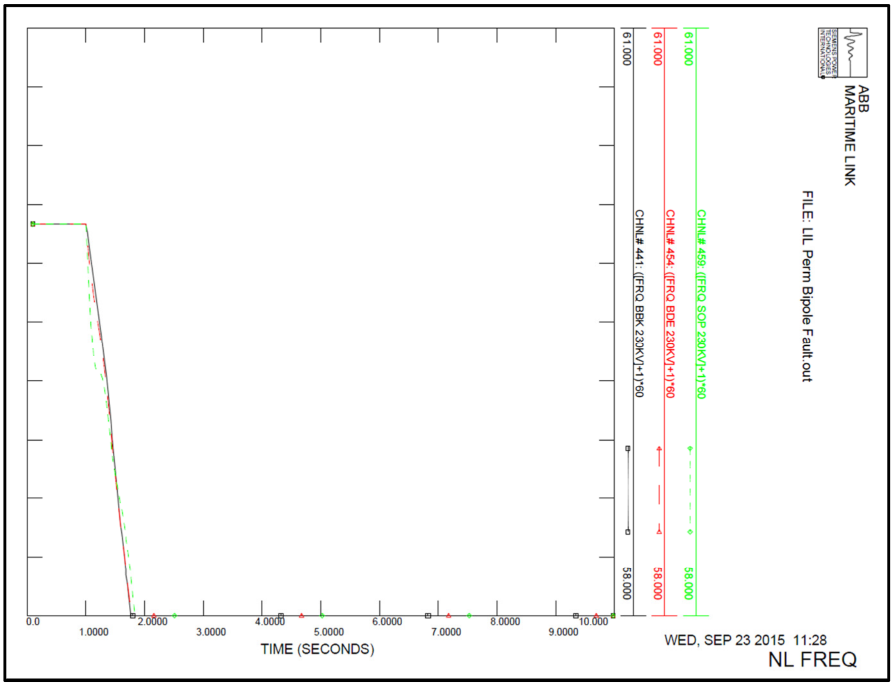

Figure 100: Base Case 8006 – LIL Permanent Bipole Fault

No Curtailment of ML Export Power

NL Frequency Response at BBK, BDE and SOP

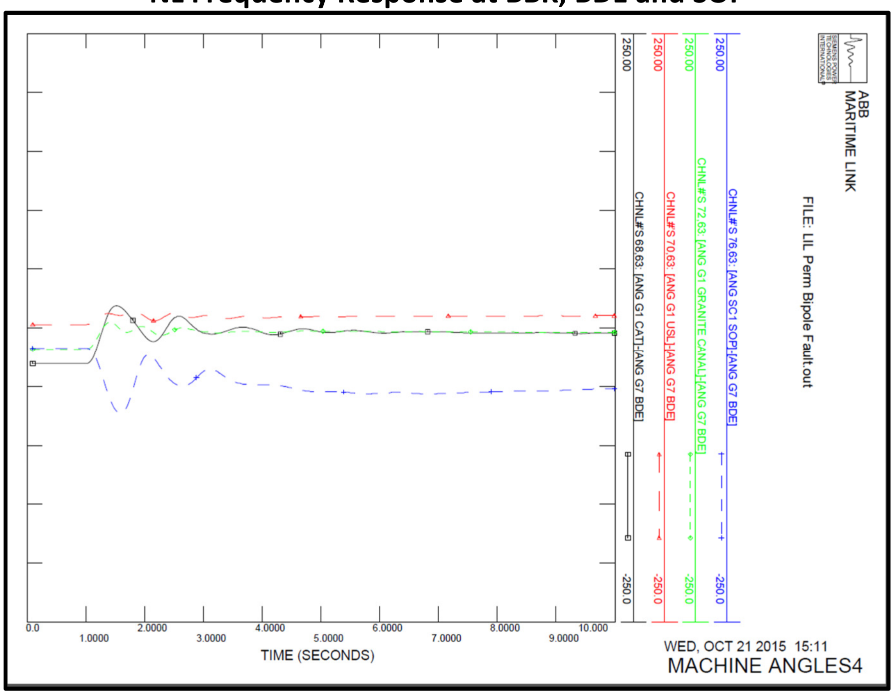

Figure 101: Base Case 8006 – LIL Permanent Bipole Fault

500 MW Curtailment of ML Export Power

CAT, USL, GCL and SOP Machine Relative Rotor Angles

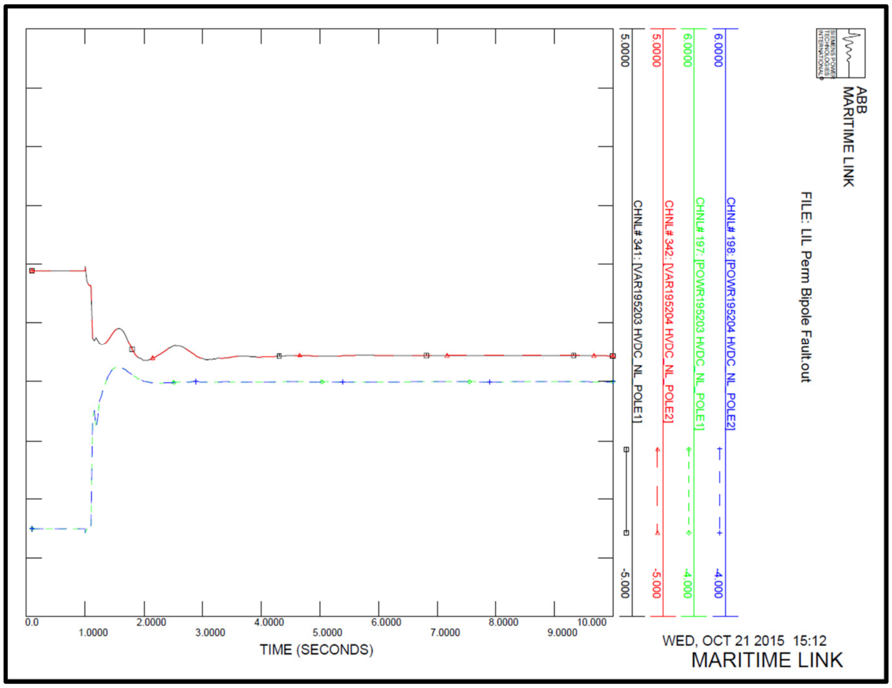

Figure 102: Base Case 8006 – LIL Permanent Pole Fault
500 MW Curtailment of ML Export Power
ML Real and Reactive Power Output at BBK (per Pole)

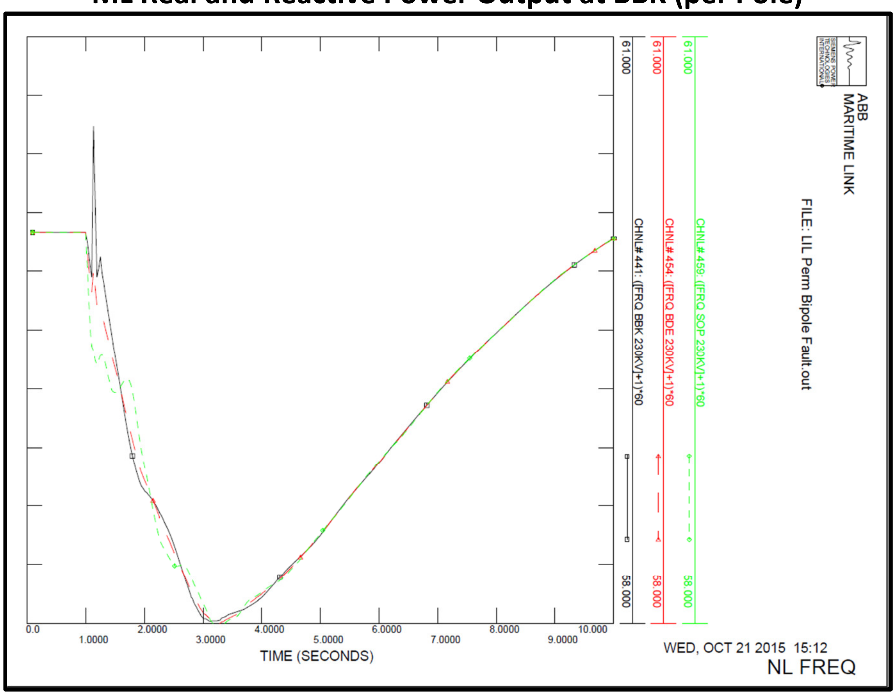

Figure 103: Base Case 8006 – LIL Permanent Bipole Fault
500 MW Curtailment of ML Export Power
NL Frequency Response at BBK, BDE and SOP

6.5 LOSS OF GENERATION WITHIN THE ISLAND SYSTEM

The Island Interconnected Transmission System historically has been designed to survive the loss of the largest generator online by providing sufficient spinning reserve on the hydro fleet, and an underfrequency load shedding scheme to respond to the generation shortfall. With the addition of the Labrador Island Link (LIL), Maritime Link (ML) and interconnection of Labrador and Nova Scotia to the Island of Newfoundland, operating reserves can be put in place to eliminate under frequency load shedding on the Island Interconnected System for loss of the largest on Island generator.

In the new interconnected state, analysis indicates that much of the spinning reserve for loss of the largest unit (BDE G7) should be held in Labrador with approximately 120 MW of transmission headroom remaining on the LIL. The advantage of using the LIL for spinning reserve is the speed at which the LIL HVdc frequency controller can respond and inject current from Labrador into SOP. Hydro units would require more time for wicket gates to move and increased water flow realized at the turbine, which is usually measured in seconds not milliseconds like an LCC HVdc system. A sudden increase of 120 MW of load in Labrador will not result in any noticeable power swings and will be absorbed quickly by the 5428 MW CHF hydro facility and the 735 kV HQT interconnection.

The ML has been designed to provide a firm 250 MW of capacity from BBK in NL to Woodbine in NS measured at the BBK 230 kV bus. Of this 250 MW, a nominal 170 MW (excluding transmission losses) is considered the “NS Block” of energy, while the remaining 80 MW shall be available to Nalcor Energy for energy sales. As shown in section *5.4 Permanent Pole Faults*, the ML can be curtailed in the event of a major outage to provide sufficient generating reserve to maintain Island Interconnected System frequency without loss of Island load.

In the event that generation is lost on the Island Interconnected System with LIL at maximum import (900 MW) and the hydro generation set to maximum output, the Island’s UFLS protection system may activate and disconnect customer loads as shown in Table 18. This was found to be the case for contingencies involving the trip of BDE G7 for base cases 8003 and 8006 where the LIL cannot inject additional power into the system to maintain frequency on the Island. In these cases a runback of the ML provided sufficient generating reserve to maintain supply for all customers.

Base case 8003 was the defining case for UFLS as it was designed to maximize export to NS over the ML with all Island generation at maximum output and rated import over the LIL. In this case, a trip of generation at BDE, USL or CAT would activate the UFLS protection system. To avoid UFLS, export over the ML must be curtailed to the firm 250 MW export during these events. The same can be said about base case 8006 where 200 MW were curtailed from the ML export to maintain customer loads for the trip of BDE G7.

In addition to generator trips, three phase faults on the high voltage buses (230 kV) were studied with a critical clearing time of 6 cycles and a trip of the unit. UFLS was activated for base case 8001, 8002, 8003 and 8006 as shown in Table 18.

It should be noted that a three-phase fault at BDE has been considered an “Exceptional Contingency” and therefore, UFLS is permitted for this case. Curtailment of the ML improved system recovery performance and avoided activation of the UFLS system for base cases 8001, 8003 and 8006. Base case 8002 was unable to recover from a three-phase fault and trip of BDE G7.

Table 18: Island Interconnected System Generation Loss – Summary of UFLS Results

Base Case	LIL Import (MW)	ML export (MW)	Generating Unit	3Φ HV Fault +Trip (UFLS)	Unit Trip (UFLS)	3Φ HV Fault +Trip + Curtail ML (UFLS)
8001	900	158	**BDE G7**	**YES**	**NO**	**NO[15]**
			USL G1	NO	NO	-
			GCL G1	NO	NO	-
			CAT G1	NO	NO	-
			TL247 + CAT G1/G2	NO	NO	-
8002	677	158	**BDE G7**	**YES**	**NO**	**YES**
			USL G1	NO	NO	-
			GCL G1	NO	NO	-
			CAT G1	NO	NO	-
			TL247 + CAT G1/G2	NO	NO	-
8003	900	350	**BDE G7**	**YES**	**YES**	**NO[16]**
			USL G1	**YES**	**YES**	**NO[5]**
			GCL G1	NO	NO	-
			CAT G1	**YES**	**YES**	**NO[5]**
			TL247 + CAT G1/G2	**YES**	**YES**	**NO[5]**
8005	722	158	BDE G7	NO	NO	
			USL G1	NO	NO	
			GCL G1	NO	NO	
			CAT G1	NO	NO	
			TL247 + CAT G1/G2	NO	NO	
8006	900	500	**BDE G7**	**YES**	**YES**	**NO[17]**
			USL G1	NO	NO	-
			GCL G1	NO	NO	-
			CAT G1	NO	NO	-
			TL247 + CAT G1/G2	NO	NO	-
8007	370	337	BDE G7	NO	NO	
			USL G1	NO	NO	
			GCL G1	NO	NO	
			CAT G1	NO	NO	
			TL247 + CAT G1/G2	NO	NO	

[15] ML Curtailment to 0 MW

[16] ML curtailment to 250 MW firm transfer

[17] ML curtailment to 300 MW

6.6 LOSS OF A SYNCHRONOUS CONDENSER AT SOLDIERS POND

Unlike previous system studies, it was determined that a three phase fault of a HISC at SOP following by the trip of a unit would not have an adverse impact on the LIL. It is clear from the results of this dynamic power system study that the fault and loss of a HISC during peak, intermediate and light load scenarios will not result in commutation failure of the Labrador Island LCC HVdc Link. Figure 104 - Figure 106 show the system angular, voltage and LIL HVdc MW injection response for base case 8001 which simply blocks the LIL for before restarting to full power. The response of the LIL for base cases 8002, 8003, 8005, 8006 and 8007 are shown in Figure 107-Figure 110 respectively.

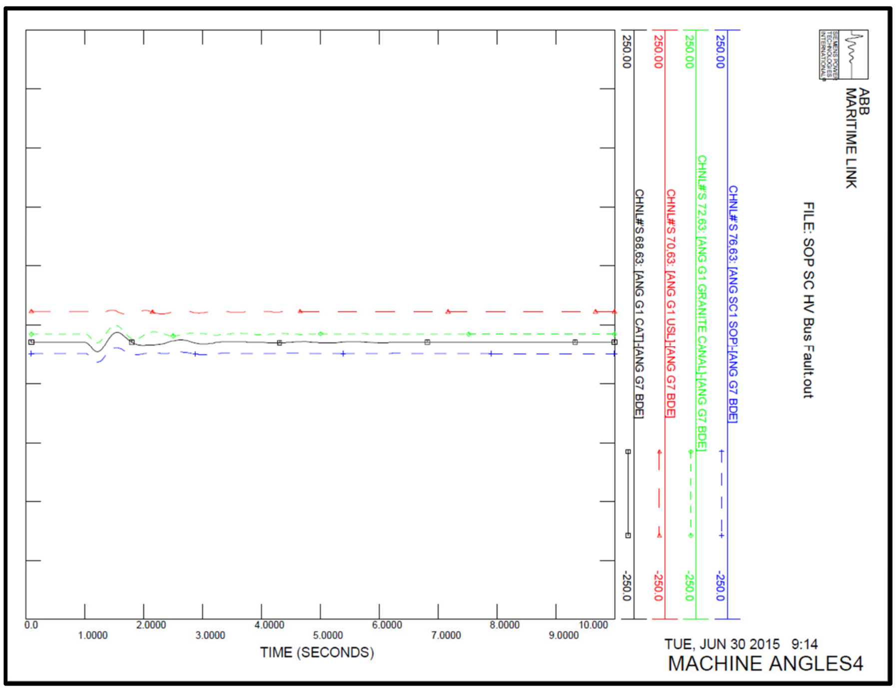

Figure 104: Base Case 8001 – SOP HISC 3 Phase HV Fault and Trip CAT, USL, GCL and SOP Machine Relative Rotor Angles

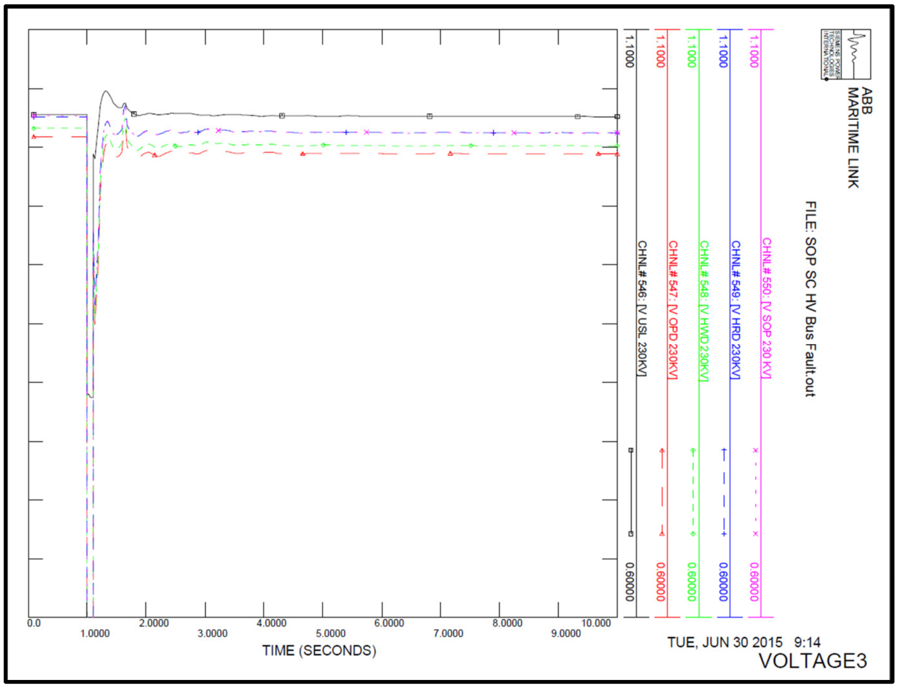

Figure 105: Base Case 8001 – SOP HISC 3 Phase HV Fault and Trip 230 kV Bus Voltages at USL, OPD, HWD, HRD, SOP

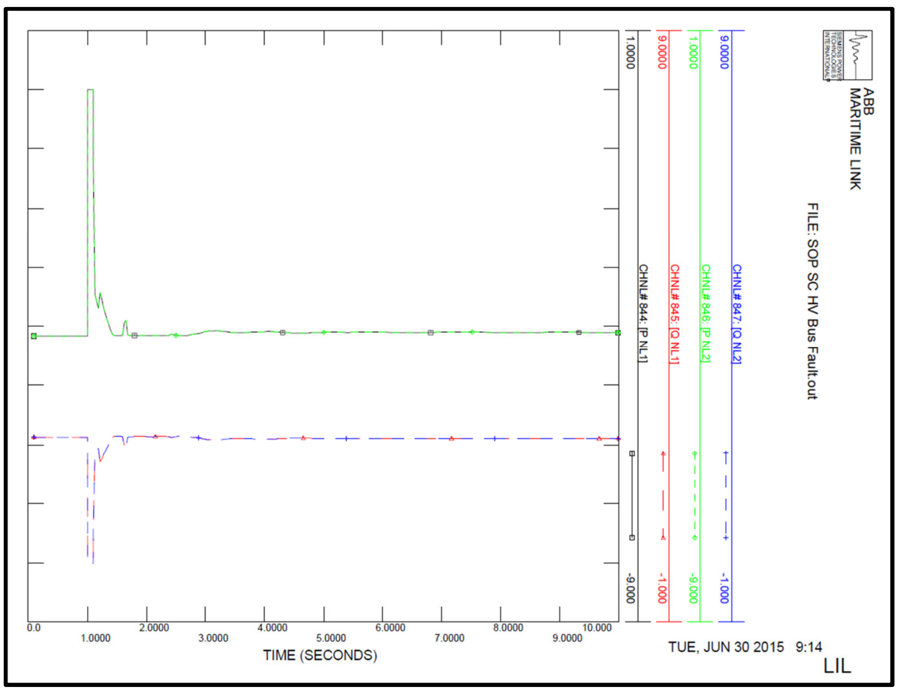

Figure 106: Base Case 8001 – SOP HISC 3 Phase HV Fault and Trip LIL Real and Reactive Power Output at SOP (per Pole)

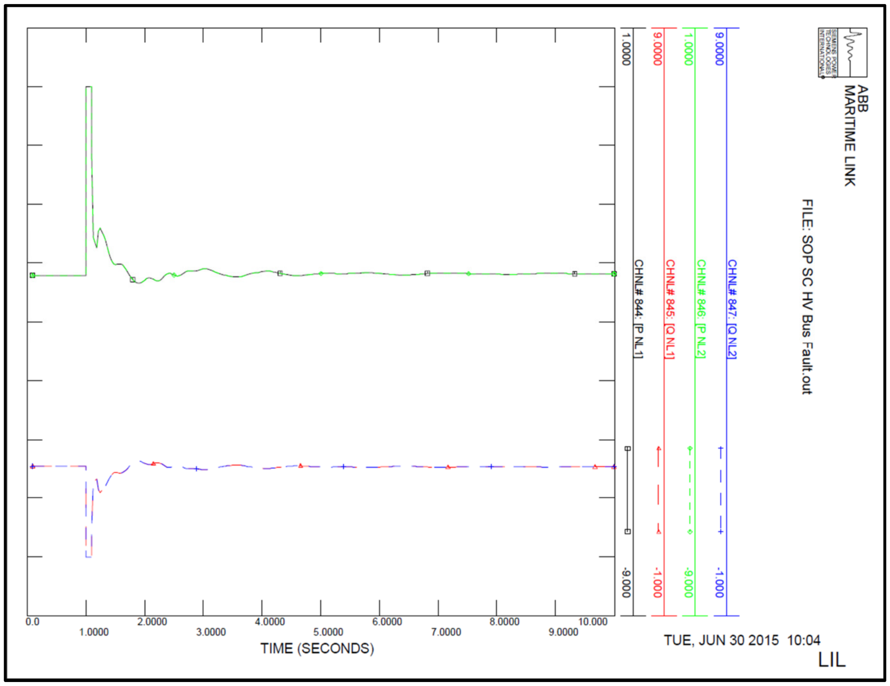

Figure 107: Base Case 8002 – SOP HISC 3 Phase HV Fault and Trip LIL Real and Reactive Power Output at SOP (per Pole)

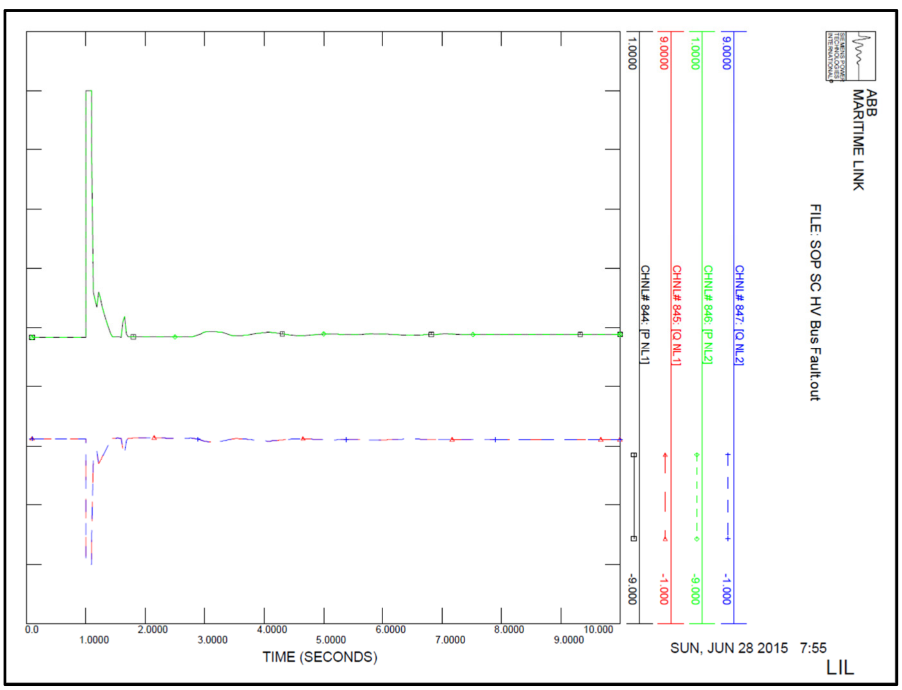

Figure 108: Base Case 8003 – SOP HISC 3 Phase HV Fault and Trip LIL Real and Reactive Power Output at SOP (per Pole)

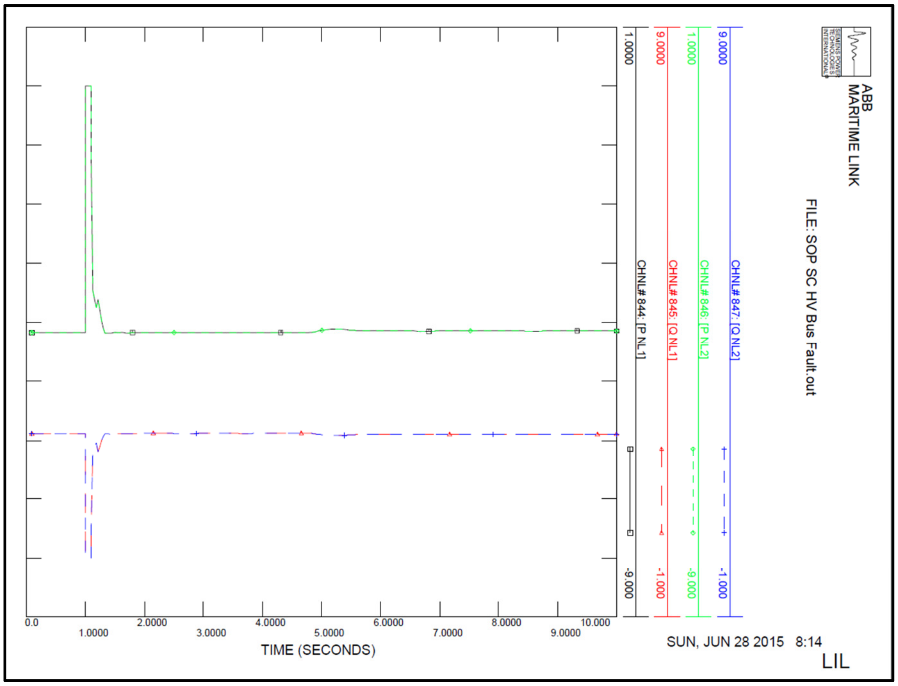

Figure 109: Base Case 8006 – SOP HISC 3 Phase HV Fault and Trip LIL Real and Reactive Power Output at SOP (per Pole)

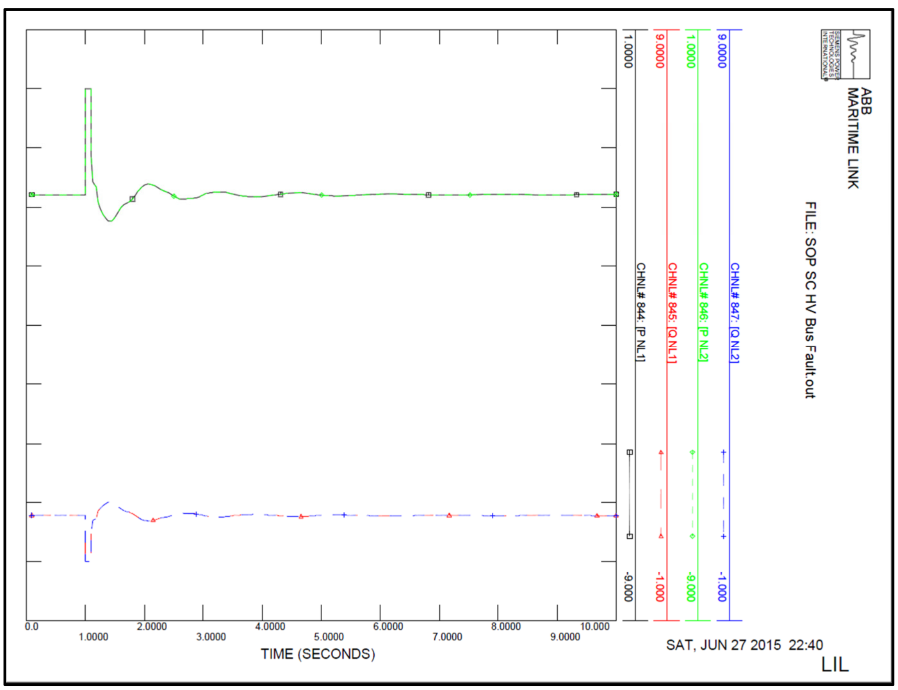

Figure 110: Base Case 8007 – SOP HISC 3 Phase HV Fault and Trip LIL Real and Reactive Power Output at SOP (per Pole)

7 CONCLUSIONS

A transient stability analysis was performed to identify unacceptable conditions arising from disturbances within the Island Interconnected System. Recommendations for these conditions are listed in Table 19.

Table 19 – Summary of Transient Stability Analysis

Contingency	Required Remedial Action
Faults at BDE	***No Action Required*** Accepted as *"Exceptional Contingency"* Opportunity to prevent system collapse and improve system response through the introduction of high speed automated runbacks of the ML to maximum export of 250 MW.
Faults at BBK, BUC, GCL, MDR, STB, and USL	Curtailment of ML Export to a maximum of 250 MW.
LIL Temporary Bipole Fault	Curtailment of ML Export to 0 MW.
LIL Permanent Pole Faults	Curtailment of ML Export to 0 MW.
LIL Faults (Monopole)	Curtailment of ML Export to 0 MW.
LIL Permanent Bipole Fault	Curtailment of ML Export to 0 MW.
Loss of Island Generation	Development of operating instructions to maintain required spinning reserve.
Loss of a Synchronous Condenser at Soldiers Pond	***No action required.***

It should be noted that the analysis described in this report is a follow up to the preliminary analysis report, *Maritime Link Preliminary Interconnection Study (July 2014)* released August 13, 2014. Table 20 summarizes the study results for the worst case contingencies for all studied cases. It forms the basis of limitations that must be imposed for more complex run-back systems. Given the objective of developing a robust run-back system design, Table 20 has been reconfigured to display the recommended maximum export for the ML following a single transmission contingency event for all cases, as in Table 21. It is assumed the time delay is no more than 150 ms for the Table 21 run-back design.

7.1 COMMUNICATION REQUIREMENTS – IMPLICATIONS

An important aspect of the steady state and dynamic power system analysis is the identification of required protection systems. In some cases, such as transmission line thermal overloads, a SCADA alarm point is required for operators at the ECC to take decisive action. In other more onerous cases, automatic protection systems are required as operator intervention is not practical. For these automated systems, a dedicated protection grade telecommunications path is required. Therefore, details on the communications interfaces at each end and the type and speed of the signal is required for design.

7.1.1 FAULTS ON THE LIL HVDC SYSTEM

Included in the Island Interconnected System upgrades for the integration of the LIL and ML HVdc transmission systems is the installation of a high speed fibre optic/microwave connection between both the LIL and ML converter stations at SOP and BBK. The intent is to provide high speed (protection grade) communications between the SOPCS and BBKTS such that in the event of a LIL pole or bipole fault, the ML will receive a signal to curtail all export power. This is required to maintain system stability and avoid UFLS for NLH and NF Power customers on the Island for a permanent and/or temporary blocking of power on the LIL.

The communications between SOP and BBK shall have redundant channels, A and B. It is expected that “A” channel is routed from SOP on the HVdc OPGW to Four Mile Hill where it is patched into NLH’s microwave system. The signal will travel to NLH’s microwave station at Granite Canal where it is patched back into the OPGW on TL269 running into Bottom Brook. The “B” channel will utilize OPGW from SOP to the Hampden repeater on the HVdc transmission circuit. From there, the signal will travel on third party leased fibre to Deer Lake and onto Bottom Brook to tie into the BBKCS.

The remaining questions on the design involve the type of signal to be transmitted from the LIL HVdc controls and the interfacing requirements for the ML HVdc control system. Details regarding the design of both control systems are currently underway and it is important to ensure compatibility of communications between both converters for issues on the LIL.

7.1.2 FAULTS ON ML HVDC SYSTEM

Under normal operation, the ML will export power from the NLH Island Interconnected System, therefore faults on the ML which result in loss of a single pole or the entire bipole scheme will look like a sudden loss of load for the AGC in Newfoundland. In these cases, on Island governor action in addition to the LIL frequency controller will respond automatically to reduce Island Interconnected System frequency. Therefore, no communications are required between the LIL and ML HVdc systems for issues with the ML.

7.1.3 ISLAND BULK TRANSMISSION SYSTEM CONTINGENCIES

Single contingency outages of equipment on the Island Interconnected System require a number of different approaches to maintain a stable ac system on the Island. These approaches range from operator intervention, automatic runback schemes and the operation of frequency controllers.

7.1.3.1 230 kV Transmission Line Thermal Overloads

The ML was designed to provide a maximum of 250 MW of firm transmission of power from Muskrat Falls to Nova Scotia. As a 500 MW bipole VSC HVdc, a loss of either pole will derate the link to 250 MW. The 230 kV ac transmission system on the Island will have three connections into Bottom Brook; TL211 from Massey Drive; TL233 from Buchans; and TL269 from Granite Canal.

Power system load flow analysis utilizing PSS®E has identified a number of transmission line overloads, particularly during the spring/fall seasons when NLH customer loads are reduced and excess capacity can be transmitted over the ML. With exports in excess of 250 MW during the spring/fall and summer months, a sudden loss of a 230 kV transmission line connecting to BBK can result in mild to severe thermal overloads. Therefore, in the SCADA design for the new BBK Terminal Station (BBKTS2), monitoring of these lines is crucial and alarms shall be provided to operators to intervene. Operators will refer to operating instructions to reduce export power orders on the ML. Alternatively, a SCADA speed system can be developed such that the NLH ECC provides a signal to runback the ML to alleviate the overload.

7.1.3.2 System Instability at ML Power Orders Above 250 MW

Power system dynamic analysis utilizing PSS®E identified a number of operating configurations which would result in system instability following a three-phase fault and trip of critical 230 kV transmission lines connected to BBK. It was determined that export power orders greater than 250 MW would increase the risk of instability following a system disturbance. Therefore, it has been recommended that ABB tune the HVdc control system to provide an automatic runback of the VSC system once a disturbance has been detected. This operating scheme is known as "ac line emulation" and has been utilized in a VSC back-to-back installation at Mackinac in Michigan. As a result, efforts will be made to ensure additional communications channels and complex protection schemes are not required and can be delivered as part of the ML Project.

7.1.3.3 Generation Loss within the Island Interconnected System

With the decommissioning of the thermal generators in Holyrood, the Island Interconnected System's largest generator is Bay d'Espoir unit 7 at 154 MW, with the next largest generation loss being two units at BDE (150 MW) followed by two units at Cat Arm (127 MW). As a result, dynamic studies have shown that the LIL will operate on its power frequency controller to maintain Island frequency, provided it has the required capacity prior to the generation loss. Ready for Integration (RFI) will determine, through operational studies, the frequency controller settings necessary to provide the optimal power injection by the LIL and the Island's hydro units.

Therefore, no additional high speed communication paths are required between generating stations at the LIL or the ML.

Table 20: Study Results Worst Case Contingencies Summary Table

Station	Line Fault	*HVac System Response*	*ML Runback Required for Acceptable HVac Response*						Min ML RB TL Thermal Ratings (MW)	Comments
		No ML Curtailment[1]	ML Curtailment Only		ML Curtailment with BBK Caps					
					50 MVAR Shunt		100 MVAR Shunt			
			Power (MW)	Time Delay (ms)	Power (MW)	Time Delay (ms)	Power (MW)	Time Delay (ms)		
BBK	TL269	Voltage and frequency instability. System maintains angular stability.	250	500	50	500	50	750	396	Static reactive support and ML export curtailment required to prevent fault recovery voltages at the 230 kV busbar <0.70 pu
BDE[3]	TL202/TL206	Recovery voltage at BUC below 0.70 pu. System maintains angular Stability	250	200	**Runback Not Required**		**Runback Not Required**		**Runback Not Required**	Static reactive support and ML export curtailment required to prevent fault recovery voltages at the 230 kV busbar <0.70 pu
	TL204/TL231	Recovery voltage at BUC below 0.70 pu. System maintains angular Stability	250	150	**Runback Not Rrquired**		**Runback Not Required**		**Runback Not Required**	Static reactive support and ML export curtailment required to prevent fault recovery voltages at the 230 kV busbar <0.70 pu
	TL234	System is stable - No UFLS	**Runback Not Required**						488	ML export curtailment required to maintain a damped machine response at CAT, GCL and USL.
GCL	TL263	Voltage and frequency instability. System maintains angular stability.	100	750	100	750	50	100	418	Static reactive support and ML export curtailment required to prevent fault recovery voltages at the 230 kV busbar <0.70 pu
	TL269	Voltage and frequency instability. System maintains angular stability.	250	300	250	400	250	600	396	Static reactive support and ML export curtailment required to prevent fault recovery voltages at the 230 kV busbar <0.70 pu
USL	TL234	Voltage and frequency instability. System maintains angular stability.	100	750	100	750	**Runback Not Required**		488	Static reactive support and ML export curtailment required to prevent fault recovery voltages at the 230 kV busbar <0.70 pu
	TL263	Recovery voltage at BUC below 0.70 pu. System maintains angular Stability	250	300	**Runback Not Required**		**Runback Not Required**		418	Static reactive support and ML export curtailment required to prevent fault recovery voltages at the 230 kV busbar <0.70 pu
SOP	LIL Temp Bipole	System is stable - No UFLS	**Runback Not Required[3]**						**N/A**	The Island Interconnected System has been designed to survive a temporary bipole fault on the LIL. This contingency determined the size of the HISCs at SOP.
	LIL Temp Pole	System is stable - No UFLS	**Runback Not Required[3]**						**N/A**	The LIL has been designed such that a temporary pole fault does not have a large impact the ac system. The 2.0 pu current overload on the second pole reduces the power transmission shortfall.
	LIL Perm Pole	UFLS	500	100	**N/A**		**N/A**		**N/A**	The ML is required to be curtailed in the event of the permanent loss of a pole as specified in the PPA to avoid UFLS on the Island Interconnected System.
	SC HV Bus Fault	System is stable - No UFLS	**Not Required**		**Not Required**		**Not Required**		**N/A**	The ML is required to be curtailed in the event of the permanent loss of a pole as specified in the PPA to avoid UFLS on the Island Interconnected System.

1) Base Case 8006 Pre-Contingency, ML 500 MW Export, LIL 900 MW Import, Island Load = 1414 MW
2) Three-phase faults at BDE which cause instability or a system response which does not meet NLH Transmission Planning Criteria has been deemed acceptable.
3) Results to be verified using GE Grid's Updated PSS®E Model in Detailed Design. Performance results established using CDC4T LCC Model.

Table 21: Study Results - Worst Case Contingencies – ML Export Limit Recommendations

Station	Fault Location	HVac System Response	Ml Runback Required for Acceptable HVac Response		Recommended Maximum ML Export Post Contingency
		No ML Curtailment[1]	ML Curtailment – From 500 MW Bipole Rating		
			Power (MW)	Time Delay (ms)	Power (MW)
BBK	TL269	Voltage and frequency instability. System maintains angular stability.	250	500	250
BDE[2]	TL202/TL206	Recovery voltage at BUCTS below 0.70 pu. System maintains angular stability.	250	200	250
	TL204/TL231	Recovery voltage at BUCTS below 0.70 pu. System maintains angular stability.	250	150	250
GCL	TL263	Voltage and frequency instability. System maintains angular stability.	100	750	250
	TL269	Voltage and frequency instability. System maintains angular stability.	250	300	250
USL	TL234	Voltage and frequency instability. System maintains angular stability.	100	750	250
	TL263	Recovery voltage at BUCTS below 0.70 pu. System maintains angular stability.	250	300	250
SOP[3]	LIL Temp. Bipole	System maintains angular stability – No UFLS	**No action required - GE Grid System Studies to Verify**		0
	LIL Temp. Pole	System maintains angular stability – No UFLS	**No action required - GE Grid System Studies to Verify**		0
	LIL Perm. Pole	UFLS	500	100	0

1) Base Case 8006 Pre-Contingency, ML 500 MW Export, LIL 900 MW Import, Island Load = 1414 MW
2) Three-phase faults at BDE which result in instability or a system response which violates NLH Transmission Planning Criteria has been deemed acceptable.
3) All HVdc transmission line faults were completed using the PSS®E CDC4T 2-terminal DC dynamic model. GE Grid to complete contingency studies using the GE Grid PSS®E user written model. All results from this study will be verified through review of GE Grid's system studies.

APPENDIX A

TECHNICAL NOTE: BOTTOM BROOK VSC EXPORT LIMITS – MARITIME LINK RUNBACK SUMMARY (SEPTEMBER 25, 2013) – RELEASED NOVEMBER 19, 2013

Approved for Release	Nov 19, 2013 Date

TECHNICAL NOTE

BOTTOM BROOK VSC EXPORT LIMITS – MARITIME LINK RUNBACK SUMMARY

Date: September 25, 2013

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1.0 INTRODUCTION

Newfoundland and Labrador Hydro (NLH) owns and operates an interconnected generation and transmission system on the Island of Newfoundland. At present the Island Interconnected Transmission System is electrically isolated from the North American grid, and as such, the system must be self-sufficient in meeting the electrical needs of customers on the island portion of the province.

In December 2012 the Government of Newfoundland and Labrador announced sanction of the Lower Churchill Project as the least cost alternative to meet the long term load growth requirements of the Province. The project includes development of the 824 MW hydro-electric generating station at Muskrat Falls (MFA), two 315 kV ac transmission lines between Churchill Falls (CHF) and Muskrat Falls, a 900 MW, ±350 kV HVdc transmission line between Muskrat Falls in Labrador and Soldiers Pond (SOP) in Newfoundland, and a 500 MW, ±200 kV HVdc transmission line between Bottom Brook Terminal Station (BBK) on the west coast of Newfoundland and Cape Breton, Nova Scotia. The shutdown of the Holyrood Thermal Generating Station as a producer of electric power and energy combined with the addition of an HVdc transmission interconnection with Labrador will change the overall system loading and dynamic performance on the Island Interconnected Transmission System.

This report analyses the Island ac transmission system performance following a single contingency outage and its effect on operations of the Maritime Link (ML). In many operating conditions during the summer, spring and fall surplus generation and transmission capacity is available within the province of Newfoundland and Labrador. During this period the ML is planned to operate at the rating of the converter (500 MW) to deliver non-firm power and energy to market. Operating at this export level, heavily loaded transmission lines west of Bay d’Espoir (BDE), will exceed thermal ratings in the event of an outage. Studies have shown that in such an event the ML is required to run back from its set power order instantaneously to alleviate serious transmission line overloads and, in some cases prevent system voltage collapse. As a result, a Special Protection System (SPS) must be designed to run back the converter for a number of outages. In this report, the results of the steady state load flow analysis, in conjunction with transmission line outage statistics, are used to determine the frequency and duration of the ML runbacks.

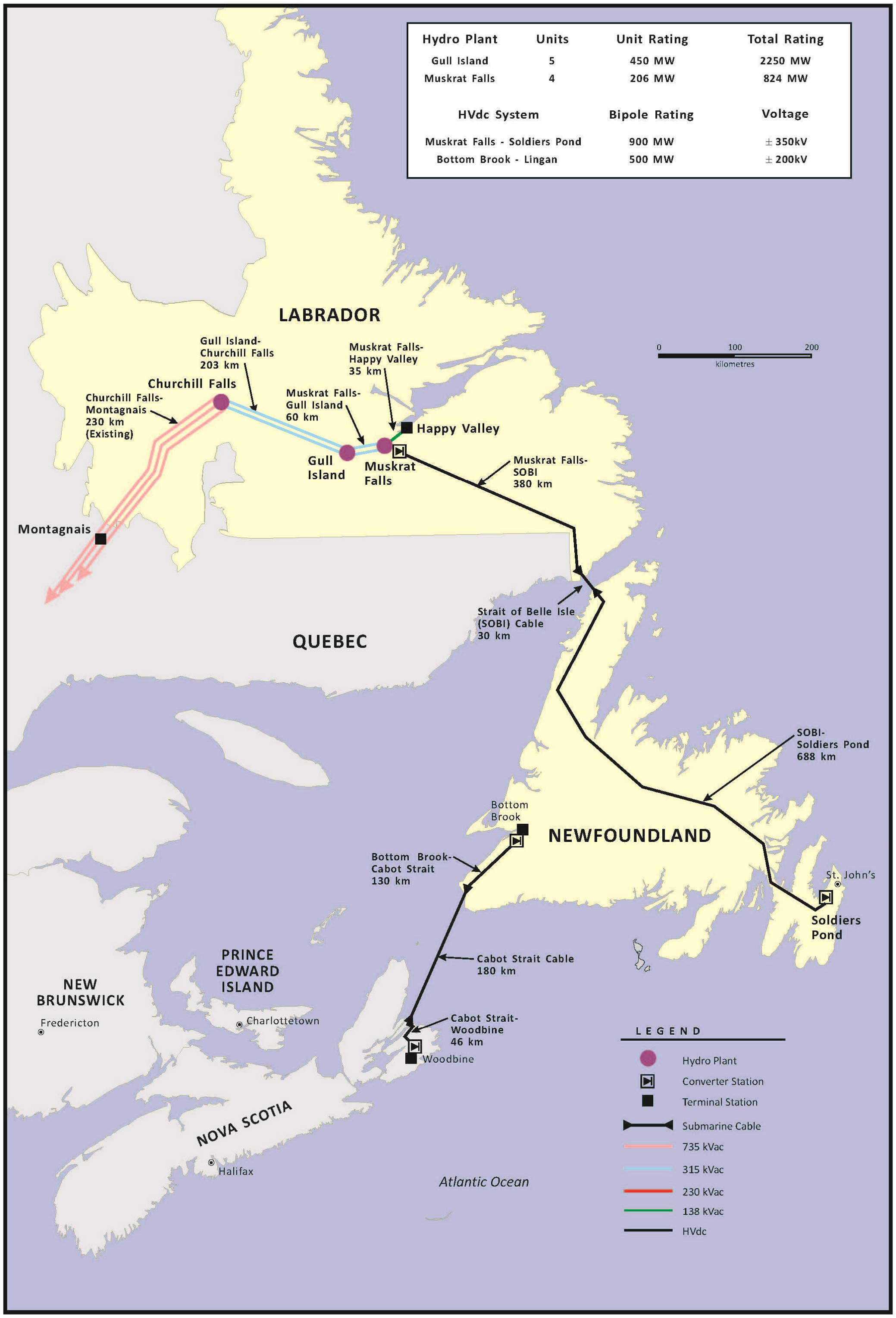


Figure 1-1 – Proposed Transmission System for the LCP

Figure 1-2 - Provincial Transmission Grid

2.0 EXISTING SYSTEM

NLH owns and operates 1,609 km of 230 kV transmission line on its Island Interconnected Transmission System. There are eleven 230 kV lines totaling 628 km in length connecting the Bay d'Espoir Generating Station to the major load centers and generation in the eastern portion of the province. There are twelve 230 kV lines totaling 855 km in length connecting Bay d'Espoir to major load centers and generation in the central and western portions of the province. The remaining 126 km of 230 kV transmission line consists of two lines which connect the Granite Canal and Upper Salmon Generating Stations to Bay d'Espoir. Figure 2-1 provides a diagram of the Island Interconnected 230 kV transmission system.

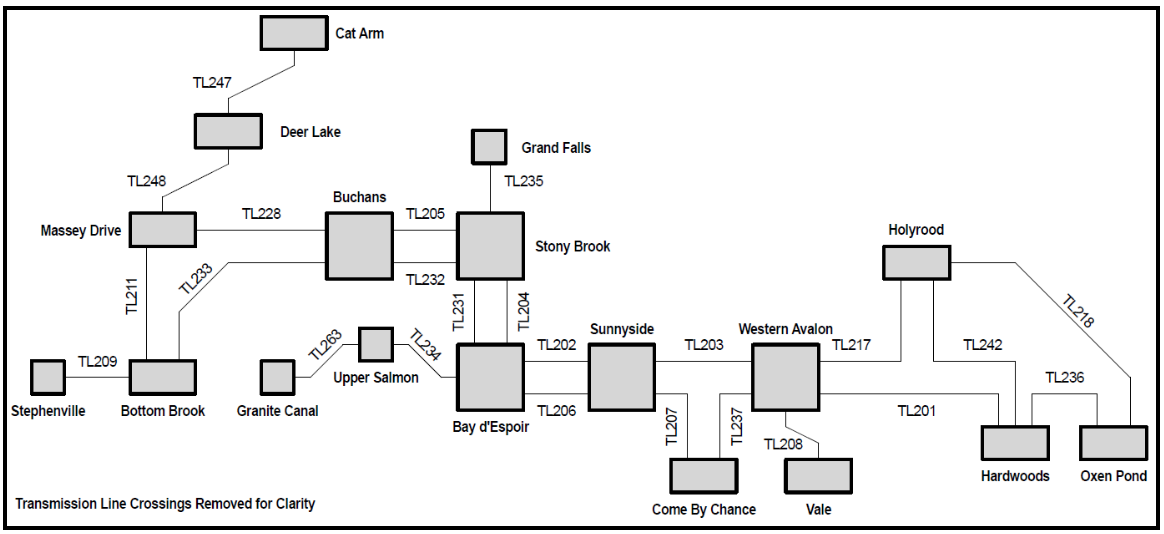


Figure 2-1 - Island Interconnected 230 kV Transmission System

The 230 kV transmission system east of Bay d'Espoir is characterized as being heavily loaded. Conversely, the 230 kV transmission system west of Bay d'Espoir is characterized as being a more lightly loaded system. Table 2-1 provides a summary of east and west loads at the time of system peak for the period ranging from 2008 – 2012.

**Table 2-1 - Bay d'Espoir East and West
230 kV Transmission System Peak Loads, 2008 to 2012**

Year	Bay d'Espoir – East[1] (MW)	Bay d'Espoir – West[2] (MW)
2008	827	416
2009	878	447
2010	836	378
2011	802	435
2012	900	441

Notes

1- Bay d'Espoir – East load equal to TL-202 and TL-206 flow plus Paradise River, Holyrood, Hardwoods, and wind generation at time of peak.

2- Bay d'Espoir – West load equal to TL-204 and TL-231 flow plus Cat Arm, Hinds Lake, Stephenville, Hawke's Bay, St. Anthony Diesel Plant generation and Non-Utility Generation purchases at time of peak.

3- Connaigre Peninsula loads not included.

4- Values based on the Hydro Energy Management System (EMS) hourly data and are not weather adjusted

The Bay d'Espoir – East 230 kV transmission system experiences significant voltage drop during peak load conditions. As a result, this portion of the system requires voltage support in the form of reactive power (MVAR) injection in order to bring system voltages up to minimum acceptable levels. The Holyrood Thermal Generating Station, the Hardwoods Combustion Turbine operating as a synchronous condenser and shunt capacitor banks at Come By Chance, Hardwoods and Oxen Pond Terminal Stations provide the MVAR injection into the 230 kV system to counteract the voltage drop.

Based upon the east – west load splits and the NLH generation fleet at the time, the Hardwoods and Oxen Pond capacitor bank additions in 1999 were designed to ensure maximum use of the existing hydroelectric resources following the shutdown in the late spring and prior to the start-up of the Holyrood thermal plant each fall. The capacitor bank additions, along with the voltage support described above, provided sufficient voltage support for the loss of any single element (transmission line or voltage support device), without having to operate thermal generation at Holyrood for voltage support. Consequently, Holyrood thermal generation was placed in operation only when required to supply the system load.

With the closure of the paper mill in Stephenville, the load on the 230 kV transmission system west of Bay d'Espoir experiences high voltages, particularly during the summer months.

Following the closure of the pulp and paper mill in Grand Falls – Winsor, Nalcor Energy installed four 230 kV shunt capacitor banks with a nominal total installed capacity of 150 MVAR at the Come By Chance Terminal Station to assist in voltage support to deliver Exploits River hydro-electric generation to the Avalon Peninsula and delay start-up of the second and third units at Holyrood each fall.

2.1 Impact of HVdc Interconnections

The addition of the 900 MW, ±350 kV HVdc transmission line between Labrador and Newfoundland, also known as the Labrador Island Link (LIL), combined with the closure of the Holyrood Thermal Generating Station as a producer of electric capacity and energy will change the nature of the power flows on the Island Interconnected Transmission System and also its dynamic performance. Soldiers Pond has been selected as the site for the HVdc converter station in Newfoundland. The site is in a location where all major 230 kV transmission lines between generation and the St. John's load center are in close proximity. In addition, the site is located between the major load center and the thermal generating station that is to be shut down. Consequently, locating the converter station at Soldiers Pond reduces the requirement for extensive 230 kV transmission line construction on the Avalon Peninsula to connect the new 900 MW source to the load.

The converter station at Soldiers Pond requires a strong connection to the existing ac transmission system to ensure proper operation. As well, multiple transmission paths are required to ensure that the power delivered from Labrador can be delivered to the load centers during an outage to a single transmission line. To this end three of existing 230 kV transmission lines will be routed through the Soldiers Pond Converter Station to provide for six 230 kV transmission line connections including:

- TL201 (Western Avalon to Hardwoods yielding two 230 kV transmission lines
    - TL201 (Western Avalon to Soldiers Pond); and
    - TL266 (Soldiers Pond to Hardwoods)
- TL217 (Western Avalon to Holyrood) yielding two 230 kV transmission lines
    - TL217 (Western Avalon to Soldiers Pond); and
    - TL265 (Soldiers Pond to Holyrood)

- TL242 (Holyrood to Hardwoods) yielding two 230 kV transmission lines
    - TL242 (Soldiers Pond to Hardwoods); and
    - TL268 (Soldiers Pond to Holyrood).

The 230 kV transmission line TL218 (Holyrood to Oxen Pond) is not routed through the Soldiers Pond station. TL218 provides a non-Soldiers Pond path between the St. John's load center and future combustion turbine generation at Holyrood in the event of a catastrophic failure at Soldiers Pond.

The addition of a 500 MW, ±200 kV HVdc transmission system between western Newfoundland and Nova Scotia (the Maritime Link) increases the transmission system loading west of Bay d'Espoir and, in turn, alleviates many of the high voltage issues on the existing lightly loaded system. Emera Newfoundland Limited (ENL) will be constructing an HVdc converter station at the existing NLH Bottom Brook Terminal Station location with a combined overhead and submarine cable transmission line to connect to the second converter station at Woodbine Substation in Cape Breton, NS. The Bottom Brook location was chosen as it is the closest point on the existing Island Interconnected Transmission System for bulk 230 kV power deliveries. To ensure power deliveries of up to 250 MW over the Maritime Link with one 230 kV transmission line out of service in western Newfoundland, ENL will be constructing a new 230 kV transmission line between Granite Canal and Bottom Brook (TL269). A 230 kV terminal station near the existing Granite Canal Terminal Station will be constructed to connect to the existing 230 kV transmission line TL263 to Upper Salmon with the existing 230 kV line section between the new 230 kV tap and Granite Canal renumbered TL270.

Figure 2-2 provides a diagram of the 230 kV portion of the Island Interconnected Transmission System with Soldiers Pond and the Maritime Link added including the proposed transmission line TL267 between Bay d'Espoir and Western Avalon. During off peak operating conditions in the spring, fall and summer, an injection of up to 825 MW into the Soldiers Pond converter station on the Avalon and exports of up to 500 MW at Bottom Brook over the ML results in a net system power flow from Soldiers Pond west to Bottom Brook. This operation is contrary to how the system is operated today with net flows heading east and west from BDE year round.

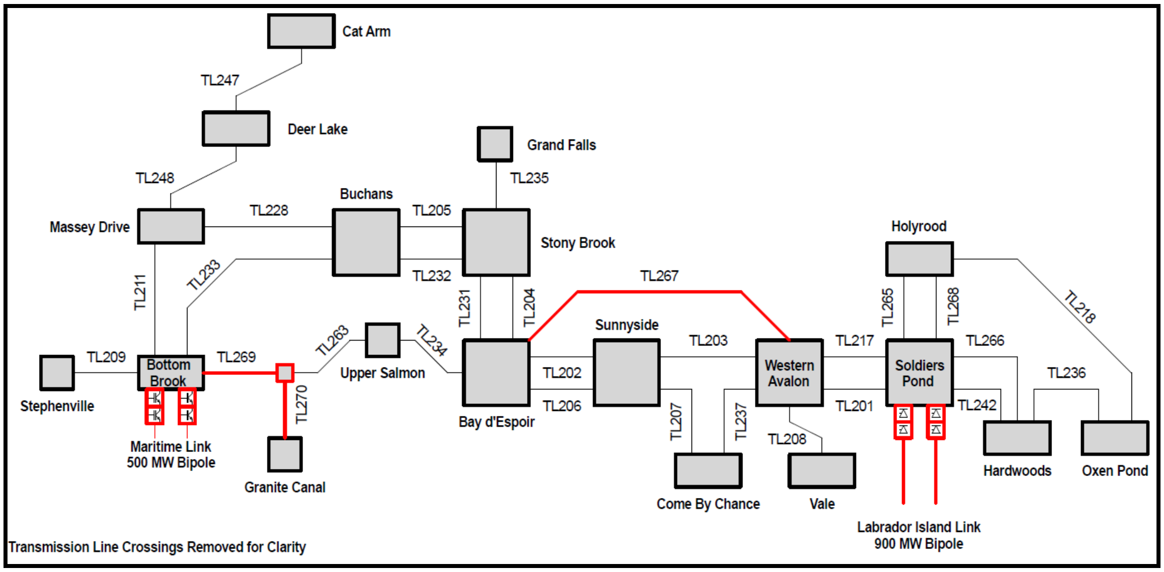


Figure 2-2 - Island Interconnected 230 kV Transmission System with HVdc Added

Power transfer to and from the Avalon Peninsula will be limited by the capacity of TL201 and TL217 which both connect the Western Avalon Terminal Station to the proposed 230 kV terminal station at Soldiers Pond. Under heavy and intermediate seasonal loads, the majority of the power delivered over the LIL will be transferred east from Soldiers Pond over TL266, TL242, TL268, TL265 and TL218 to the Hardwoods (HWD) and Oxen Pond (OPD) Terminal Stations.

During the summer months with light system loads, the majority of the power received over the LIL at Soldiers Pond will flow over TL201 and TL217 to the Western Avalon terminal station to feed loads west of Bay d'Espoir including a maximum of 500 MW export at Bottom Brook. TL217 has roughly double the current carrying capacity of the parallel line TL201 (341.8 MVA and 175.5 MVA respectively). This results in thermal overloads on TL201 for a loss on TL217. It has been suggested for some time to upgrade TL201 to match that of TL217 so as to have the same power transfer limits. Early studies identified thermal overloads on TL201 with all lines in service during light load conditions. As a result, capital work on TL201 to upgrade its transfer capacity has been identified and therefore for the purposes of this report is assumed to be rebuilt to the NLH standard 3" ice load steel tower design supporting 804 kcmil AASCR/TW conductor. The new line capacity of TL201 is calculated at a hot conductor temperature of 80°C to be 355.8/411.5/459.6 MVA for Rate A (30°C), Rate B (15°C) and Rate C (0°C) ambient temperatures respectively.

3.0 BASE CASES

The System Planning Department of NLH has developed 22 base case scenarios that cover the full range of system operating conditions and have been used throughout the design phase of the Project. Each base case scenario provides the Island loading, the Island hydro dispatch, the power order on the LIL and the export to NS over the ML. Each scenario has been modeled in detail using Siemens PTI PSS®E Version 32.0.0. Table 3-1 outlines all 22 base case scenarios with highlighted rows indicating study cases which require run back of the ML converter.

Table 3-1 - System Planning DG3 Base Case Models

NO.	NLH System Load	NS Export @ Bottom Brook	Island Import @ Soldiers Pond	Island Generation	Comments
BC1	Peak - 2018 (1600 MW)	158 MW	Full Import (815 MW)	Economic dispatch	Winter Peak
BC2	Peak - 2018 (1600 MW)	239 MW	Full Import (815 MW)	Maximum	Winter Peak
BC3	Peak - 2018 (1600 MW)	158 MW	Import 730 MW	Maximum	Winter Peak
BC4	Future Peak - 2041 (1900 MW)	0 MW	Full Import (815 MW)	Maximum	Winter Peak
BC5	Intermediate (1100 MW)	158 MW	Full Import (815 MW)	Economic dispatch	Spring / Fall day
BC6	Intermediate (1100 MW)	158 MW	Import 268 MW	Maximum	Spring / Fall day
BC7	Intermediate (1100 MW)	500 MW	Full Import (815 MW)	Economic dispatch	Spring / Fall day
BC8	Light (700 MW)	158 MW	Reduced Import (400 MW)	Minimum	Summer Day
BC9	Light (700 MW)	158 MW	Reduced Import (80 MW)	Economic dispatch	Summer Day
BC10	Light (700 MW)	500 MW	Full Import (815 MW)	Economic dispatch	Summer Day
BC11	Extreme Light (420 MW)	0 MW	Reduced Import (80 MW)	Economic dispatch	Summer Night
BC12	Extreme Light (420 MW)	320 MW	Reduced Import (80 MW)	Economic dispatch	Summer Night
BC13	Extreme Light (420 MW)	320 MW	Reduced Import (435 MW)	Minimum	Summer Night
BC14	Peak - 2017 1552 MW - Monopole	-260 MW (Import)	260 MW Import	Maximum	Winter Peak
BC15	Intermediate 1100 MW – Monopole	158 MW	333 MW Import	Economic dispatch	Spring / Fall day
BC16	Light 700 MW - Monopole	500 MW	518 MW Import	Minimum	Summer Day
BC17	Extreme Light 420 MW - Monopole	0 MW	200 MW Import	Minimum	Summer Night
BC18	Peak - 2017 (1552 MW)	158 MW	Full Import (815 MW)	Economic dispatch	Winter Peak – Max. Muskrat Generation
BC19	Intermediate (1100 MW)	500 MW	Full Import (815 MW)	Economic dispatch	Spring / Fall day – Max. Muskrat Gen.
BC20	Peak 2018 Bipole Outage	-146 MW (Import)	0 MW	Maximum dispatch including Gas Turb.	Winter Peak
BC21	Peak 2018 Bipole Outage	-292 MW (Import)	0 MW	Maximum dispatch including Gas Turb.	Winter Peak
BC22	Light 700 MW - Monopole	-146 MW (Import)	80 MW	Economic dispatch including Gas Turb.	Summer Day

Steady state load flow analysis was completed on the 230 kV bulk transmission system west of Bay d'Espoir for each of the three selected base case scenarios. These base cases were selected due to the number of, and severity of, transmission line overloads experienced during the analysis. The following is meant to summarize the transmission element outages which will require a run back of the Voltage Source Converter (VSC) at Bottom Brook (BBK) through the use of a Special Protection System (SPS). It has been assumed for this analysis that the capacitor banks at Come By Chance (CBC), the proposed third circuit from Bay d'Espoir to Western Avalon (TL267) and the proposed 230 kV transmission line from Granite Canal (GCL) to Bottom Brook (TL269) are in service. In addition, for the purposes of this analysis, the thermal rating of TL228 between Buchans (BUC) and Massey Drive (MDR) has been uprated to a hot conductor temperature of 55°C and TL201 is assumed to be rebuilt to the NLH standard 3" ice loading steel tower design supporting 804 kcmil AACSR/TW conductors along its length.

Transmission line studies completed on TL228 by NLH's Transmission and Distribution (T&D) Department indicated that conductor sag limits would not be violated if operated at a hot conductor temperature of 55°C due to high conductor stringing tension. Early studies had indicated that maximum export power orders over the ML were limited by the transfer capacity of TL228 under specific contingencies.

In the case for TL201, early steady state load flow studies identified a requirement to upgrade transmission capacity on this line to supply 500 MW to Bottom Brook during the summer with all lines in service.

4.0 LOAD FLOW ANALYSIS

A steady state load flow analysis was completed on the three selected base cases (BC7, BC10 and BC13) to identify transmission element overloads and bus voltage violations with all elements in service and under single contingency outages. These base cases were selected to cover all contingencies for spring/fall and summer operating conditions from Island loads ranging from 420 MW to 1100 MW. Earlier studies identified these as stress cases for the bulk transmission system connecting Soldiers Pond to Bottom Brook, requiring adjustments in import power over the LIL and export power orders on the ML.

In the event of transmission line overloads or unacceptable bus voltages, the ML and LIL would be run back to maintain Island hydro dispatch while clearing the violation. This would provide the highest level of system stability following a transmission element outage as both converter stations can respond much quicker than the governors on the Island hydro units. The results from this load flow analysis forms the basis of the Special Protection System (SPS) design which is required to protect the bulk 230 kV transmission system in the event a transmission line element is out of service.

4.1 Emera Contractual Obligations – Firm Exports

The Maritime Link will be designed to connect the Island Interconnected Transmission System to Nova Scotia's power grid. Through a contract with Emera, Nalcor Energy will deliver approximately 168 MW and 0.98 TWh (less losses) measured at the Muskrat Falls rectifier commutating bus, to customers in Nova Scotia. The remaining capacity on the link will be used by Nalcor to export power into other markets. The Island Interconnected Transmission System has been designed to deliver 158 MW at the Bottom Brook ac commutating bus for all contingencies on the Island for all operating conditions. The only exceptions are major events on the Labrador Island Link. Complete curtailment of the Emera block of energy is required for the permanent loss of the LIL pole or bipole. Following a permanent loss of the bipole, NLH plans to import power from Nova Scotia over the ML to supply load shed due to operation of the UFLS protection scheme. A loss of a pole would force the healthy pole to ramp up to 2.0 p.u. current, importing 900 MW at the rectifier end for 10 minutes. This would give operators time to start up standby generation and prevent UFLS. After 10 minutes the healthy pole would ramp down to 1.5 p.u. current importing up to 675 MW at the rectifier.

ML export power is limited by hydro generating capacity during the winter months, however under lighter systems loads during the spring, summer and fall operating periods additional power is available for export. In these cases, the system has been designed to deliver a firm capacity of 250 MW for a loss of any single transmission line element. This limit is established by the firm transfer capacity of transmission lines west of BDE for the loss of a single transmission element. Specifically, this worst case export occurs for loss of TL233 between Buchans and Bottom Brook during a summer day with flows limited by the thermal line rating of TL228 which connects Buchans with Massey Drive.

With all lines in service, the exports are limited to 470 MW in the summer due to the thermal rating of TL228. The VSC rated transfer capacity of 500 MW can be exported under spring/fall operating conditions with all lines in service.

4.2 Secondary Energy Sales

Export power orders above the firm export power limit of 250 MW will be curtailed in the event of a contingency outage on the Island's ac transmission system. An SPS will be designed to protect the bulk 230 kV transmission system when the Maritime Link is operating above 250 MW by automatically running back the ML and LIL following a transmission element outage. The system will monitor breaker status and power flows on each identified transmission line to determine the required runback power order.

A comprehensive steady state analysis was completed to determine the maximum export limits for single contingency outages on the Island Interconnected system during off peak operating conditions. The results of this analysis are found in sections 4.2.1 to 4.2.3.

4.2.1 Spring/Fall Operating Conditions (BC7)

BC7 is a base case developed to simulate typical spring and fall (shoulder period) operating conditions on the Island Interconnected Transmission System with an intermediate load of 1100 MW and economic hydro dispatch. The results of the contingency analysis for this case also cover BC5 and BC6. Table 4-1 summarizes the maximum export power orders on the ML for each single contingency line outage.

Table 4-1 - Spring/Fall Operating Conditions - Maximum Export

Operating Condition	Contingency	Import (MW)	Export (MW)	Comments
Spring/Fall Intermediate (1100 MW)	TL211	828	443	Export Limited by TL233
	TL233	828	373	Export Limited by TL228
	TL228	828	470	Export limited by TL233
	TL232	828	407	Export Limited by TL205
	TL234	828	496	Export Limited by TL211
	TL263*	828	423	Export Limited by TL211
	TL269*	828	392	Minimal Acceptable Voltage at Buchans TS

Assumptions: TL228 is permitted to operate at 55°C, TL201/TL242 uprated to 80°C, +/-250 MVAR available at BBK
****System is VAR Limited - Potential Voltage Collapse***

4.2.2 Summer Day Operating Conditions (BC10)

BC10 is a base case developed to simulate a typical summer day operating conditions on the Island Interconnected Transmission System with a light load of 700 MW and economic hydro dispatch. The results of the contingency analysis for this case also cover BC8 and BC9. Table 4-2 summarizes the maximum export power orders on the ML for each single contingency line outage.

Table 4-2 - Summer Day Operating Conditions - Maximum Export

Operating Conditions	Contingency	Import (MW)	Export (MW)	Comments
Summer Day Light (700 MW)	N-0	825	470	Export Limited by TL228
	TL211	825	329	Export limited by TL233
	TL233	530	250	Export Limited by TL211
	TL228	624	305	Export Limited by TL233
	TL217	730	391	Export Limited by TL201 and BDE Gen. Dispatch
	TL201	718	383	Export Limited by TL217 and BDE Gen. Dispatch
	TL205	707	378	Export limited by TL232
	TL232	571	262	Export Limited TL205
	TL231	702	371	Export limited by TL204
	TL204	704	372	Export limited by TL231
	TL234	708	377	Export limited by TL233
	TL263*	633	310	Export Limited by TL228
	TL269*	607	284	Export limited by TL228
	TL237	794	446	Export Limited by TL203 and BDE Gen. Dispatch
	TL247	804	420	Export limited by TL228
	TL248	781	402	Export limited by TL228

Assumptions: TL228 is permitted to operate at 55°C, TL201/TL242 uprated to 80°C, +/-250 MVAR available at BBK
****System is VAR Limited - Potential Voltage Collapse***

4.2.3 Summer Night Operating Conditions (BC13)

BC13 is a base case developed to simulate a typical summer night operating conditions on the Island Interconnected Transmission System with an extreme light load of 420 MW and minimum hydro dispatch. The results of the contingency analysis for this case also cover BC11 and BC12. Table 4-3 summarizes the maximum export power orders on the ML for each single contingency line outage.

Table 4-3 - Summer Night Operating Conditions - Maximum Export

Operating Conditions	Contingency	Import (MW)	Export (MW)	Comments
Summer Night Extreme Light (420 MW)	TL233	435	288	Export Limited by TL211
	TL232	435	301	Export Limited TL205

Assumptions: TL228 is permitted to operate at 55°C, TL201/TL242 uprated to 80°C, +/-250 MVAR available at BBK
****System is VAR Limited - Potential Voltage Collapse***

4.2.4 ML Runback Summary

The results from the steady state load flow analysis determine the maximum export limits for single contingency outages on the Island Interconnected System during off peak operating conditions. These maximums will be used as a basis for the Maritime Link SPS design. Table 4-4 is a summary table which clearly identifies the bulk 230 kV transmission lines that must be monitored by the ML SPS with the shaded blocks indicating the time of the year in which the contingency of the specified line will require a runback of the VSC converter. The values in each block indicate the maximum export power order (MW) on the ML which will become the runback power order following the line outage.

A number of contingencies during the summer months require the runback of the Labrador Island Link (LIL) to clear transmission line thermal overloads. These runback values have been marked with a star in the table. Outages to TL201, TL217 and TL237 are simulated to overload transmission lines between SOP and BDE and therefore can only be cleared by reducing the power order of the LIL. For the purposes of this analysis the system operating philosophy was maintained and both HVdc links ramped back to maintain Island hydro generation dispatch. The maximum power order listed for these contingencies assume Island hydro generation is maintained and not maximized. Therefore, the maximum export for these contingencies is dependent on the Island hydro dispatch. Further system dynamic studies are required to establish limits on the amount of load the hydro units can pick up and maintain stable operation. The results from these studies may impact the maximum export values shown in this table for these cases.

Table 4-4 - ML Maximum Export Summary

Contingency	Required Runback Power Order (MW)			
	Winter	Spring/Fall	Summer Day	Summer Night
LIL Bipole	0			
LIL Pole	0			
TL201			383*	
TL204			372	
TL205			378	
TL211		443	329	
TL217			391*	
TL228		470	305	
TL231			371	
TL232		407	262	301
TL233		373	250	288
TL234		496	377	
TL237			446*	
TL247			420	
TL248			402	
TL263		423	310	
TL269		392	284	
Average		**429**	**334**	**295**
Export is Dependent on Island Generation Dispatch				

5.0 ML RUNBACK FREQUENCY AND DURATION

Following up on a request from NSPI, NLH's System Planning Department has put together forced outage statistics on the Island ac bulk transmission system combined with CIGRÉ HVdc system reliability survey data to determine the frequency of runbacks of the ML. The CIGRÉ 2010 paper B4_209_2010 *A Survey of the Reliability of HVdc Systems Throughout the World During 2007-2008* provides the latest available statistics for HVdc transmission systems worldwide and was used in this analysis.

5.1 Labrador Island Link (LIL)

Outages to the Labrador Island Link will affect the operation of the Maritime Link only for permanent loss of a pole or the bipole. For the loss of a pole, CIGRÉ statistics indicate one can expect between 0.38 and 4.90 pole outages per year with average durations ranging from 2.6 to

484.2 hours. This translates to 0.76 to 9.8 pole outages per year on a bipole system with one converter station per pole similar to the LIL. Using a worst case frequency of 9.8 pole outages per year and average outage duration of 60 hours, taken from the CIGRÉ paper, one can calculate the unavailability of the LIL as 6.7%. It should be noted that the statistics include reporting for dc systems operating new and old HVdc technologies. Pole outages for any significant duration are usually caused by failure of the converter transformer rather than the valves or OHL. In recent years, the reliability of HVdc systems have improved significantly, therefore it is possible that the LIL unavailability could be as low as 0.023% assuming 0.76 outages per year for 2.6 hours.

A failure of the LIL bipole will also curtail the ML, however the probability of losing the converter station is limited to 0.42 outages per year for less than 3 hours a year. The overhead line is designed to experience the rated ice/wind load once every 50 years for a probability of 0.02 bipole outages per year. Historically, NLH has repaired major transmission infrastructure failures within a two week window. With these considerations, the overall unavailability of the LIL due to a failure of the bipole is calculated to be 0.091%.

For the purposes of this analysis, the unavailability of the LIL as it relates to export of the Emera block of energy is 6.77%.

5.2 TL269 Estimated Outage Statistics

TL269 is a proposed new 180 km 230 kV transmission line which is to be built by Emera as part of the Maritime Link between the Granite Canal and Bottom Brook Terminal Stations. The additional circuit to Bottom Brook will ensure a firm transfer of 250 MW under contingency during off-peak hours and provide a higher ESCR for a stronger system. As outage statistics for this line is not available, existing forced outage statistics for other 230 kV transmission lines were used in determining an estimated reliability of the line.

TL269 is proposed to be similar in design to that of TL263 between Upper Salmon and Granite Canal Terminal Stations which are designed as H-frame wood structures with steel cross arms supporting a minimum 795 kcmil ACSR “DRAKE” conductor operated at 75°C hot conductor temperature. Unlike TL263, TL269 will have overhead ground (OHG) wire along its entire length.

This line will be the second transmission line on the Island to have OHG wire along its entire length. TL233 connecting Buchans to Bottom Brook is the only 230 kV transmission line to have OHG wire along its entire length and TL206 between Bay d'Espoir and Sunnyside is the only transmission line to have surge arrestors on each phase and every structure to improve lightning performance on these lines.

For the purposes of this analysis, the lightning performance is assumed similar to TL233 and TL206 while performance due to weather events can be similar to TL263 as it has a similar tower design and is located in the same area. Table 5-1 outlines outage data for transmission lines TL206, TL233 and TL263 including the cause of the outage and its duration.

Table 5-1 – TL206/TL233/TL263 Outage Statistics – 2003 to 2012

Surge ID	Date/Time	HYDRO_ID	Outage Duration (hrs)	Outage Duration (mins)	Primary Cause	Subcomponet	Failure Mode	Failure Type
5790	Feb 26, 2011 09:13	TL206	0	23	Snow	05	Correct Operation	Phase to Phase
5955	Dec 08, 2011 17:44	TL206	1	22	Wind	03	Correct Operation	Phase to ground
3871	Aug 14, 2003 17:53	TL233	0	2	Adverse Weather	05	Correct Operation	Ph to Ph to gnd
4333	Aug 11, 2005 03:32	TL233	0	2	Adverse Weather	05	Correct Operation	Three Phase
4545	Jun 22, 2006 20:54	TL233	22	1	Lightning	09	Correct Operation	Ph to Ph to gnd
5135	Jul 18, 2008 16:03	TL233	0	0	Lightning	05	Correct Operation	Phase to ground
5128	Jul 30, 2008 20:22	TL233	0	2	Lightning	05	Correct Operation	Ph to Ph to gnd
5177	Sep 04, 2008 09:16	TL233	0	0	Lightning	05	Correct Operation	Phase to ground
5393	Jun 26, 2009 17:14	TL233	0	2	Lightning	05	Correct Operation	Phase to ground
5406	Jul 05, 2009 12:00	TL233	0	4	Lightning	05	Correct Operation	Phase to ground
5445	Aug 08, 2009 11:23	TL233	0	0	Lightning	05	Correct Operation	Phase to ground
5660	Jul 13, 2010 12:30	TL233	0	7	Contact by Trees	04	Correct Operation	Phase to ground
4088	Jun 04, 2004 03:43	TL263	0	2	Adverse Weather	05	Correct Operation	Phase to ground
5058	Jun 12, 2008 12:36	TL263	0	24	Lightning	05	Correct Operation	Phase to ground
5069	Jun 22, 2008 14:43	TL263	0	11	Lightning	05	Correct Operation	Phase to ground
5207	Oct 04, 2008 03:46	TL263	10	46	Lightning	05	Correct Operation	Phase to ground
5412	Jul 06, 2009 00:01	TL263	0	14	Lightning	05	Correct Operation	Phase to ground
6044	Jun 30, 2012 11:05	TL263	0	6	Lightning	05	Correct Operation	Phase to ground
6054	Jun 30, 2012 16:52	TL263	0	44	Lightning	05	Correct Operation	Phase to ground
6094	Aug 24, 2012 09:37	TL263	2	27	Lightning	05	Correct Operation	Phase to ground

Using the highlighted rows from the line outage data assuming the lightning performance of TL206 and TL233 with the weather performance of TL263 the estimated frequency and duration of forced outages was calculated. Table 5-2 displays the estimated forced outage data for future line TL269.

Table 5-2 – TL269 Estimated Forced Outage Statistics – Prorated by Length

TL269 Estimated Forced Outage Statistics (TL206/TL233/TL263)					
Hydro ID	**Outages**	**Outage Duration (hours)**	**Mean Duration (hours)**	**Frequency/Year**	**% Unavailability/Year**
TL269	11.6	22.18333	1.912356319	0.58	0.01266172

5.3 Island ac Transmission Line Outage Statistics

In an effort to understand the frequency of runbacks on the Maritime Link, the frequency and duration of outages on the LIL as well as bulk 230 kV transmission lines identified in earlier load flow studies were determined. It is clear that permanent outages on a pole of the LIL or a failure of the entire bipole would result in the blocking of the VSC converter station at BBK. For the purposes of this analysis, the unavailability of the LIL as it relates to export of the Emera block of energy is between 0.114% and 6.77%.

The annual unavailability of each transmission line was determined from the operational forced outage statistics from 2003 to 2012 and adjusted depending on the time of year when the line outage is to present an SPS automated runback of the ML. Forced outage statistics for TL269 was estimated using data from TL206, TL233 and TL263 assuming lightning performance was similar to TL206 and TL233 and weather performance was similar to TL263. As a result, the annual unavailability of key circuits from the LIL to the VSC converter station at BBK which will cause runback of the ML is 0.09%; the majority of which is dependent on LIL pole outages.

Therefore, the overall availability of the ML as it relates to normal operation is between 93.14% and 99.8%.

Table 5-3 – Maritime Link Runback Frequency and Duration Summary – Worst Case LIL Pole Performance

Contingency	Maritime Link Runback Frequency and Duration	
	% Unavailability/year	% Unavailability/period
LIL Bipole	0.09109589	0.09109589
LIL Pole	6.681563927	6.681563927
TL201	0.020405251	0.00680175
TL204	0.000123668	4.12227E-05
TL205	0.000637367	0.000212456
TL211	0.003928843	0.002619229
TL217	0.002197489	0.000732496
TL228	0.05417618	0.036117453
TL231	0.000294901	9.83004E-05
TL232	0.026208143	0.017472095
TL233	0.012747336	0.008498224
TL234	0.00032344	0.000215627
TL237	0.000494673	0.000164891
TL247	0.009046804	0.003015601
TL248	9.51294E-06	3.17098E-06
TL263	0.008504566	0.005669711
TL269	0.01266172	0.008441147
Sum Total		6.862763191
	% Availability	93.13723681

Table 5-4 - Maritime Link Runback Frequency and Duration Summary – Best Case LIL Pole Performance

Contingency	Maritime Link Runback Frequency and Duration	
	% Unavailability/year	**% Unavailability/period**
LIL Bipole	0.09109589	0.09109589
LIL Pole	0.022557078	0.022557078
TL201	0.020405251	0.00680175
TL204	0.000123668	4.12227E-05
TL205	0.000637367	0.000212456
TL211	0.003928843	0.002619229
TL217	0.002197489	0.000732496
TL228	0.05417618	0.036117453
TL231	0.000294901	9.83004E-05
TL232	0.026208143	0.017472095
TL233	0.012747336	0.008498224
TL234	0.00032344	0.000215627
TL237	0.000494673	0.000164891
TL247	0.009046804	0.003015601
TL248	9.51294E-06	3.17098E-06
TL263	0.008504566	0.005669711
TL269	0.01266172	0.008441147
Sum Total		0.203756342
	% Availability	99.79624366

6.0 CONCLUSION

The results of the steady state load flow analysis determined that significant thermal overloads and or unacceptable low voltage conditions would result from a loss of a single transmission element on the bulk 230 kV transmission system. As such, an SPS will be designed to runback the Maritime Link and Labrador Island Link to protect the bulk transmission system under contingency.

The Island Interconnected Transmission System has been designed to deliver 250 MW at the Bottom Brook ac commutating bus for all single 230 kV transmission line contingencies on the Island for all operating conditions. The only exceptions are major events on the Labrador Island Link. Complete curtailment of the Emera block is required for the permanent loss of the LIL pole or bipole.

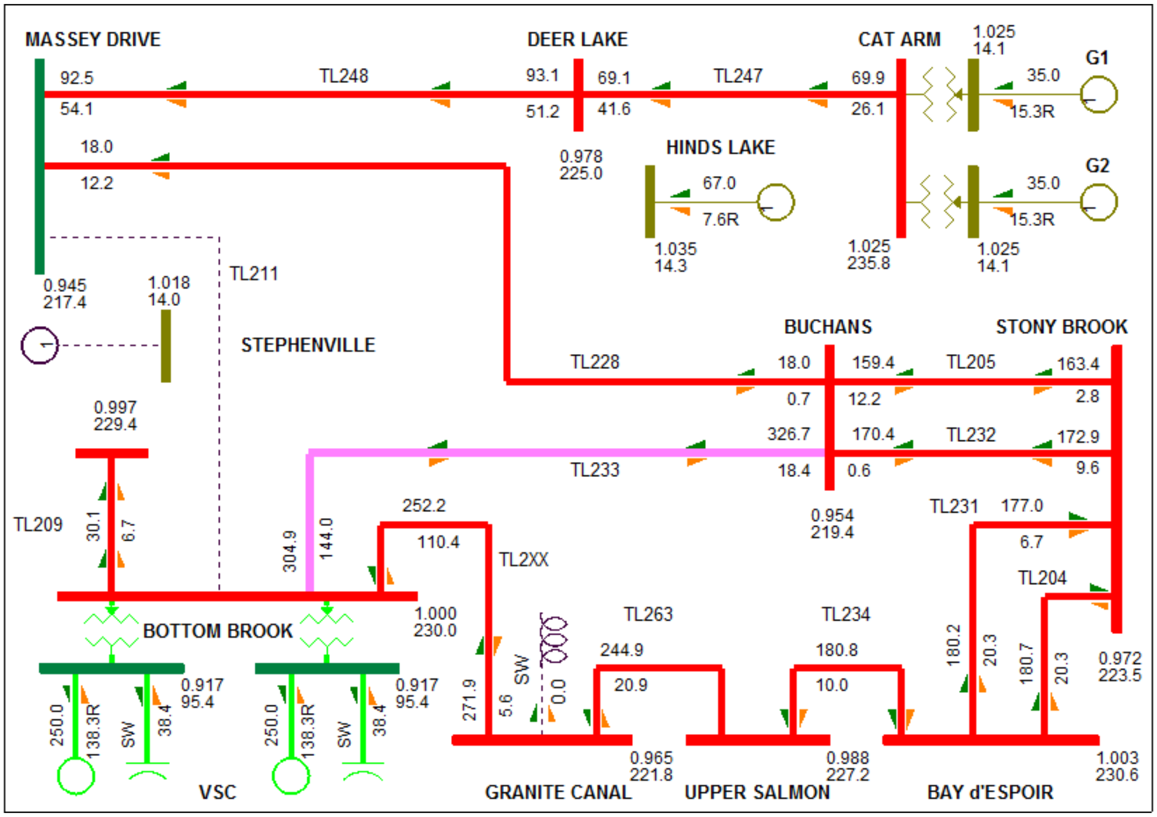
ML export power is limited by hydro-electric generating capacity during the winter months. However, under lighter systems loads during the spring, summer and fall operating period, additional power is available for export. During the summer a maximum of 470 MW can be exported over the link which is limited by the transmission capacity of TL228. The rated 500 MW can be exported over the ML in the shoulder period in the spring and fall. In these cases, the system has been designed to deliver a firm capacity of 250 MW for a loss of any single transmission line element.

The number of runbacks required when the Maritime Link is operating between 250 MW and 500 MW in the off-peak period was determined from the steady state load flow analysis. Using historical forced line outage statistics of the bulk 230 kV transmission lines the annual unavailability of lines which would signal the SPS to runback the ML was calculated.

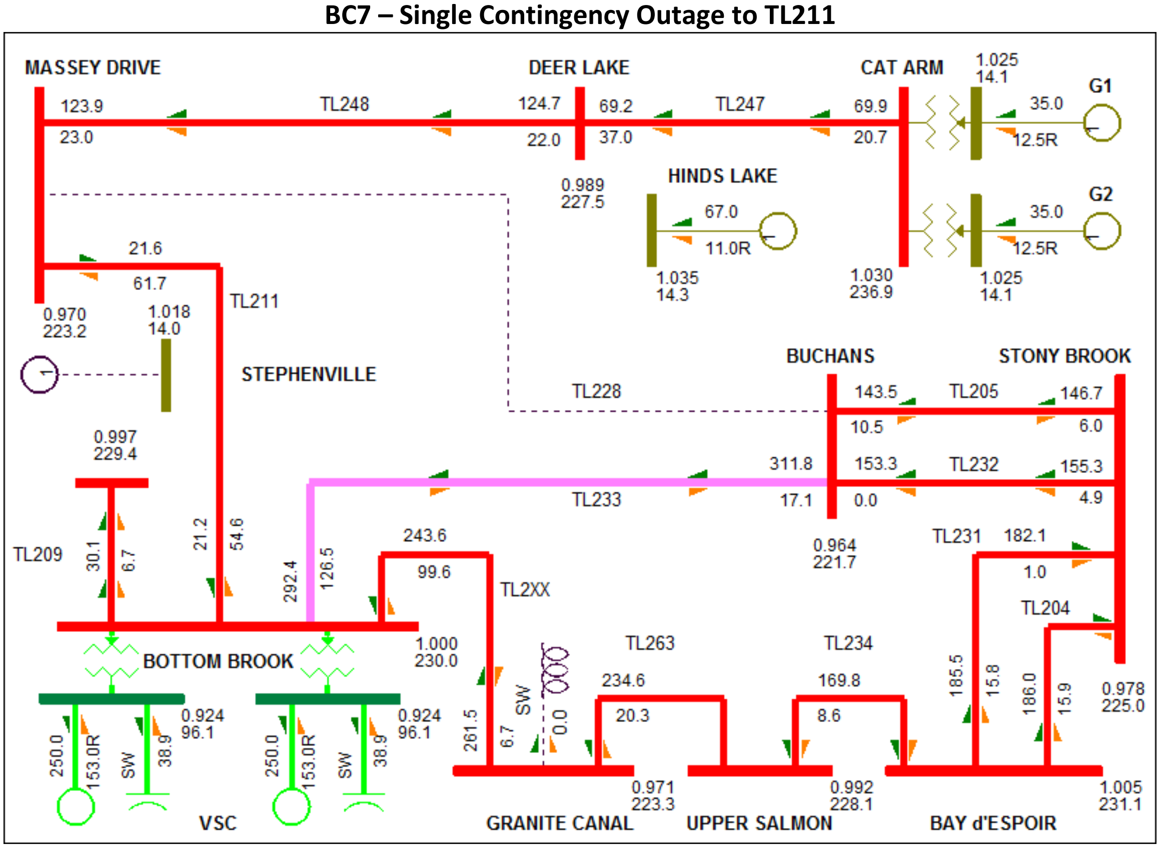
Using forced outage statistics from the CIGRÉ 2010 paper B4_209_2010, *A Survey of the Reliability of HVdc Systems Throughout the World During 2007-2008* and NLH outage statistics for the period 2003 to 2012*,* it was determined that the ML would be blocked or unavailable from 0.114% to 6.77% of the year due to permanent pole outages on the LIL. As a result the overall availability of the ML as it relates to normal operation is between 93.14% and 99.8%.

APPENDIX A
Base Case 7- Load Flow PSS®E Plots

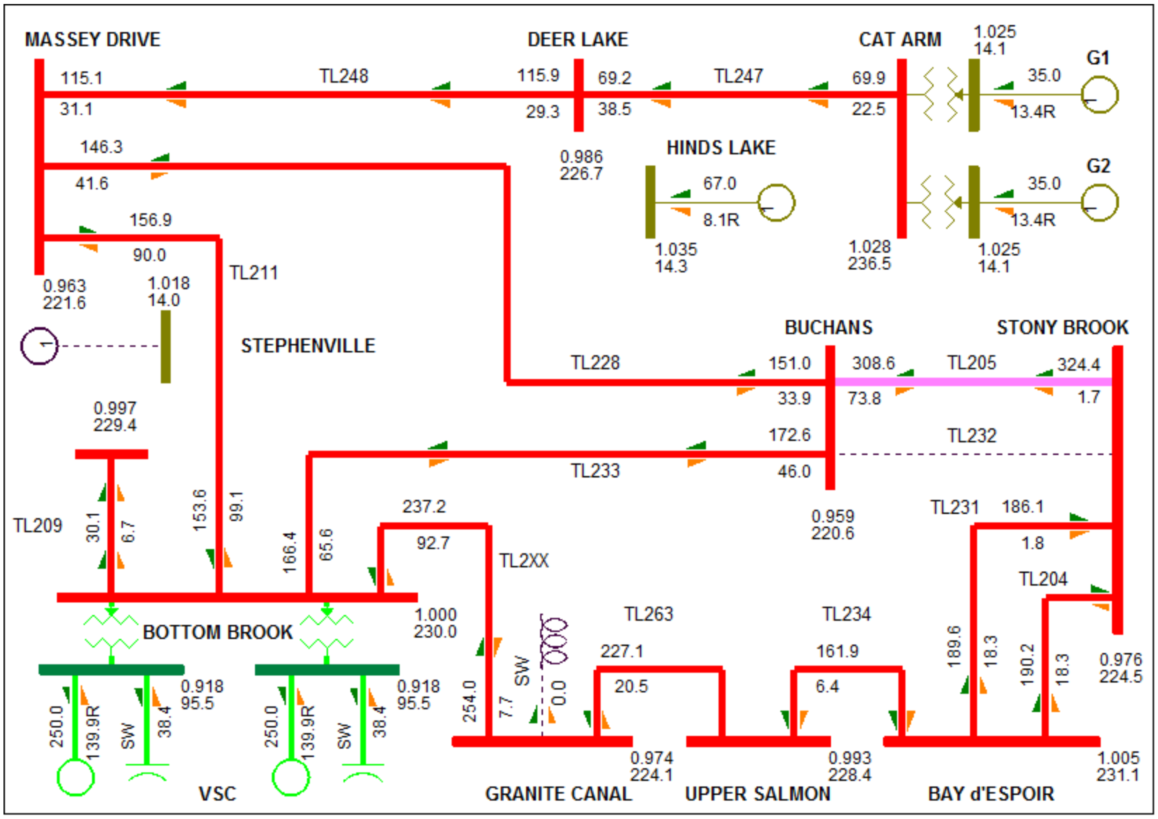
ATTACHMENT A-1
Base Case 7 Single Line Outage Load Flow Plots



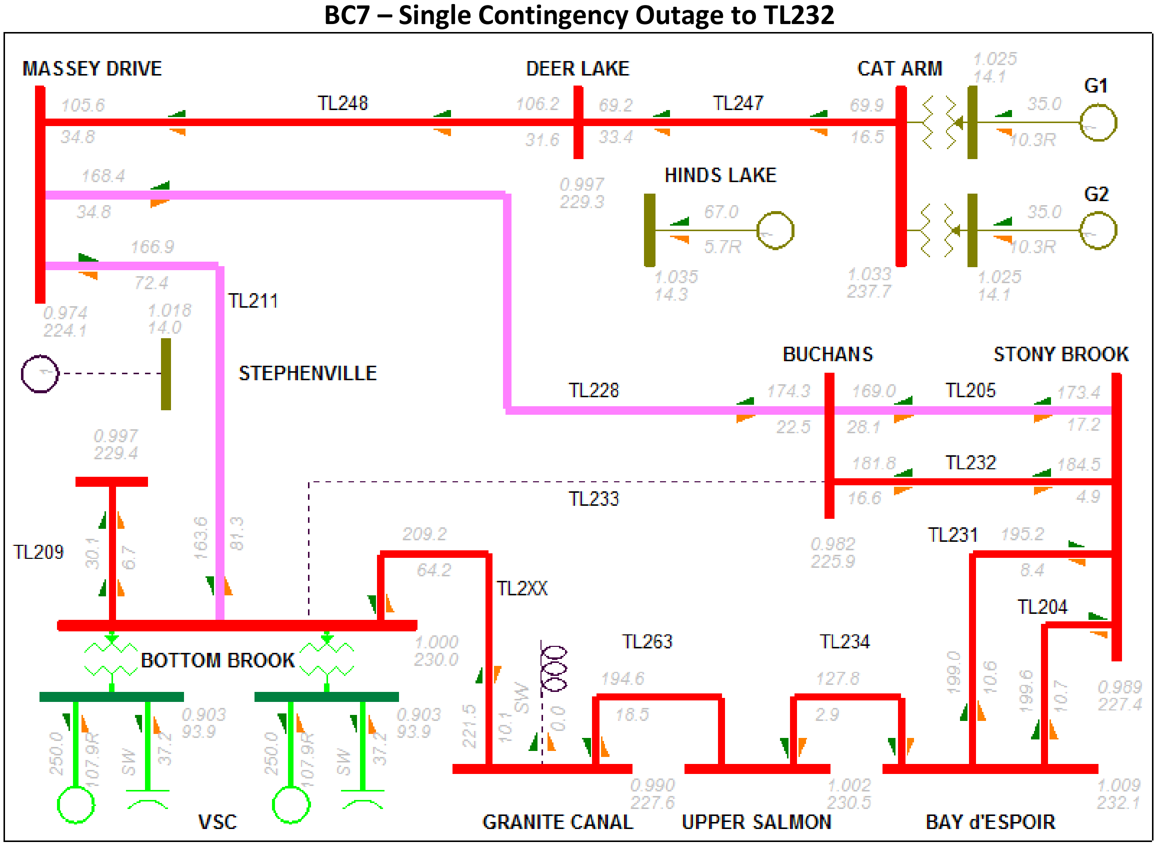
BC7 – Single Contingency Outage to TL211



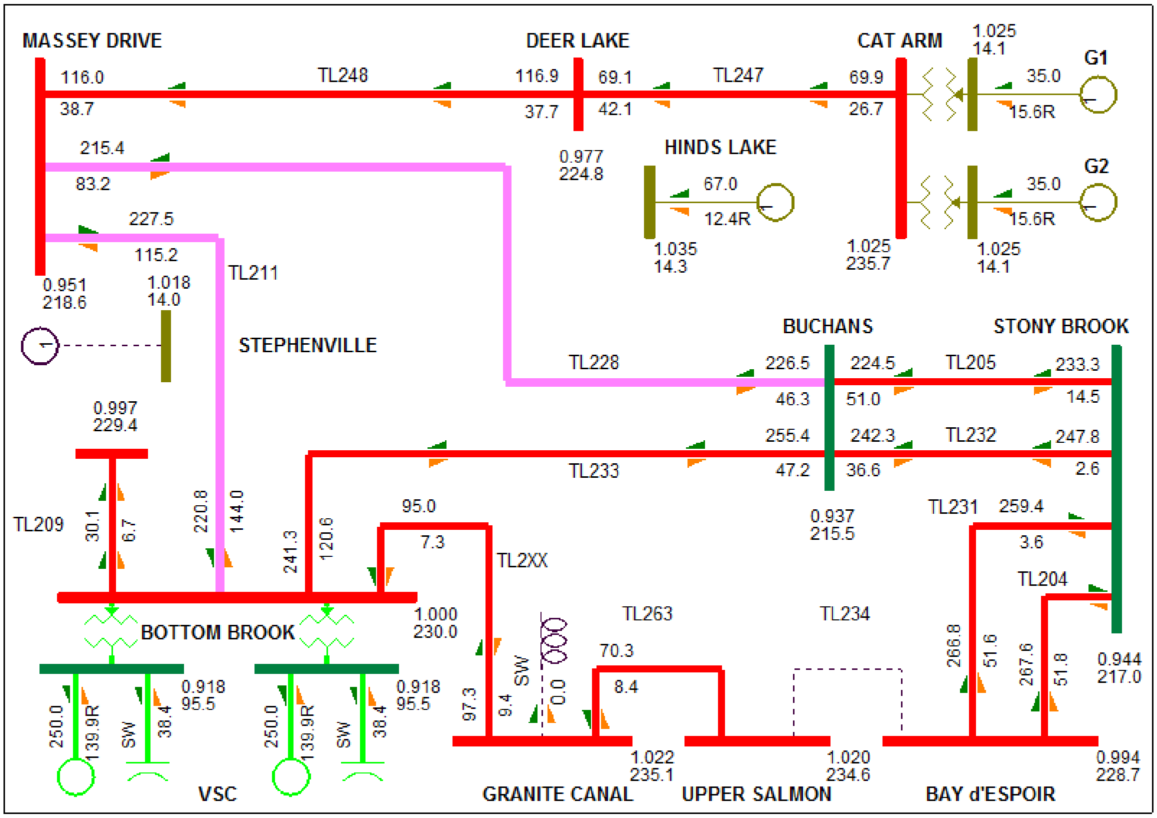
Base Case 7 – Single Contingency Outage to TL228



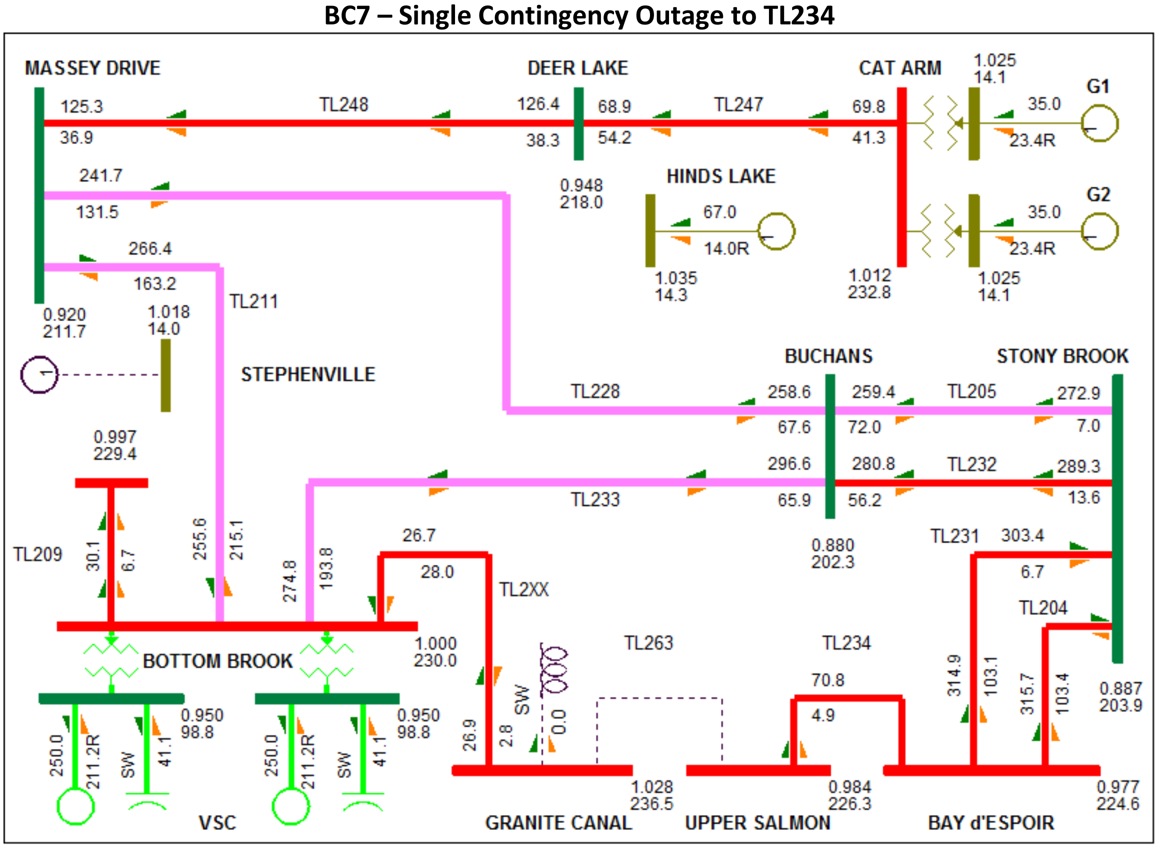
BC7 – Single Contingency Outage to TL232



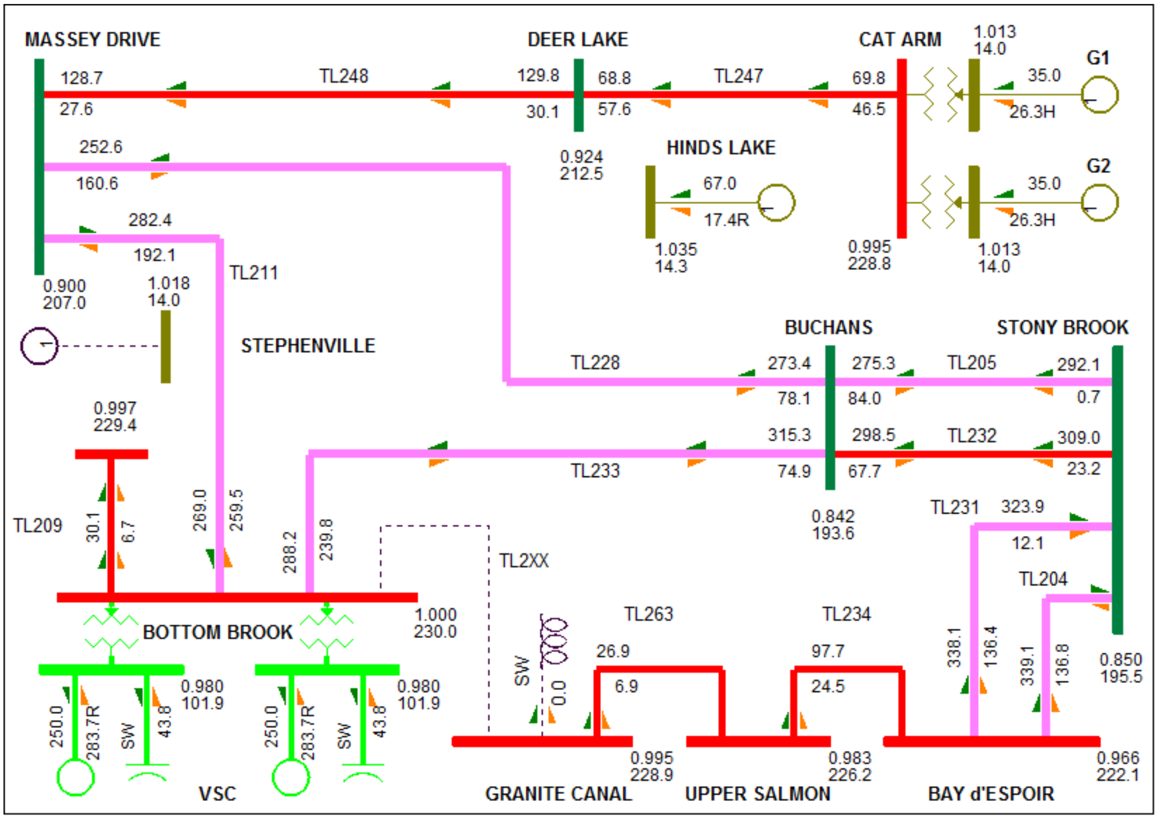
BC7 – Single Contingency Outage to TL233



BC7 – Single Contingency Outage to TL234

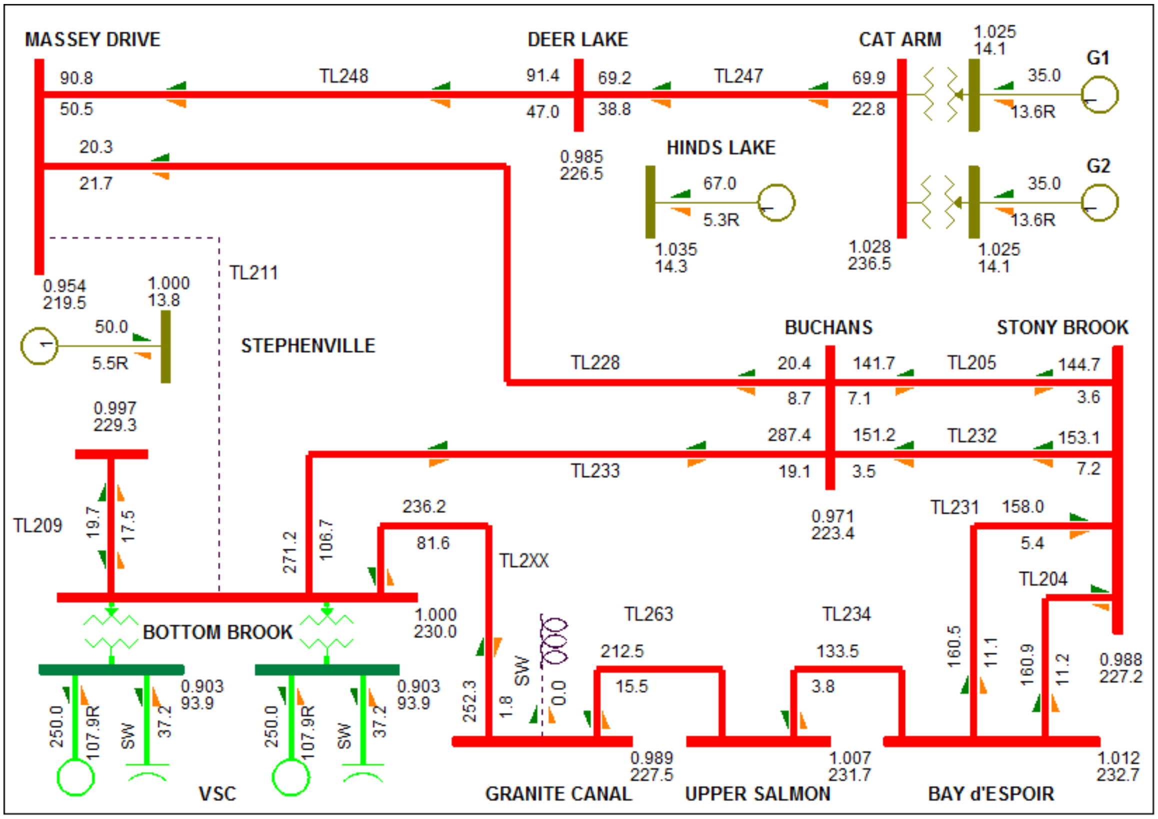


BC7 – Single Contingency Outage to TL263

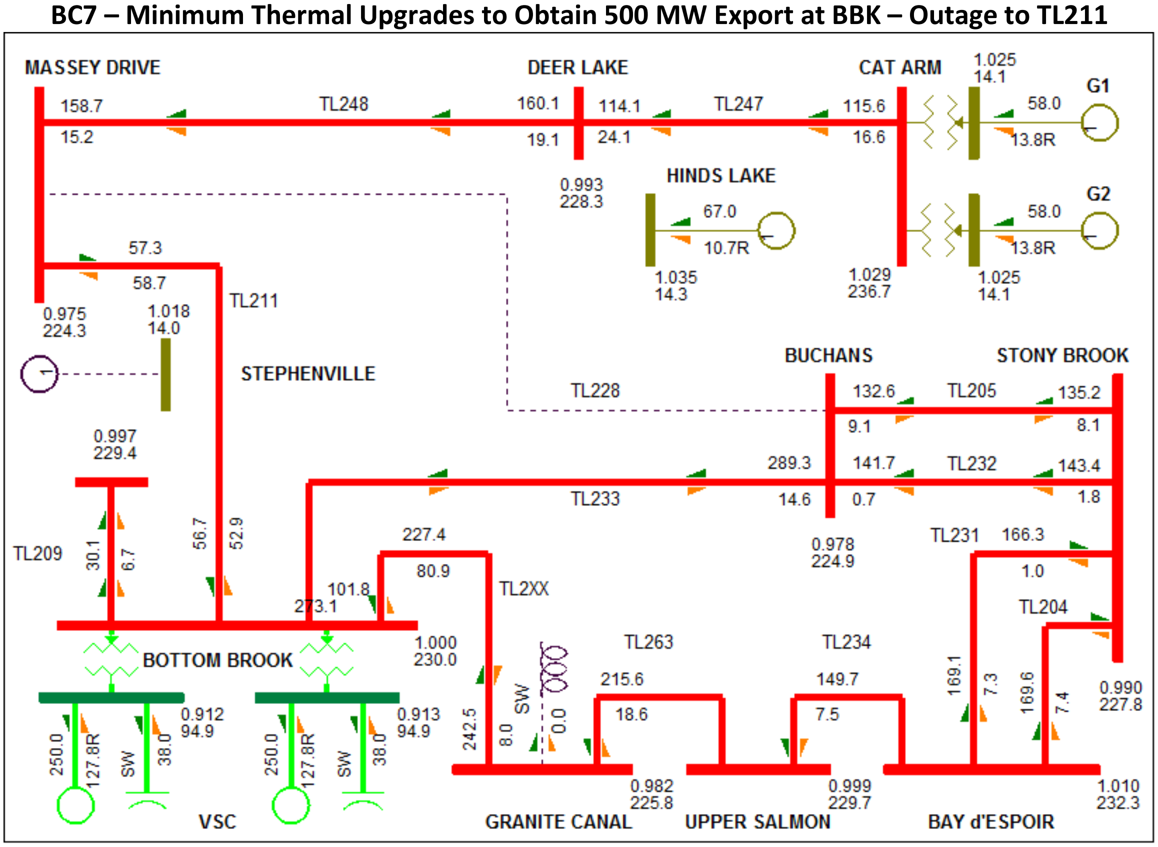


Single Contingency Outage to TL2XX

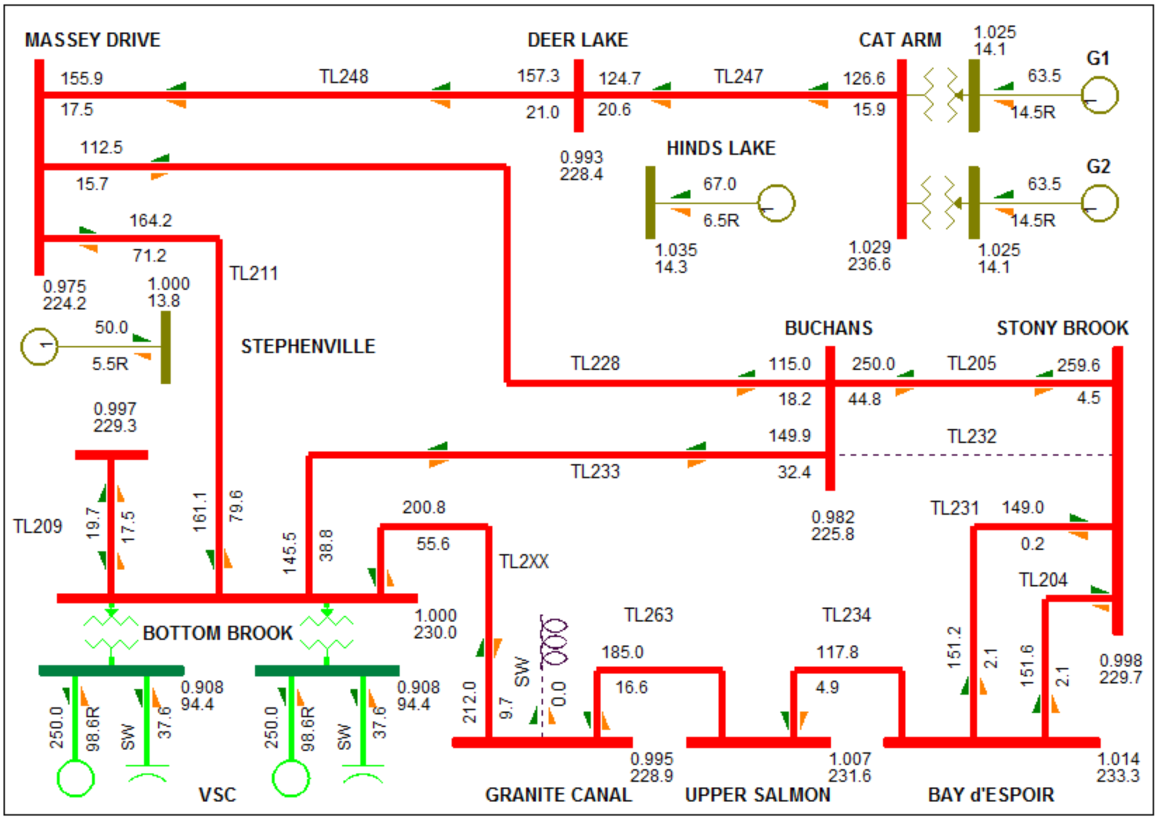
ATTACHMENT A-2
Base Case 7 Minimum Thermal Upgrades Load Flow Plots



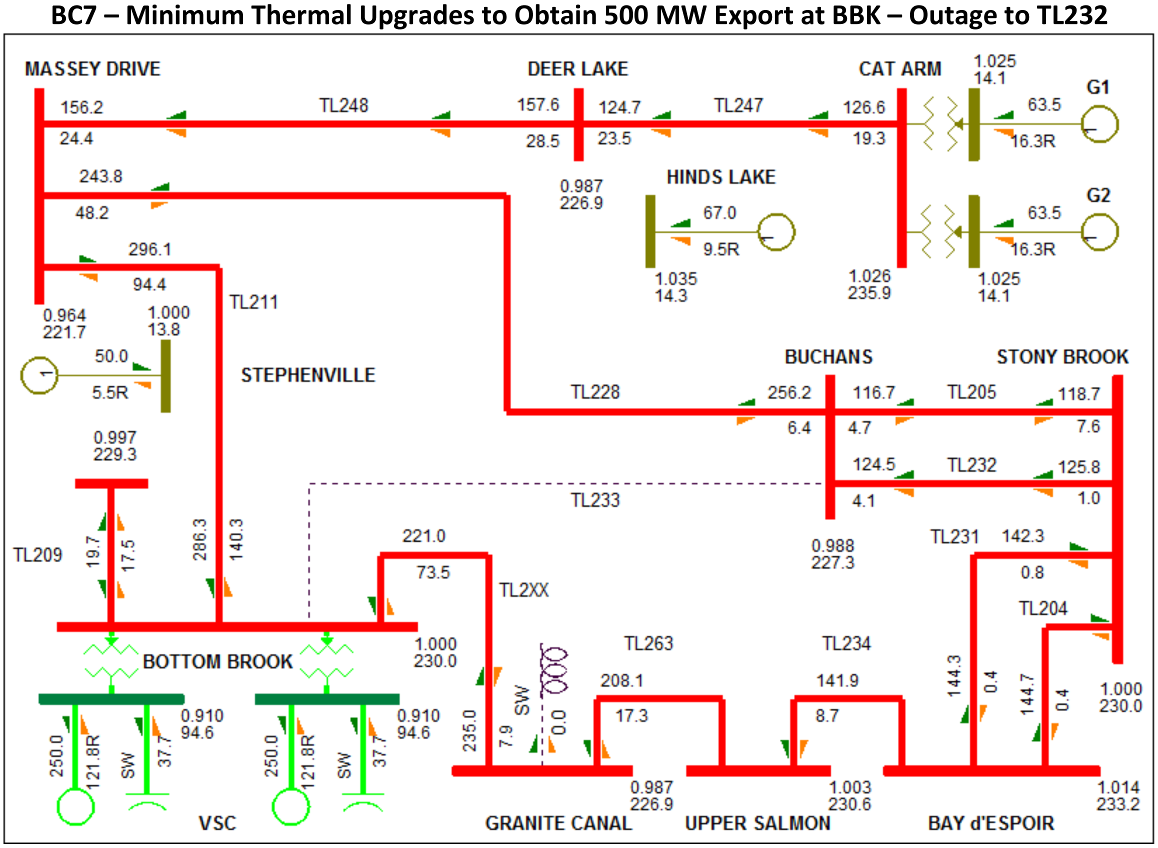
BC7 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL211



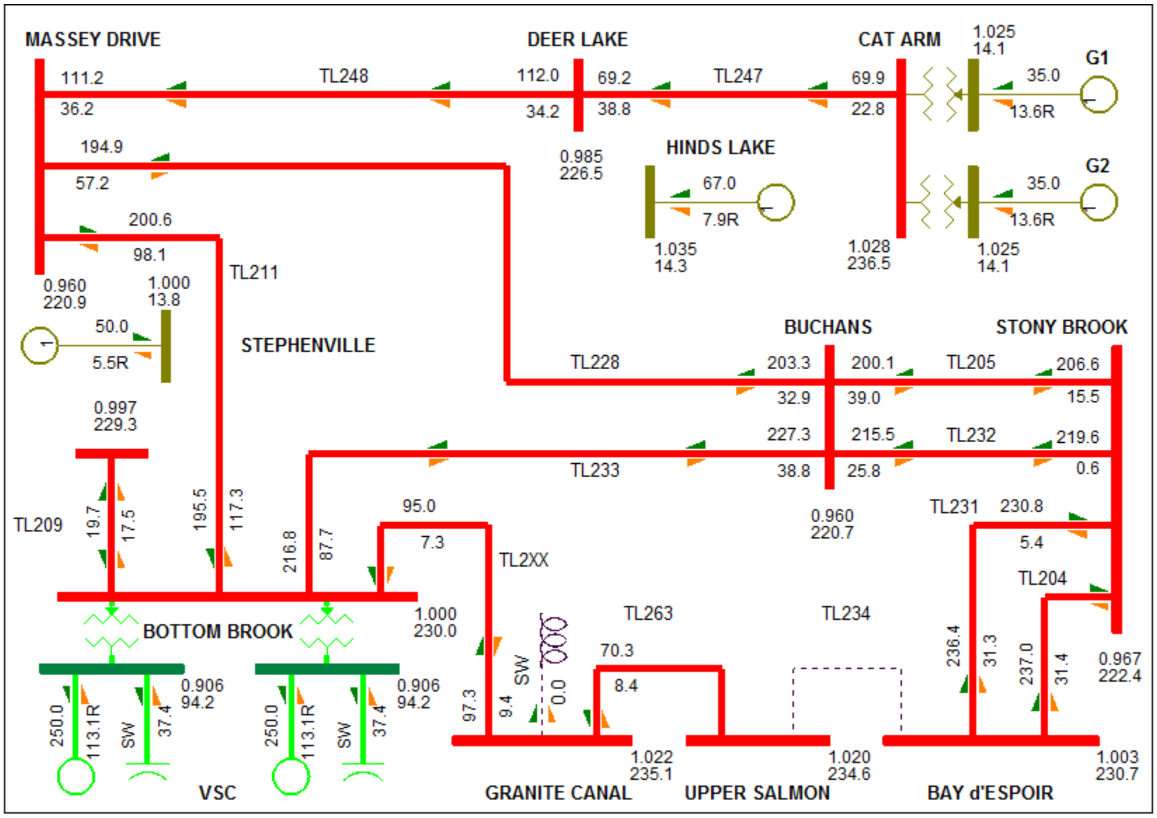
BC7 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL228



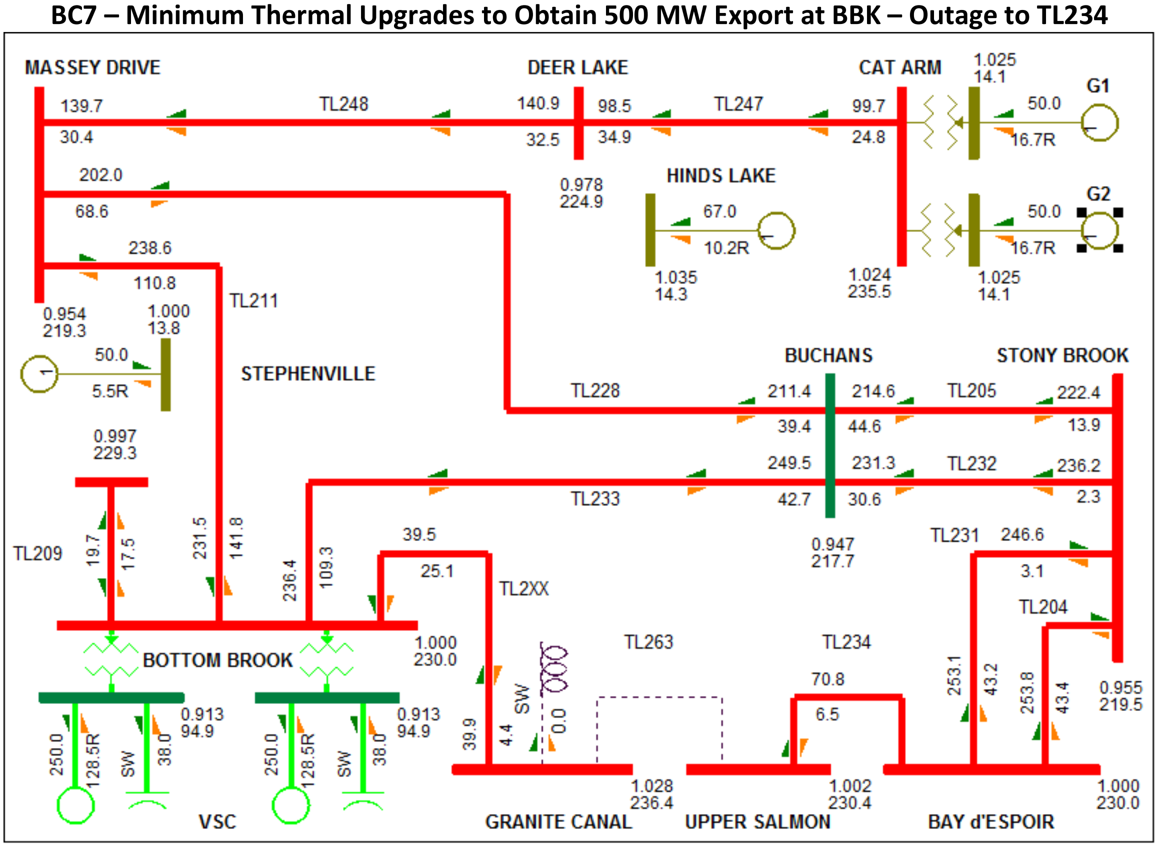
BC7 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL232



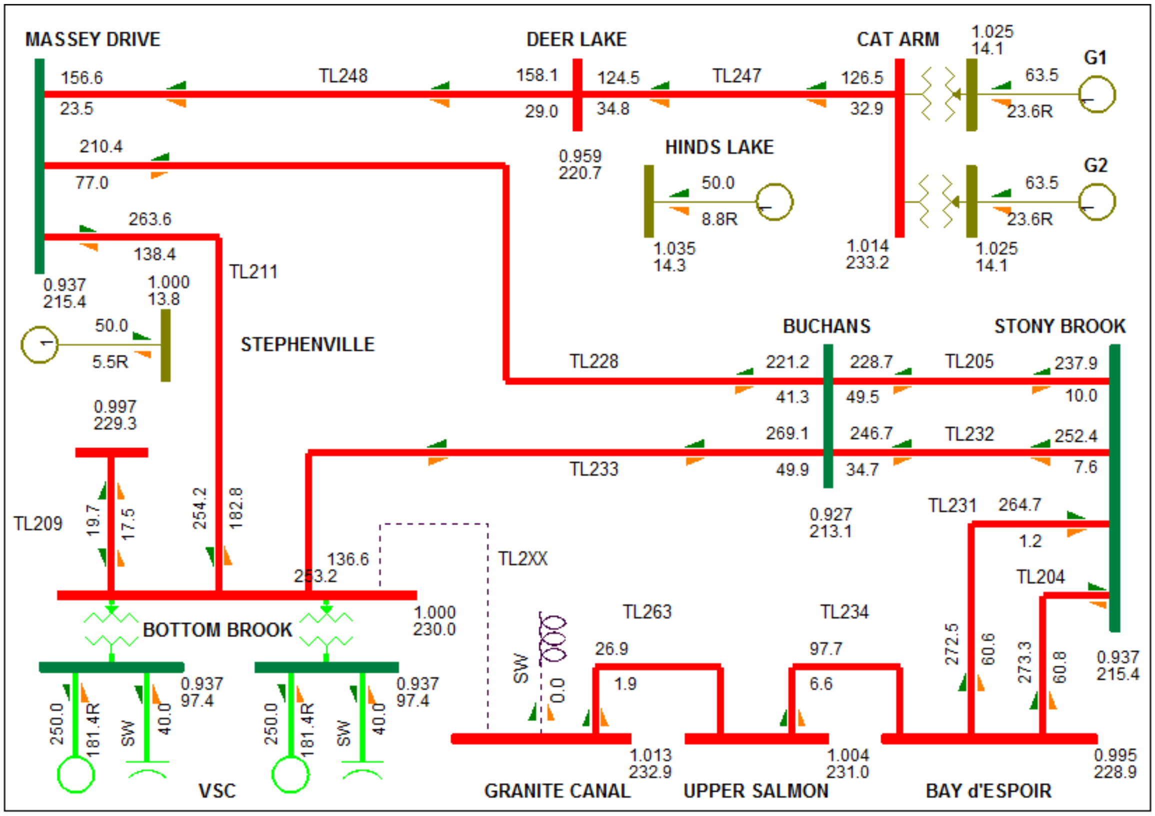
BC7 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL233



BC7 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL234

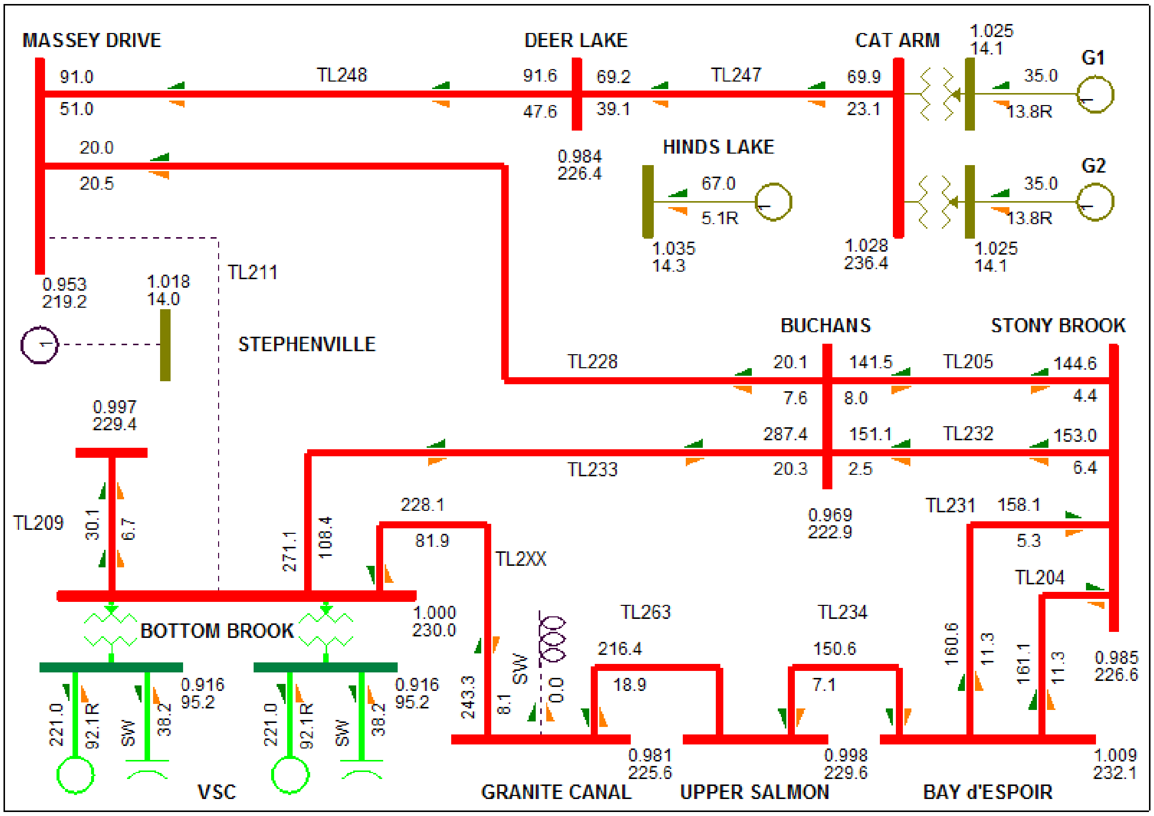


BC7 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL263

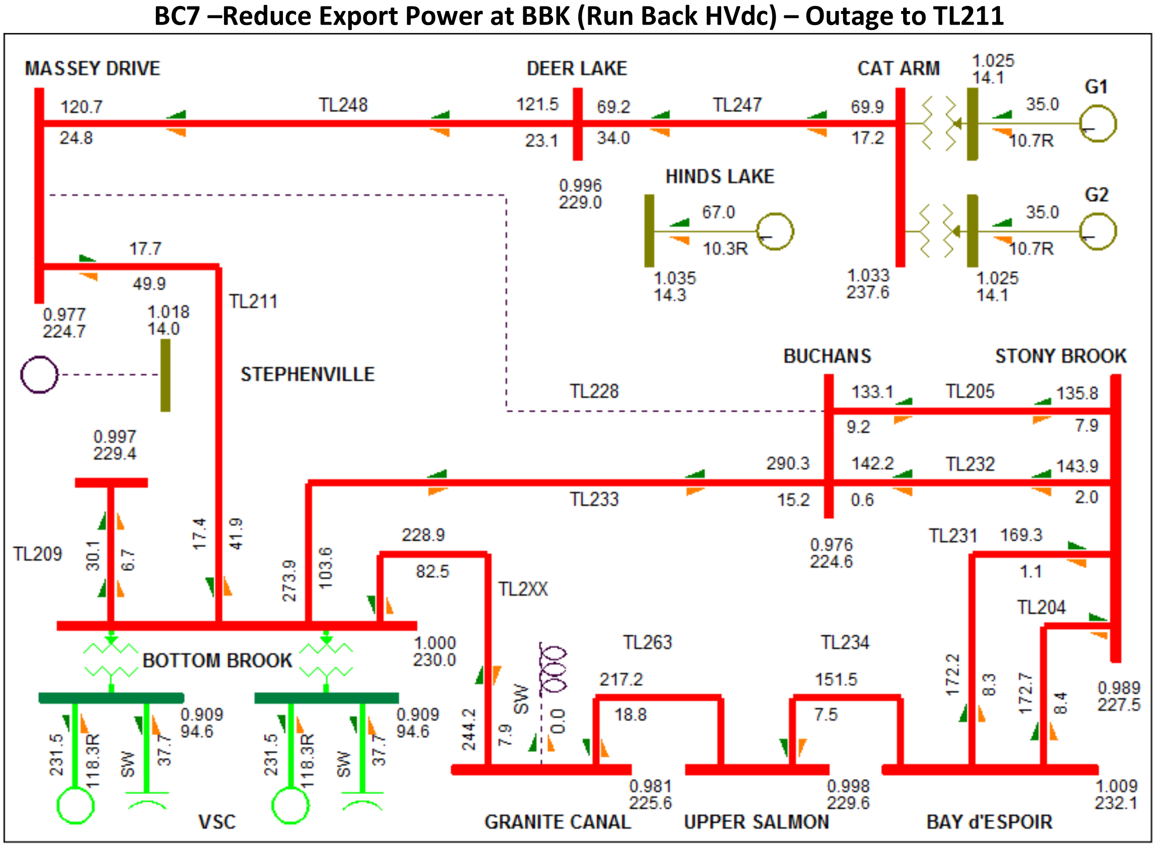


BC7 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL2XX

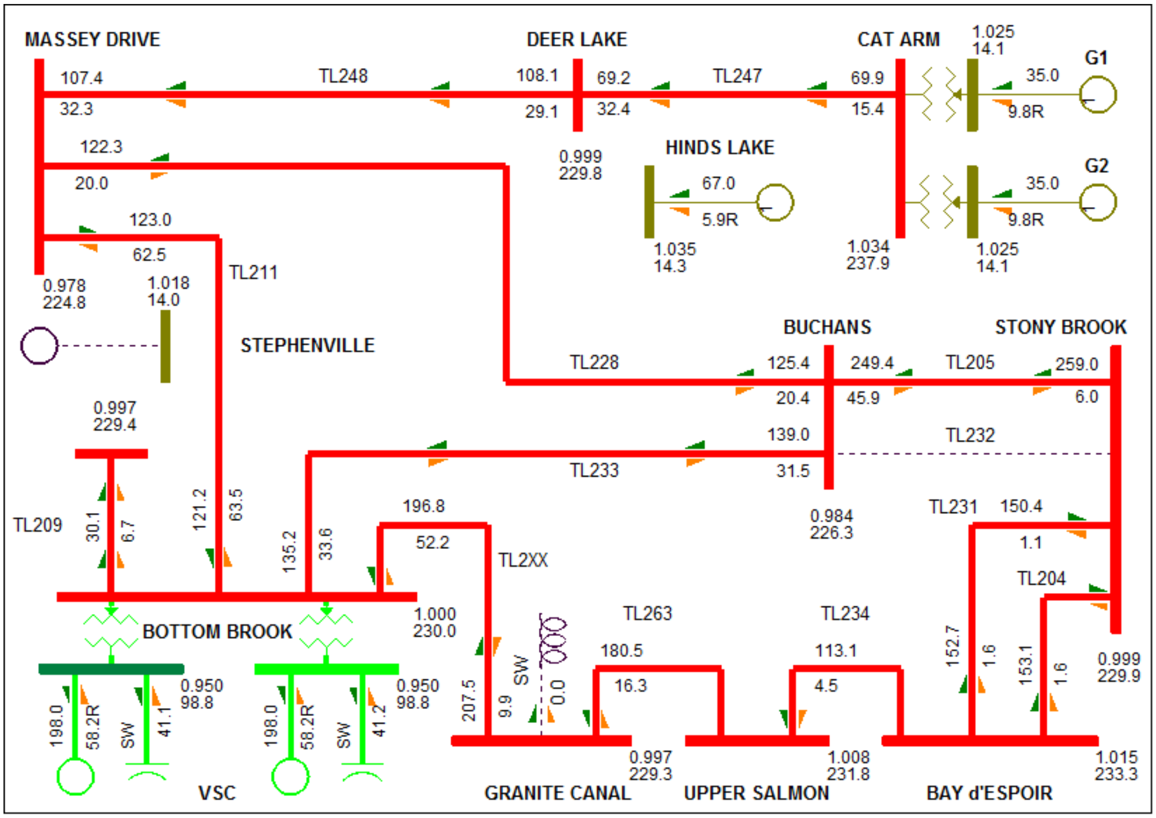
ATTACHMENT A-3
Base Case 7 Reduced Export Load Flow Plots



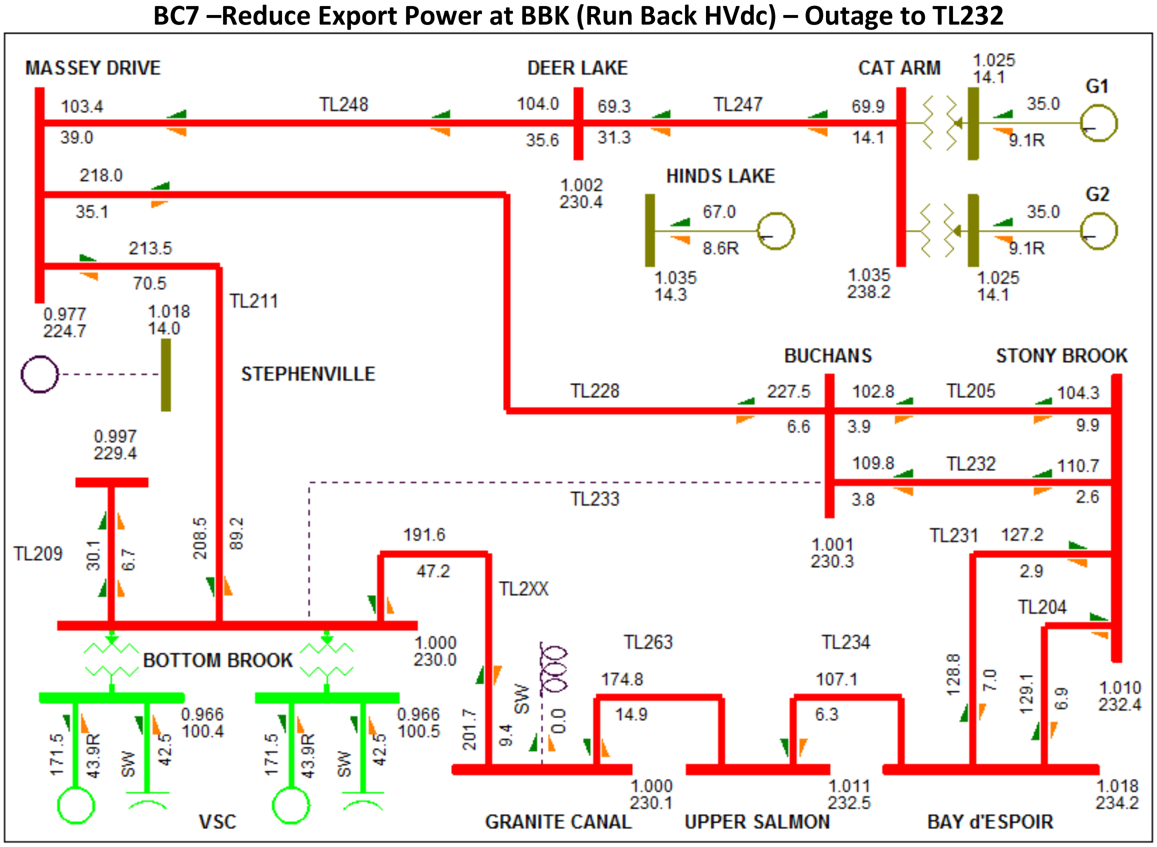
BC7 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL211



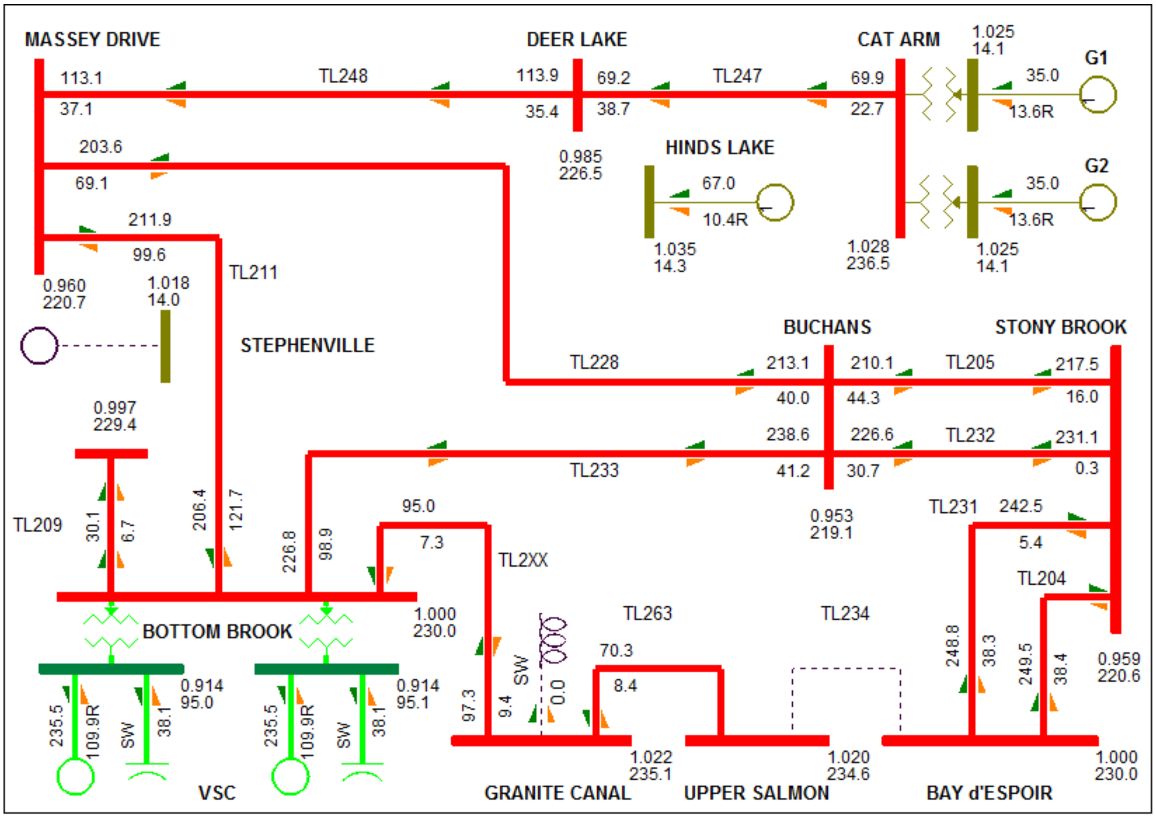
BC7 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL228



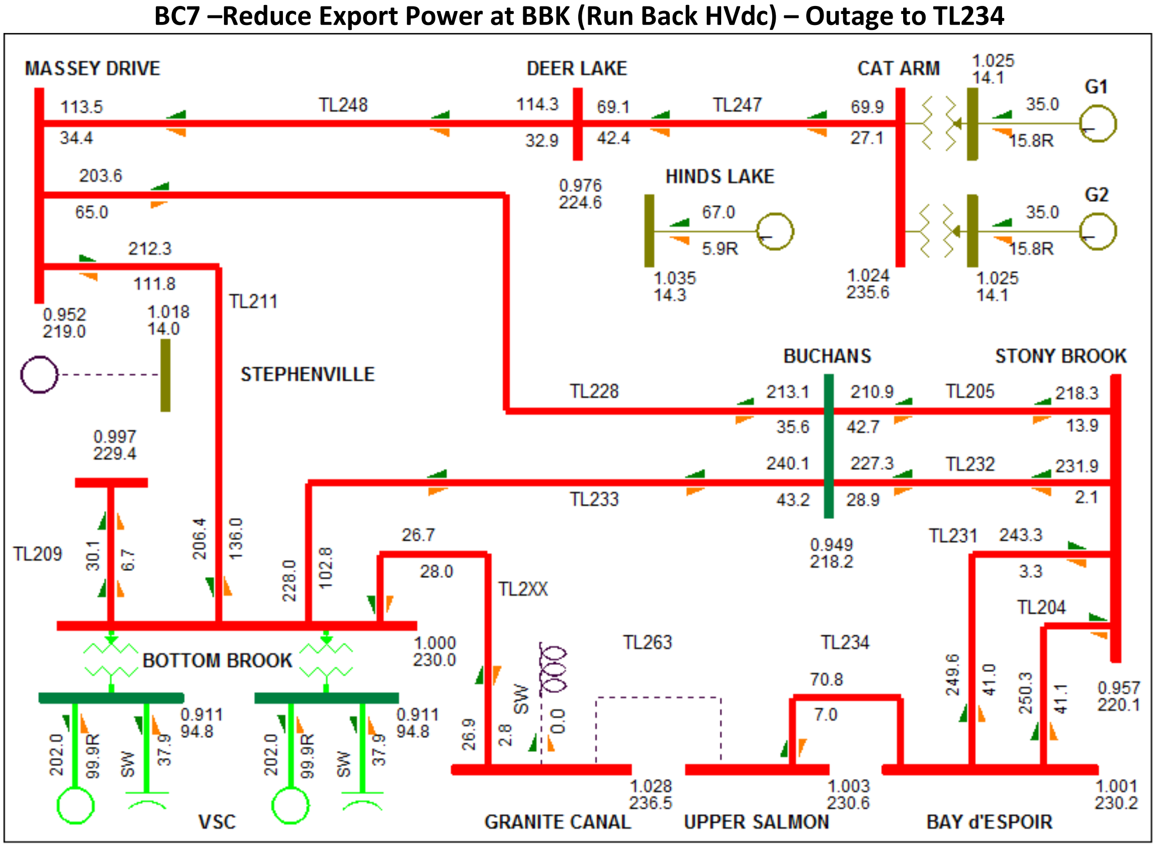
BC7 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL232



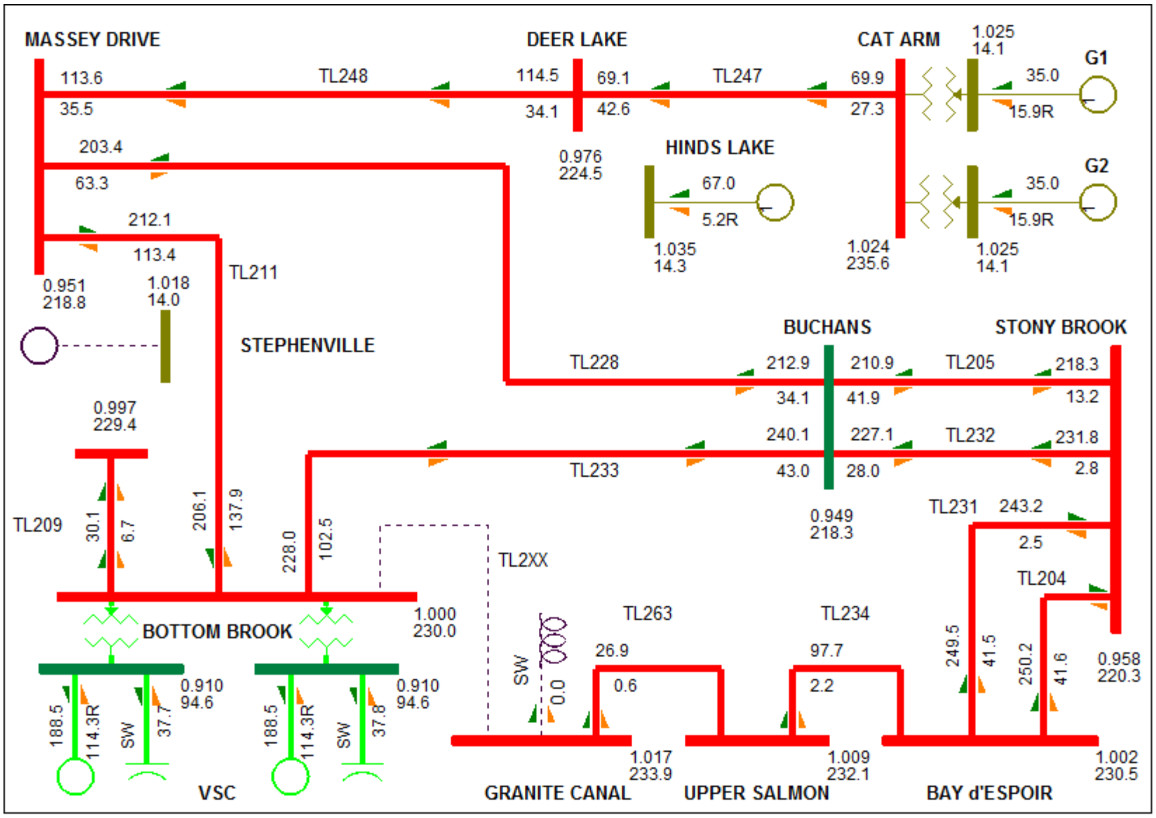
BC7 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL233



BC7 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL234



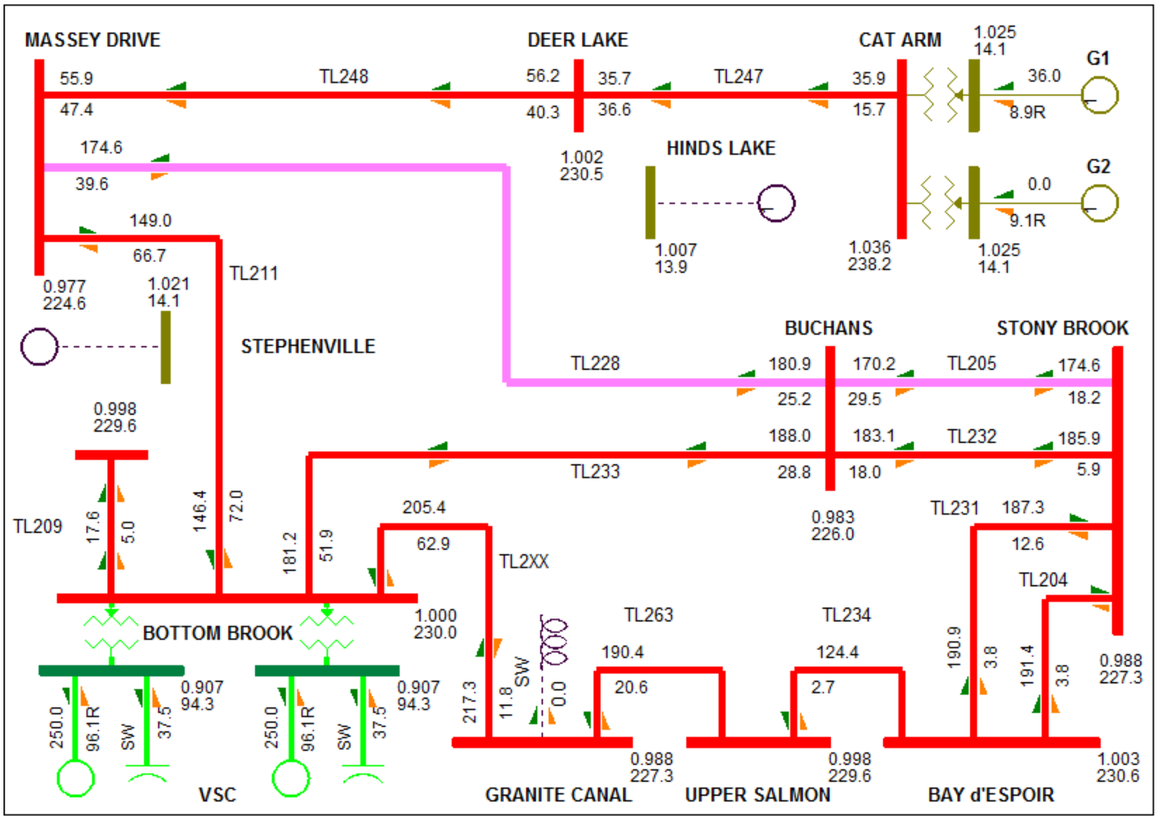
BC7 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL263



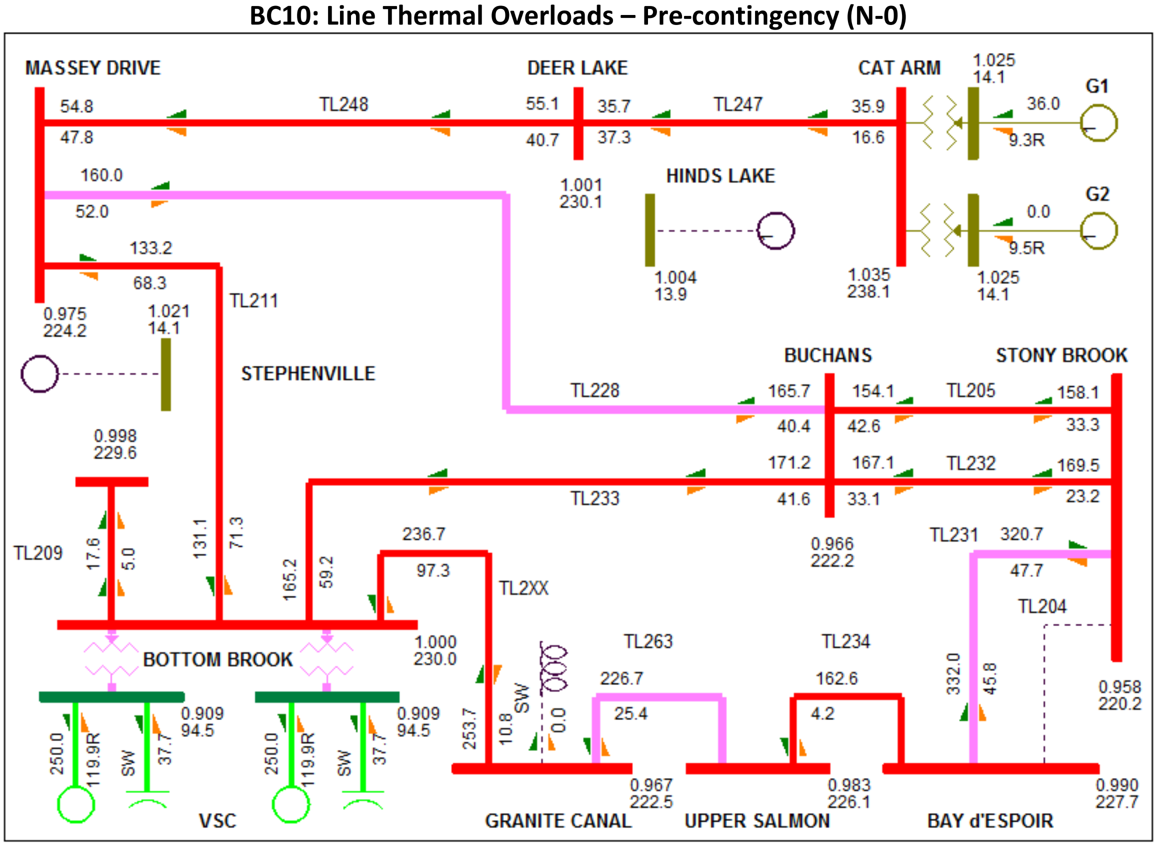
BC7 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL2XX

APPENDIX B
Base Case 10- Load Flow PSS®E Plots

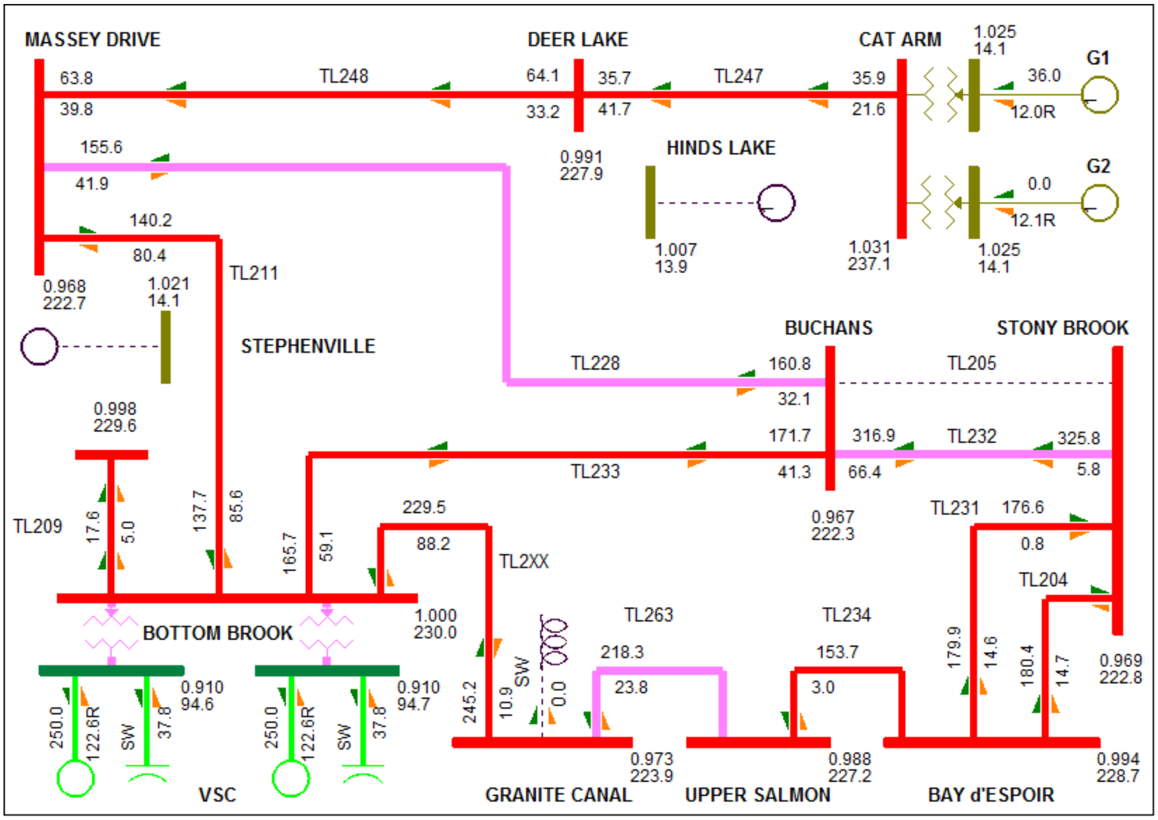
ATTACHMENT B-1
Base Case 10 Single Line Outage Load Flow Plots



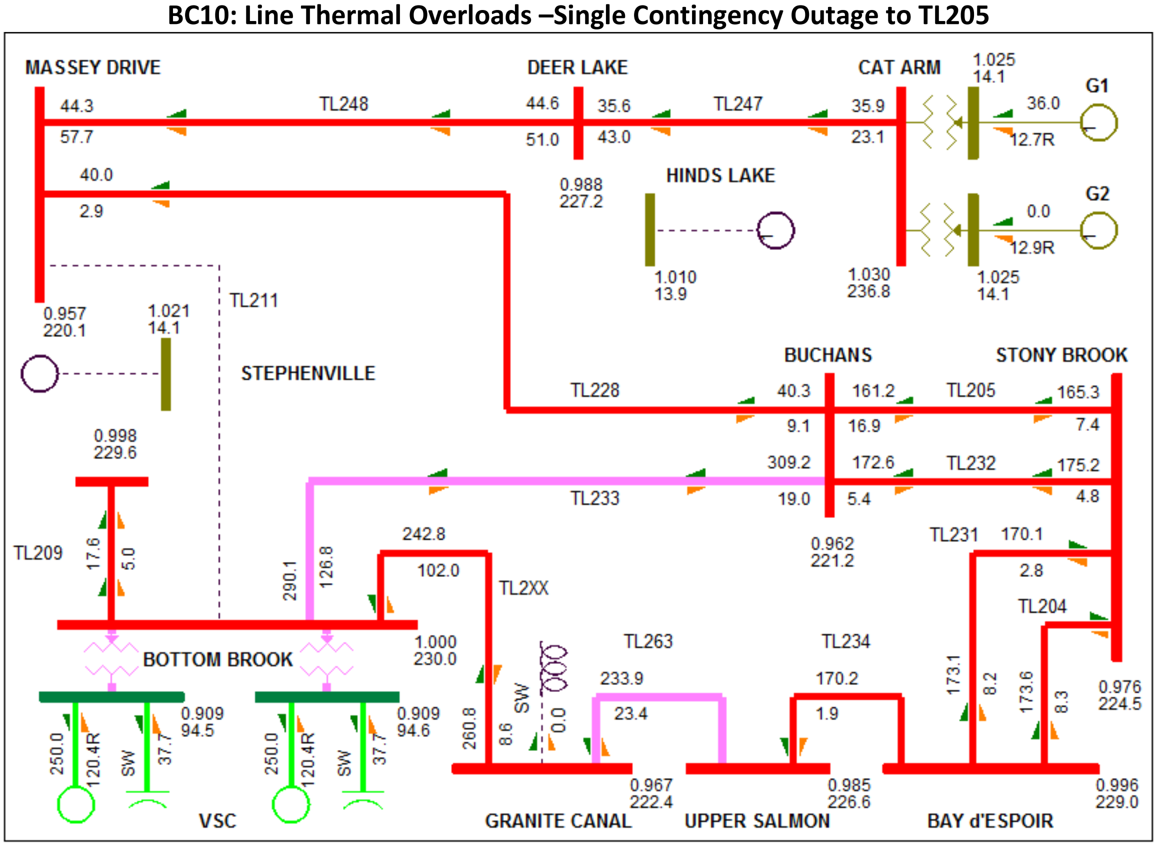
BC10: Line Thermal Overloads – Pre-contingency (N-0)



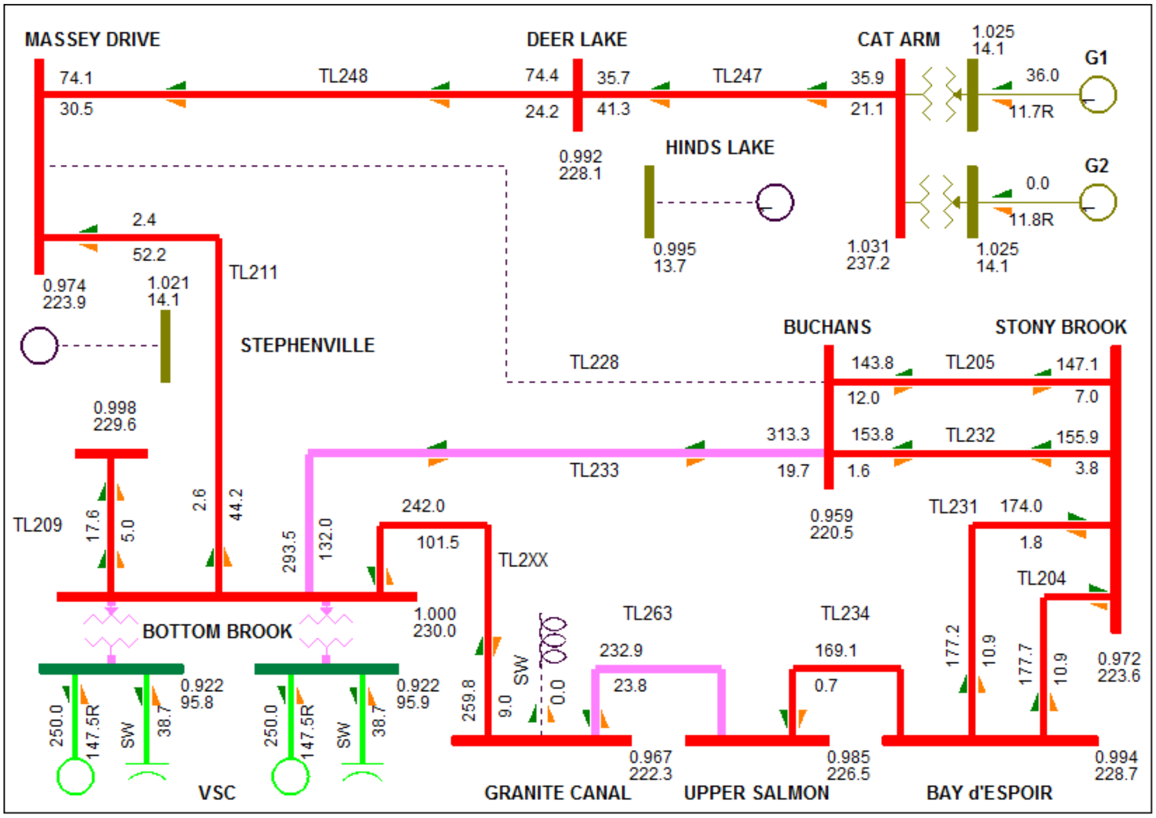
BC10: Line Thermal Overloads –Single Contingency Outage to TL204



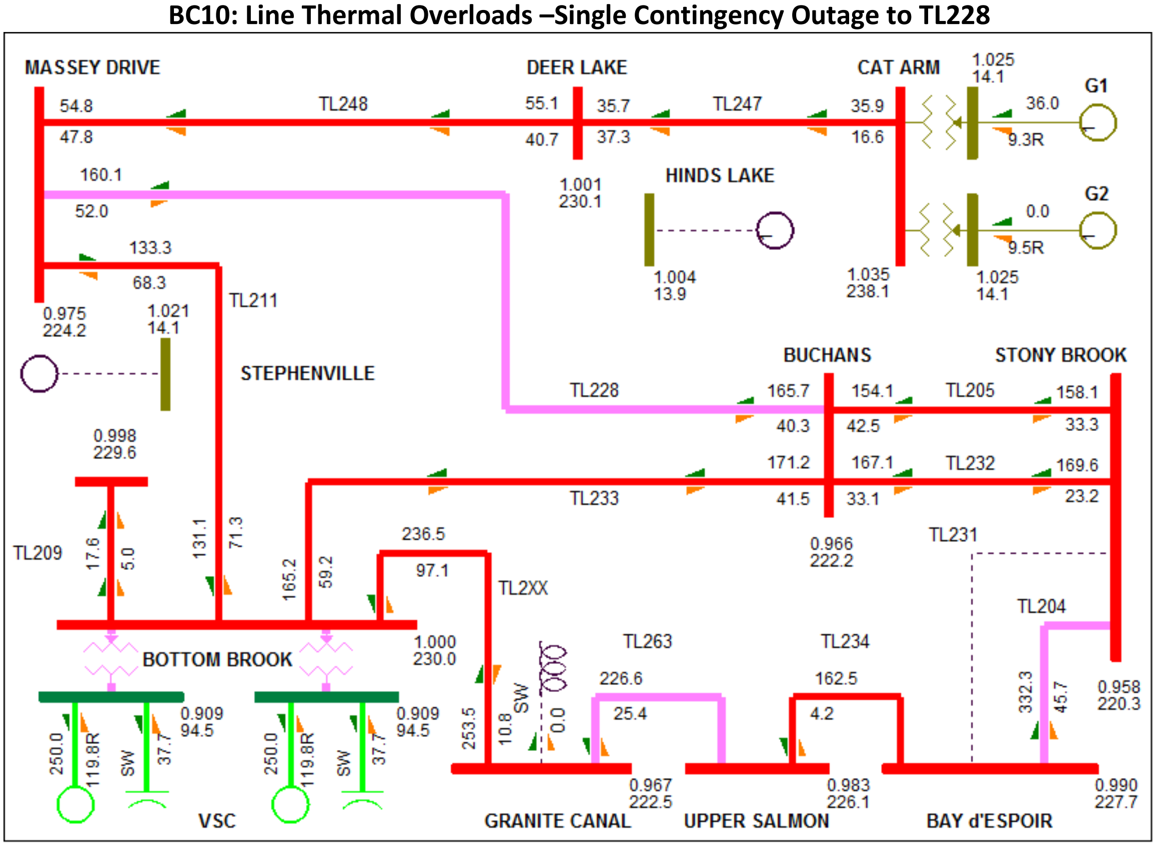
BC10: Line Thermal Overloads –Single Contingency Outage to TL205



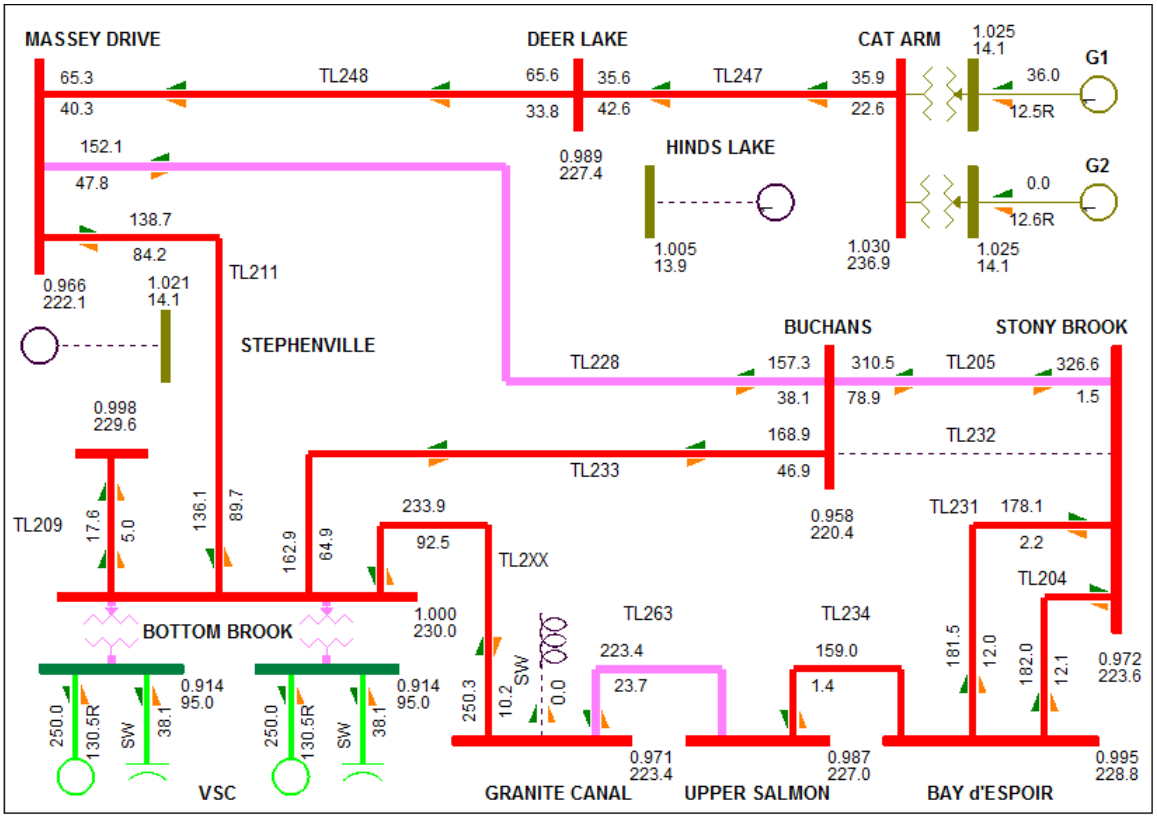
BC10: Line Thermal Overloads –Single Contingency Outage to TL211



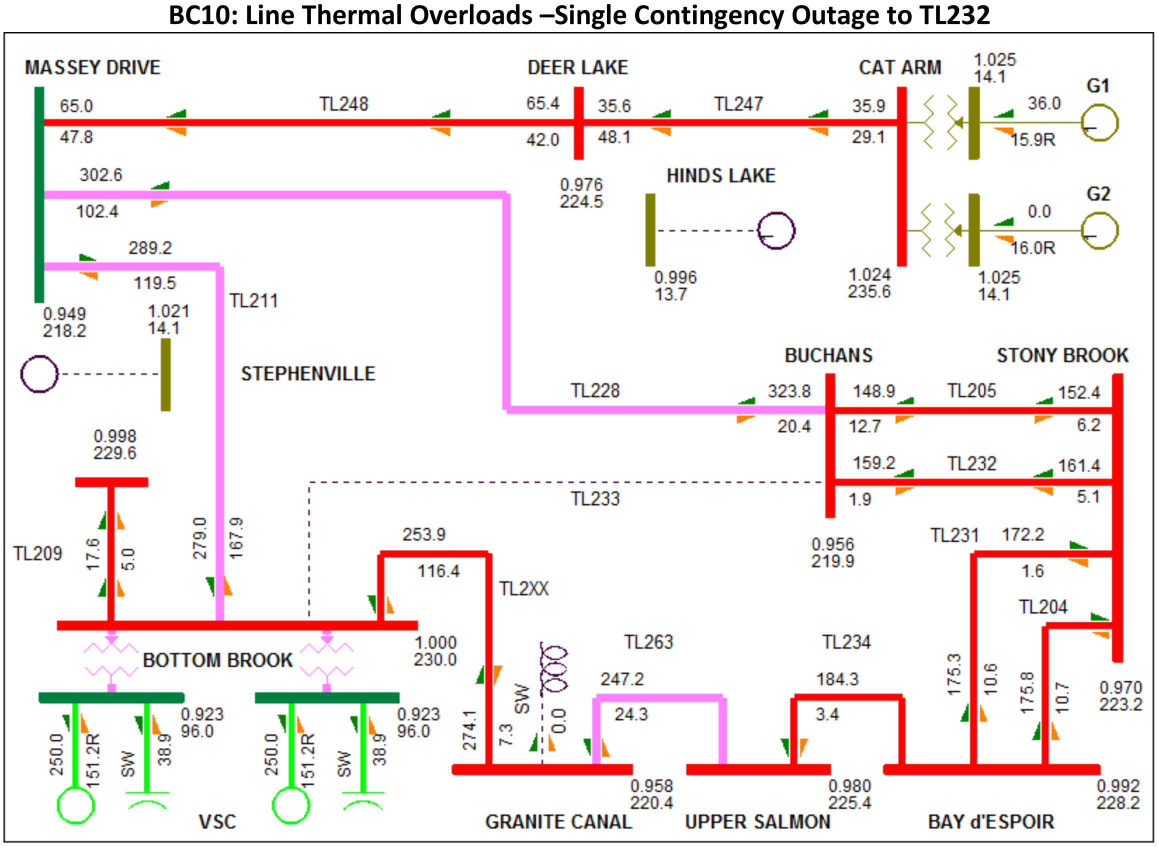
BC10: Line Thermal Overloads –Single Contingency Outage to TL228



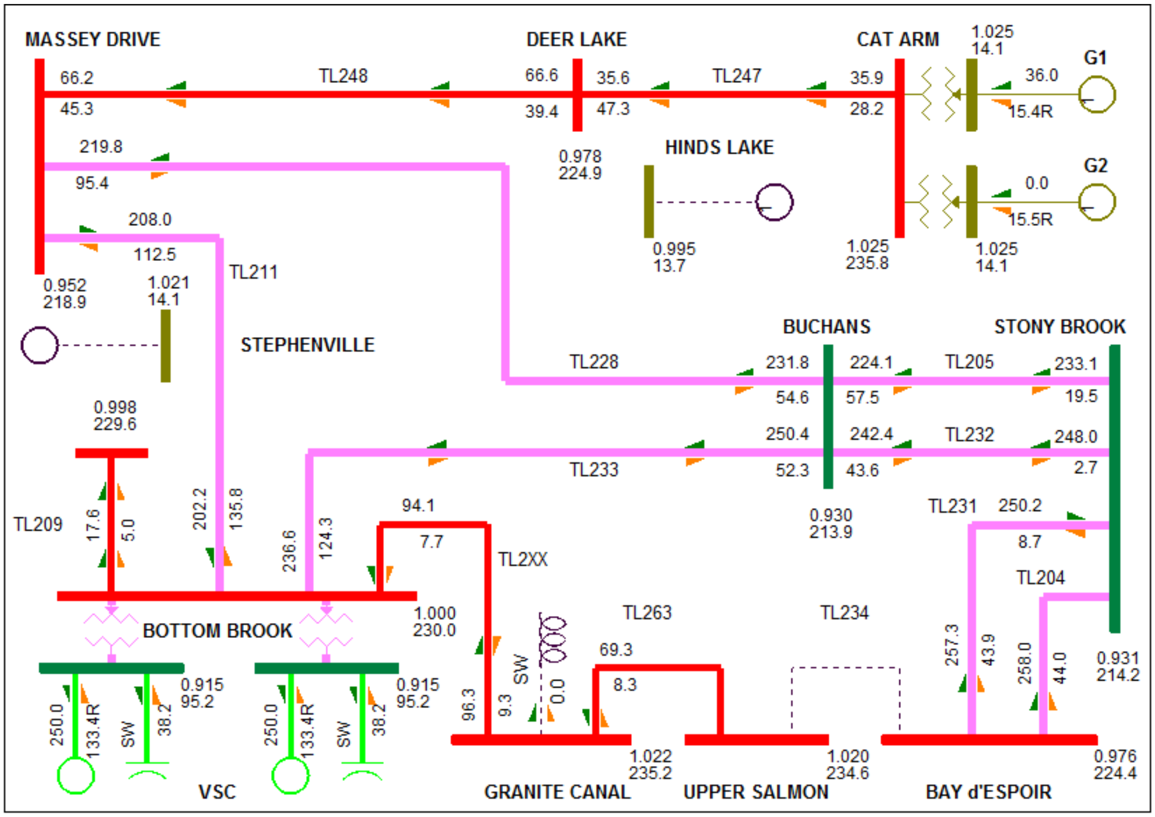
BC10: Line Thermal Overloads –Single Contingency Outage to TL231



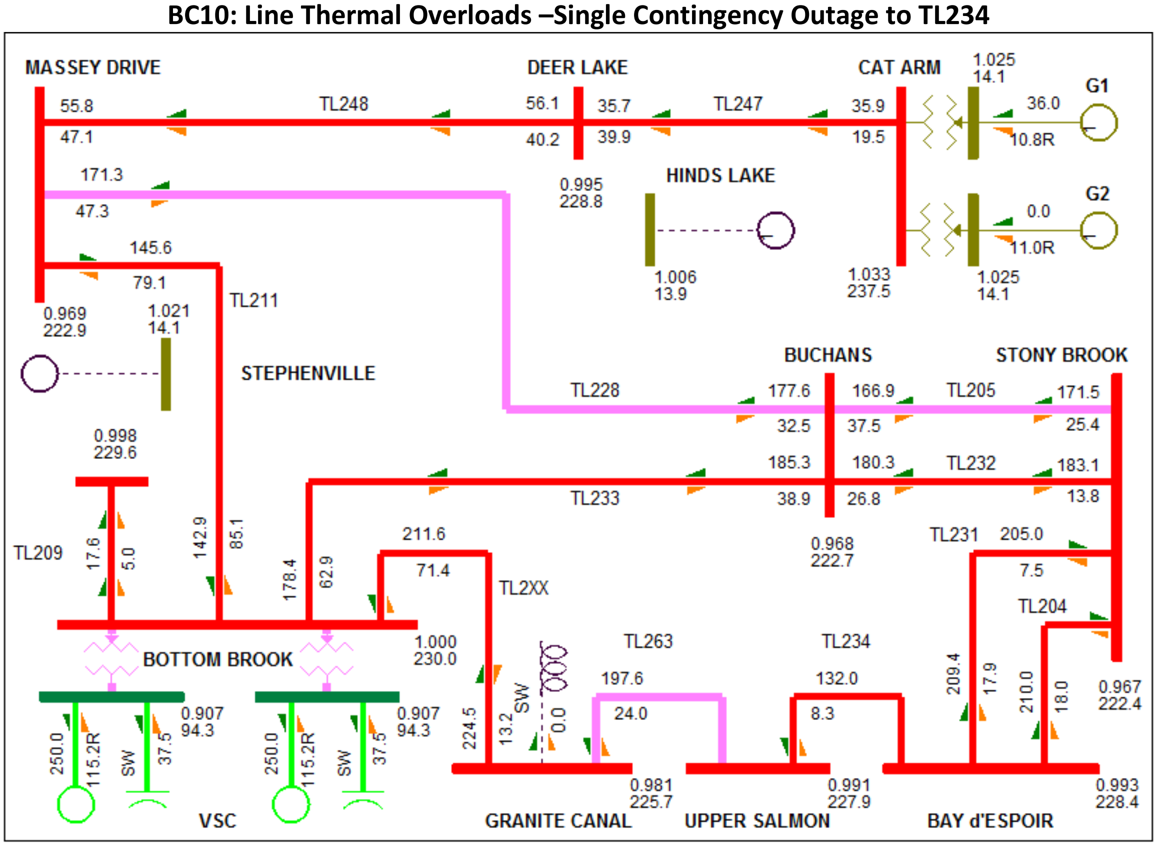
BC10: Line Thermal Overloads –Single Contingency Outage to TL232



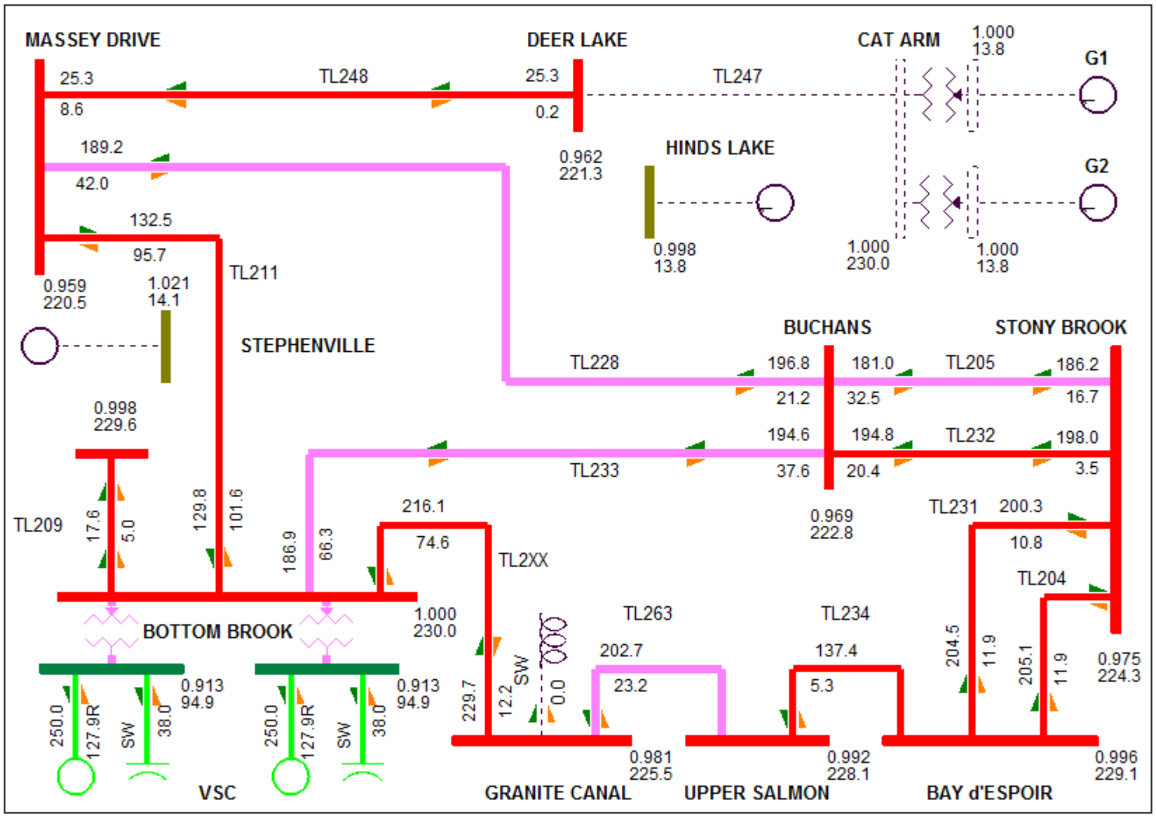
BC10: Line Thermal Overloads –Single Contingency Outage to TL233



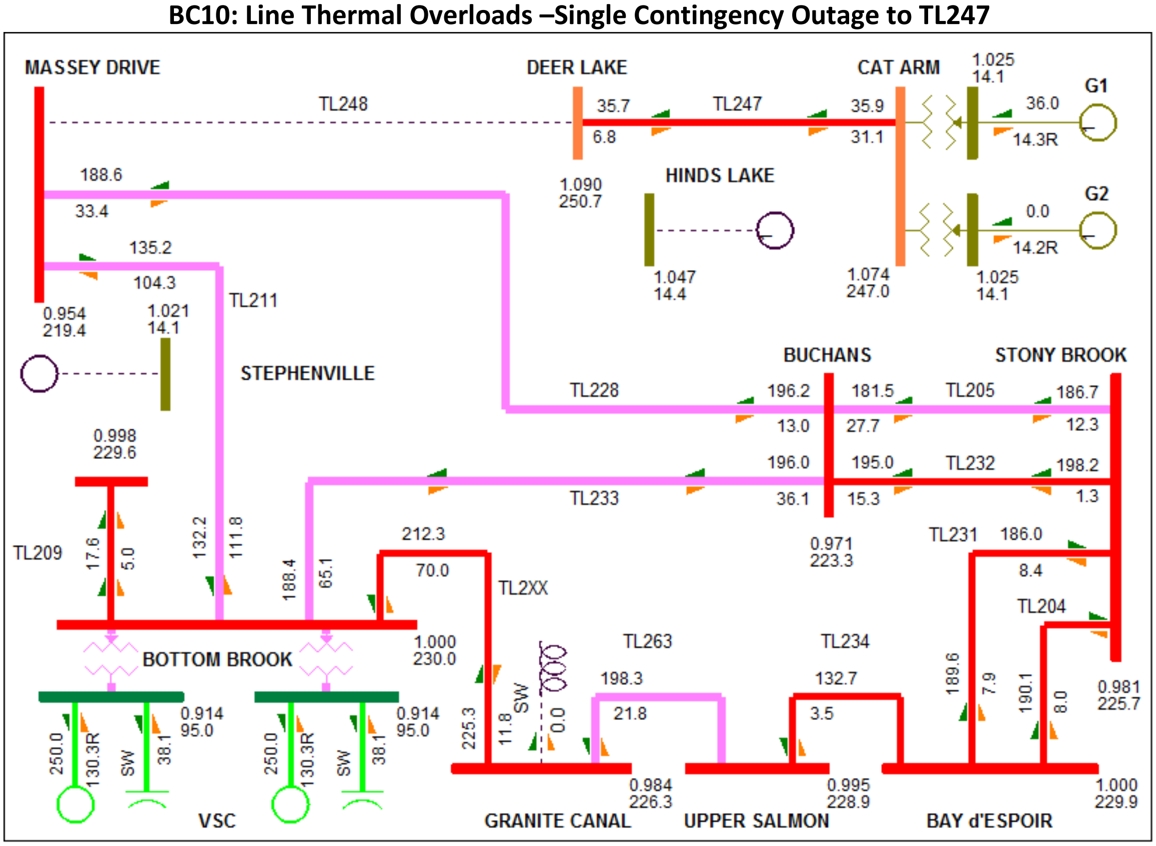
BC10: Line Thermal Overloads –Single Contingency Outage to TL234



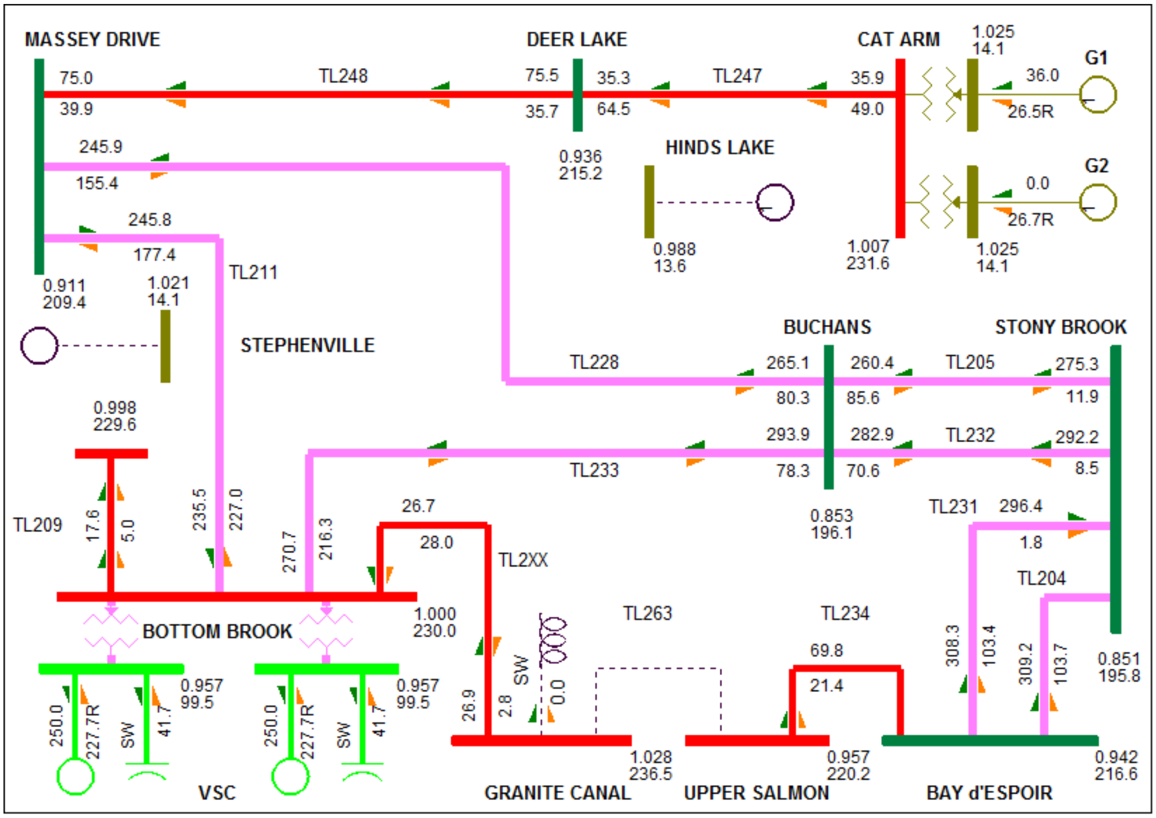
BC10: Line Thermal Overloads –Single Contingency Outage to TL235



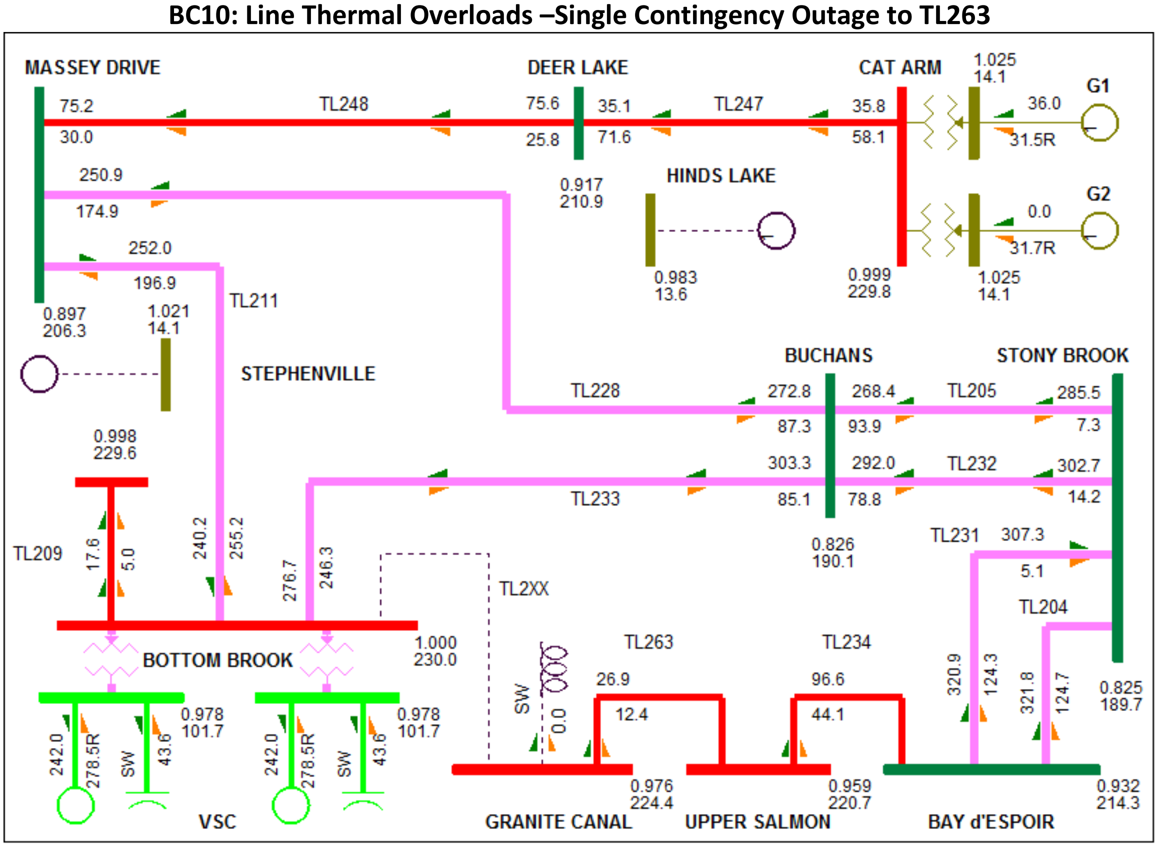
BC10: Line Thermal Overloads –Single Contingency Outage to TL247



BC10: Line Thermal Overloads –Single Contingency Outage to TL248

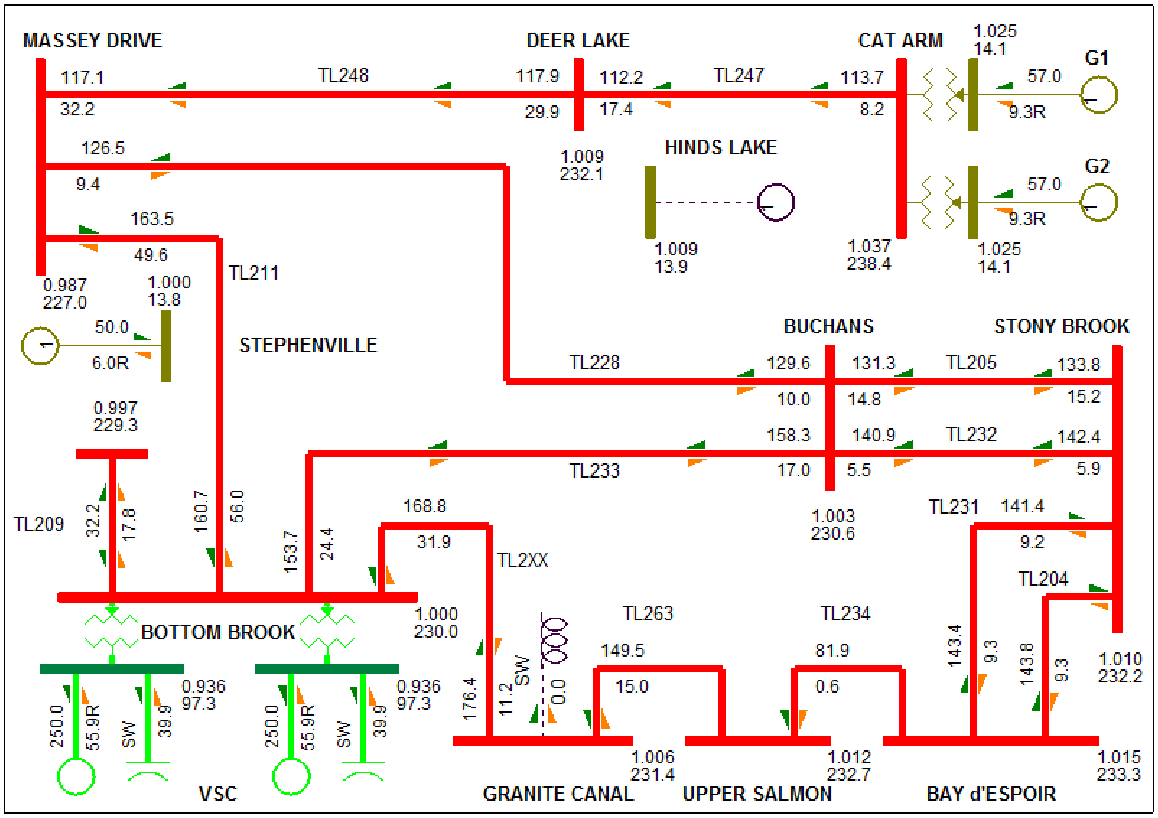


BC10: Line Thermal Overloads –Single Contingency Outage to TL263

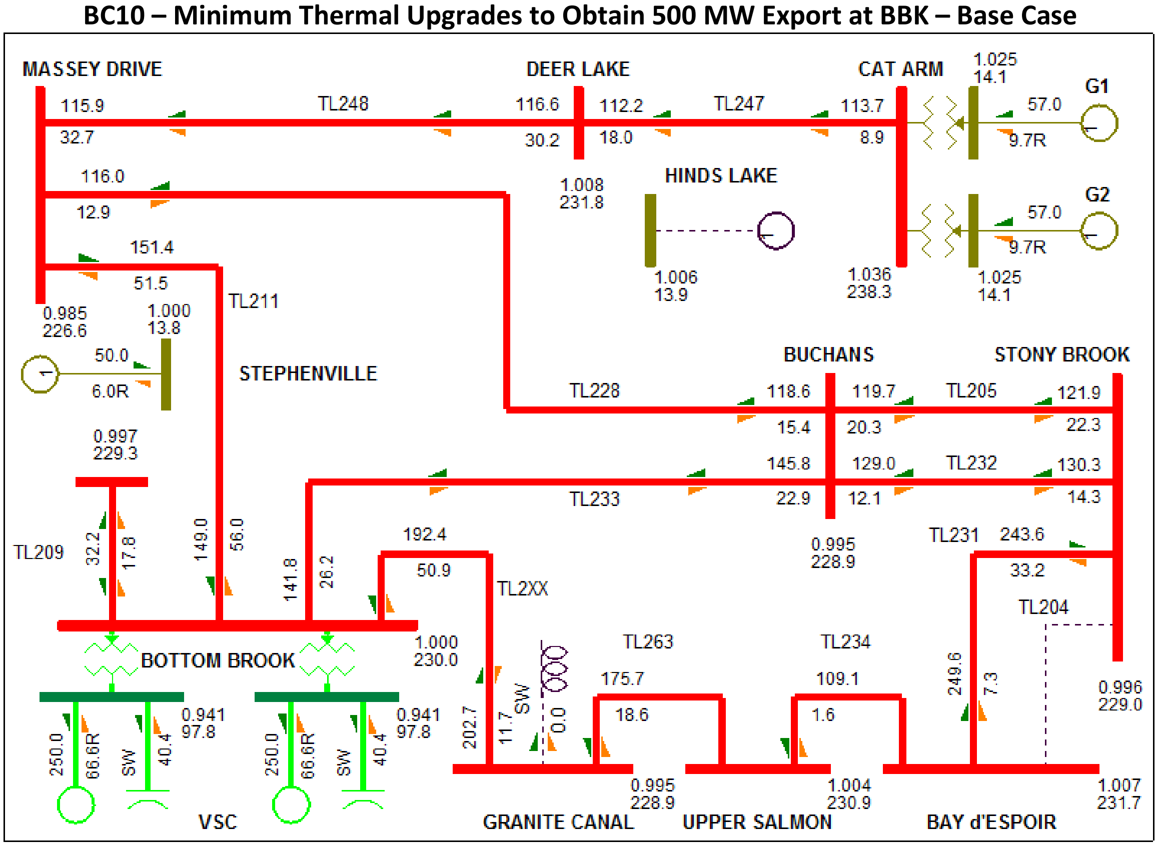


BC10: Line Thermal Overloads –Single Contingency Outage to TL2XX

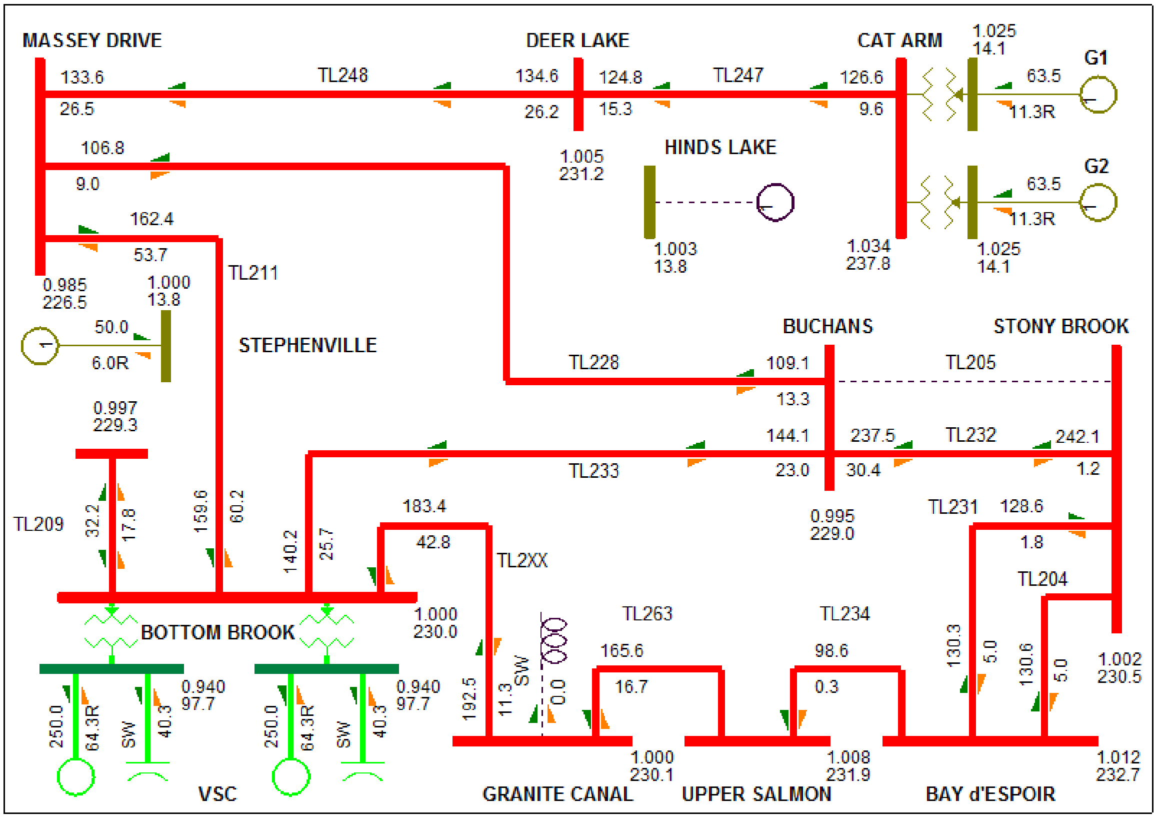
ATTACHMENT B-2
Base Case 10 Minimum Thermal Upgrades Load Flow Plots



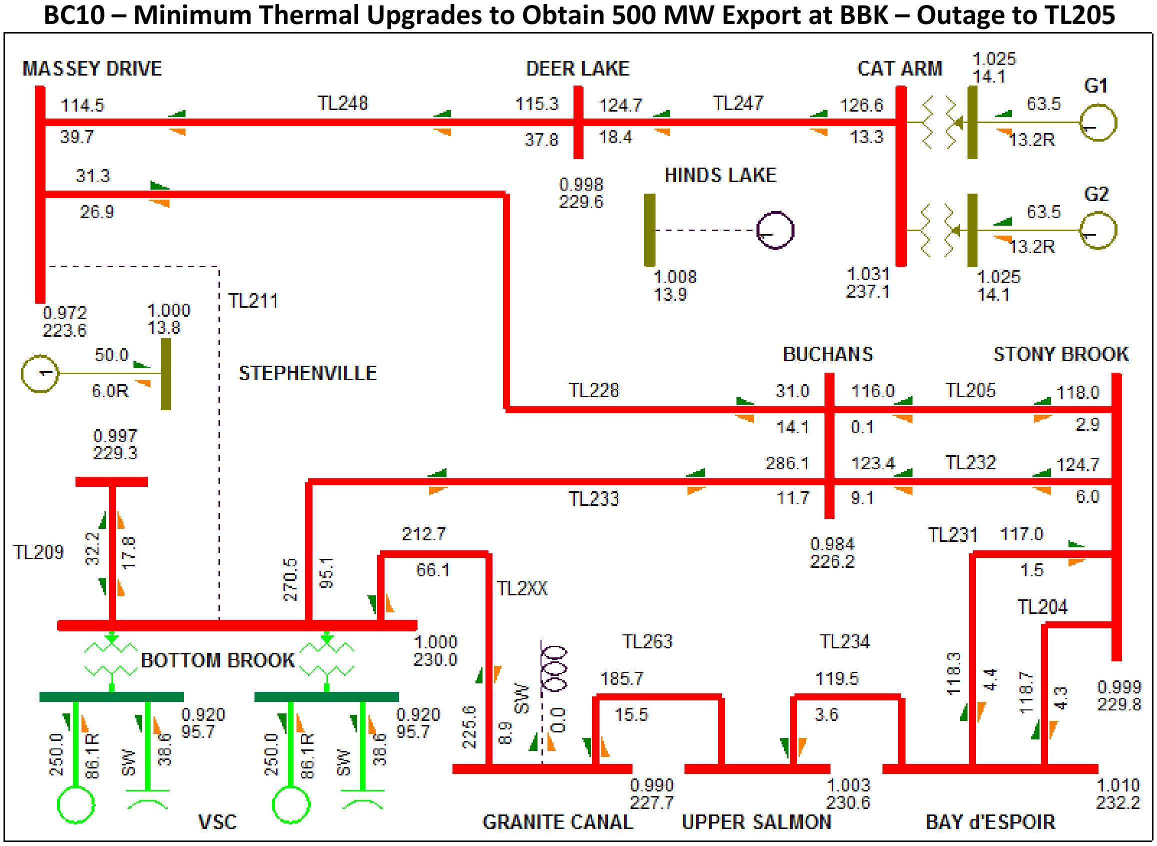
BC10 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Base Case



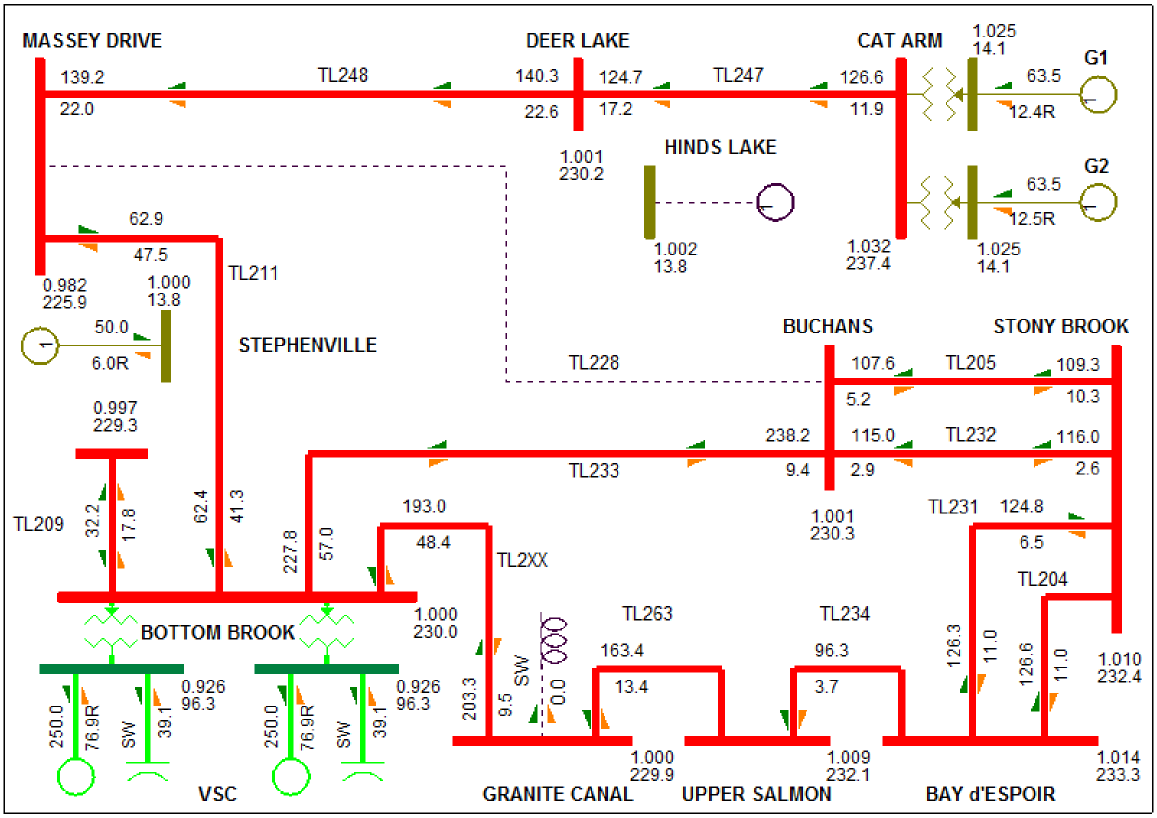
BC10 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL204



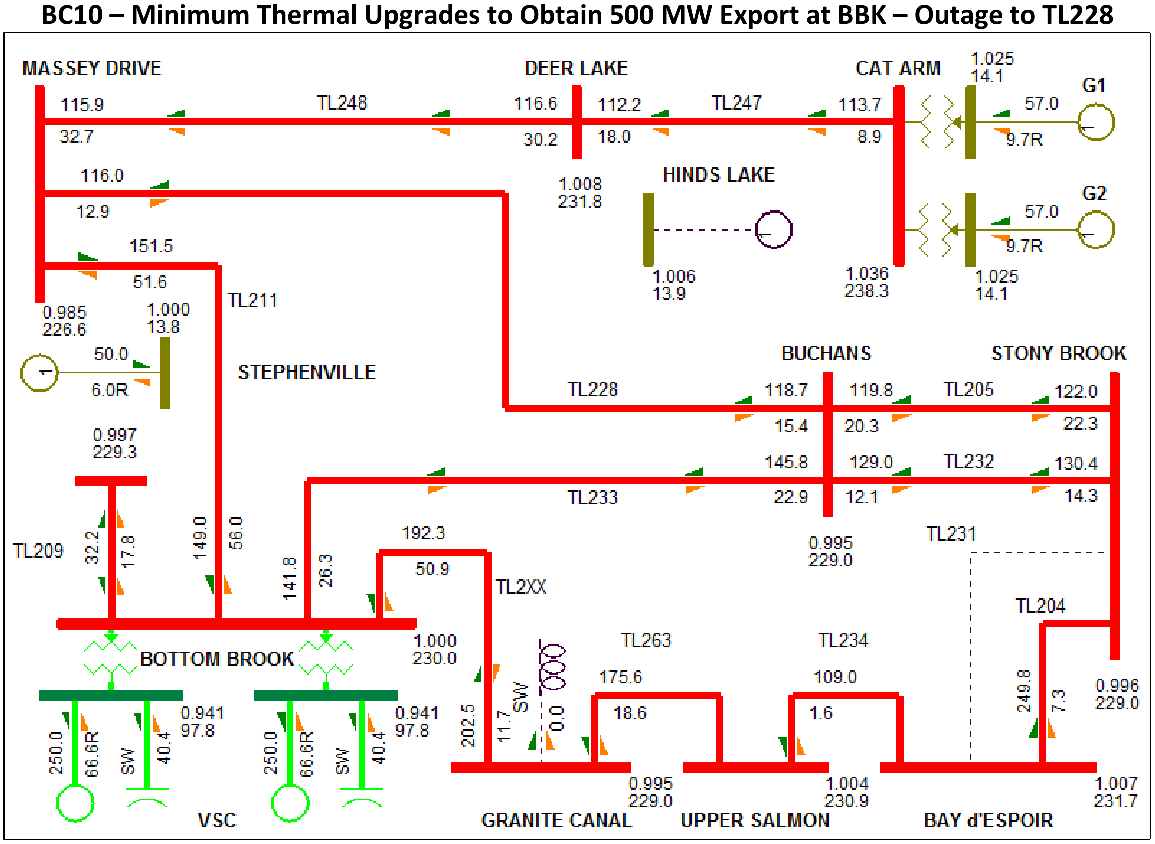
BC10 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL205



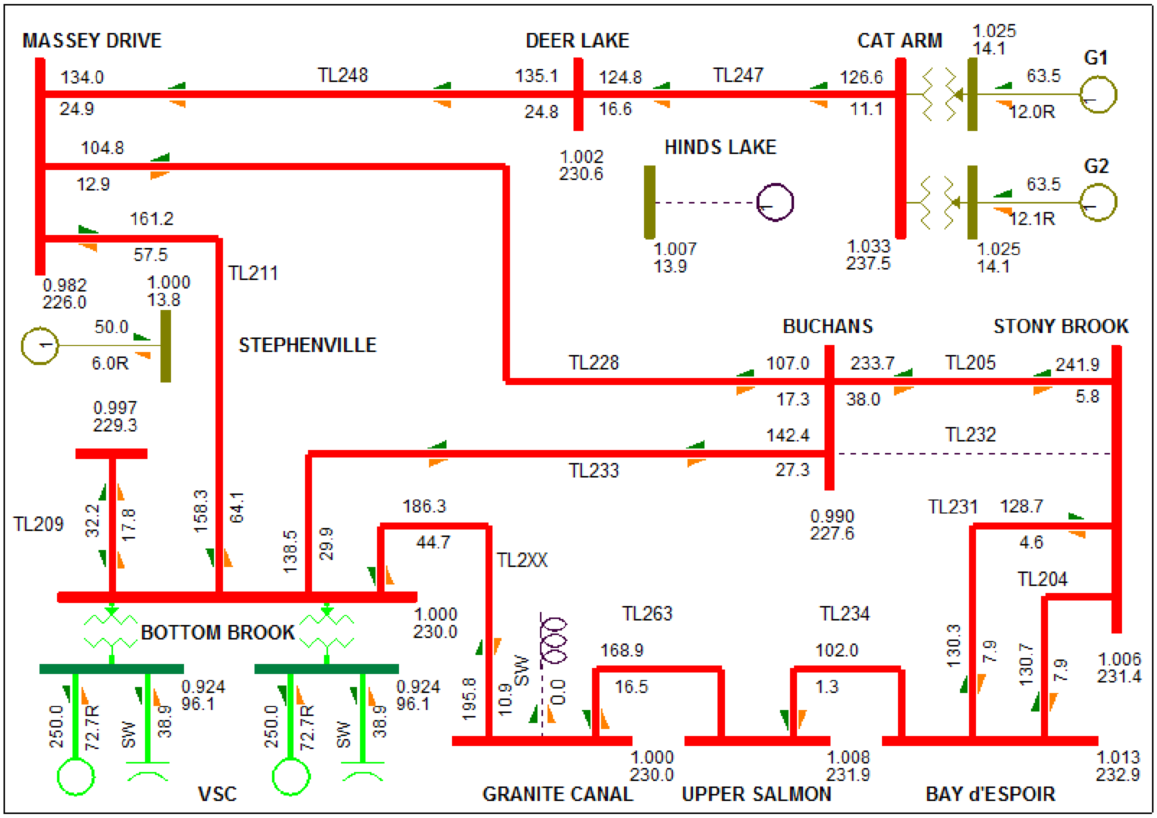
BC10 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL211



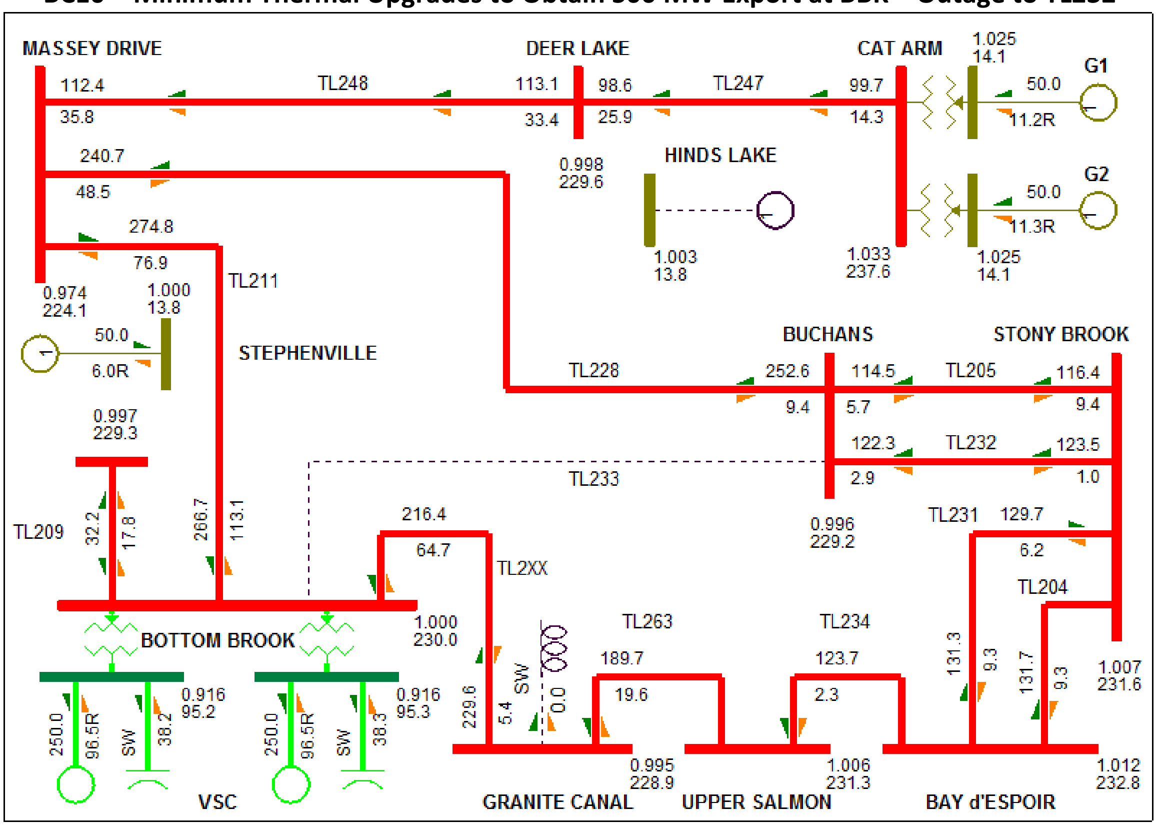
BC10 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL228



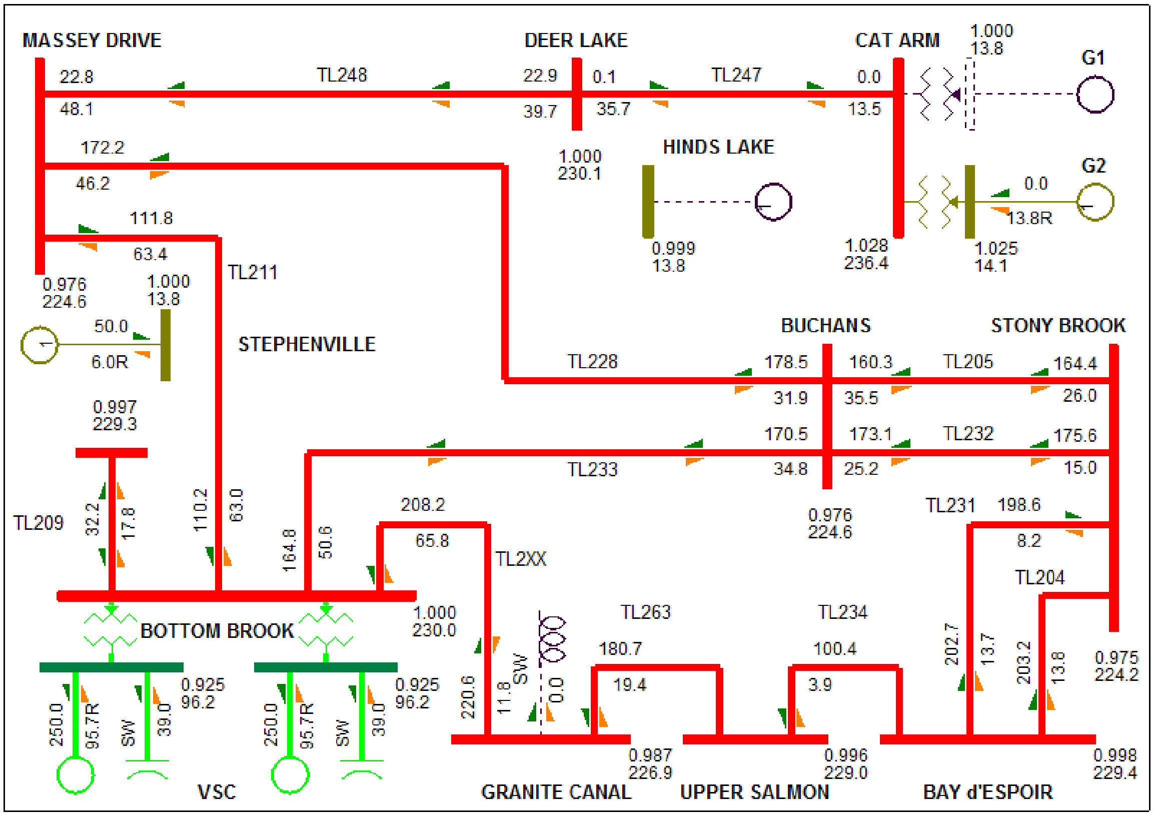
BC10 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL231



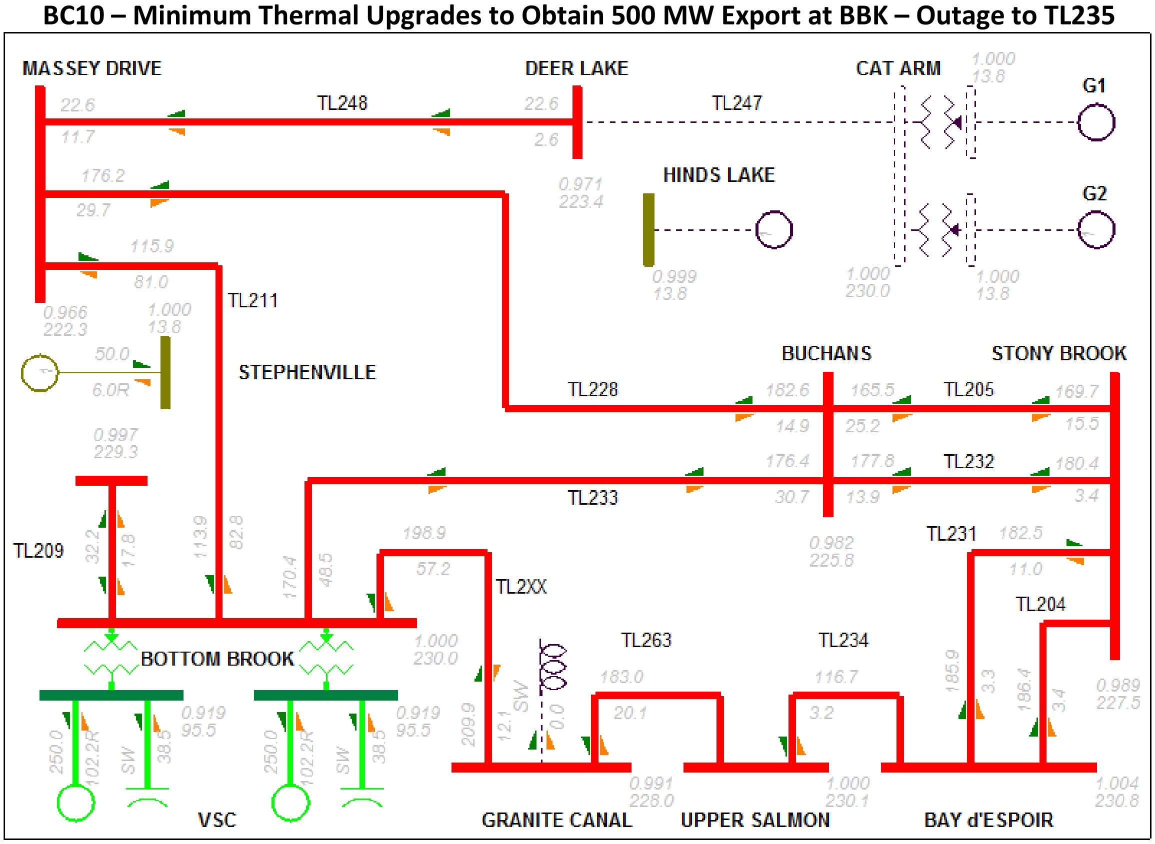
BC10 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL232



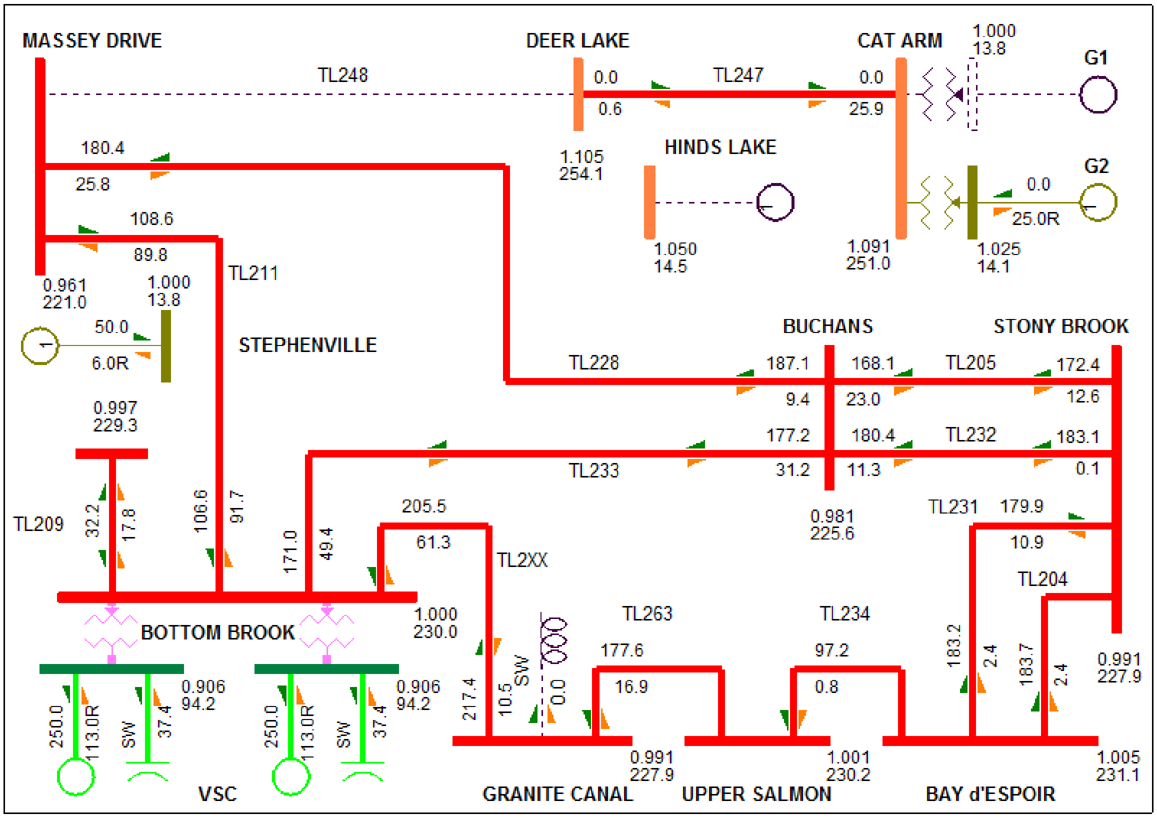
BC10 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL233



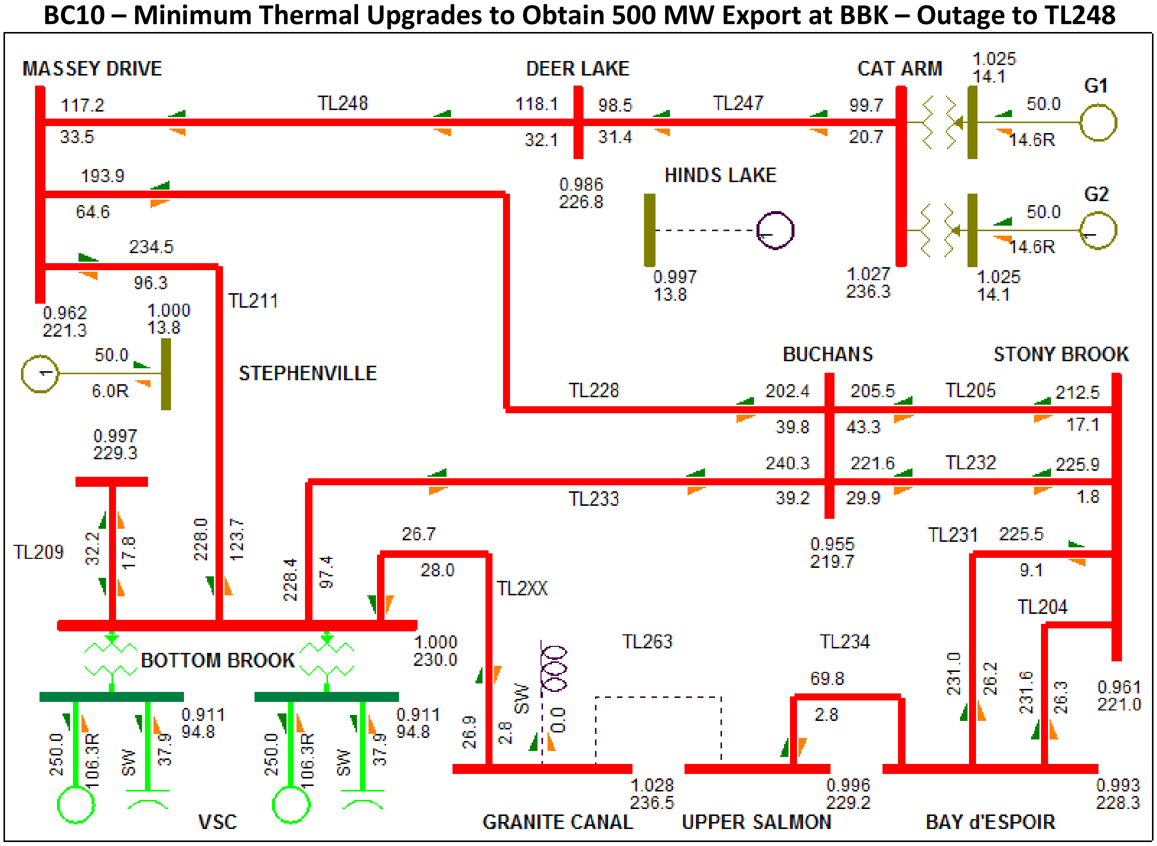
BC10 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL235



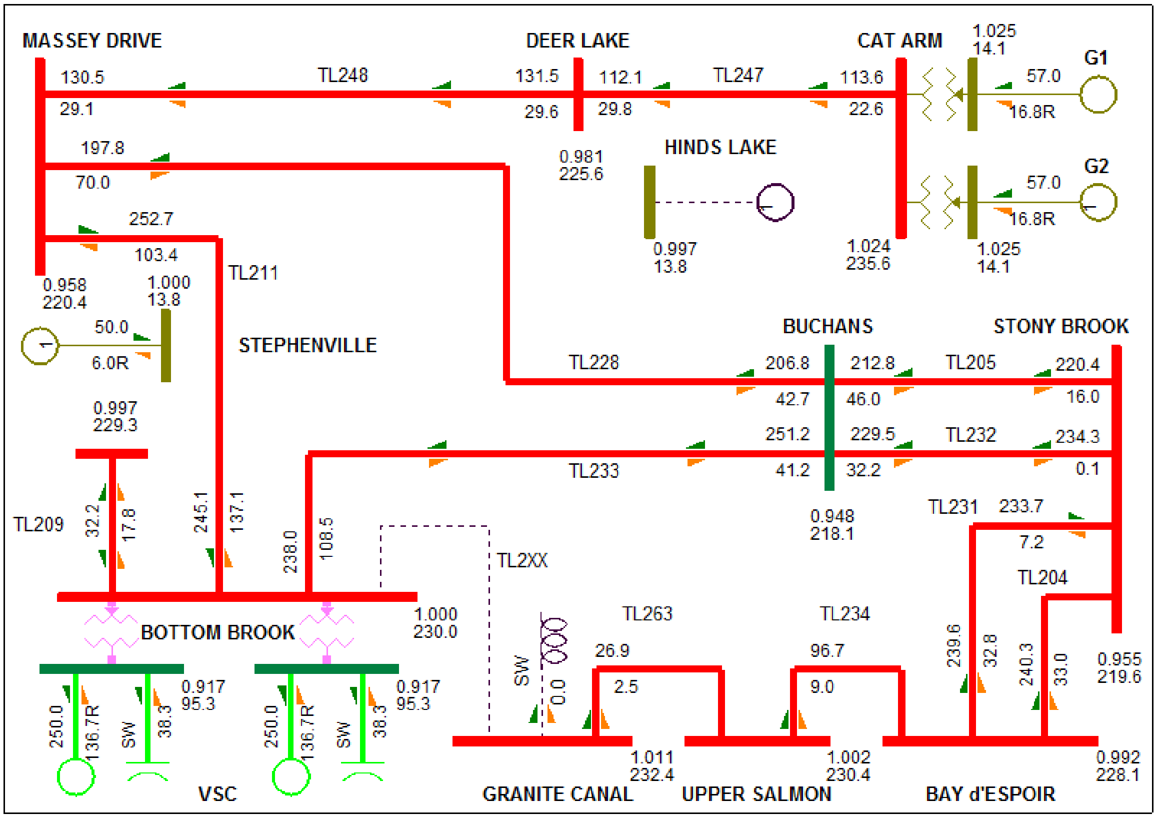
BC10 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL247



BC10 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL248

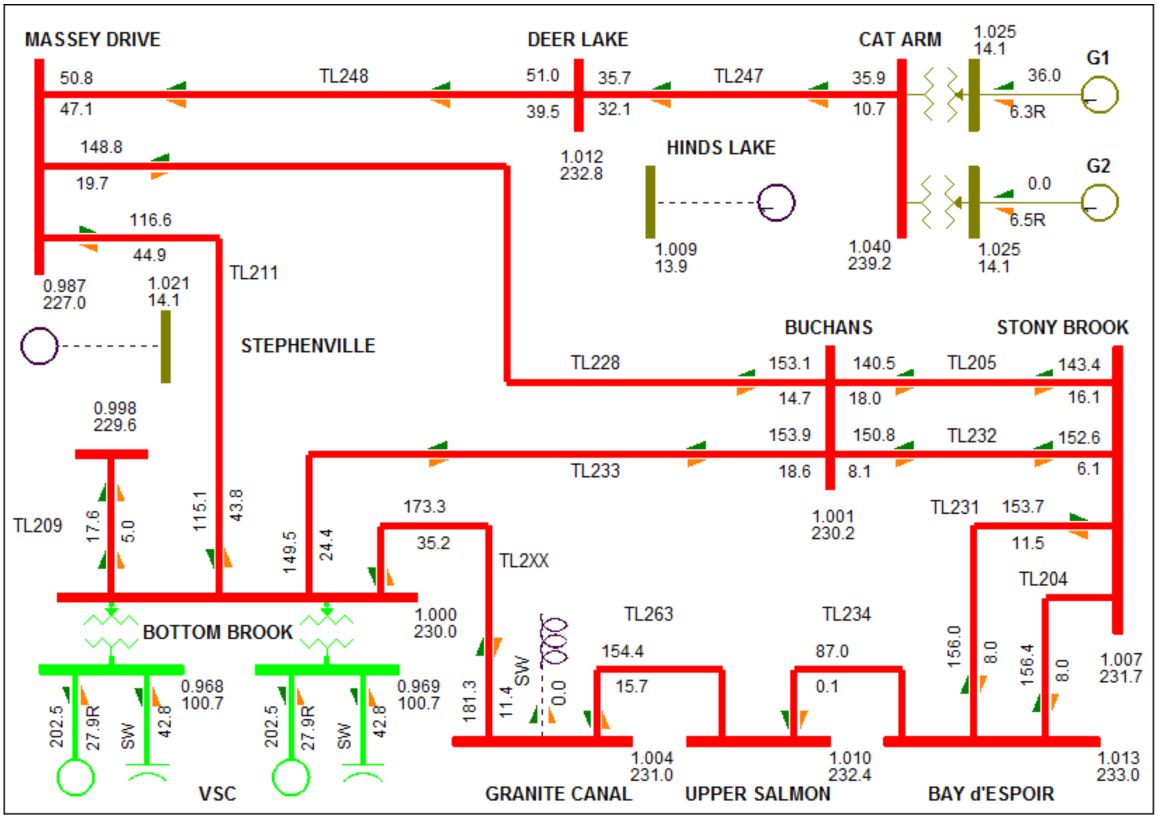


BC10 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL263

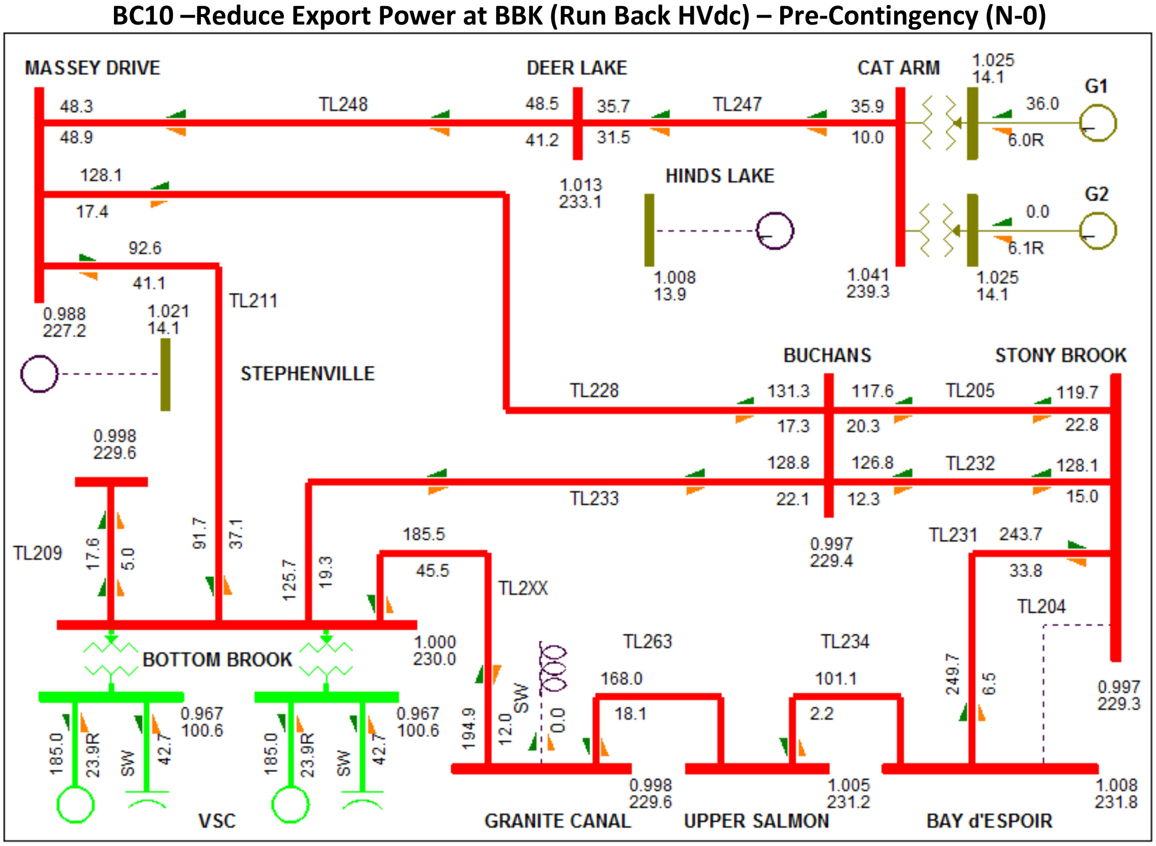


BC10 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL2XX

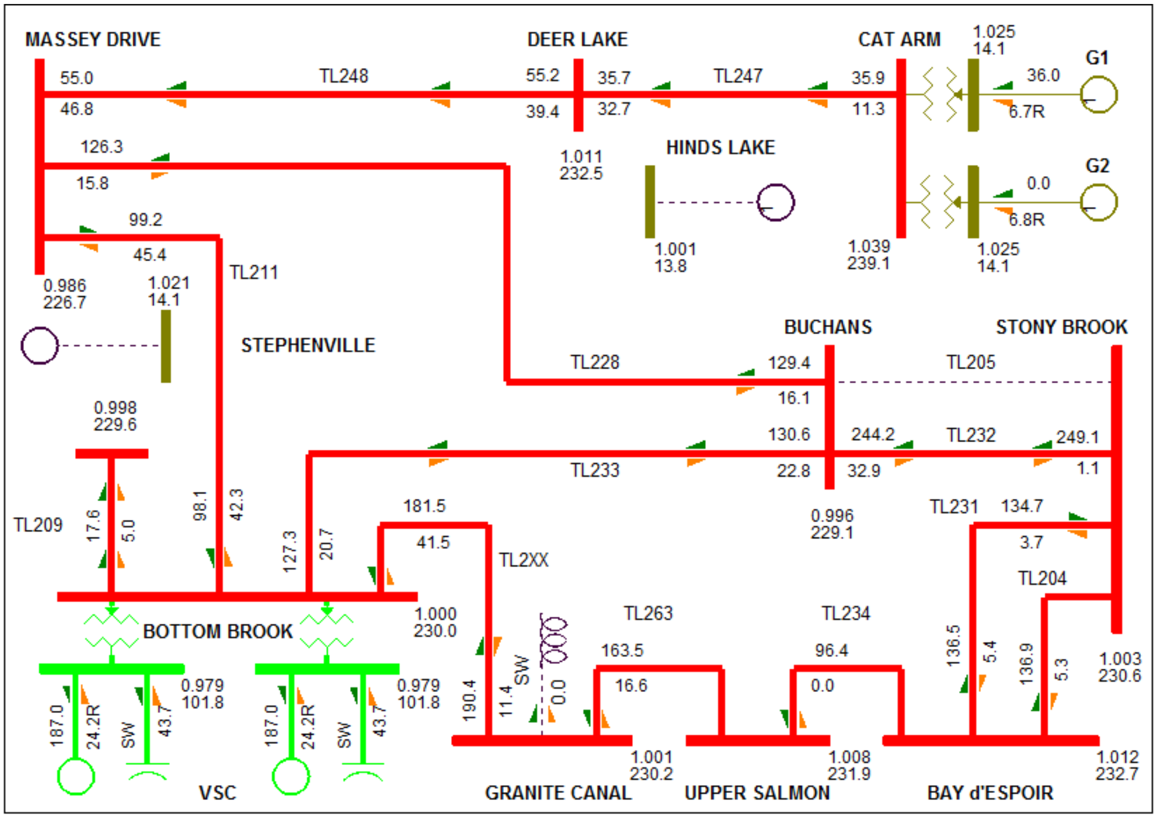
ATTACHMENT B-3
Base Case 10 Reduced Export Load Flow Plots



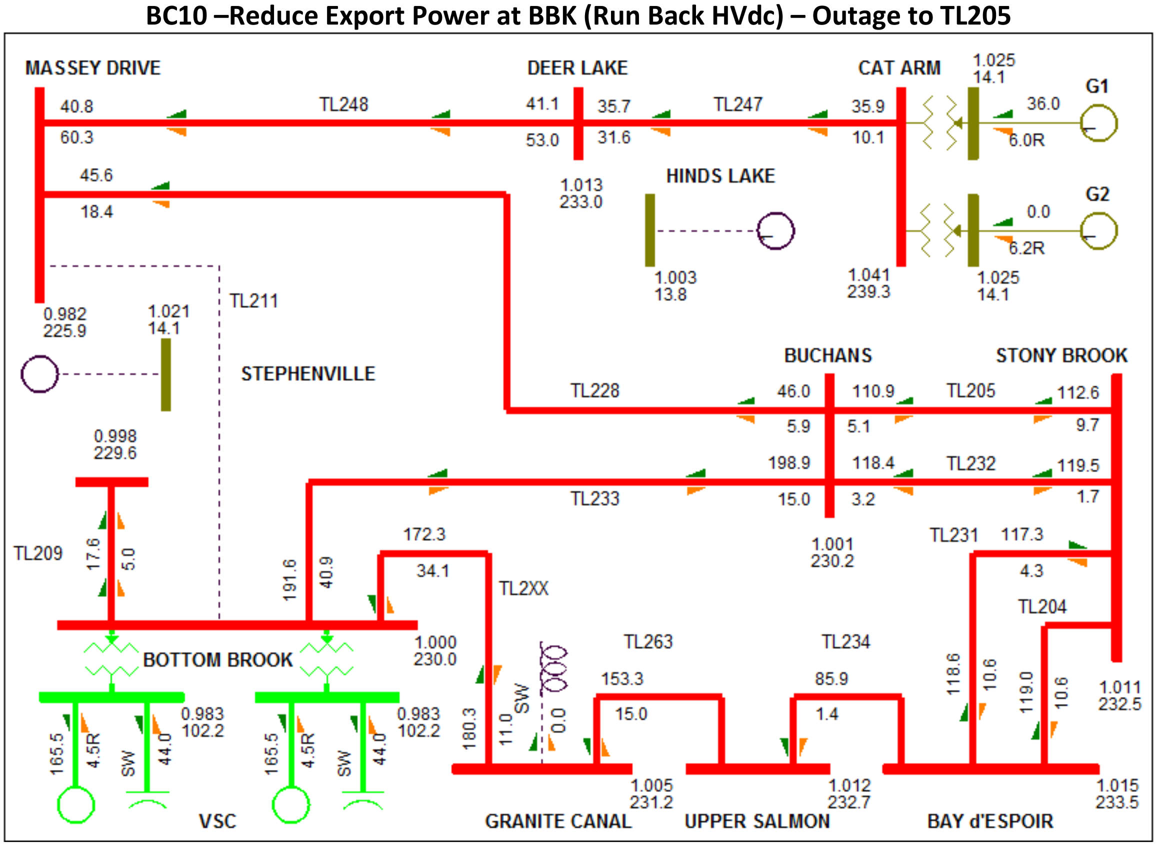
BC10 –Reduce Export Power at BBK (Run Back HVdc) – Pre-Contingency (N-0)



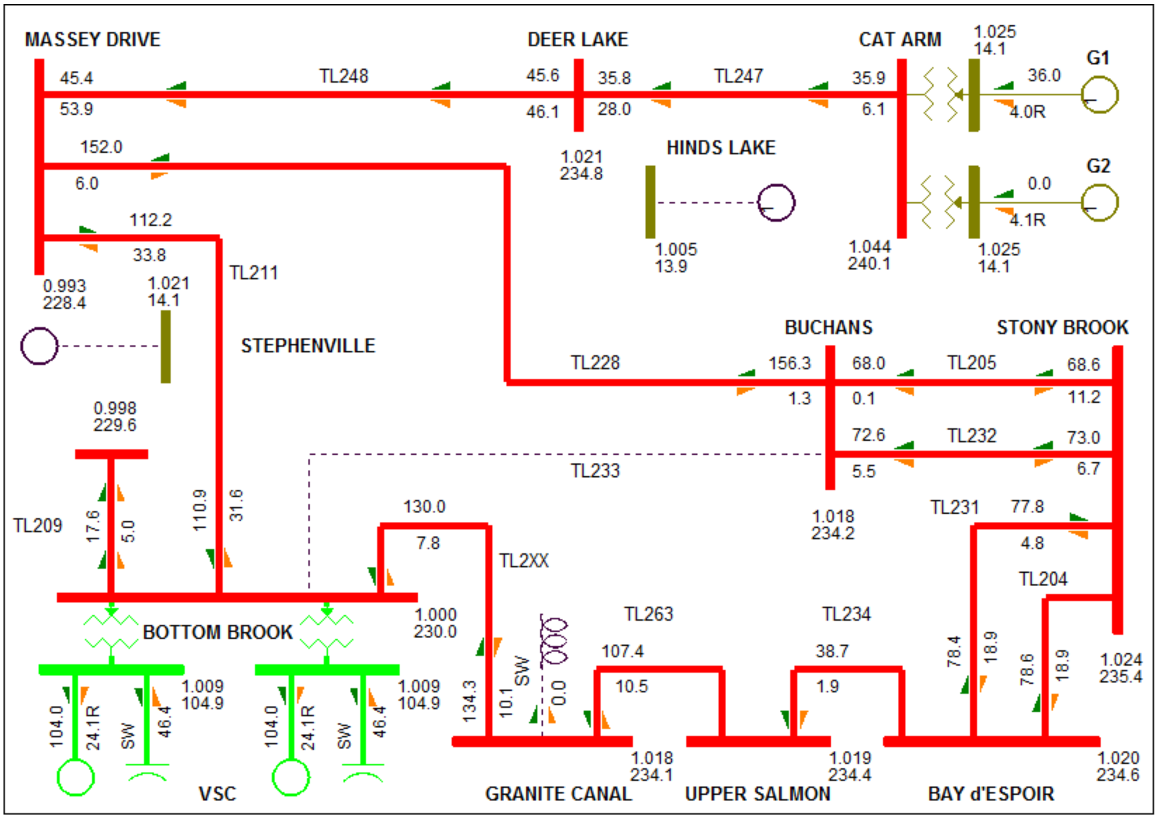
BC10 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL204



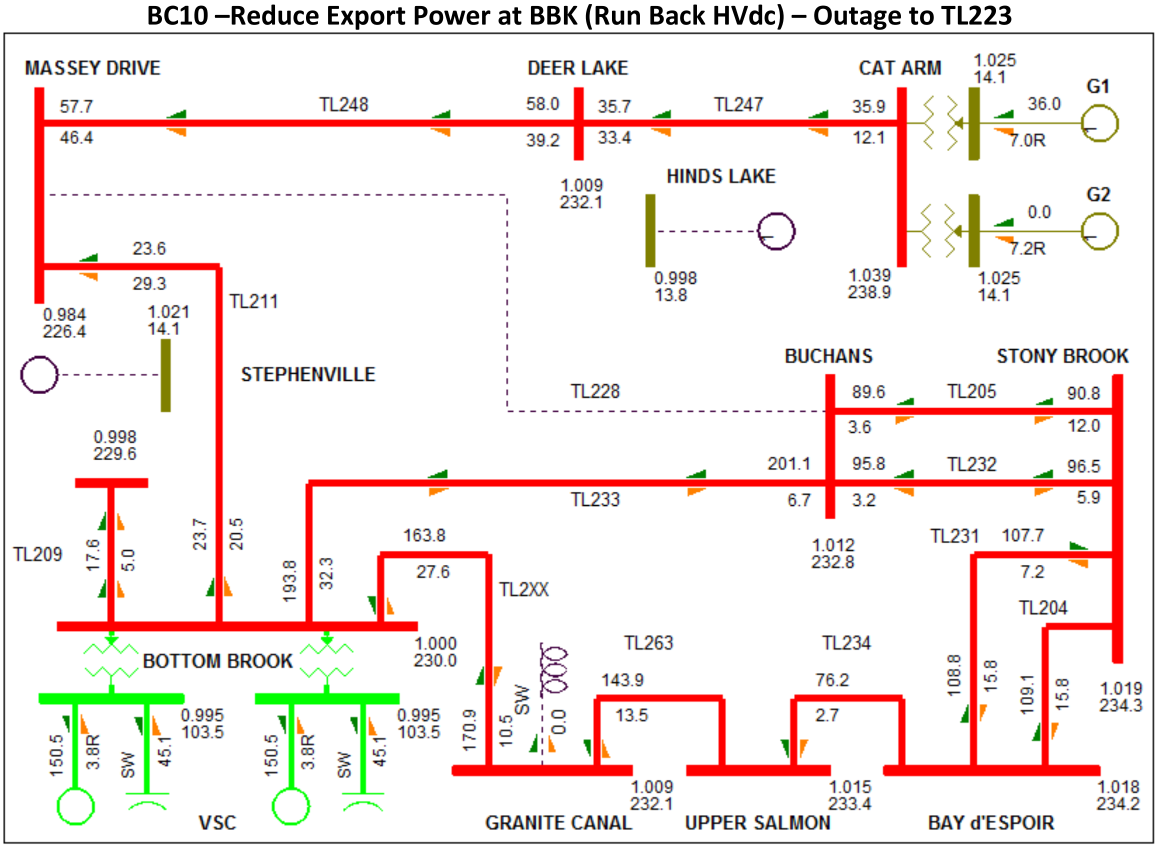
BC10 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL205



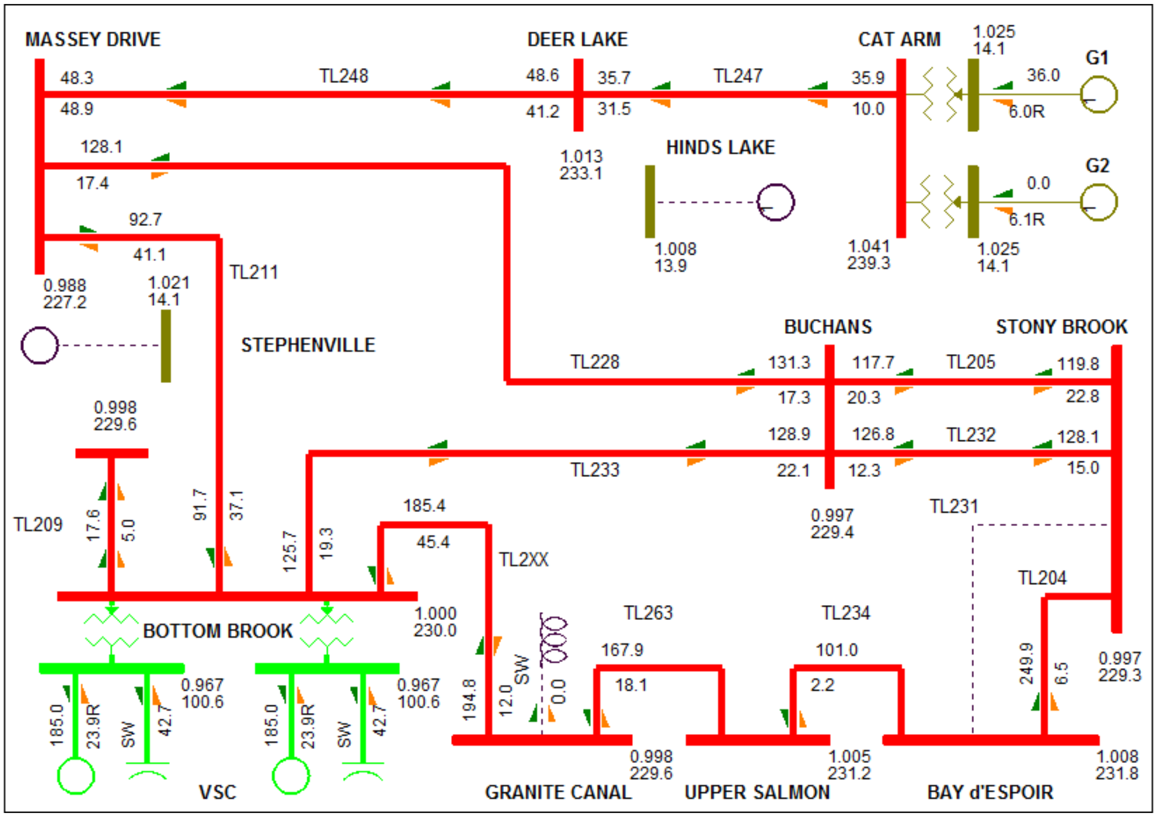
BC10 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL211



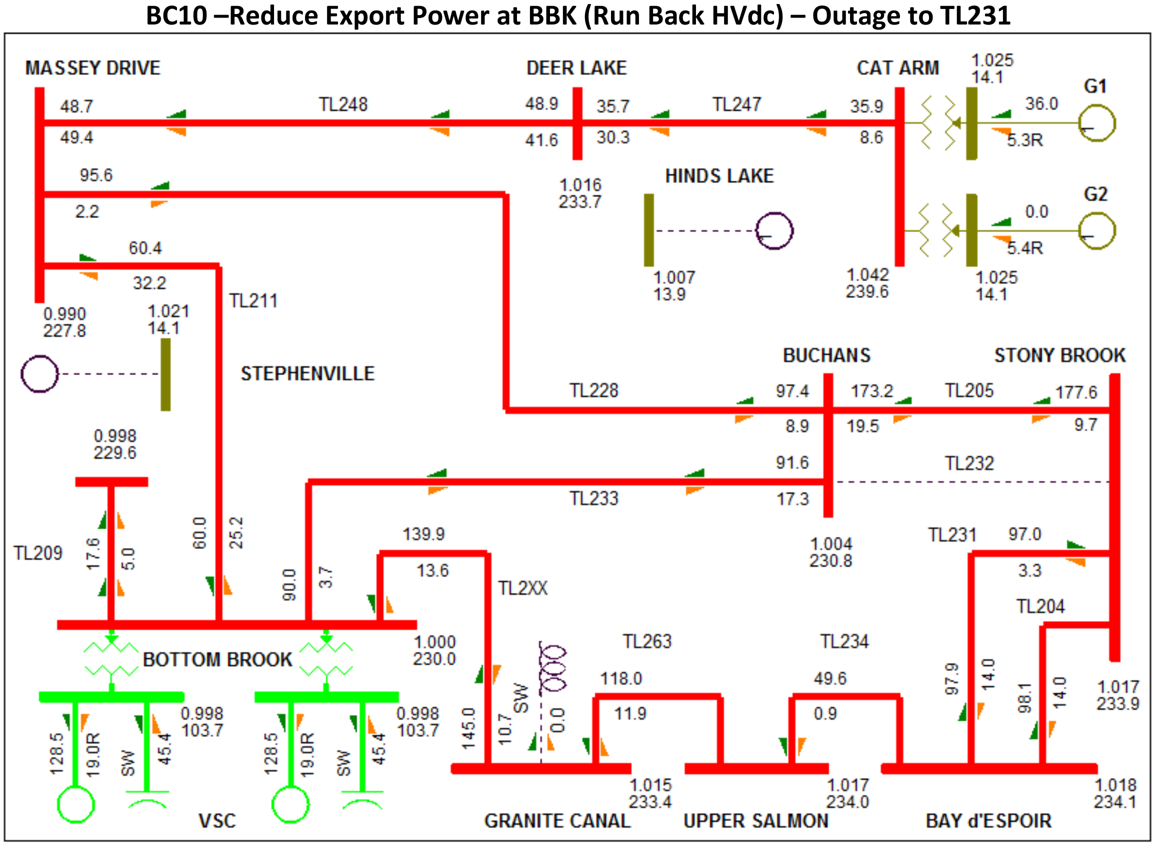
BC10 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL223



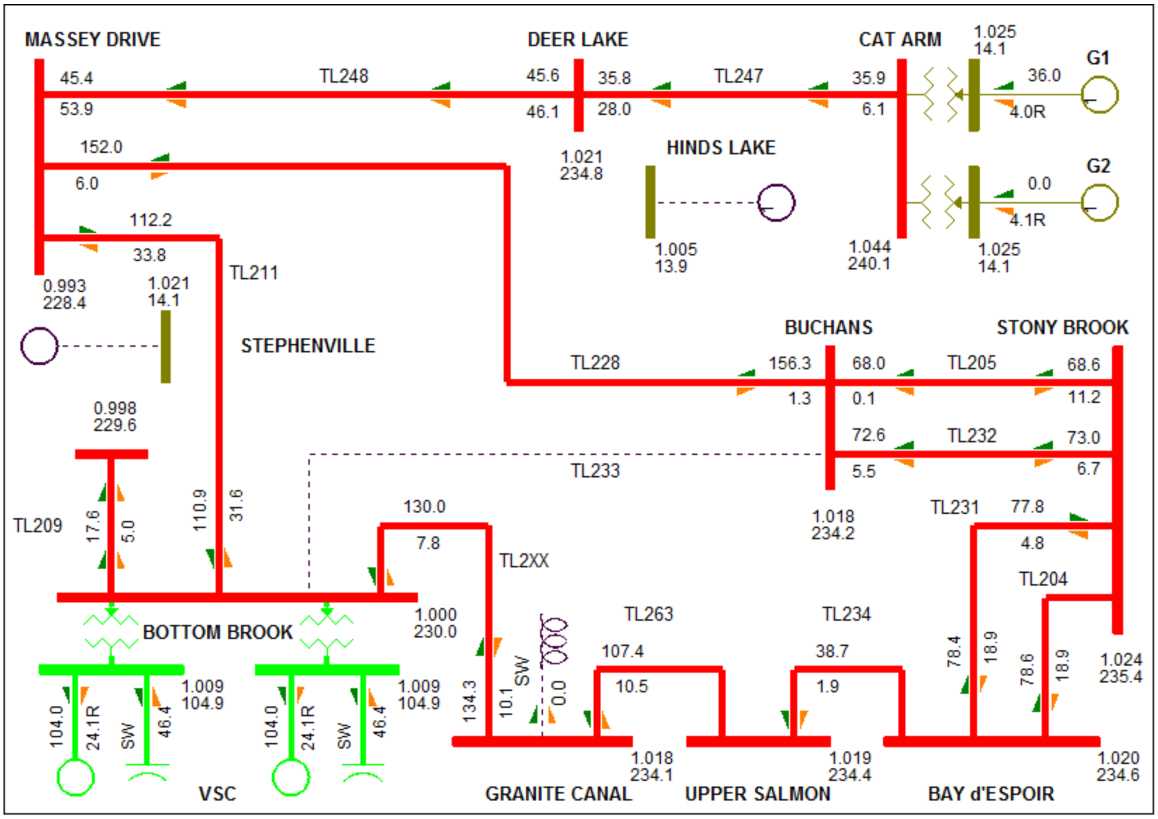
BC10 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL228



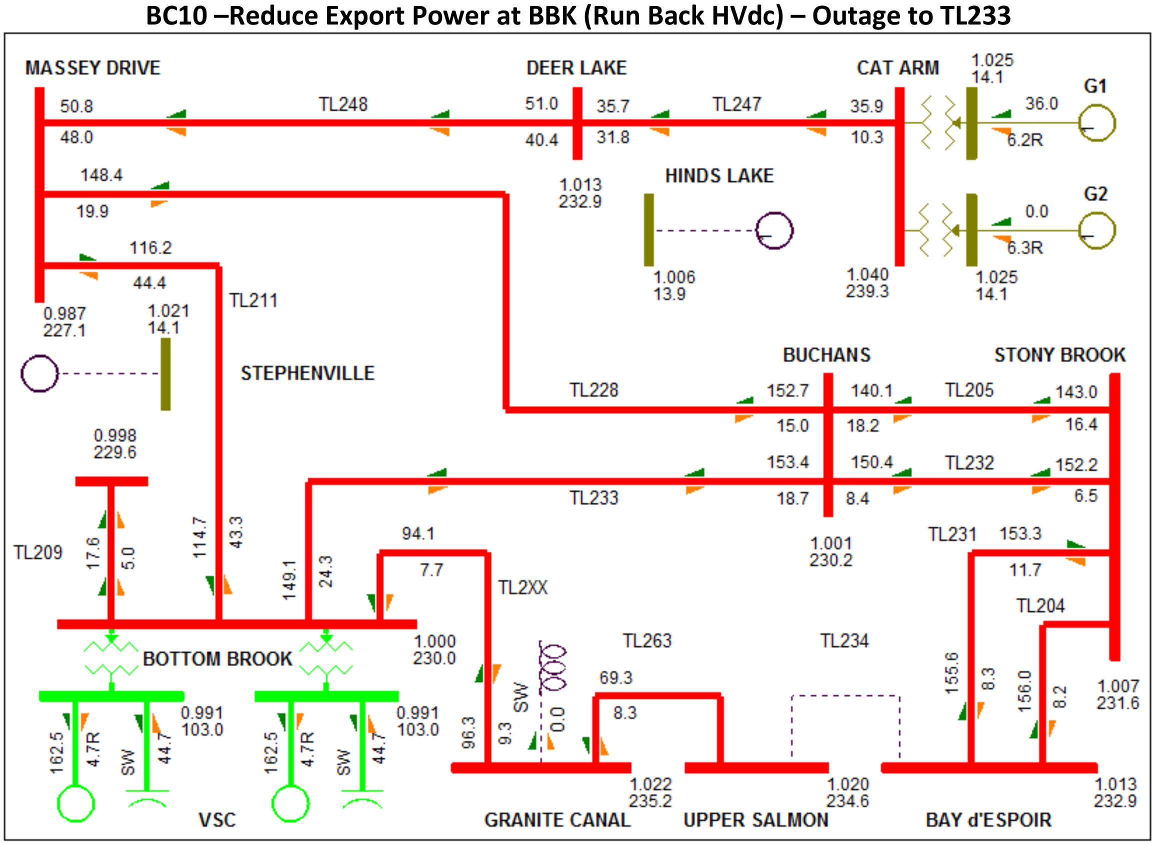
BC10 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL231



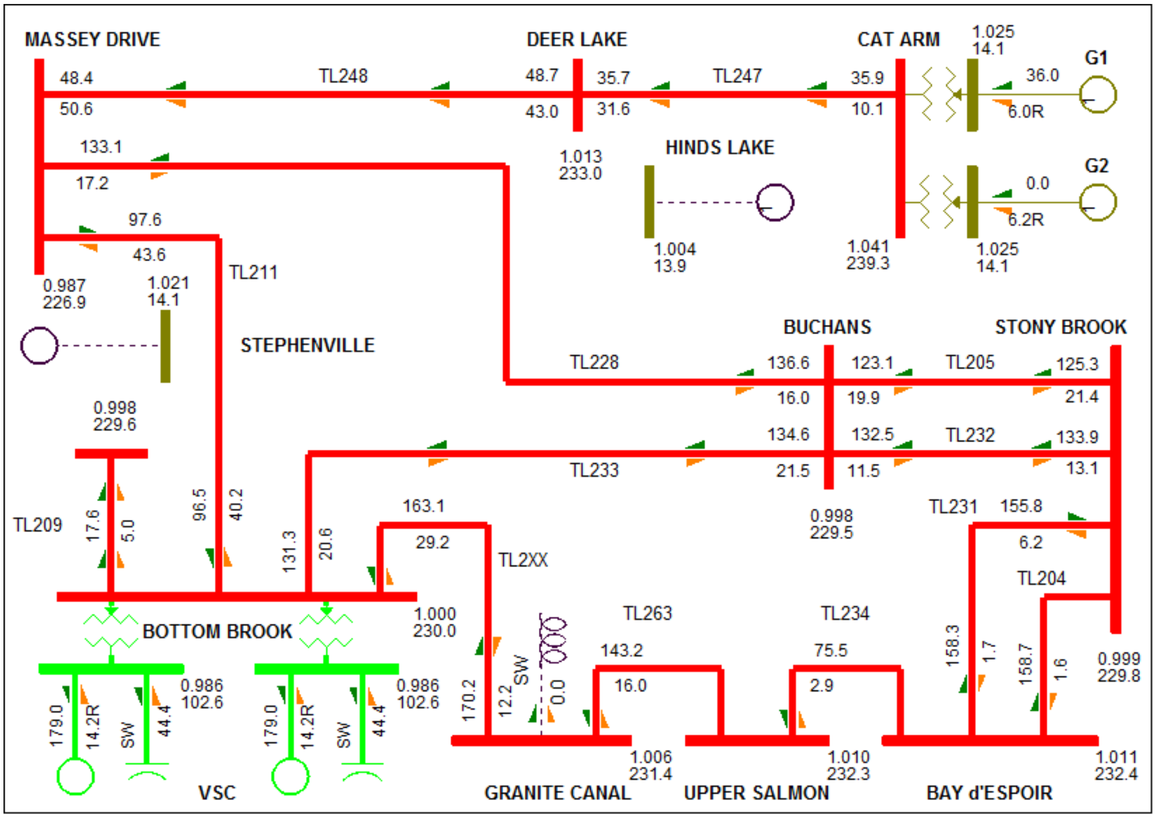
BC10 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL232



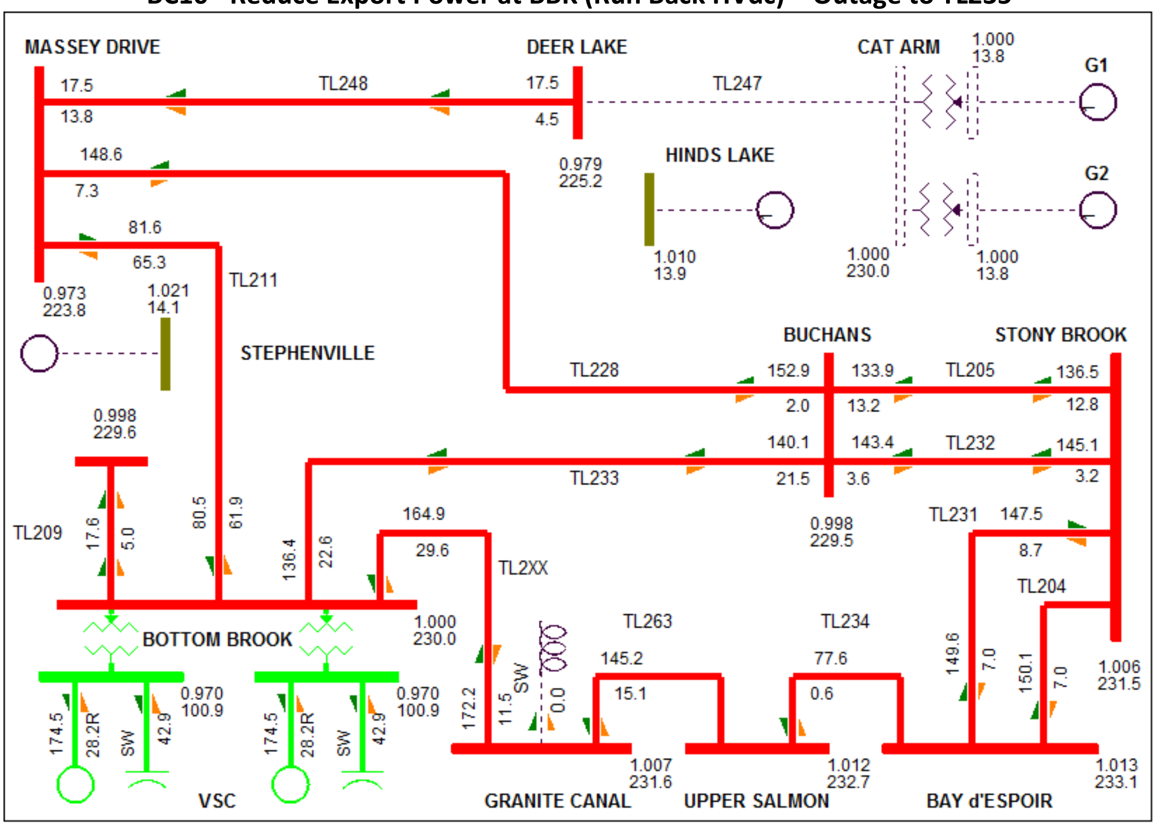
BC10 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL233



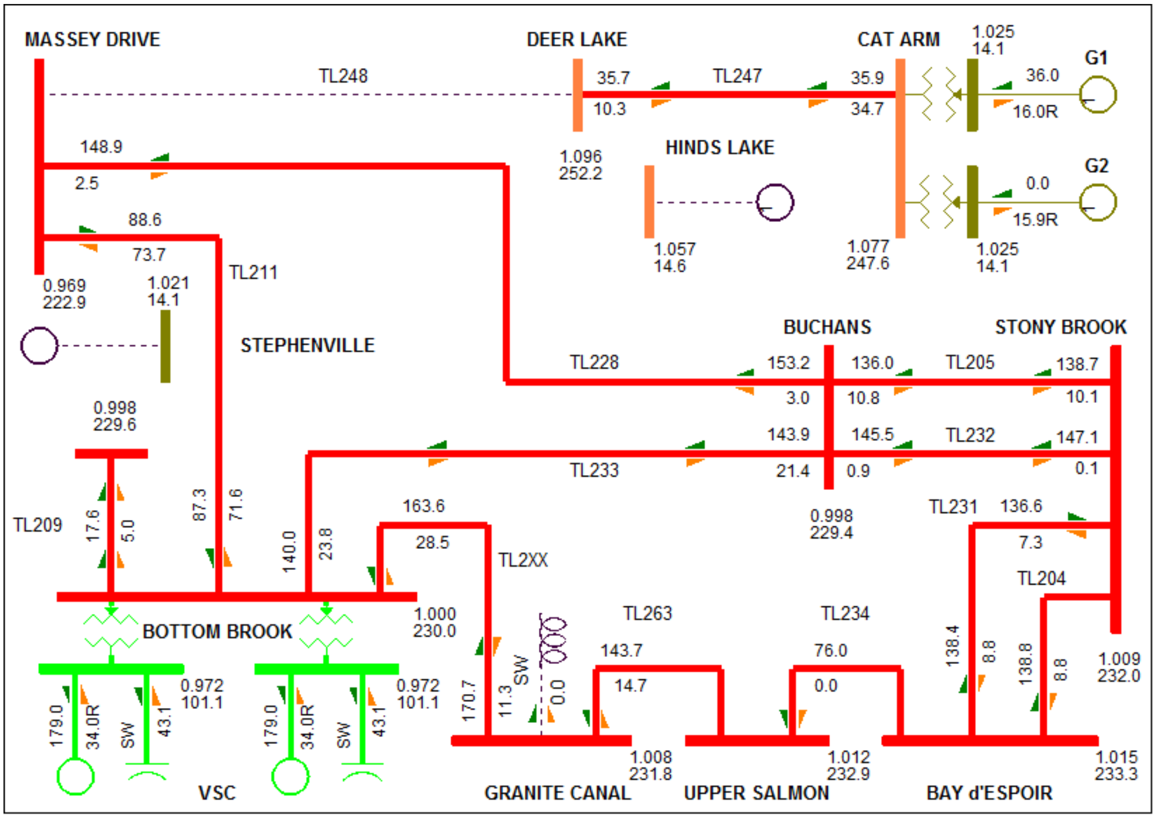
BC10 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL234



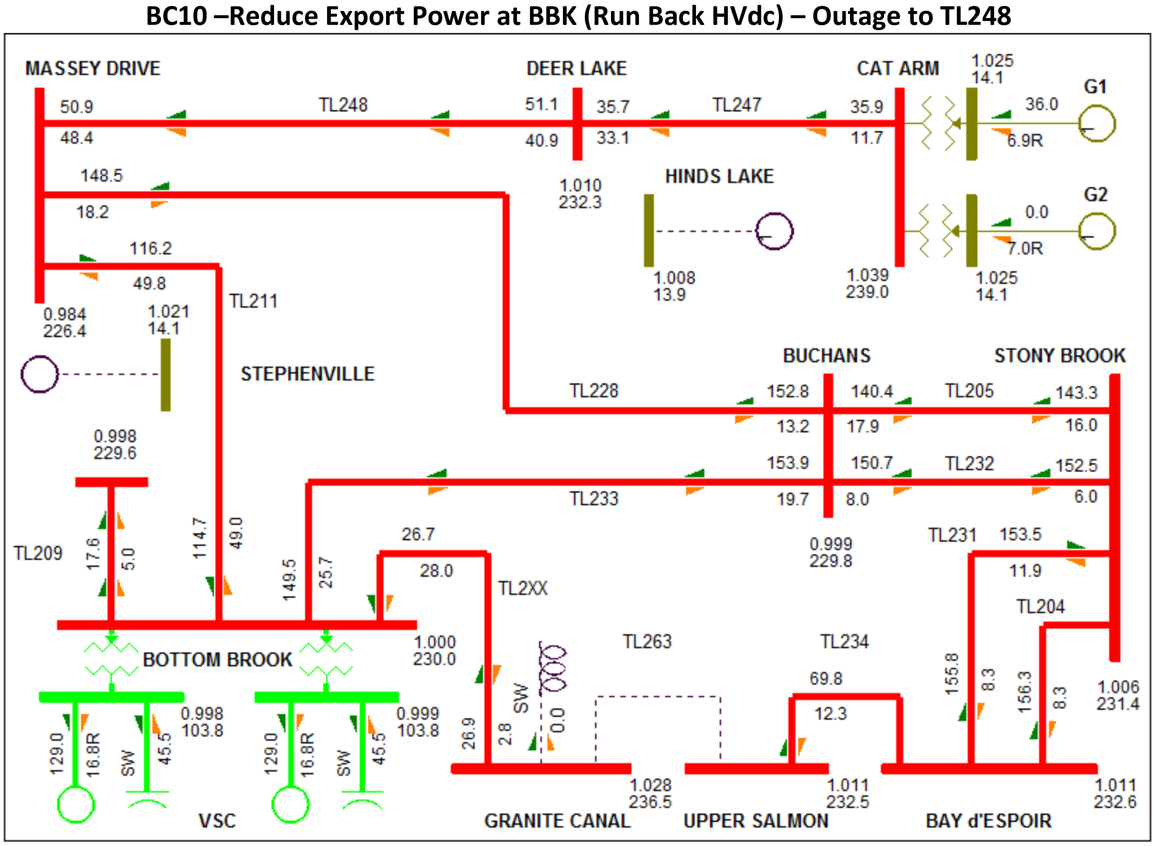
BC10 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL235



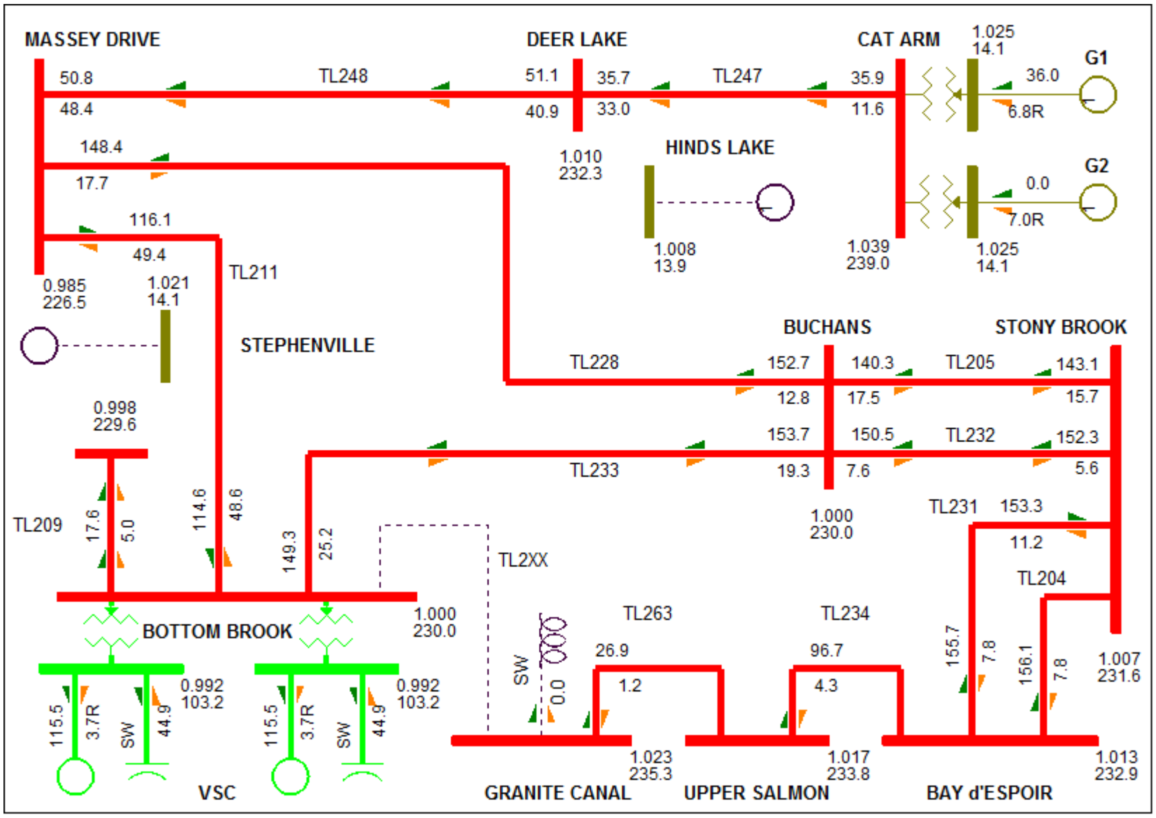
BC10 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL247



BC10 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL248



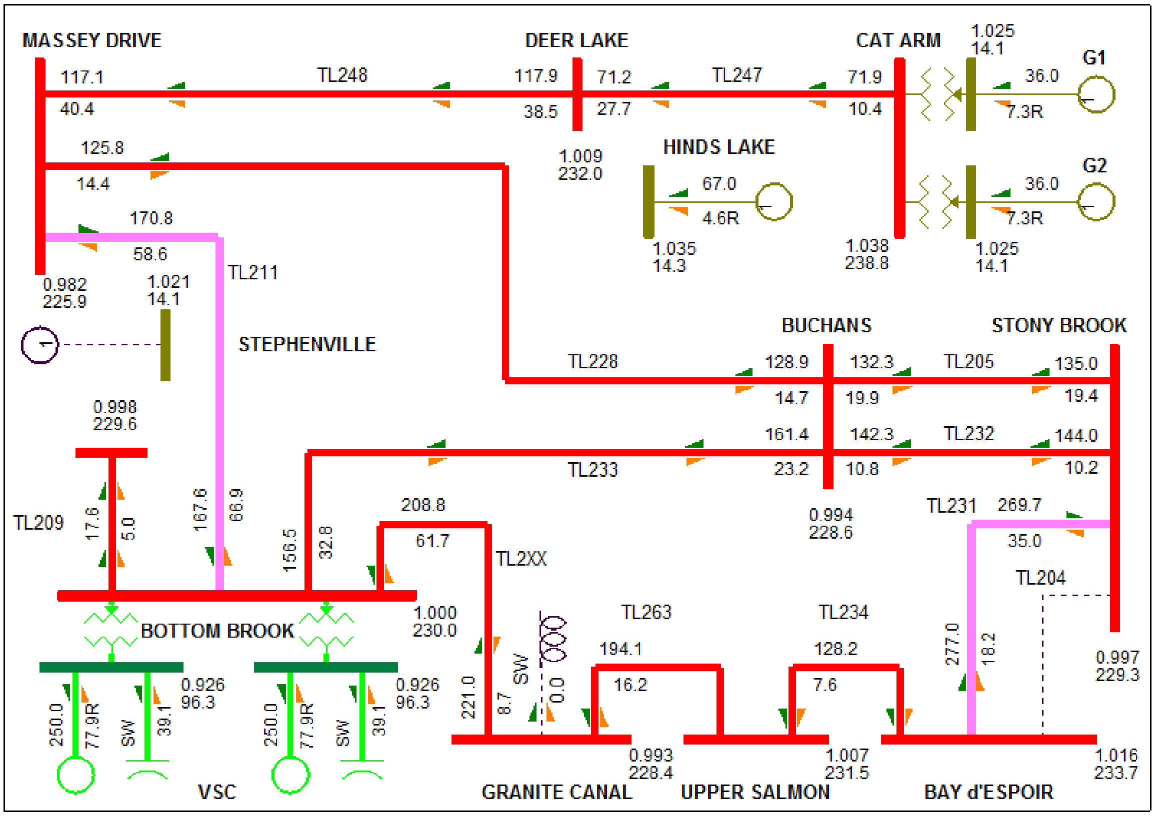
BC10 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL263



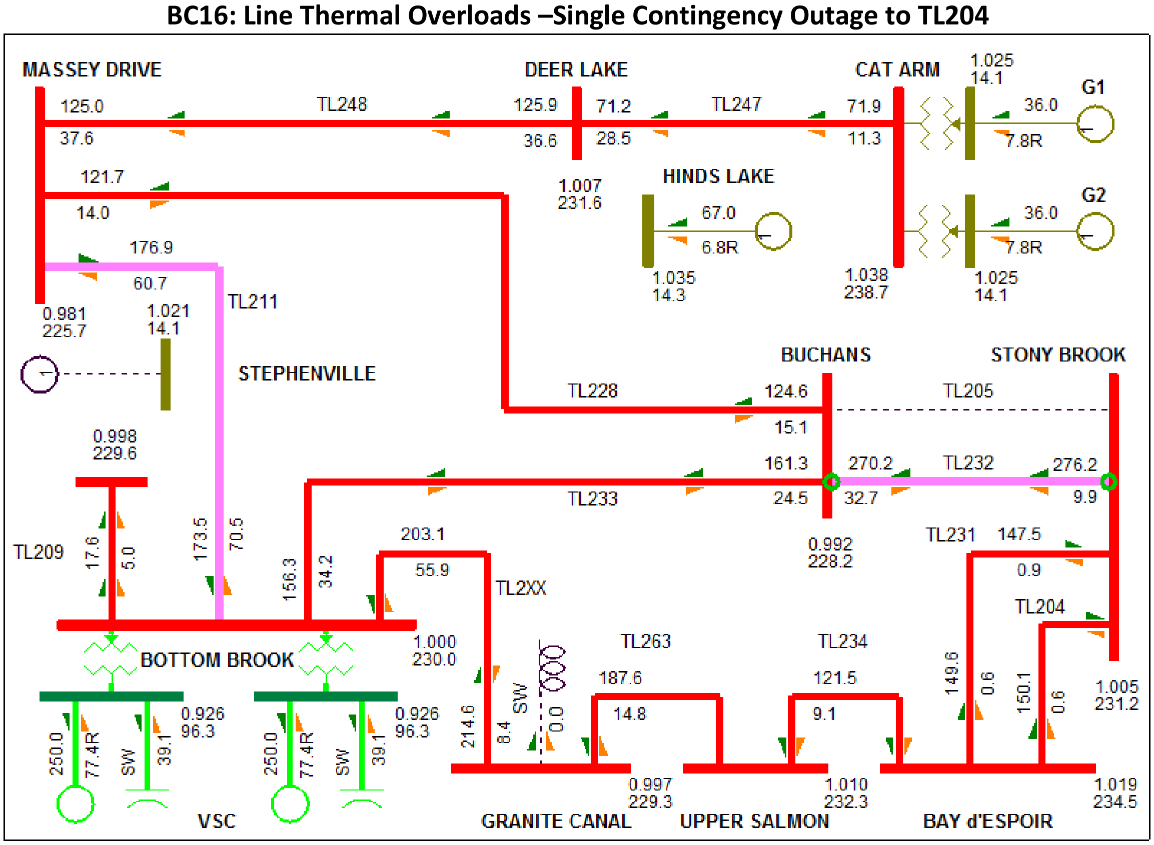
BC10 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL2XX

APPENDIX C
Base Case 16 - Load Flow PSS®E Plots

ATTACHMENT C-1
Base Case 16 Single Line Outage Load Flow Plots



BC16: Line Thermal Overloads –Single Contingency Outage to TL204



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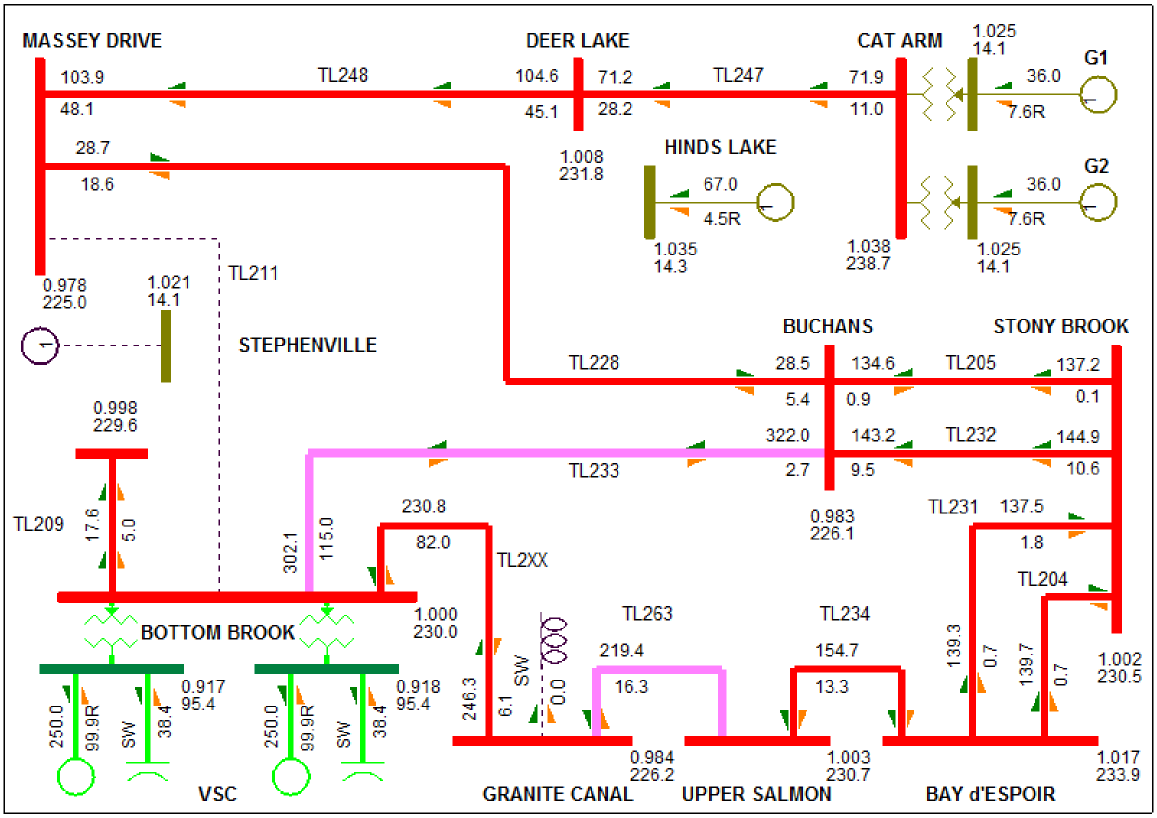

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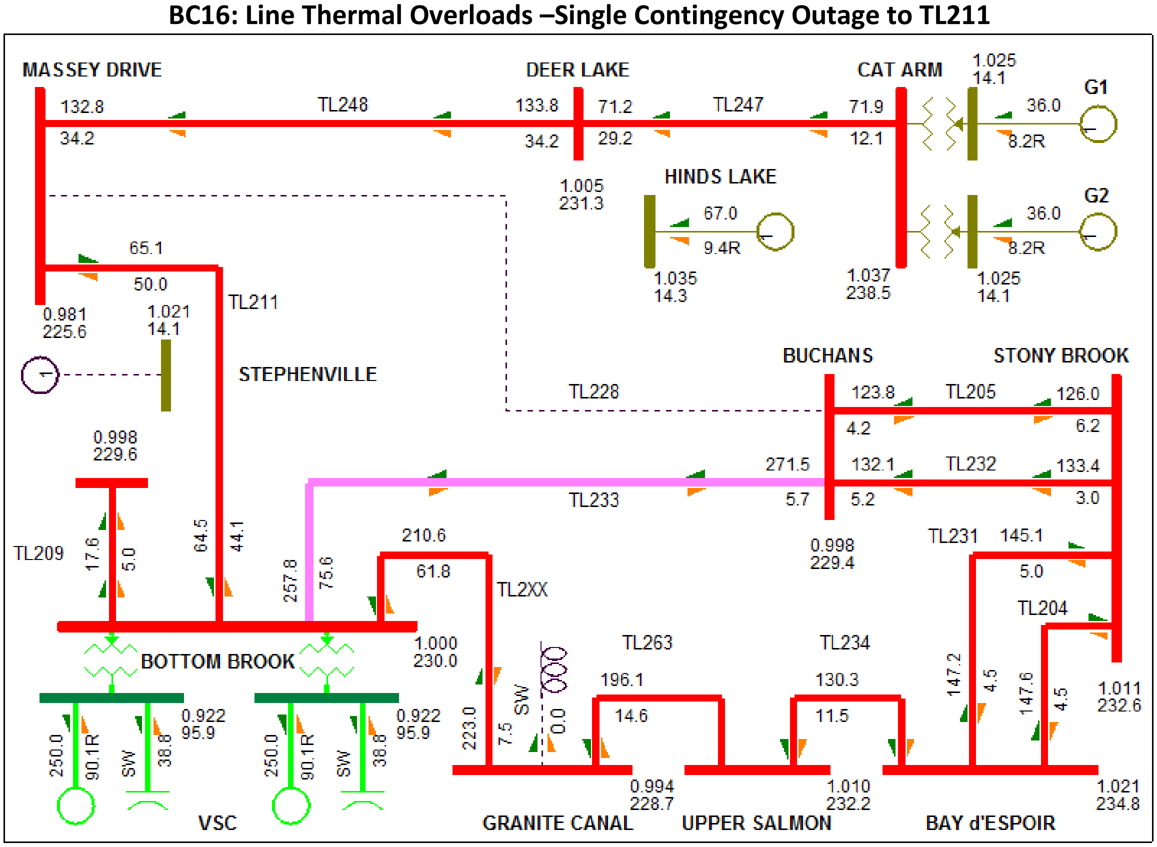
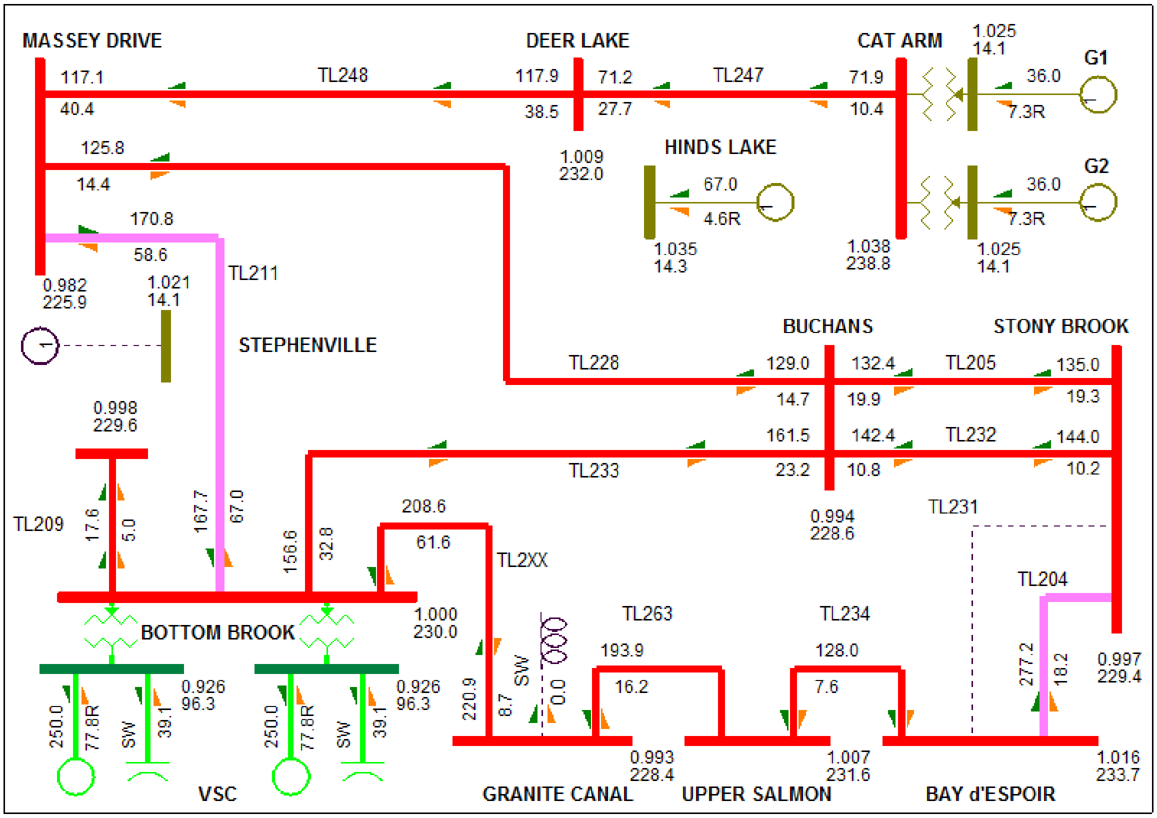


BC16: Line Thermal Overloads –Single Contingency Outage to TL228



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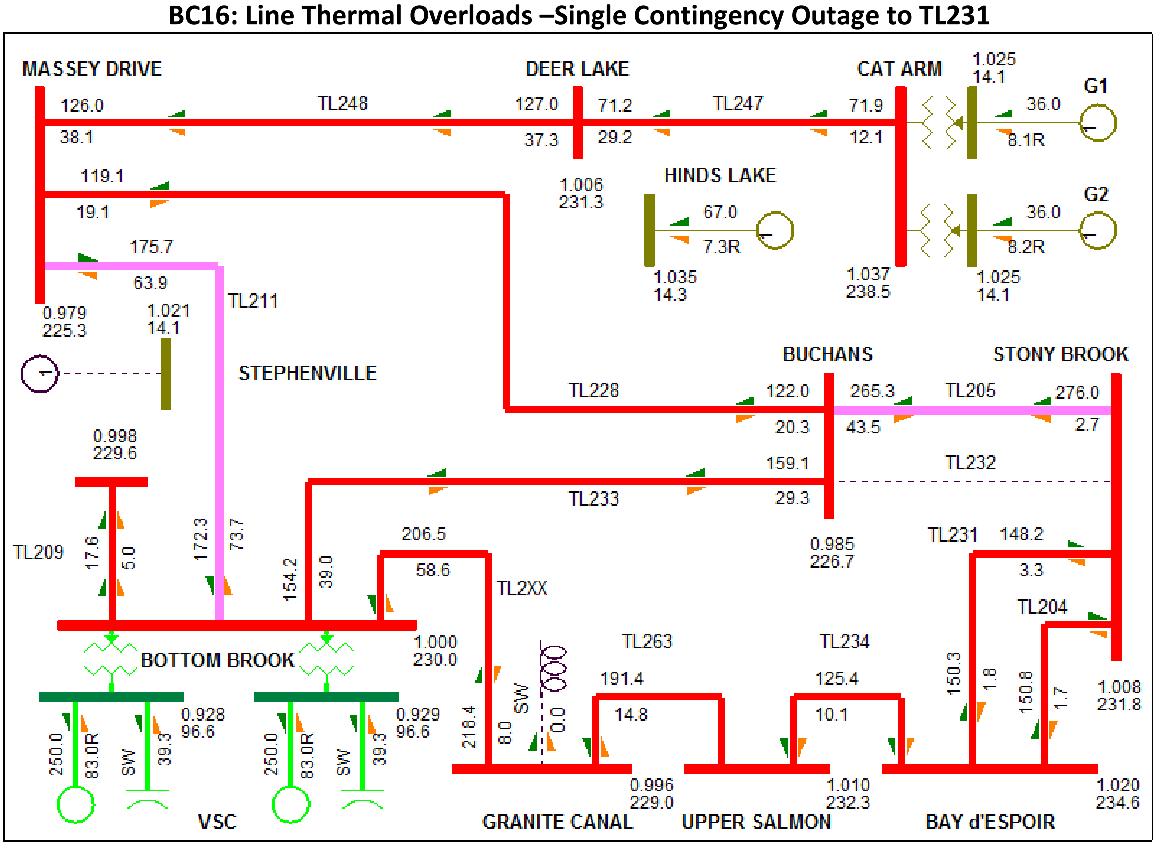

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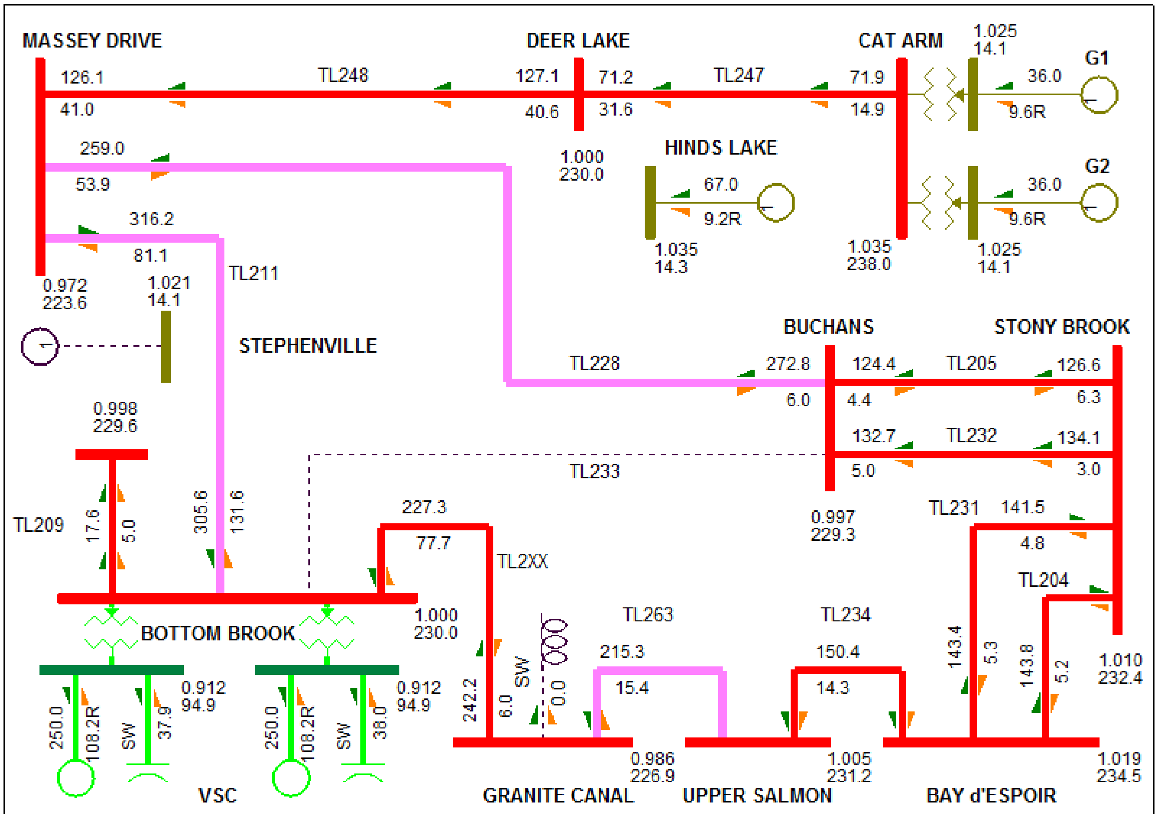

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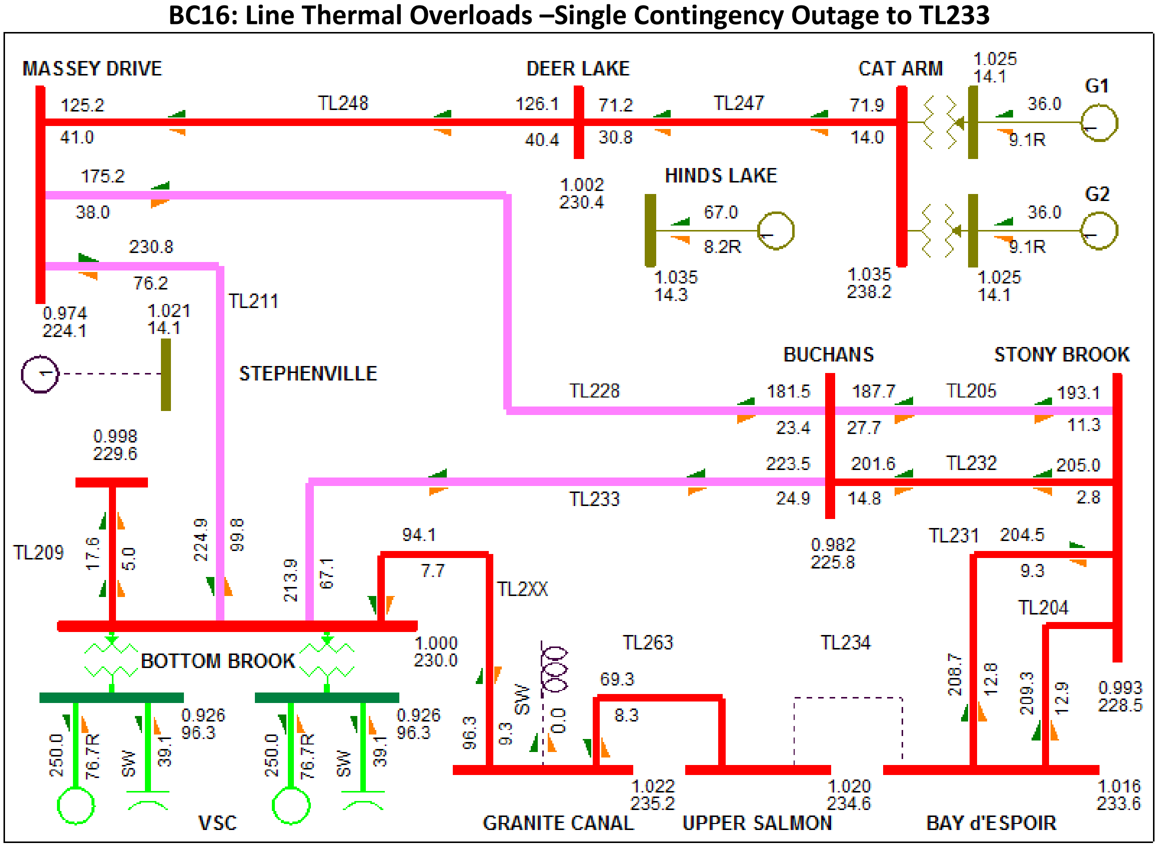
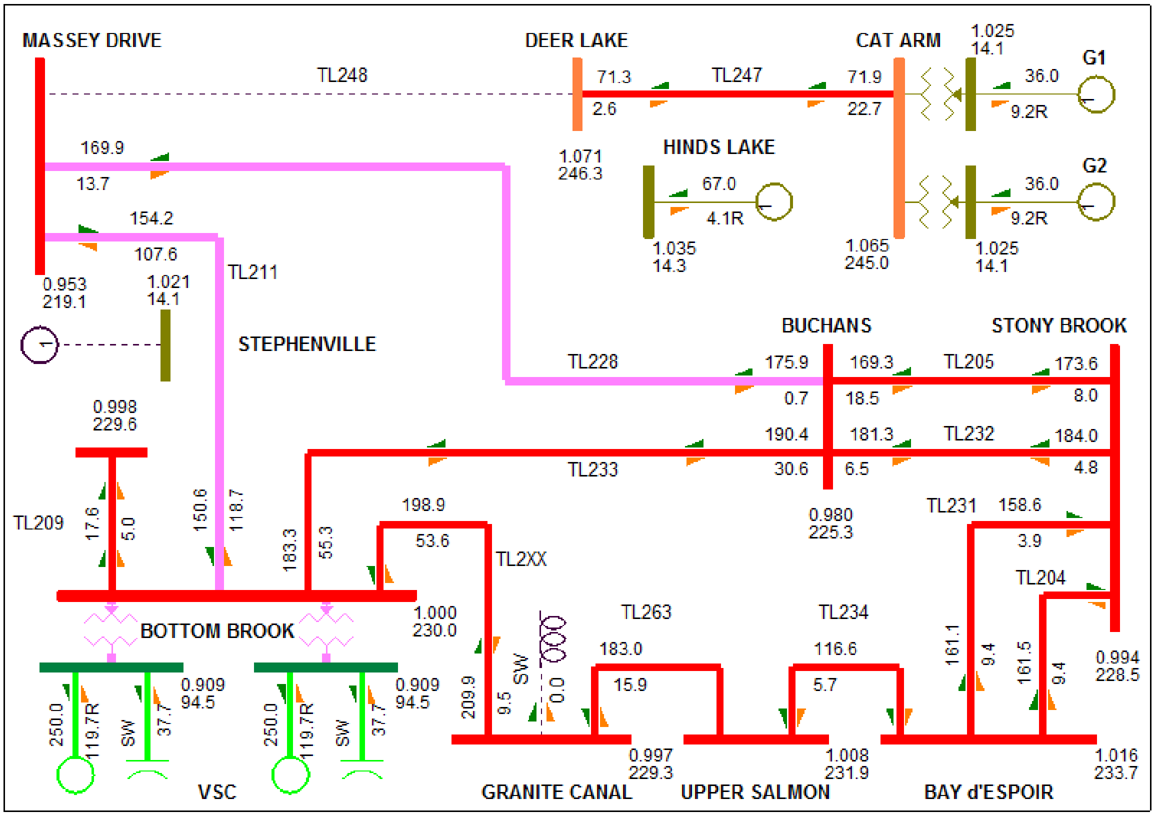
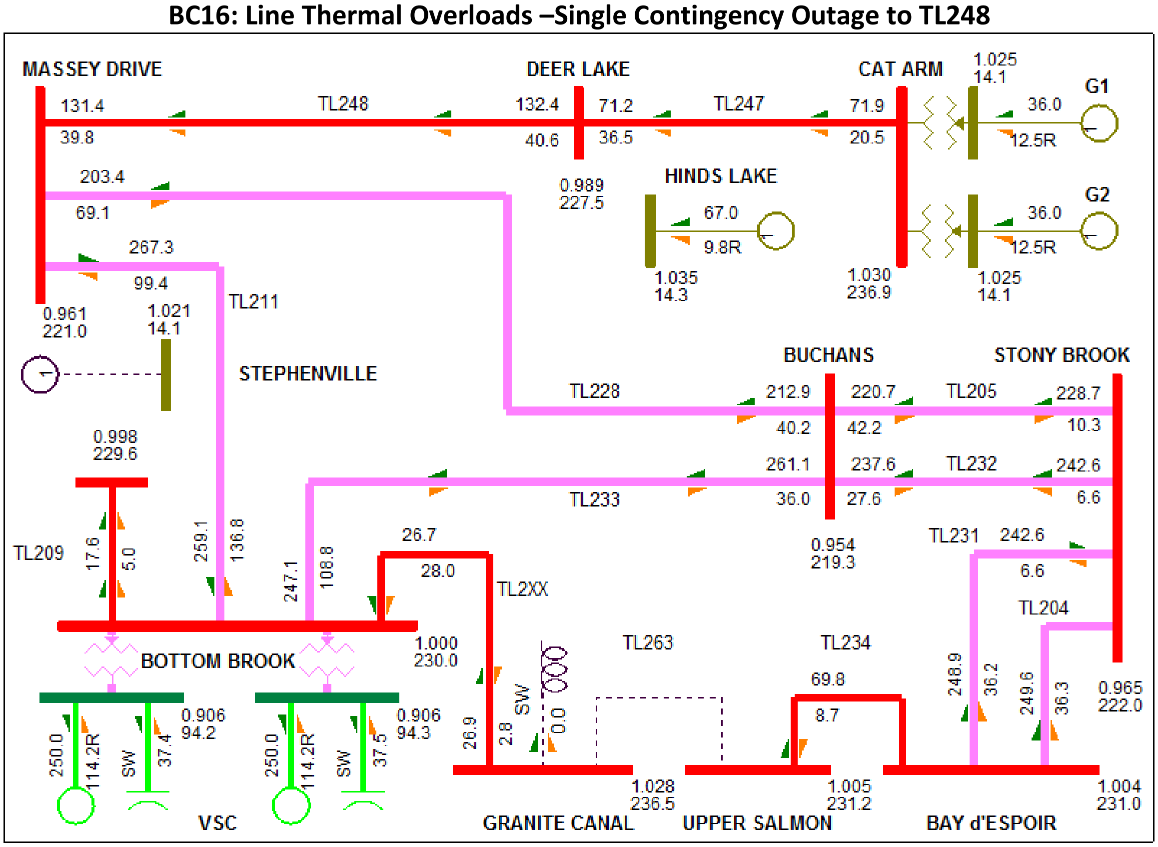


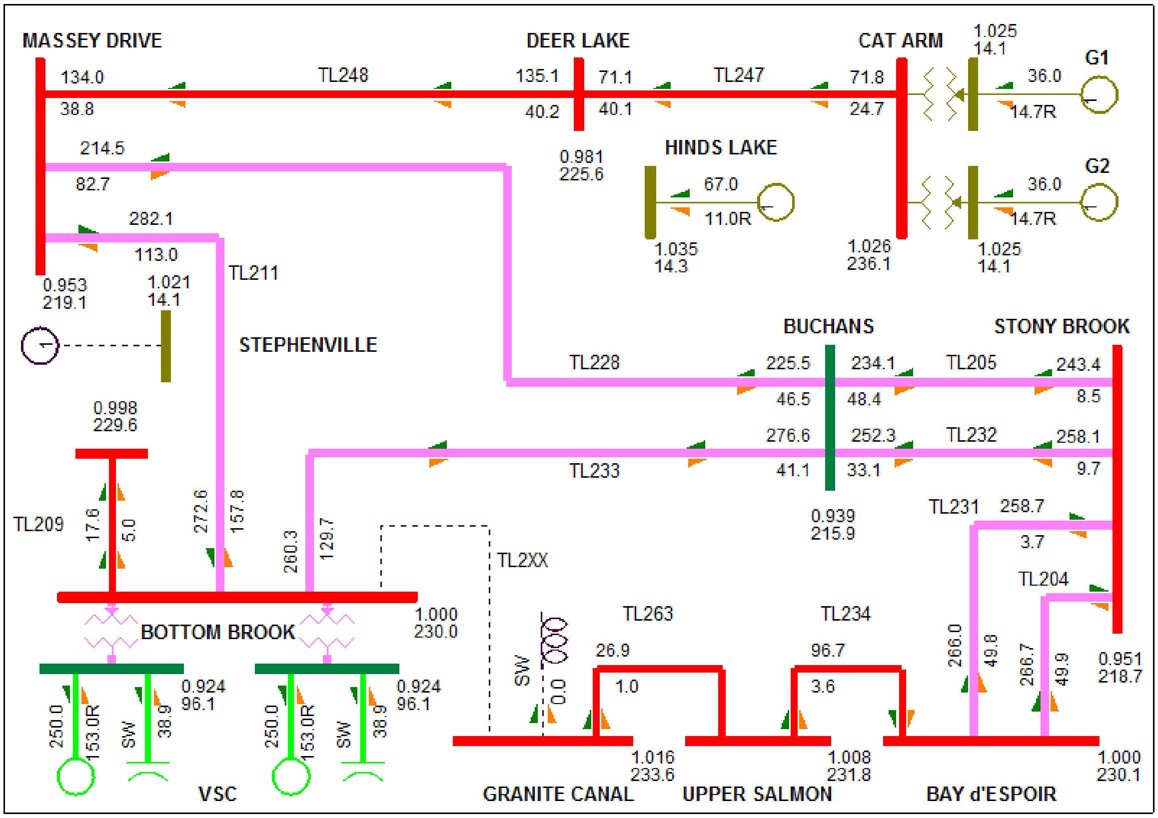
BC16: Line Thermal Overloads –Single Contingency Outage to TL234



BC16: Line Thermal Overloads –Single Contingency Outage to TL248

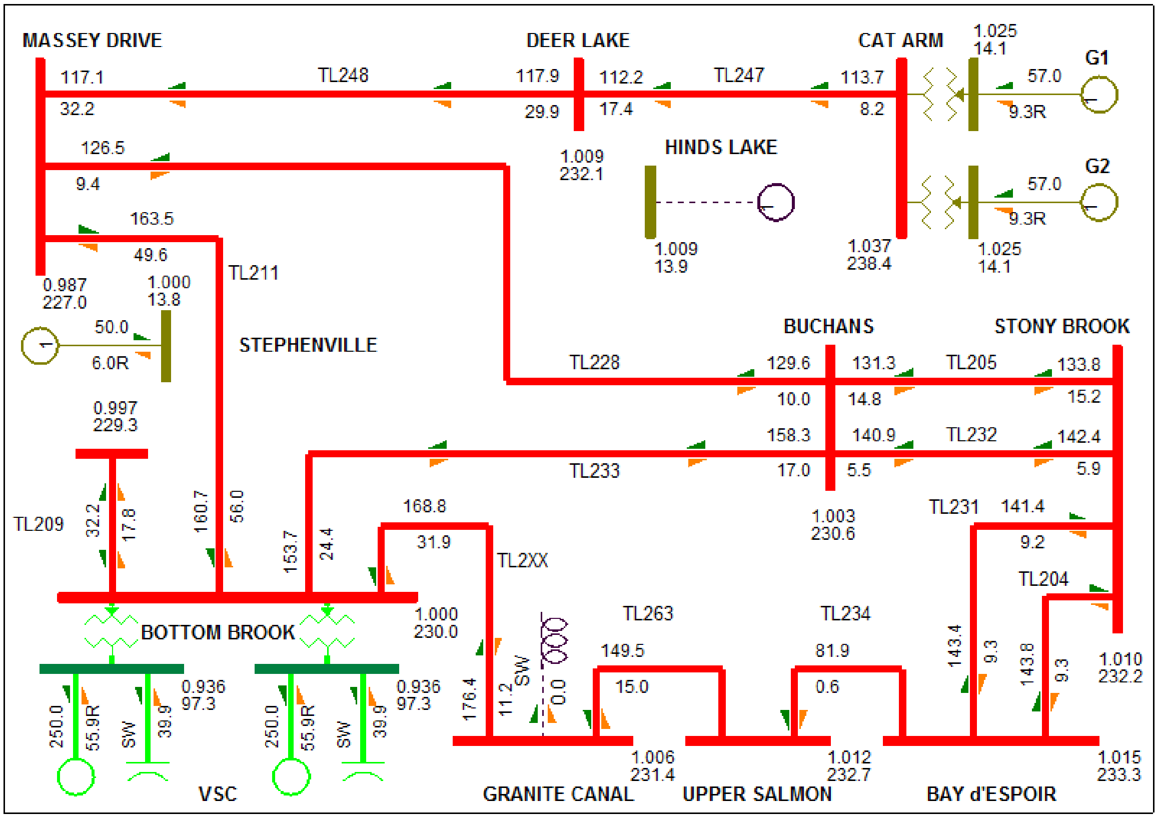


BC16: Line Thermal Overloads –Single Contingency Outage to TL263

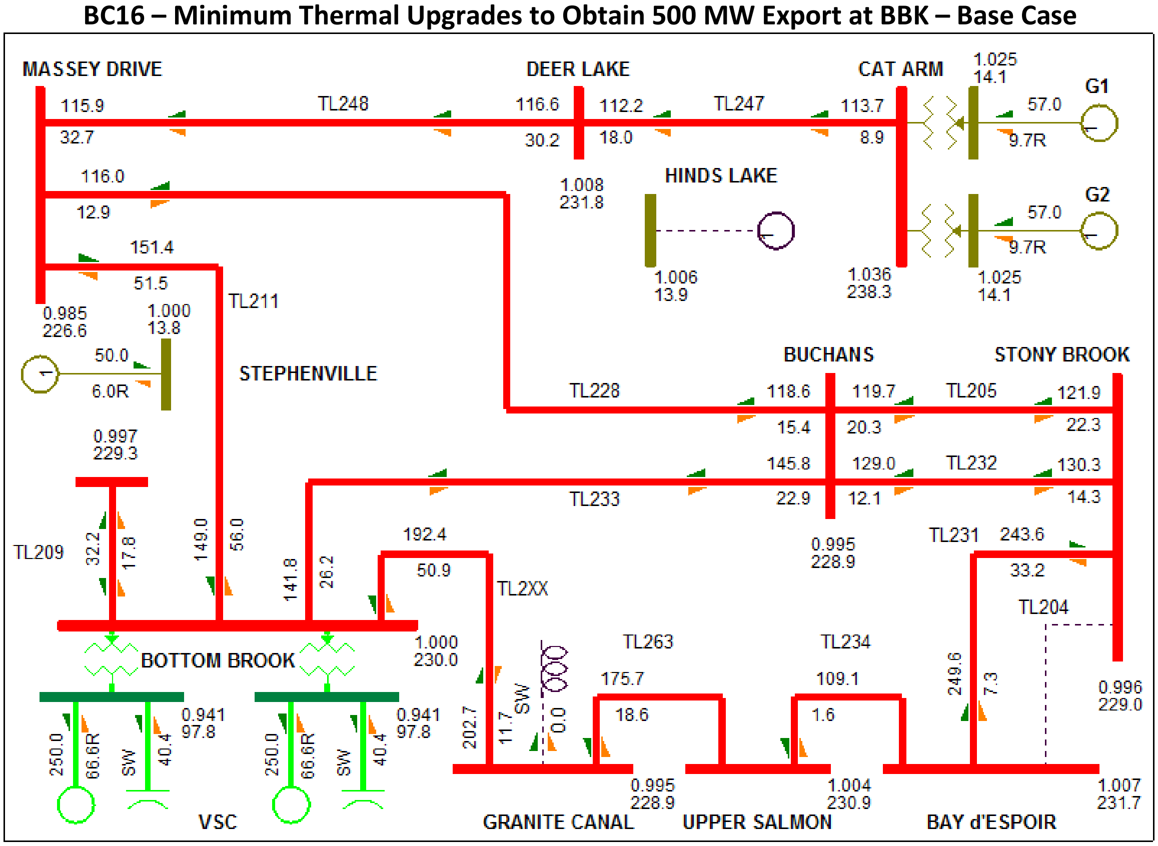


BC16: Line Thermal Overloads –Single Contingency Outage to TL2XX

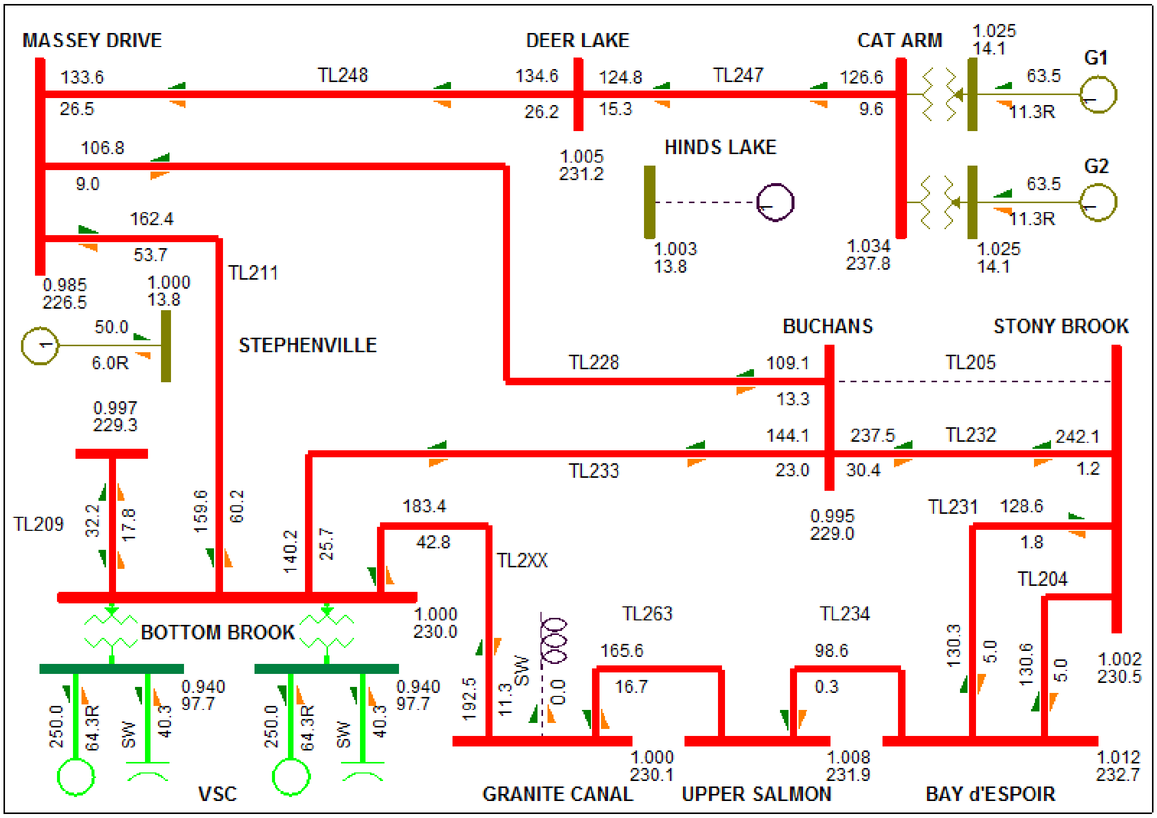
ATTACHMENT C-2
Base Case 16 Minimum Thermal Upgrades Load Flow Plots



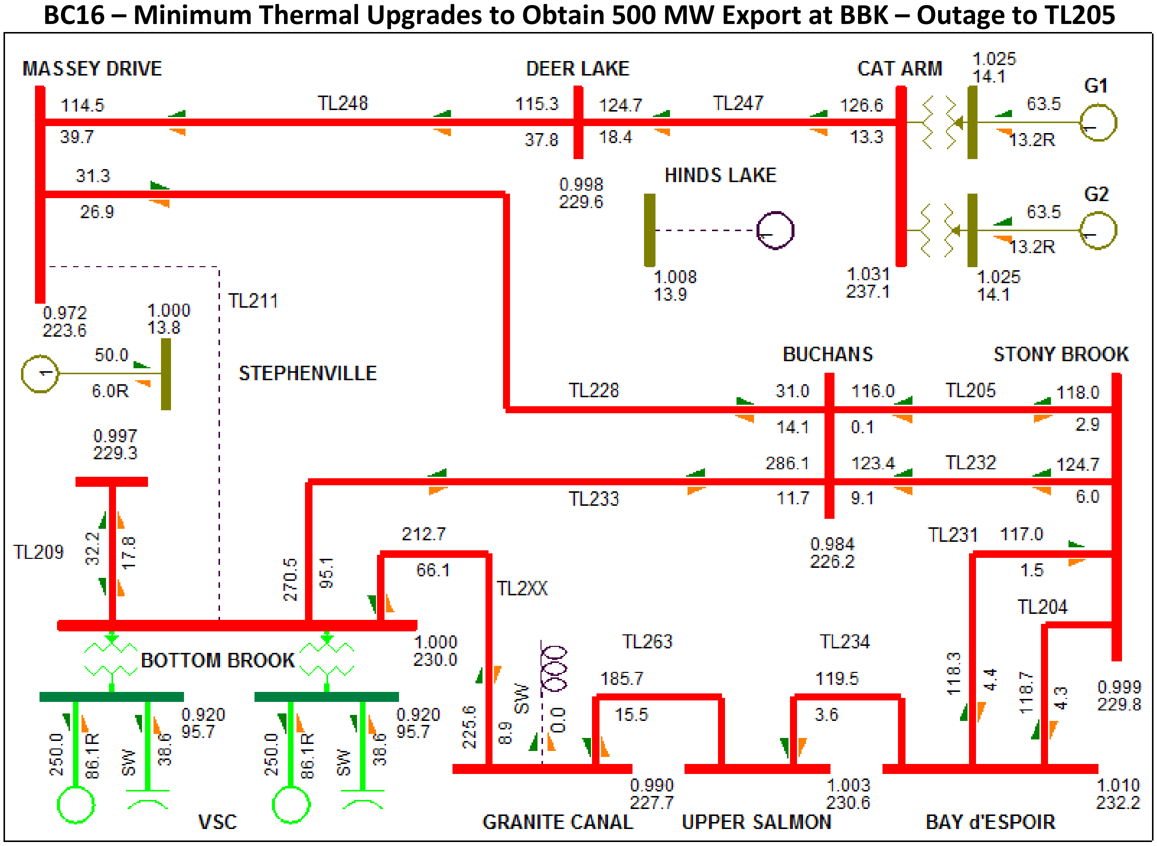
BC16 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Base Case



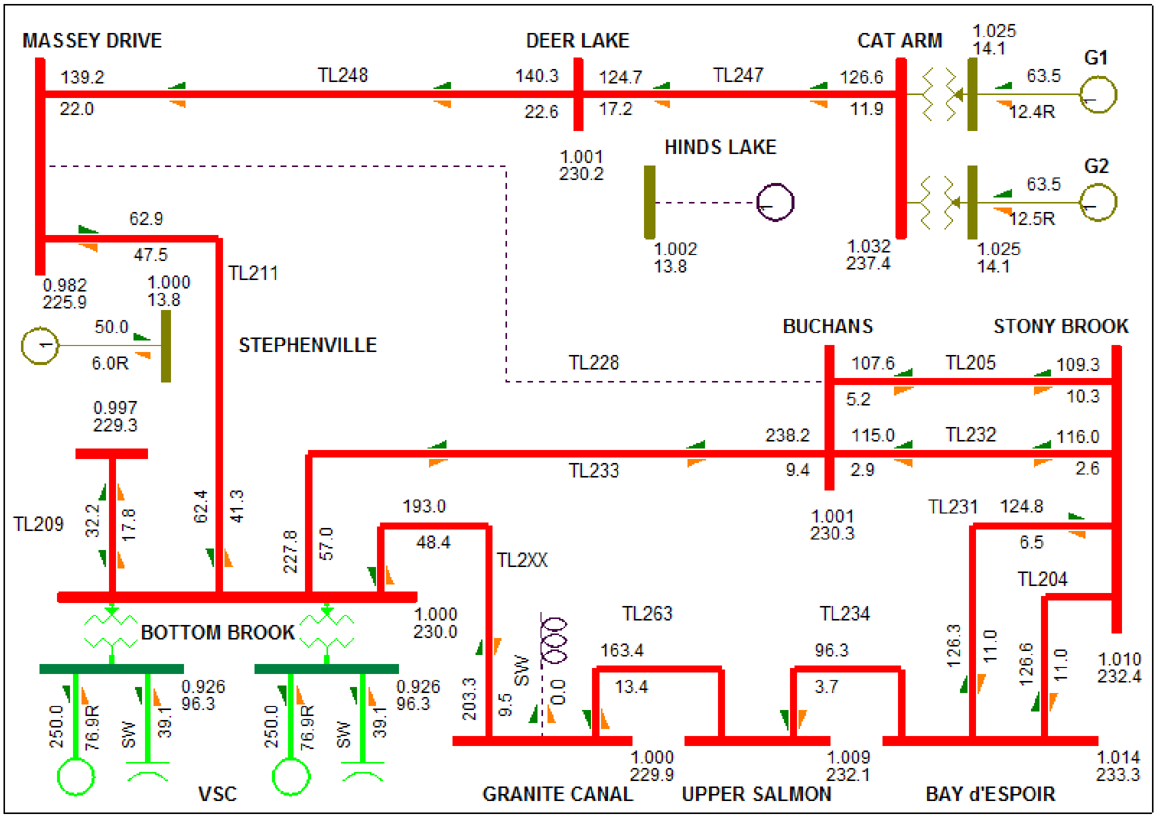
BC16 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL204



BC16 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL205



BC16 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL211



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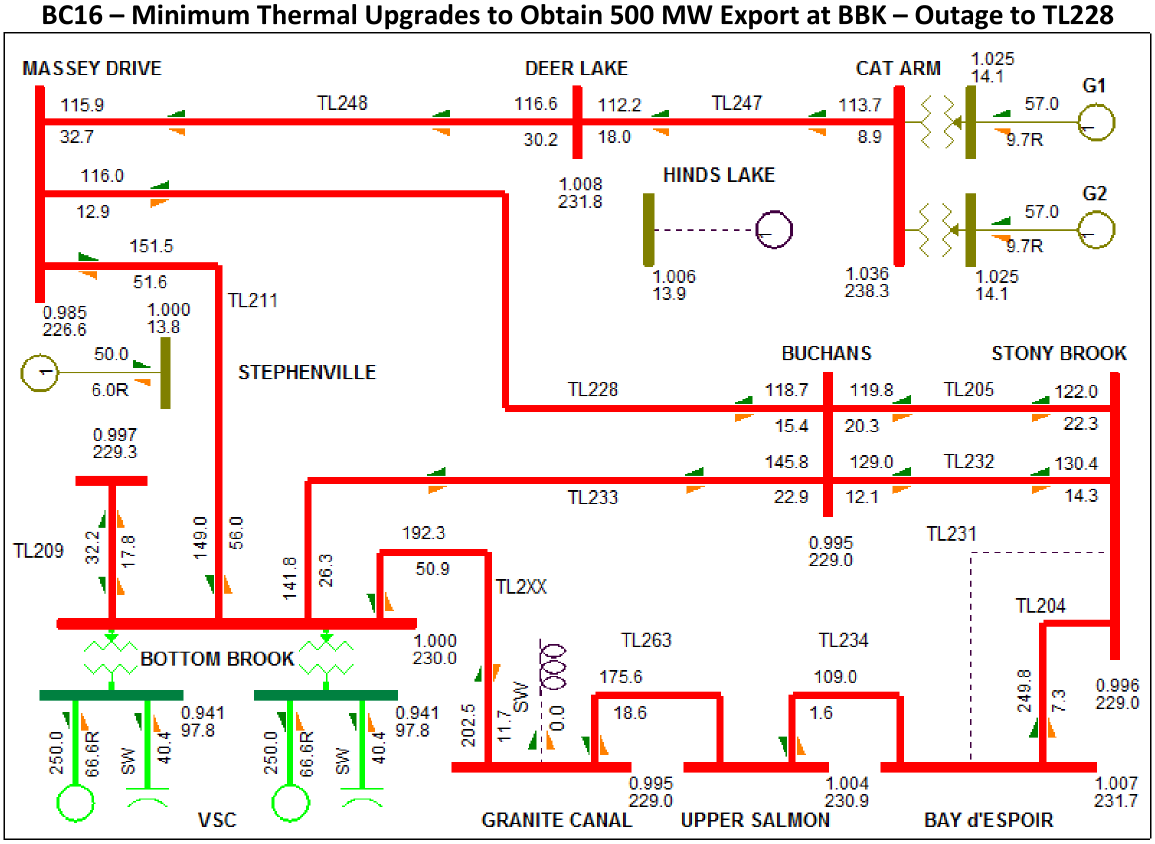
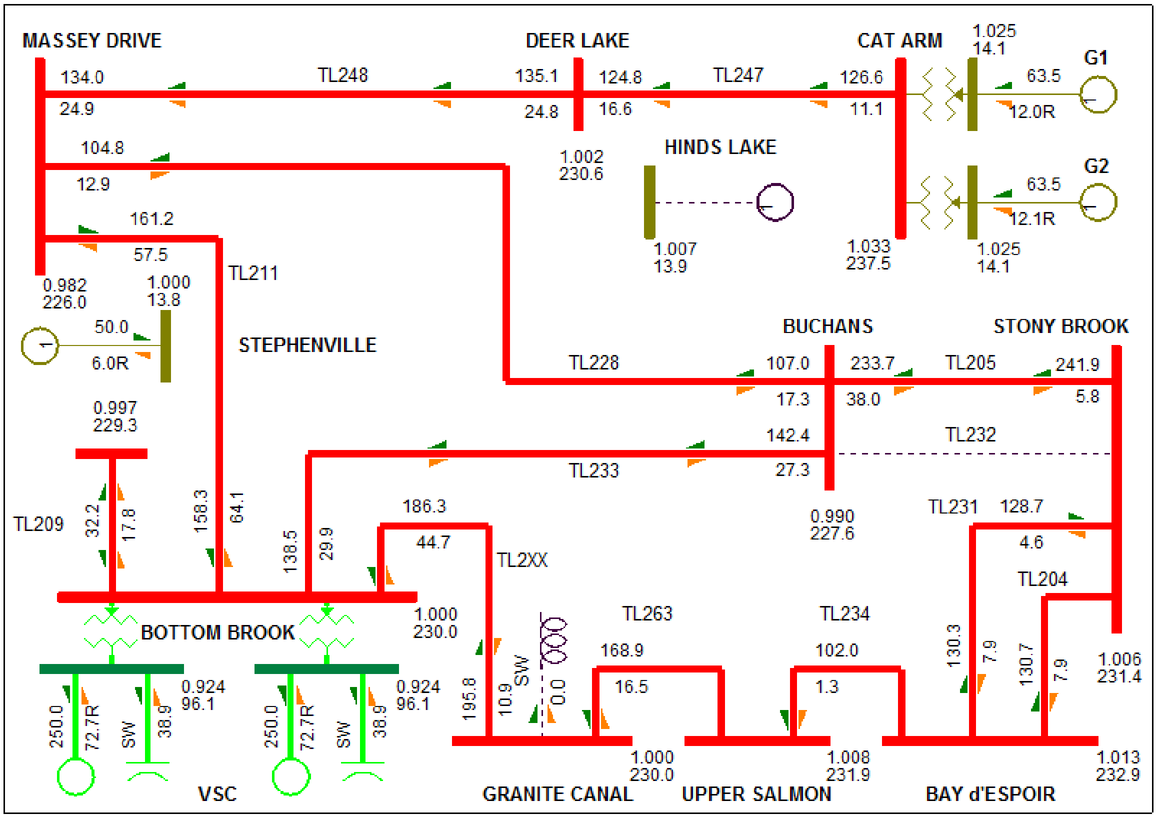
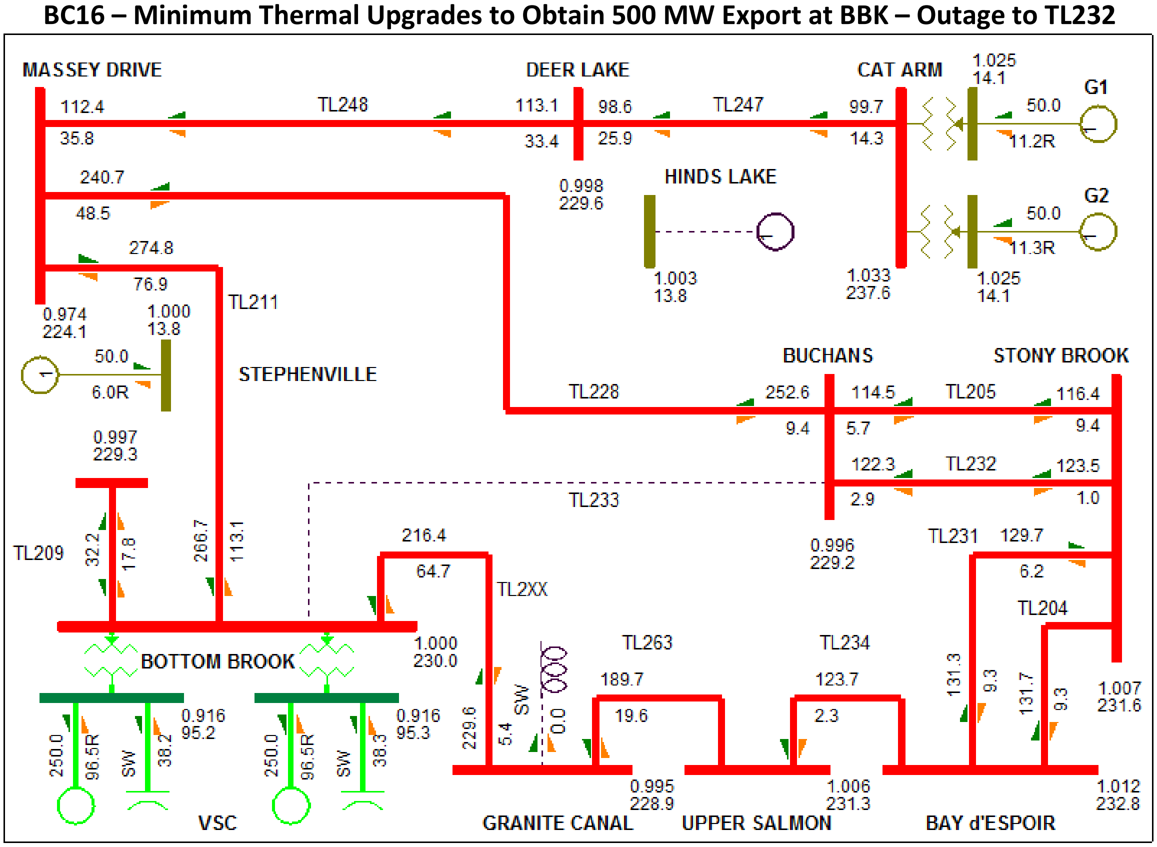


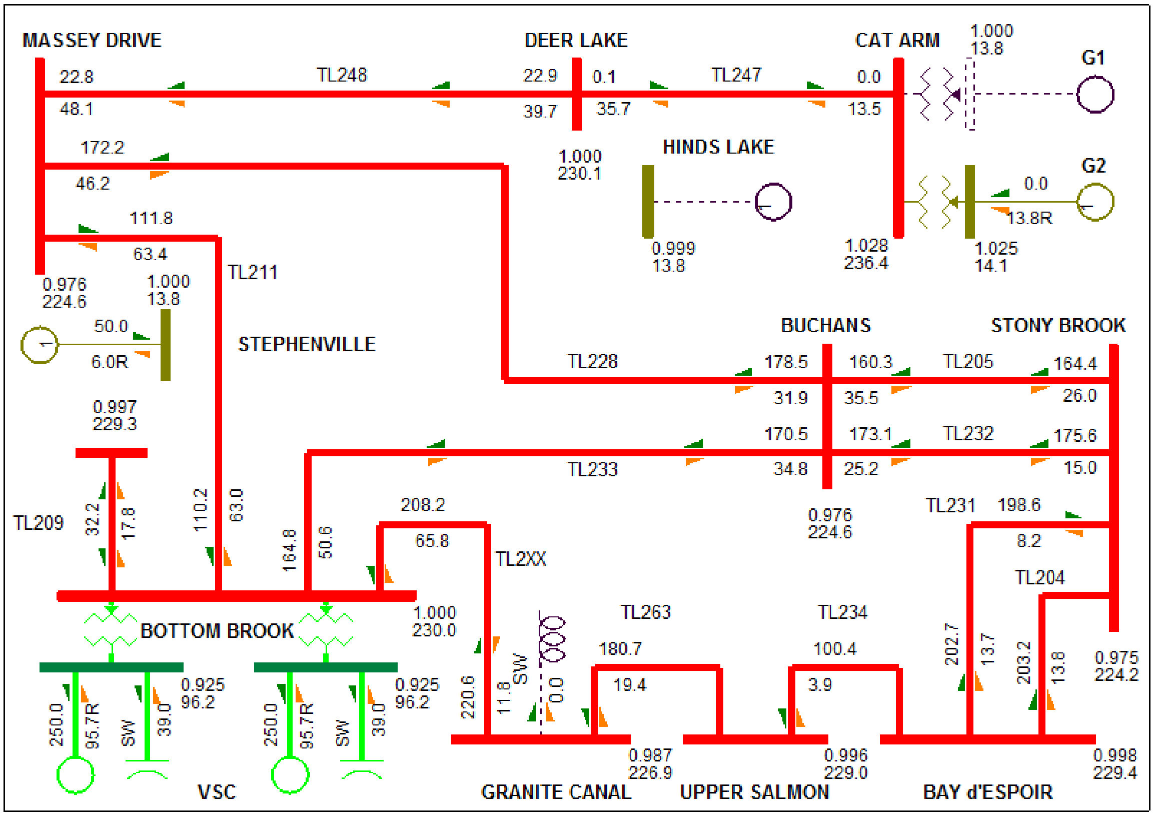
BC16 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL231



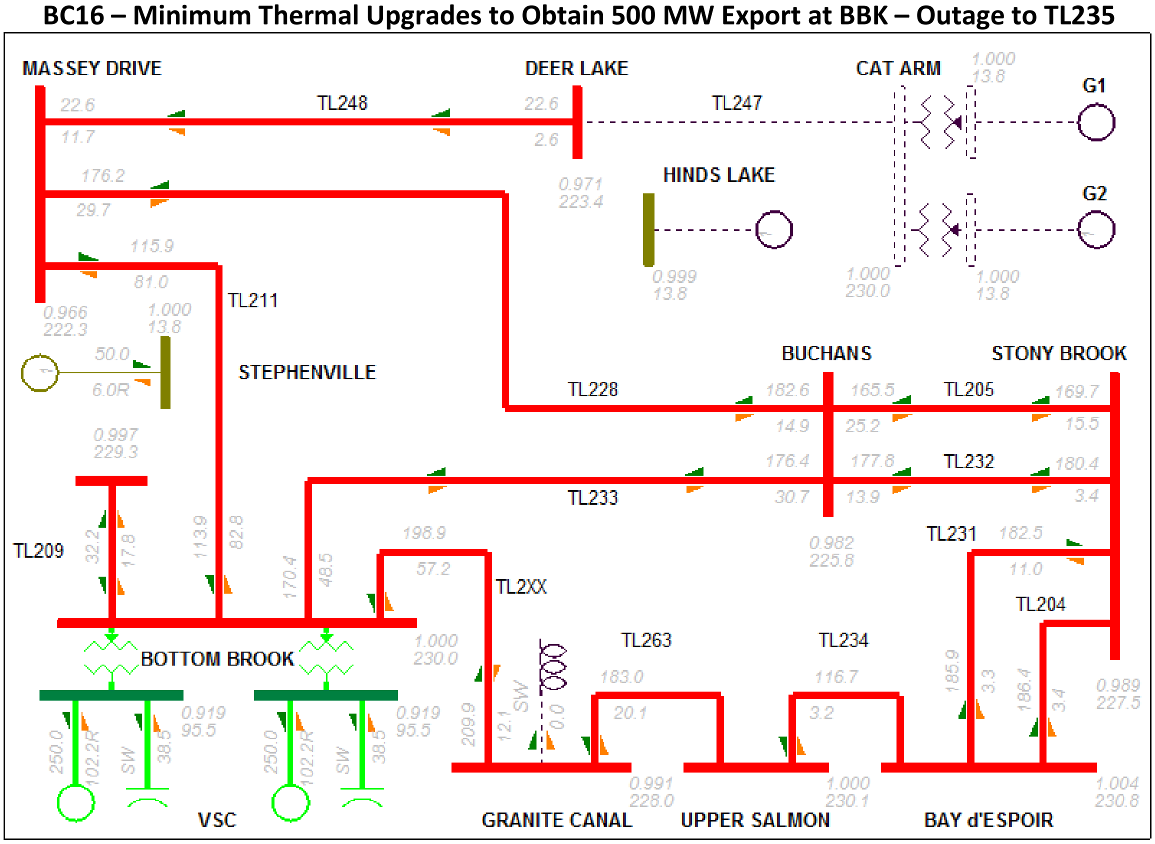
BC16 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL232



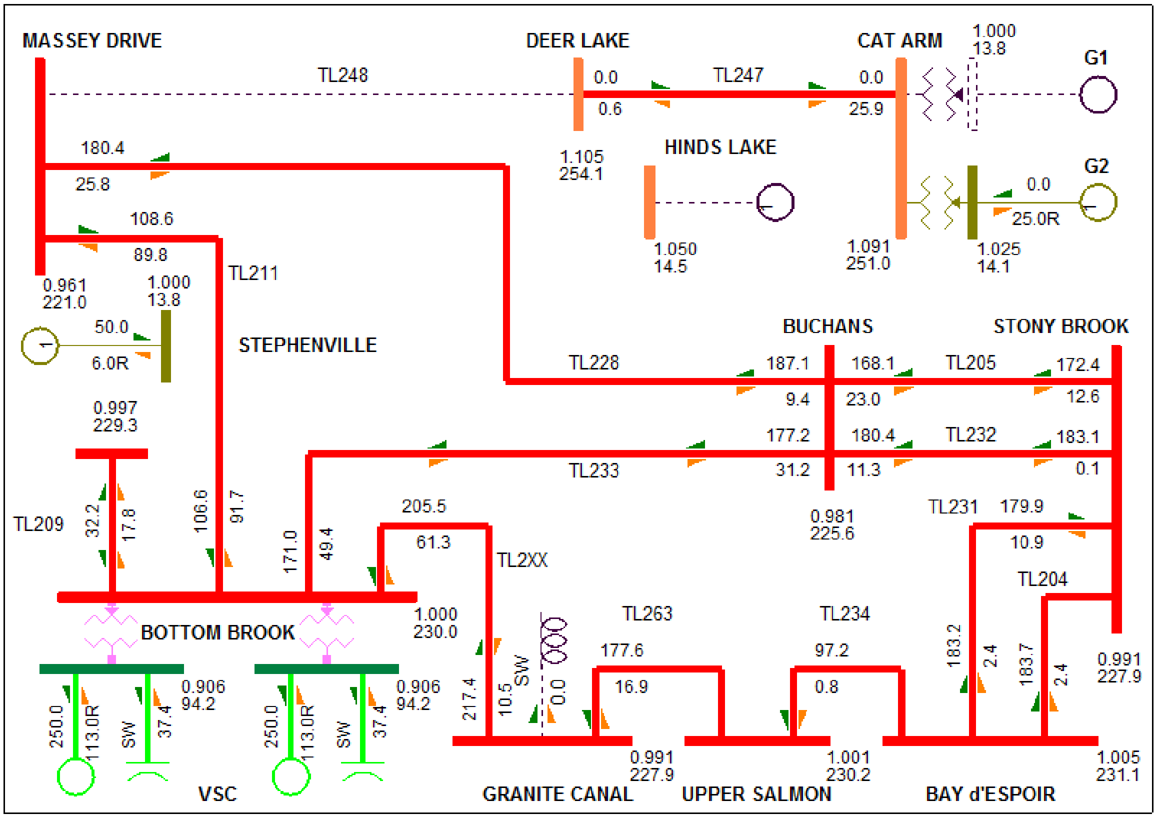
BC16 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL233



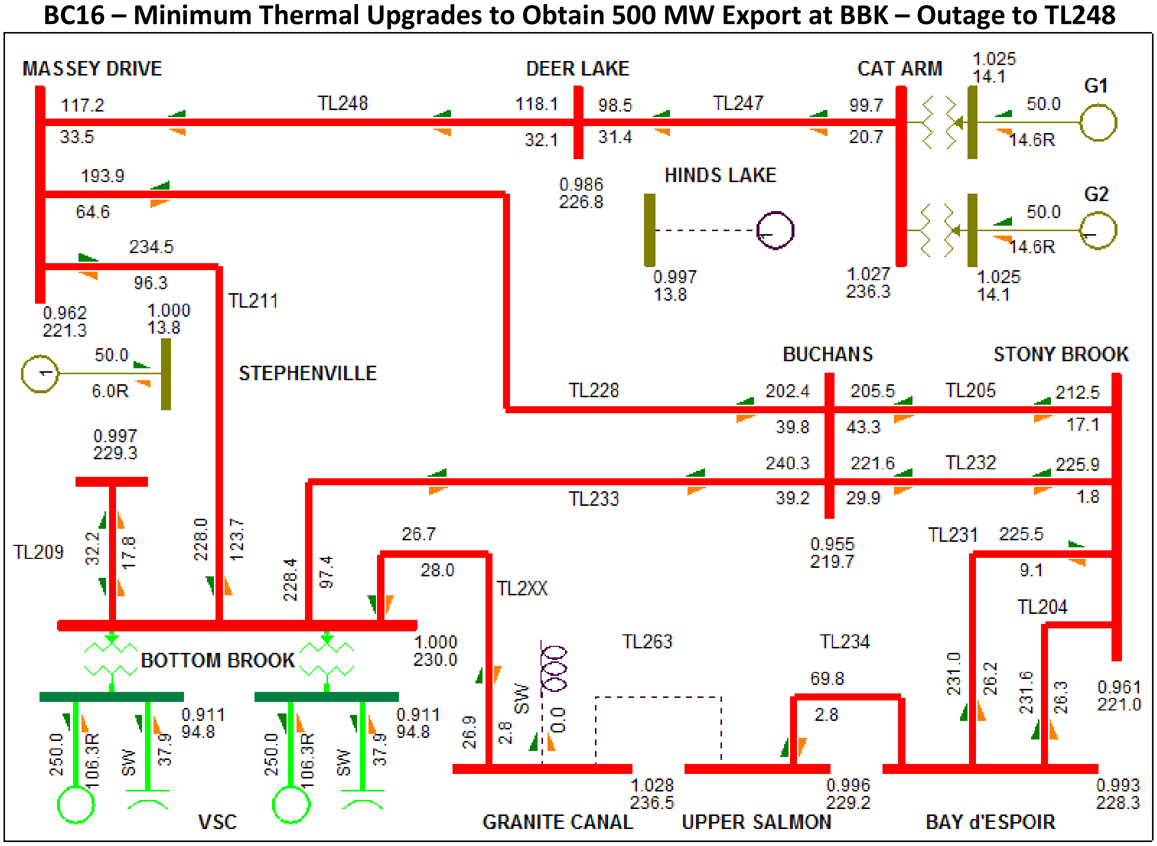
BC16 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL235



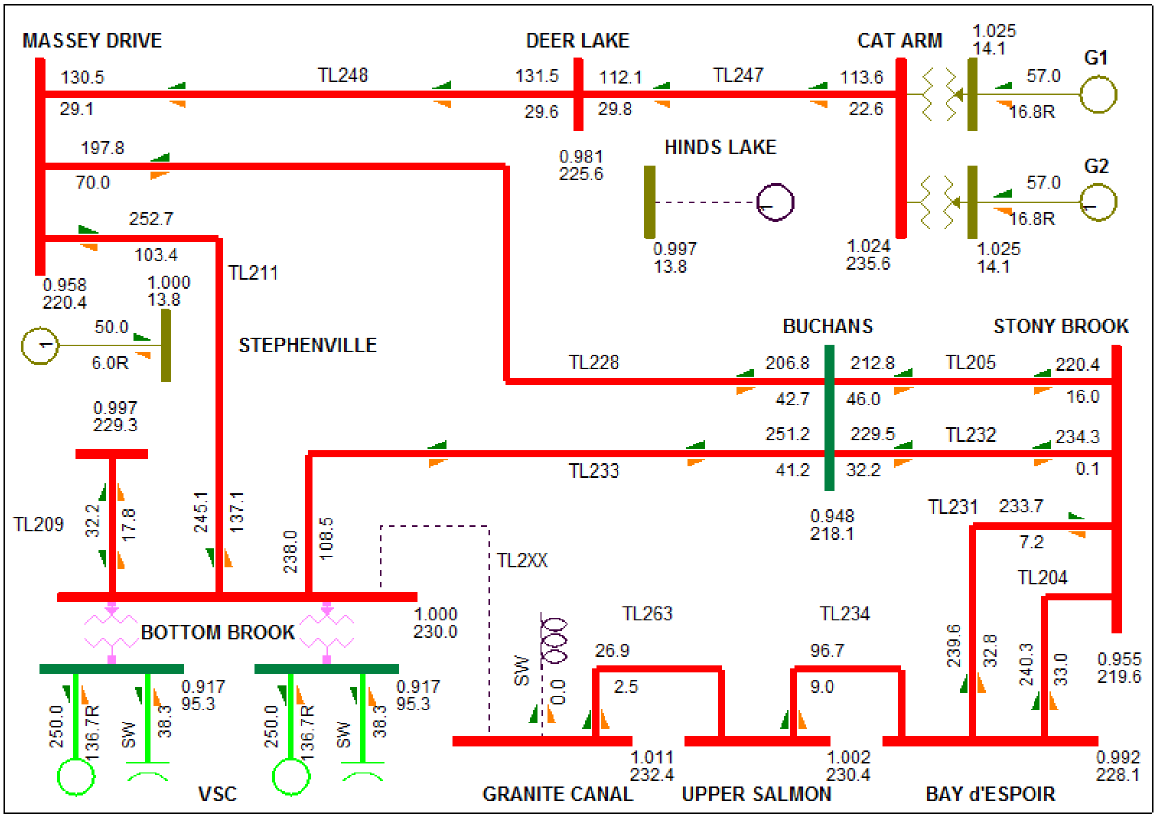
BC16 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL247



BC16 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL248

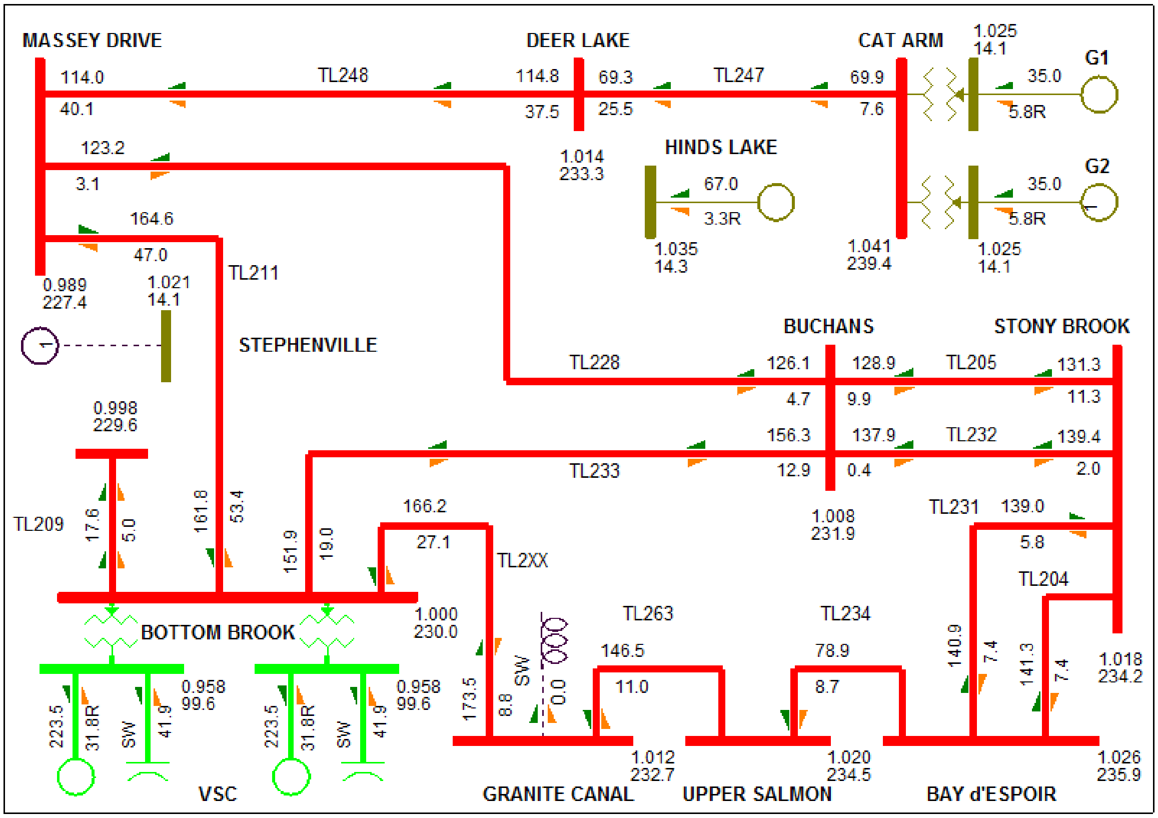


BC16 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL263

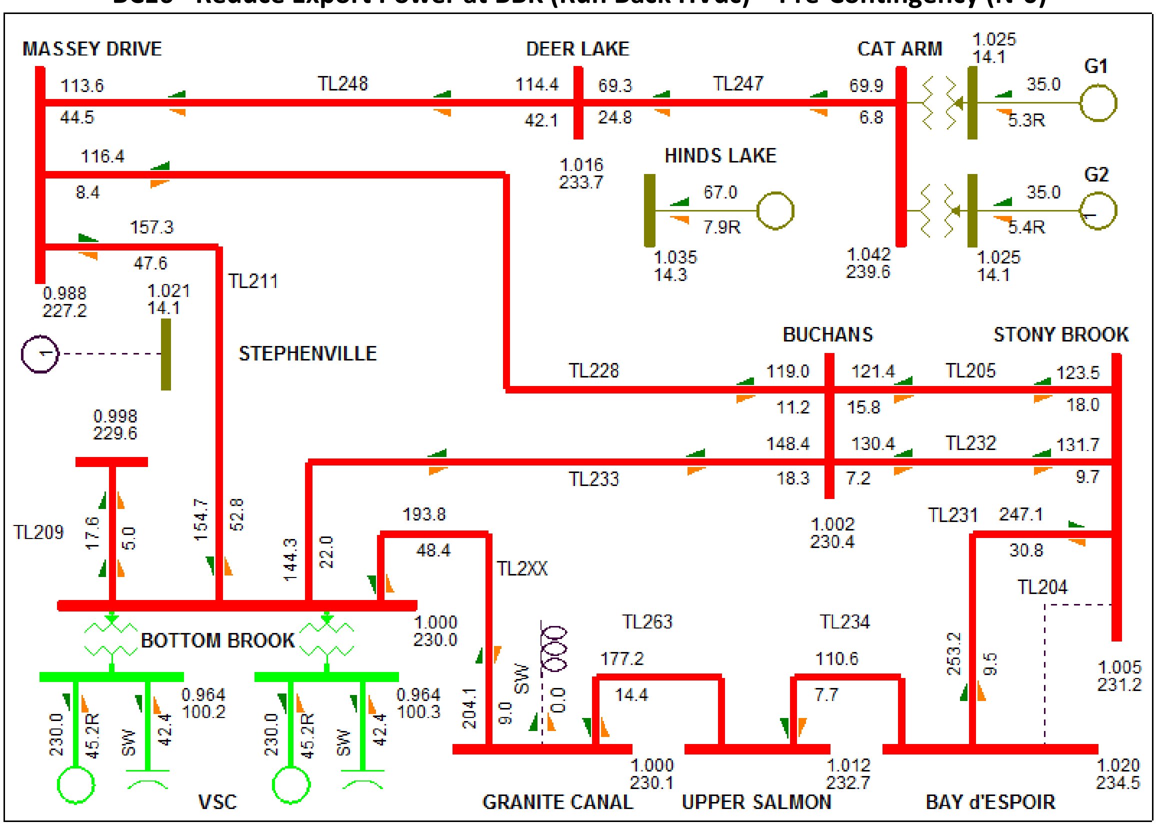


BC16 – Minimum Thermal Upgrades to Obtain 500 MW Export at BBK – Outage to TL2XX

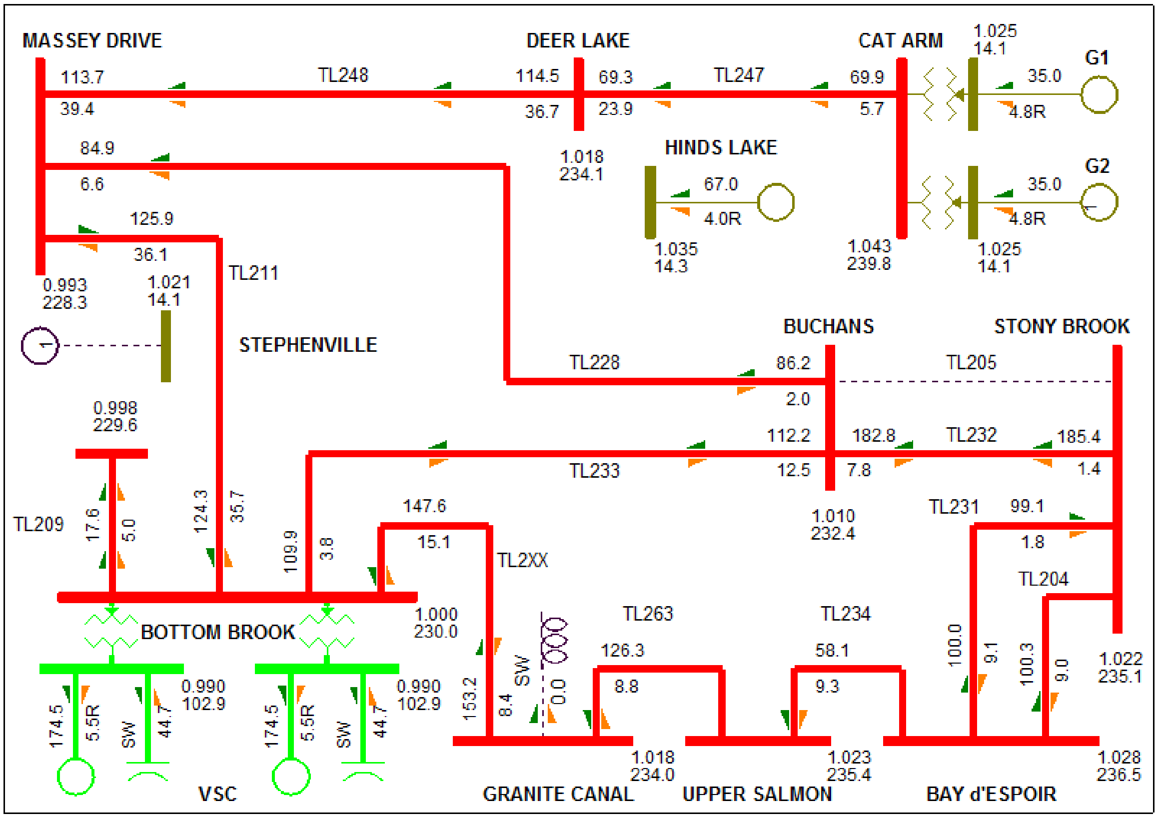
ATTACHMENT C-3
Base Case 16 Reduced Export Load Flow Plots



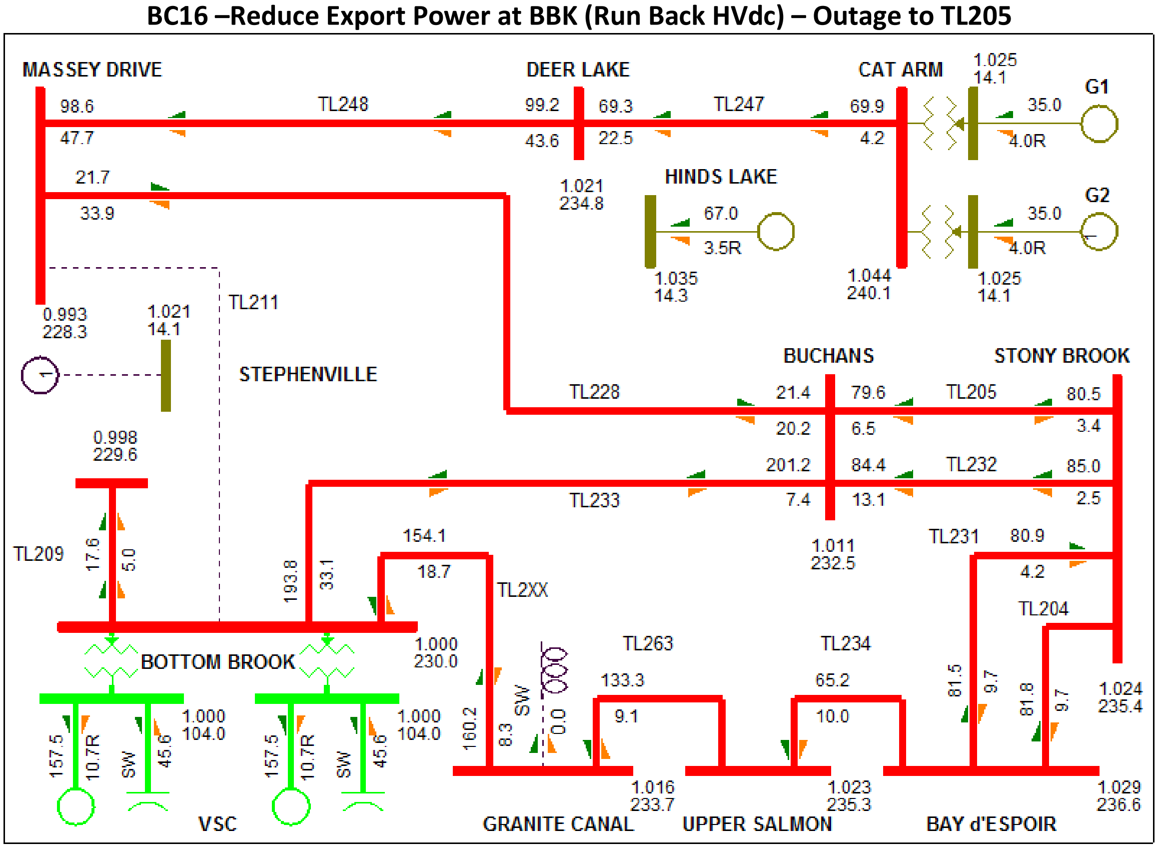
BC16 –Reduce Export Power at BBK (Run Back HVdc) – Pre-Contingency (N-0)



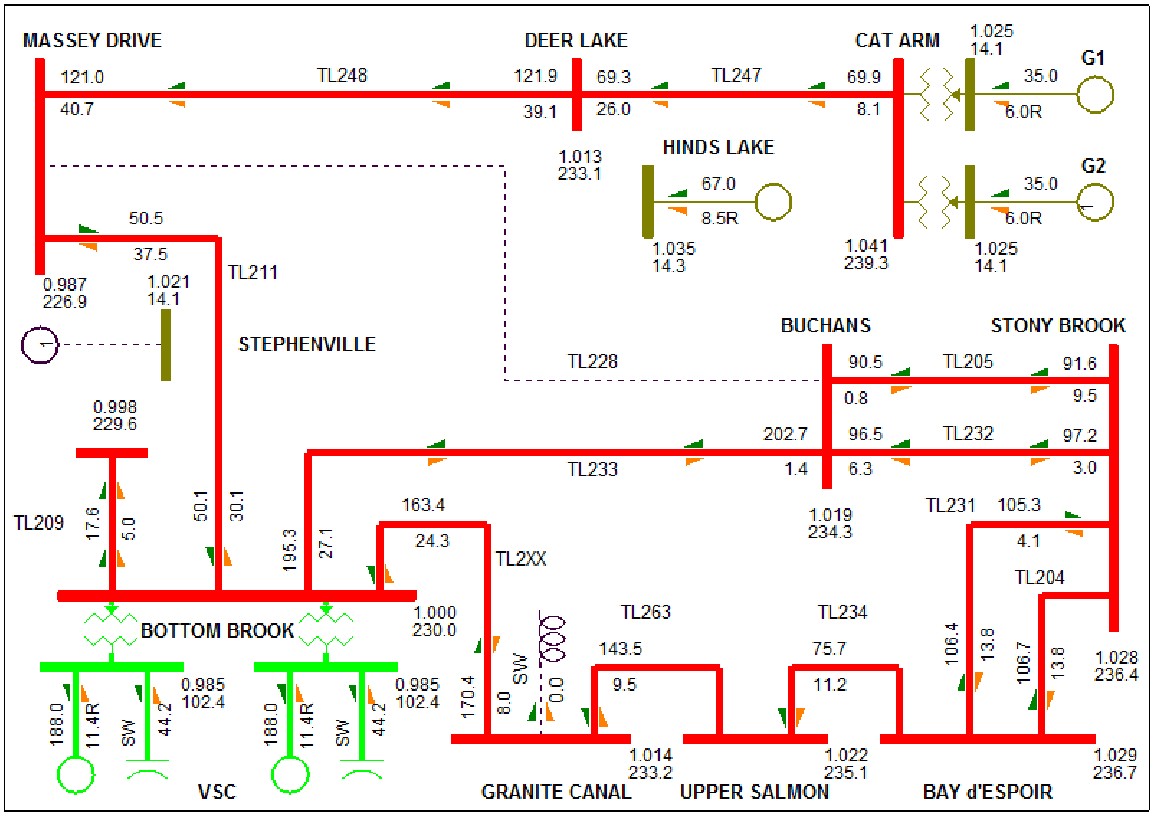
BC16 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL204



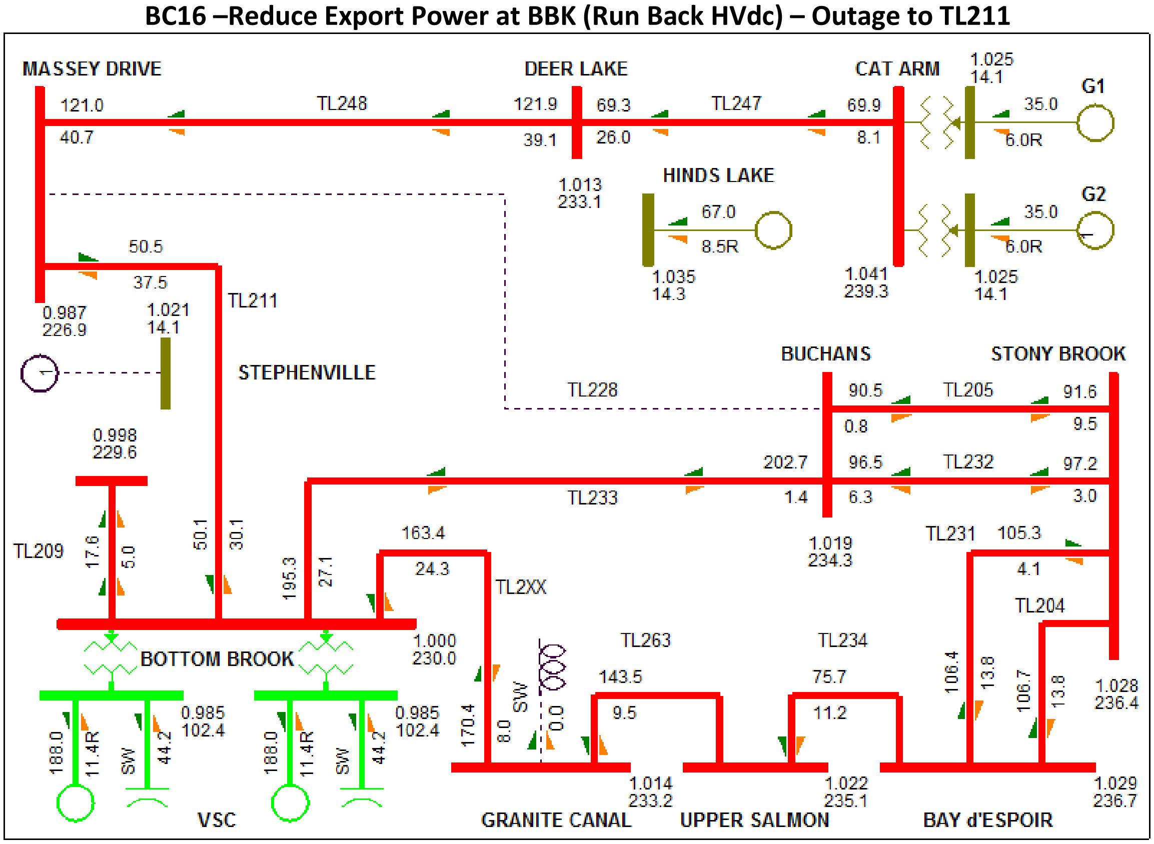
BC16 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL205



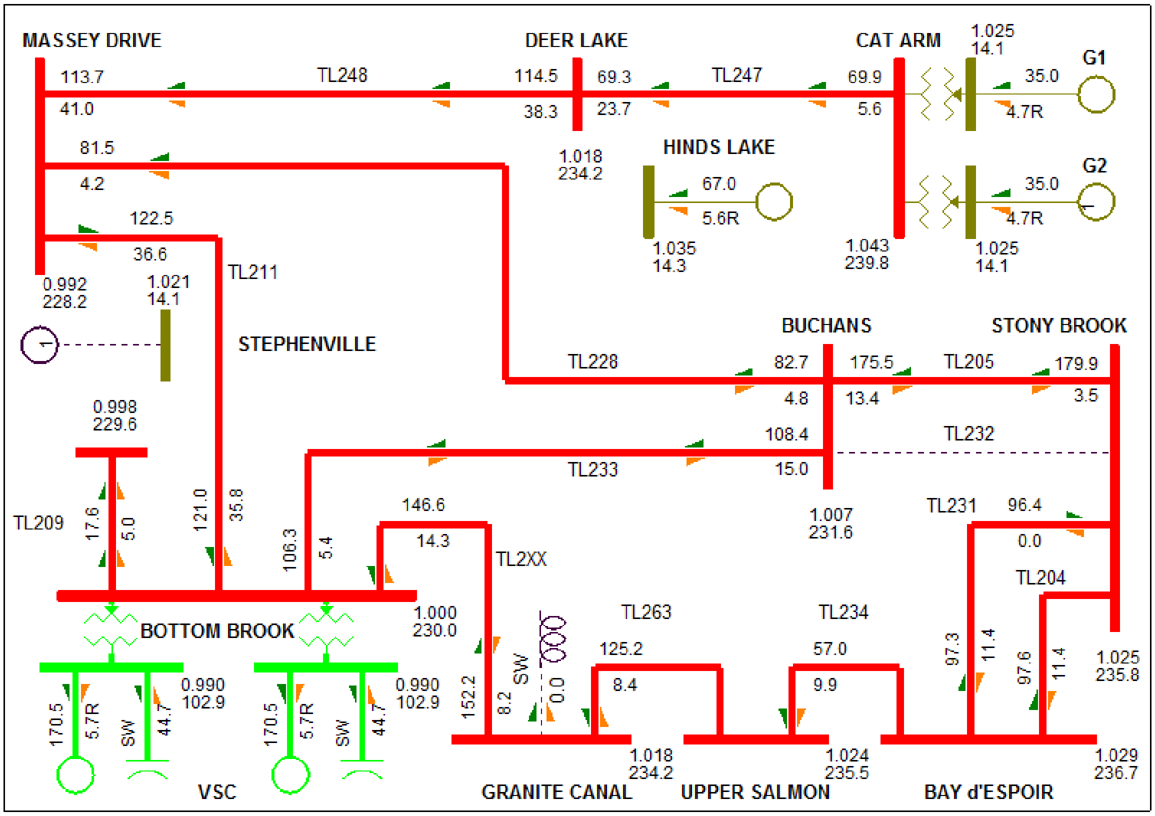
BC16 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL211



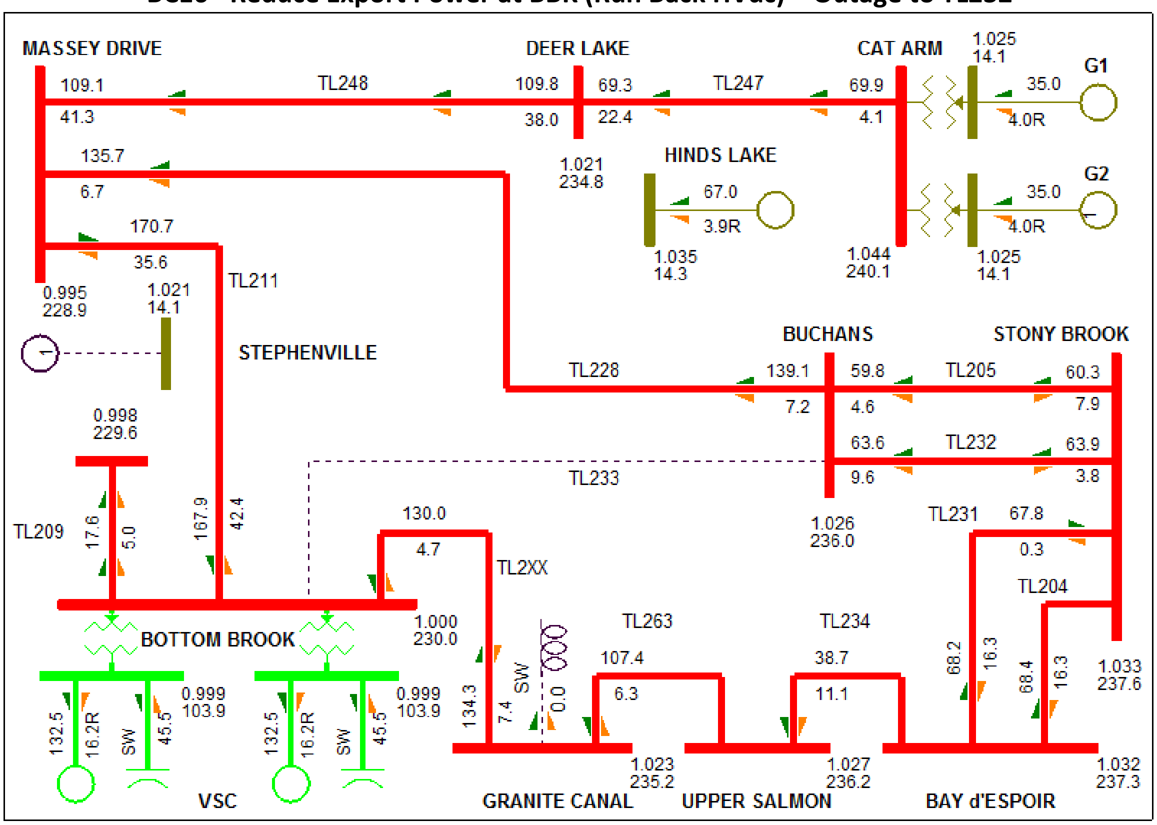
BC16 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL211



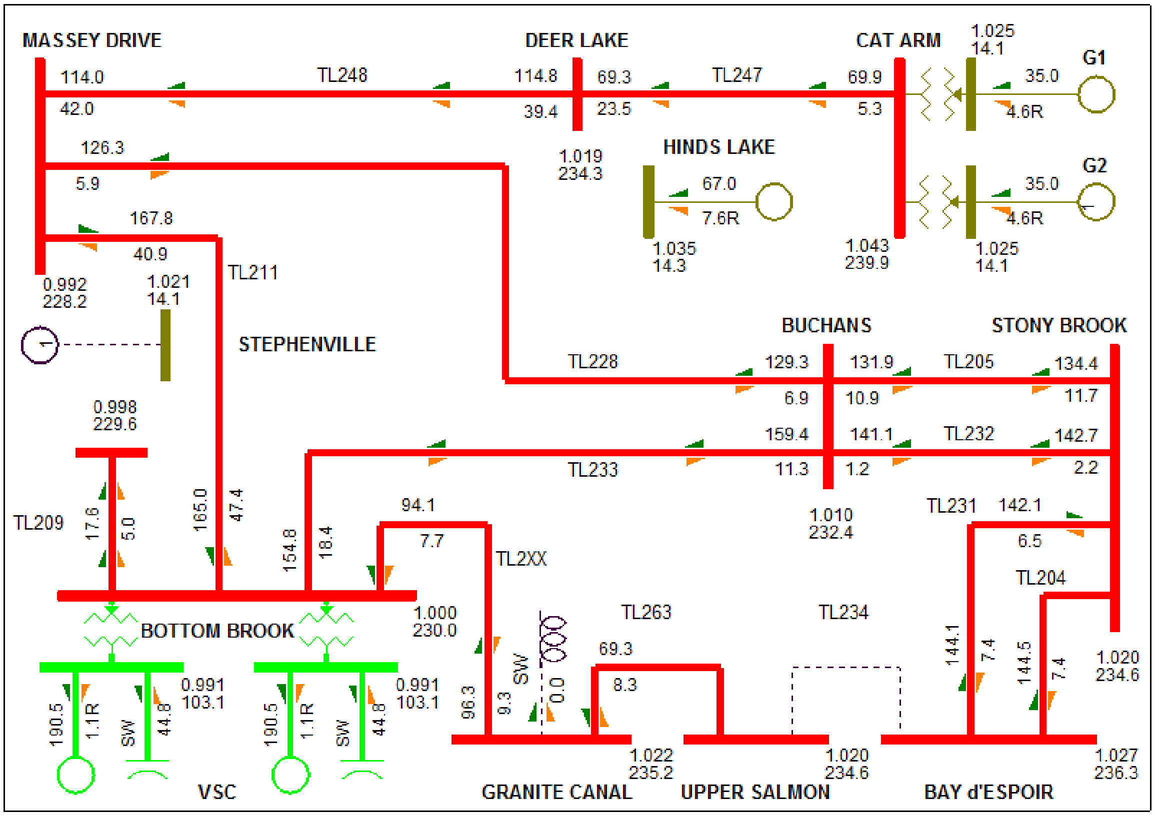
BC16 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL228



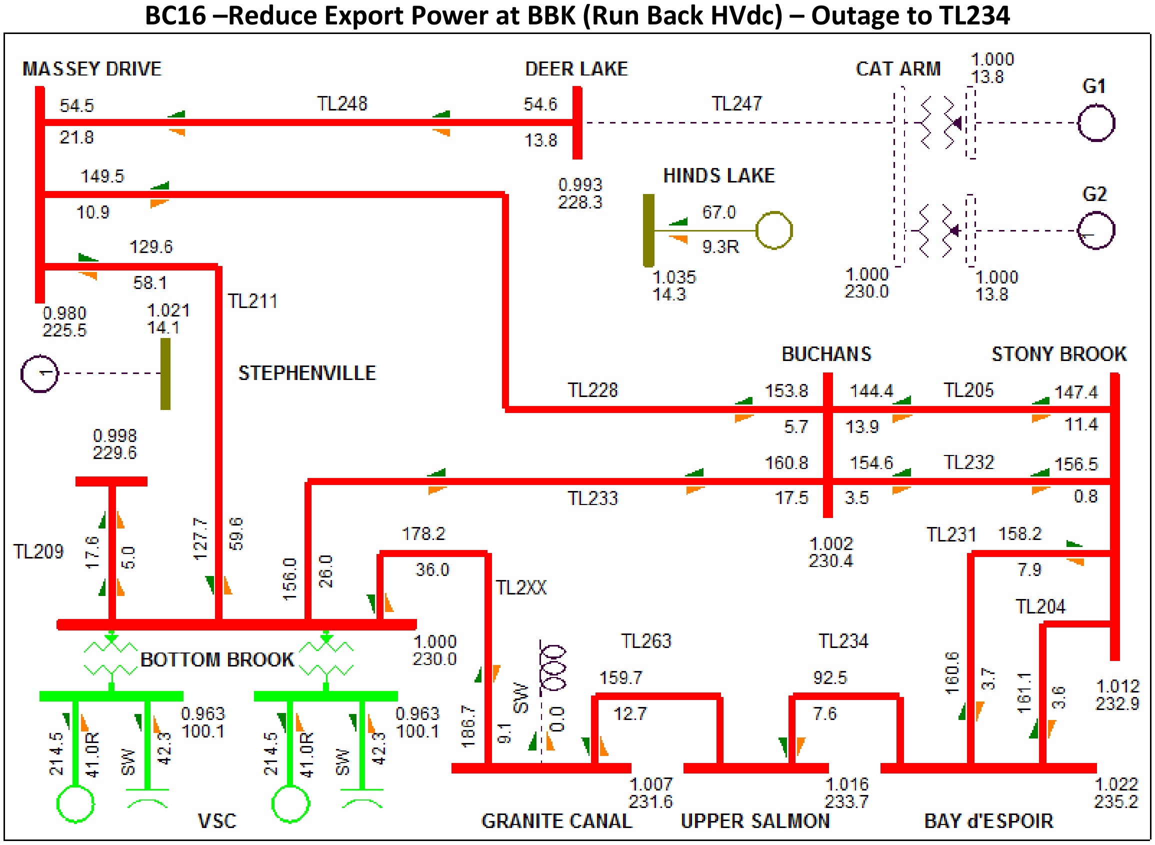
BC16 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL232



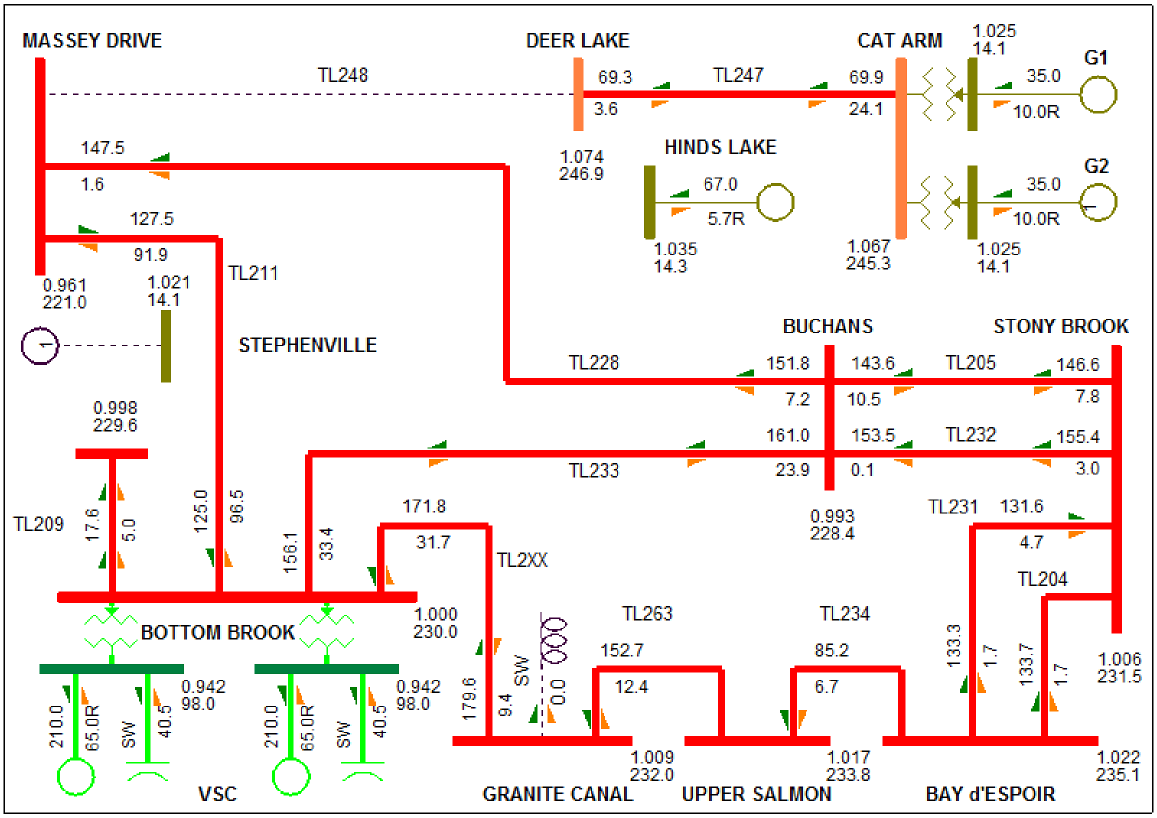
BC16 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL233



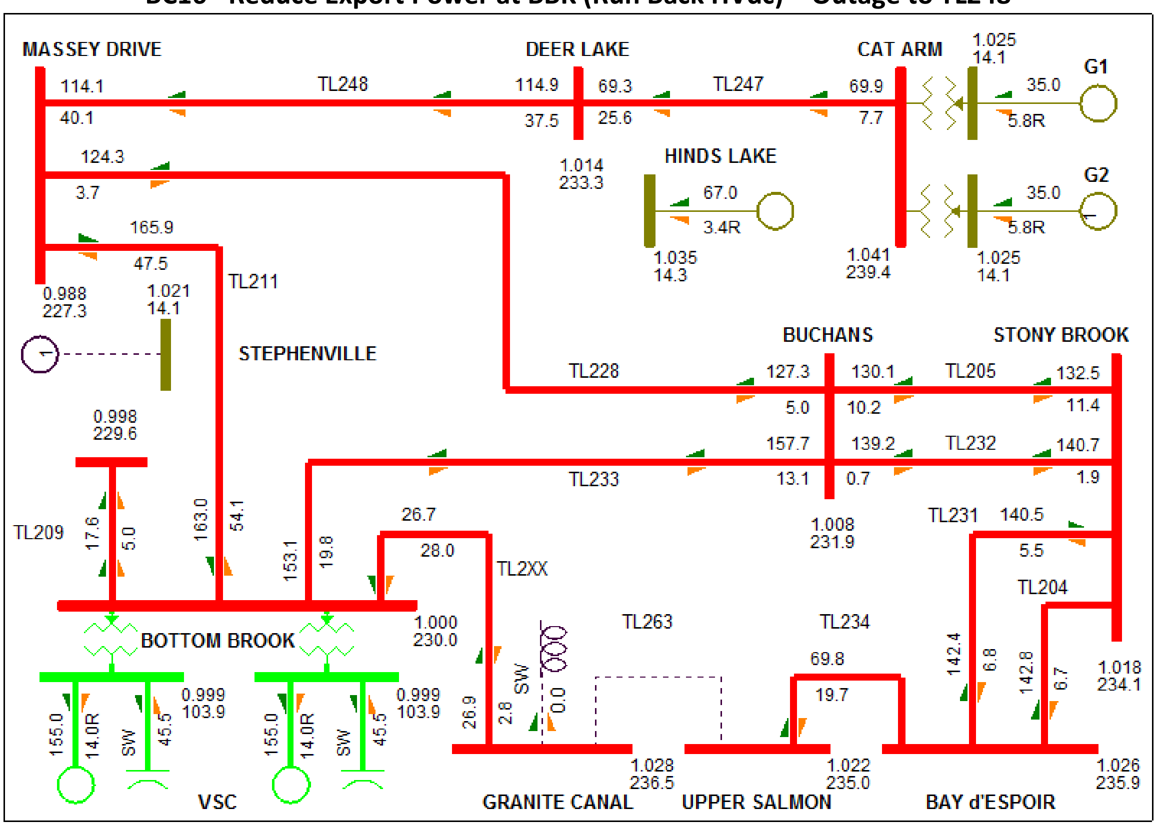
BC16 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL234



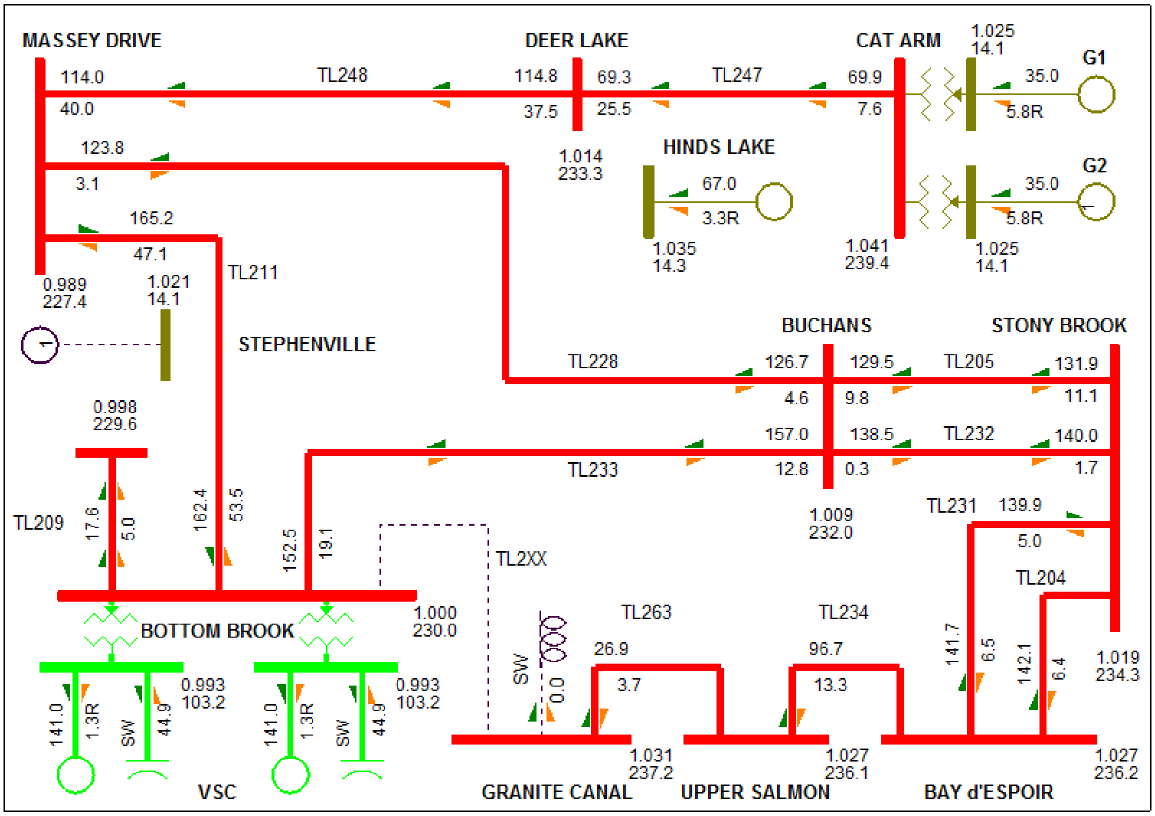
BC16 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL247



BC16 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL248



BC16 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL263



BC16 –Reduce Export Power at BBK (Run Back HVdc) – Outage to TL2XX

APPENDIX B

MARITIME LINK PRELIMINARY INTERCONNECTION STUDY (JULY 2014) – RELEASED AUGUST 13, 2014

Approved for Release	August 13, 2014 Date

MARITIME LINK
PRELIMINARY INTERCONNECTION STUDY

Newfoundland and Labrador Hydro

July 2014

newfoundland labrador hydro
a nalcor energy company

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1. INTRODUCTION

On November 29, 2013, the Nova Scotia Utility and Review Board approved the Maritime Link Project. The Maritime Link (ML) requires the construction of a ± 200 kV, 500 MW HVdc transmission link between Bottom Brook Terminal Station (BBK) in western Newfoundland and Woodbine Substation in Cape Breton, Nova Scotia. In addition, Emera Newfoundland Limited (ENL), the owner of ML, will be constructing a new 230 kV transmission line between Granite Canal Terminal Station (GCL) and BBK to provide sufficient transfer capacity for the ML.

This report provides the results of a preliminary system planning study undertaken by Newfoundland and Labrador Hydro (Hydro). The objective of the study is to assess the interconnection of the ML to the Island-Interconnected Transmission System and to determine high-level system reinforcements and/or control schemes to ensure that the Island Interconnected System remains stable following disturbances.

The scope of the study includes the modeling and analysis of the transmission systems in both Newfoundland and Labrador with equivalent system representations in Nova Scotia and Quebec. The study includes an analysis of system stability during transient events with consideration of reactive power requirements for the ML.

The study builds on the steady-state and load flow analysis completed by Hydro’s System Planning Department: “Bottom Brook VSC Export Limits – Maritime Link Runback Summary”, completed in 2013.

The transient stability analysis was completed using Version 32 of PSS®E software from Siemens PTI.

2. ASSUMPTIONS

The analysis was performed using the following assumptions:

1. The Labrador-Island Link (LIL) is in service, along with all prerequisite upgrades to the Island Interconnected Transmission System, including:
    - A new 230 kV transmission line between Bay d'Espoir Terminal Station (BDE) and Western Avalon Terminal Station (WAV).
    - A new 230 kV transmission line between GCL and BBK.
    - A new 60 MW gas turbine is available at Holyrood (HRD) and is in service as a synchronous condenser. The generator is equivalent to a Brush BDAX 8-445ER.
    - Three 175 MW high-inertia synchronous condensers (HISCs) are in service at Soldiers Pond (SOP). For the purposes of this investigation, it is assumed that one of the three units is offline for maintenance[1].

2. Reserve for the Island Interconnected Transmission System is available either on the Island or in Labrador. The full capacity of the LIL available in response to transient events. When operating as a bipole, each pole can be adjusted to provide a power flow in the range between 45 MW and 450 MW. When operating as a monopole, power flow over the pole can be adjusted to anywhere in the range between 45 MW and 900 MW.

3. During transient events, the ML may be tripped to avoid instability or underfrequency load shedding within the Island Interconnected Transmission System.

4. There shall be no underfrequency load shedding for loss of a pole on the LIL while operating as a bipole. Underfrequency load shedding within the Island System is acceptable for loss of a monopole. As specified in "Hydro Operating Instruction T-068 - Guideline for Unit Maximum Loading", the loss of supply should not result in the loss of load set to trip at 58.0 Hz.

[1] It is assumed that all three HISCs are in service when the LIL is in monopole operation or in "future peak" cases.

5. Following a temporary pole fault on the LIL, full power on that pole can be restored within 300 ms.

6. The ML has a specified reactive power limit of 125 MVAR per pole. At Bottom Brook.

3. SYSTEM PLANNING CRITERIA

The following list is provided as summary of Hydro's Transmission Planning Practices as accepted by the Public Utilities Board:

- Hydro's bulk transmission system[2] is planned to be capable of sustaining the single contingency loss of any transmission element without loss of system stability;
- In the event a transmission element is out of service, power flow in all other elements of the power system should be at or below normal rating;
- The Hydro system is planned to be able to sustain a successful single pole reclose for a line to ground fault based on the premise that all system generation is available;
- Transformer additions at all major terminal stations (i.e. two or more transformers per voltage class) are planned on the basis of being able to withstand the loss of the largest unit;
- For single transformer stations there is a back-up plan in place which utilizes NLH's and/or Newfoundland Power's mobile equipment to restore service;
- For normal operations, the system is planned on the basis that all voltages be maintained between 95% and 105%;
- For contingency or emergency situations voltages between 90% and 110% is considered acceptable; and
- For new terminal stations connected to the bulk system, Hydro's preferred bus arrangement is a breaker-and-one-half scheme. Where there are a limited number of elements, a ring bus arrangement is acceptable.

[2] Hydro's bulk transmission system on the Island of Newfoundland is generally considered to be the 230 kV transmission system and the underlying 138 kV transmission loops between connection points on the 230 kV system including Western Avalon to Holyrood and Deer Lake-Stony Brook-Sunnyside.

For analysis of the Island Interconnected Transmission System with the HVdc connection to Labrador included, the following criteria are used to assess the need for system reinforcements:

3.1. STEADY STATE ANALYSIS CRITERIA

- With a transmission element (line, transformer, synchronous condenser, shunt or series compensation device) is out of service, power flow in all other elements of the power system should be at or below normal rating;

- Transformer additions at all major terminal stations (i.e. two or more transformers per voltage class) are planned on the basis of being able to withstand the loss of the largest unit;

- For normal operations all voltages be maintained between 95% and 105%;

- For contingency or emergency situations all voltages be maintained between 90% and 110%; and

- Analysis will be conducted with one high inertia synchronous condenser out of service at Soldiers Pond.

3.2. TRANSIENT ANALYSIS CRITERIA

- System response shall be stable and well damped following a disturbance;

- System disturbances include:
    - Successful single pole reclosing on line to ground faults;
    - Unsuccessful single pole reclosing on line to ground faults;
    - Three phase faults except a three phase fault on the Bay d'Espoir 230 kV bus with tripping of a 230 kV transmission line;

- Loss of the largest generator on line on the Island System with and without fault;
- Line to ground or three phase fault with tripping of a synchronous condenser;
- Temporary pole fault;
- Permanent pole fault; and
- Temporary bipole fault.

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

- Post fault system frequencies shall not drop below 58 Hz;

- Under frequency load shedding:
  - shall not occur for loss of island generation with the HVdc link in service;
  - shall not occur for permanent loss of HVdc pole;
  - shall not occur for a temporary bipole outage; and
  - shall be controlled for a permanent bipole outage.

- There shall be no commutation failures of the HVdc link during post fault recovery.

4. BASE CASES

Analysis was performed using system models that were developed for LIL integration studies. These models reflect system conditions where the Island Transmission System is interconnected to Labrador via the LIL and to Nova Scotia via the ML.

In the base cases, the LIL was modeled using the PSS®E CDC4T Line-Commutated Converter (LCC) model with a PAU1XT frequency controller. The ML was modeled as a Voltage Source Converter (VSC) system using Version 1.1.10 of the HVdc Light Open Model from ABB.

Eleven base cases were considered for this analysis. The base cases were developed to assess the impacts of the following system variations:

1. System loading conditions (i.e. heavy, intermediate, light, and extreme light)
2. Island dispatch (i.e. maximum generation, economic dispatch, or minimum generation)
3. Import to the Island Transmission System over the LIL (i.e. 0 MW to 830 MW)
4. Export over the ML (i.e. 0 MW to 500 MW)

The base cases are listed in Table 1. Load flow plots for the base cases are provided in Appendix A.

Table 2 provides the Hydro's Island Interconnected System generation capacities used in preparing the base cases.

Table 1 – Base Case Scenarios

Case	System Condition	Island Load (MW)	LIL Mode	LIL Power (MW)	Island Generation	ML Mode	ML Power (MW)
BC1	Heavy Load	1757	Bipole	830	1085	Bipole	158
BC2	Heavy Load	1588	Bipole	830	915	Bipole	158
BC3	Heavy Load	1594	Bipole	676	1075	Bipole	158
BC4	Heavy Load	1471	Monopole	396	1258	Bipole	182
BC5[3]	Heavy Load	1500	Offline	0	1258	Bipole	-250
BC6	Heavy Load	1415	Bipole	830	1085	Bipole	500
BC7	Intermediate Load	1261	Bipole	830	931	Bipole	500
BC8	Intermediate Load	1261	Bipole	676	1085	Bipole	500
BC9	Light Load	700	Bipole	830	370	Bipole	500
BC10	Light Load	700	Monopole	550	650	Bipole	500
BC11	Extreme Light Load	400	Bipole	415	335	Bipole	350

[3] Base Case 5 represents an extreme condition where the LIL bipole is out of service. Transient stability analysis was not performed for this mode of operation.

Table 2 - Hydro System Capability

Source	**Rated Capacity (MW)**	**Comments**
Hydro		
Bay d'Espoir	604	Bay d'Espoir generation is calculated as 6 x 75 MW + 1 x 154 MW. Units 1 to 6 at Bay d'Espoir have a sustained capacity of 73 MW per unit and a peak capacity of 75 MW. (6 x 73 + 154 = 592 MW)
Cat Arm	127	2 x 63.5 MW
Upper Salmon	84	
Hinds Lake	75	
Granite Canal	40	
Paradise River	8	
Snook's, Venam's, Roddickton	0	For load flow analysis, the value of generation is netted out with load that it supplies
Subtotal Hydro	938	
Non-Utility/PPA		
Star Lake	15	Nameplate rating
Exploits	90.8	Grand Falls + Bishop's Falls

Corner Brook Cogen	15	
Rattle Brook	4	
St. Lawrence Fermeuse	11 11	The wind farms are not considered in capacity planning due to the variability of wind but are included in this analysis to assess transient response of the wind farms to system contingencies. For the purposes of this investigation, wind farms are generating at approximately 40% of rated capacity.
Subtotal NUG/PPA	146.8	
Total capacity	1084.8 (1085)	
Standby Generation		
Hardwoods CT	50	
Stephenville CT	50	
Hawke's Bay Diesel	5	
St. Anthony Diesel	9.7	
Total Standby capacity	114.7	
Spinning Reserve Requirement	154	Largest unit on system with Holyrood offline

5. RESULTS OF DYNAMIC ANALYSIS

The transient stability of a transmission system refers to its ability to maintain synchronism following a severe disturbance such as a fault. For the purposes of this investigation, base cases were subjected to the disturbances listed in Appendix B.

It was found that a subset of the contingencies resulted in undesirable system performance such as instability, underfrequency load shedding (UFLS), or other violations to System Planning Criteria. These contingencies are categorized as follows:

1. Faults at Bay d'Espoir
2. Ac Transmission Line Faults in Western Newfoundland
3. Temporary Bipole Faults
4. Permanent Pole Faults
5. Loss of Generation within the Island System
6. Loss of a Synchronous Condenser at Soldiers Pond

These cases are described in the sections below.

5.1. FAULTS AT BAY D'ESPOIR

In peak load cases with maximum generation online within the Island Interconnected System, faults at BDE result in system instability. The scenarios are summarized in Table 3.

Table 3 – Notable System Conditions Following Faults at BDE

Base Case	Contingency	System Condition
Base Case 1	Fault at BDE, Trip of TL202	Instability
Base Case 1	Fault at BDE, Trip of TL204	Instability
Base Case 1	Fault at BDE, Trip of TL234	Instability
Base Case 1	Fault at BDE, Trip of Unit	Instability
Base Case 3	Fault at BDE, Trip of TL202	Instability
Base Case 3	Fault at BDE, Trip of TL204	Instability
Base Case 3	Fault at BDE, Trip of TL234	Instability
Base Case 3	Fault at BDE, Trip of Unit	Instability

It should be noted that faults at Bay d'Espoir have been classified as "exceptional contingencies" and it has been accepted that their occurrence under heavy load conditions may lead to instability. Detailed analysis of these faults is beyond the scope of this investigation. Some examples of instability due to BDE faults are provided in the figures below.

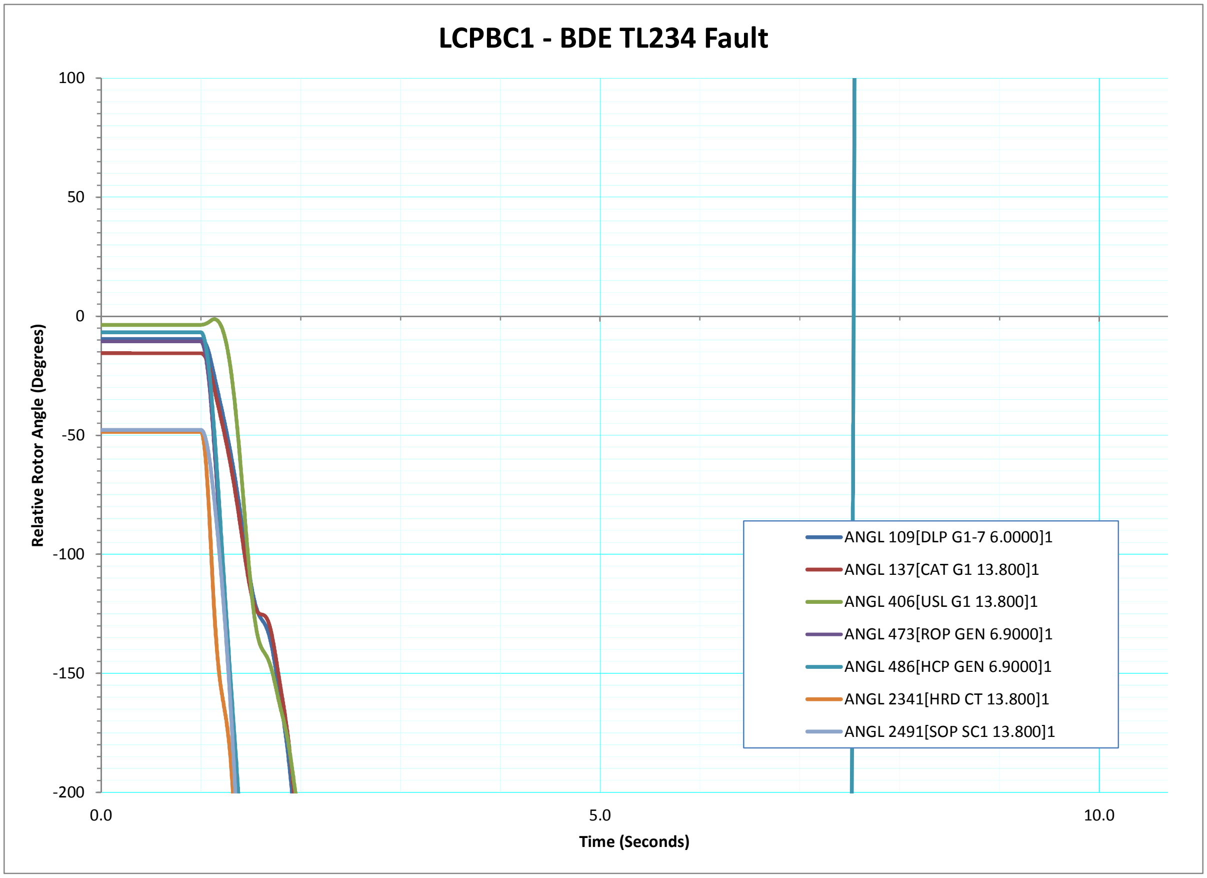


Figure 1 - LCPBC1 - BDE TL234 Fault - Relative Rotor Angle (Degrees)

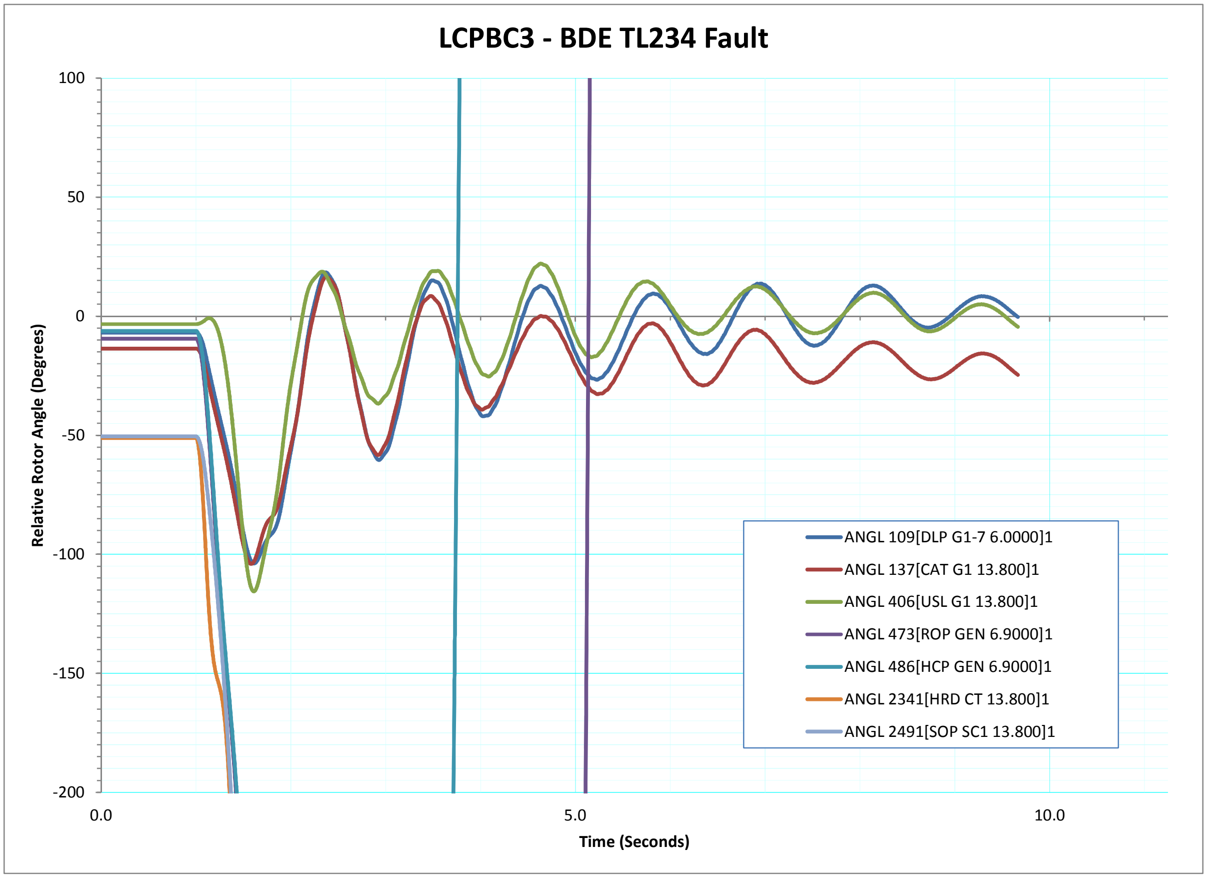


Figure 2 - LCPBC3 - BDE TL234 Fault - Relative Rotor Angle (Degrees)

5.2. AC TRANSMISSION LINE FAULTS IN WESTERN NEWFOUNDLAND

Transient analysis indicates that ac faults at selected terminals stations in western Newfoundland will cause the reactive power output of the VSC converter in BBK to exceed the specified limit of 125 MVAR per pole. This was found to be the case in load flow scenarios where the ML was operating at its rated output of 500 MW. A list of these scenarios is provided in Table 4 and illustrated in the figures below.

Analysis was performed to investigate the impact of curtailing the ML export to 250 MW in the event of these faults. The results of this analysis indicate that curtailing ML export reduces the reactive power output below specified limits in all cases. Transient stability plots of the cases with curtailed ML export are provided in Appendix C.

Table 4 – Terminal Stations Where Ac Transmission Line Faults Result in ML Reactive Power Limit Violations[4]

Terminal Station
Bottom Brook
Buchans
Granite Canal
Massey Drive
Stony Brook
Upper Salmon

[4]These violations occur in Base Cases 6, 7, 8, 9, and 10. The ML is operating at its rated output of 500 MW in these cases.

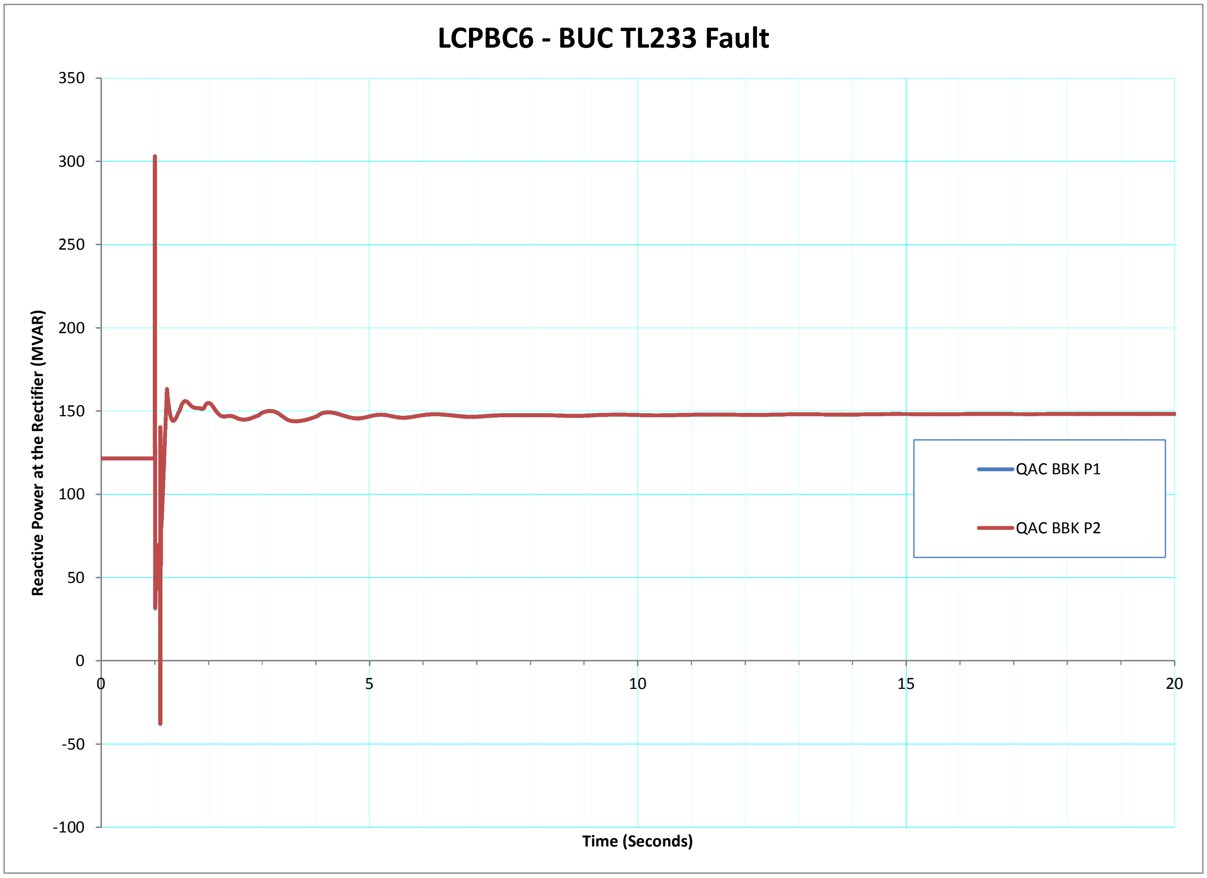


Figure 3 - LCPBC6 - BUC TL233 Fault - Reactive Power at the Rectifier (MVAR)

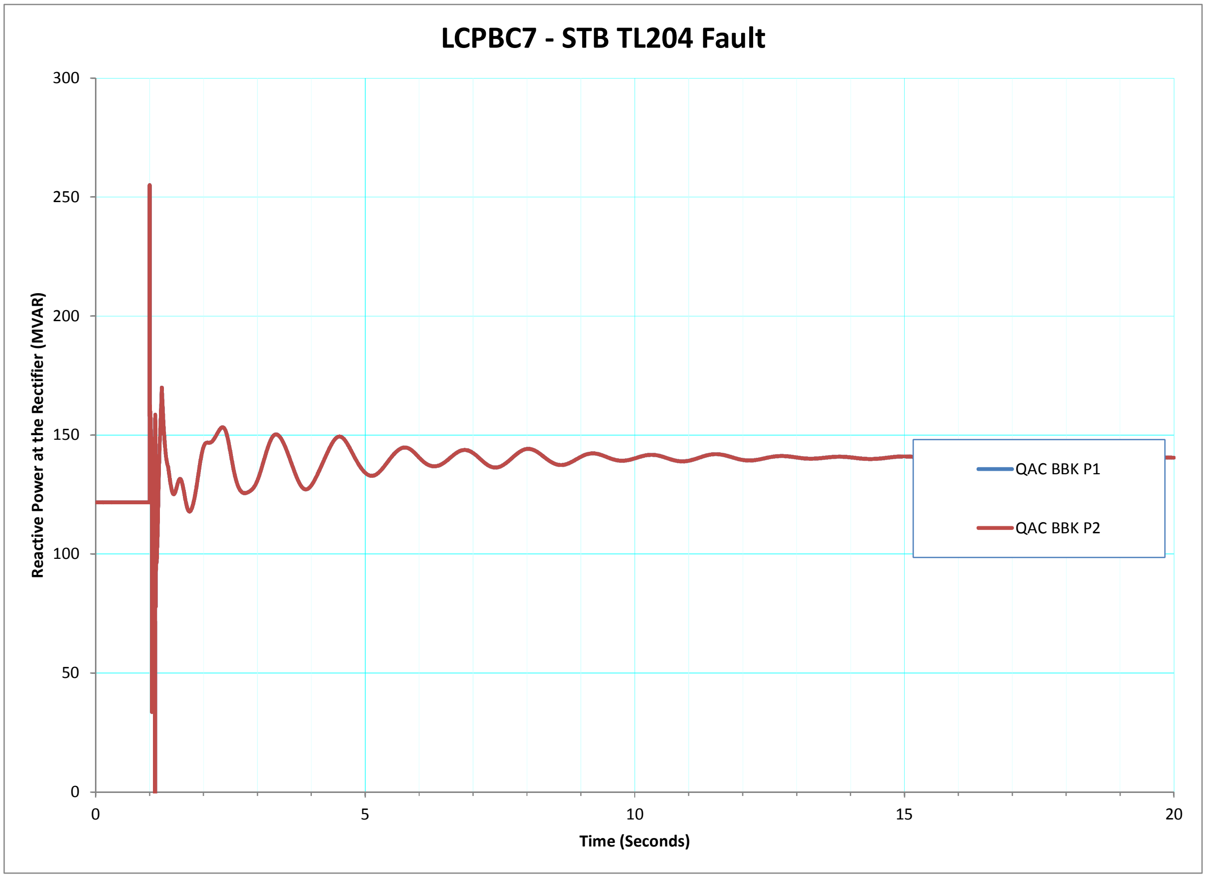


Figure 4 - LCPBC7 - STB TL204 Fault - Reactive Power at the Rectifier (MVAR)

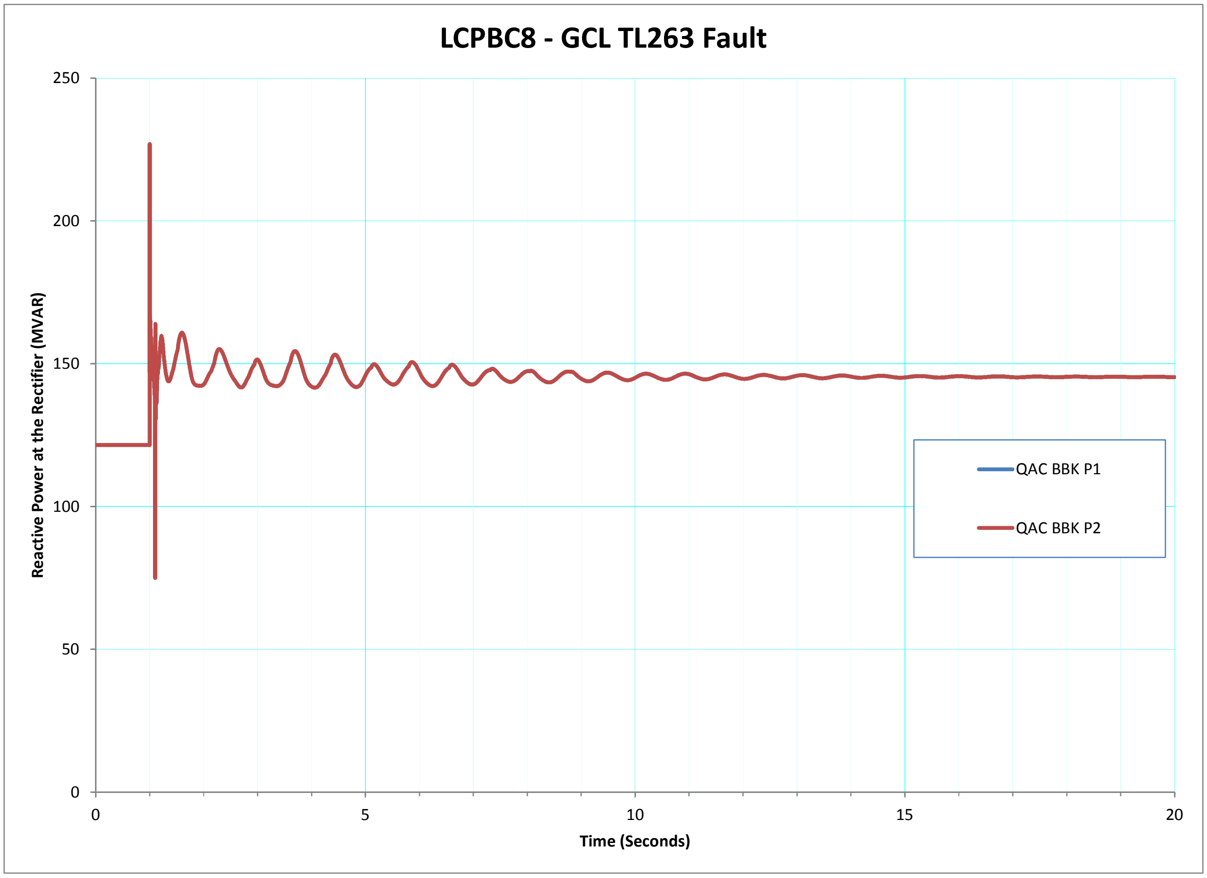


Figure 5 - LCPBC8 - GCL TL263 Fault - Reactive Power at the Rectifier (MVAR)

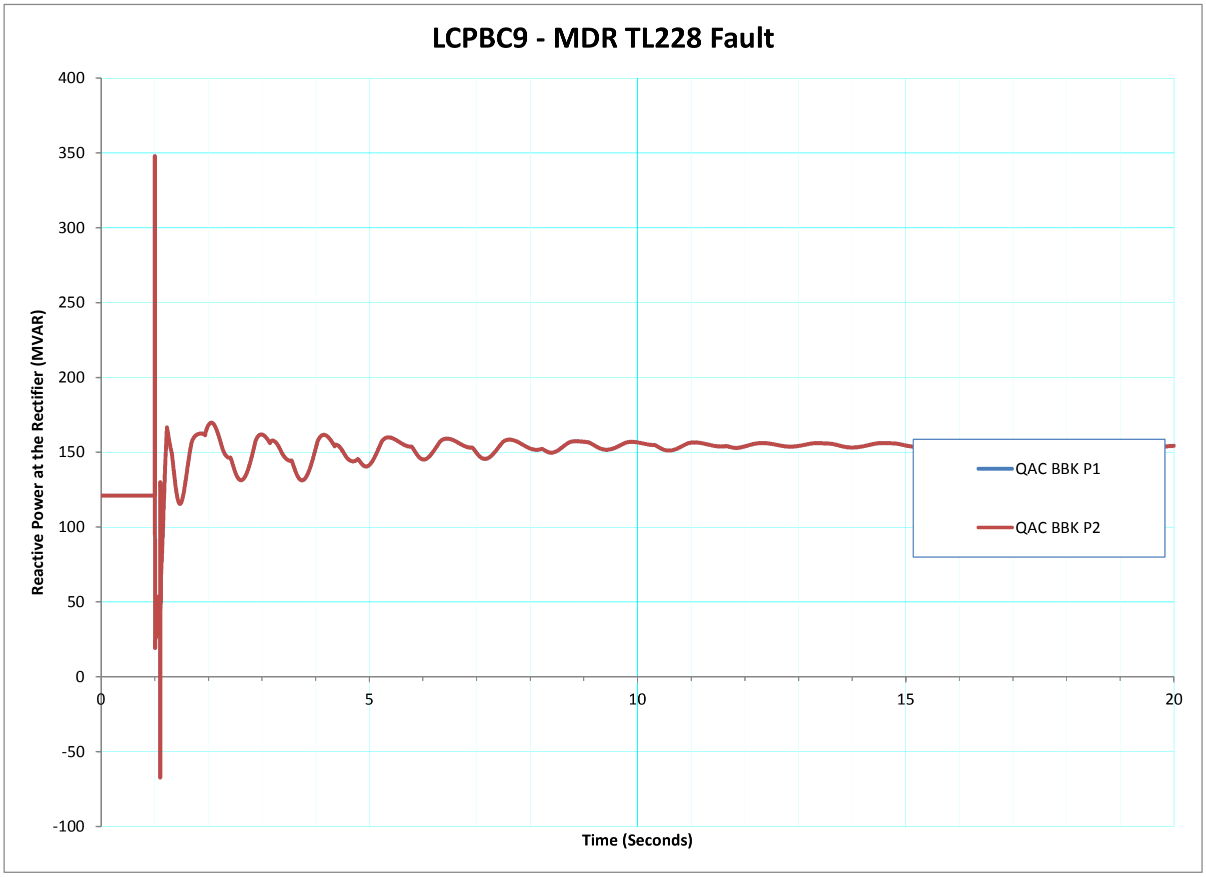


Figure 6 - LCPBC9 - MDR TL228 Fault - Reactive Power at the Rectifier (MVAR)

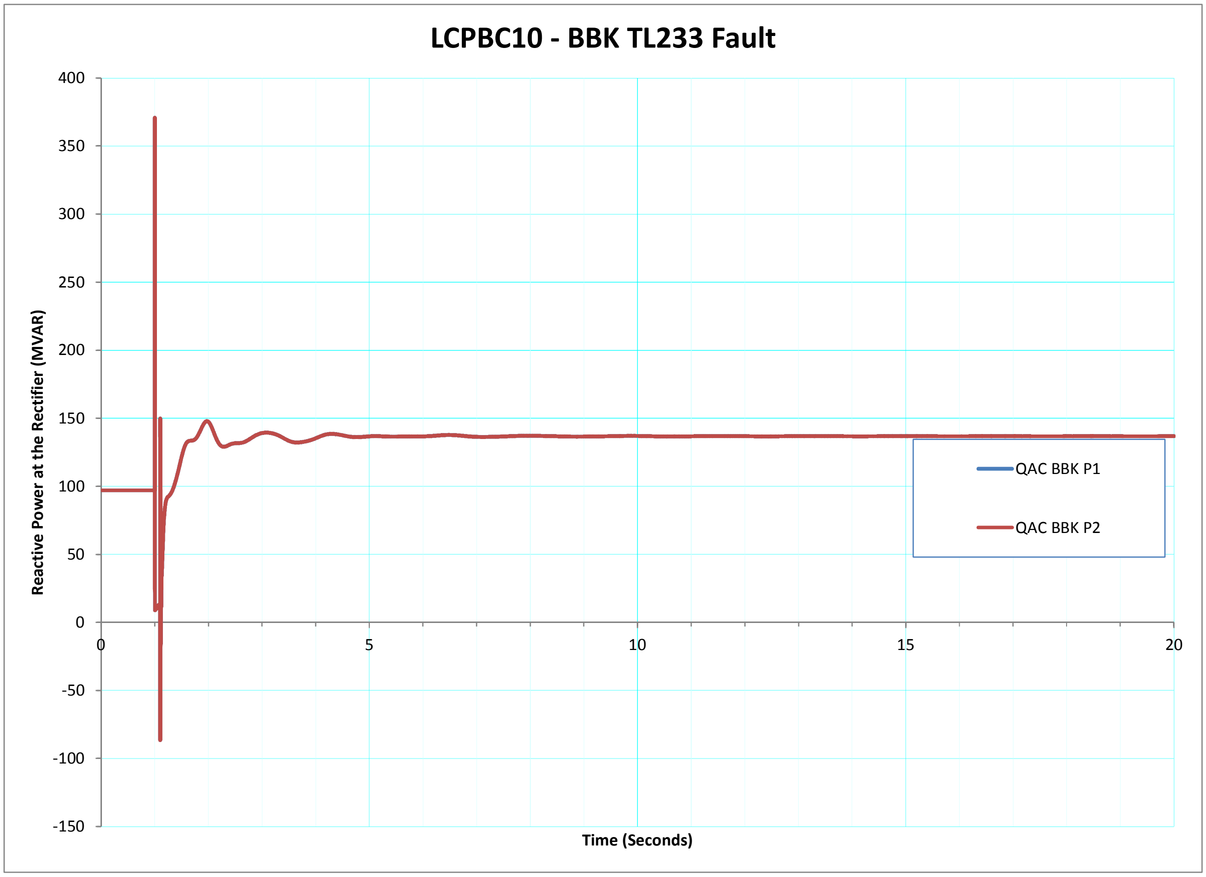


Figure 7 - LCPBC10 - BBK TL233 Fault - Reactive Power at the Rectifier (MVAR)

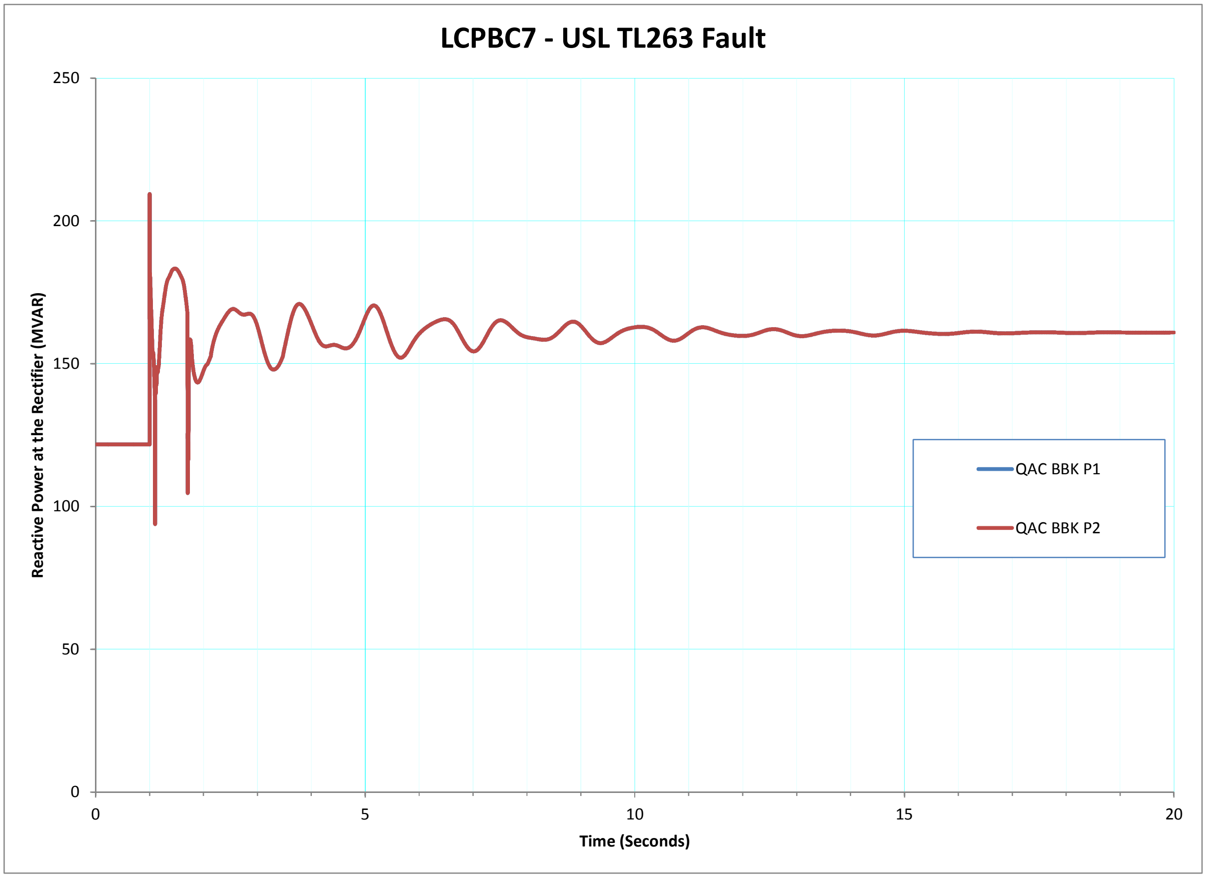


Figure 8 - LCPBC7 - USL TL263 Fault - Reactive Power at the Rectifier (MVAR)

5.3. TEMPORARY BIPOLE FAULTS

In the event of a temporary bipole fault (or a monopole fault), undesirable system conditions were found for the scenarios listed in Table 5. Plots of the system conditions are provided in the figures below.

Table 5 – Notable System Conditions Following Temporary Bipole Faults

Base Case	Contingency	System Condition
Base Case 4	Temporary Monopole Fault	LIL commutation failures
Base Case 6	Temporary Bipole Fault	UFLS
Base Case 7	Temporary Bipole Fault	UFLS
Base Case 9	Temporary Bipole Fault	UFLS
Base Case 10	Temporary Monopole Fault	LIL commutation failures

The curtailment of ML export helps to maintain system stability and to improve system performance. Appendix D contains transient stability plots demonstrating system performance in all base cases when the ML export is curtailed. In BC6 and BC7, the curtailment of ML export from 500 MW to 250 MW was sufficient to eliminate UFLS. In monopolar cases (BC4 and BC10), ML export must be curtailed to 0 MW to ensure that there are no LIL commutation failures.

It should be noted that the curtailment of ML export resulted in an undamped system response for BC9. However, this base case represents an extreme operating scenario where both the LIL and ML are operating at rated capacity while minimal generation is dispatched within the Interconnected Island System. To avoid such a response, operating limitations must be defined for the system. Such limitations will ensure that extreme operating conditions are avoided and that system performance is acceptable.

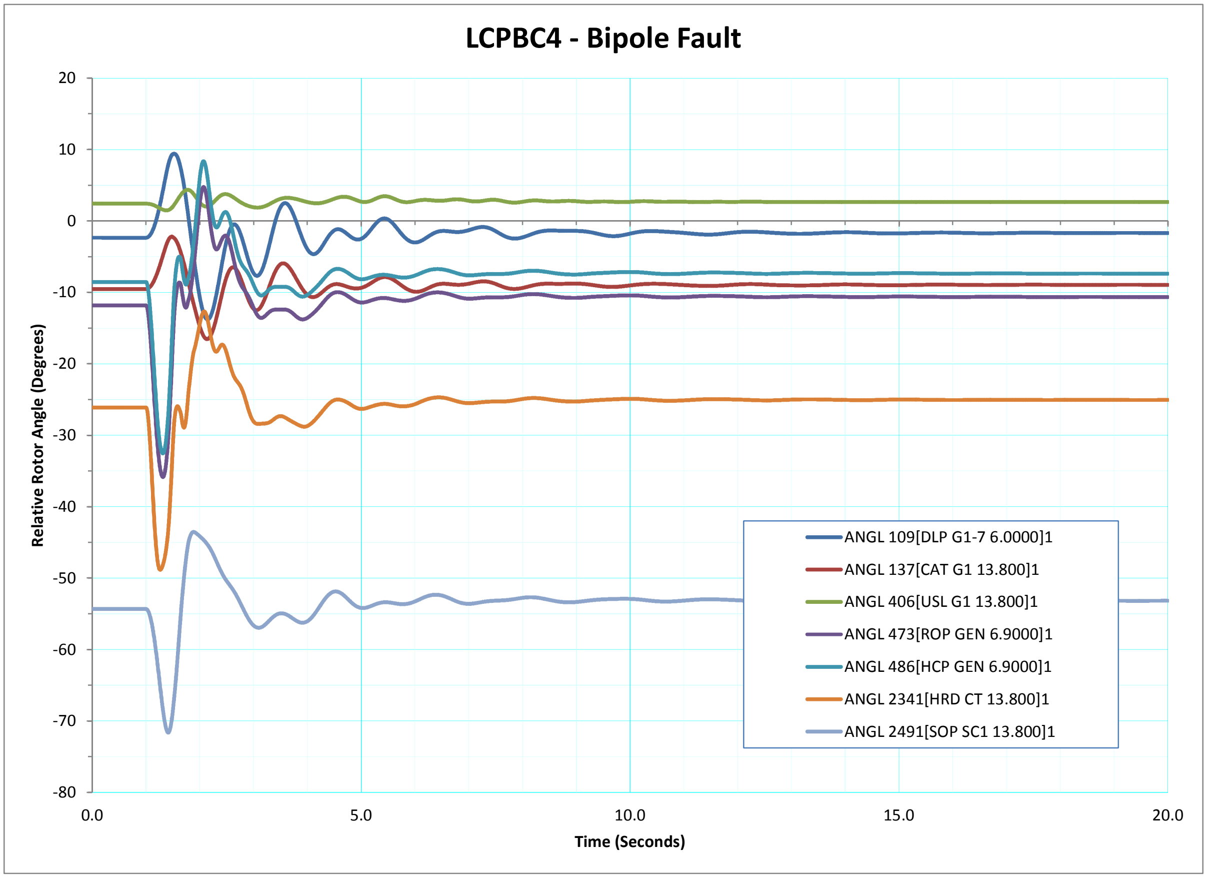


Figure 9 - LCPBC4 - Bipole Fault - Relative Rotor Angle (Degrees)

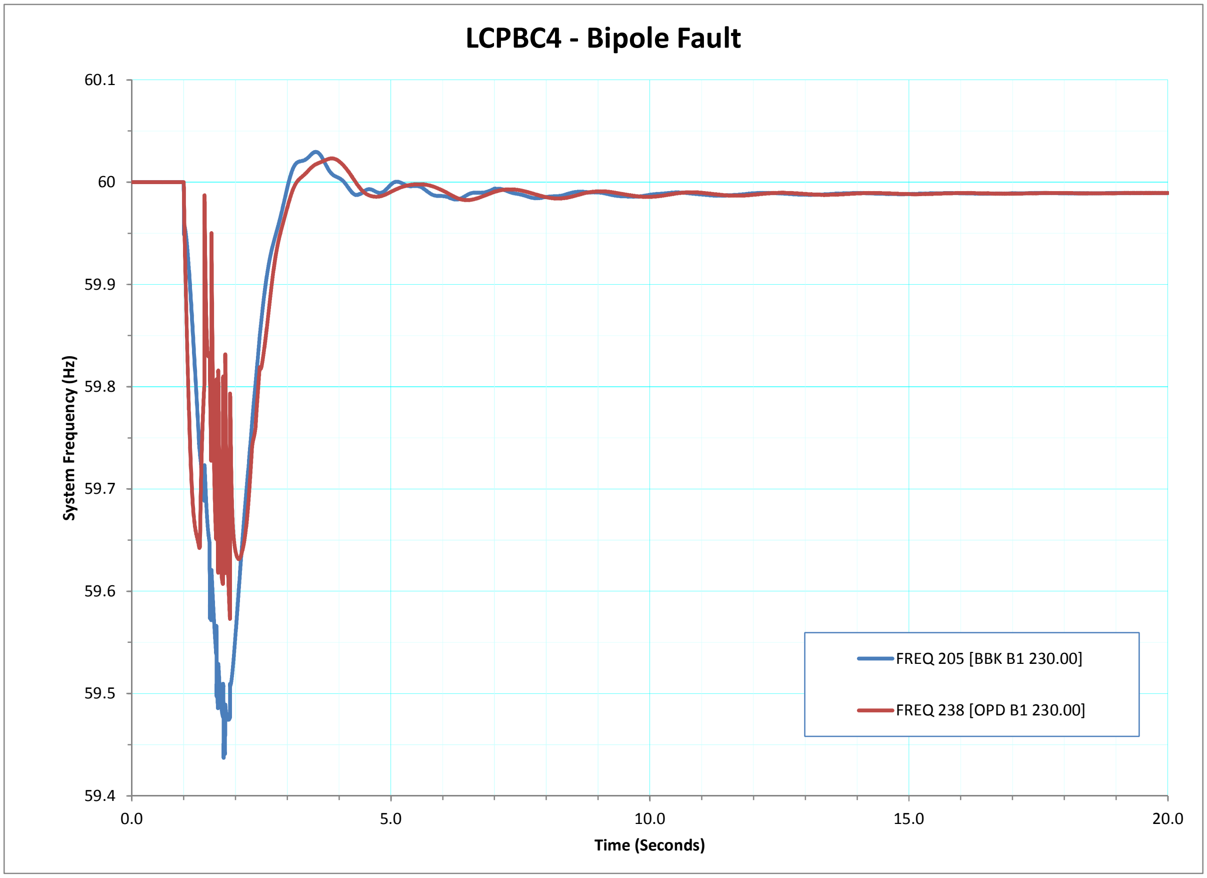


Figure 10 - LCPBC4 - Bipole Fault - System Frequency (Hz)

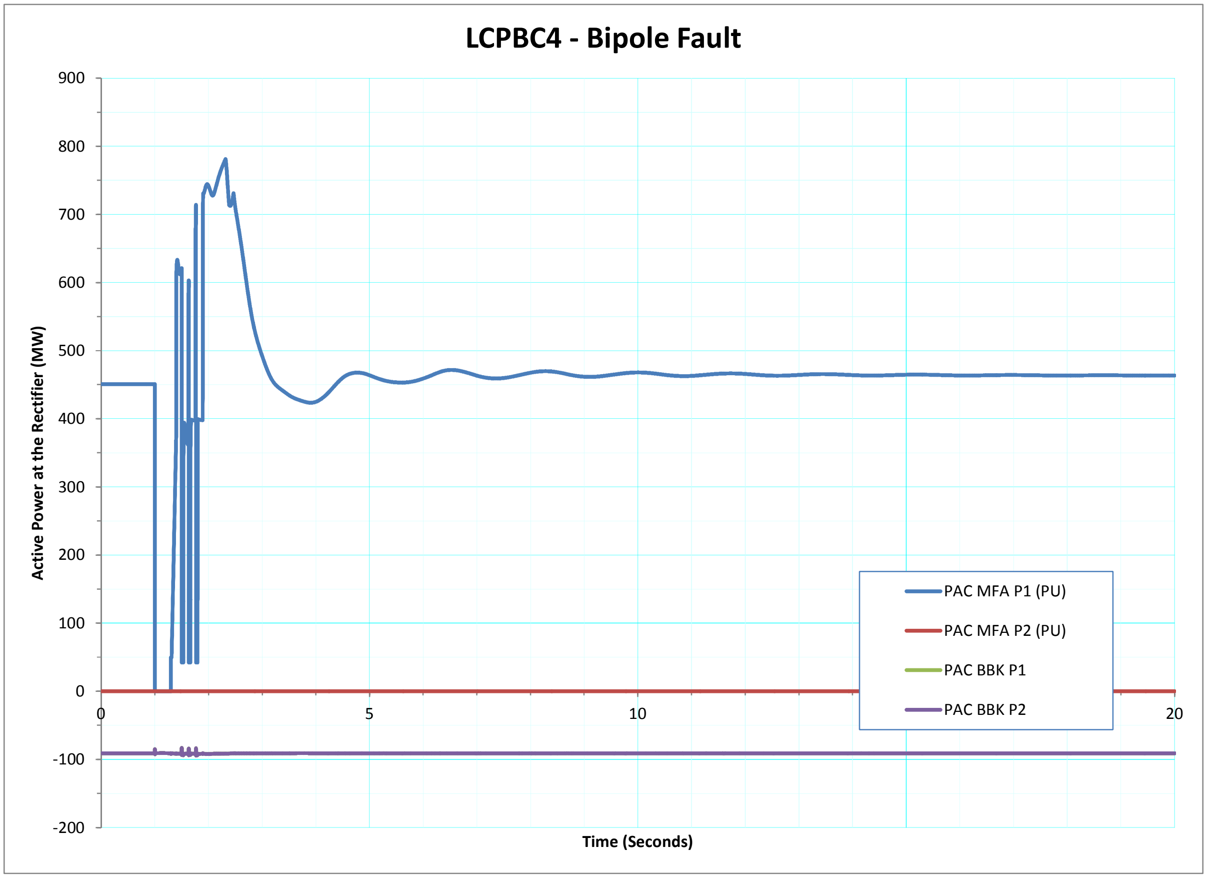


Figure 11 - LCPBC4 - Bipole Fault - Active Power at the Rectifier (MW)

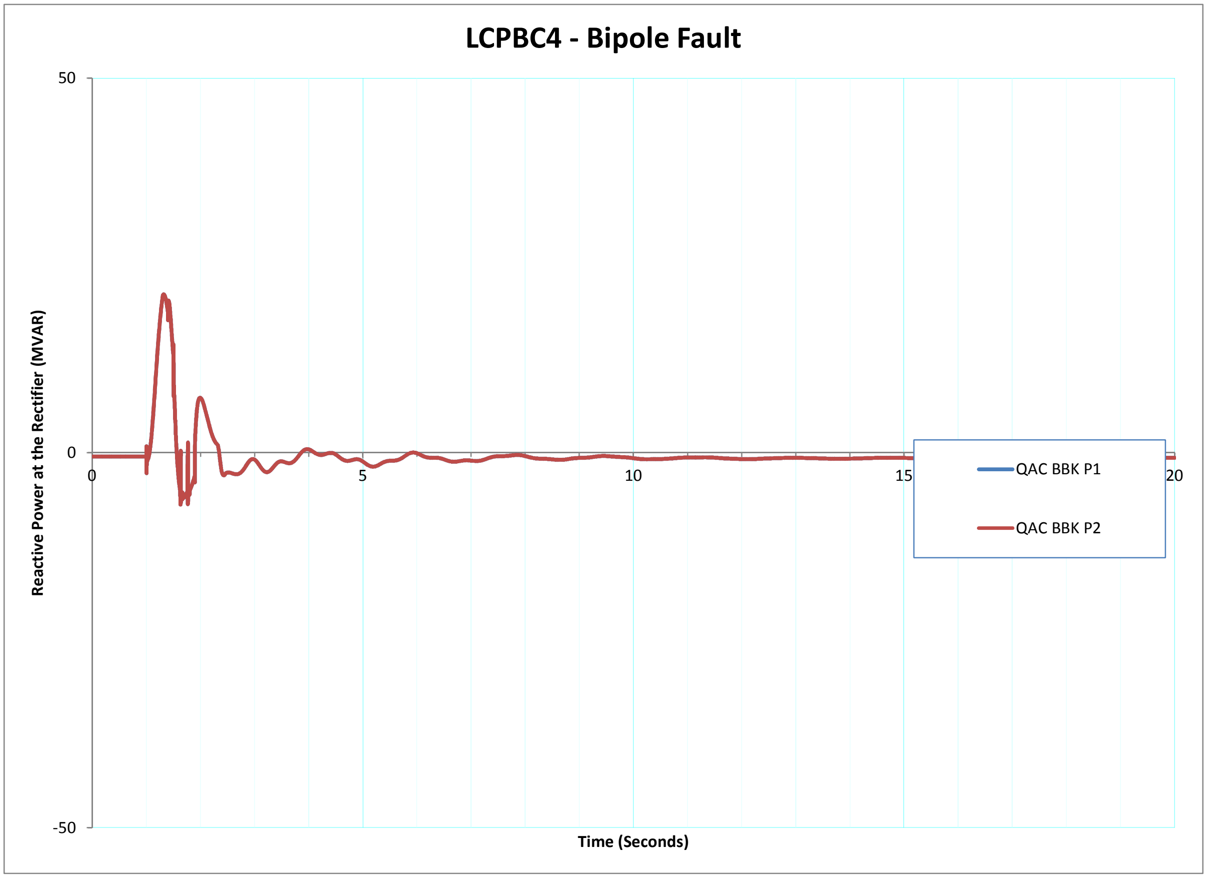


Figure 12 - LCPBC4 - Bipole Fault - Reactive Power at the Rectifier (MVAR)

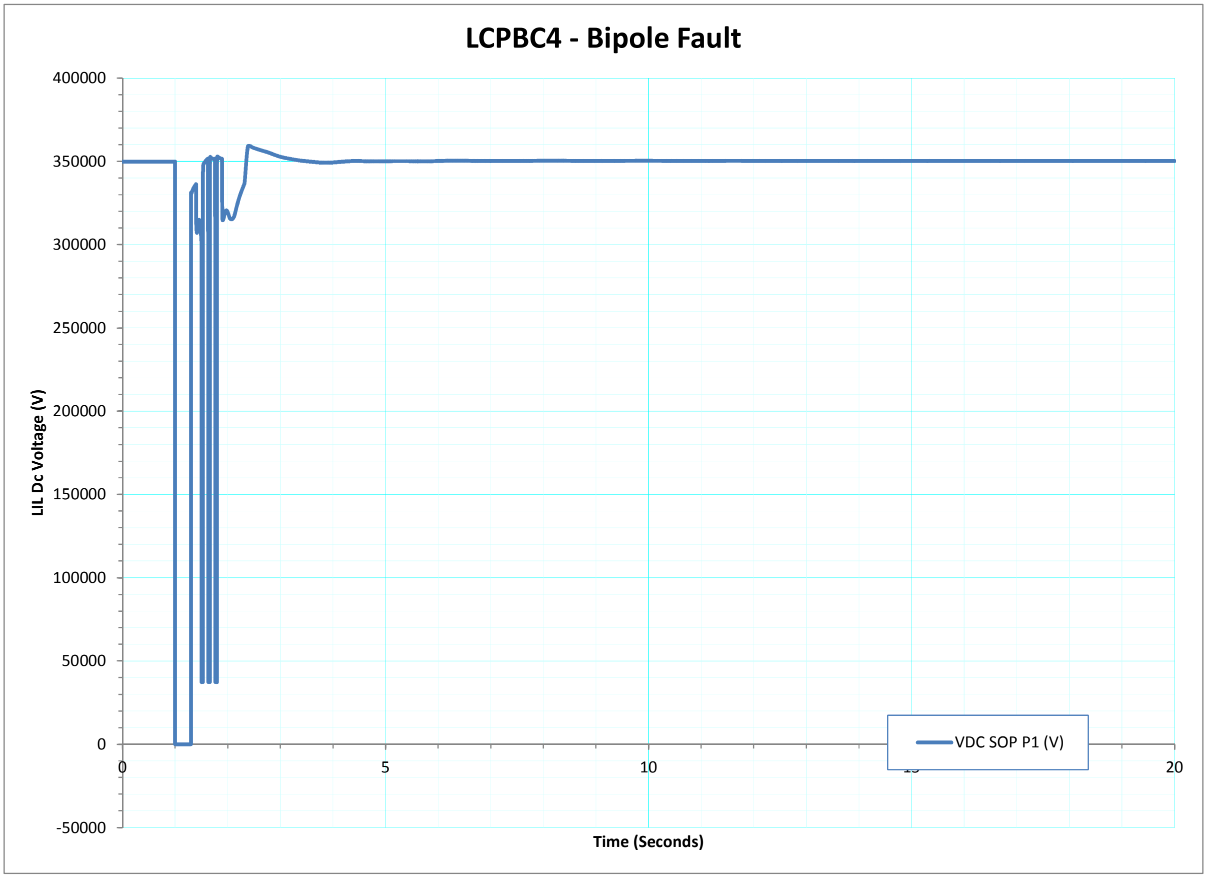


Figure 13 - LCPBC4 - Bipole Fault - LIL Dc Voltage (V)

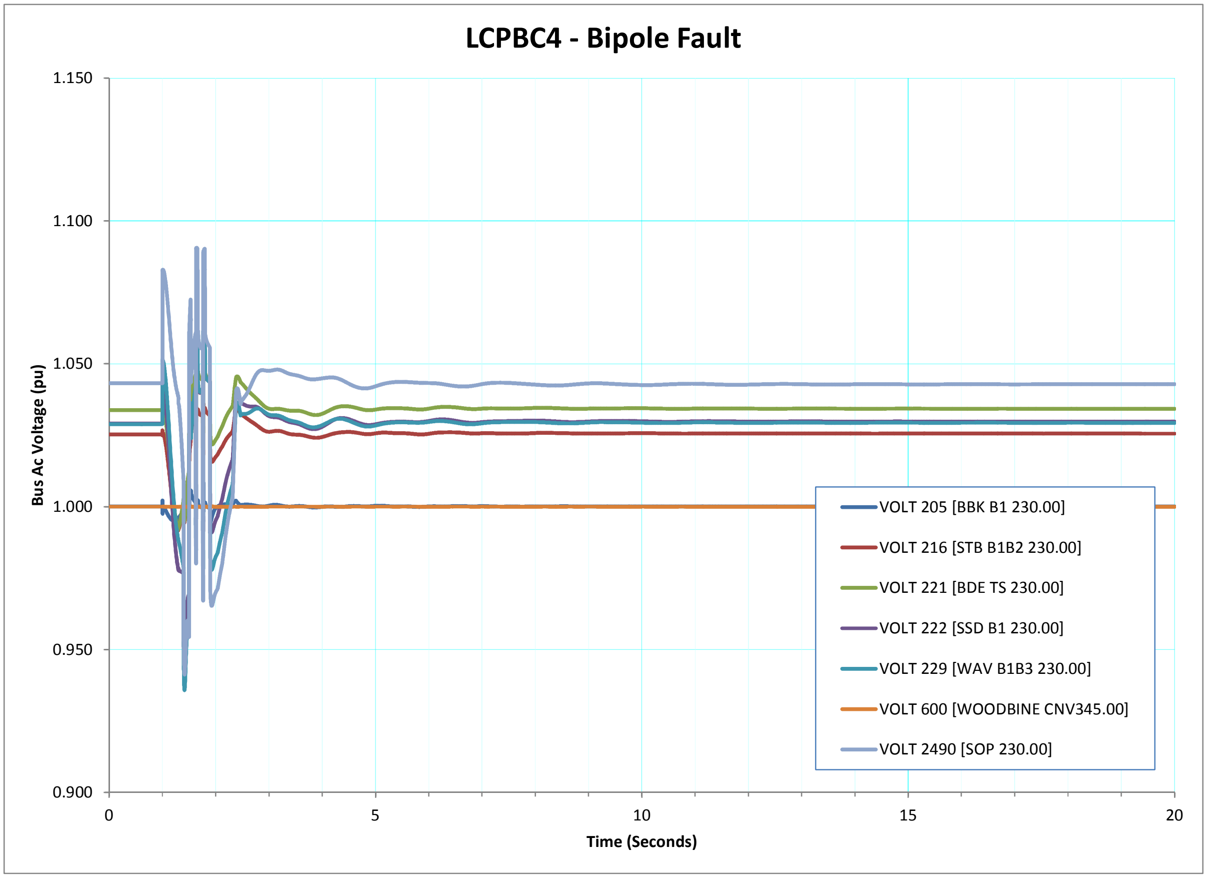


Figure 14 - LCPBC4 - Bipole Fault - Bus Ac Voltage (pu)

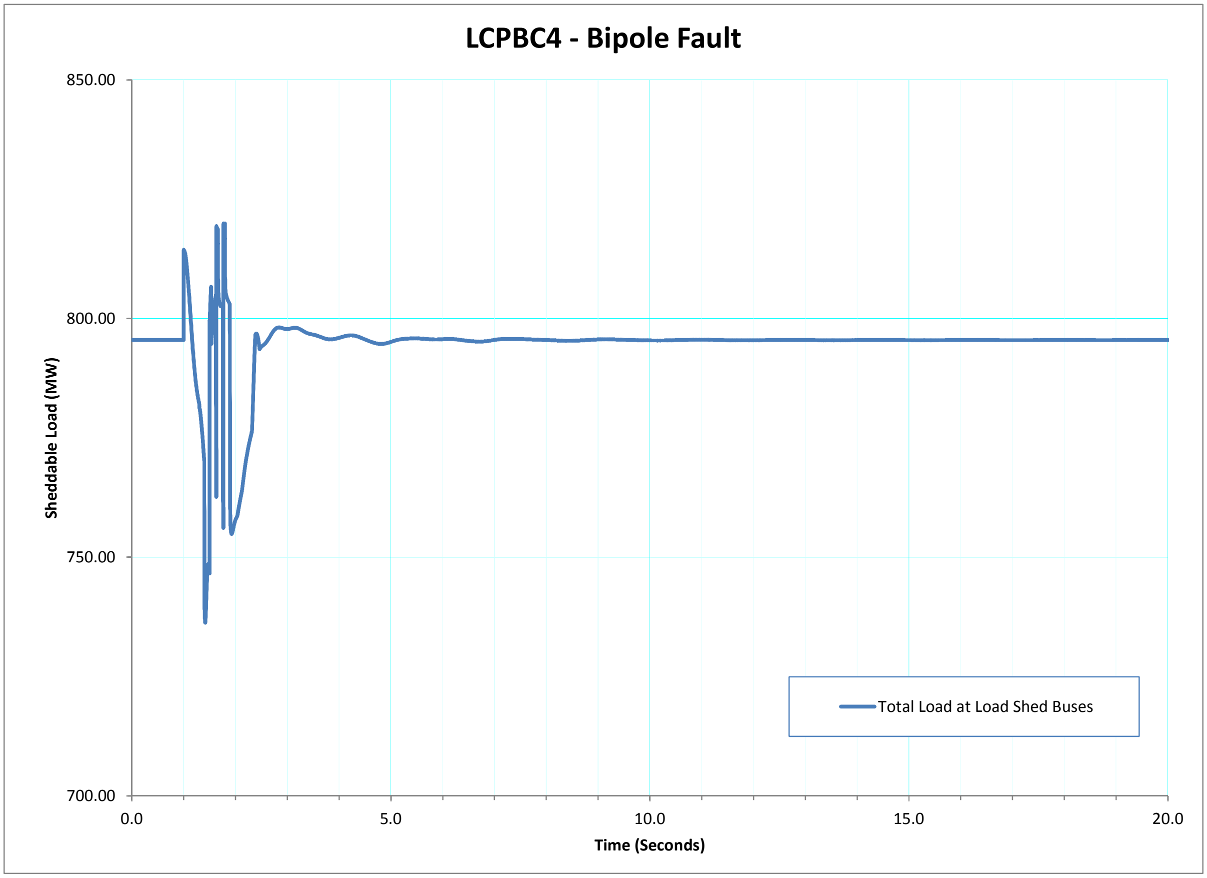


Figure 15 - LCPBC4 - Bipole Fault - Sheddable Load (MW)

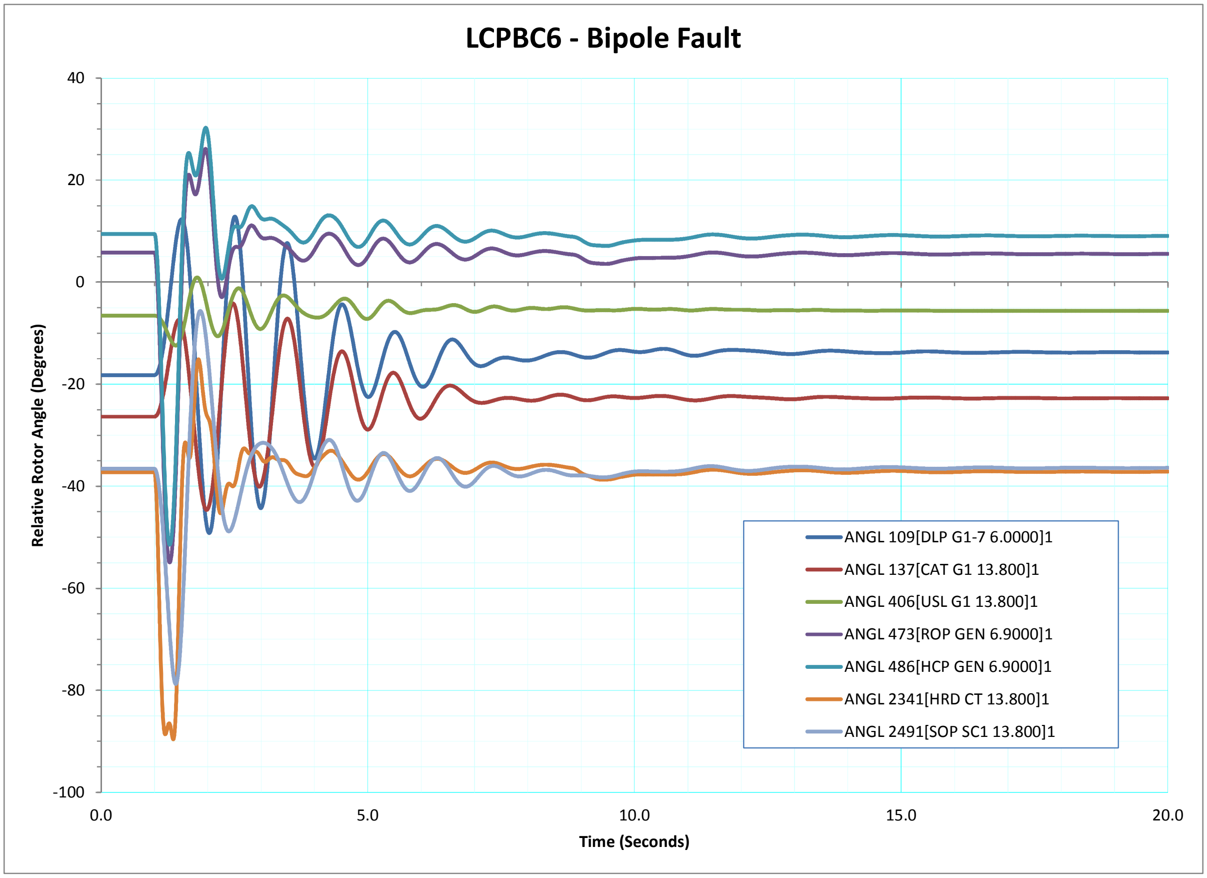


Figure 16 - LCPBC6 - Bipole Fault - Relative Rotor Angle (Degrees)

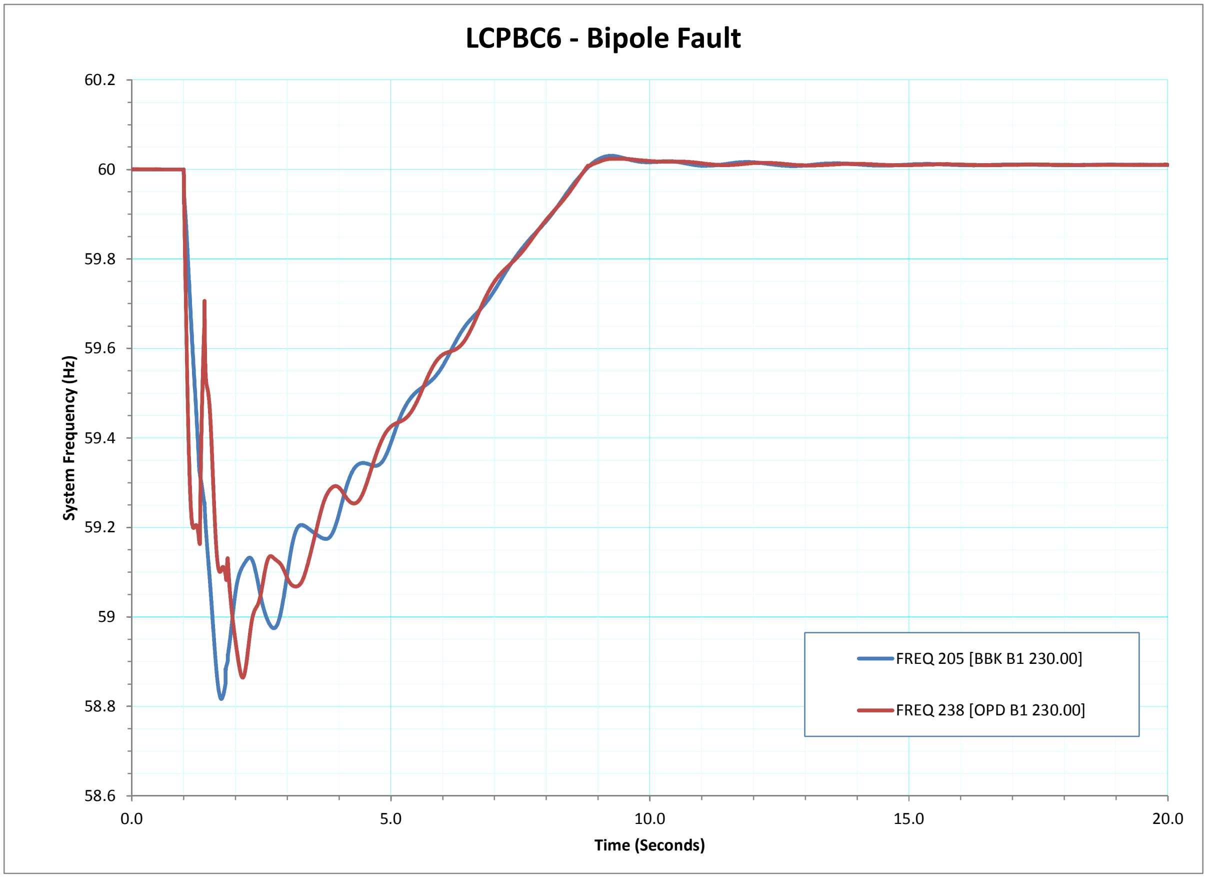


Figure 17 - LCPBC6 - Bipole Fault - System Frequency (Hz)

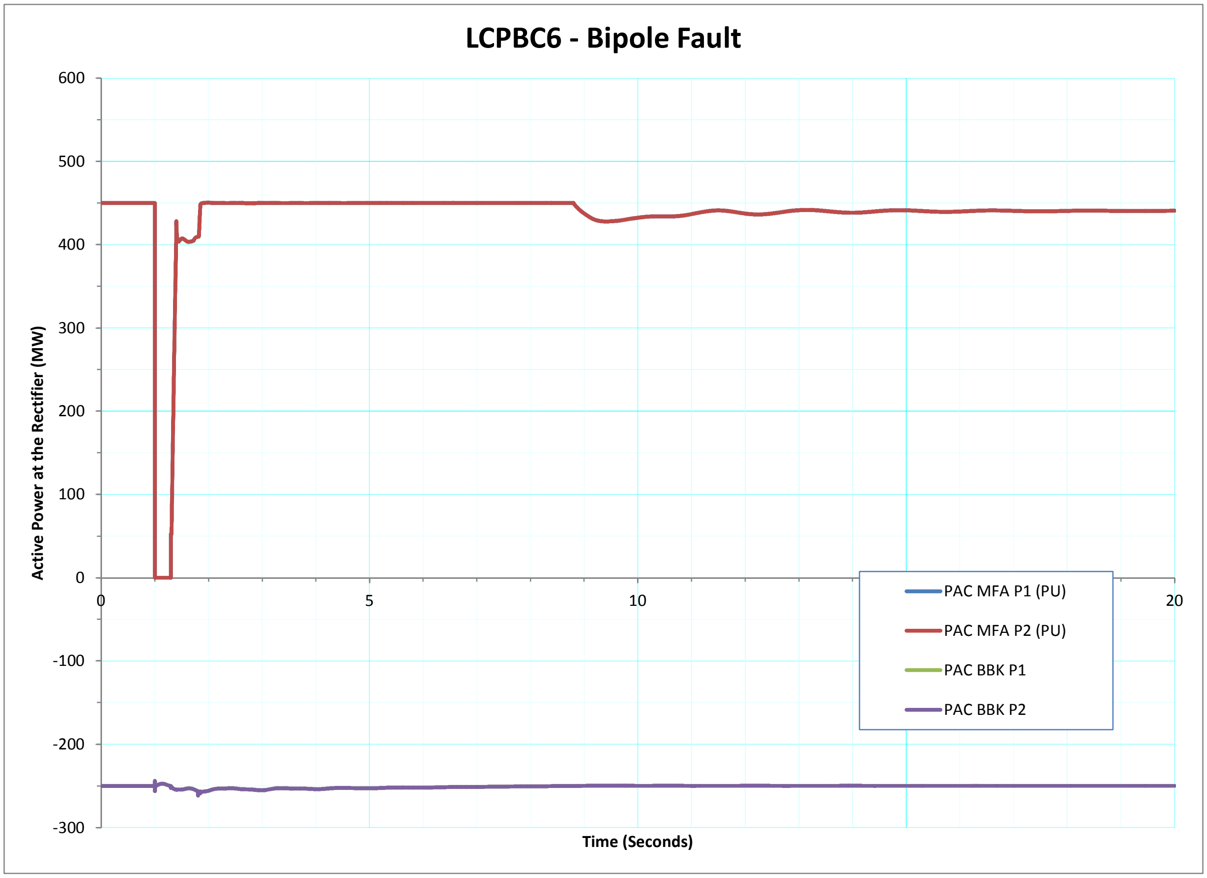


Figure 18 - LCPBC6 - Bipole Fault - Active Power at the Rectifier (MW)

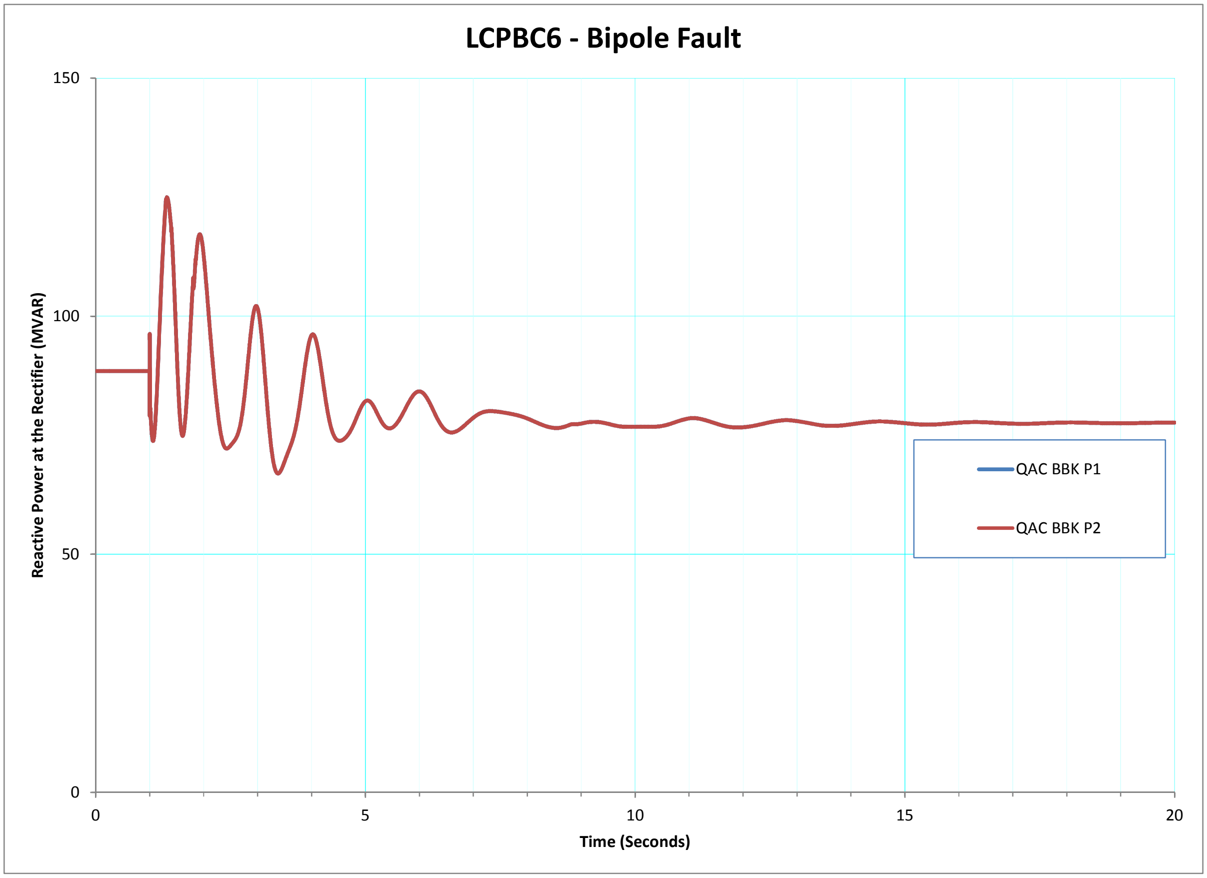


Figure 19 - LCPBC6 - Bipole Fault - Reactive Power at the Rectifier (MVAR)

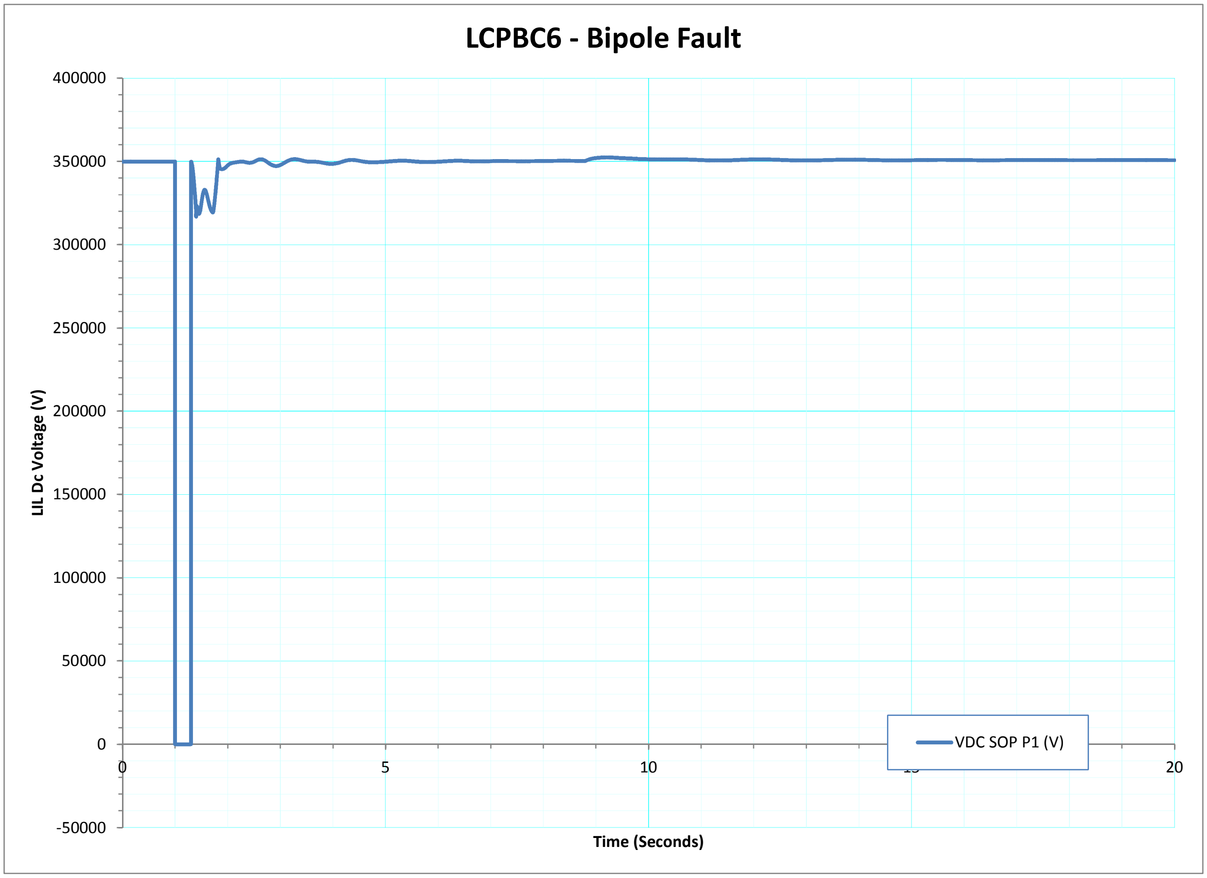


Figure 20 - LCPBC6 - Bipole Fault - LIL Dc Voltage (V)

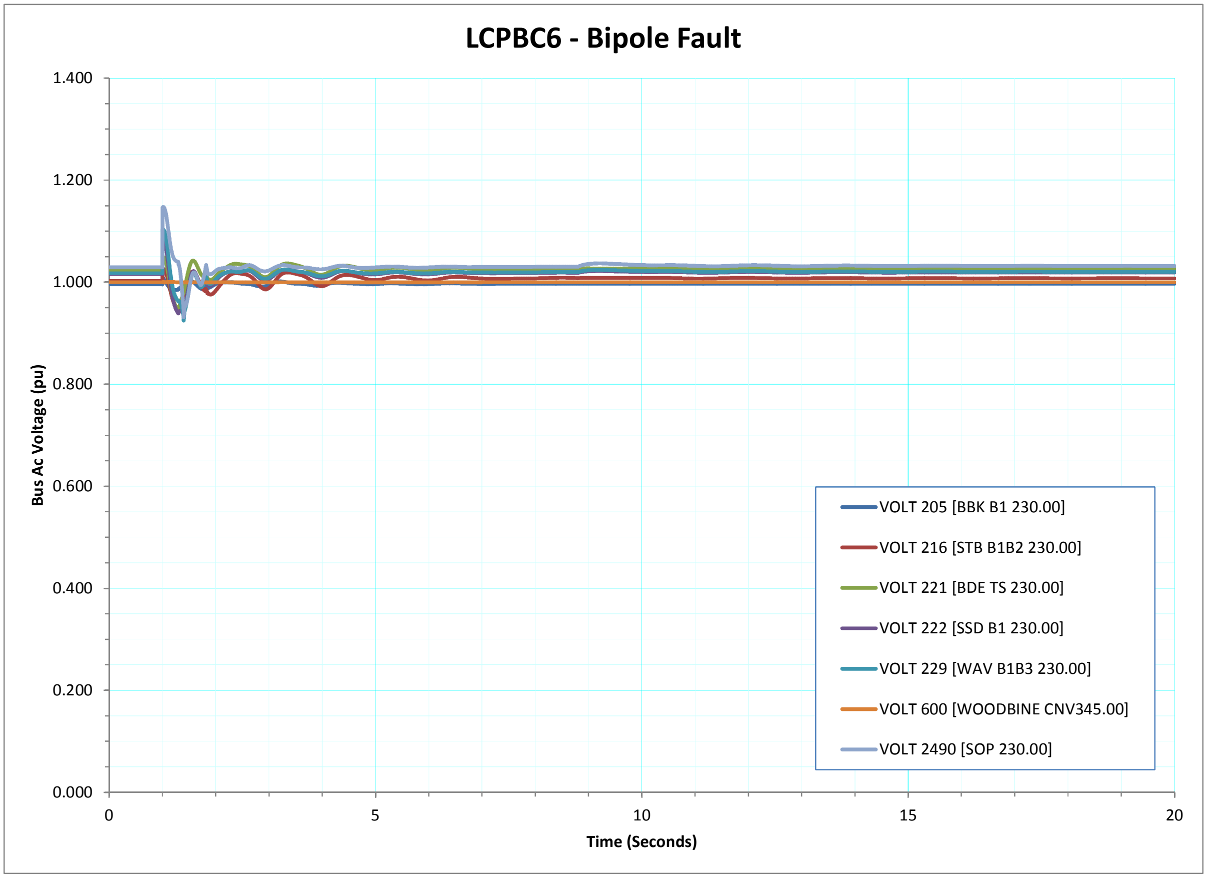


Figure 21 - LCPBC6 - Bipole Fault - Bus Ac Voltage (pu)

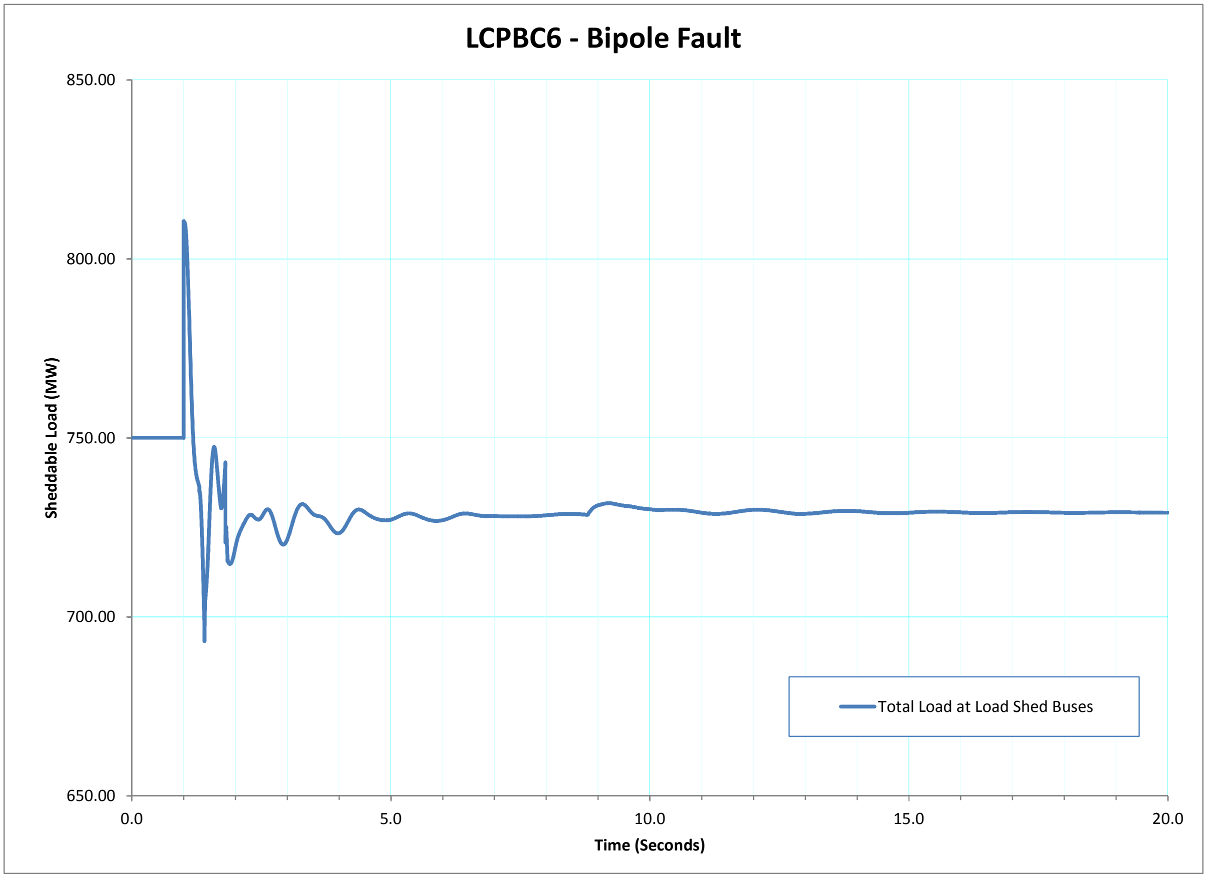


Figure 22 - LCPBC6 - Bipole Fault - Sheddable Load (MW)

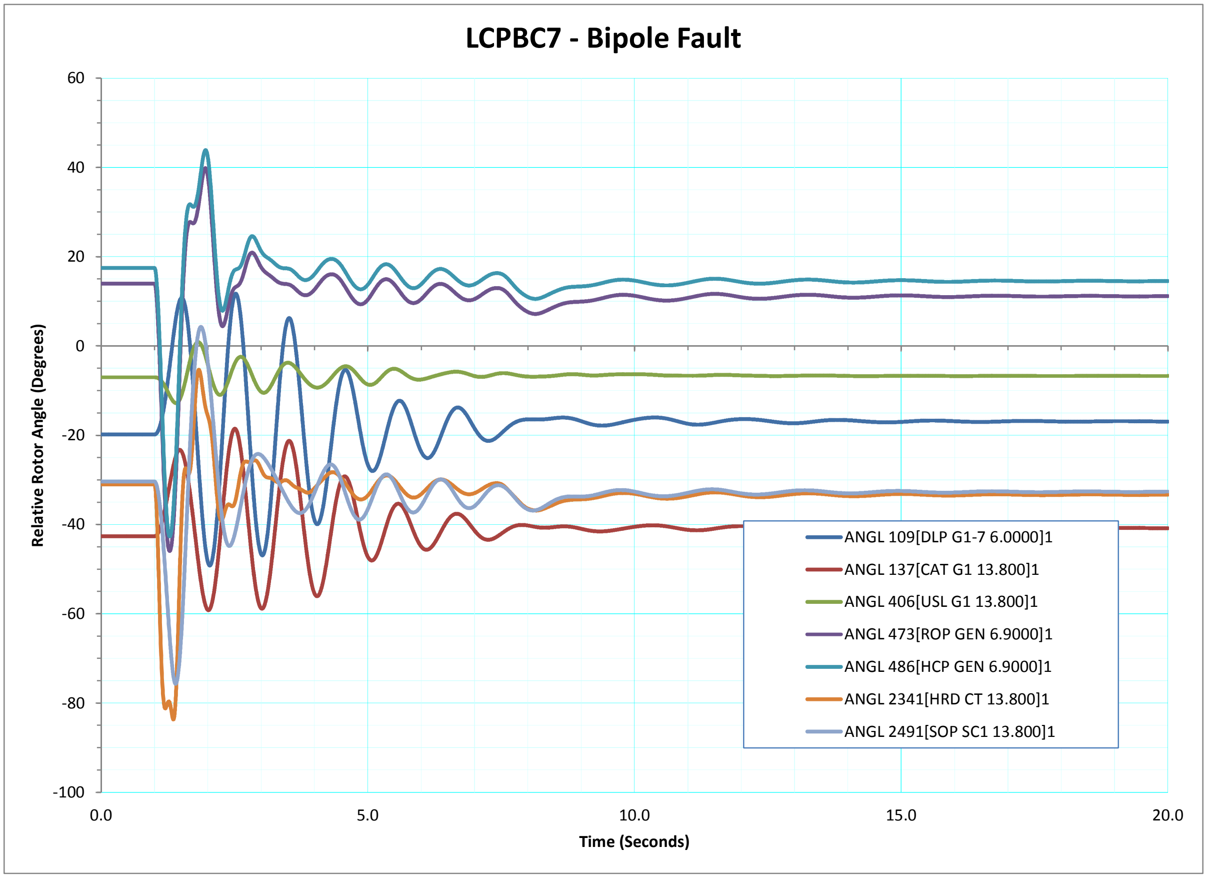


Figure 23 - LCPBC7 - Bipole Fault - Relative Rotor Angle (Degrees)

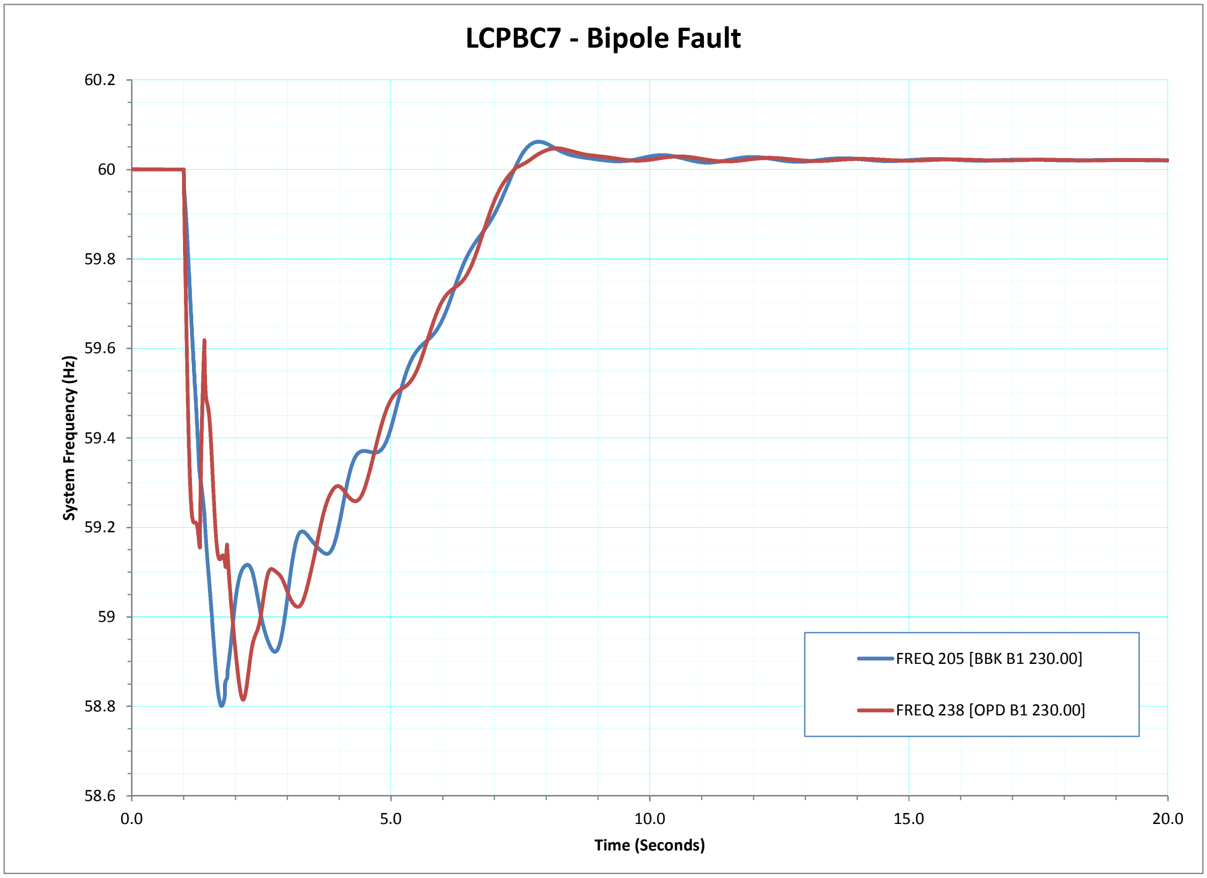


Figure 24 - LCPBC7 - Bipole Fault - System Frequency (Hz)

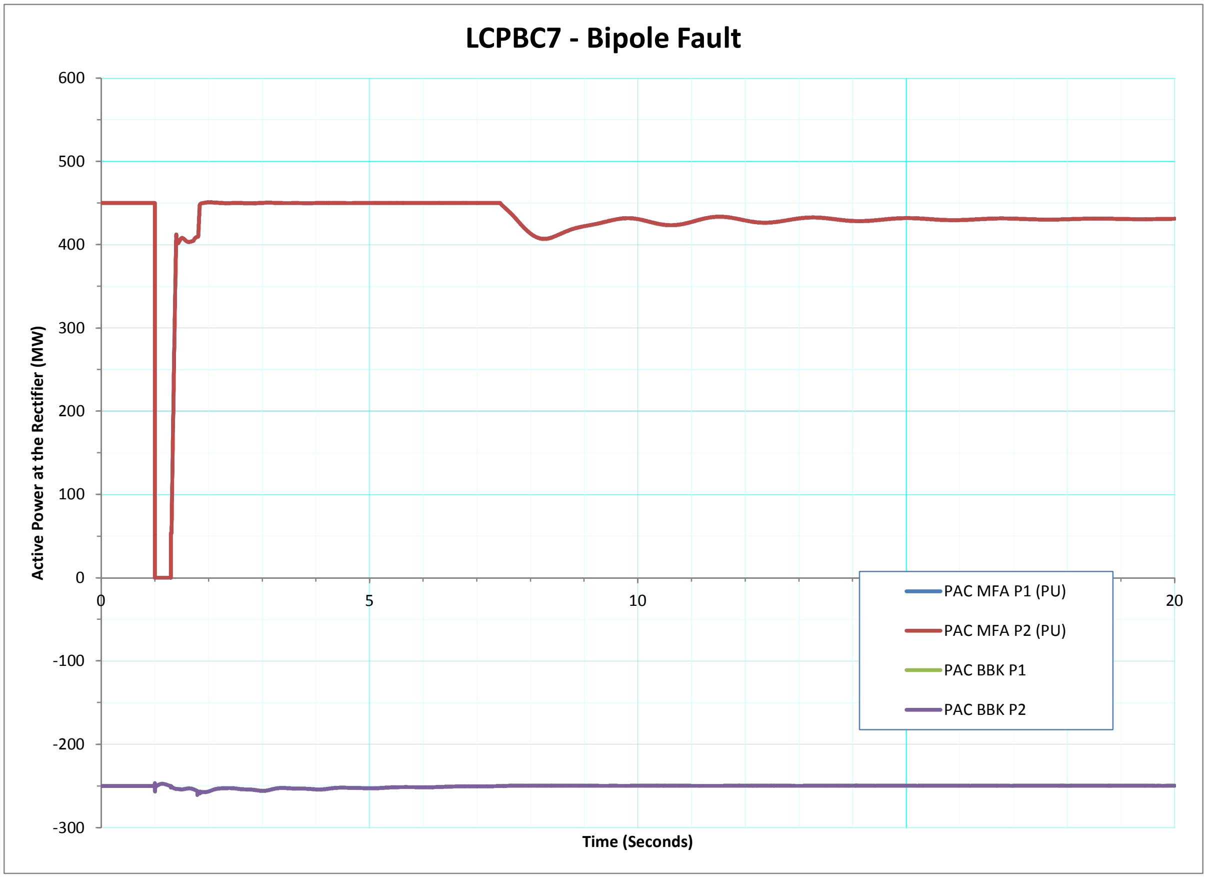


Figure 25 - LCPBC7 - Bipole Fault - Active Power at the Rectifier (MW)

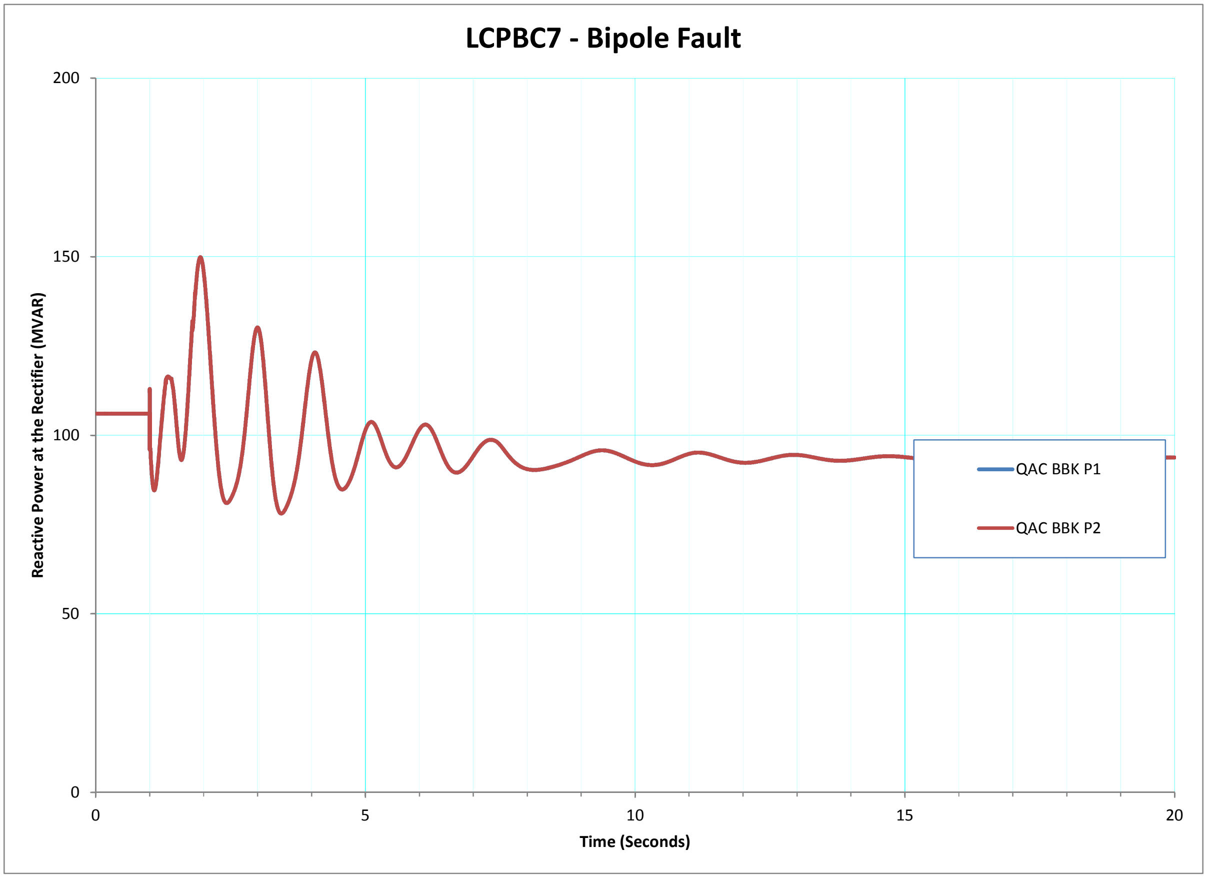


Figure 26 - LCPBC7 - Bipole Fault - Reactive Power at the Rectifier (MVAR)

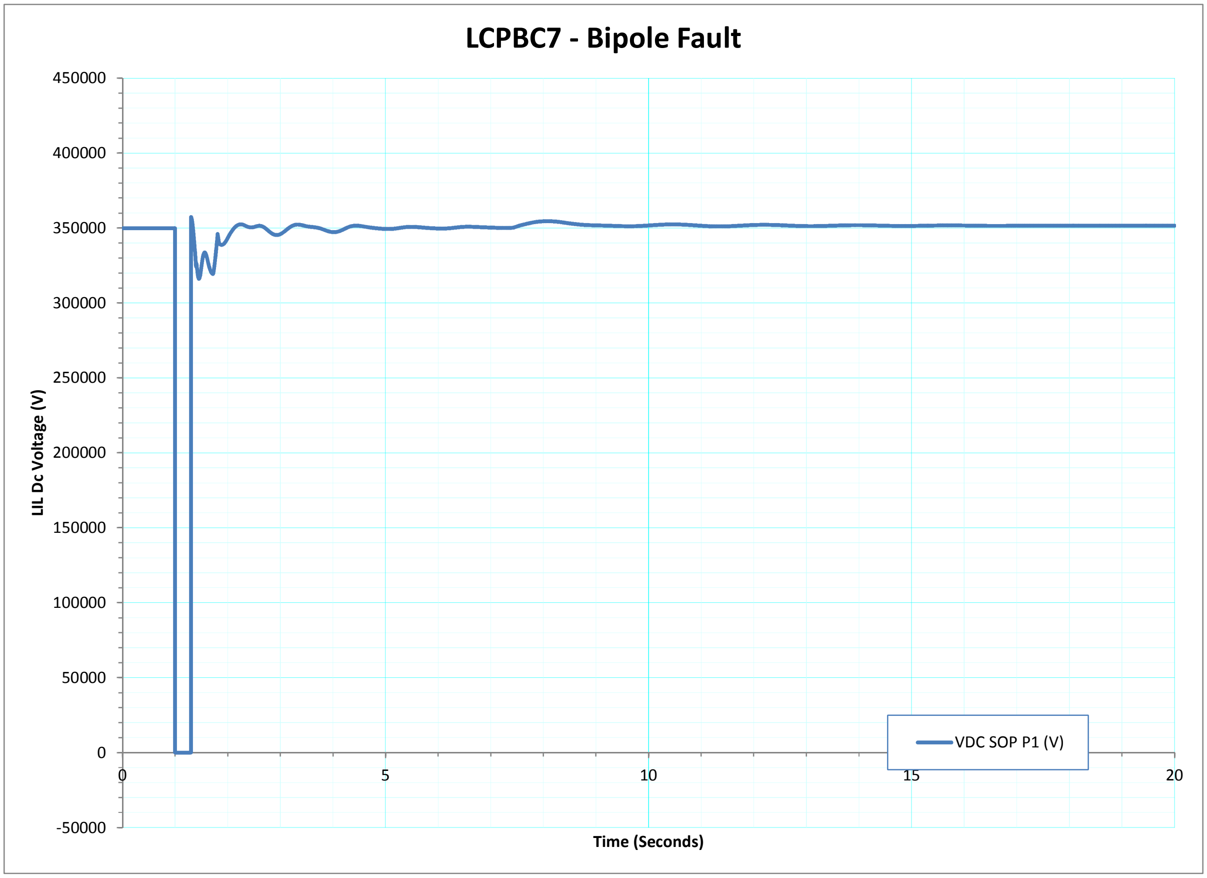


Figure 27 - LCPBC7 - Bipole Fault - LIL Dc Voltage (V)

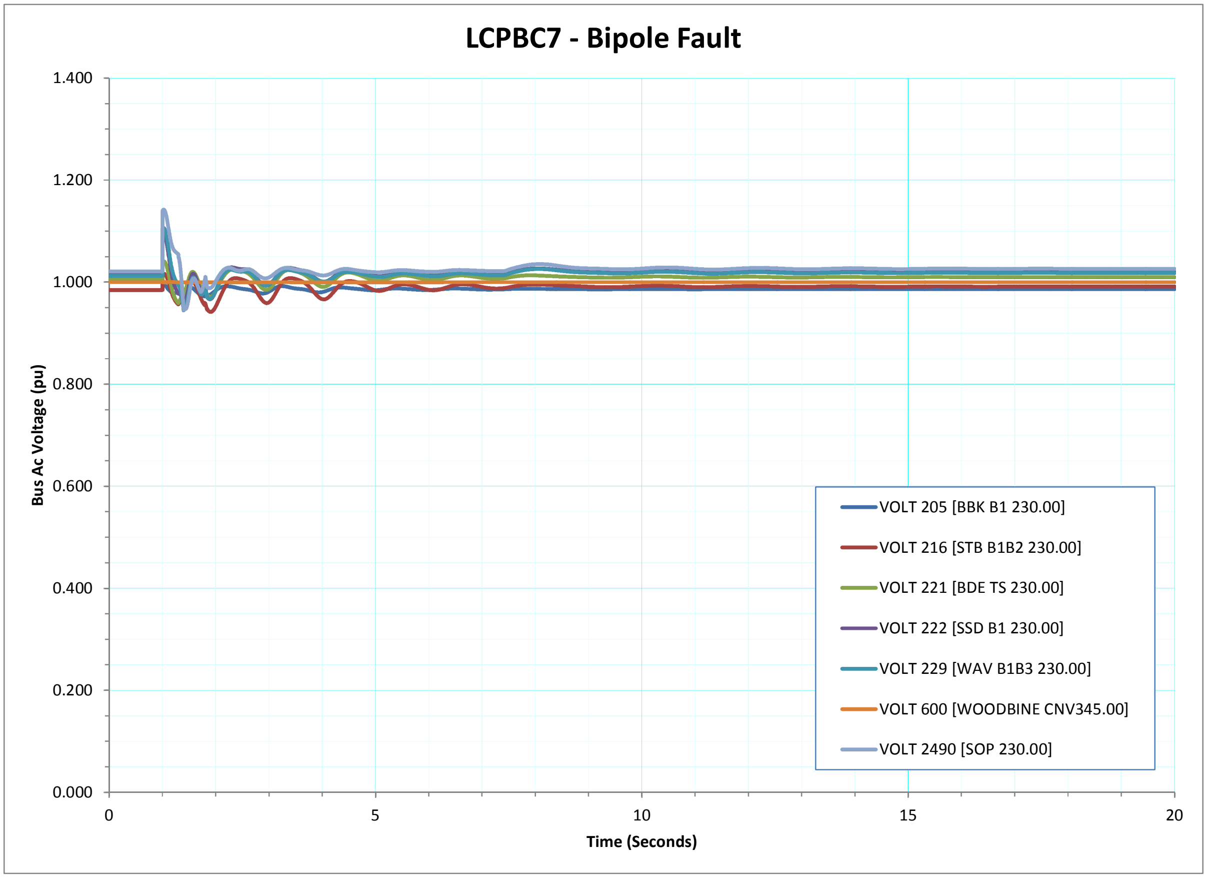


Figure 28 - LCPBC7 - Bipole Fault - Bus Ac Voltage (pu)

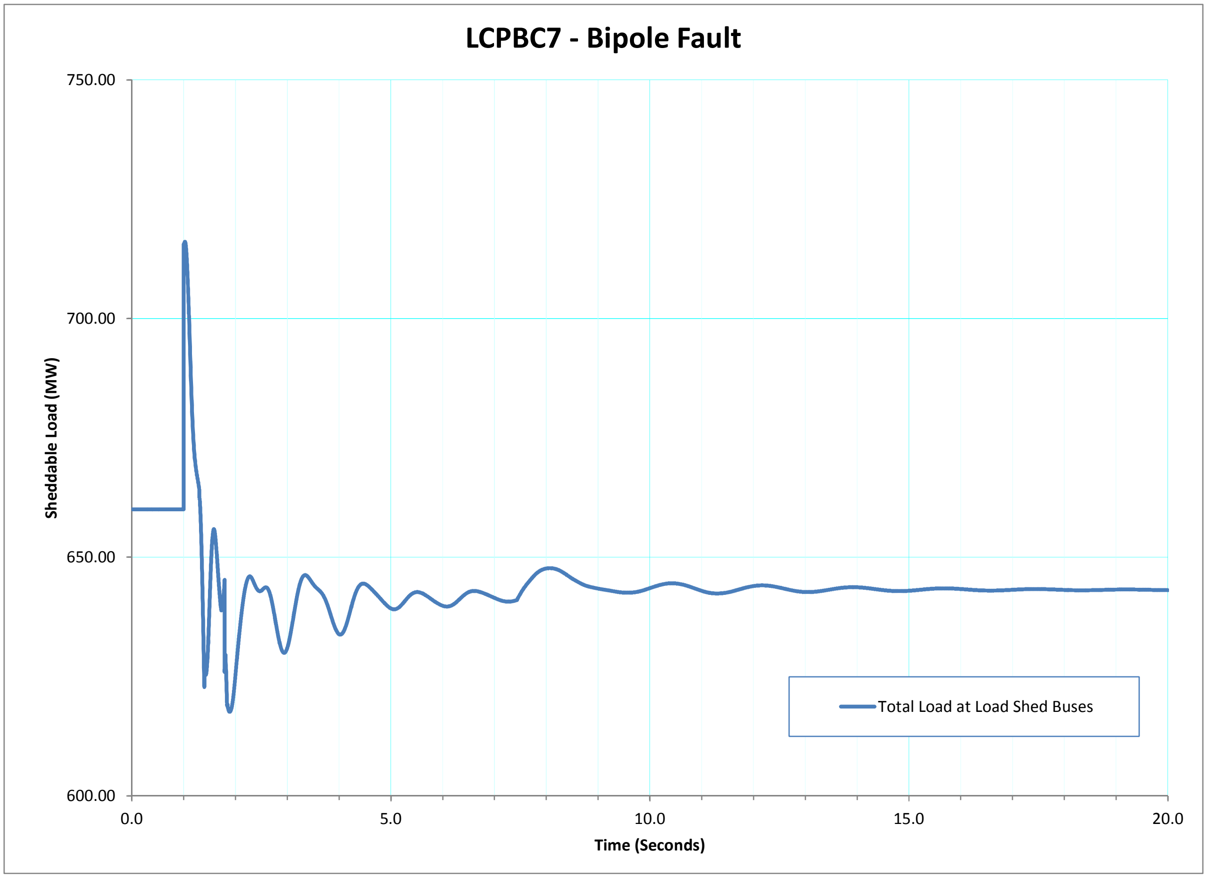


Figure 29 - LCPBC7 - Bipole Fault - Sheddable Load (MW)

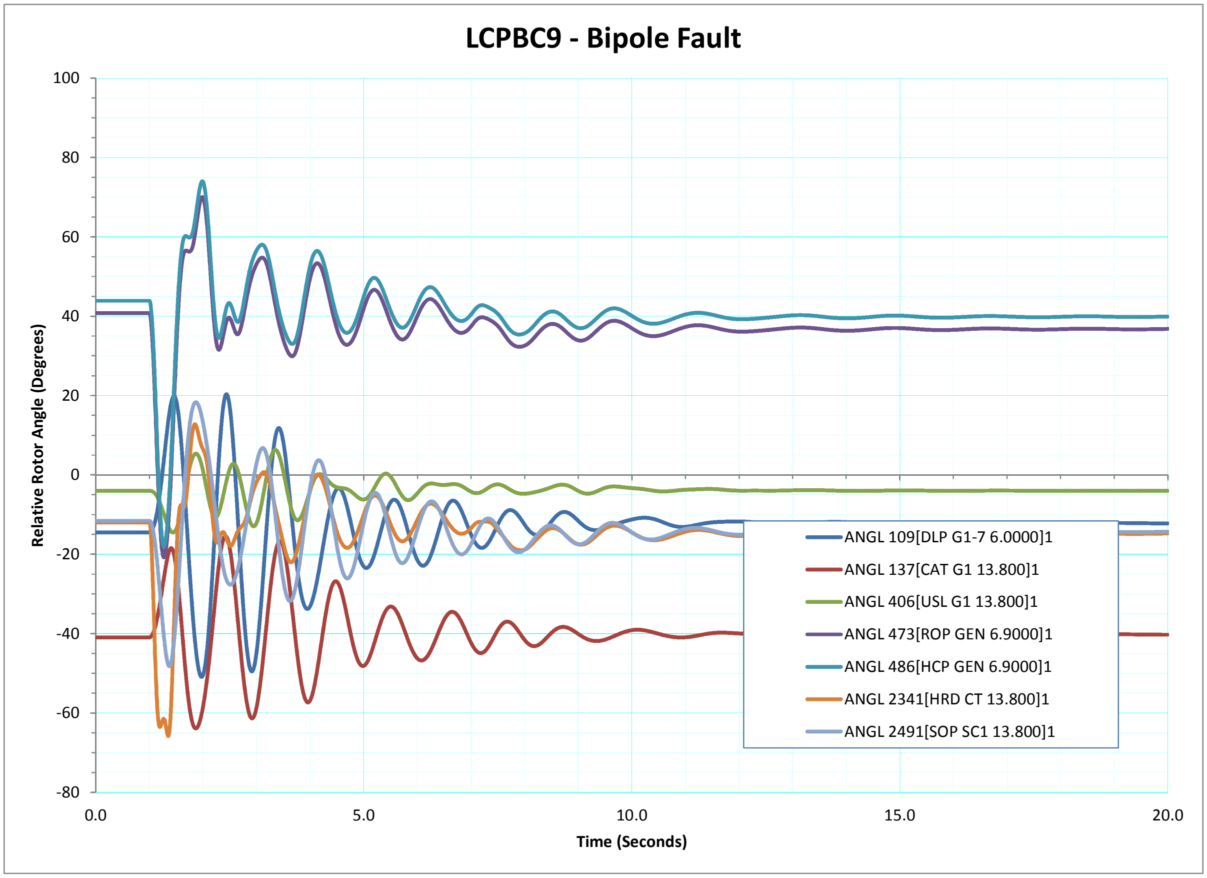


Figure 30 - LCPBC9 - Bipole Fault - Relative Rotor Angle (Degrees)

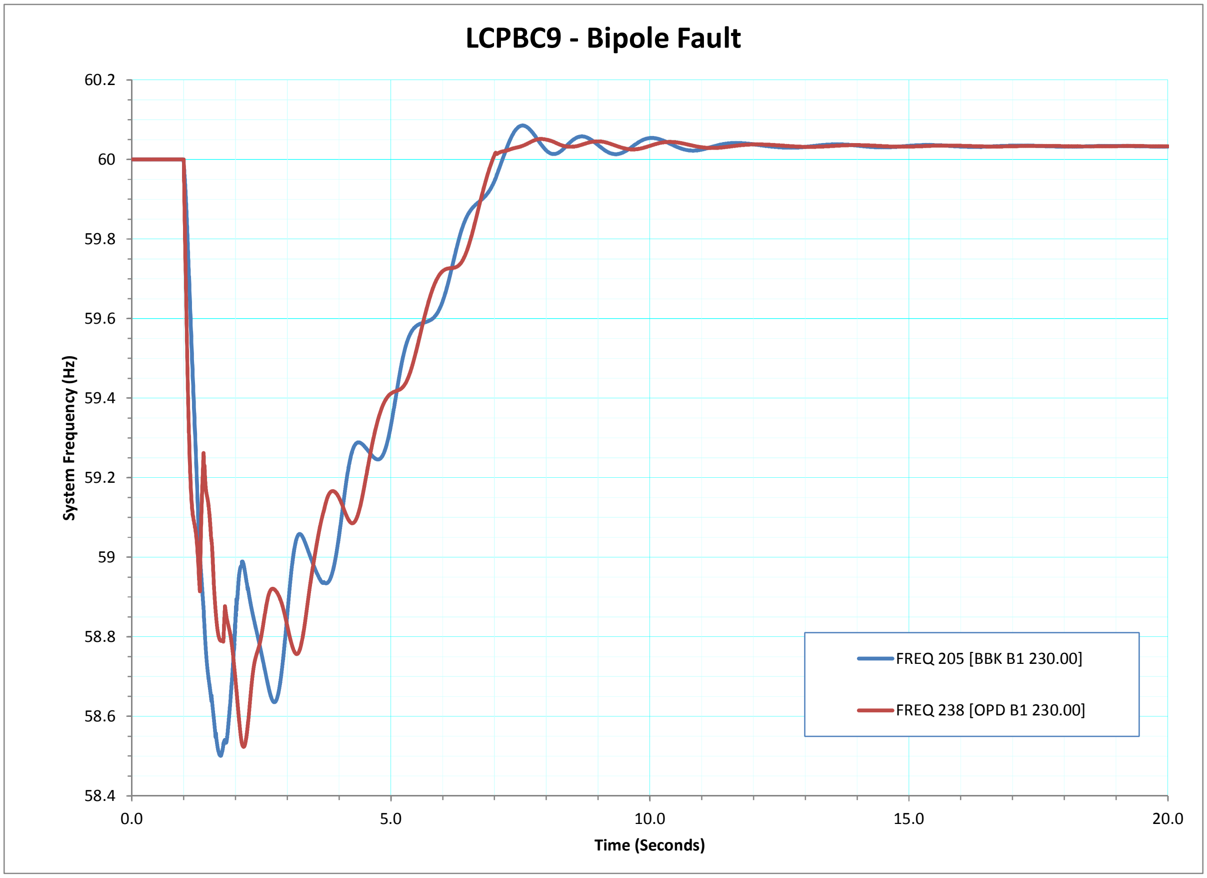


Figure 31 - LCPBC9 - Bipole Fault - System Frequency (Hz)

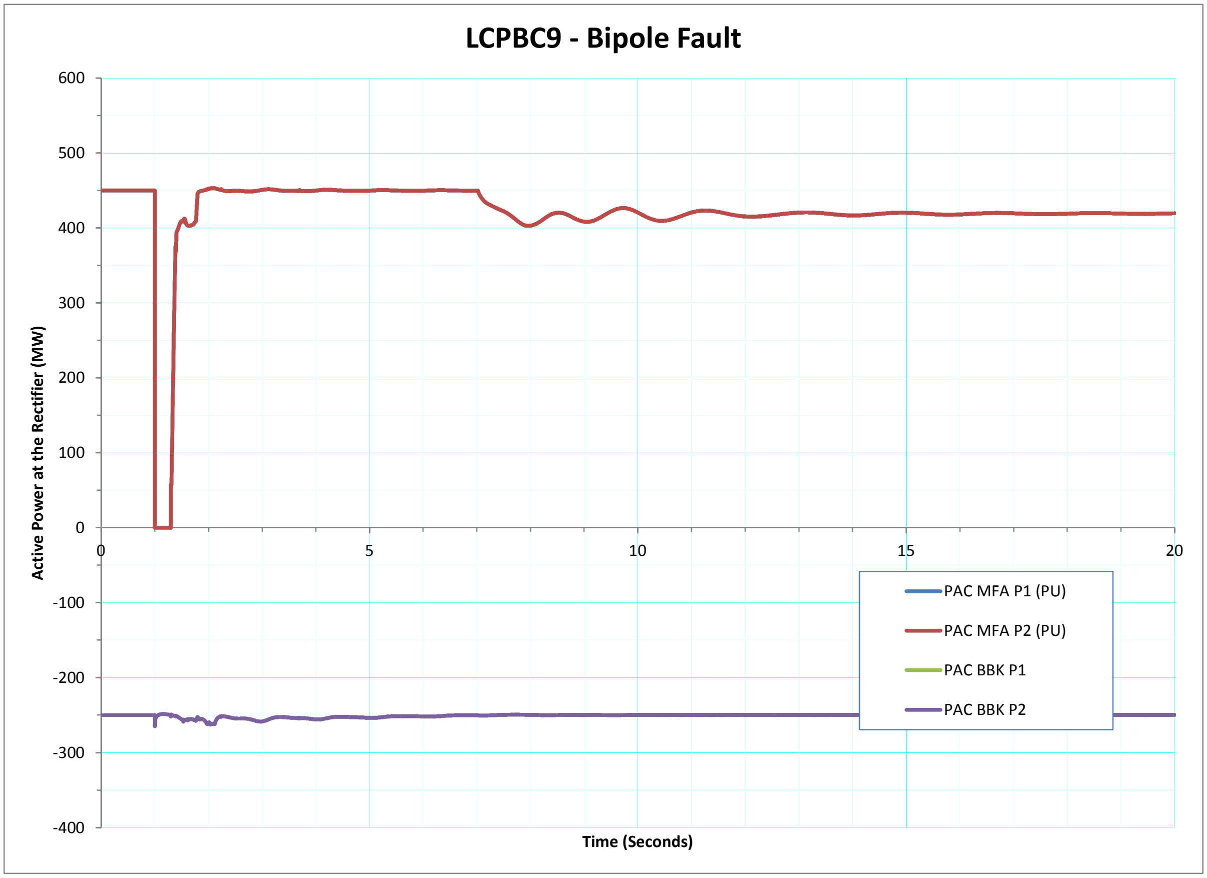


Figure 32 - LCPBC9 - Bipole Fault - Active Power at the Rectifier (MW)

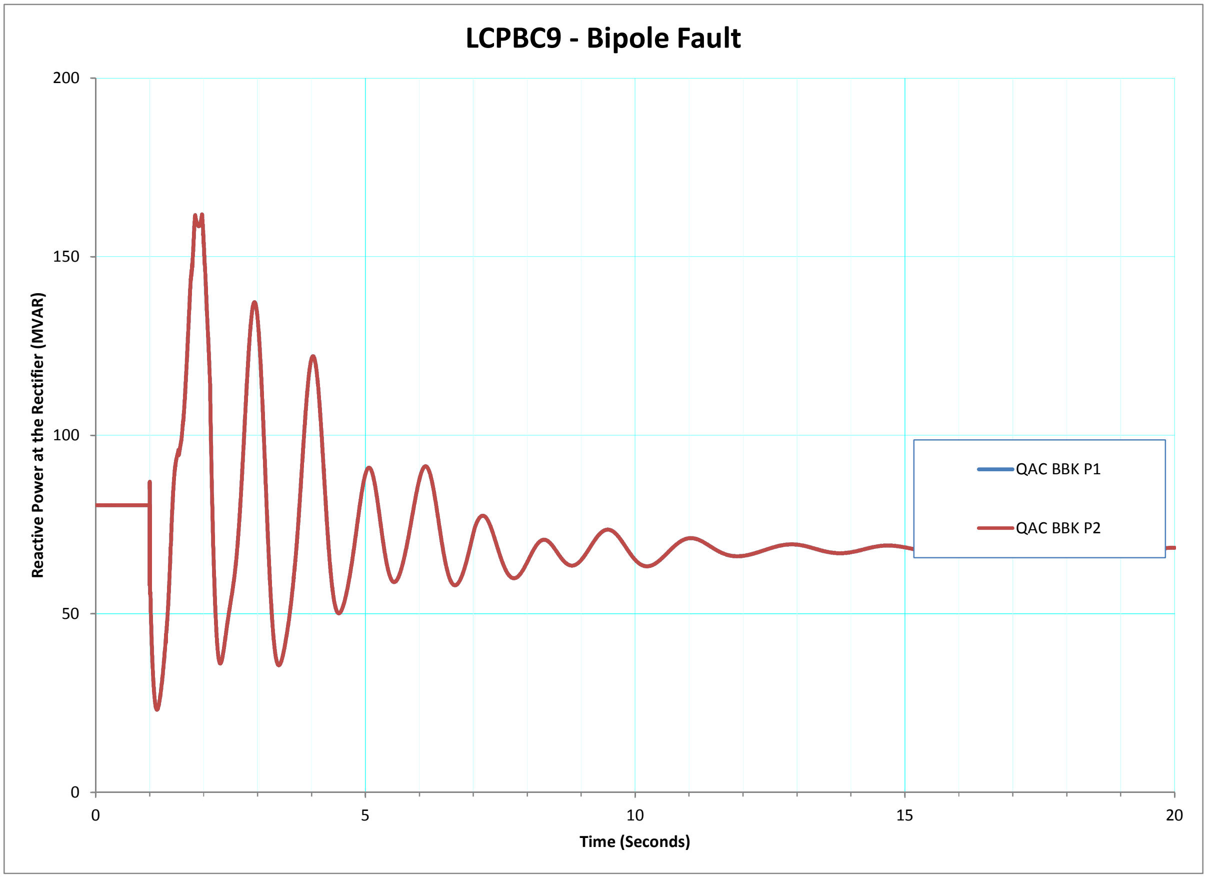


Figure 33 - LCPBC9 - Bipole Fault - Reactive Power at the Rectifier (MVAR)

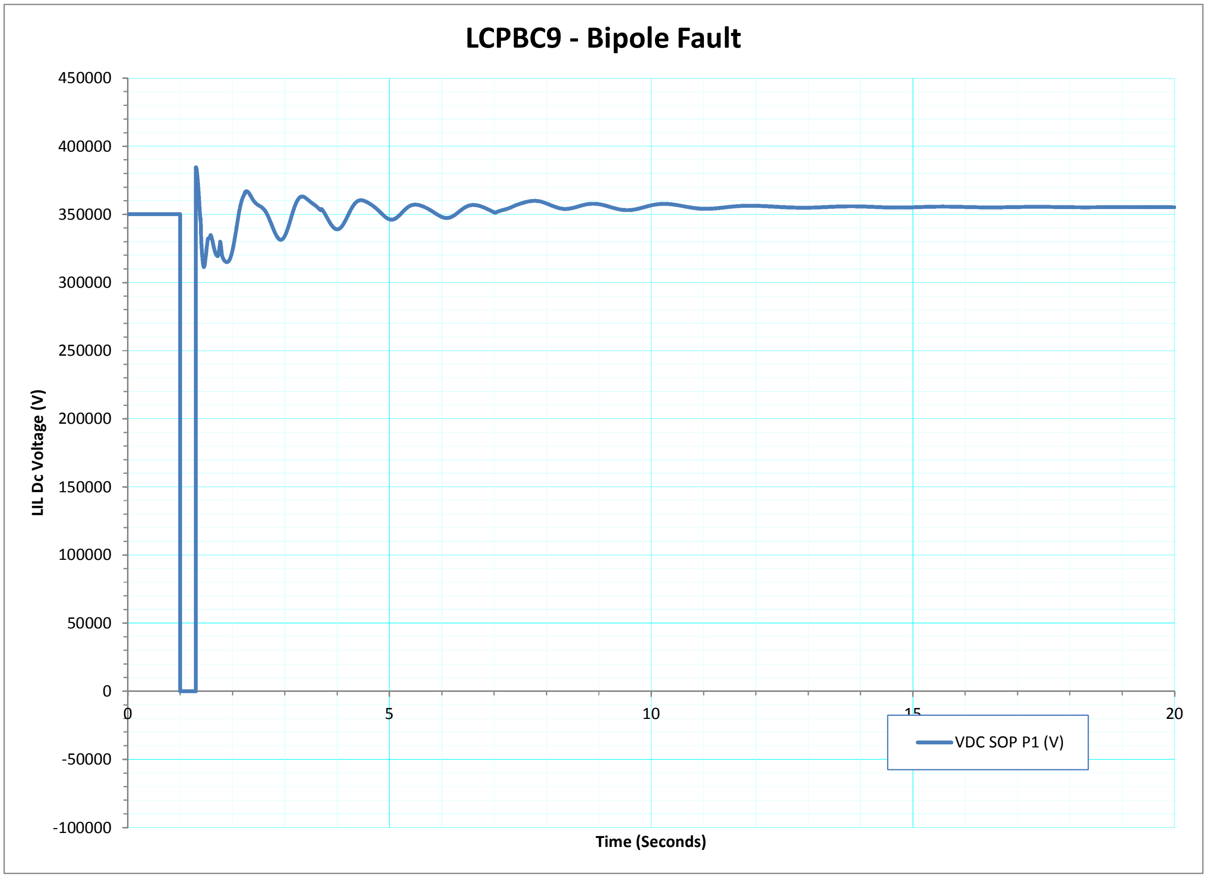


Figure 34 - LCPBC9 - Bipole Fault - LIL Dc Voltage (V)

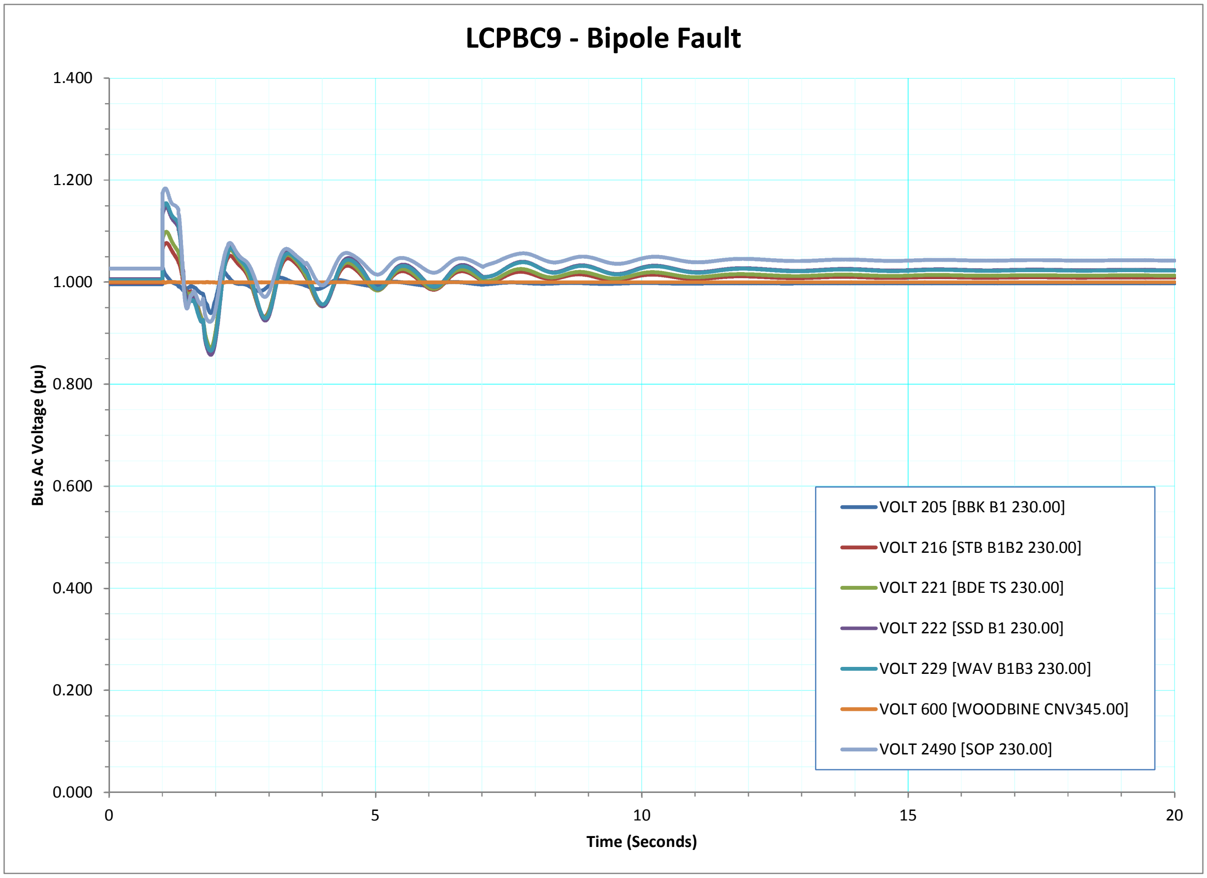


Figure 35 - LCPBC9 - Bipole Fault - Bus Ac Voltage (pu)

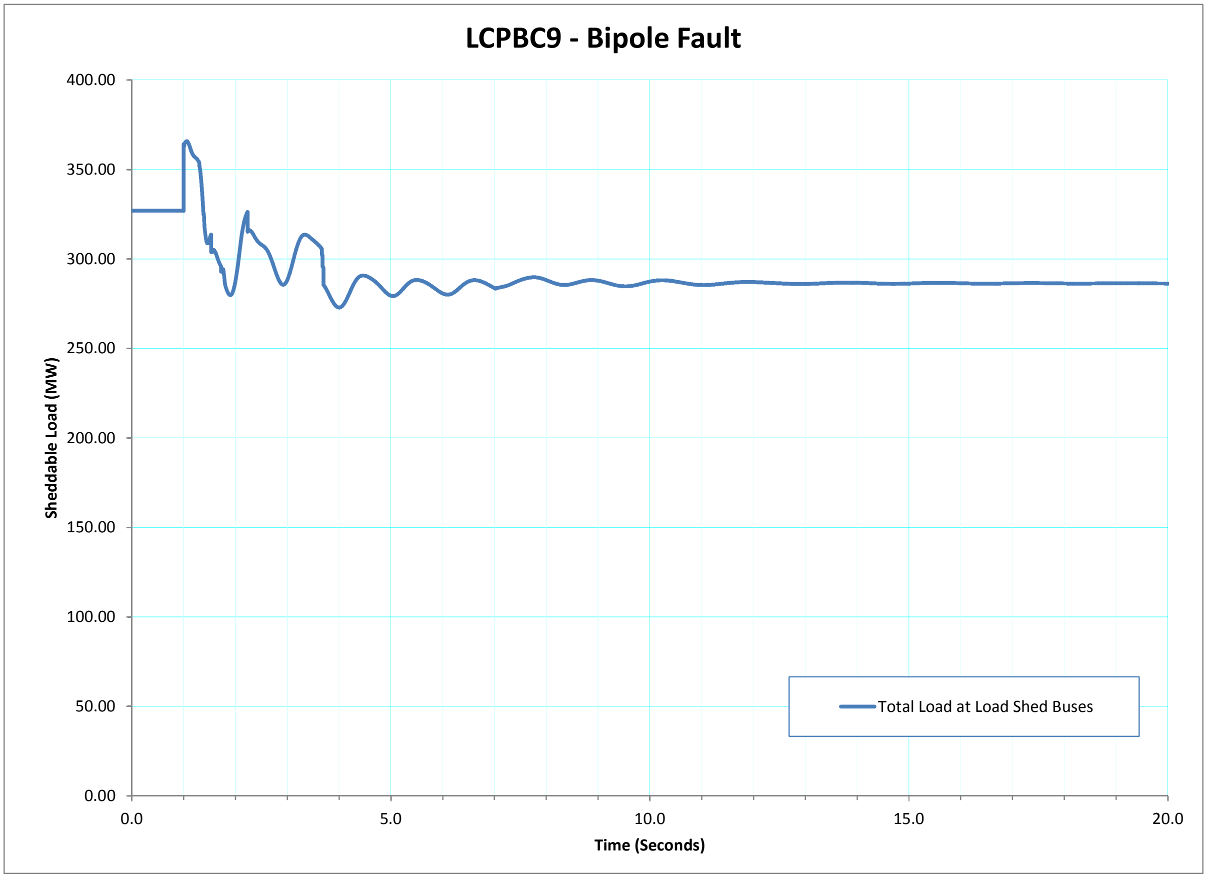


Figure 36 - LCPBC9 - Bipole Fault - Sheddable Load (MW)

5.4. PERMANENT POLE FAULTS

Analysis indicated that underfrequency load shedding and instability can result from the permanent loss of a pole on the LIL if no remedial action is taken with respect to ML export. These results are listed in Table 6.

Table 6 – Notable System Conditions Following Permanent Pole Faults

Base Case	Contingency	System Condition
Base Case 1	Permanent Pole Fault	UFLS
Base Case 2	Permanent Pole Fault	UFLS
Base Case 3	Permanent Pole Fault	UFLS
Base Case 4	Permanent Pole Fault	f < 58 Hz
Base Case 6	Permanent Pole Fault	UFLS
Base Case 7	Permanent Pole Fault	UFLS
Base Case 8	Permanent Pole Fault	UFLS
Base Case 9	Permanent Pole Fault	UFLS
Base Case 10	Permanent Pole Fault	Instability

Instability was found in BC10, a monopolar cases where 550 MW is being imported over the LIL, while 500 MW is exported over the ML. This instability is illustrated in the figures below.

It should be noted that for all other cases (with the exception of BC11) the permanent loss of a pole results in underfrequency load shedding within the Island Interconnected System if ML export is not curtailed. Appendix E illustrates how underfrequency load shedding can be avoided in all base cases if the ML export is curtailed. In Base Cases 6, 7, 8, and 9, where ML export is at 500 MW, curtailing export to 250 MW is sufficient to avoid underfrequency load shedding. In other cases, ML export is below 250 MW and must be reduced to 0 MW.

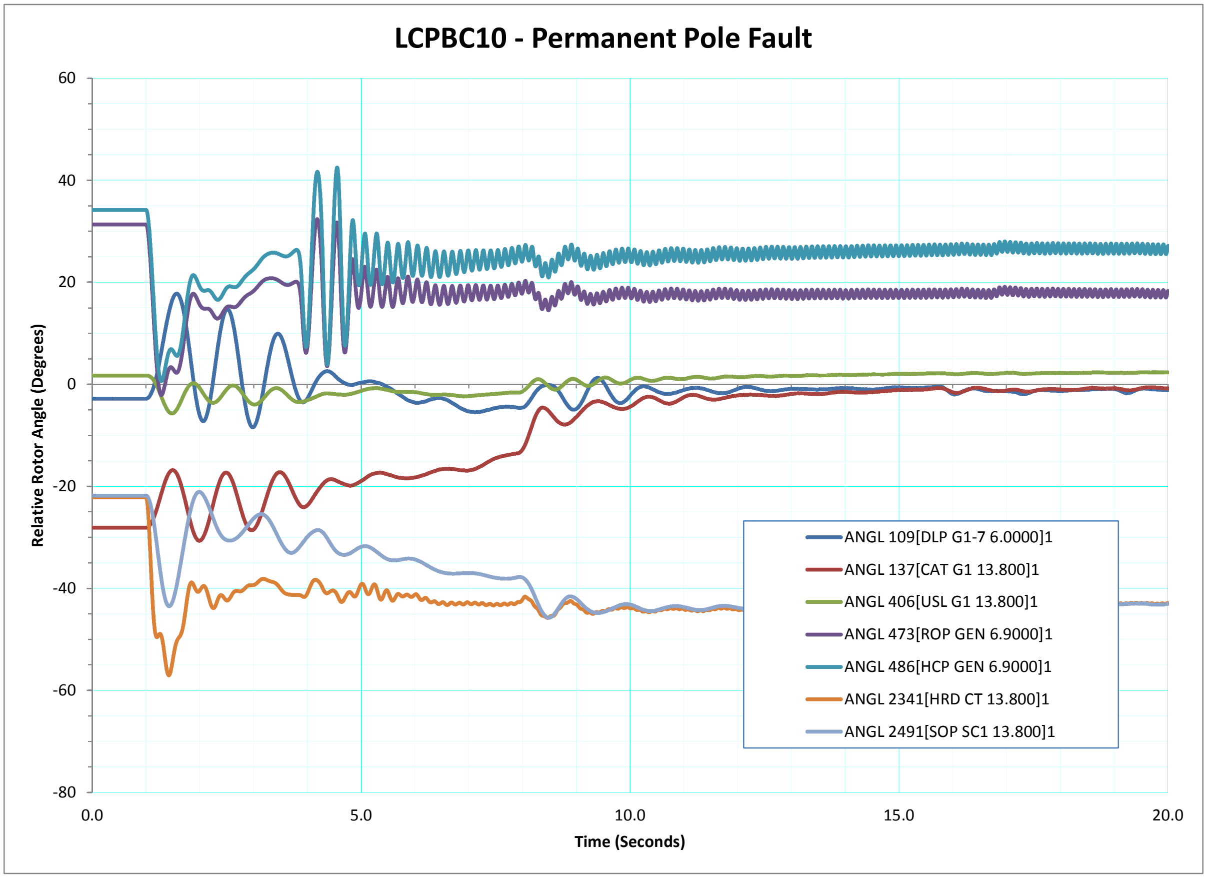


Figure 37 - LCPBC10 - Permanent Pole Fault - Relative Rotor Angle (Degrees)

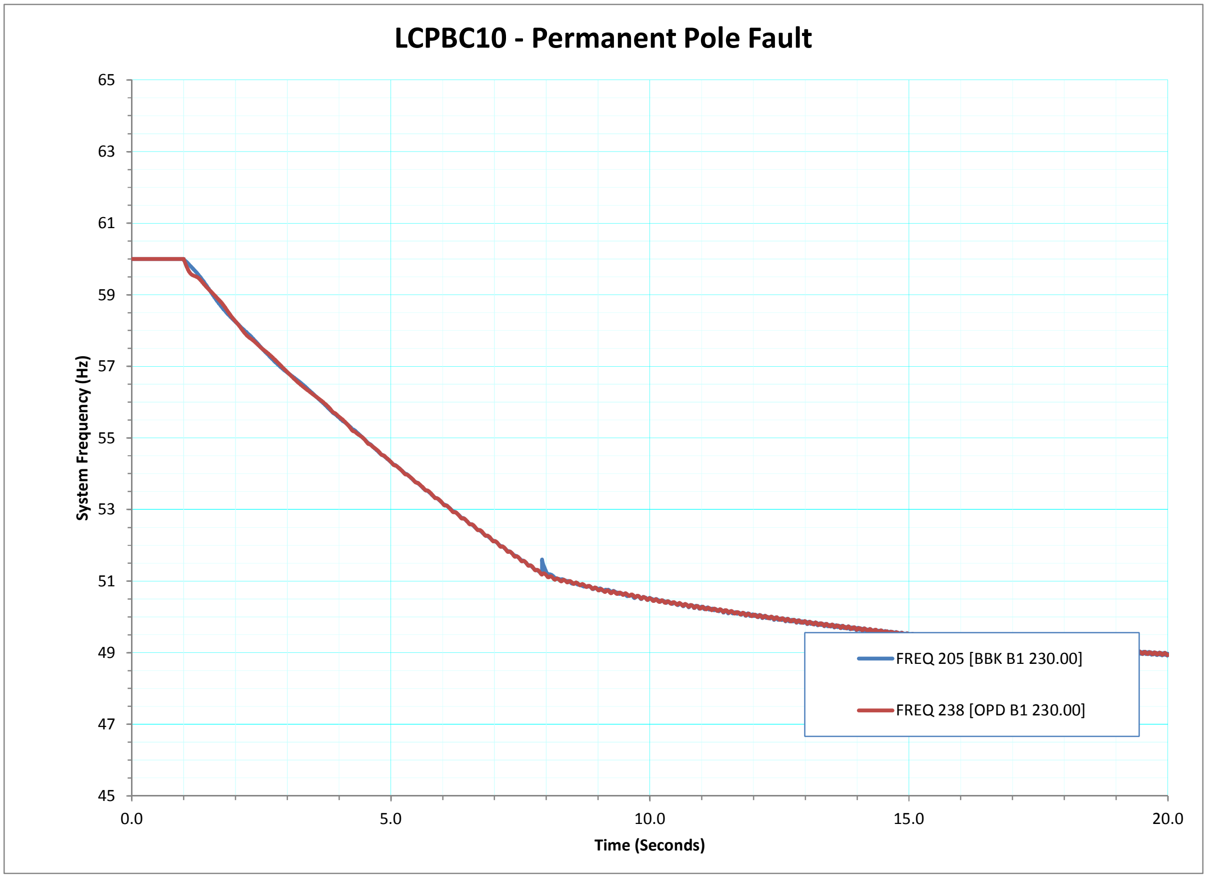


Figure 38 - LCPBC10 - Permanent Pole Fault - System Frequency (Hz)

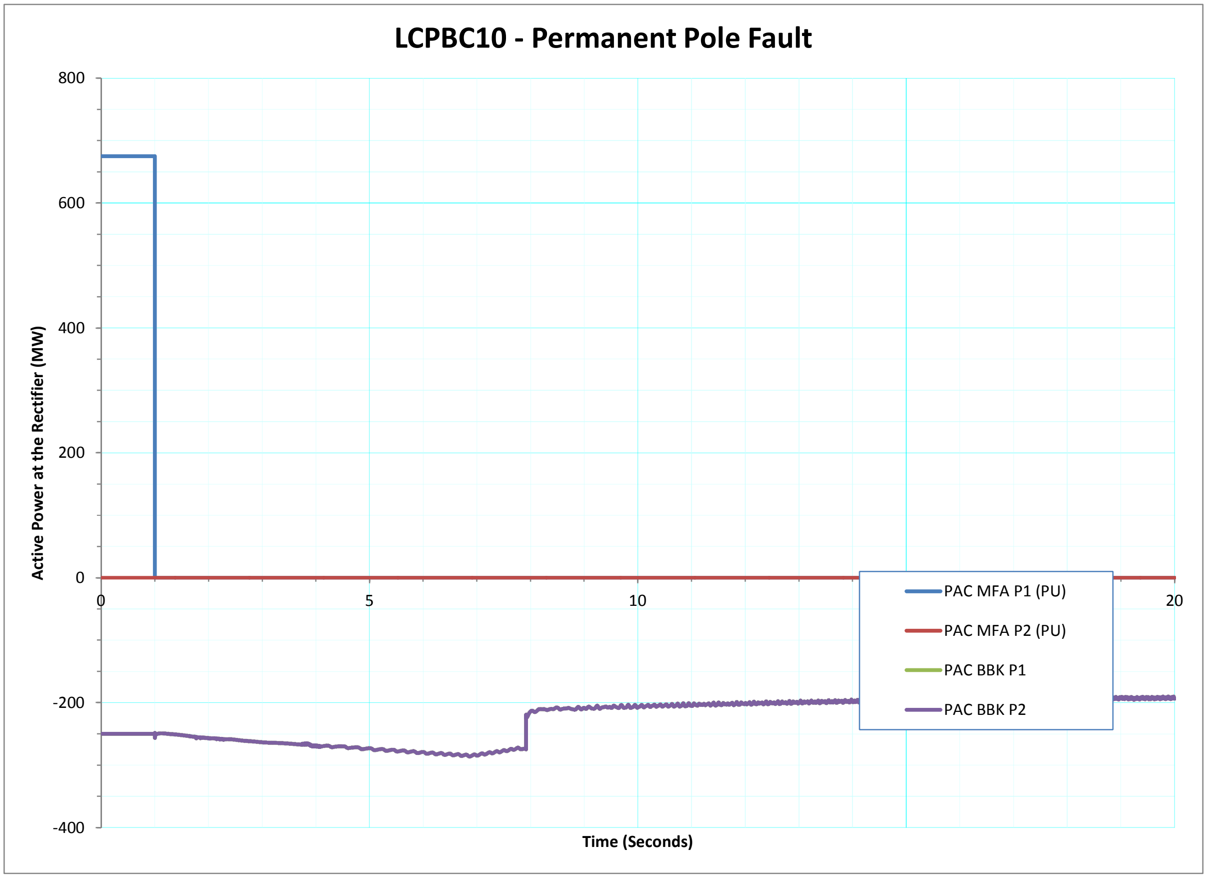


Figure 39 - LCPBC10 - Permanent Pole Fault - Active Power at the Rectifier (MW)

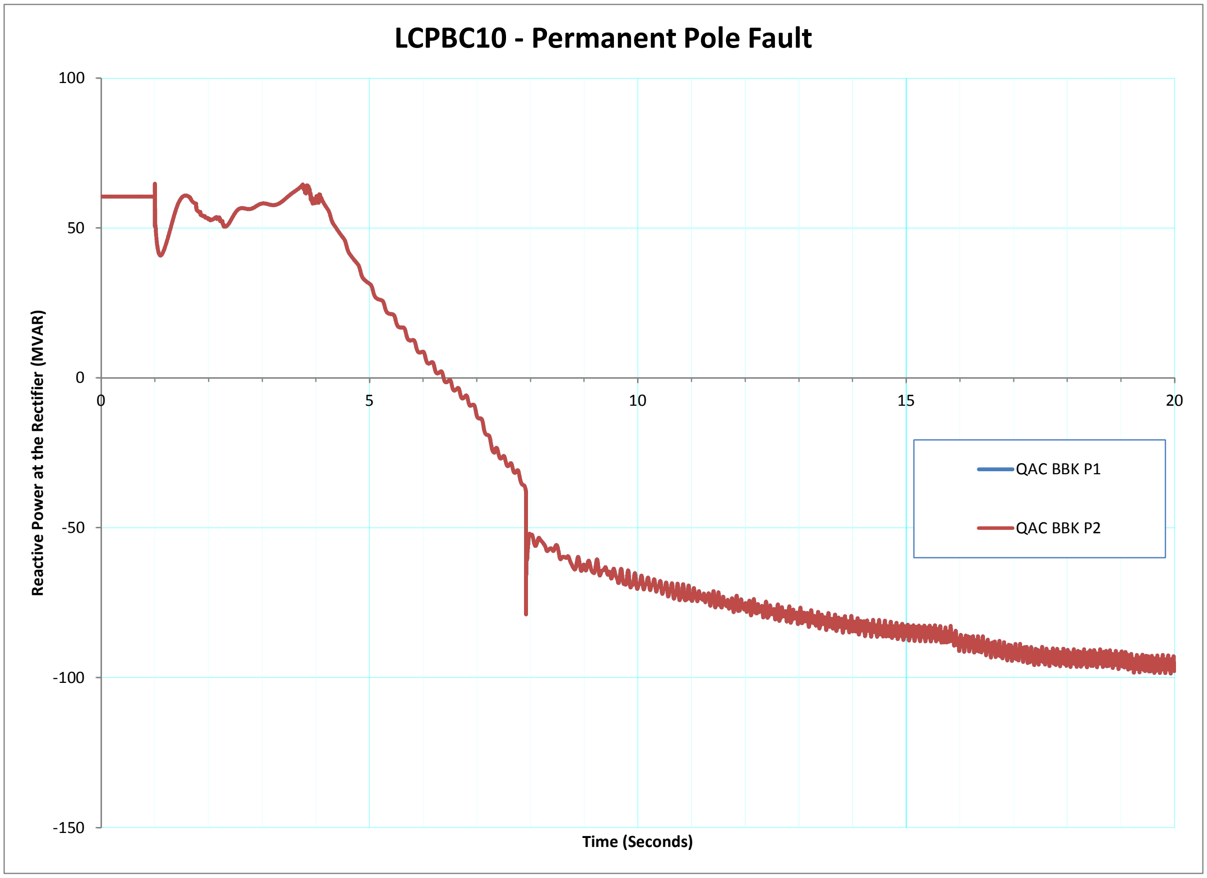


Figure 40 - LCPBC10 - Permanent Pole Fault - Reactive Power at the Rectifier (MVAR)

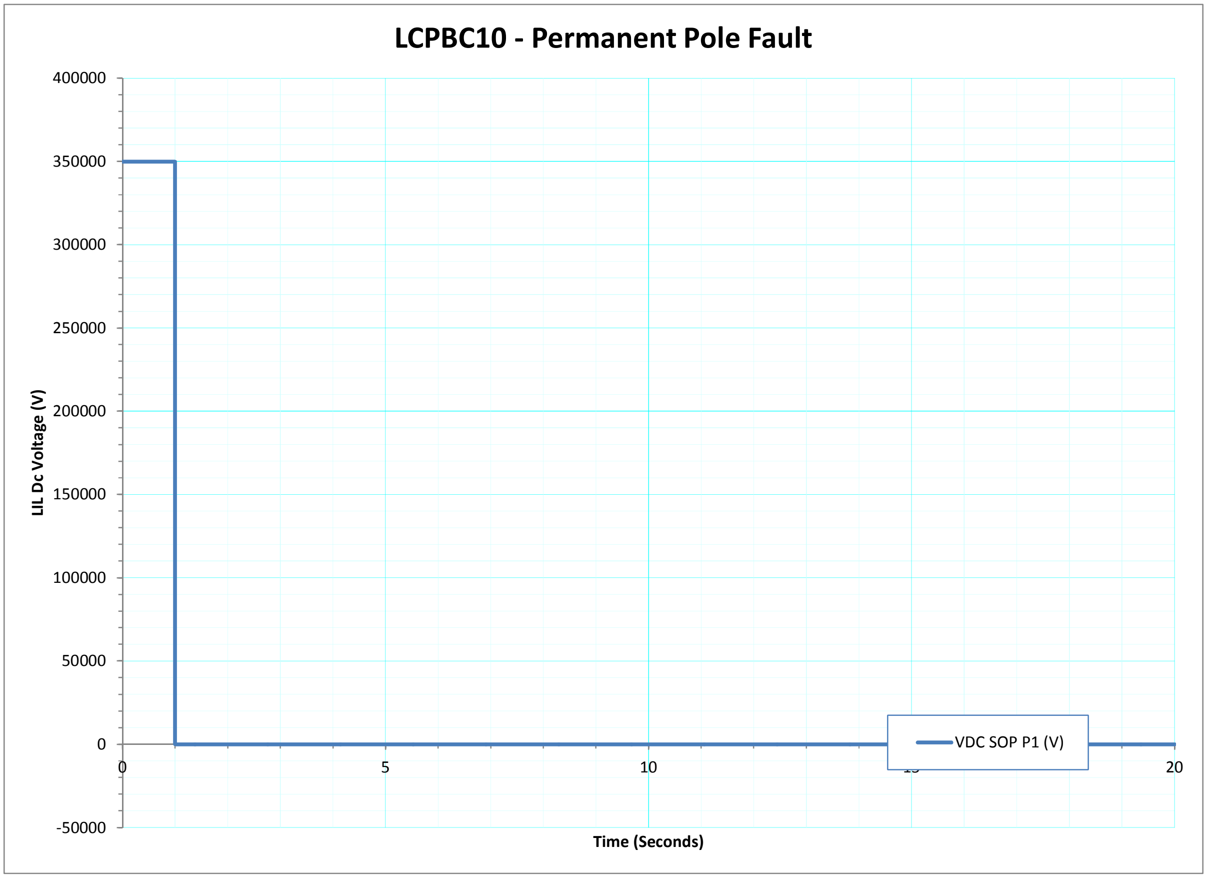


Figure 41 - LCPBC10 - Permanent Pole Fault - LIL Dc Voltage (V)

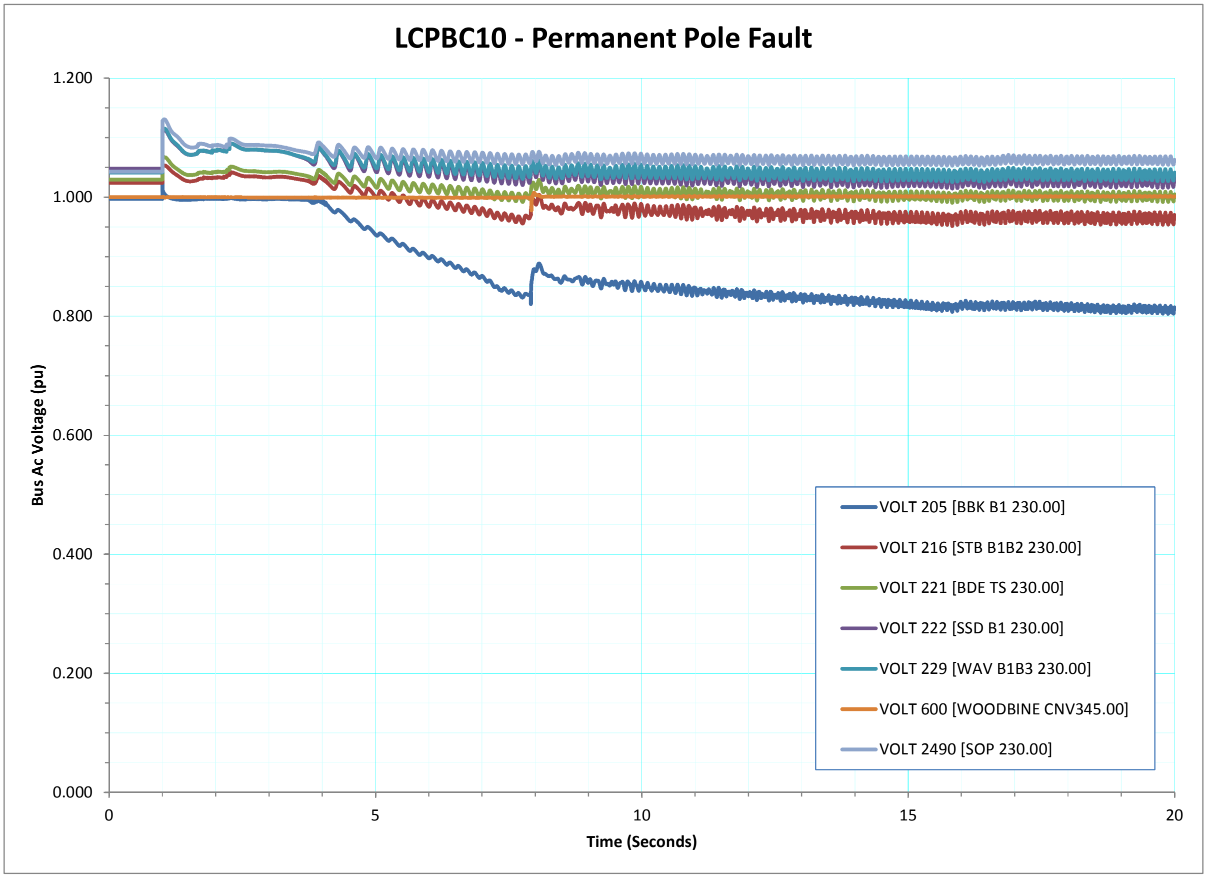


Figure 42 - LCPBC10 - Permanent Pole Fault - Bus Ac Voltage (pu)

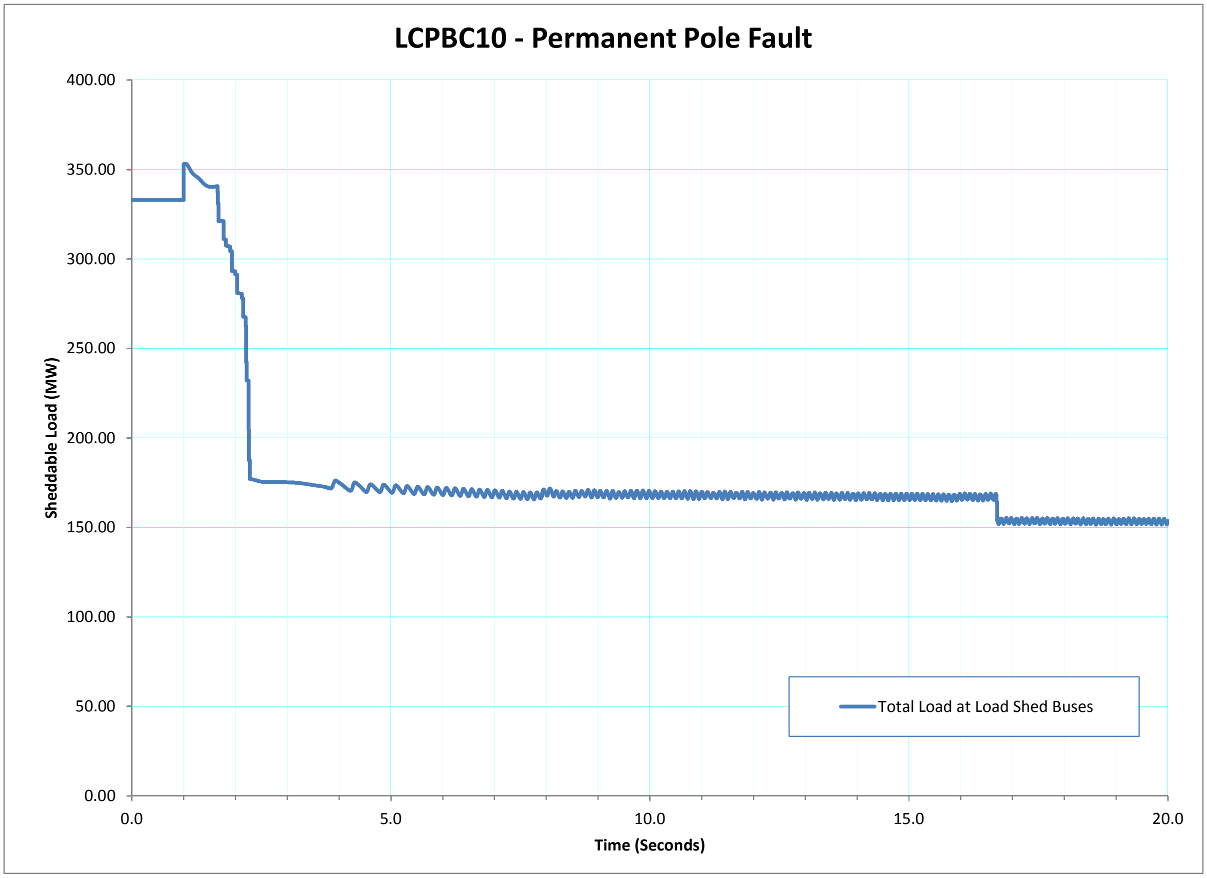


Figure 43 - LCPBC10 - Permanent Pole Fault - Sheddable Load (MW)

5.5. LOSS OF GENERATION WITHIN THE ISLAND SYSTEM

When the LIL is operating at or near rated capacity, the loss of generation within the Island Interconnected Transmission System results in UFLS. This was found to be the case for contingencies involving the loss of generation at USL, BDE, or the isolation of Cat Arm (CAT) generation during the tripping of TL248 and cross-tripping of TL247[5]. These cases are listed in Table 7 with examples provided in the figures below.

Table 7 – Notable System Conditions Following Loss of Island Generation

Base Case	Contingency	System Condition
Base Case 1	USL Fault, Trip Unit	UFLS
Base Case 1	MDR Fault, Trip TL248	UFLS
Base Case 1	BDE Fault, Trip Unit 7[6]	Instability
Base Case 2	MDR Fault, Trip TL248	UFLS
Base Case 2	BDE Fault, Trip Unit 7	UFLS
Base Case 3	BDE Fault, Trip Unit 7[7]	Instability
Base Case 4	MDR Fault, Trip TL248	UFLS
Base Case 6	USL Fault, Trip Unit	UFLS
Base Case 6	MDR Fault, Trip TL248	UFLS

[5] Faults at Deer Lake Terminal Station (DLK) or CAT followed by the tripping of TL247 or TL248 would also result in the isolation of CAT generation.

[6] Discussed in Section 5.1

[7] Discussed in Section 5.1

Base Case 6	BDE Fault, Trip Unit 7	UFLS
Base Case 7	USL Fault, Trip Unit	UFLS
Base Case 7	BDE Fault, Trip Unit 7	UFLS
Base Case 8	BDE Fault, Trip Unit 7	UFLS
Base Case 9	USL Fault, Trip Unit	UFLS
Base Case 9	MDR Fault, Trip TL248	UFLS
Base Case 9	BDE Fault, Trip Unit 7	UFLS

To avoid UFLS, export over the ML must be curtailed during these events. Appendix F illustrates how underfrequency can be avoided in all base cases if the ML export is curtailed. In Base Cases 6, 7, 8, and 9, where ML export is at 500 MW, curtailing export to 250 MW is sufficient to avoid underfrequency load shedding. In other cases, ML export is below 250 MW and must be reduced to 0 MW.

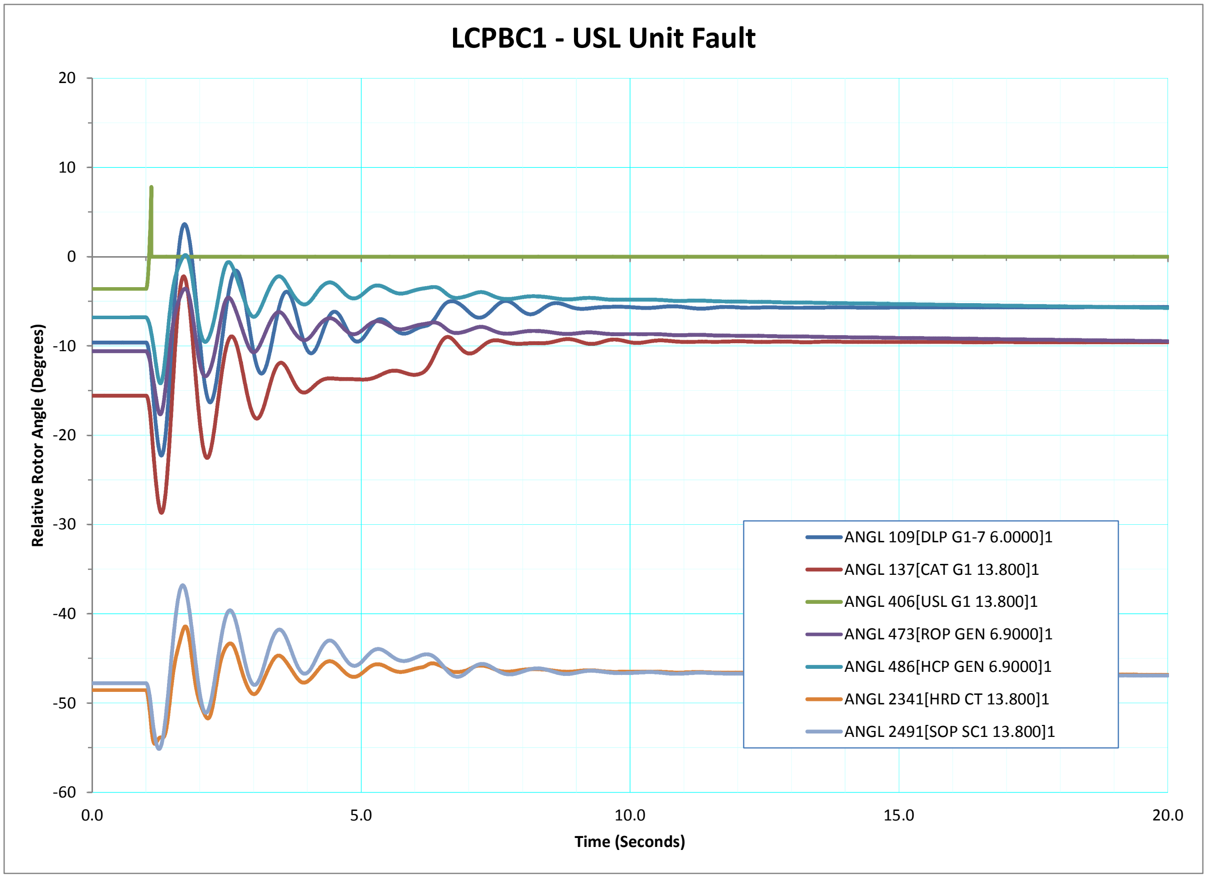


Figure 44 - LCPBC1 - USL Unit Fault - Relative Rotor Angle (Degrees)

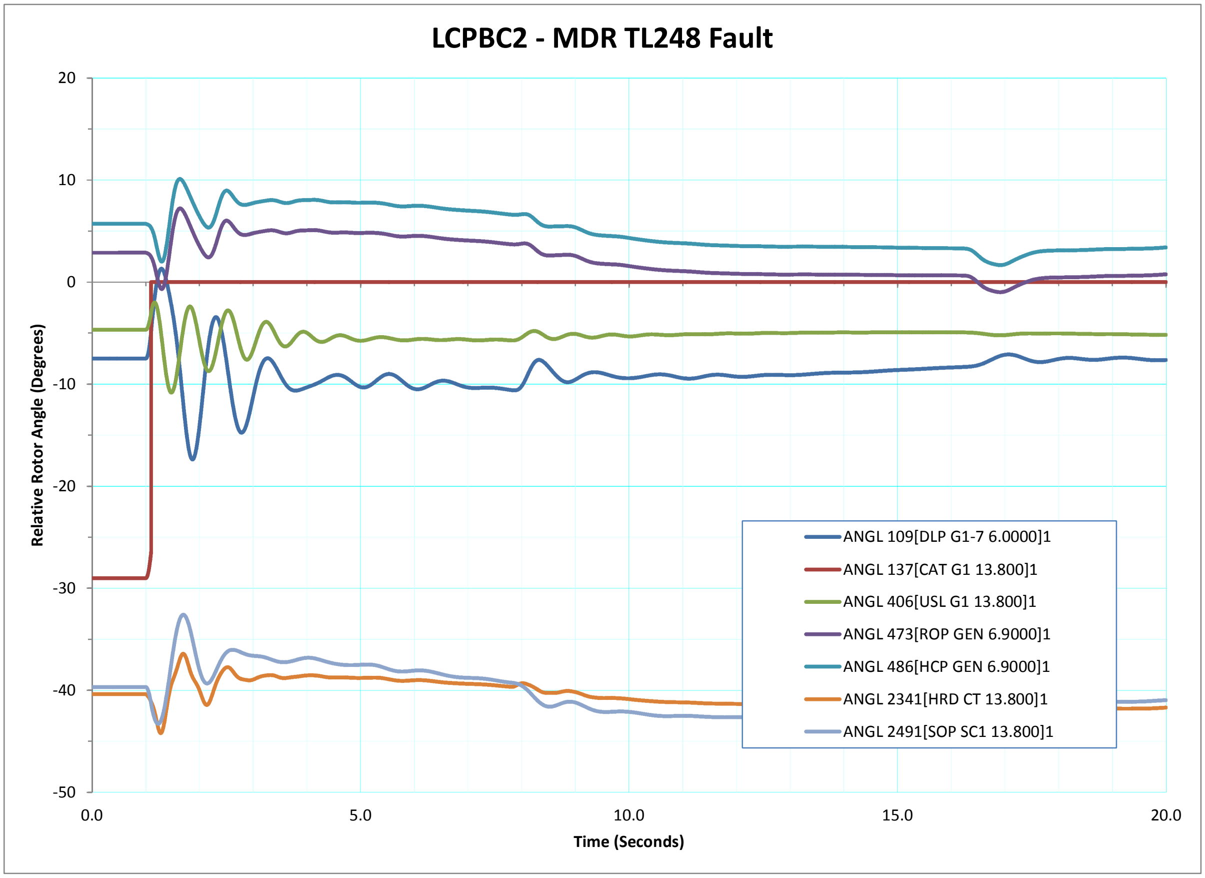


Figure 45 - LCPBC2 - MDR TL248 Fault - Relative Rotor Angle (Degrees)

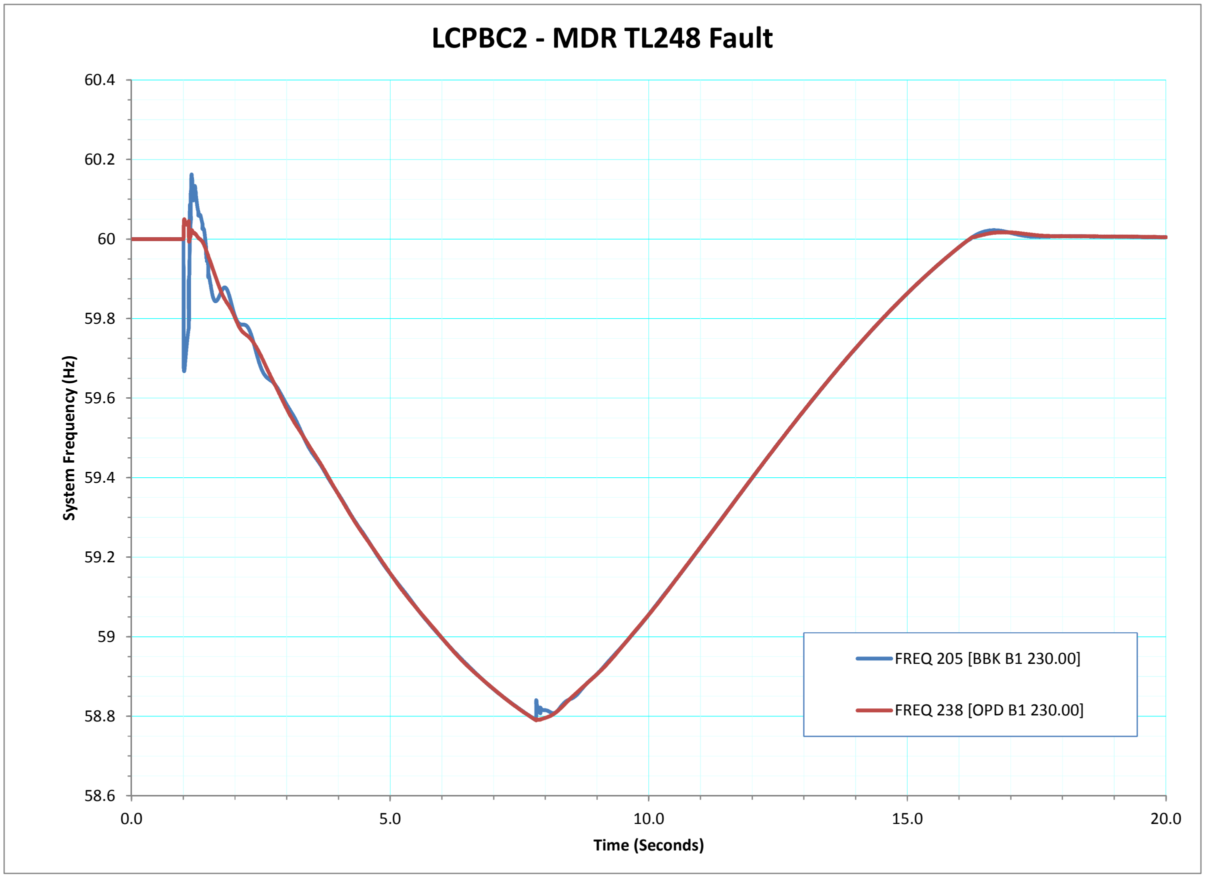


Figure 46 - LCPBC2 - MDR TL248 Fault - System Frequency (Hz)

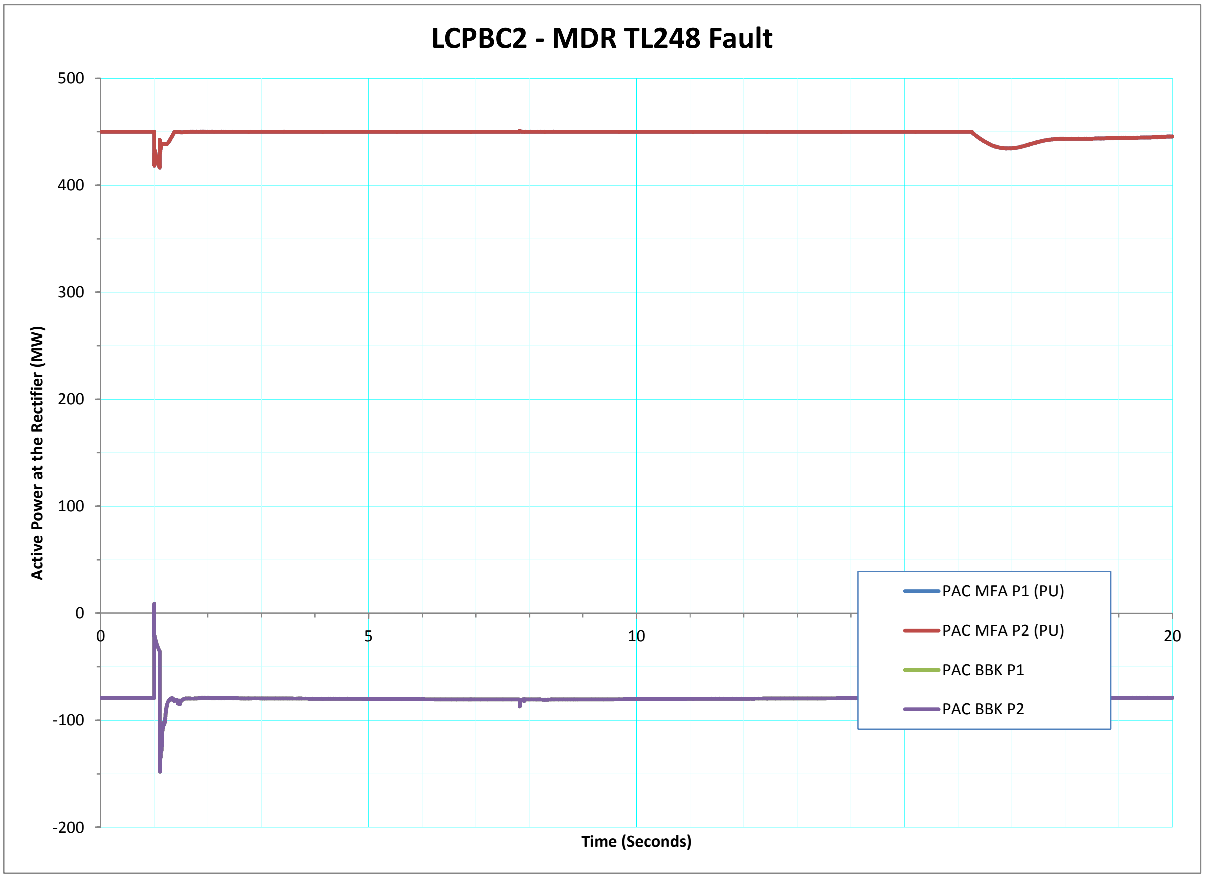


Figure 47 - LCPBC2 - MDR TL248 Fault - Active Power at the Rectifier (MW)

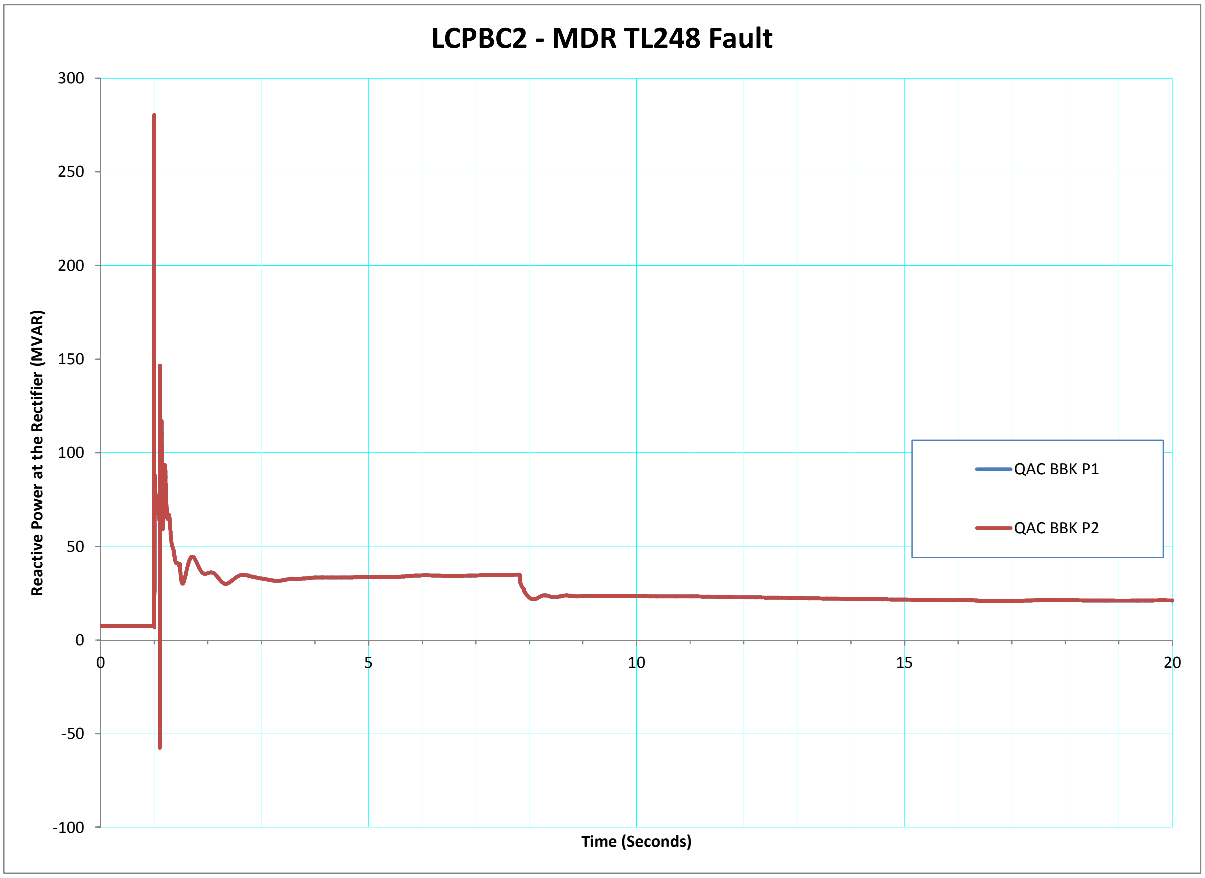


Figure 48 - LCPBC2 - MDR TL248 Fault - Reactive Power at the Rectifier (MVAR)

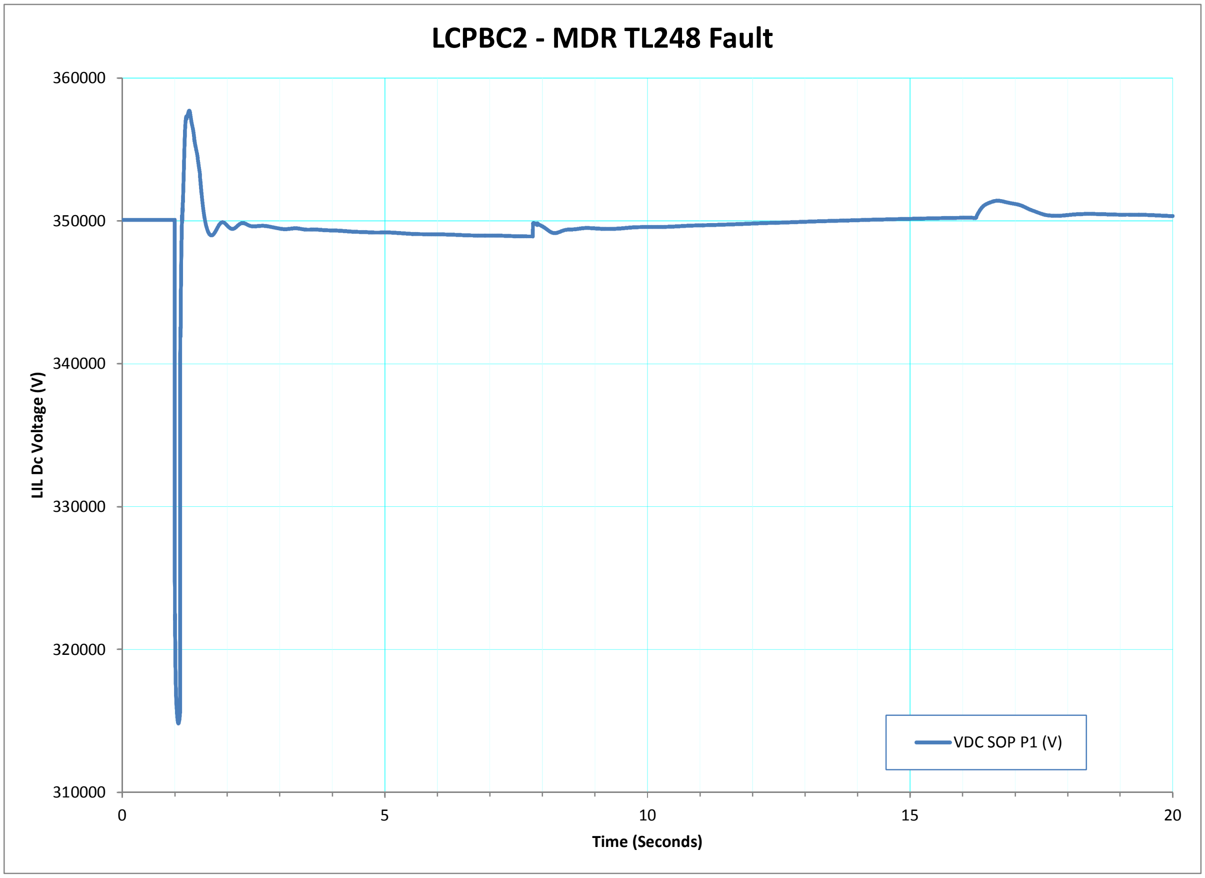


Figure 49 - LCPBC2 - MDR TL248 Fault - LIL Dc Voltage (V)

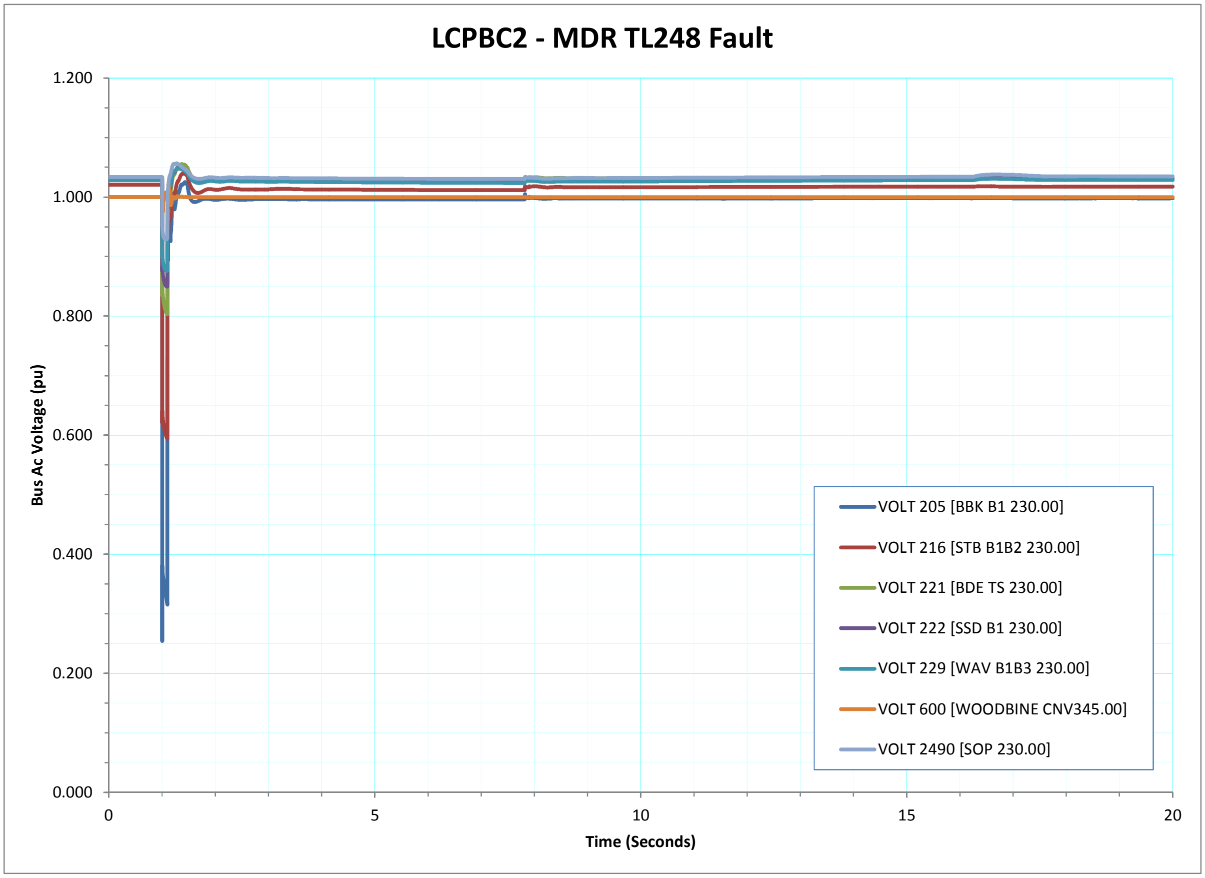


Figure 50 - LCPBC2 - MDR TL248 Fault - Bus Ac Voltage (pu)

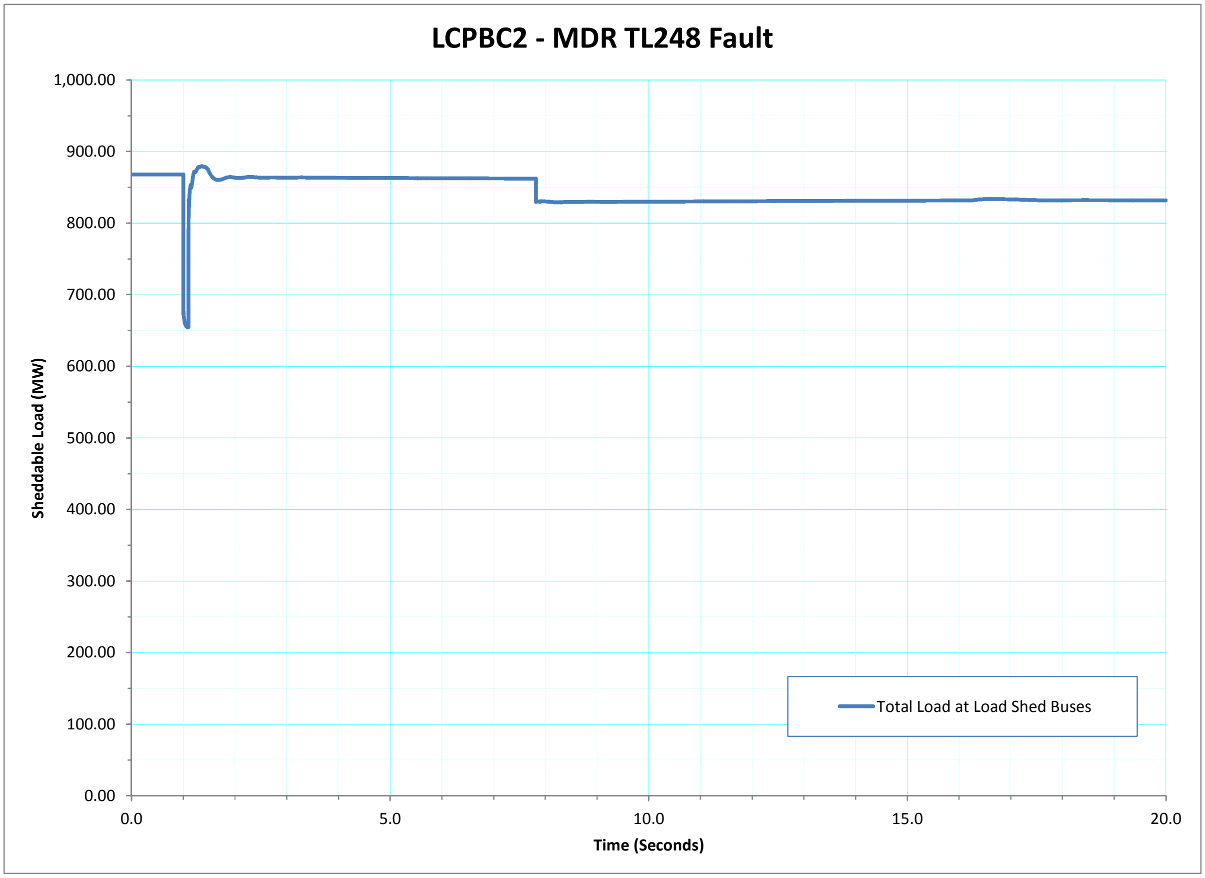


Figure 51 - LCPBC2 - MDR TL248 Fault - Sheddable Load (MW)

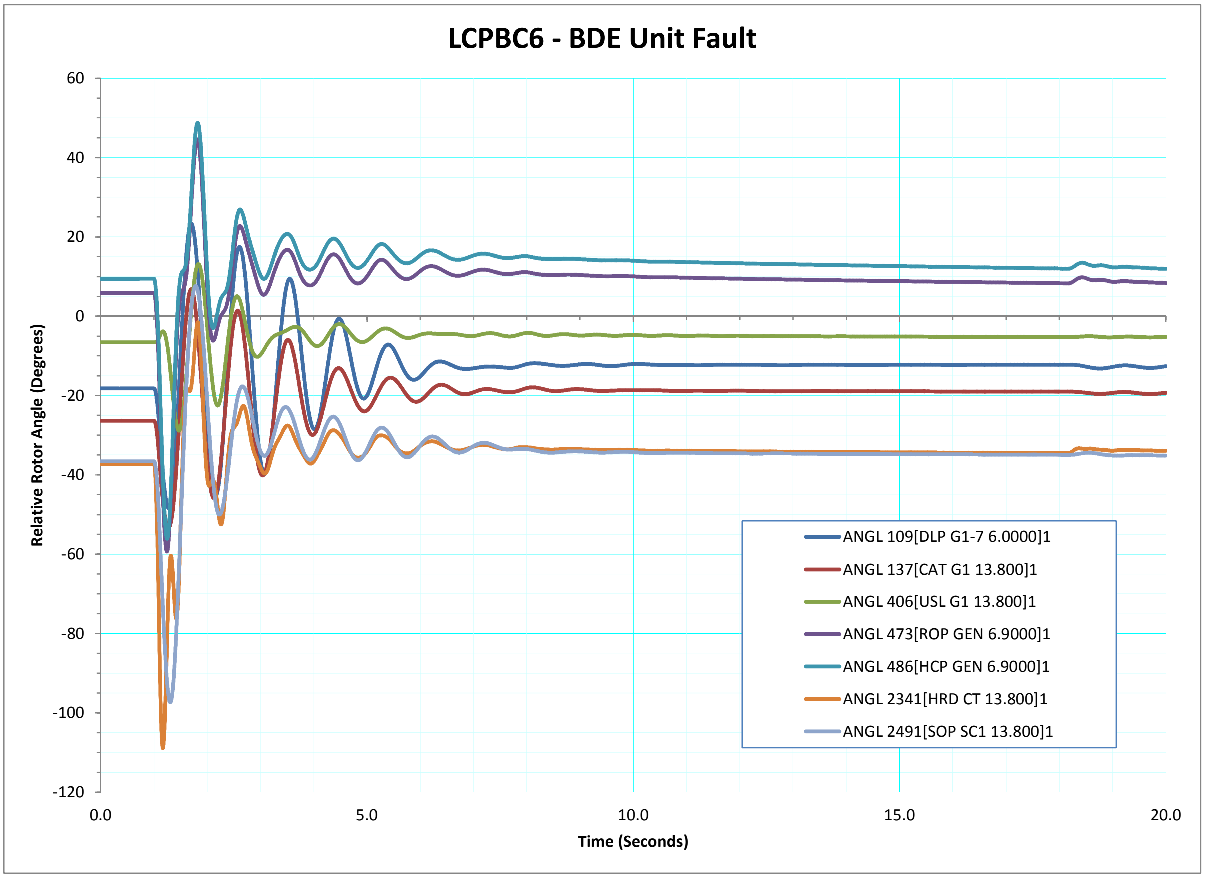


Figure 52 - LCPBC6 - BDE Unit Fault - Relative Rotor Angle (Degrees)

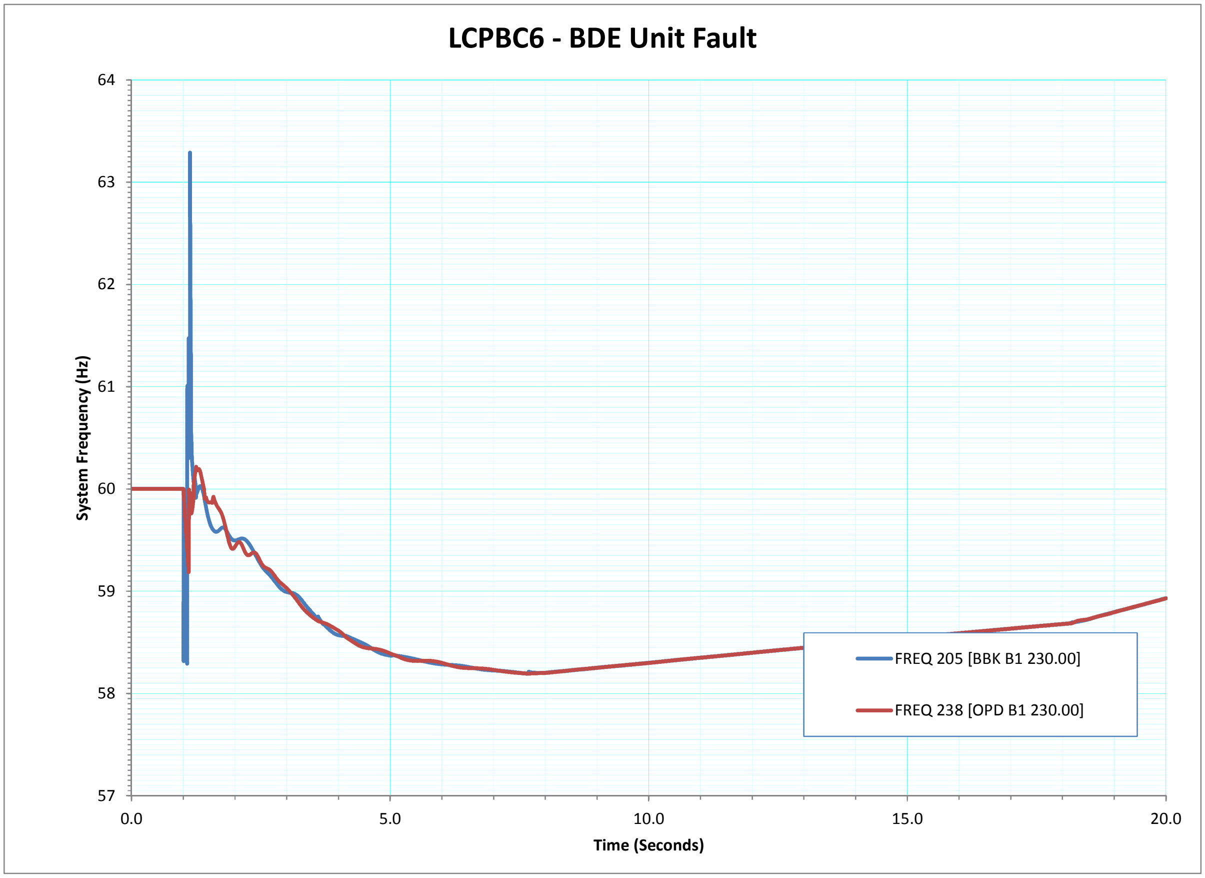


Figure 53 - LCPBC6 - BDE Unit Fault - System Frequency (Hz)

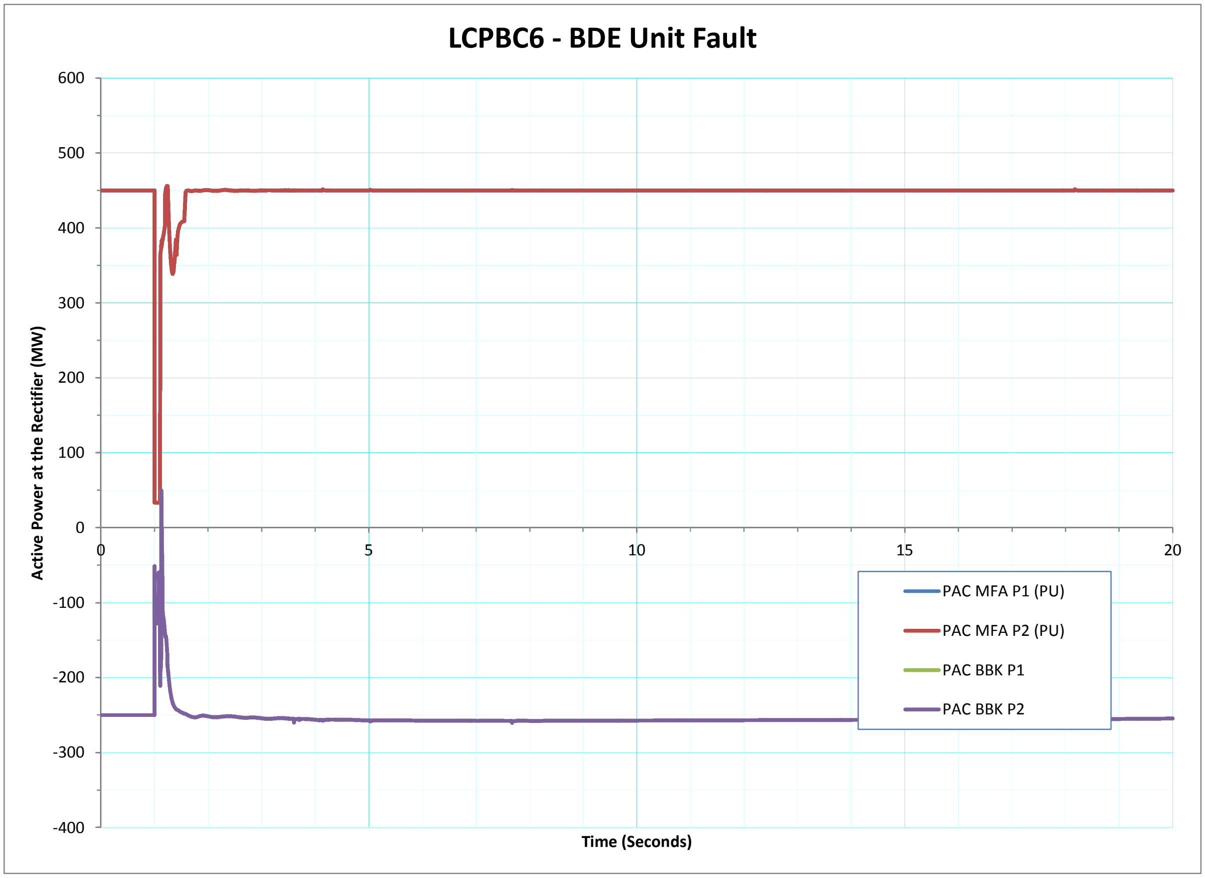


Figure 54 - LCPBC6 - BDE Unit Fault - Active Power at the Rectifier (MW)

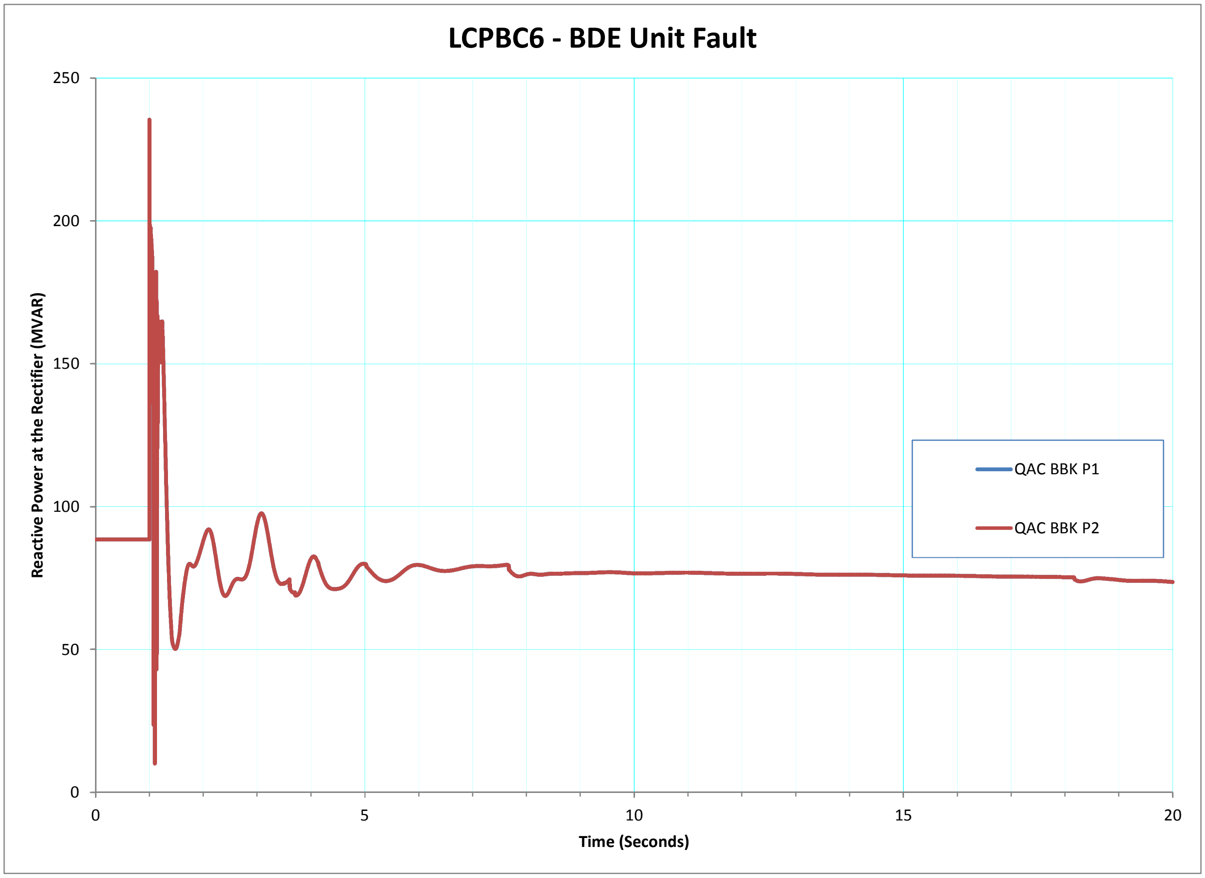


Figure 55 - LCPBC6 - BDE Unit Fault - Reactive Power at the Rectifier (MVAR)

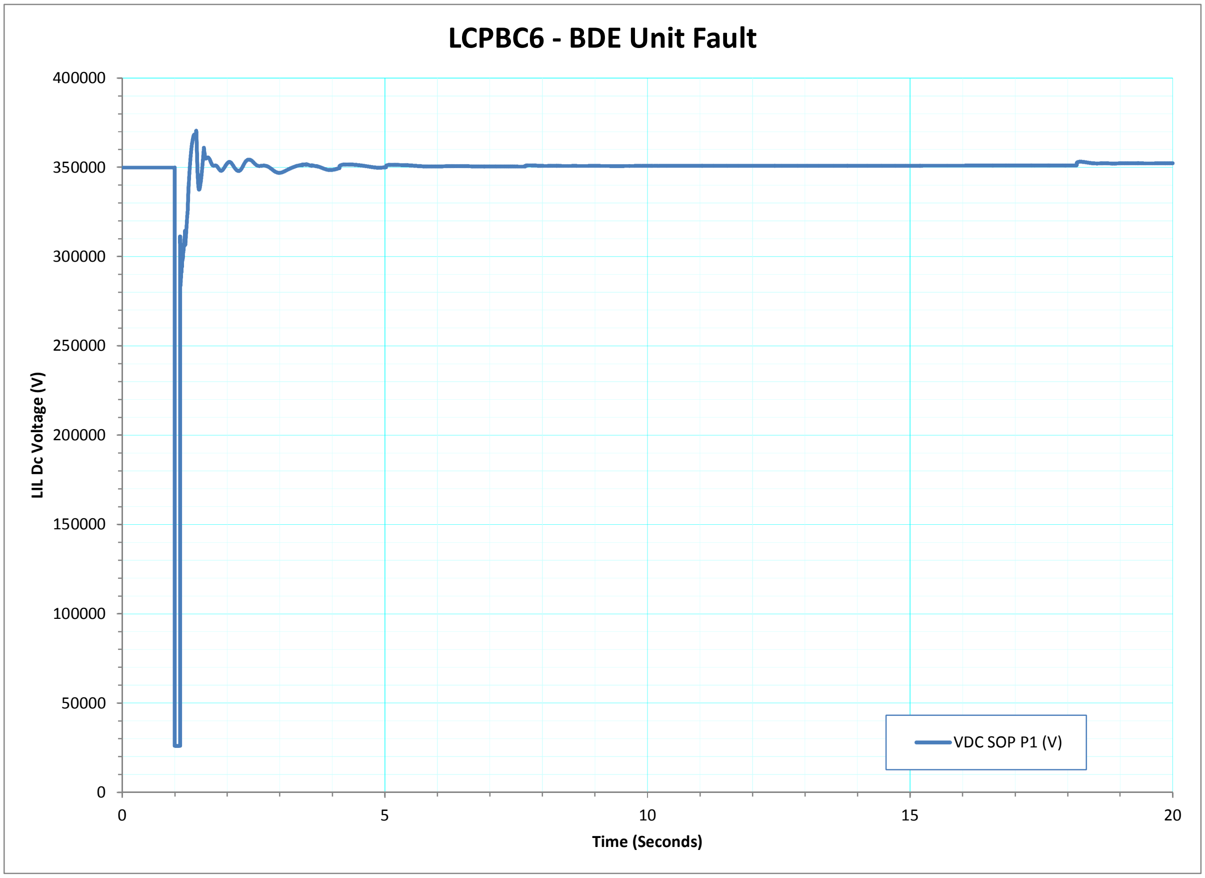


Figure 56 - LCPBC6 - BDE Unit Fault - LIL Dc Voltage (V)

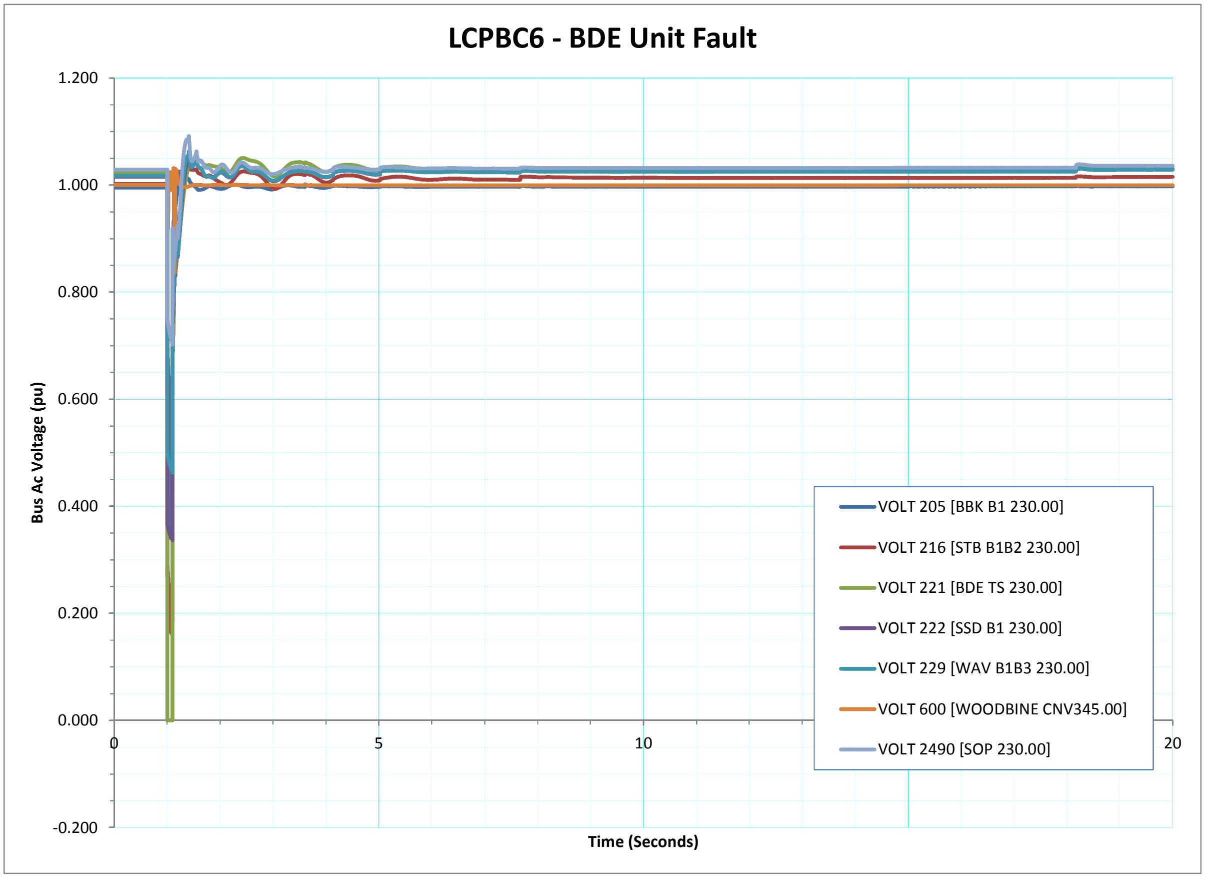


Figure 57 - LCPBC6 - BDE Unit Fault - Bus Ac Voltage (pu)

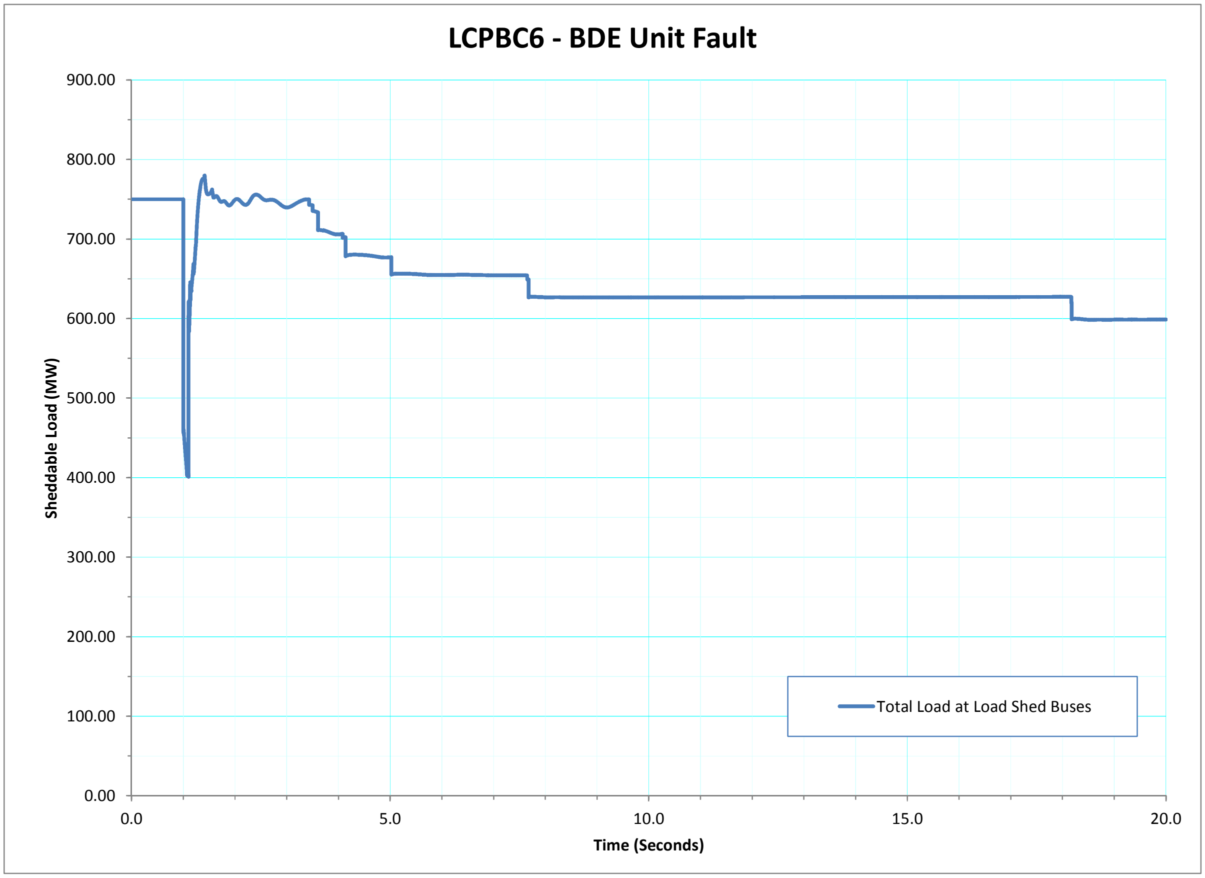


Figure 58 - LCPBC6 - BDE Unit Fault - Sheddable Load (MW)

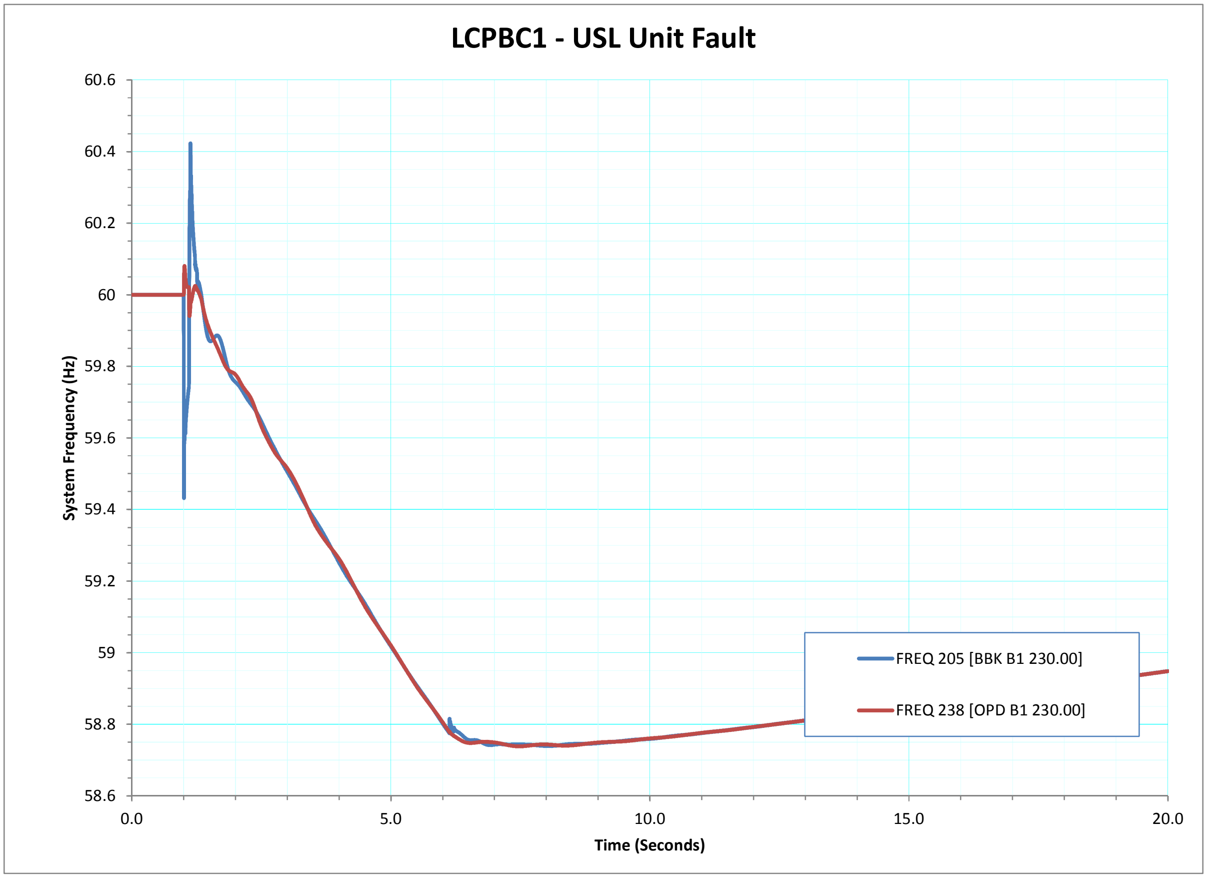


Figure 59 - LCPBC1 - USL Unit Fault - System Frequency (Hz)

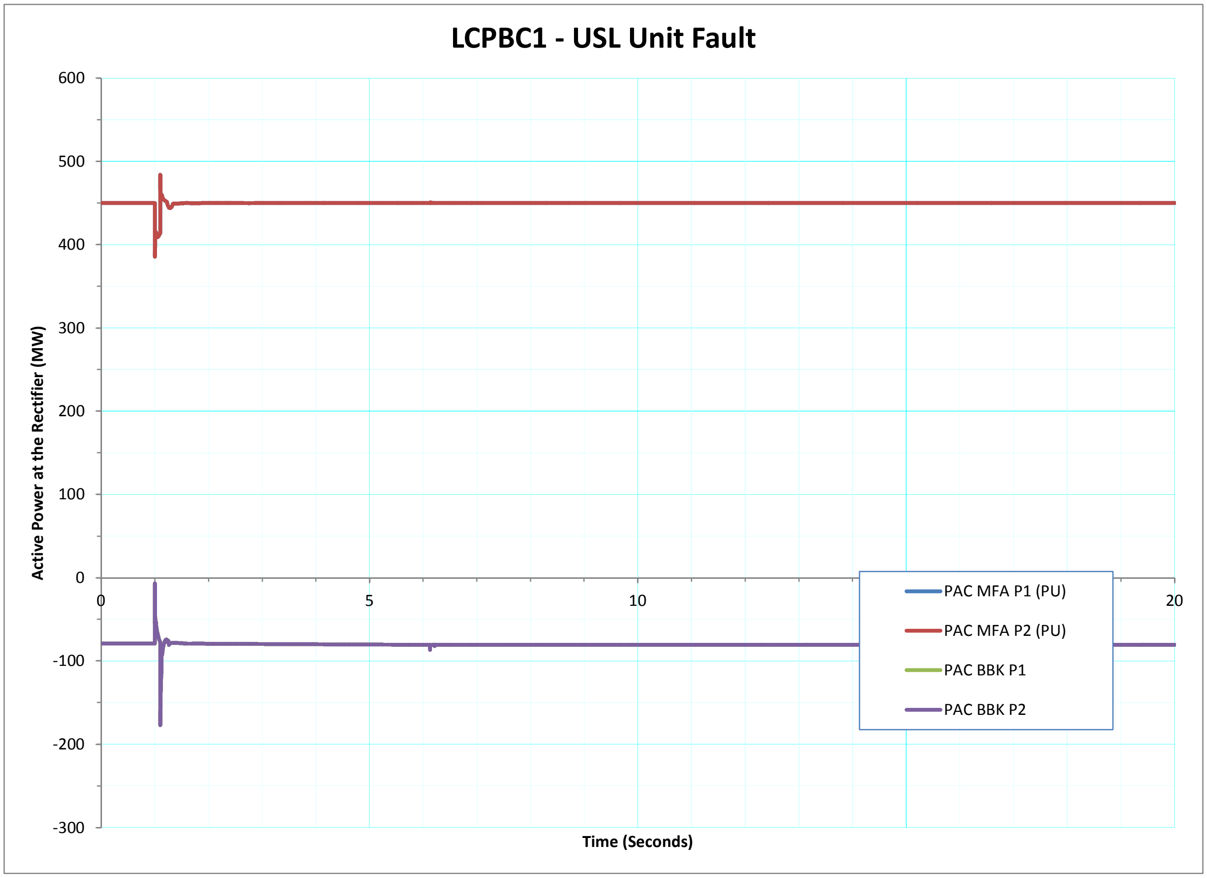


Figure 60 - LCPBC1 - USL Unit Fault - Active Power at the Rectifier (MW)

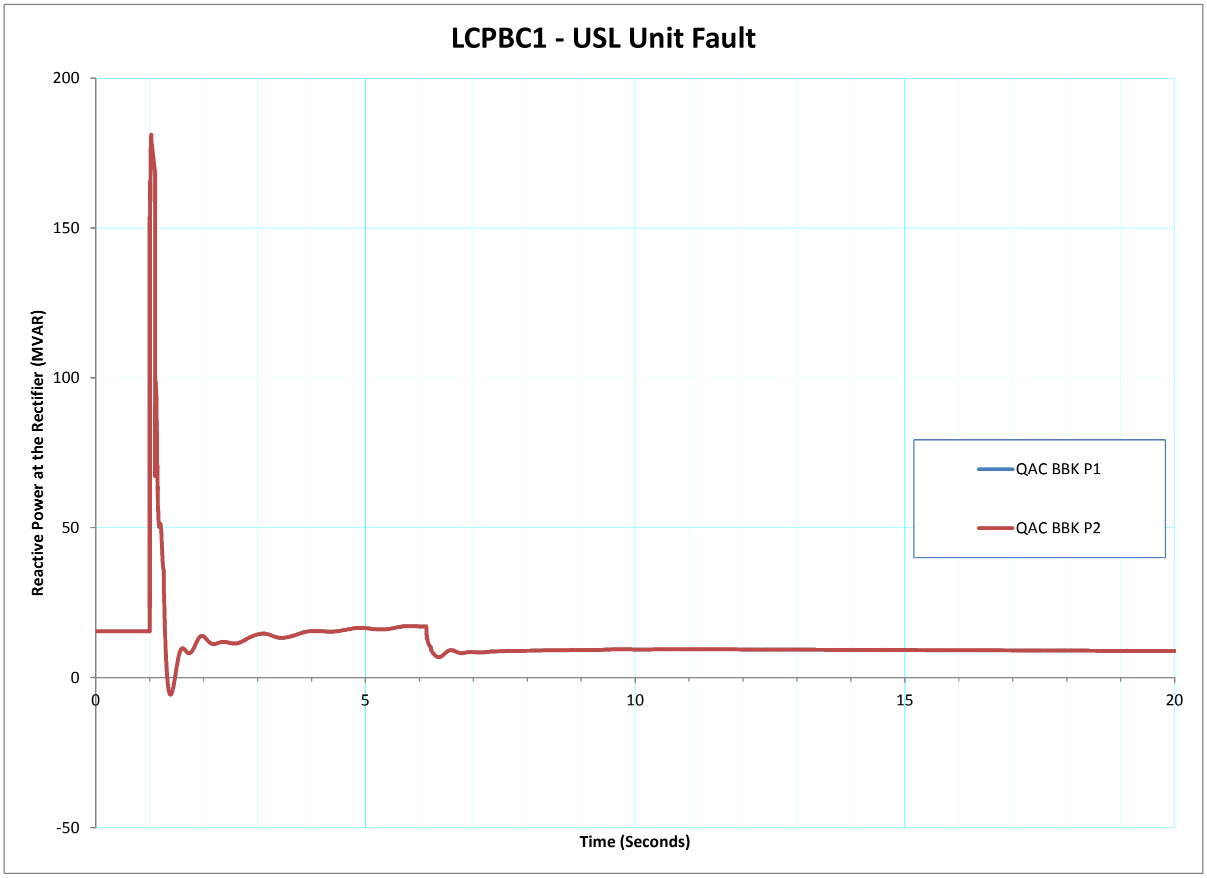


Figure 61 - LCPBC1 - USL Unit Fault - Reactive Power at the Rectifier (MVAR)

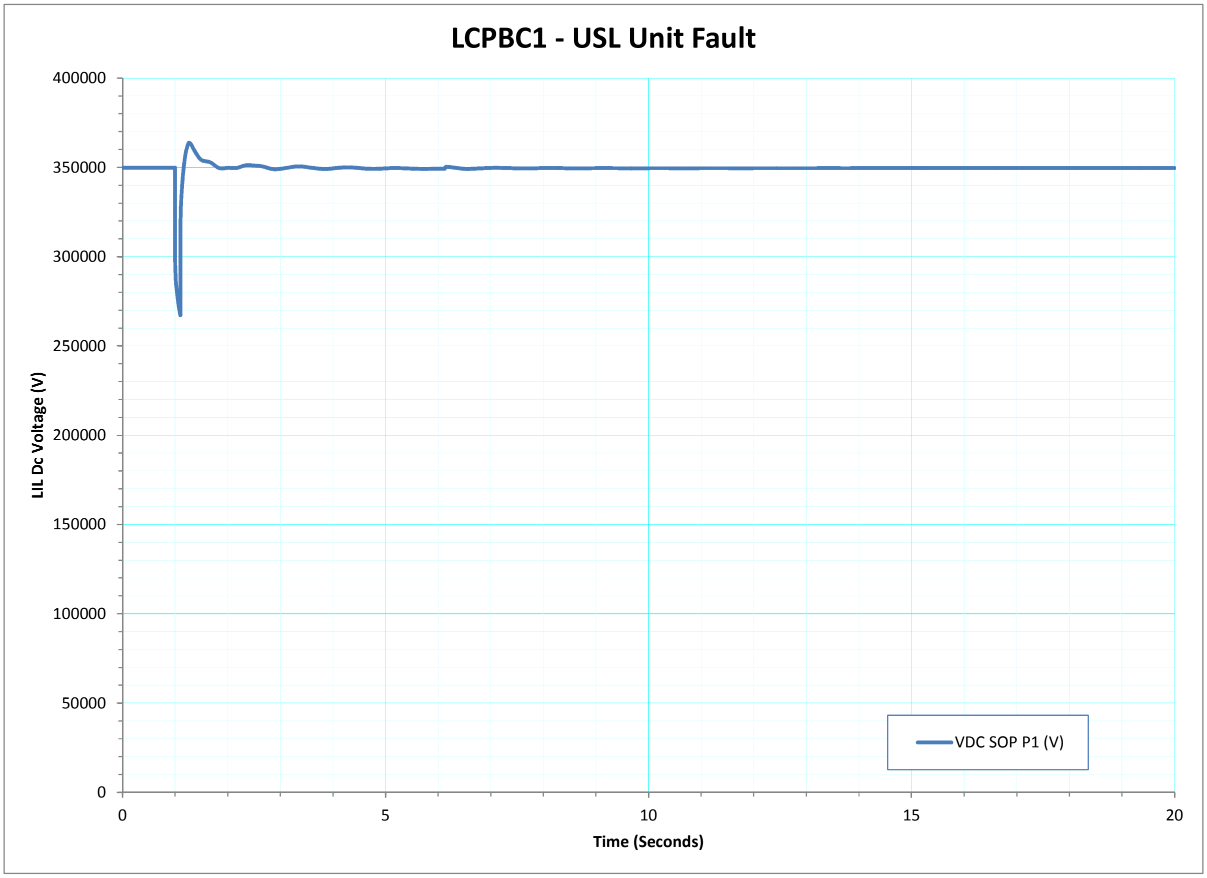


Figure 62 - LCPBC1 - USL Unit Fault - LIL Dc Voltage (V)

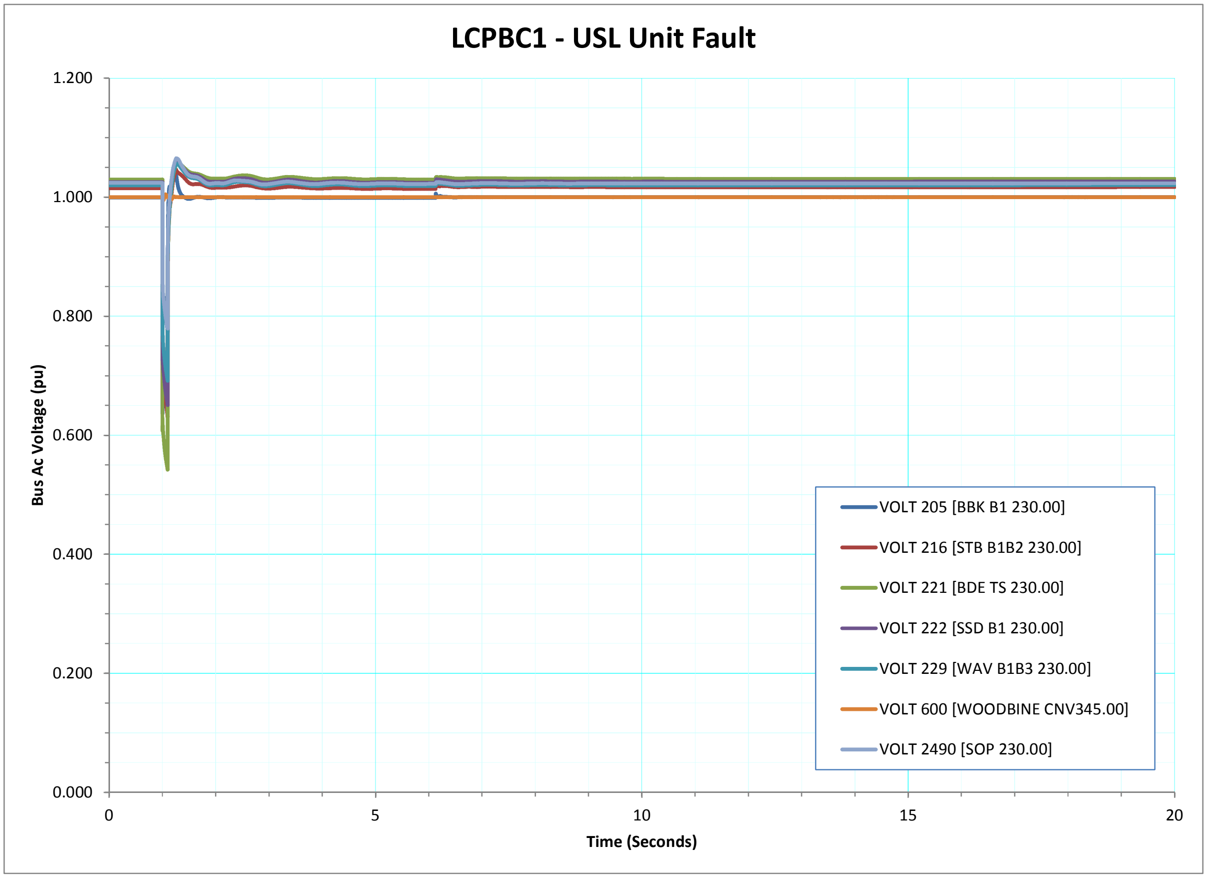


Figure 63 - LCPBC1 - USL Unit Fault - Bus Ac Voltage (pu)

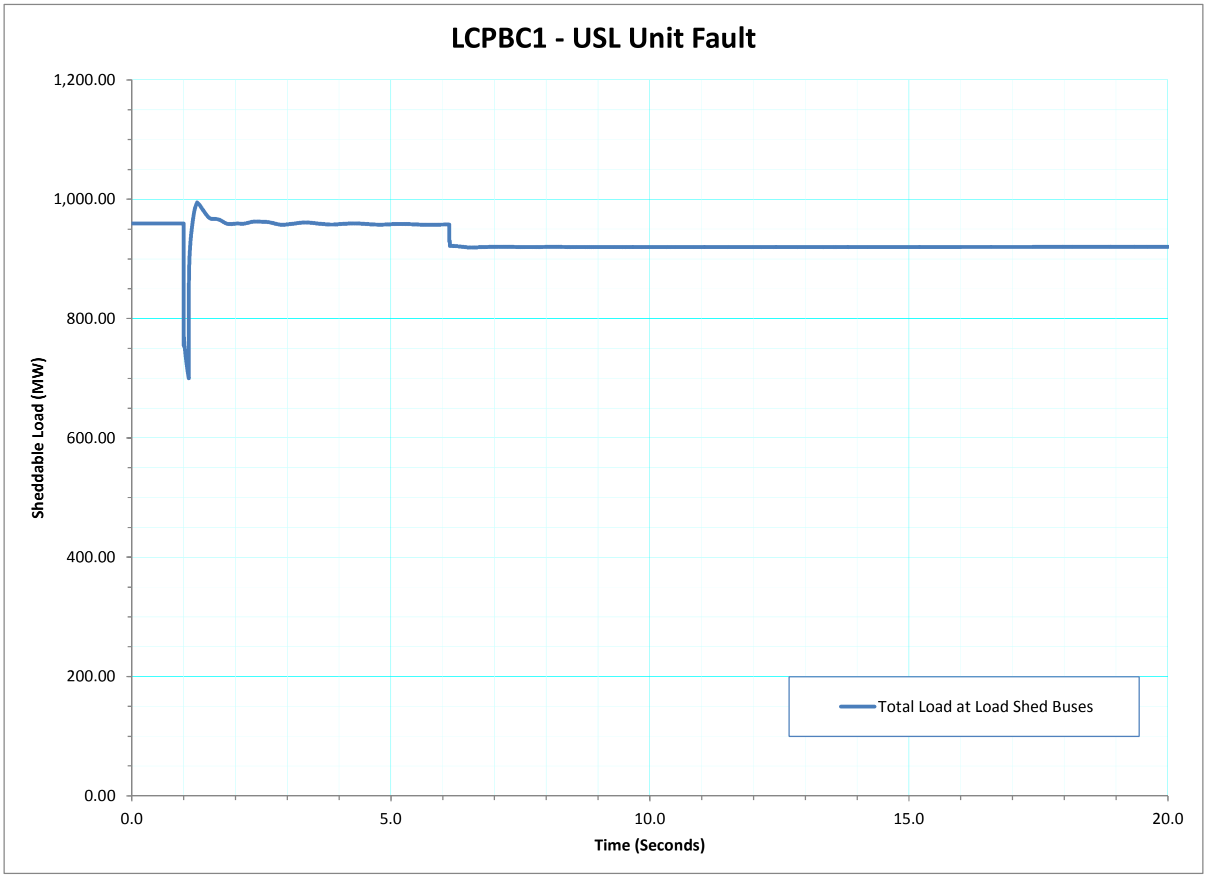


Figure 64 - LCPBC1 - USL Unit Fault - Sheddable Load (MW)

5.6. LOSS OF A SYNCHRONOUS CONDENSER AT SOLDIERS POND

As per Table 8, it was found that a three-phase fault at SOP followed by the tripping of a synchronous condenser in BC9 results in commutation failure during post-fault recovery of the HVdc voltage.

Table 8 – Notable System Conditions Following Fault at SOP and the Tripping of a Synchronous Condenser

Base Case	Contingency	System Condition
Base Case 9	SOP Fault, Trip Synchronous Condenser	LIL commutation failure

In this case, the LIL and ML are operating at capacity, while the generation on the Island Interconnected Transmission System is reduced to approximately 370 MW. The loss of a synchronous condenser at SOP results in a deficit of reactive power, particularly as the export of 500 MW over the ML is not interrupted by the fault. This is illustrated in the figures below.

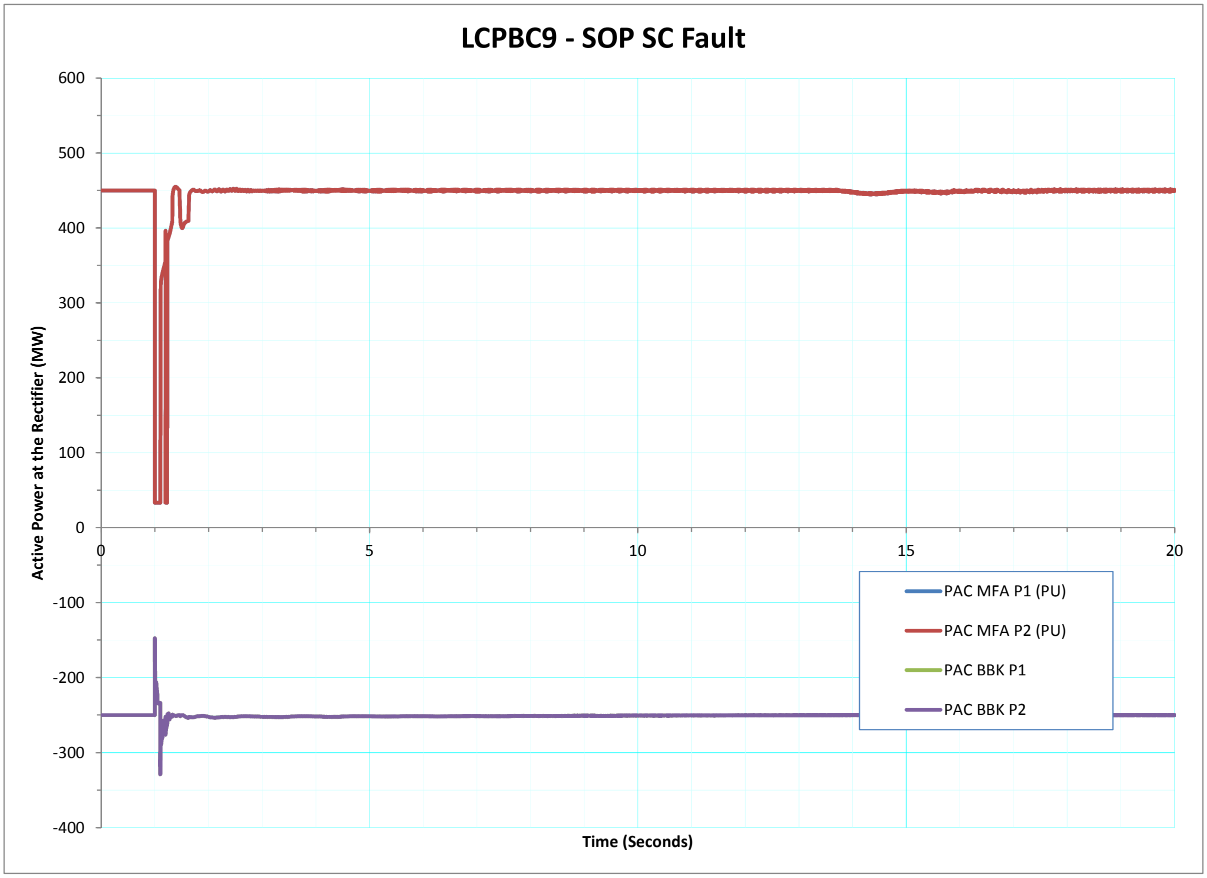


Figure 65 - LCPBC9 - SOP SC Fault - Active Power at the Rectifier (MW)

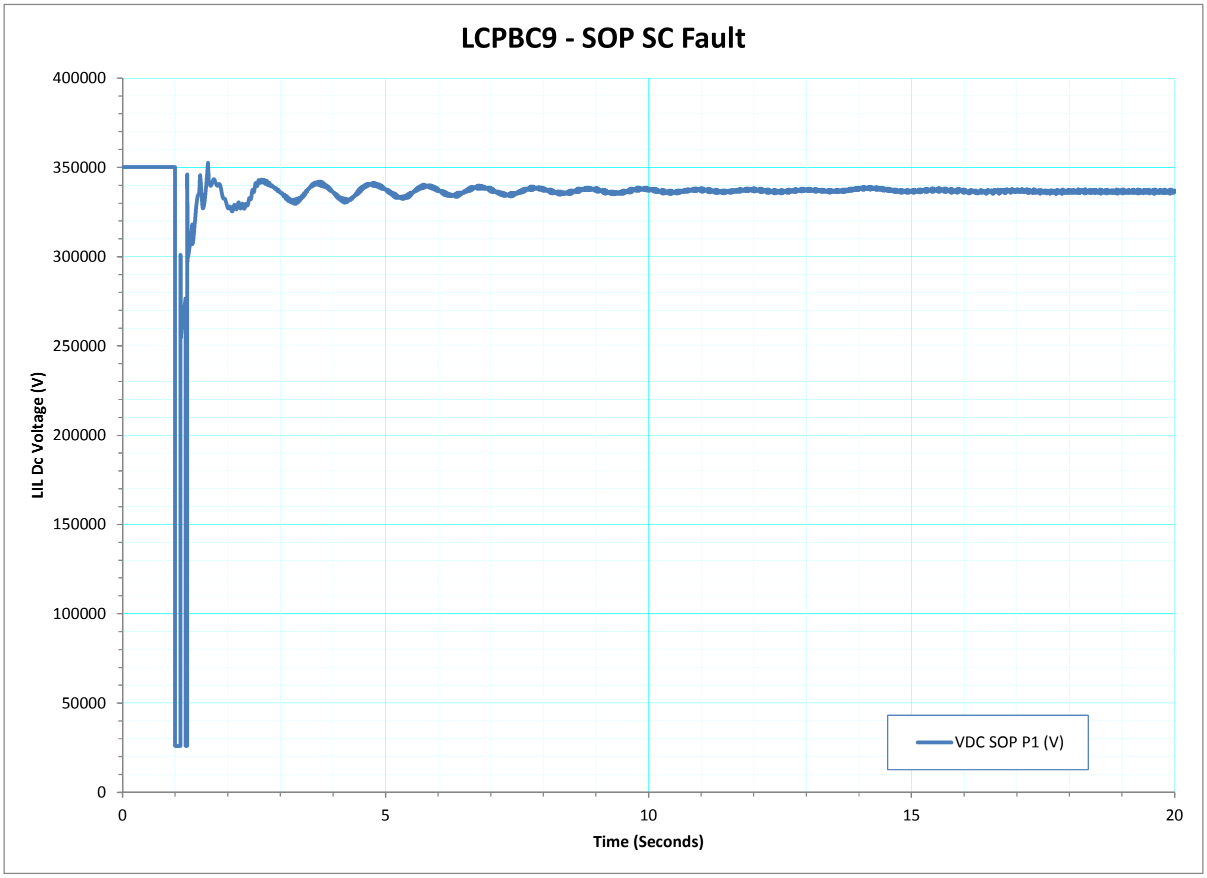


Figure 66 - LCPBC9 - SOP SC Fault - LIL Dc Voltage (V)

Additional analysis was performed to investigate the impact of curtailing the ML in the event of the SOP fault. As indicated below, the commutation failure is eliminated if the export is reduced from 500 MW to 250 MW.

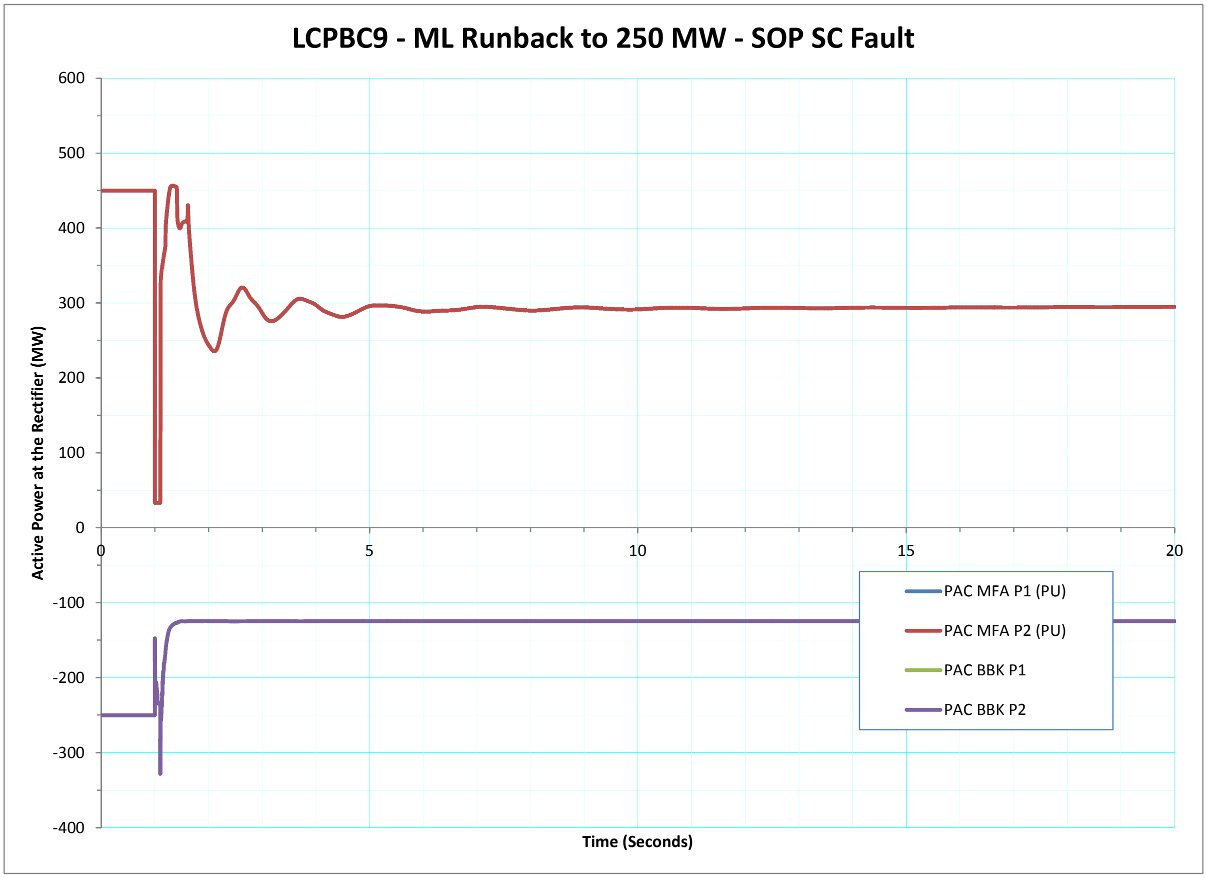


Figure 67 - LCPBC9 - ML Runback to 250 MW - SOP SC Fault - Active Power at the Rectifier (MW)

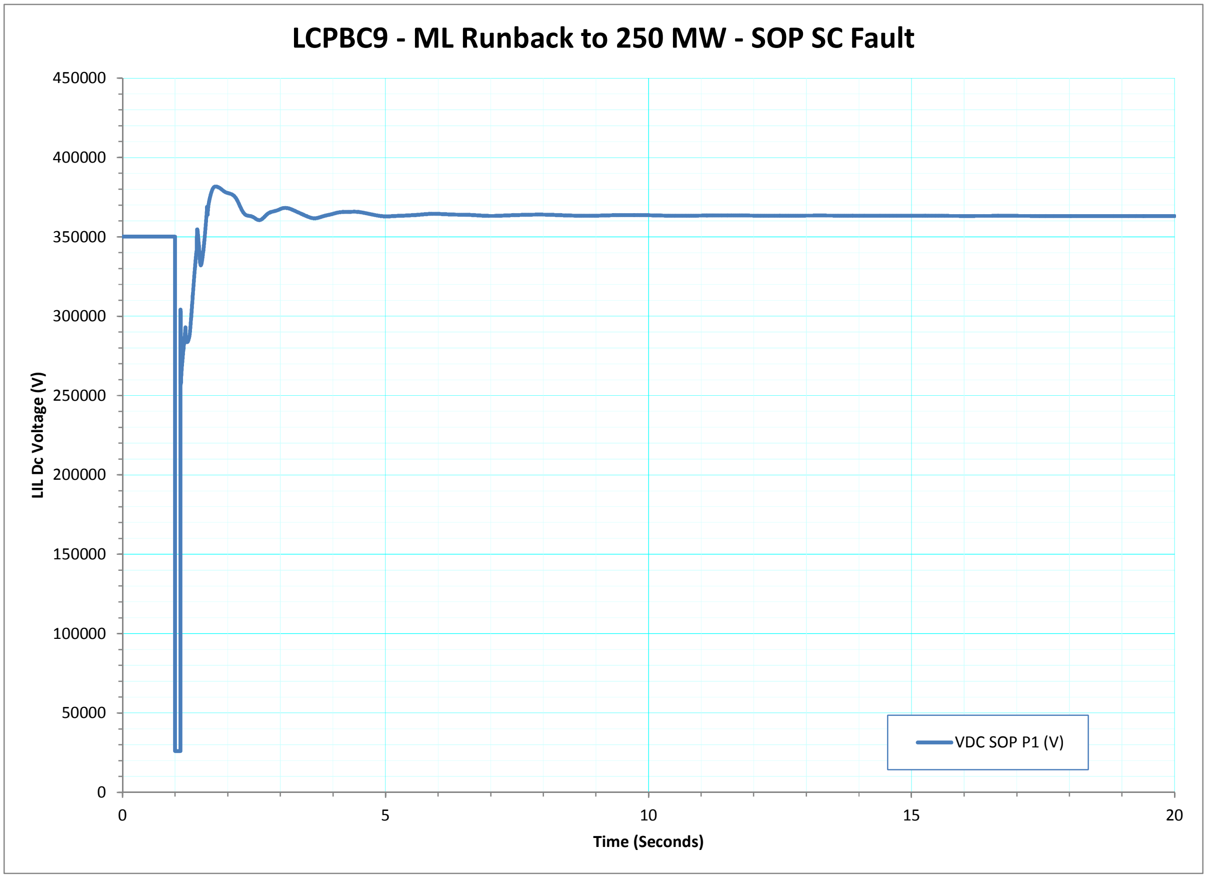


Figure 68 - LCPBC9 - ML Runback to 250 MW - SOP SC Fault - LIL Dc Voltage (V)

As discussed in Section 5.3, the BC9 case represents an extreme operating scenario where both the LIL and ML are operating at rated capacity while minimal generation is dispatched within the Interconnected Island System. Rather than curtailing ML exports for all three-phase faults at Soldiers Pond, a more practical solution would be to specify operating limitation for the system. Such limitations would ensure that extreme operating conditions are avoided and that system performance is acceptable.

6. CONCLUSIONS

A transient stability analysis was performed to identify unacceptable conditions arising from disturbances within the Island Interconnected System. Recommendations for these conditions are listed in Table 9.

Table 9 – Summary of Transient Stability Analysis

Contingency	Required Remedial Action
Faults at Bay d'Espoir	No Action Accepted as "Exceptional Contingency"
Faults at Bottom Brook, Buchans, Granite Canal, Massey Drive, Stony Brook, and Upper Salmon	Curtailment of ML Export to 250 MW.
LIL Temporary Bipole Faults	Curtailment of ML Export to 250 MW.
LIL Permanent Pole Faults	Curtailment of ML Export to 250 MW or 0 MW[8].
LIL Faults While In Monopole Mode	Curtailment of ML Export to 0 MW.
Loss of Island Generation	Curtailment of ML Export to 250 MW or 0 MW[9].
Loss of a Synchronous Condenser at Soldiers Pond	Development of Operating Instruction to avoid unacceptable system condition.[10].

It should be noted that the analysis described in this report is preliminary. It is recommended that a more comprehensive analysis be performed with detailed HVdc system models in conjunction with the vendors during the final design stages and during operational studies. Such an analysis will help to ensure the acceptable performance of the transmission system following the interconnection of the LIL and the ML.

[8] Depending on initial value of ML export.

[9] Depending on initial value of ML export.

[10] Unacceptable conditions resulting from this contingency were only observed for Base Case 9.

APPENDIX A Base Case Load Flow Plots

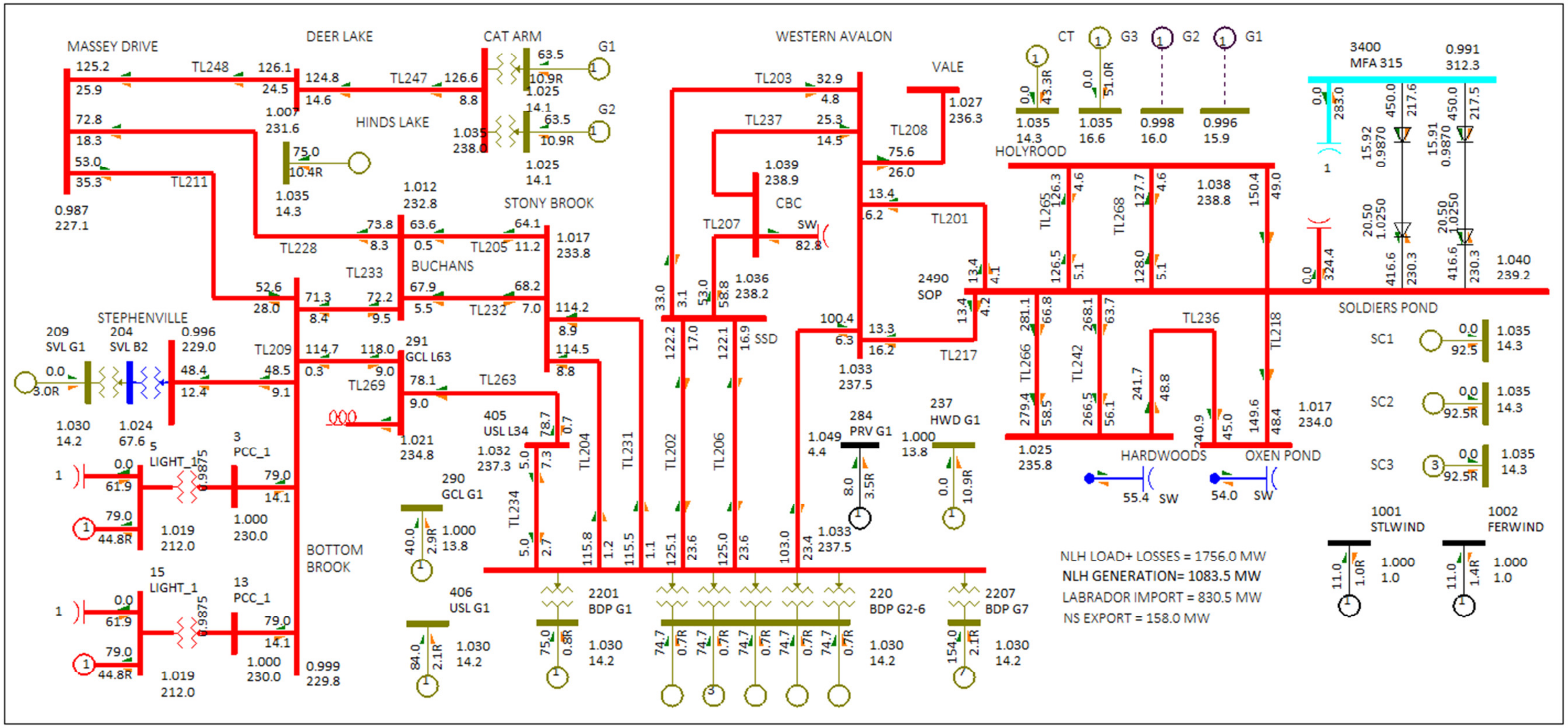


Figure 69 – Load Flow Plot – Base Case 1

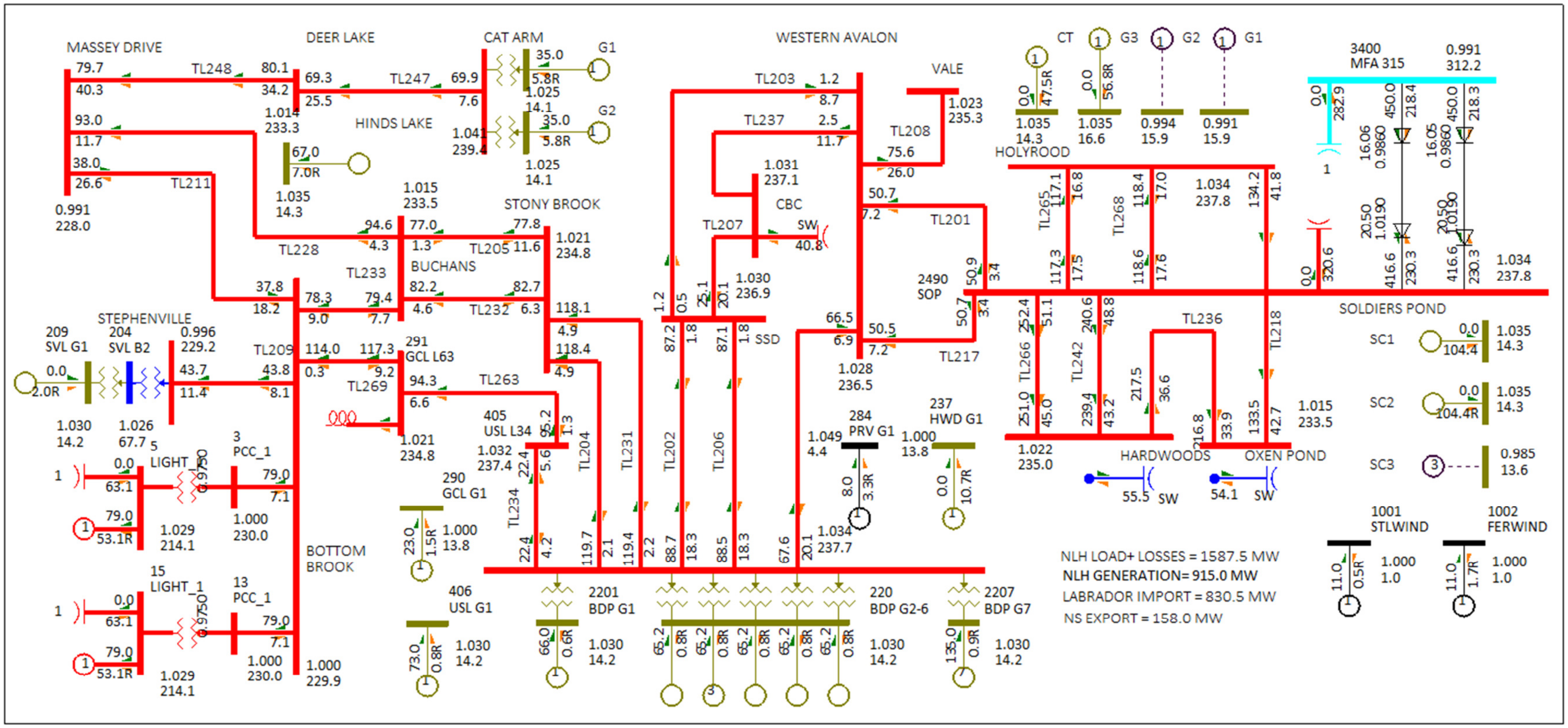


Figure 70 – Load Flow Plot – Base Case 2

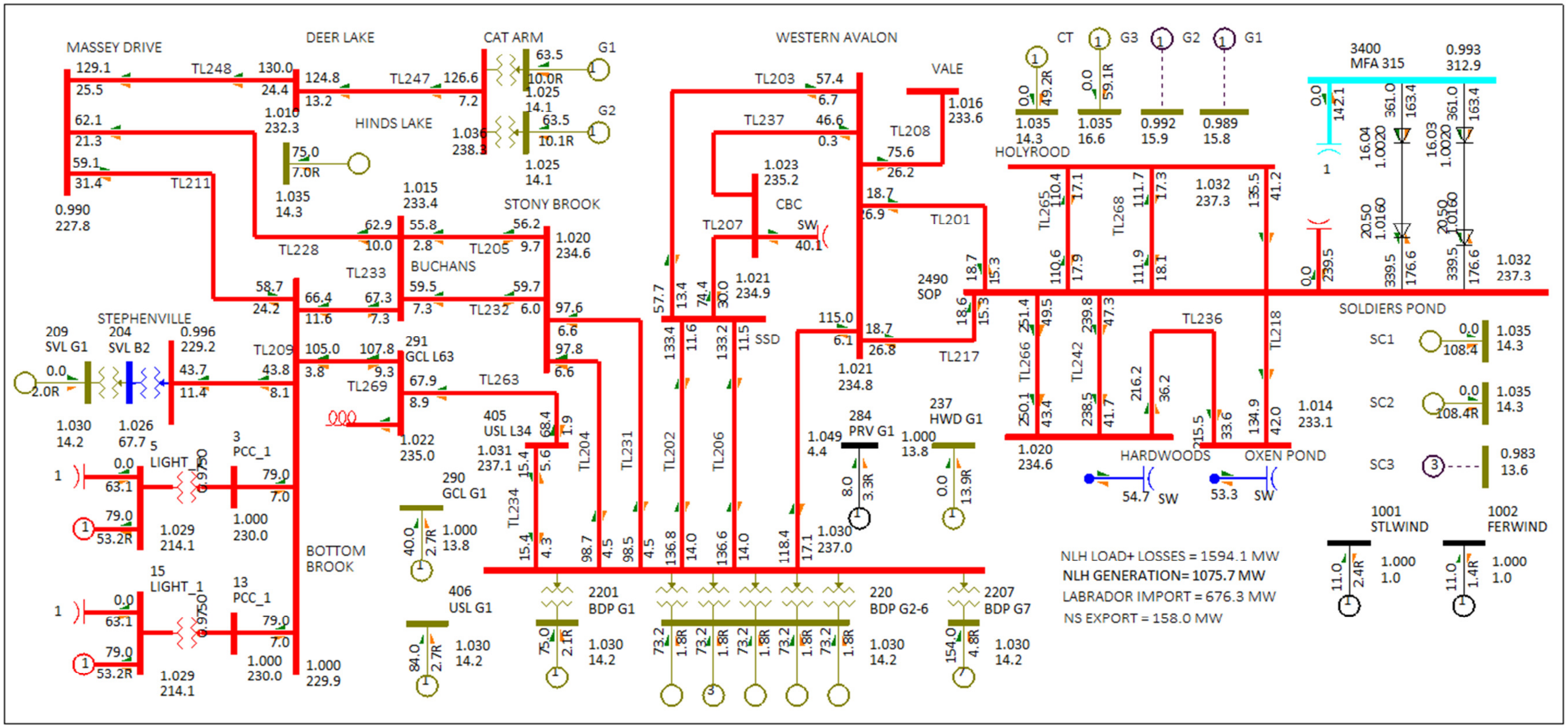


Figure 71 – Load Flow Plot – Base Case 3

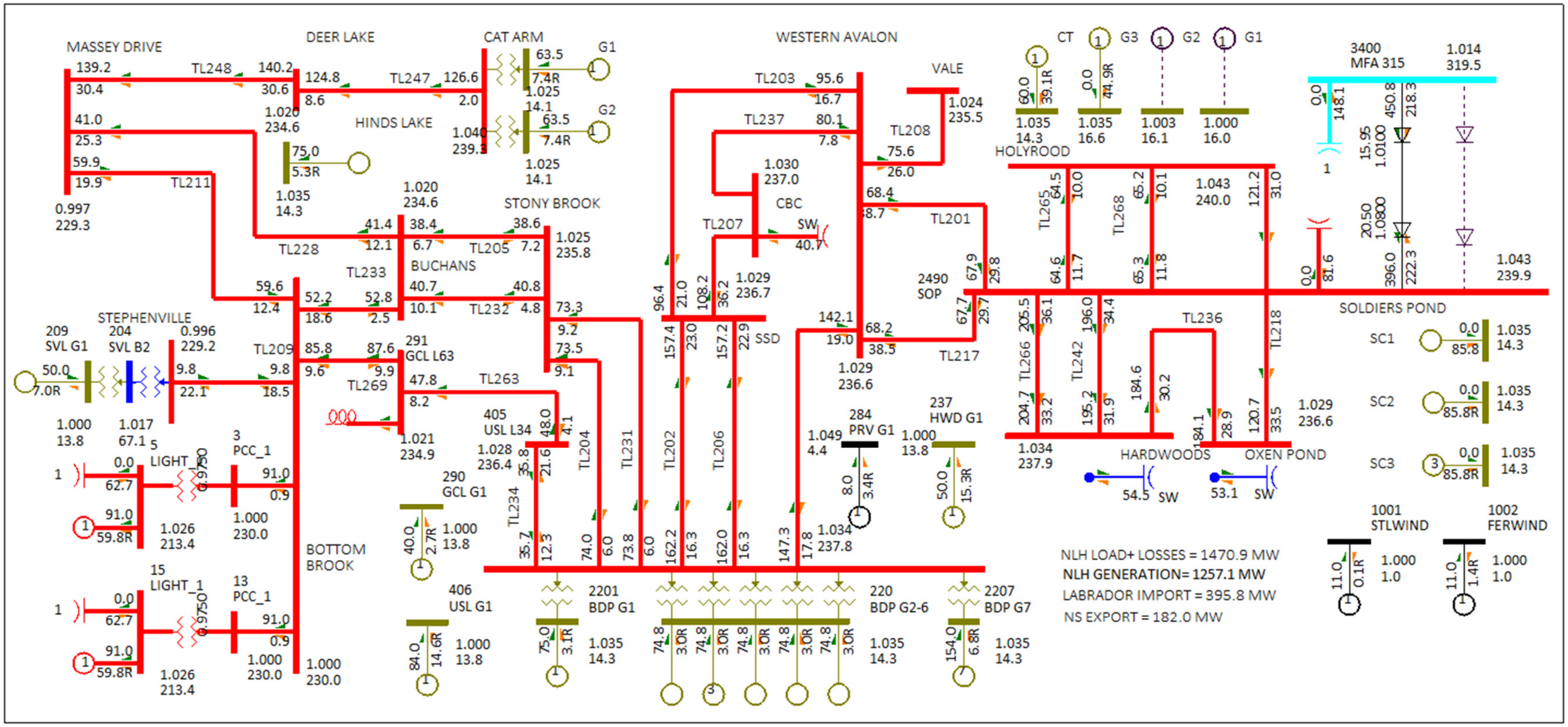


Figure 72 – Load Flow Plot – Base Case 4

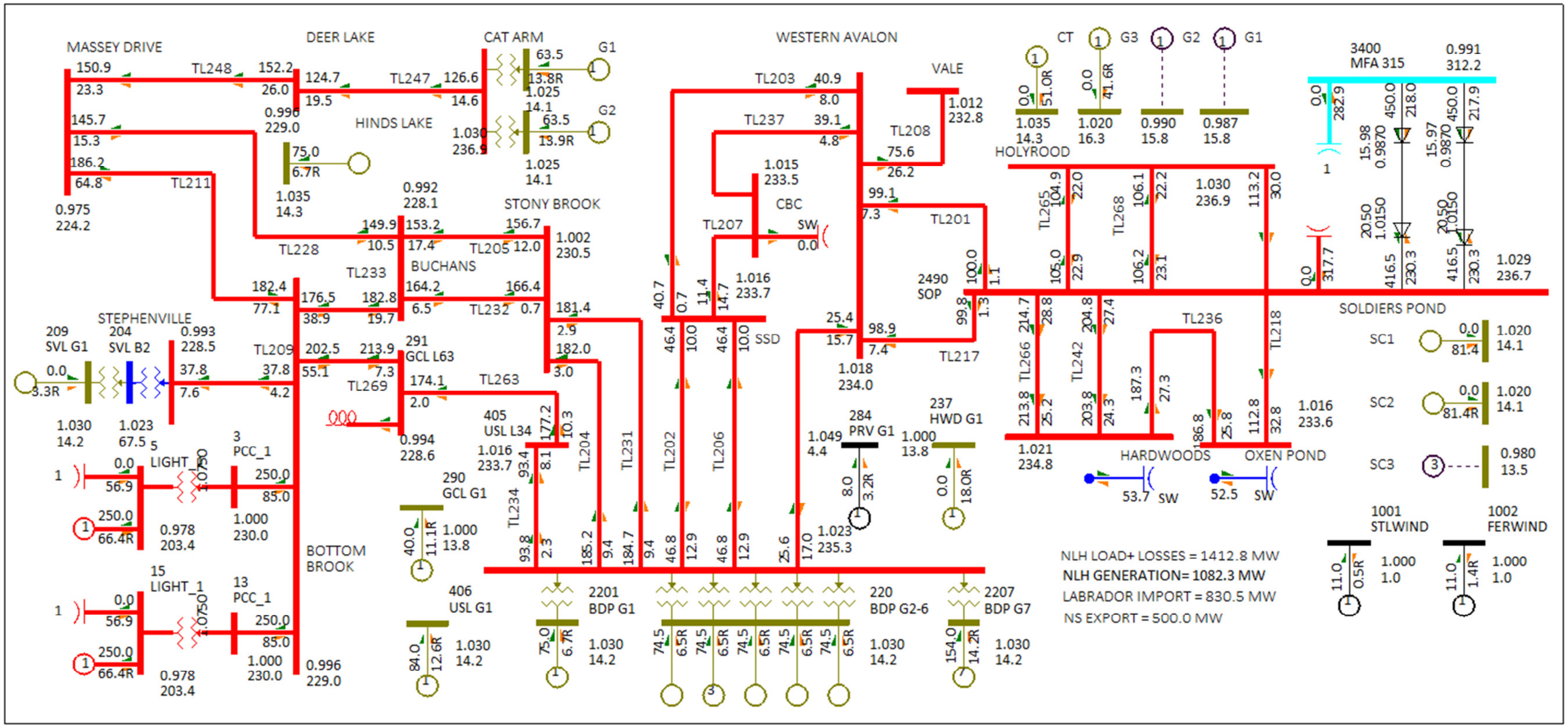


Figure 73 – Load Flow Plot – Base Case 6

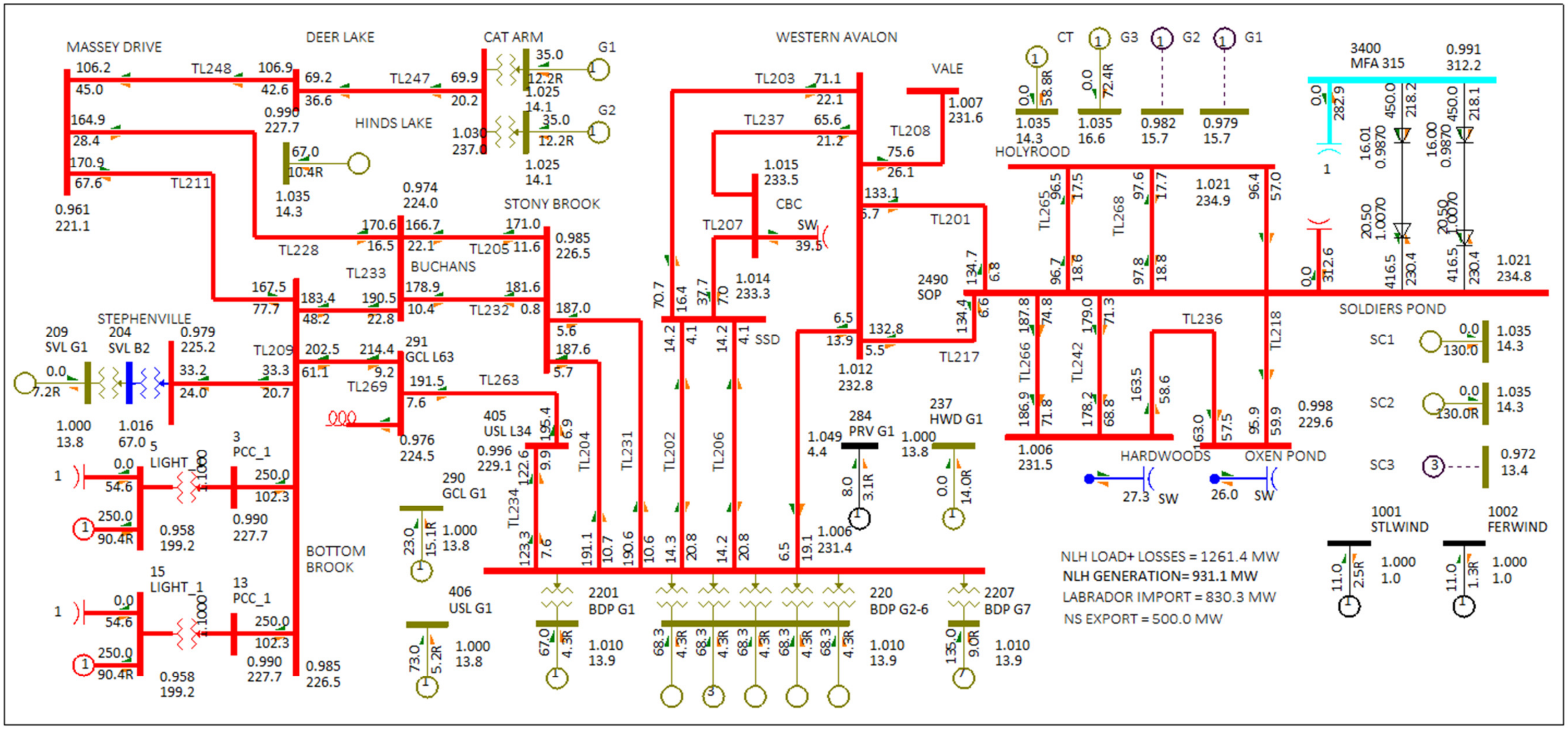


Figure 74 – Load Flow Plot – Base Case 7

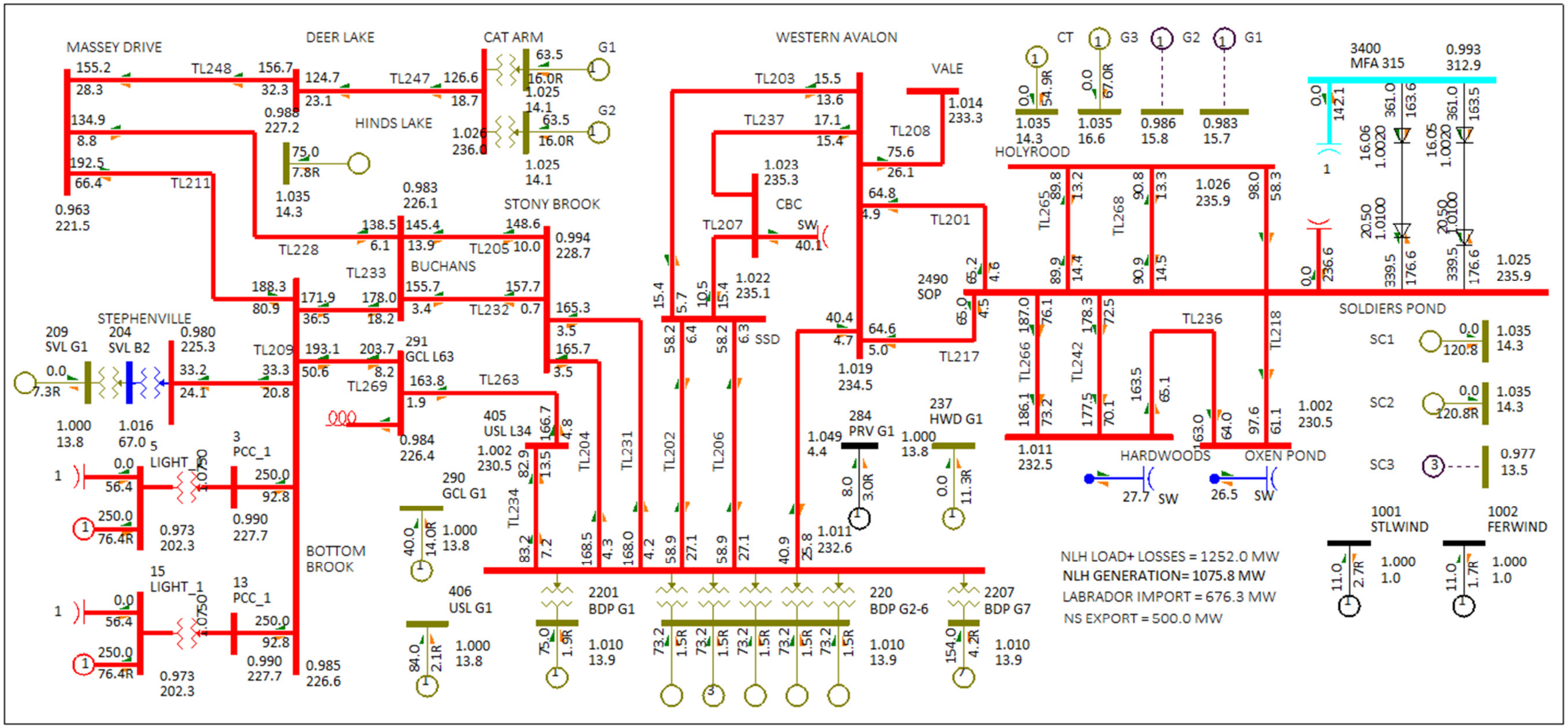


Figure 75 – Load Flow Plot – Base Case 8

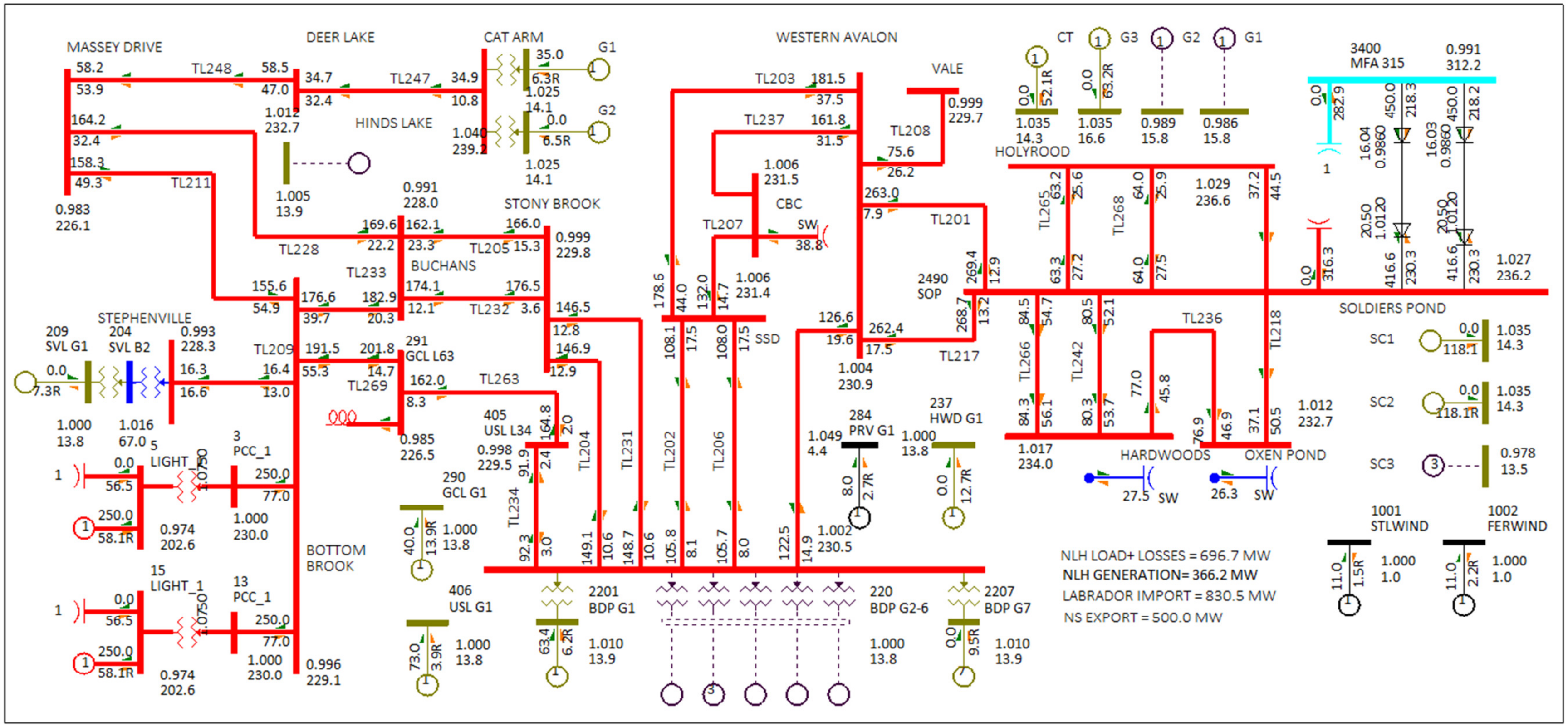


Figure 76 – Load Flow Plot – Base Case 9

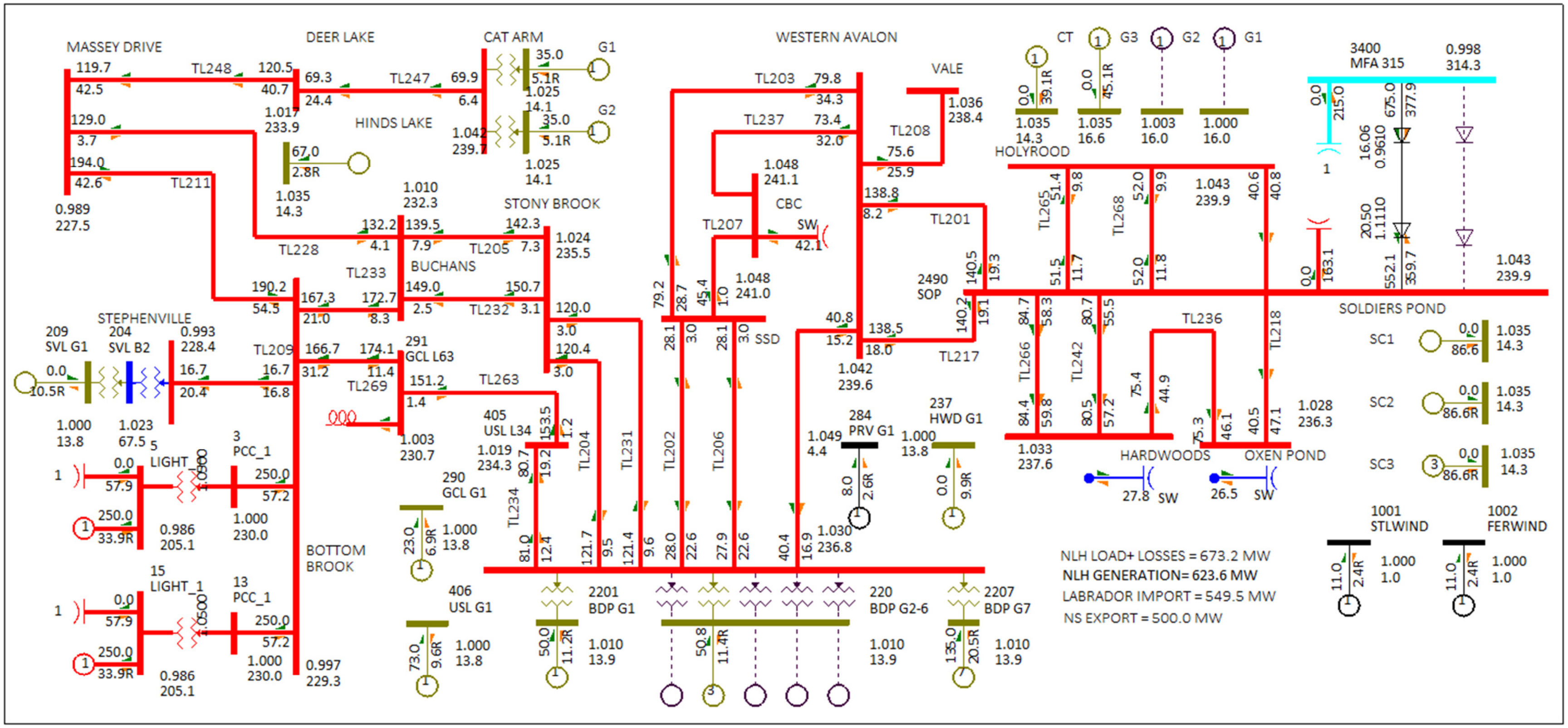


Figure 77 – Load Flow Plot – Base Case 10

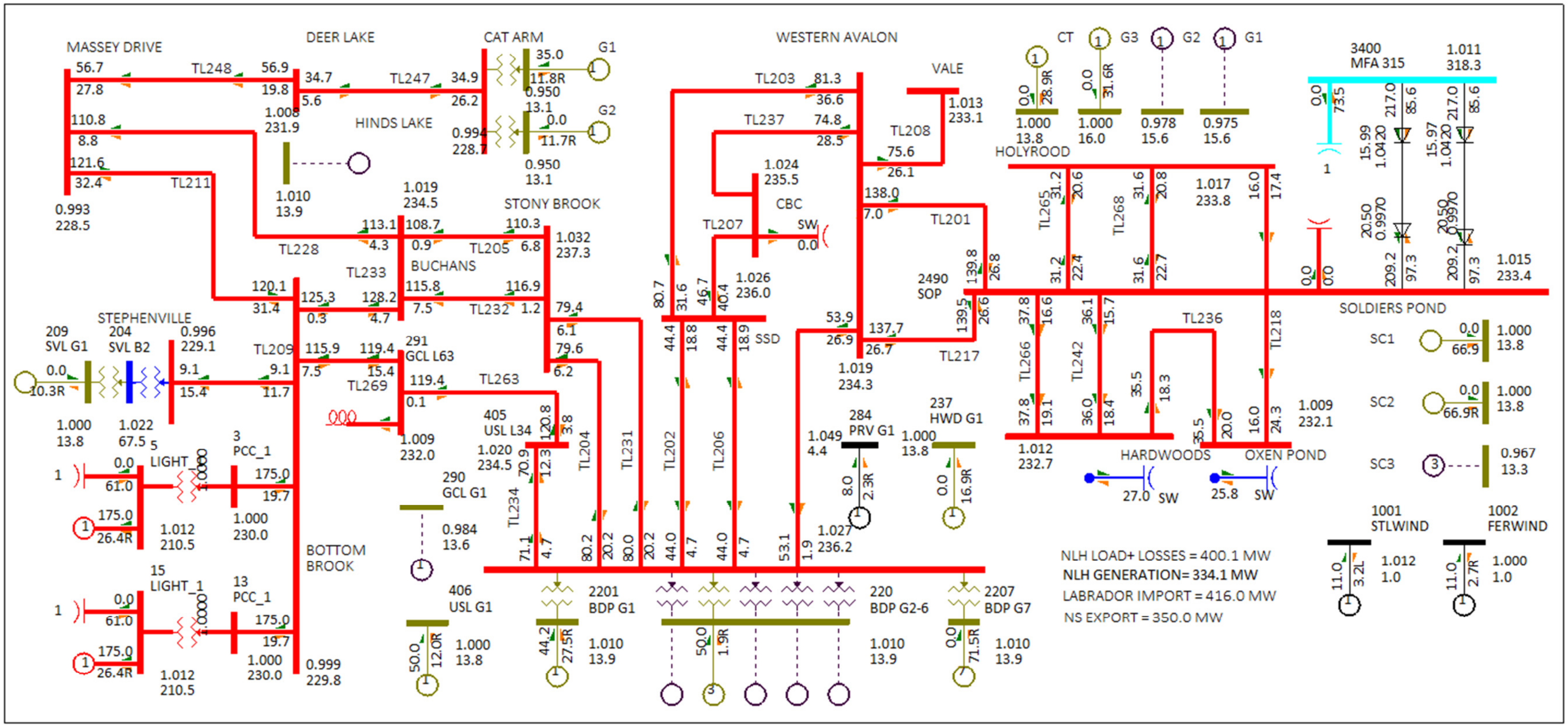


Figure 78 – Load Flow Plot – Base Case 11

APPENDIX B Contingency List

Table 10 – List of Contingencies for Dynamic Analysis

Contingency	Name	Description
CON1	Temporary Bipole Fault	LIL Bipole outage with full power restored after 300 ms.
CON2	Temporary Pole Fault[11]	LIL pole outage with full power restored after 300 ms.
CON3	Permanent Pole Fault	LIL Pole is tripped.
CON4	Three-phase fault at Soldiers Pond, followed by the tripping of a Synchronous Condenser	Synchronous condenser is tripped after 100 ms.
CON5	Three-phase fault at Soldiers Pond, followed by the tripping of TL217 to Western Avalon.	Line is tripped after 100 ms.
CON6	Three-phase fault at Soldiers Pond, followed by the tripping of TL266 to Hardwoods.	Line is tripped after 100 ms.
CON7	Three-phase fault at Western Avalon, Followed by the tripping of line to Bay d'Espoir.	Line is tripped after 100 ms.
CON8	Three-phase fault at Come-by-Chance, followed by the tripping of TL207 to Sunnyside.	Line is tripped after 100 ms.
CON9	Three-phase fault at Come-by-Chance, followed by the tripping of TL237 to Western Avalon.	Line is tripped after 100 ms.
CON10	Three-phase fault at Sunnyside, followed by the tripping of TL202 to Bay d'Espoir.	Line is tripped after 100 ms.
CON11	Three-phase fault at Sunnyside, followed by the tripping of TL203 to Western Avalon.	Line is tripped after 100 ms.
CON12	Three-phase fault at Sunnyside, followed by the tripping of TL207 to Come-by-Chance.	Line is tripped after 100 ms.
CON13	Three-phase fault at Bay d'Espoir, Followed by the tripping of TL202 to Sunnyside.	Line is tripped after 100 ms.

[11] This contingency is not considered for monopole cases as the results would be the same as CON1.

CON14	Three-phase fault at Bay d'Espoir, Followed by the tripping of TL204 to Stony Brook.	Line is tripped after 100 ms.
CON15	Three-phase fault at Bay d'Espoir, Followed by the tripping of TL234 to Upper Salmon.	Line is tripped after 100 ms.
CON16	Three-phase fault at Sunnyside, followed by the tripping of TL207 to Come-by-Chance.	Line is tripped after 100 ms.
CON17	Three-phase fault at Bay d'Espoir, Followed by the tripping of Unit.	Line is tripped after 100 ms.
CON18	Three-phase fault at Stony Brook, Followed by the tripping of TL232to Buchans.	Line is tripped after 100 ms.
CON19	Three-phase fault at Buchans, Followed by the tripping of TL233 to Bottom Brook.	Line is tripped after 100 ms.
CON20	Three-phase fault at Buchans, Followed by the tripping of TL228 to Massey Drive.	Line is tripped after 100 ms.
CON21	Three-phase fault at Massey Drive, Followed by the tripping of TL211 to Bottom Brook.	Line is tripped after 100 ms.
CON22	Three-phase fault at Massey Drive, Followed by the tripping of TL228 to Buchans.	Line is tripped after 100 ms.
CON23	Three-phase fault at Massey Drive, Followed by the tripping of TL248 to Buchans.	Line is tripped after 100 ms. TL247 is cross-tripped, isolating Cat Arm generation.
CON24	Three-phase fault at Bottom Brook Drive, followed by the tripping of TL269 to Granite Canal.	Line is tripped after 100 ms.
CON25	Three-phase fault at Bottom Brook Drive, followed by the tripping of TL209 to Stephenville.	Line is tripped after 100 ms.
CON26	Three-phase fault at Bottom Brook Drive, followed by the tripping of TL211 to Massey Drive.	Line is tripped after 100 ms.
CON27	Three-phase fault at Bottom Brook Drive, followed by the	Line is tripped after 100 ms.

	tripping of TL233 to Buchans.	
CON28	Three-phase fault at Bottom Brook, followed by the tripping of the Maritime Link	Link is tripped after 100 ms.
CON29	Three-phase fault at Stephenville, followed by the tripping of TL209 to Bottom Brook.	Line is tripped after 100 ms.
CON30	Three-phase fault at Upper Salmon, followed by tripping of unit.	Unit is tripped after 100 ms.
CON31	Three-phase fault at Upper Salmon, followed by the tripping of TL234 to Bay d’Espoir.	Line is tripped after 100 ms.
CON32	Three-phase fault at Upper Salmon, followed by the tripping of TL263 to Granite Canal.	Line is tripped after 100 ms.
CON33	Three-phase fault at Granite Canal, followed by the tripping of TL269 to Bottom Brook.	Line is tripped after 100 ms.
CON34	Three-phase fault at Granite Canal, followed by the tripping of TL263 to Upper Salmon.	Line is tripped after 100 ms.
CON35	SLG fault at Bay d’Espoir on TL202 to Sunnyside. Pole is successfully reclosed.	Bay d’Espoir circuit breaker pole recloses after 30 cycles, Sunnyside circuit breaker pole recloses after 40 ms.
CON36	SLG fault at Soldiers Pond on TL217 to Western Avalon. Pole is successfully reclosed.	Western Avalon pole recloses after 30 cycles, Soldiers Pond pole recloses after 40 ms.

APPENDIX C Remedial ML Curtailment for Ac Transmission Line Faults In Western Newfoundland

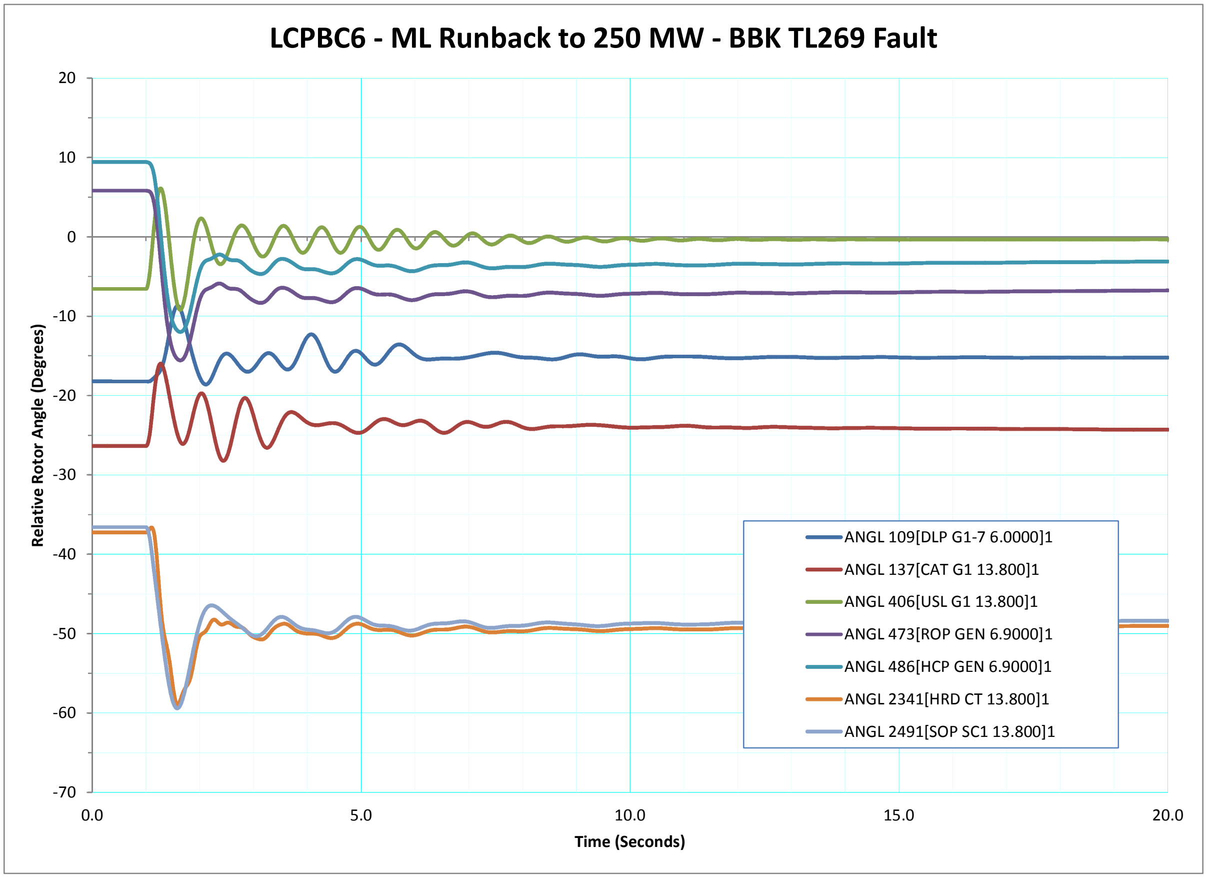


Figure 79 - LCPBC6 - ML Runback to 250 MW - BBK TL269 Fault - Relative Rotor Angle (Degrees)

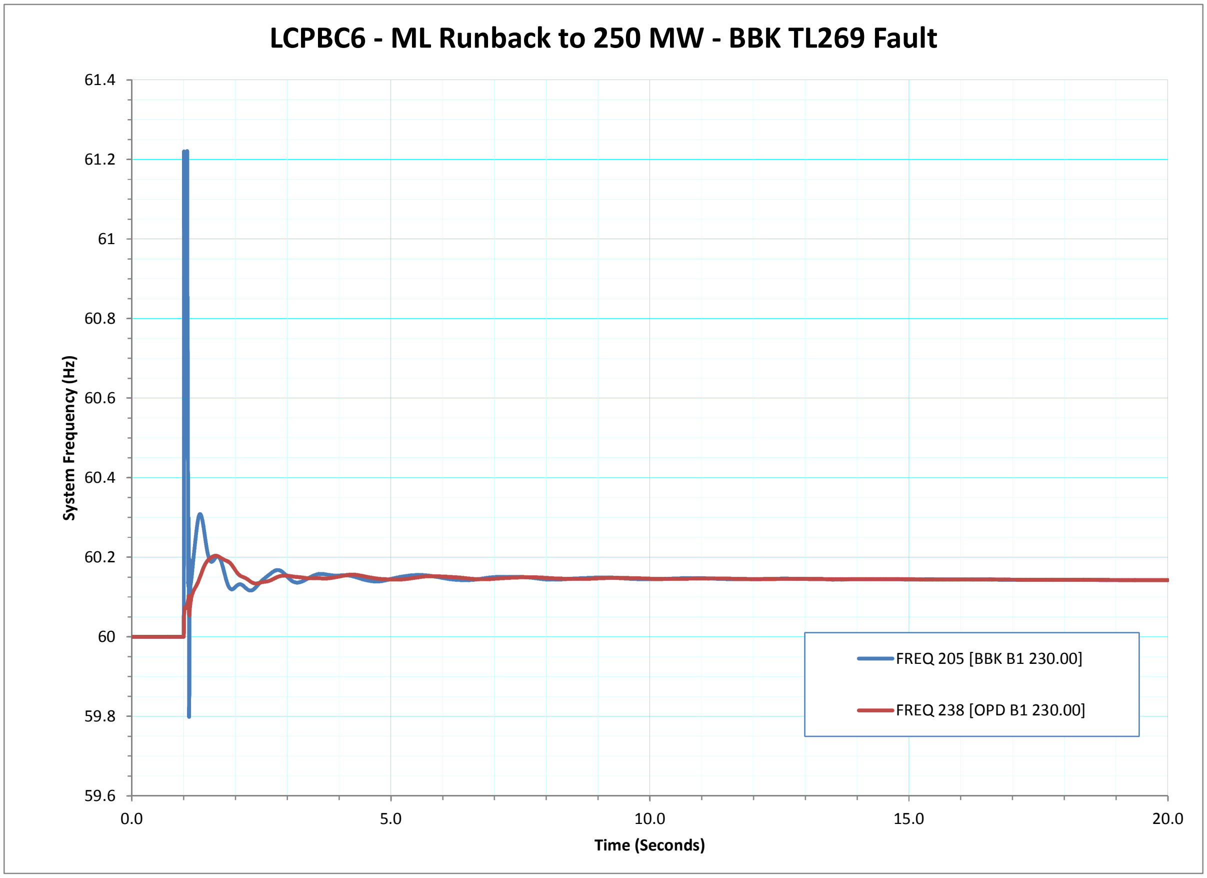


Figure 80 - LCPBC6 - ML Runback to 250 MW - BBK TL269 Fault - System Frequency (Hz)

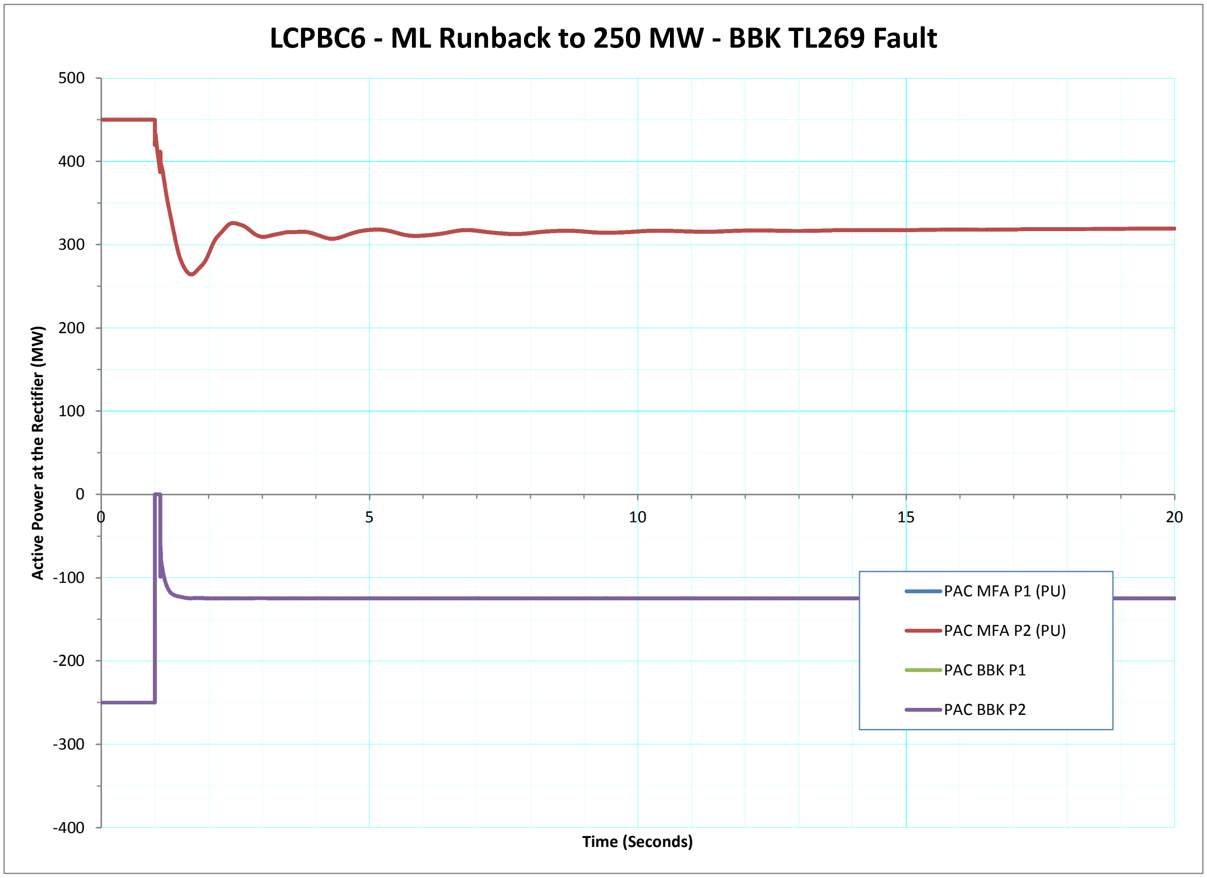


Figure 81 - LCPBC6 - ML Runback to 250 MW - BBK TL269 Fault - Active Power at the Rectifier (MW)

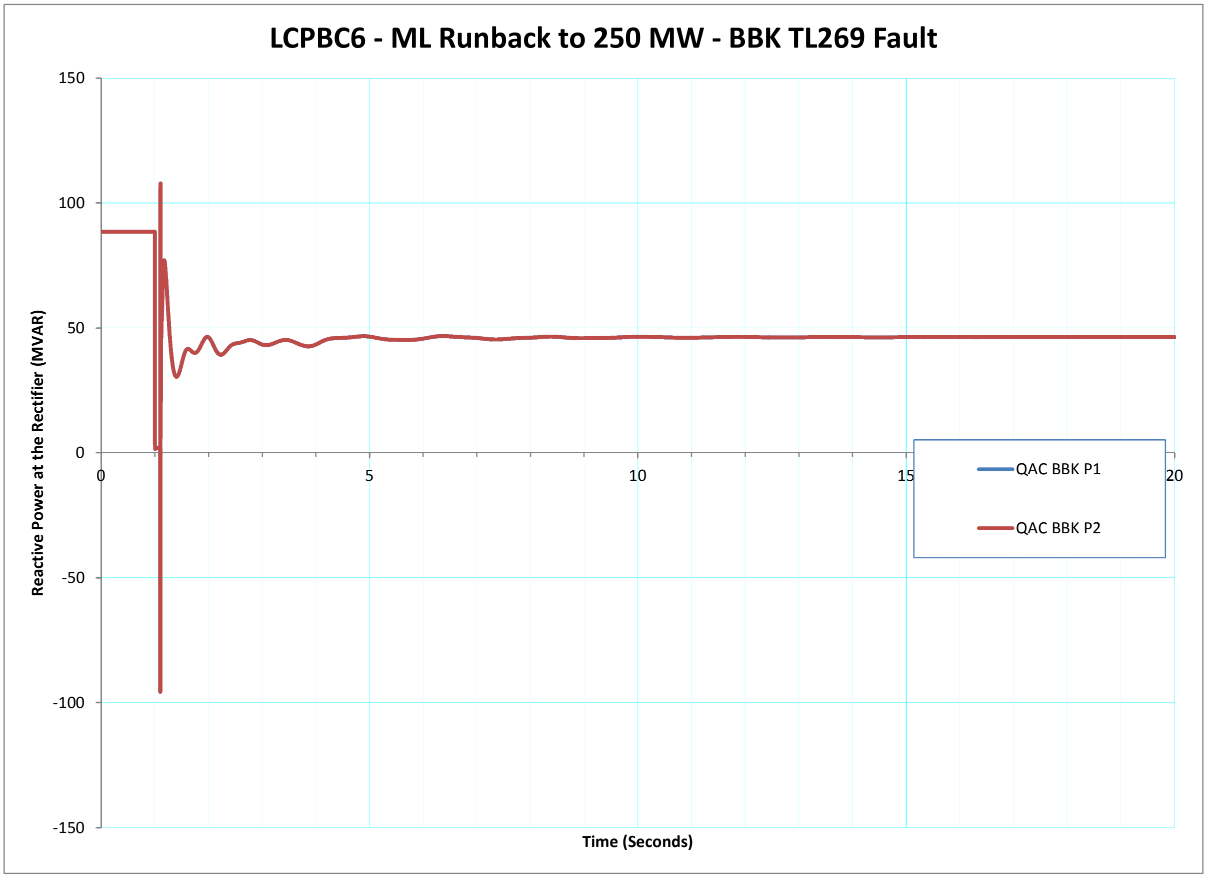


Figure 82 - LCPBC6 - ML Runback to 250 MW - BBK TL269 Fault - Reactive Power at the Rectifier (MVAR)

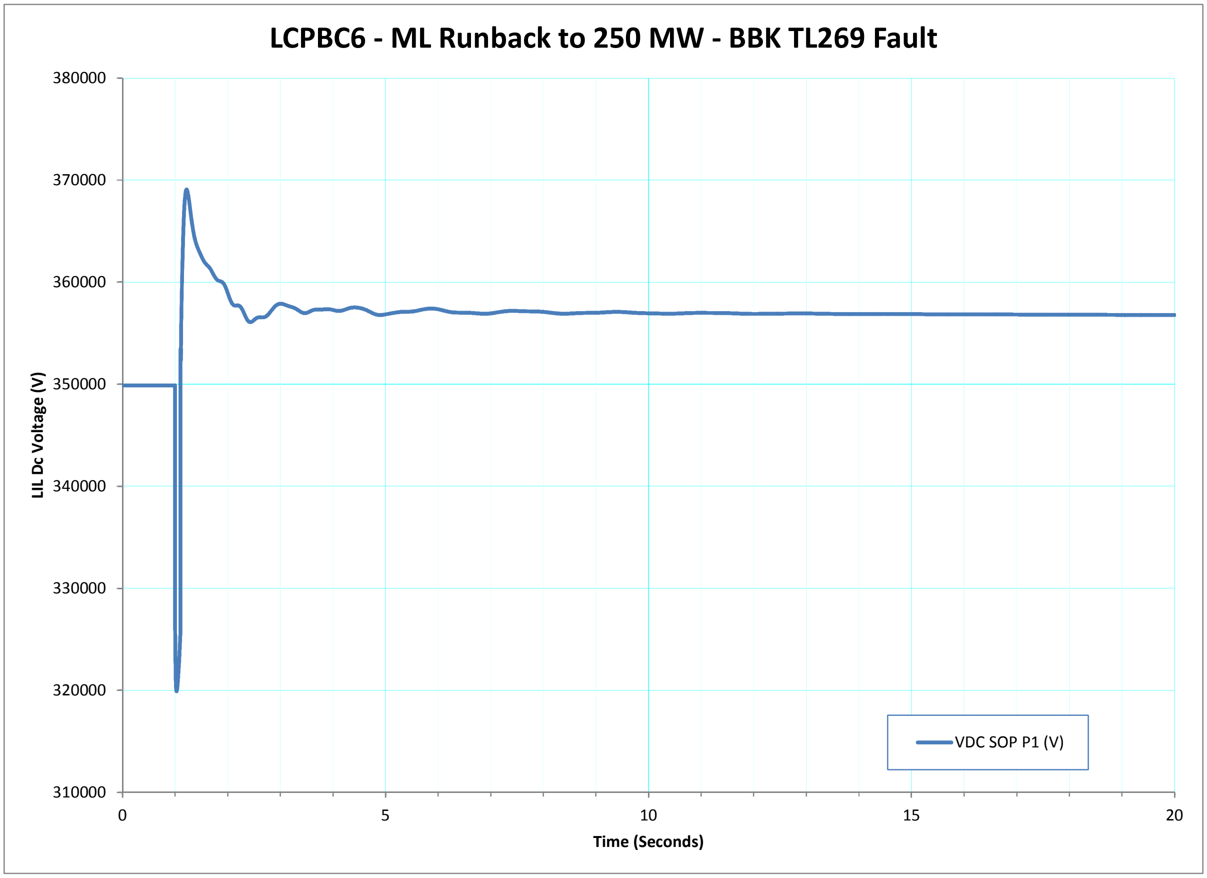


Figure 83 - LCPBC6 - ML Runback to 250 MW - BBK TL269 Fault - LIL Dc Voltage (V)

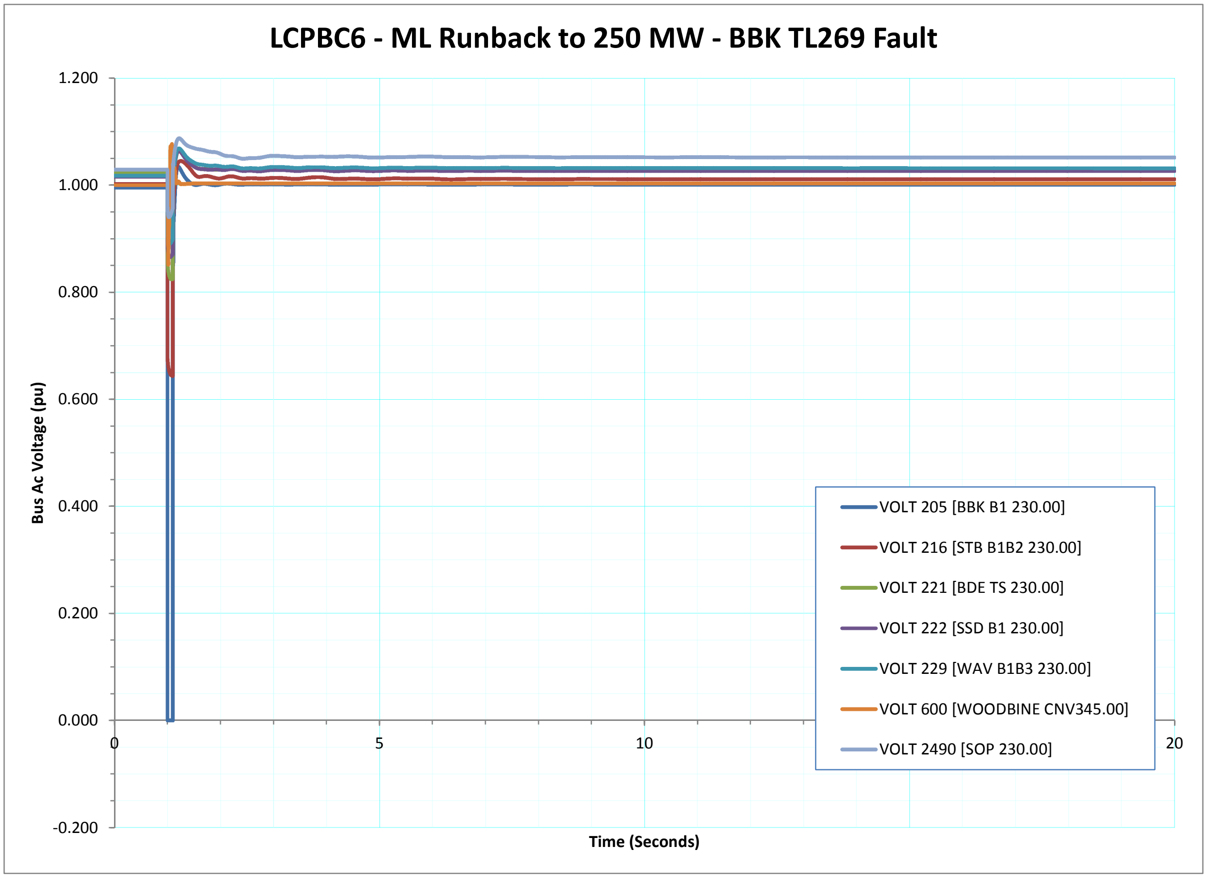


Figure 84 - LCPBC6 - ML Runback to 250 MW - BBK TL269 Fault - Bus Ac Voltage (pu)

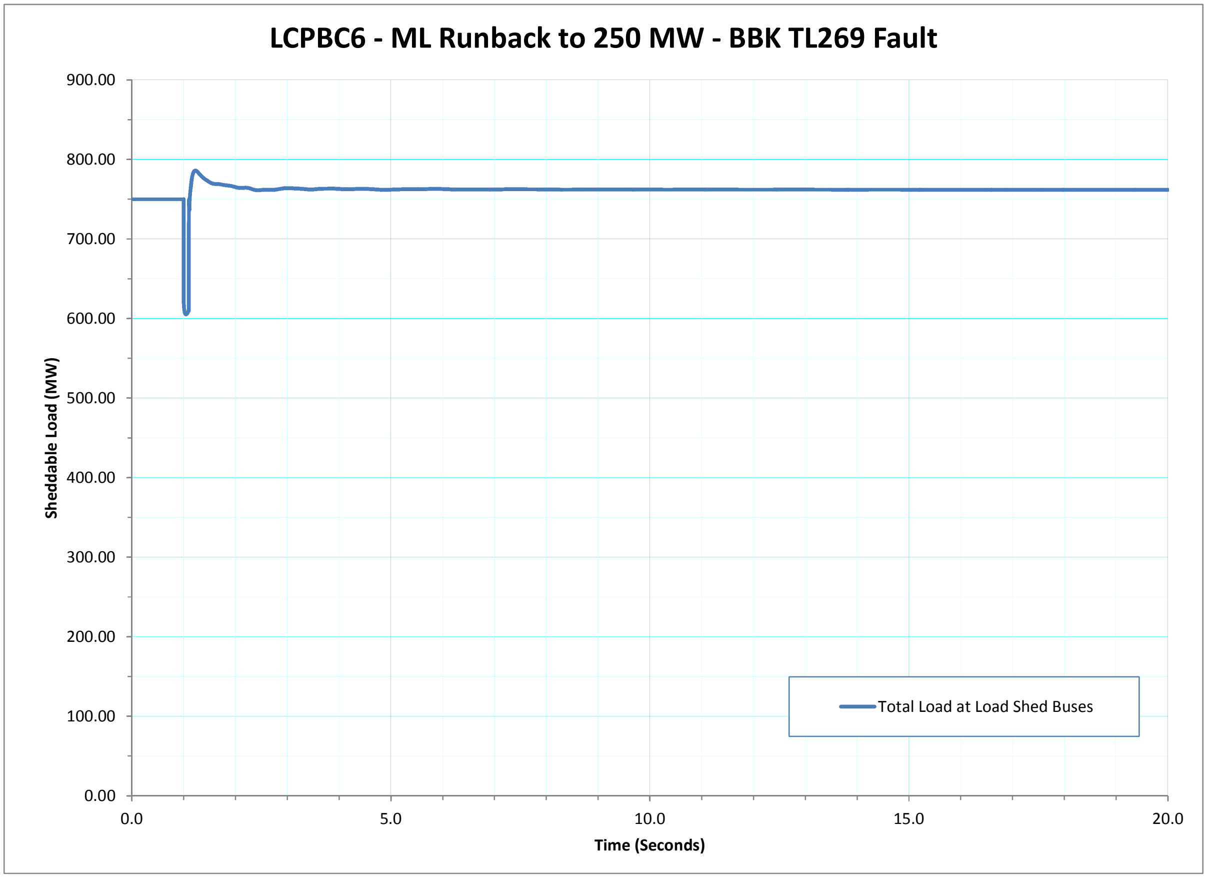


Figure 85 - LCPBC6 - ML Runback to 250 MW - BBK TL269 Fault - Sheddable Load (MW)

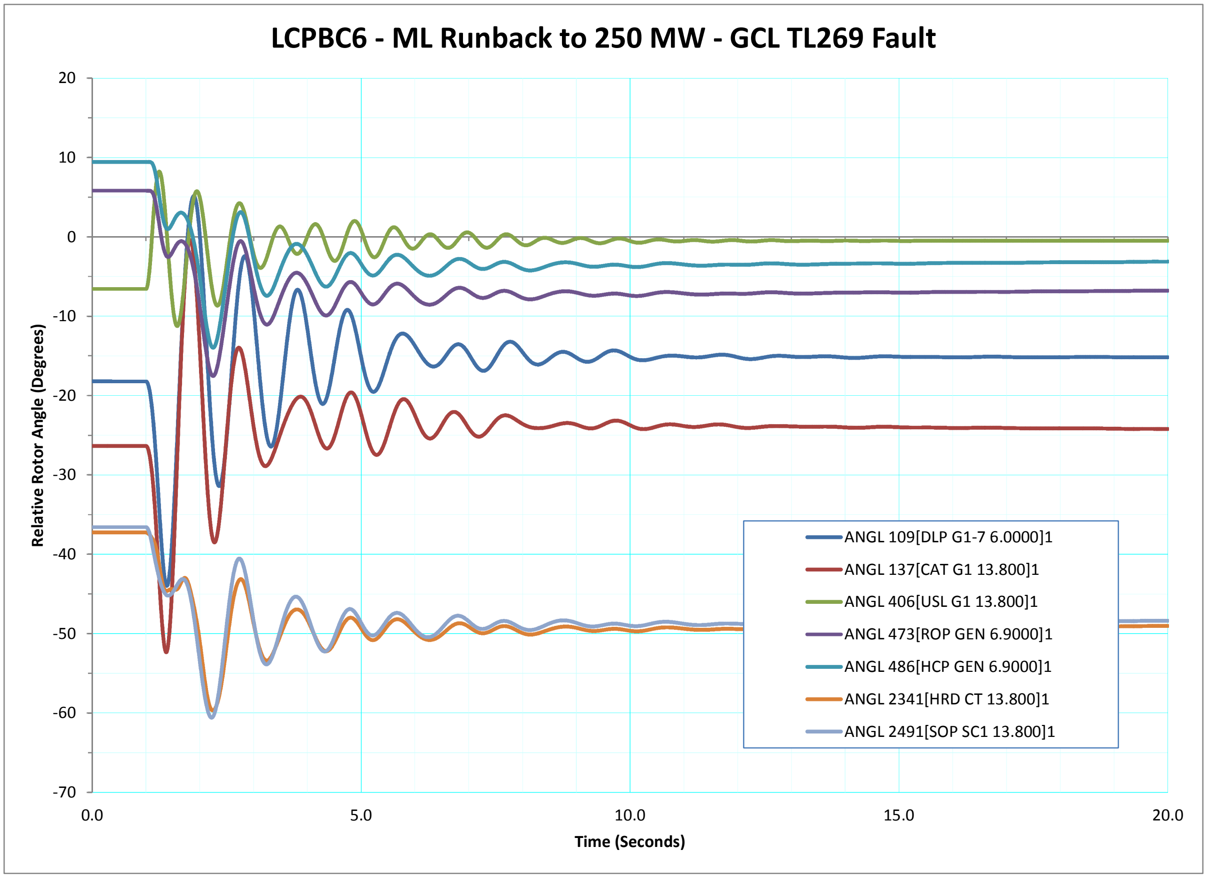


Figure 86 - LCPBC6 - ML Runback to 250 MW - GCL TL269 Fault - Relative Rotor Angle (Degrees)

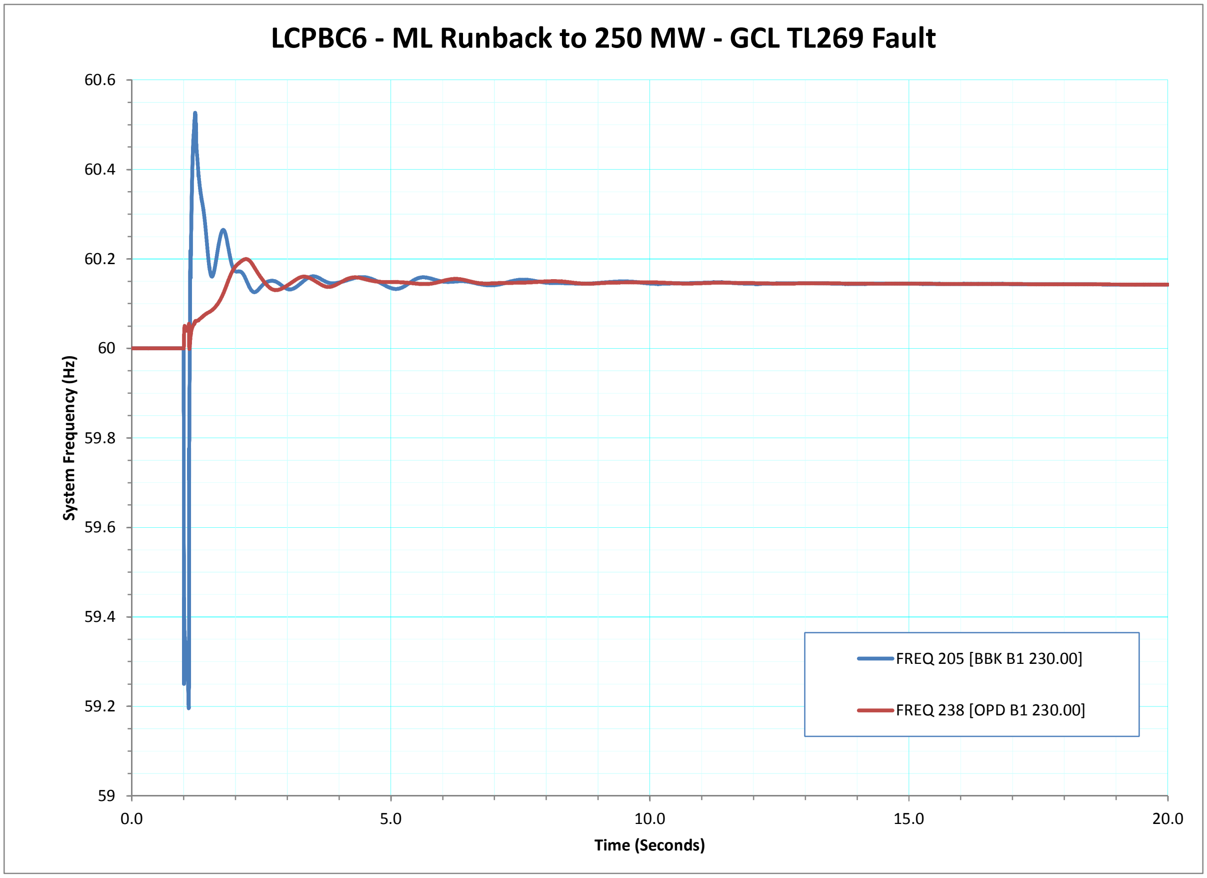


Figure 87 - LCPBC6 - ML Runback to 250 MW - GCL TL269 Fault - System Frequency (Hz)

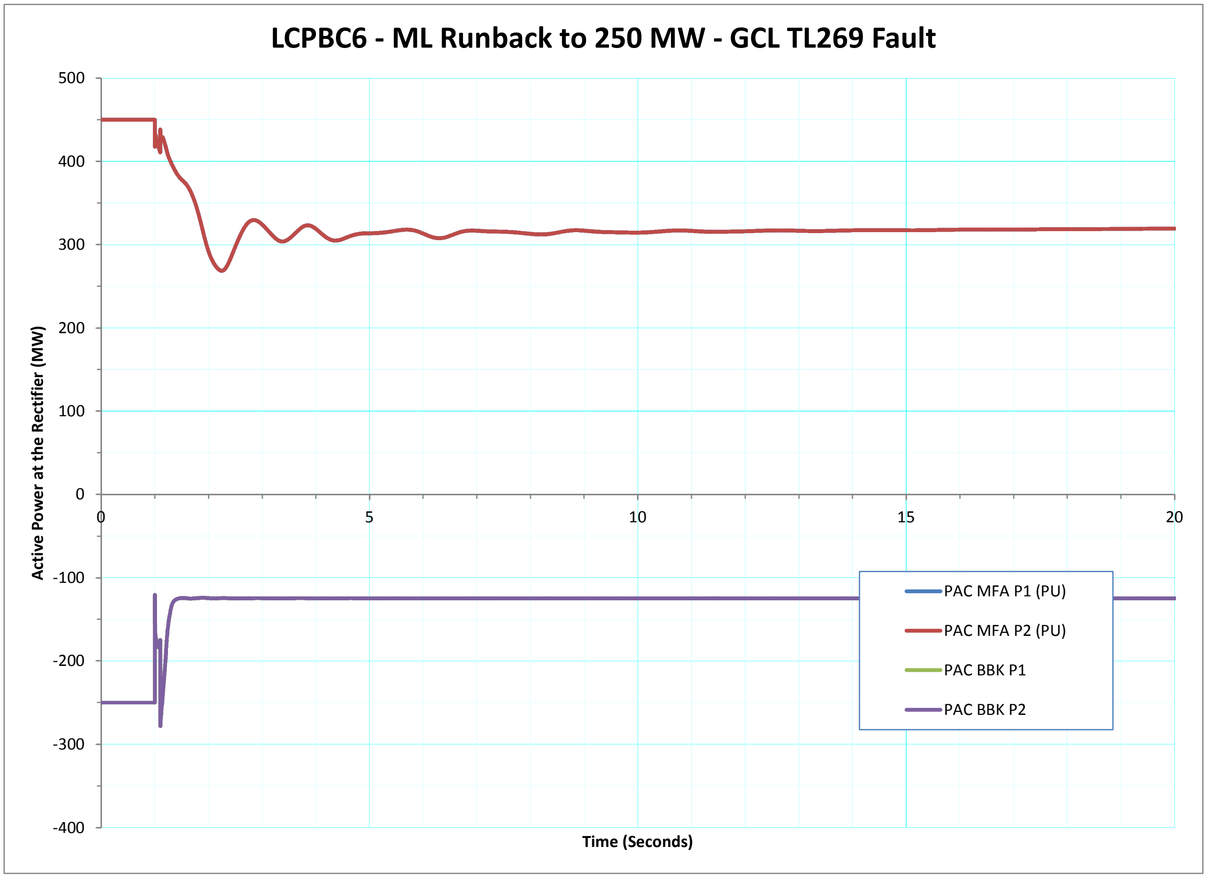


Figure 88 - LCPBC6 - ML Runback to 250 MW - GCL TL269 Fault - Active Power at the Rectifier (MW)

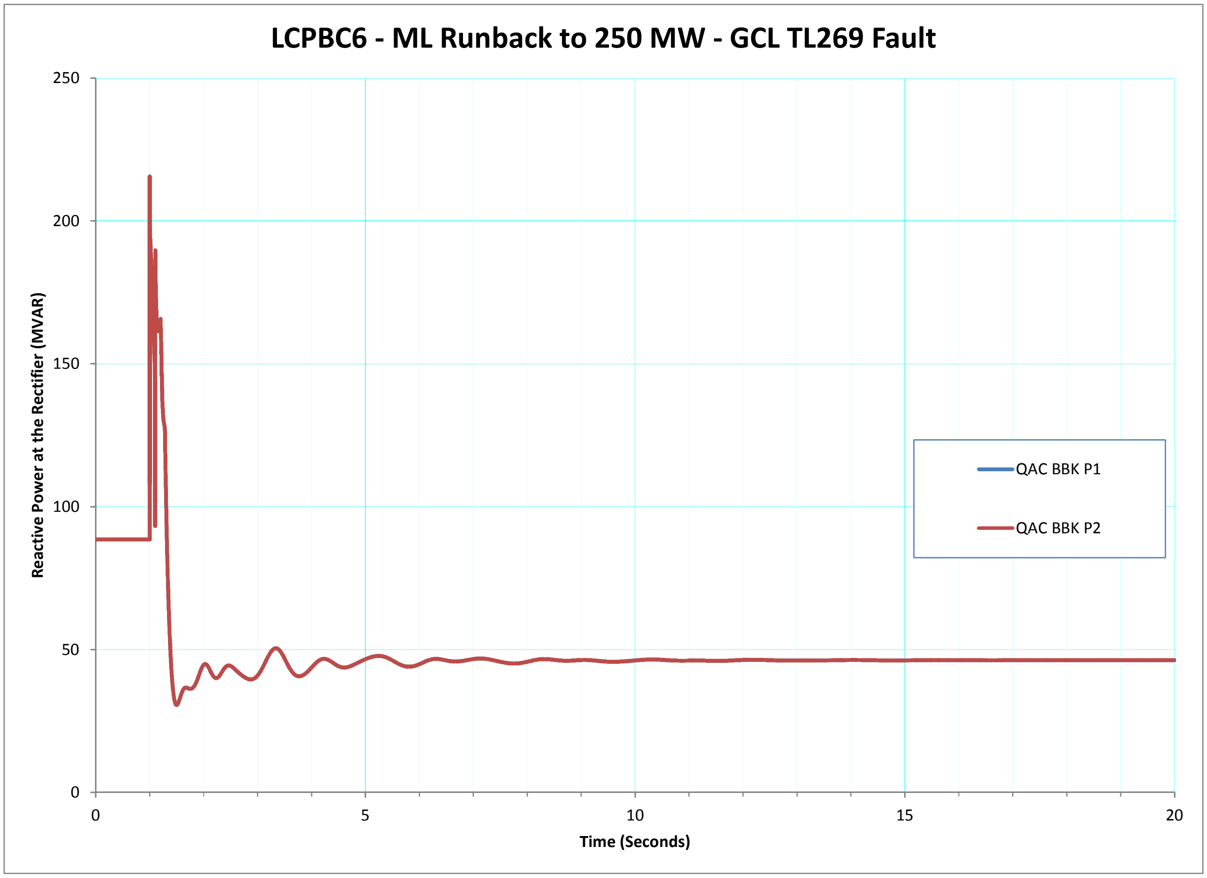


Figure 89 - LCPBC6 - ML Runback to 250 MW - GCL TL269 Fault - Reactive Power at the Rectifier (MVAR)

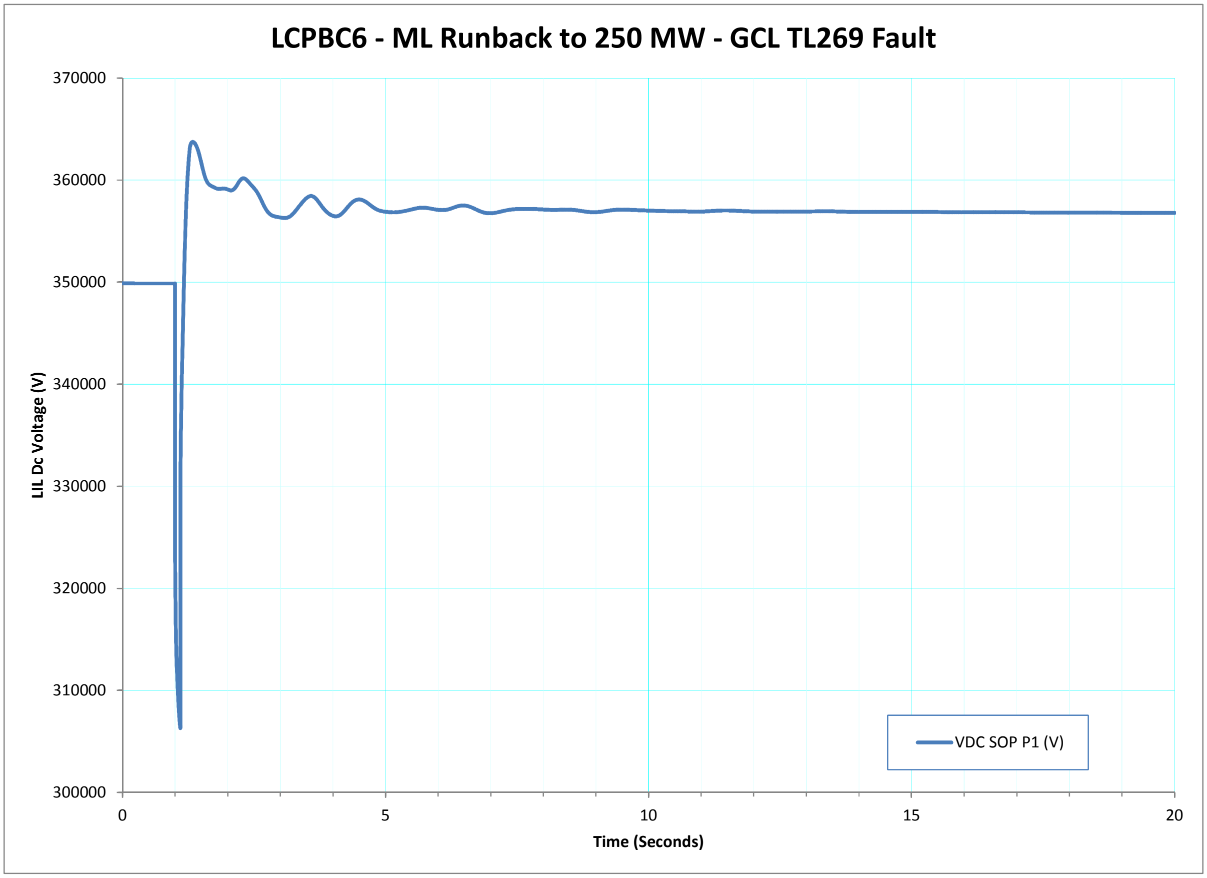


Figure 90 - LCPBC6 - ML Runback to 250 MW - GCL TL269 Fault - LIL Dc Voltage (V)

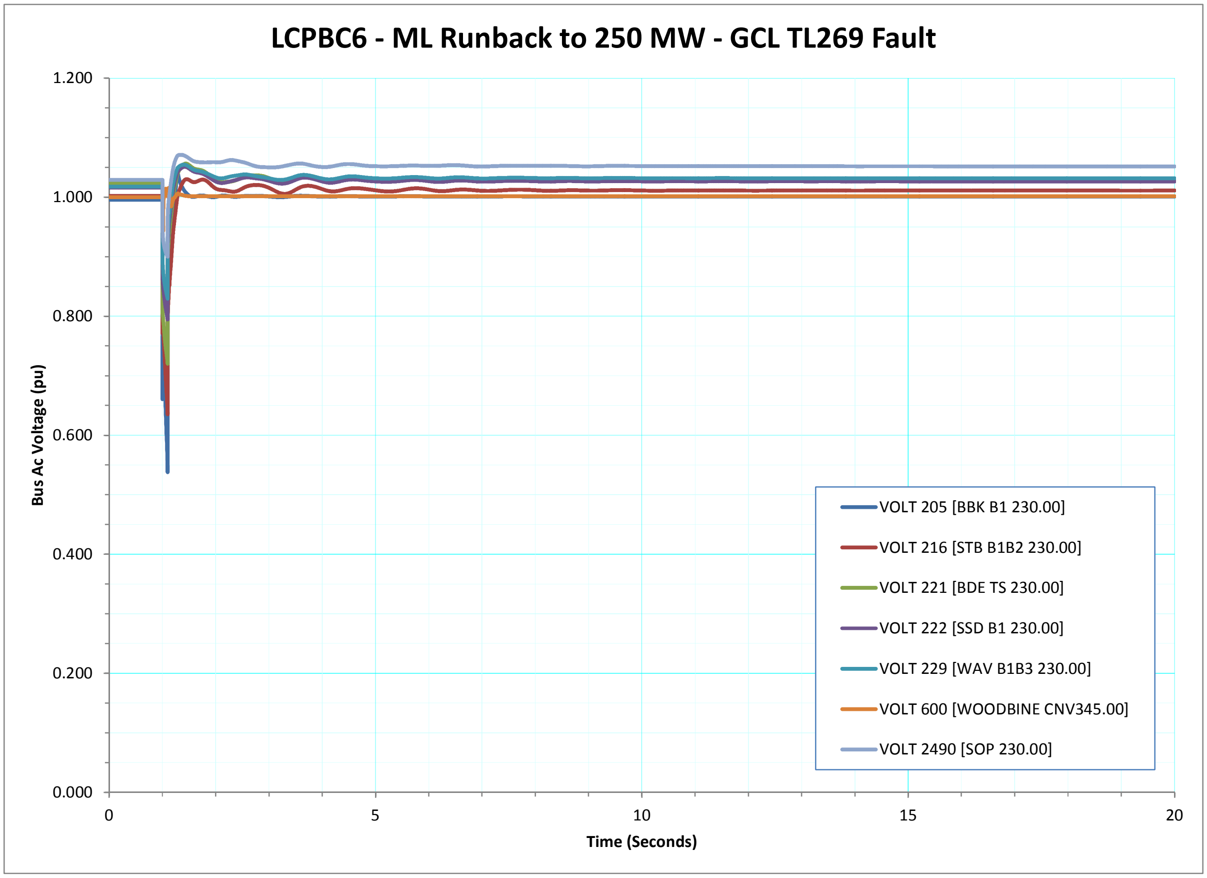


Figure 91 - LCPBC6 - ML Runback to 250 MW - GCL TL269 Fault - Bus Ac Voltage (pu)

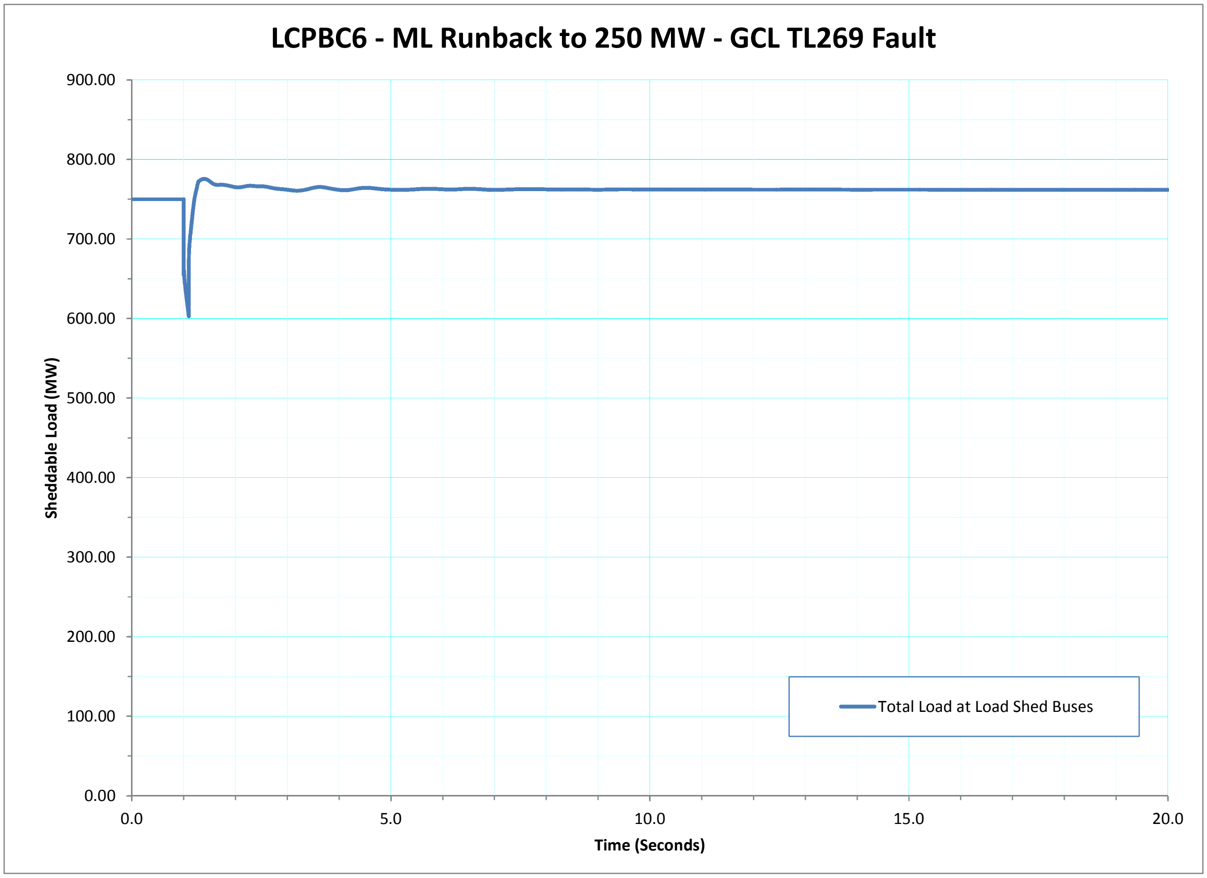


Figure 92 - LCPBC6 - ML Runback to 250 MW - GCL TL269 Fault - Sheddable Load (MW)

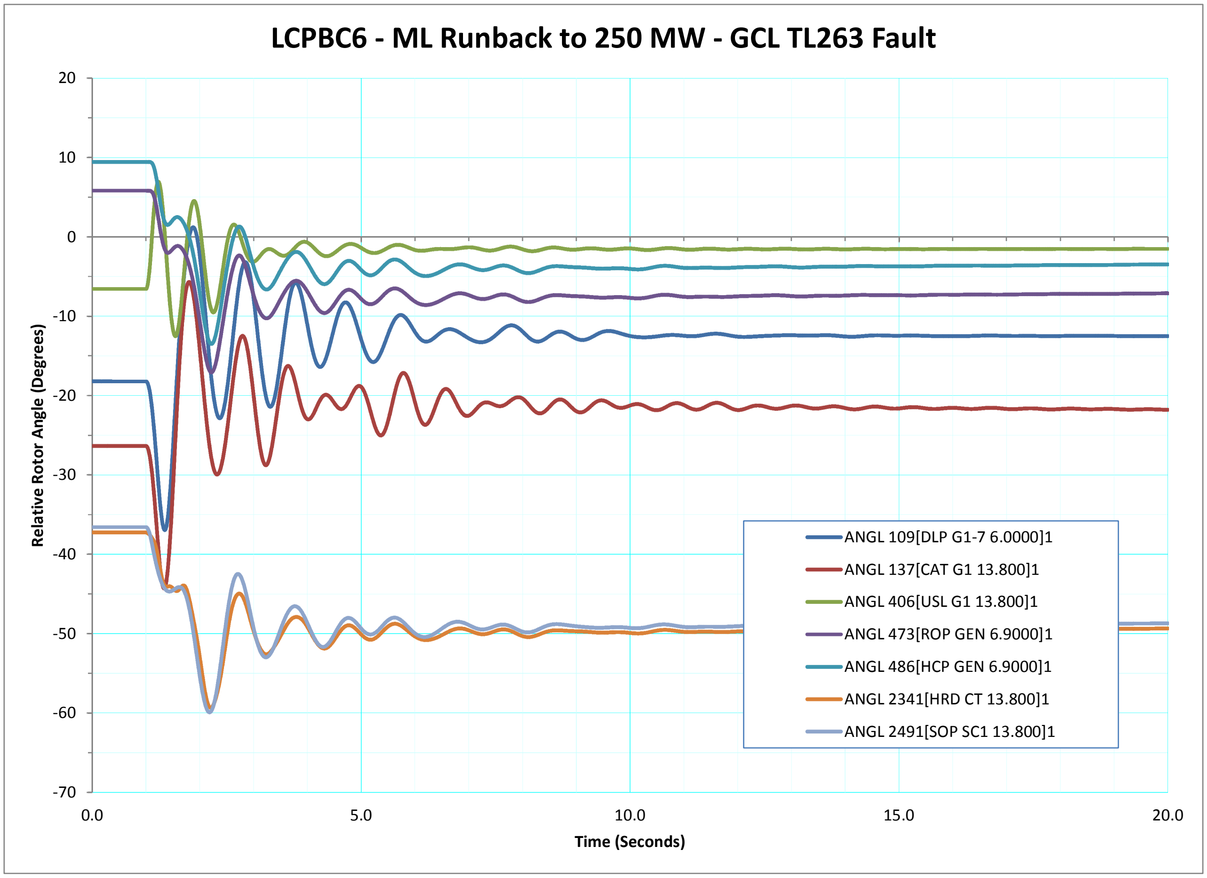


Figure 93 - LCPBC6 - ML Runback to 250 MW - GCL TL263 Fault - Relative Rotor Angle (Degrees)

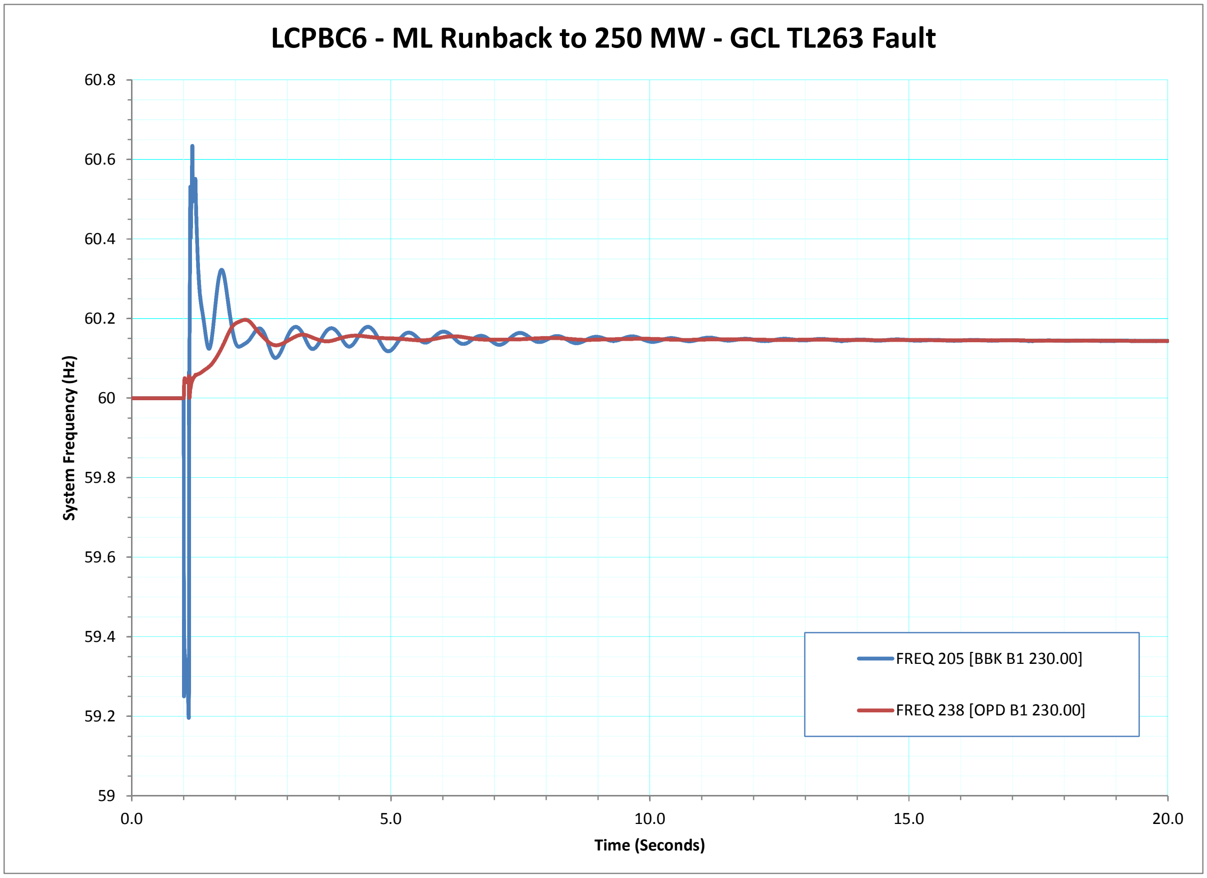


Figure 94 - LCPBC6 - ML Runback to 250 MW - GCL TL263 Fault - System Frequency (Hz)

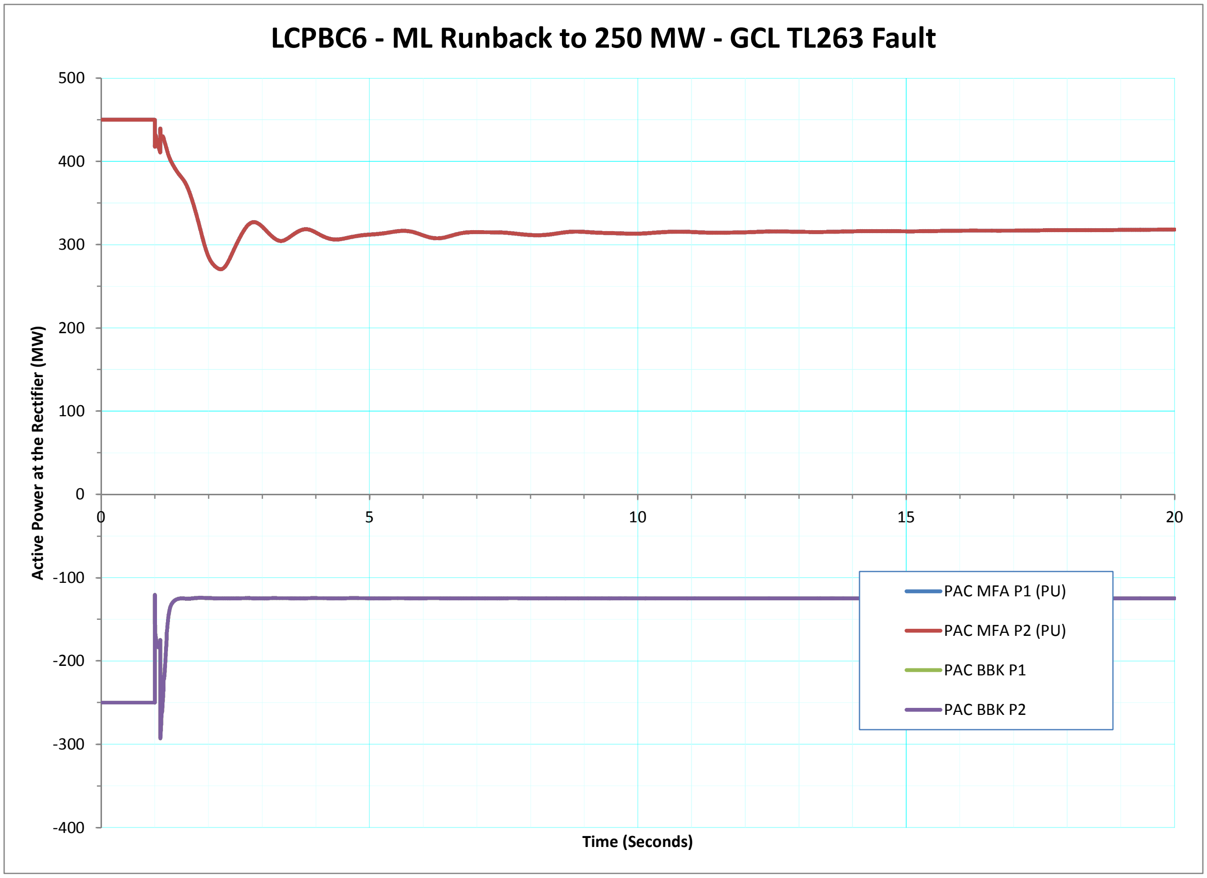


Figure 95 - LCPBC6 - ML Runback to 250 MW - GCL TL263 Fault - Active Power at the Rectifier (MW)

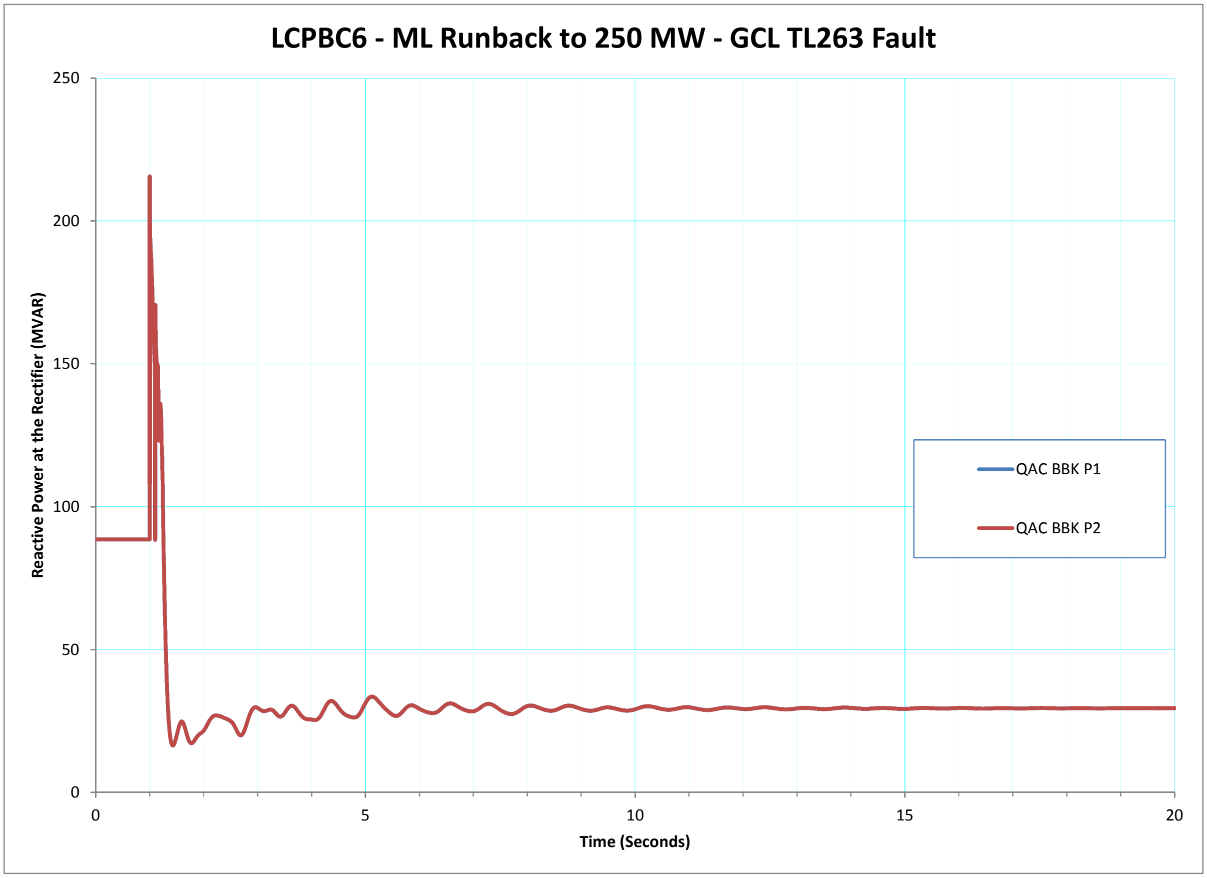


Figure 96 - LCPBC6 - ML Runback to 250 MW - GCL TL263 Fault - Reactive Power at the Rectifier (MVAR)

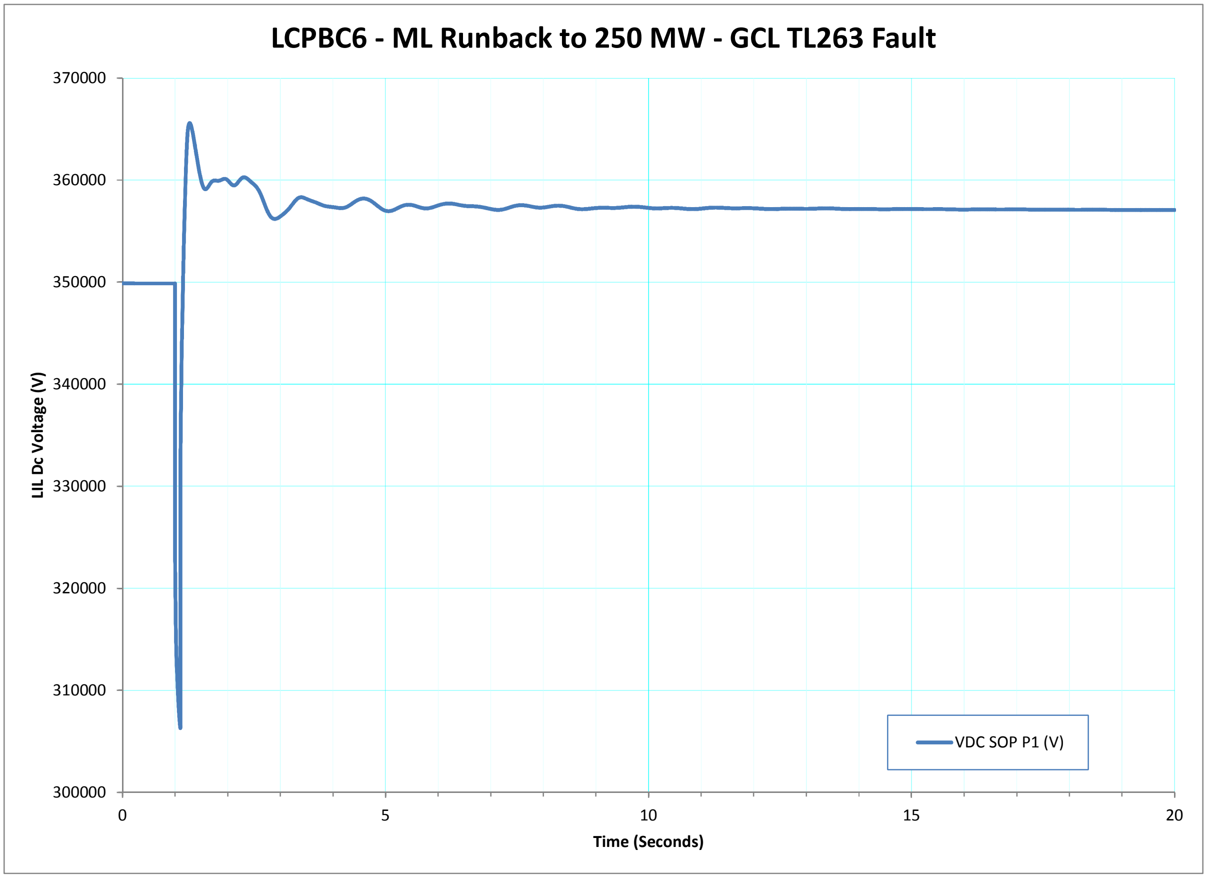


Figure 97 - LCPBC6 - ML Runback to 250 MW - GCL TL263 Fault - LIL Dc Voltage (V)

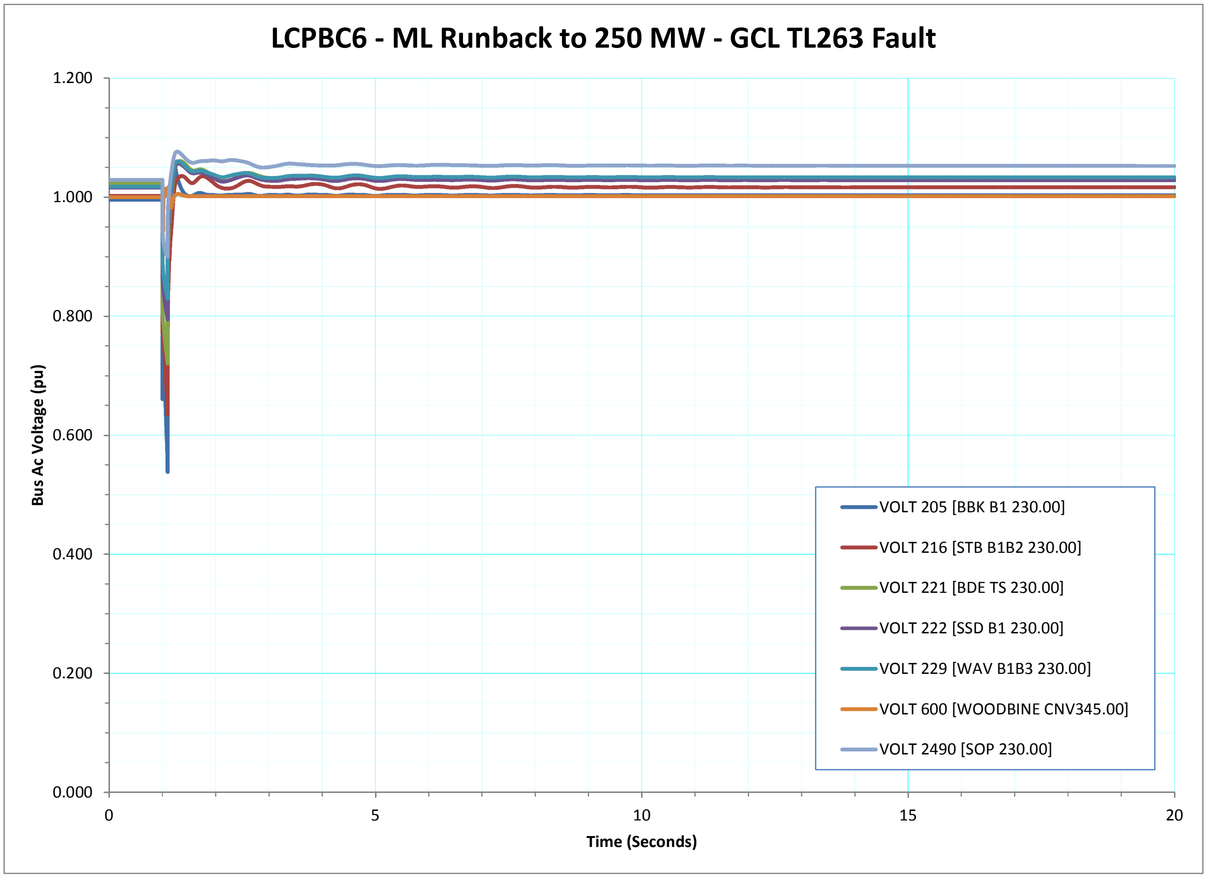


Figure 98 - LCPBC6 - ML Runback to 250 MW - GCL TL263 Fault - Bus Ac Voltage (pu)

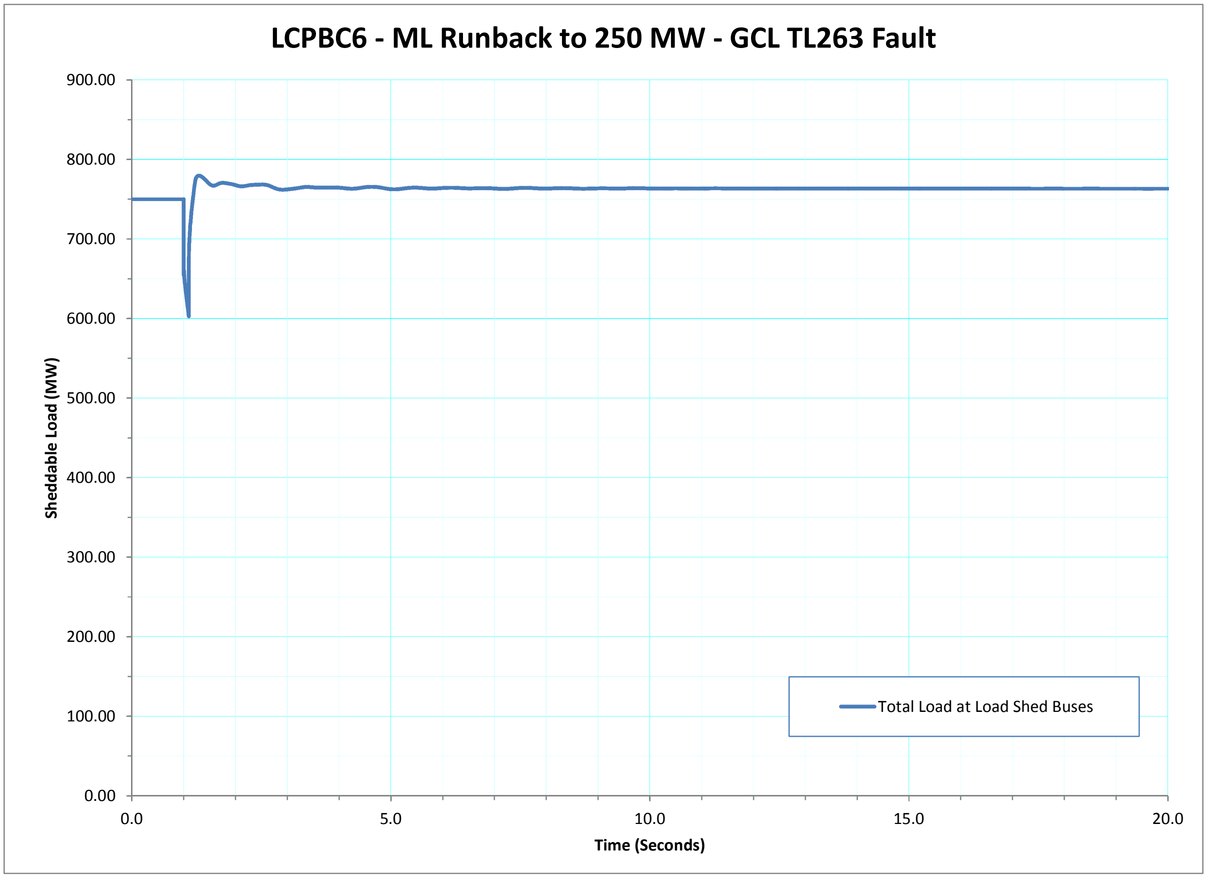


Figure 99 - LCPBC6 - ML Runback to 250 MW - GCL TL263 Fault - Sheddable Load (MW)

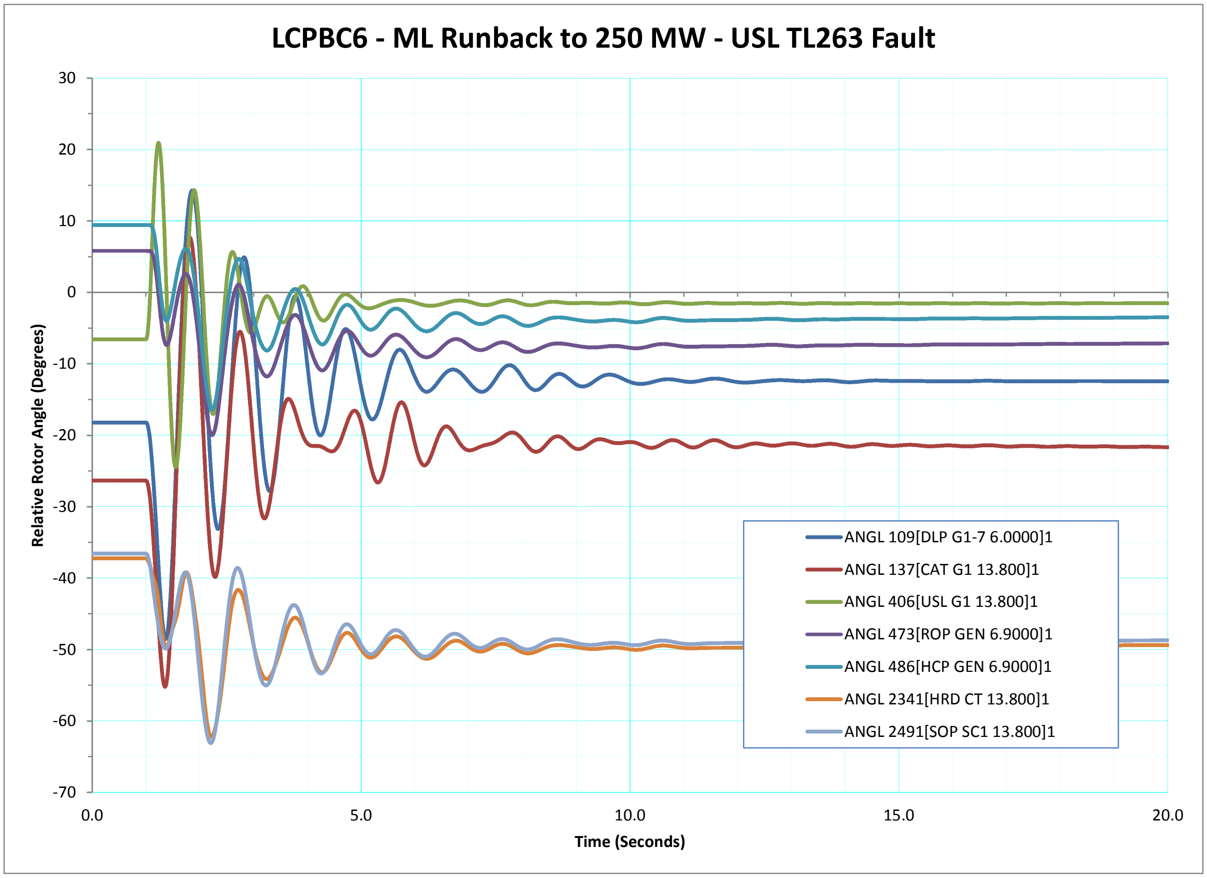


Figure 100 - LCPBC6 - ML Runback to 250 MW - USL TL263 Fault - Relative Rotor Angle (Degrees)

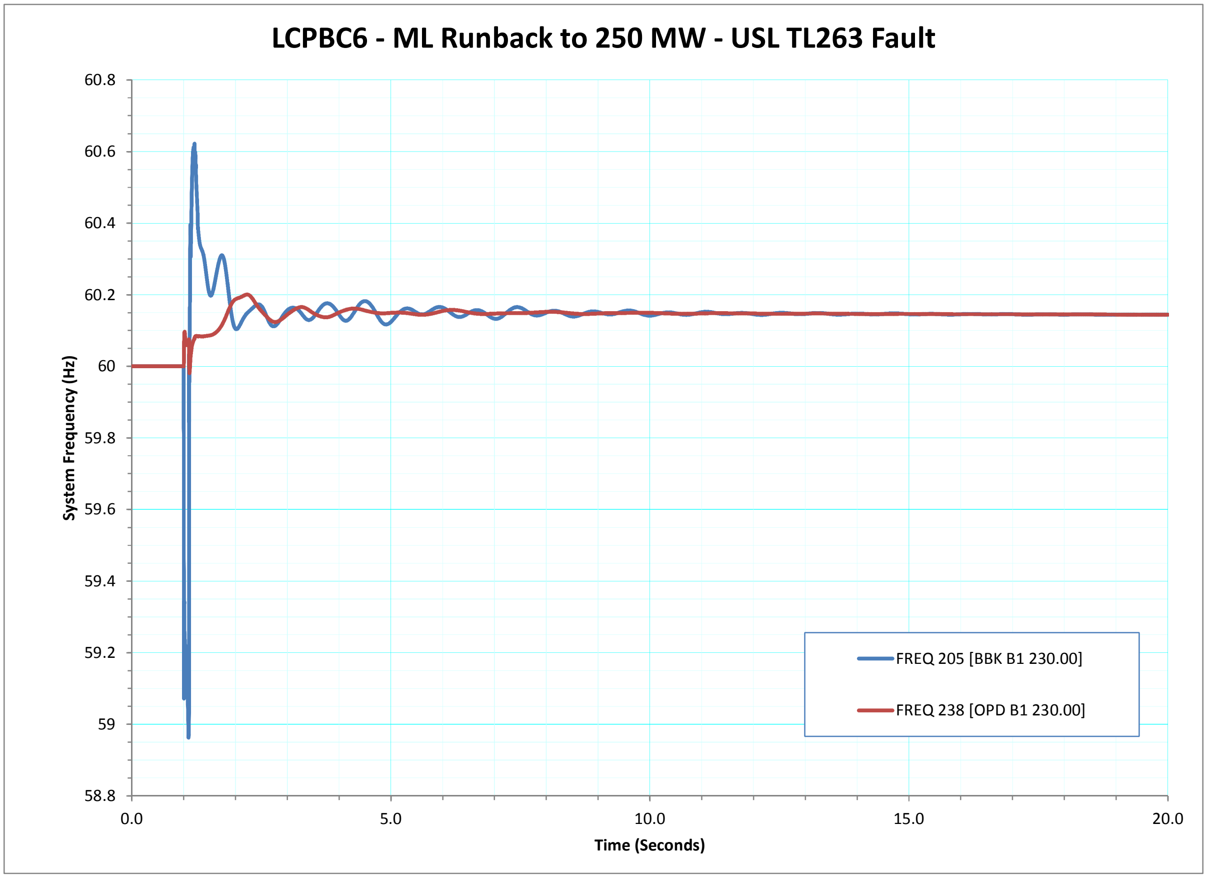


Figure 101 - LCPBC6 - ML Runback to 250 MW - USL TL263 Fault - System Frequency (Hz)

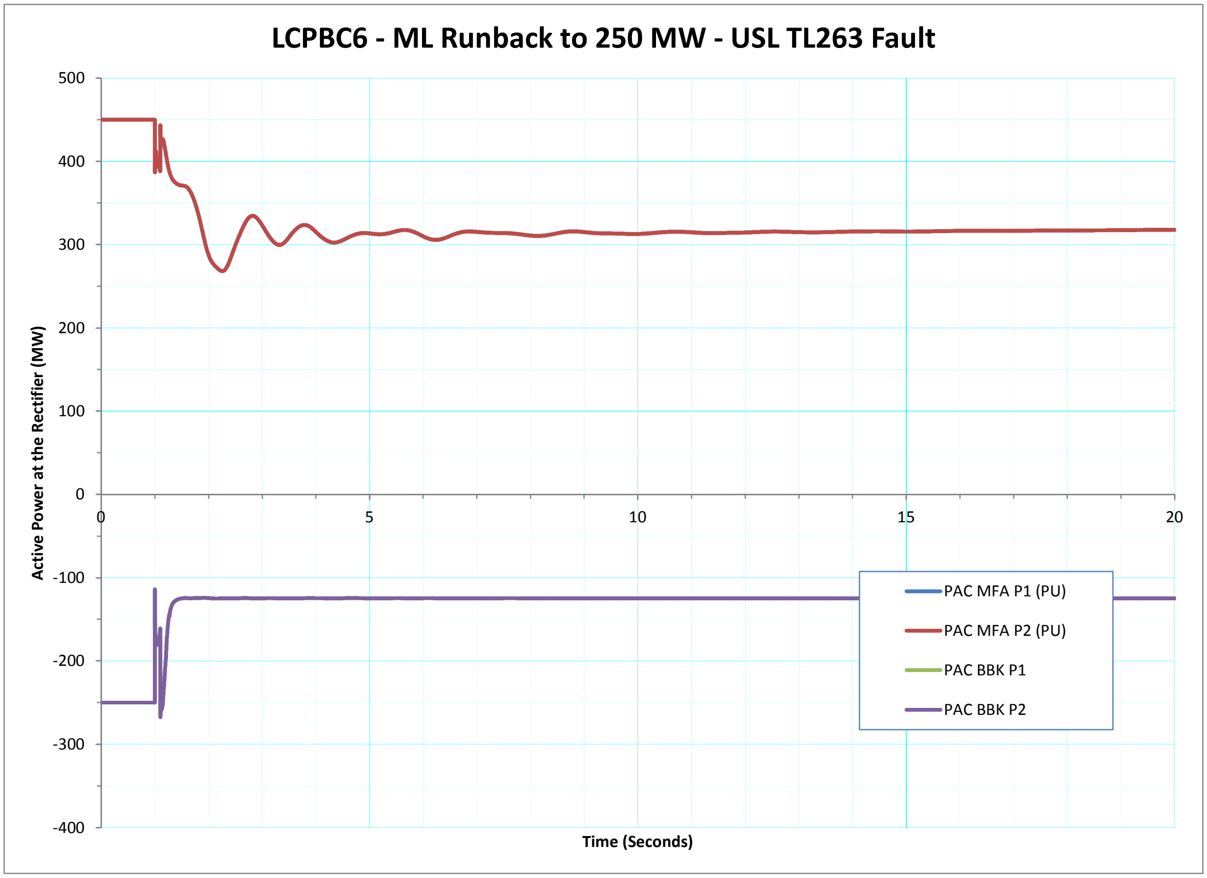


Figure 102 - LCPBC6 - ML Runback to 250 MW - USL TL263 Fault - Active Power at the Rectifier (MW)

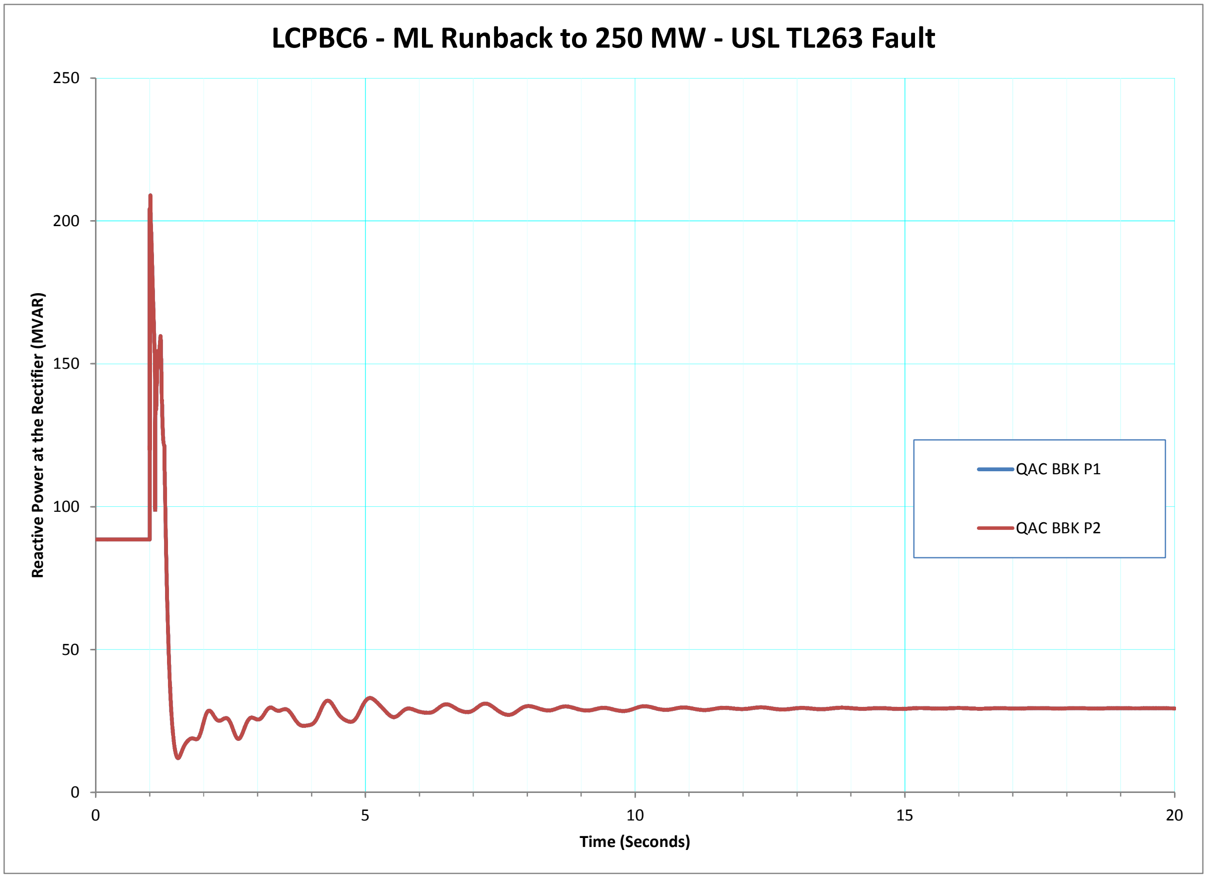


Figure 103 - LCPBC6 - ML Runback to 250 MW - USL TL263 Fault - Reactive Power at the Rectifier (MVAR)

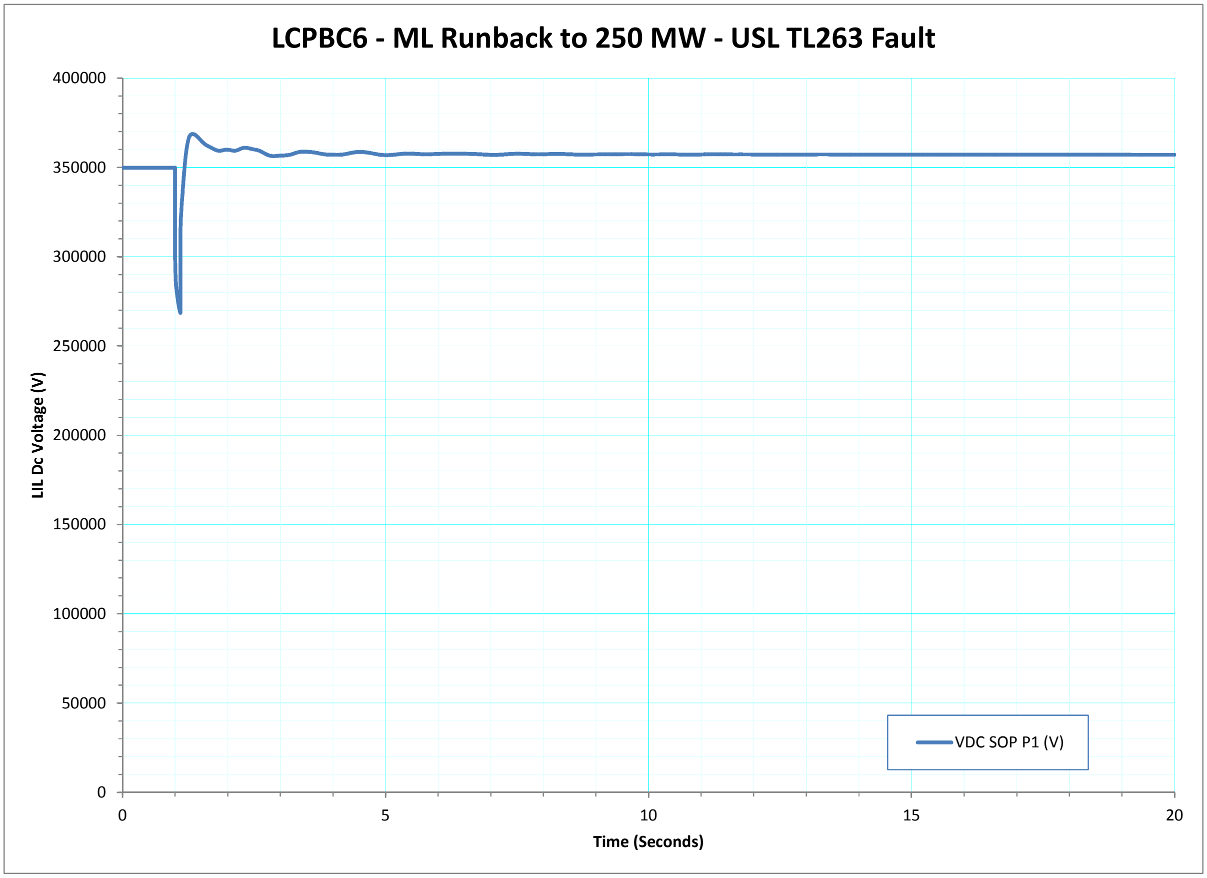


Figure 104 - LCPBC6 - ML Runback to 250 MW - USL TL263 Fault - LIL Dc Voltage (V)

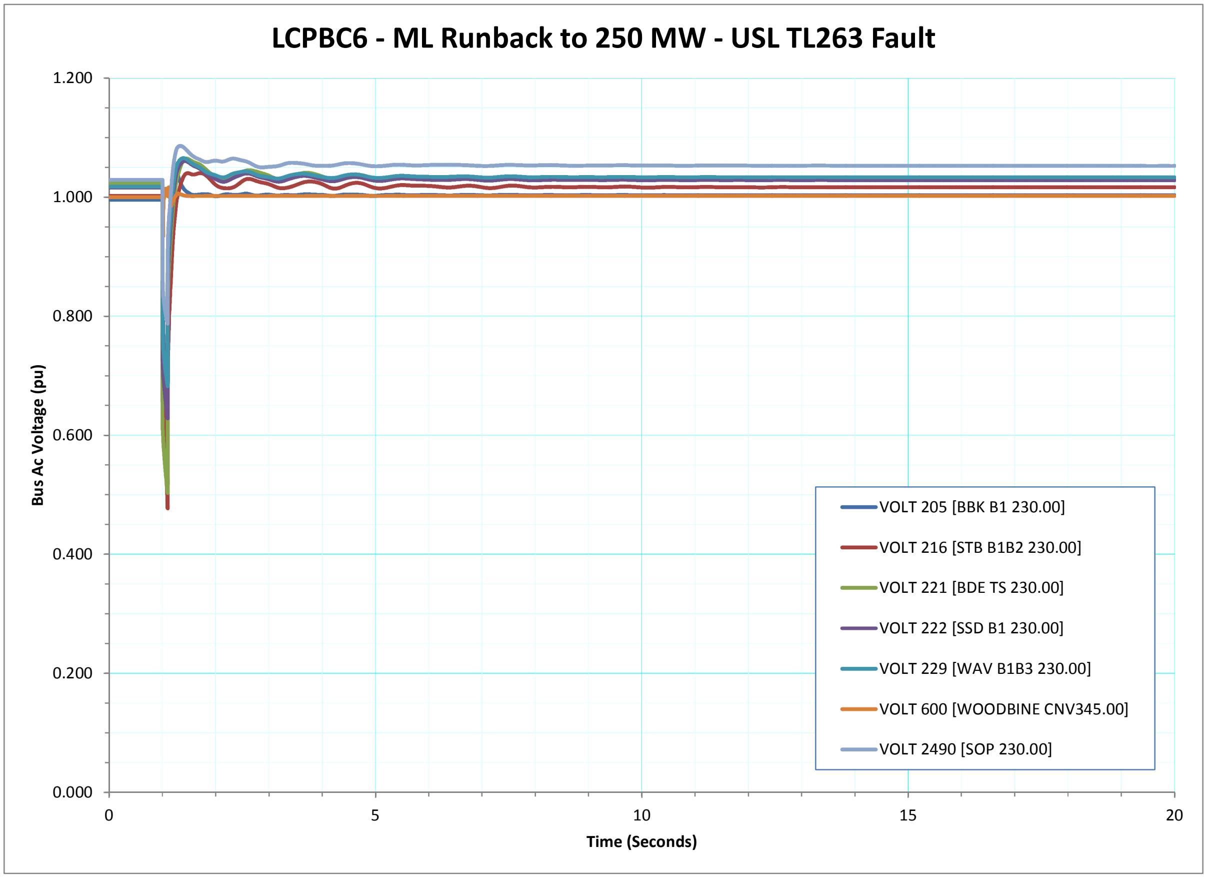


Figure 105 - LCPBC6 - ML Runback to 250 MW - USL TL263 Fault - Bus Ac Voltage (pu)

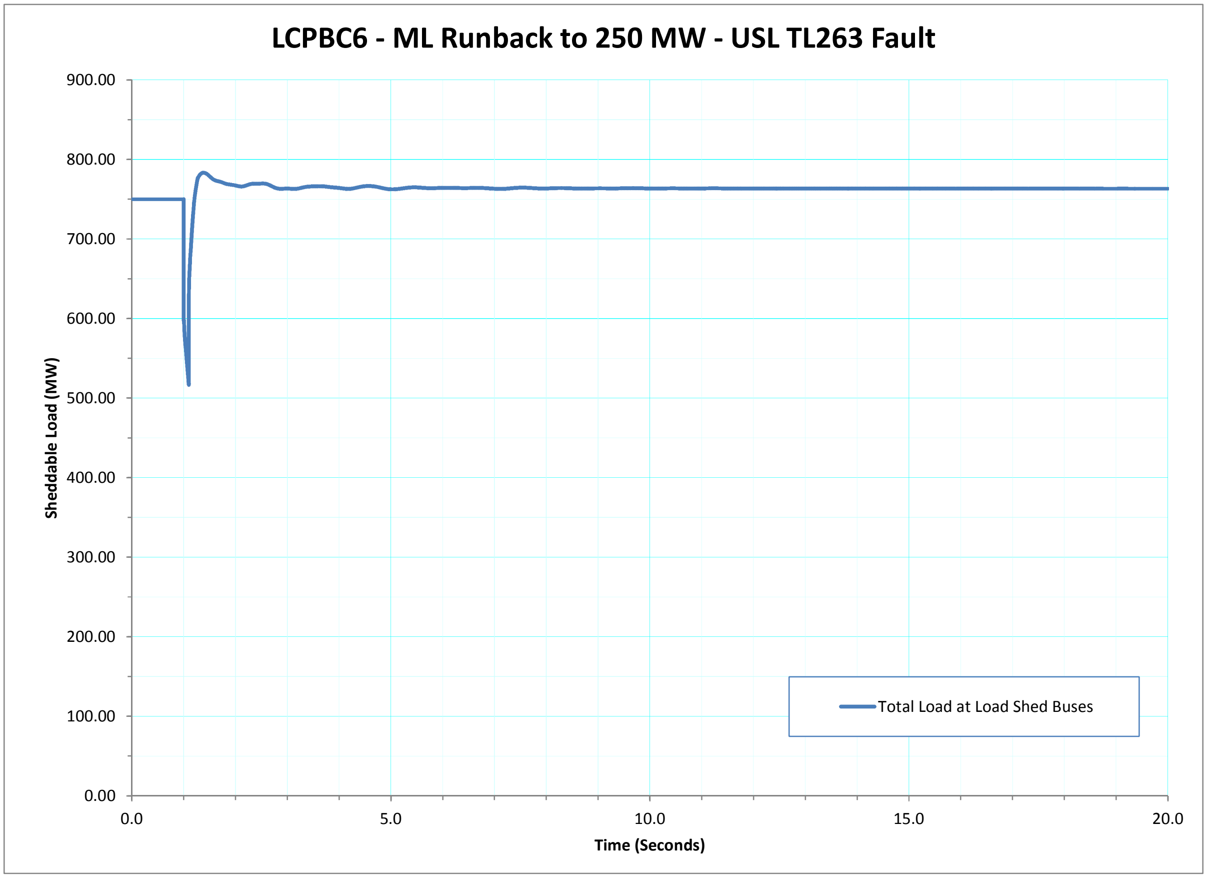


Figure 106 - LCPBC6 - ML Runback to 250 MW - USL TL263 Fault - Sheddable Load (MW)

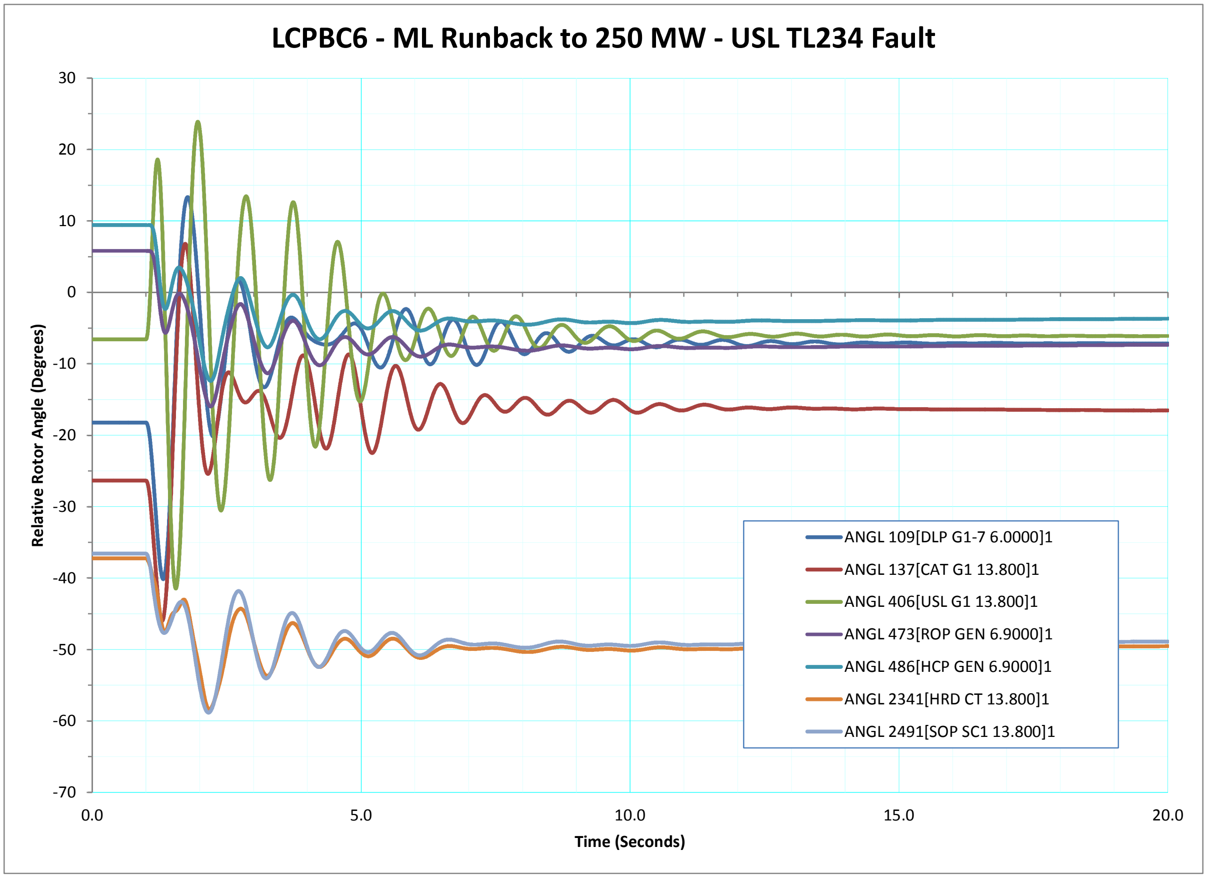


Figure 107 - LCPBC6 - ML Runback to 250 MW - USL TL234 Fault - Relative Rotor Angle (Degrees)

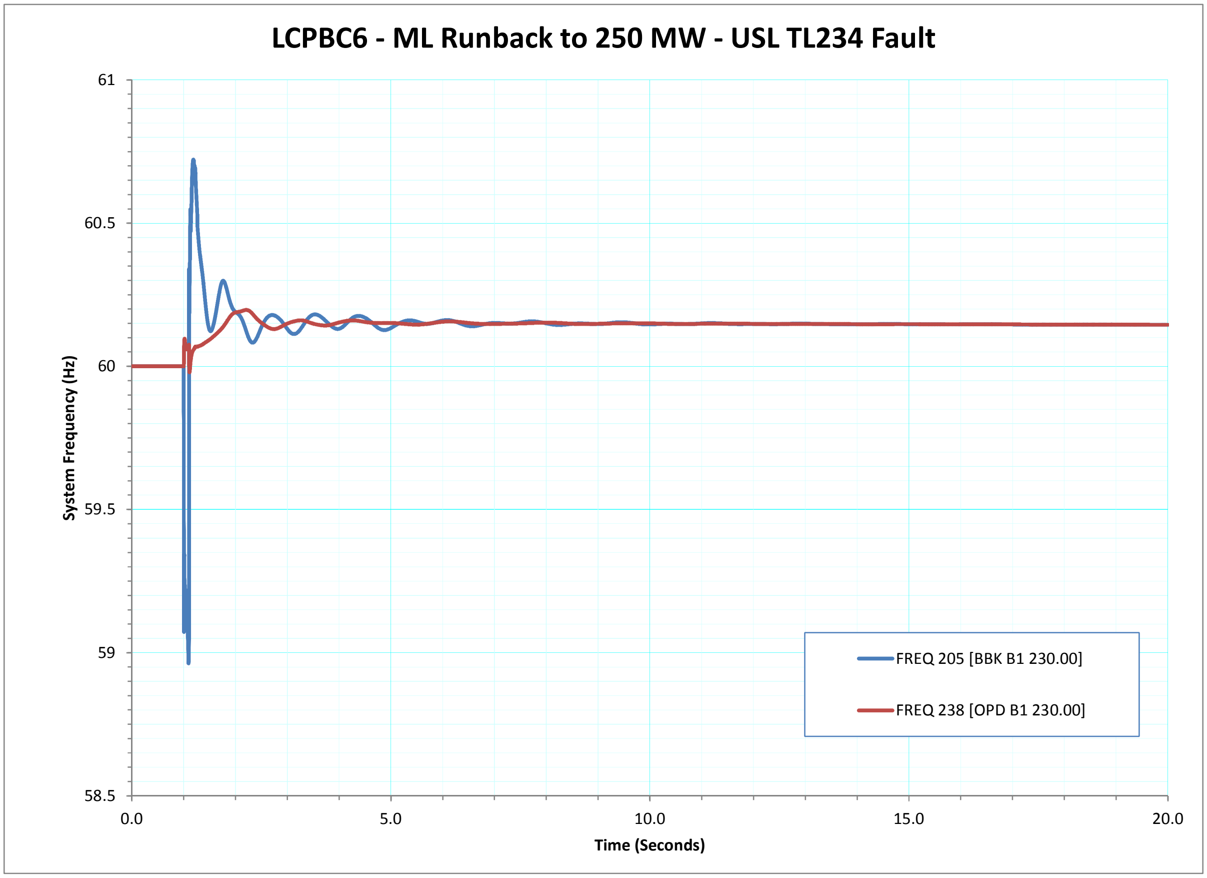


Figure 108 - LCPBC6 - ML Runback to 250 MW - USL TL234 Fault - System Frequency (Hz)

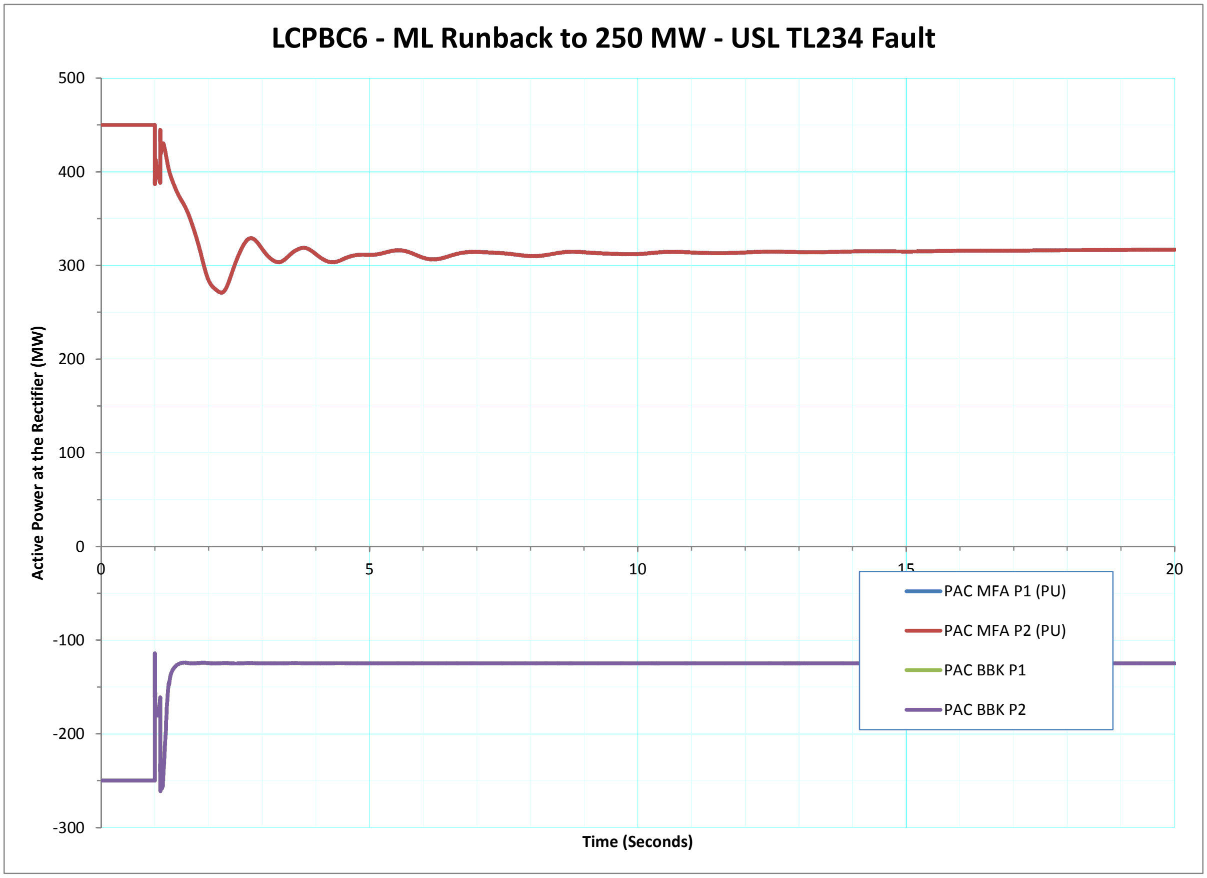


Figure 109 - LCPBC6 - ML Runback to 250 MW - USL TL234 Fault - Active Power at the Rectifier (MW)

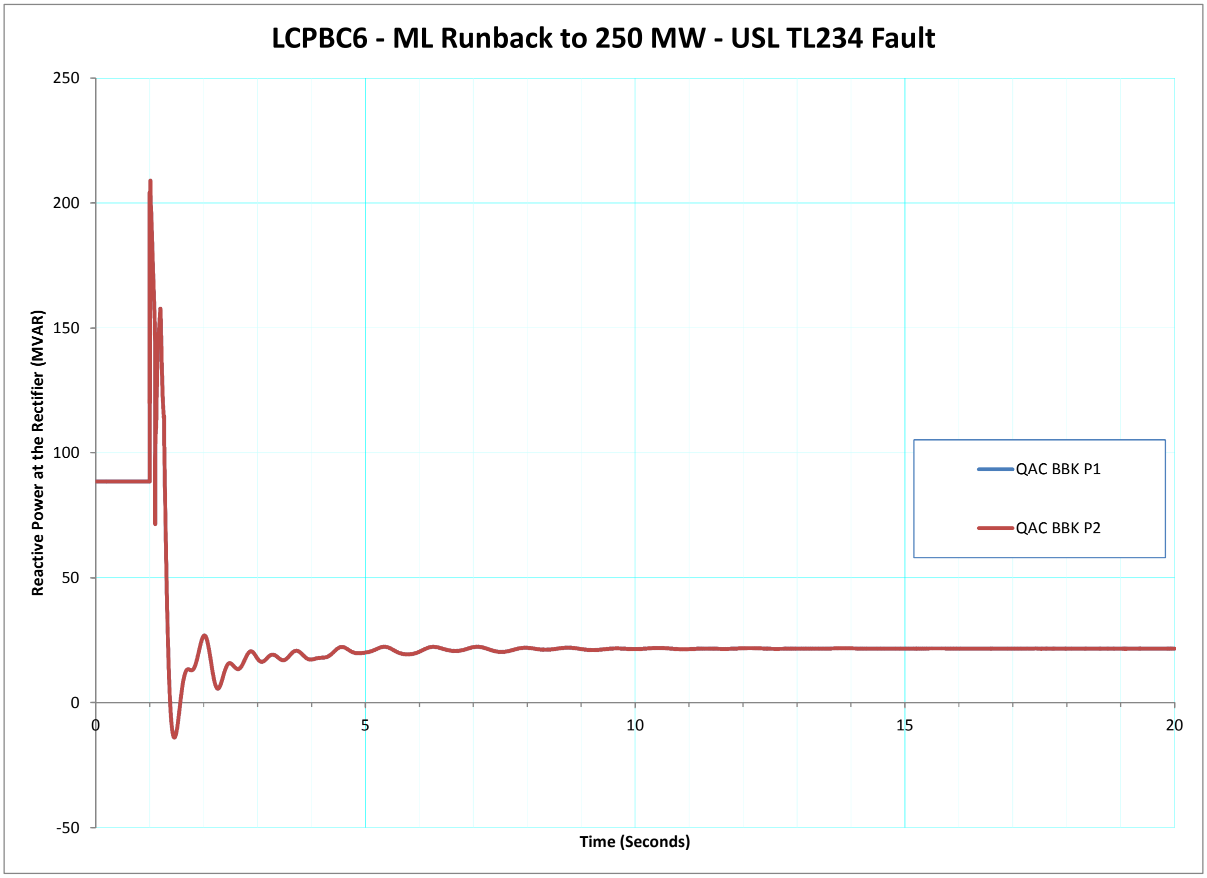


Figure 110 - LCPBC6 - ML Runback to 250 MW - USL TL234 Fault - Reactive Power at the Rectifier (MVAR)

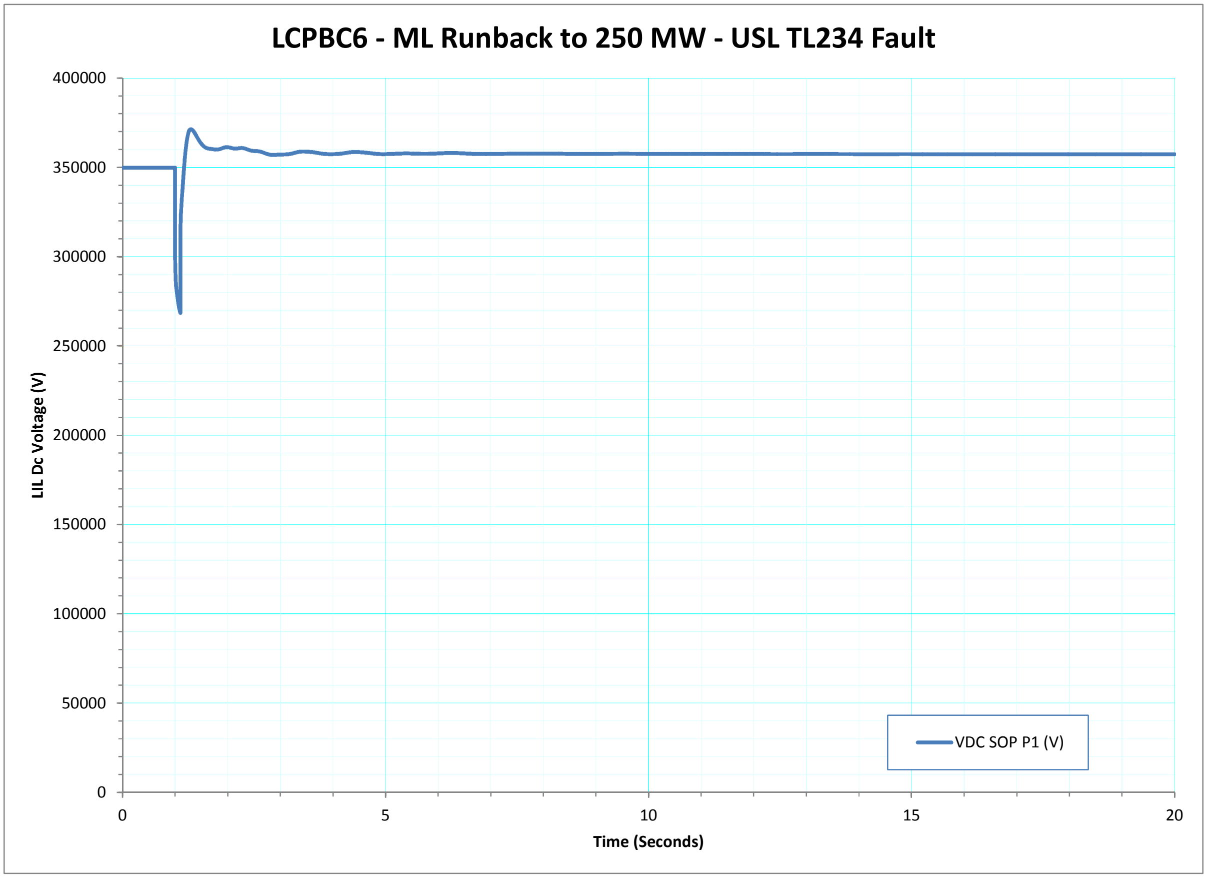


Figure 111 - LCPBC6 - ML Runback to 250 MW - USL TL234 Fault - LIL Dc Voltage (V)

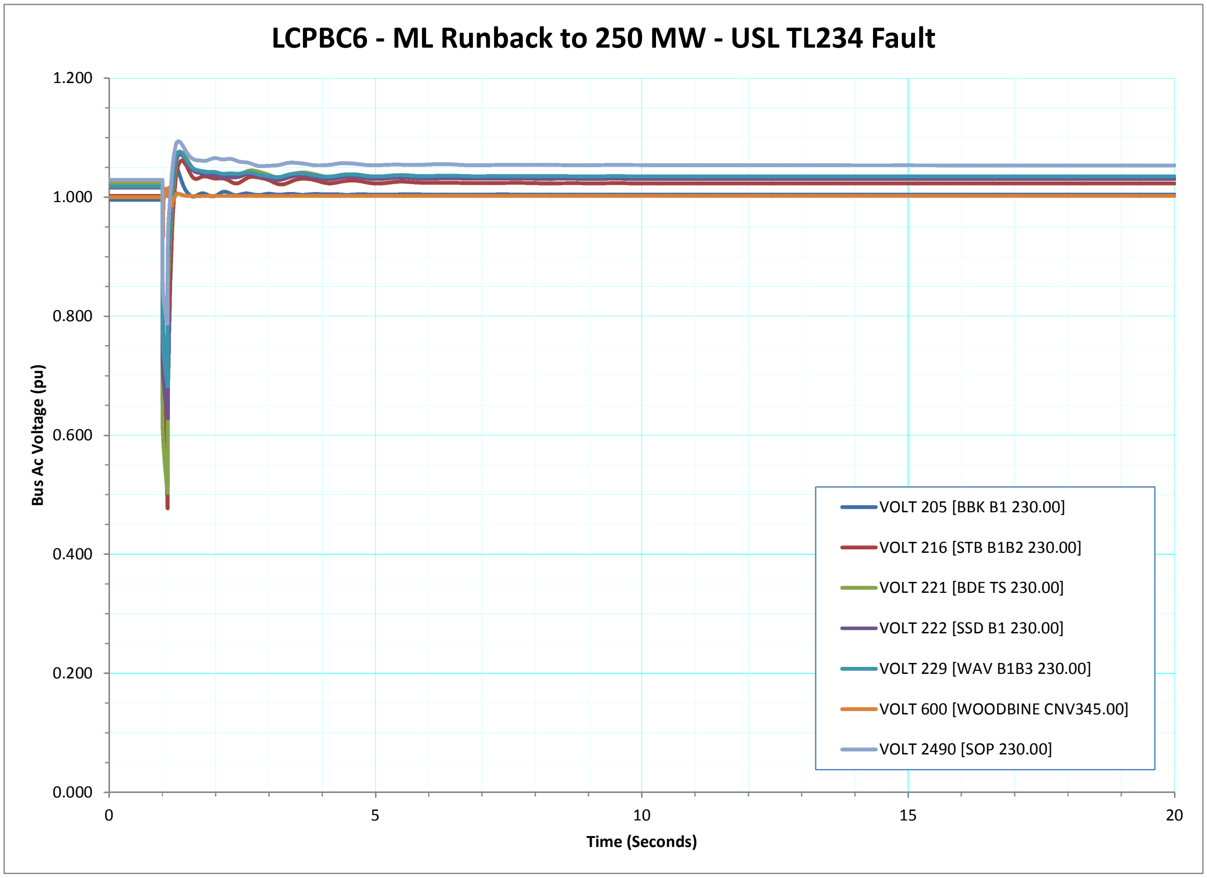


Figure 112 - LCPBC6 - ML Runback to 250 MW - USL TL234 Fault - Bus Ac Voltage (pu)

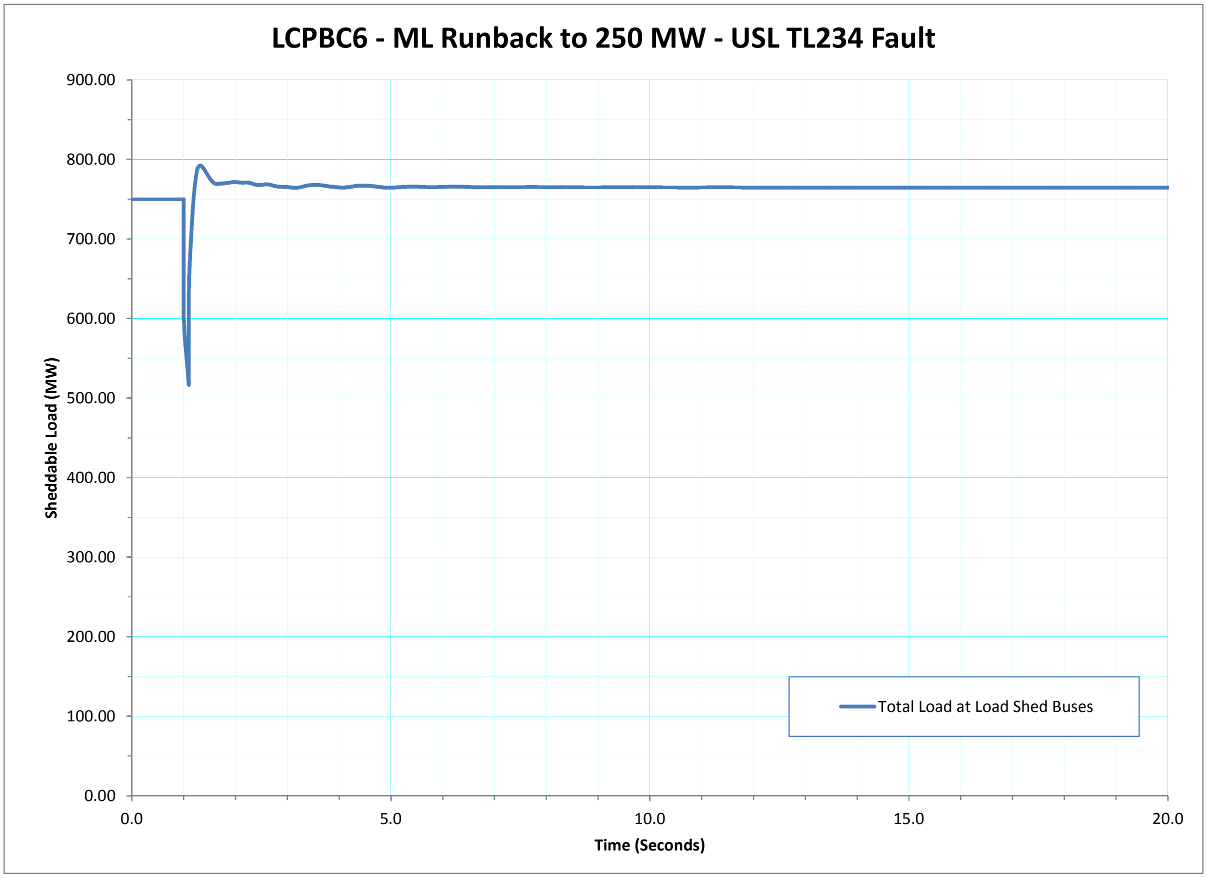


Figure 113 - LCPBC6 - ML Runback to 250 MW - USL TL234 Fault - Sheddable Load (MW)

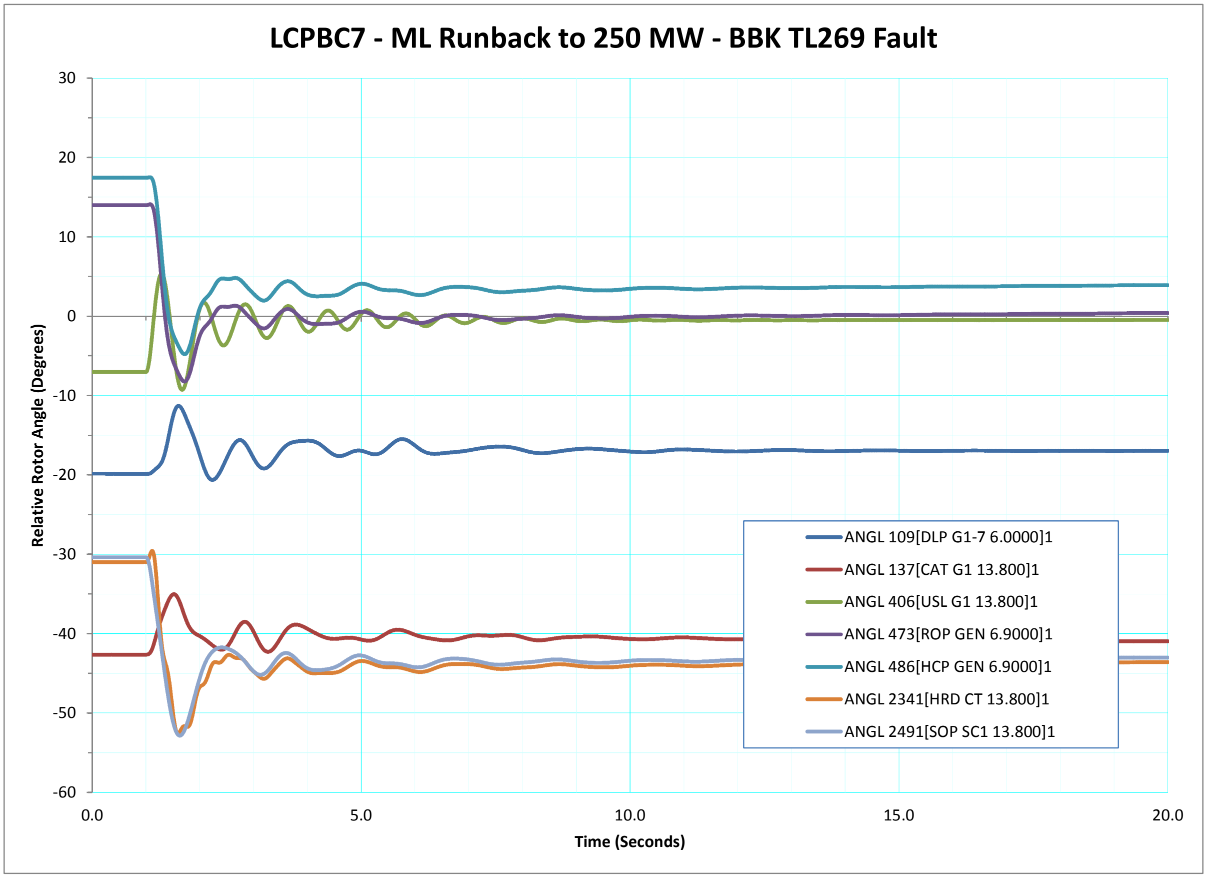


Figure 114 - LCPBC7 - ML Runback to 250 MW - BBK TL269 Fault - Relative Rotor Angle (Degrees)

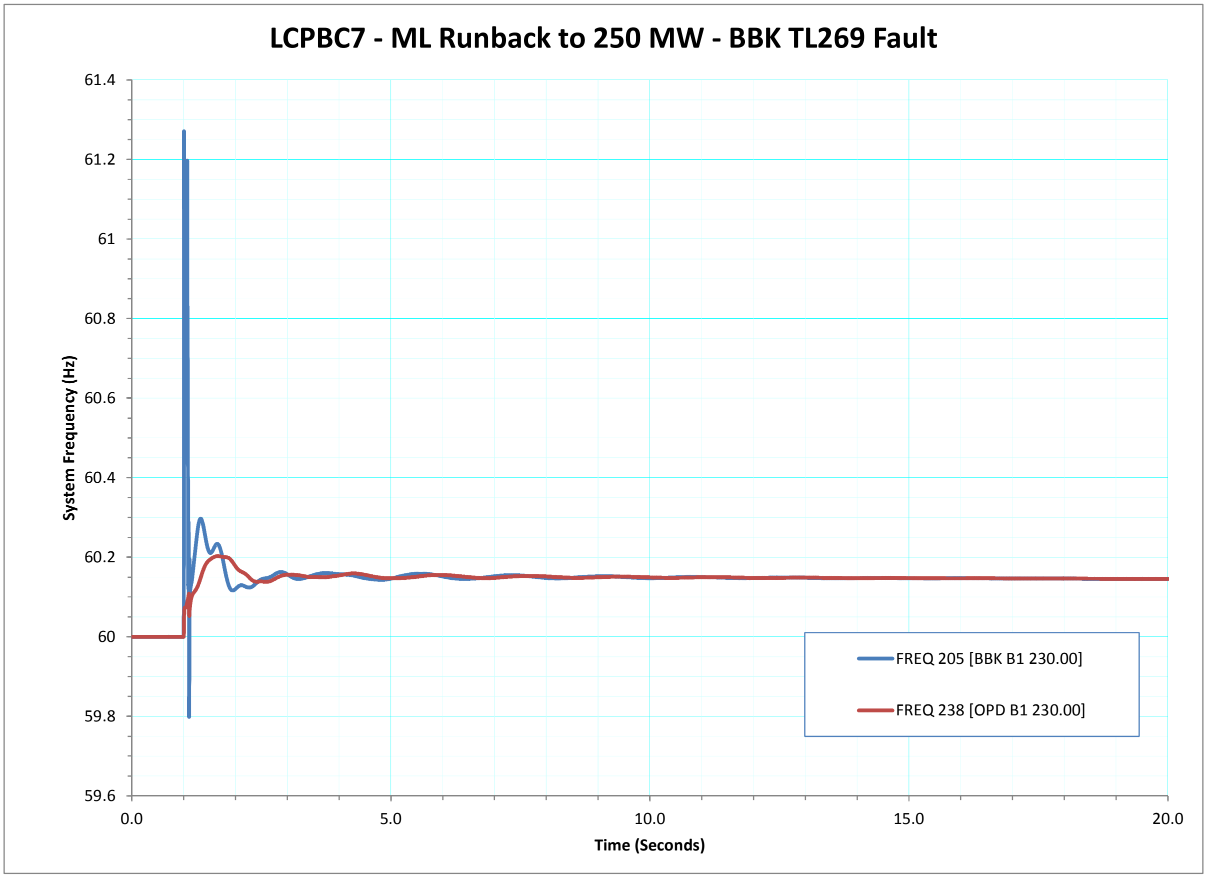


Figure 115 - LCPBC7 - ML Runback to 250 MW - BBK TL269 Fault - System Frequency (Hz)

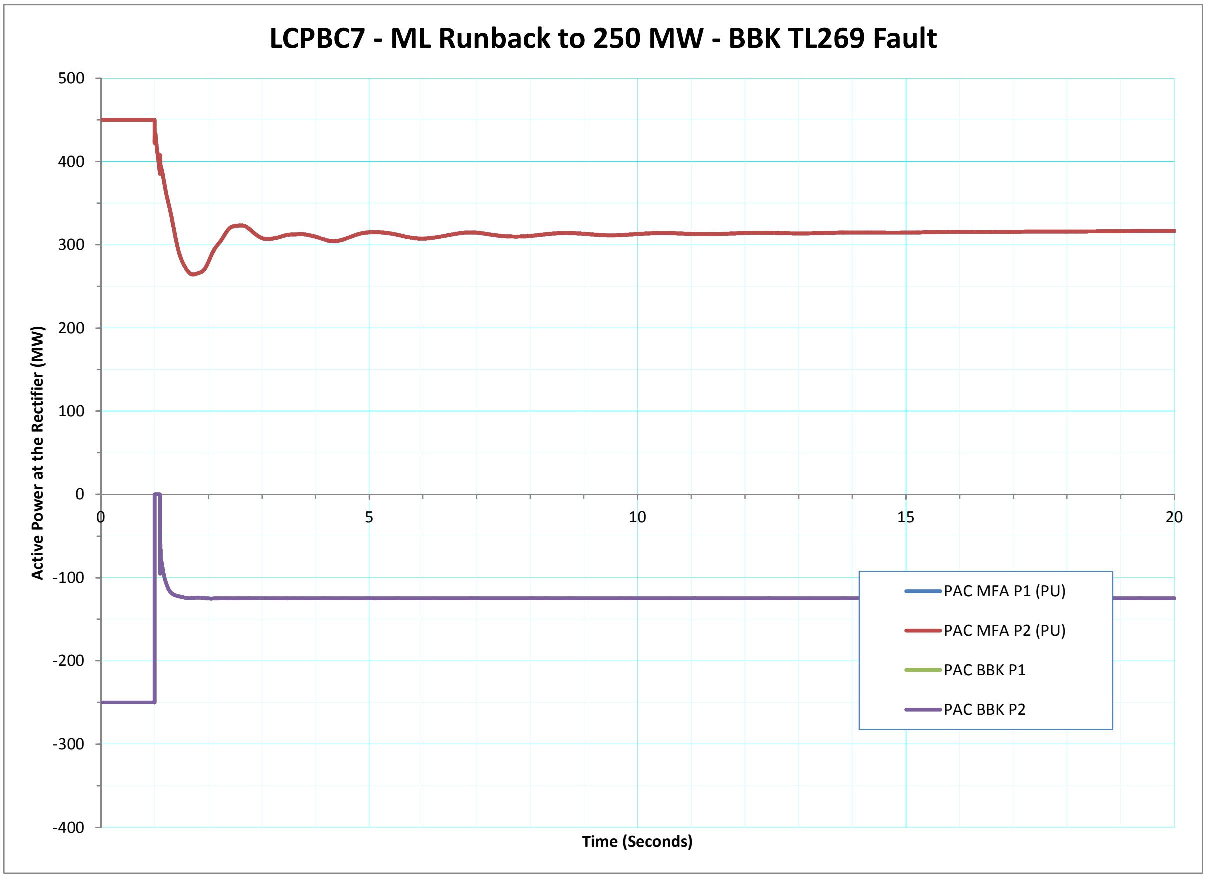


Figure 116 - LCPBC7 - ML Runback to 250 MW - BBK TL269 Fault - Active Power at the Rectifier (MW)

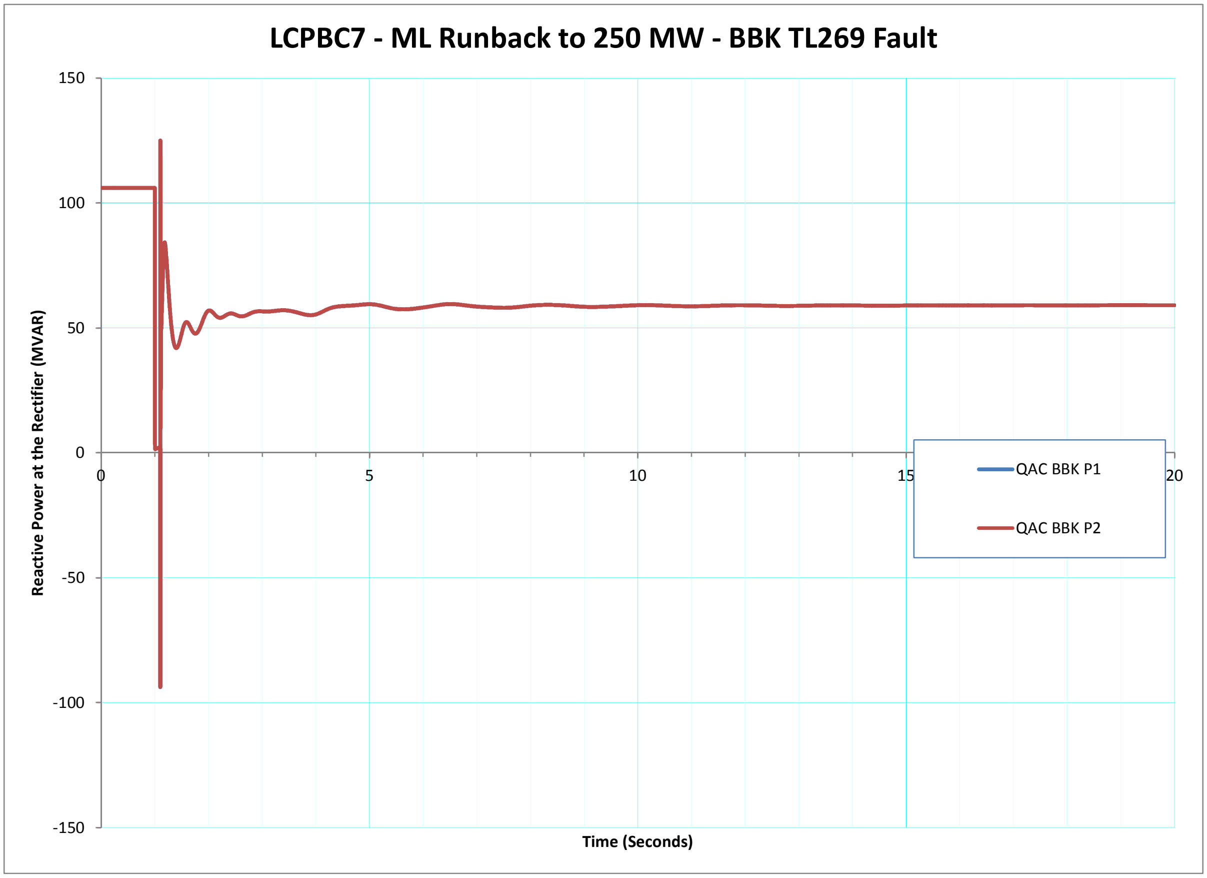


Figure 117 - LCPBC7 - ML Runback to 250 MW - BBK TL269 Fault - Reactive Power at the Rectifier (MVAR)

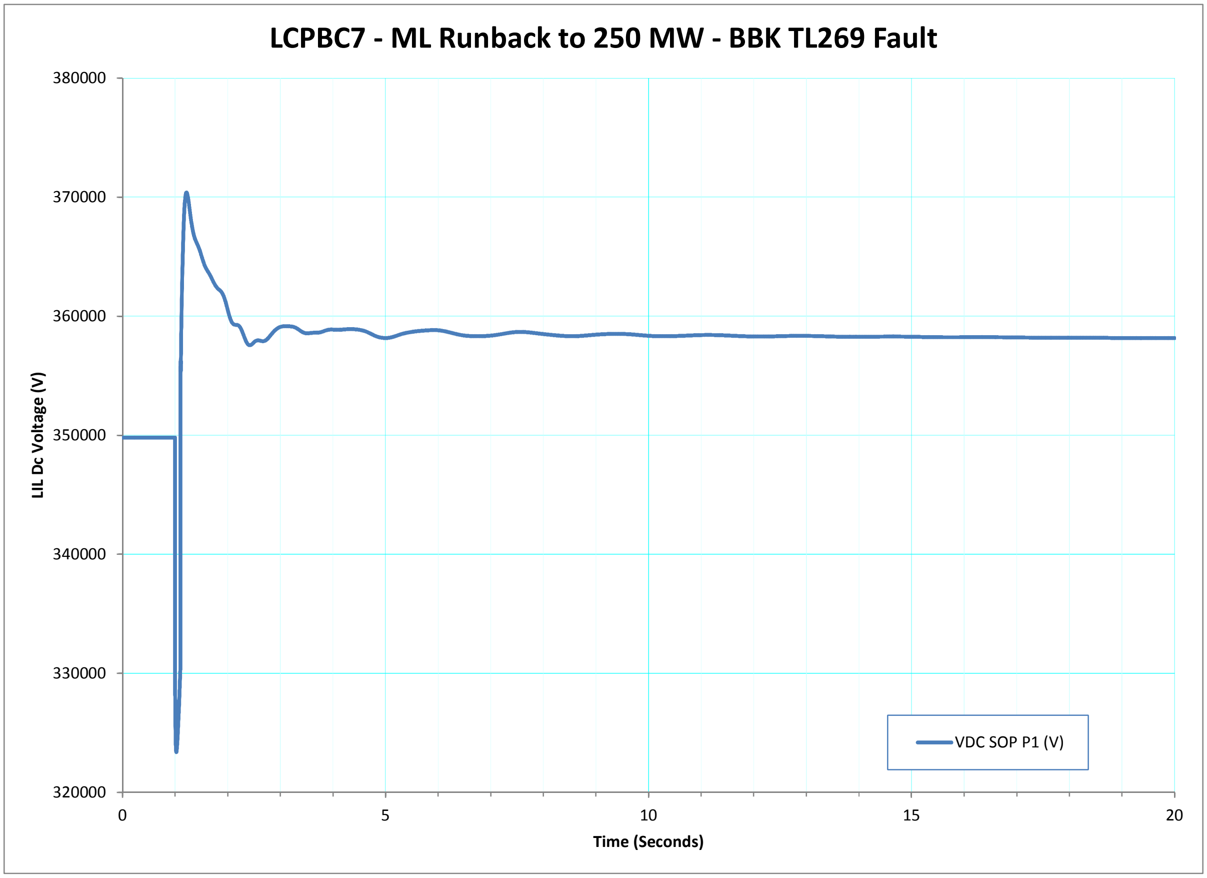


Figure 118 - LCPBC7 - ML Runback to 250 MW - BBK TL269 Fault - LIL Dc Voltage (V)

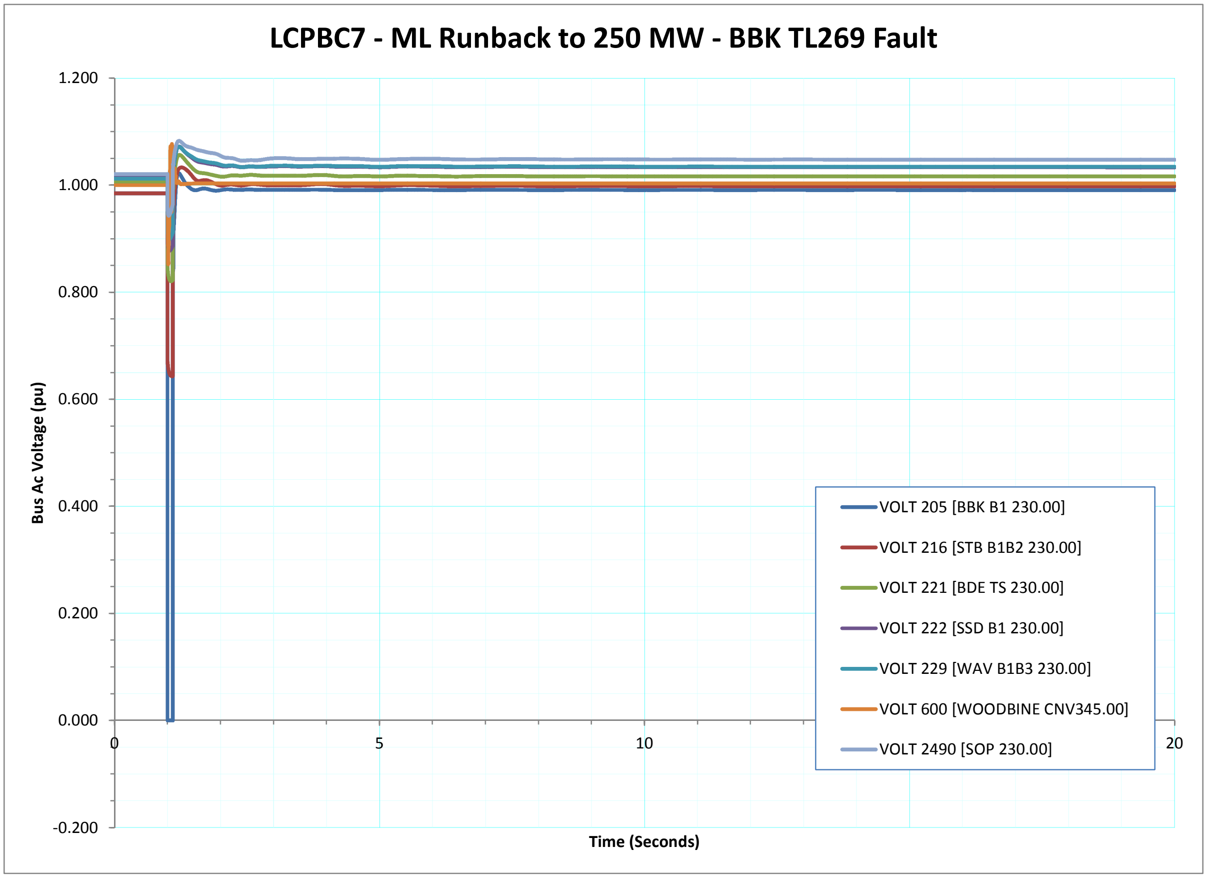


Figure 119 - LCPBC7 - ML Runback to 250 MW - BBK TL269 Fault - Bus Ac Voltage (pu)

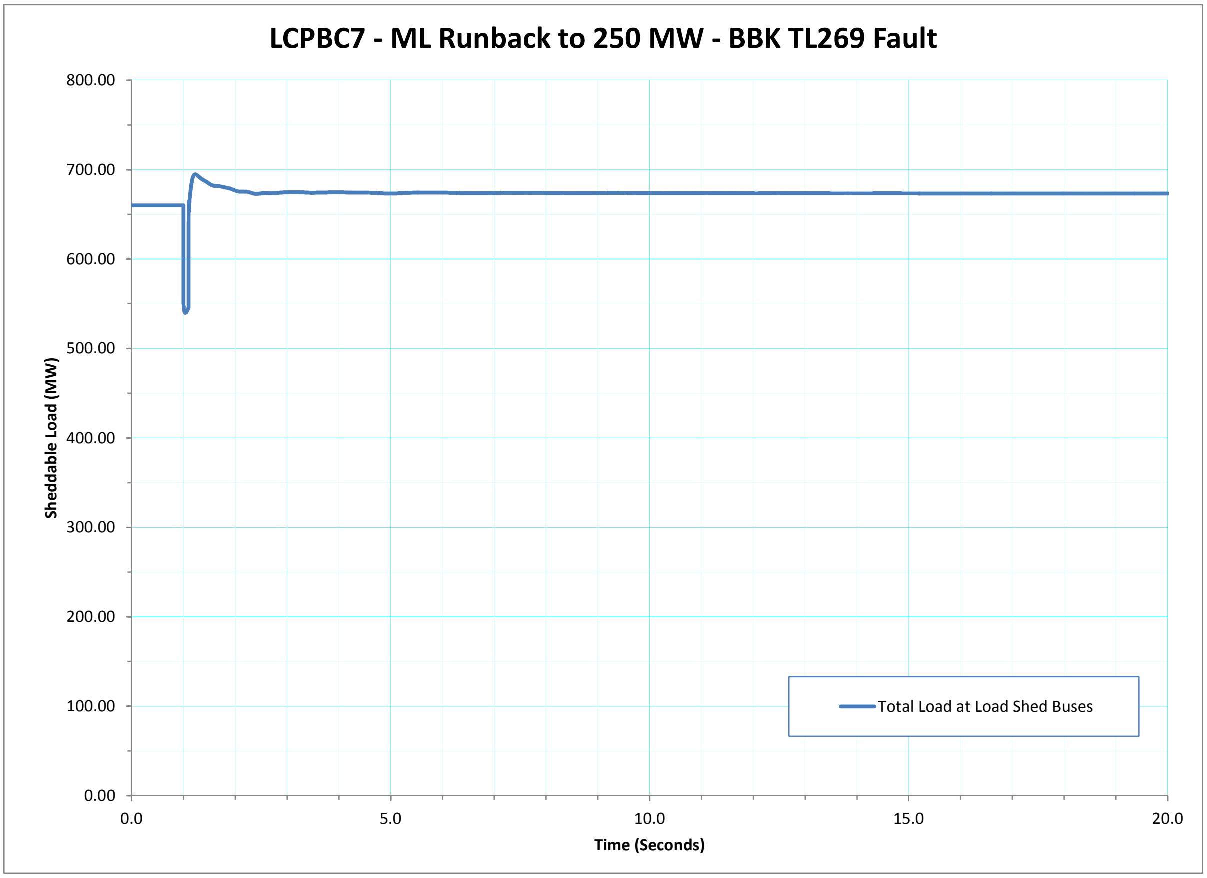

LCPBC7 - ML Runback to 250 MW - BBK TL269 Fault
Sheddable Load (MW)
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
0.0
5.0
10.0
15.0
20.0
Time (Seconds)
Total Load at Load Shed Buses

Figure 120 - LCPBC7 - ML Runback to 250 MW - BBK TL269 Fault - Sheddable Load (MW)

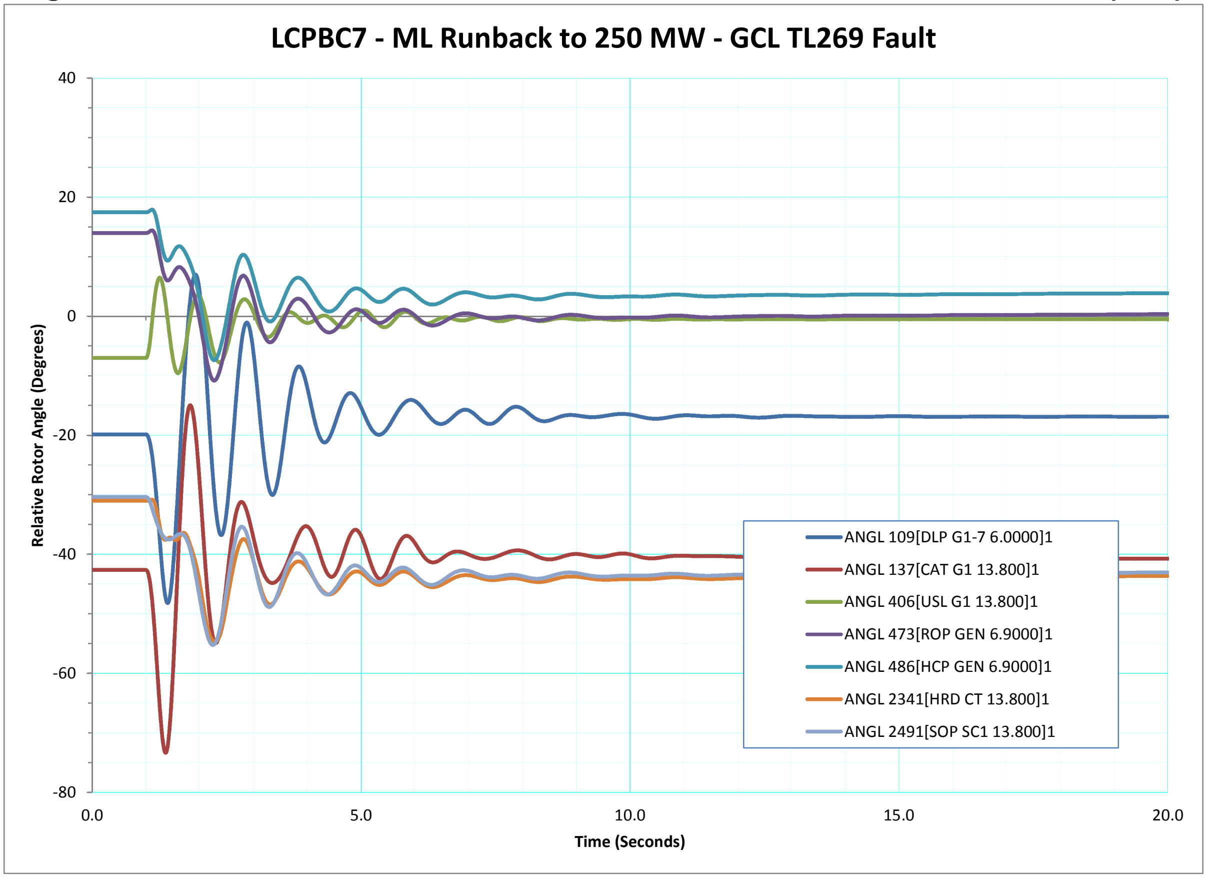


Figure 121 - LCPBC7 - ML Runback to 250 MW - GCL TL269 Fault - Relative Rotor Angle (Degrees)

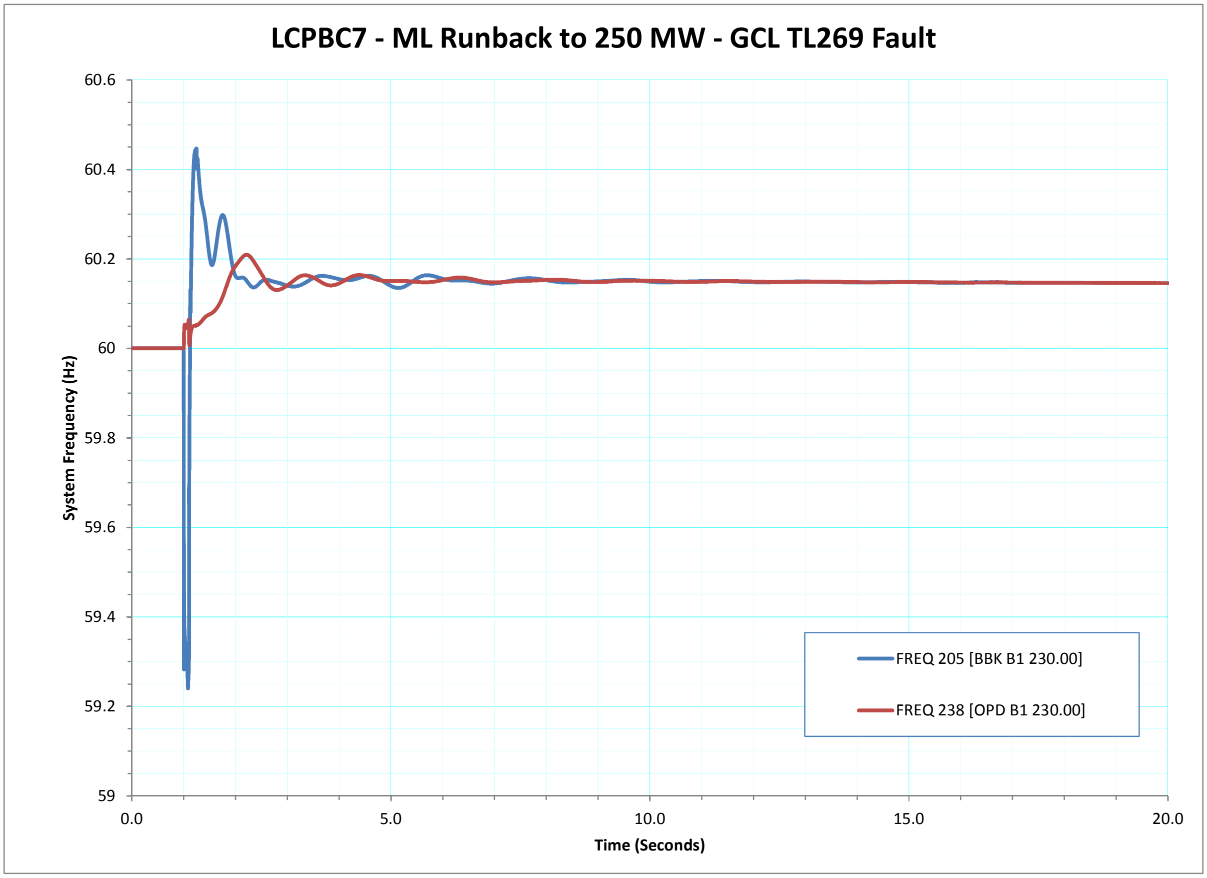


Figure 122 - LCPBC7 - ML Runback to 250 MW - GCL TL269 Fault - System Frequency (Hz)

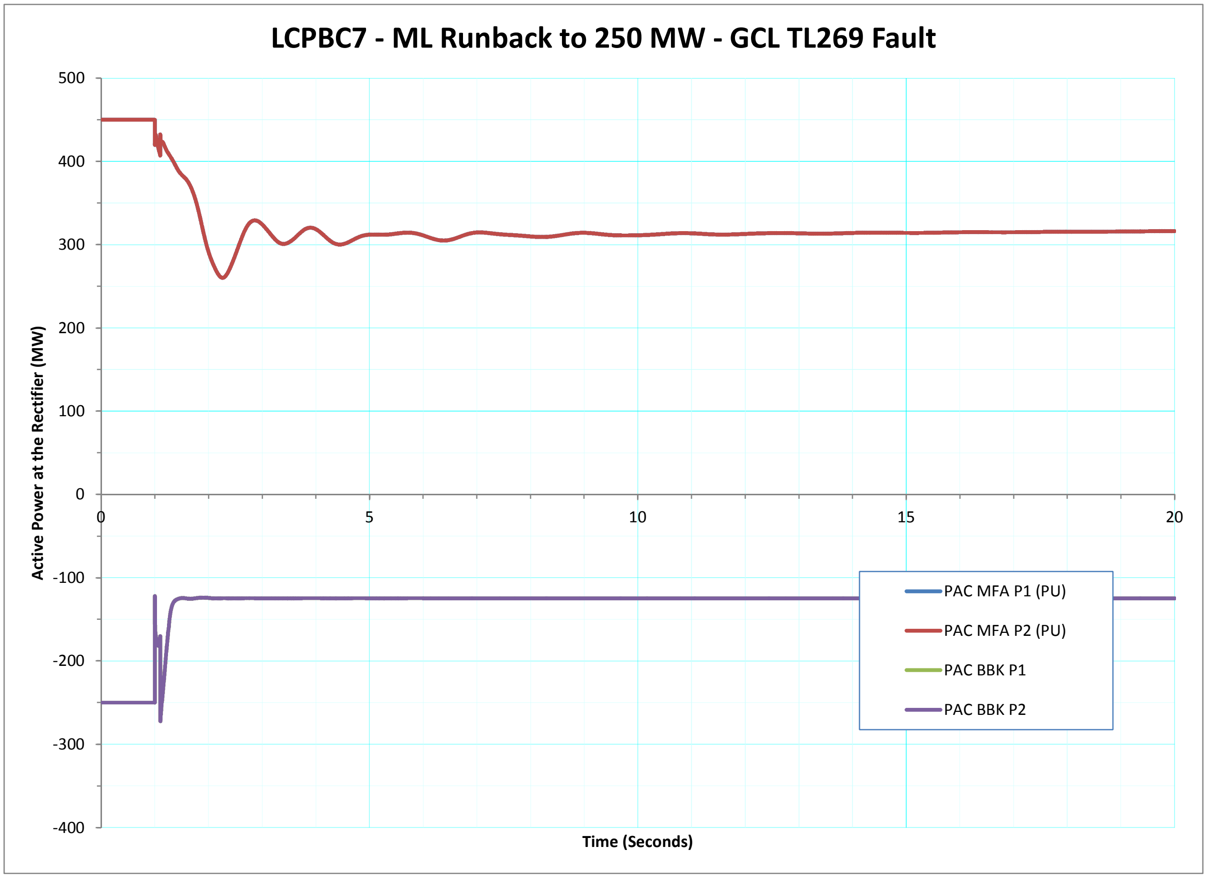


Figure 123 - LCPBC7 - ML Runback to 250 MW - GCL TL269 Fault - Active Power at the Rectifier (MW)

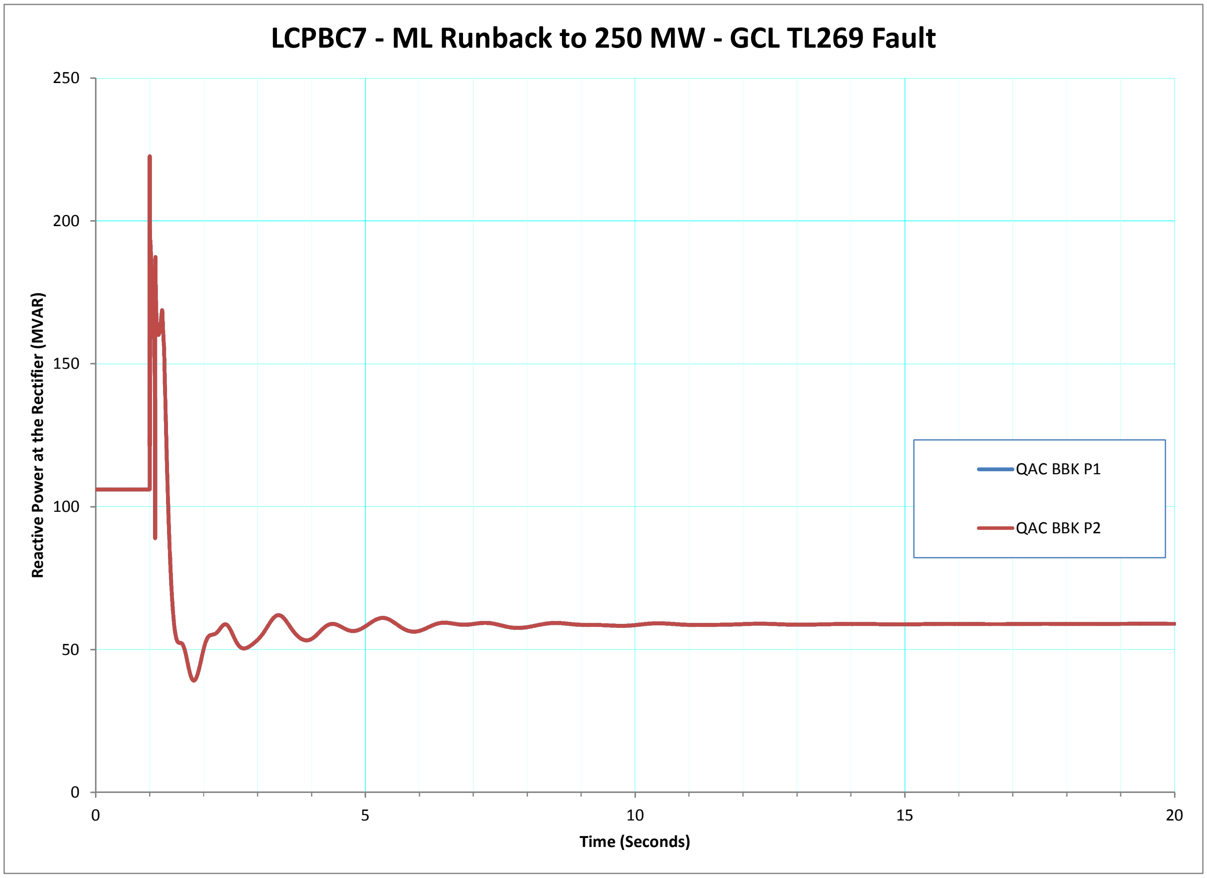


Figure 124 - LCPBC7 - ML Runback to 250 MW - GCL TL269 Fault - Reactive Power at the Rectifier (MVAR)

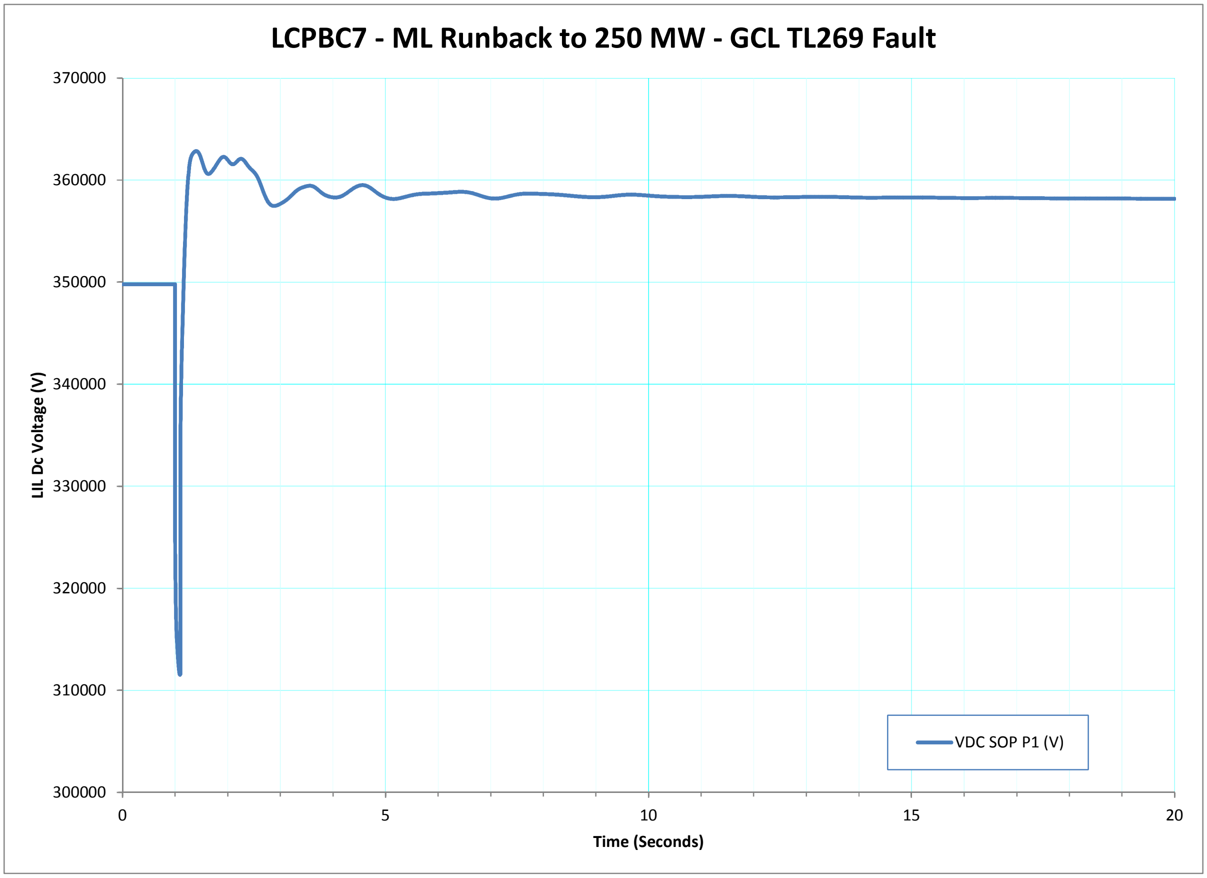


Figure 125 - LCPBC7 - ML Runback to 250 MW - GCL TL269 Fault - LIL Dc Voltage (V)

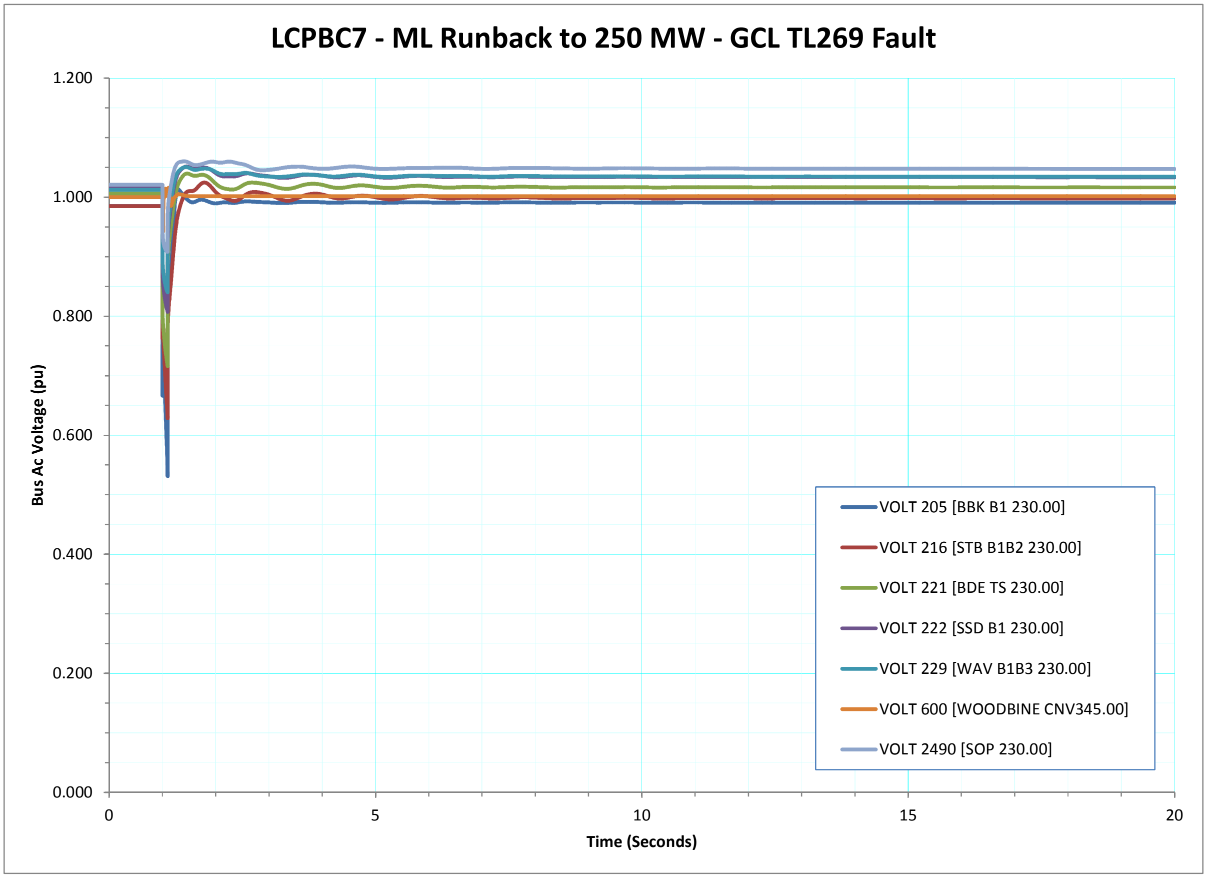


Figure 126 - LCPBC7 - ML Runback to 250 MW - GCL TL269 Fault - Bus Ac Voltage (pu)

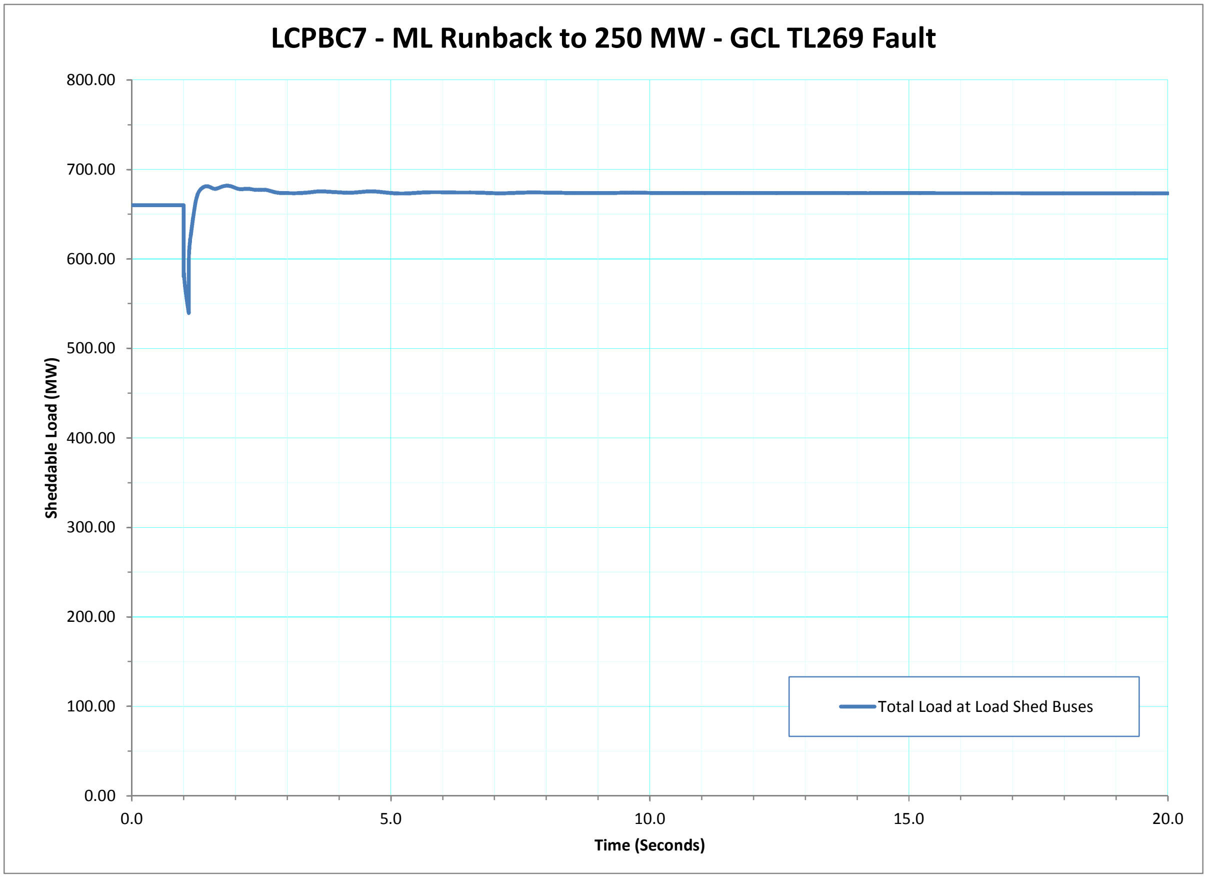


Figure 127 - LCPBC7 - ML Runback to 250 MW - GCL TL269 Fault - Sheddable Load (MW)

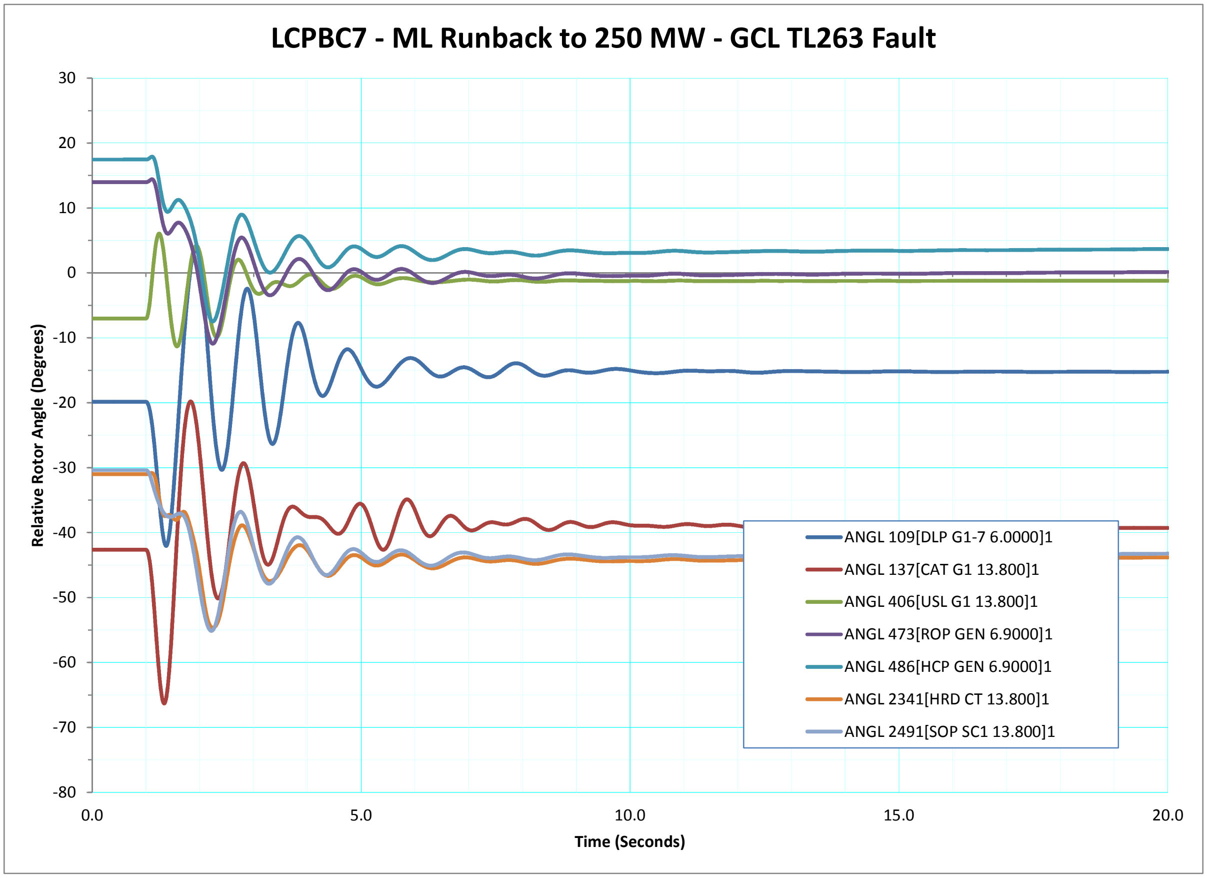


Figure 128 - LCPBC7 - ML Runback to 250 MW - GCL TL263 Fault - Relative Rotor Angle (Degrees)

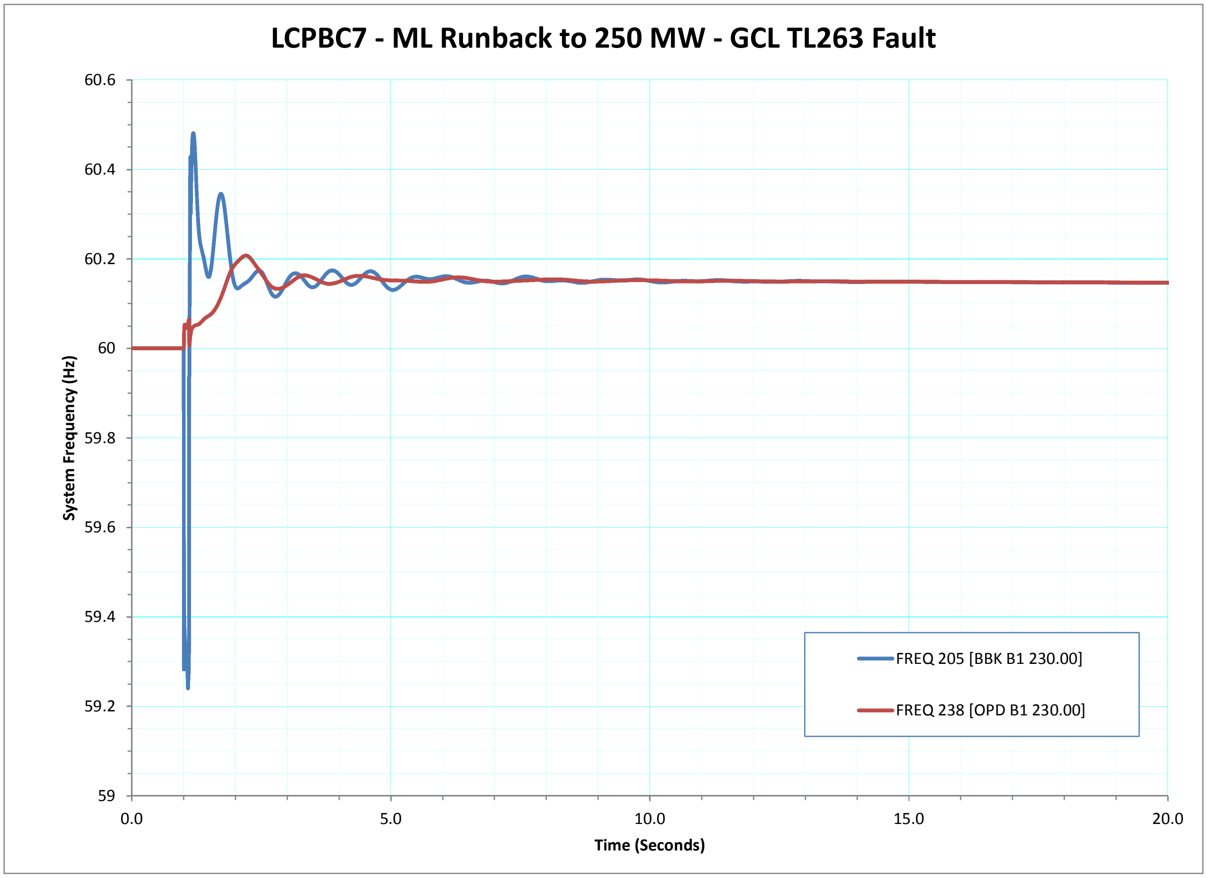


Figure 129 - LCPBC7 - ML Runback to 250 MW - GCL TL263 Fault - System Frequency (Hz)

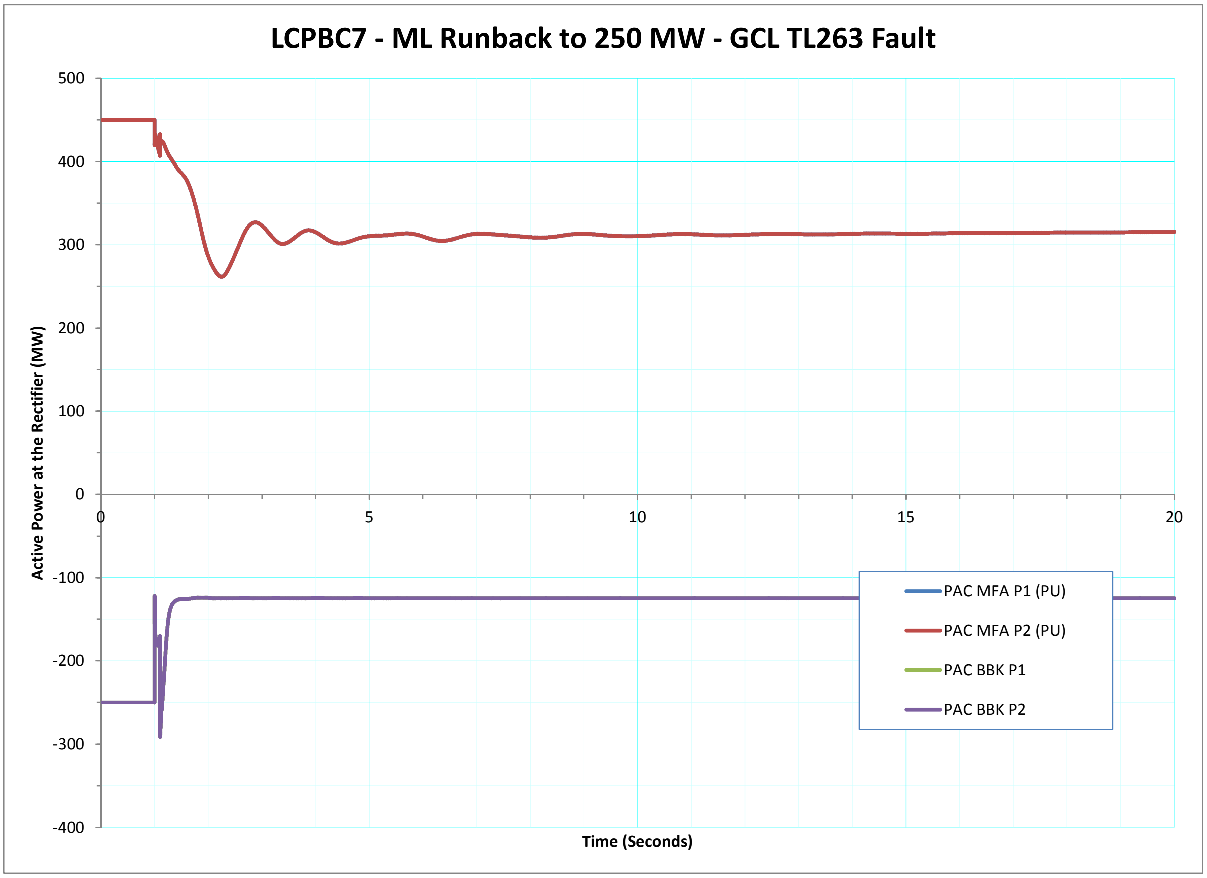


Figure 130 - LCPBC7 - ML Runback to 250 MW - GCL TL263 Fault - Active Power at the Rectifier (MW)

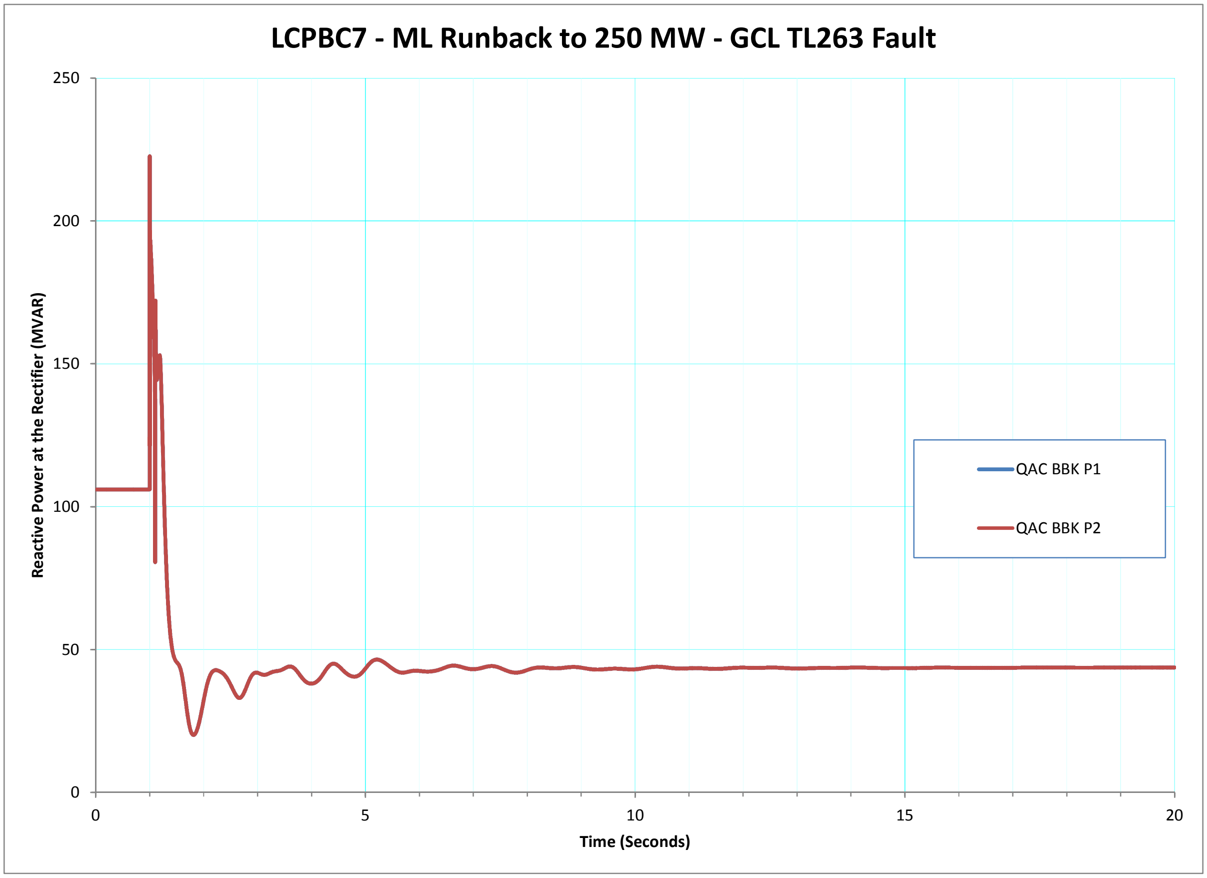


Figure 131 - LCPBC7 - ML Runback to 250 MW - GCL TL263 Fault - Reactive Power at the Rectifier (MVAR)

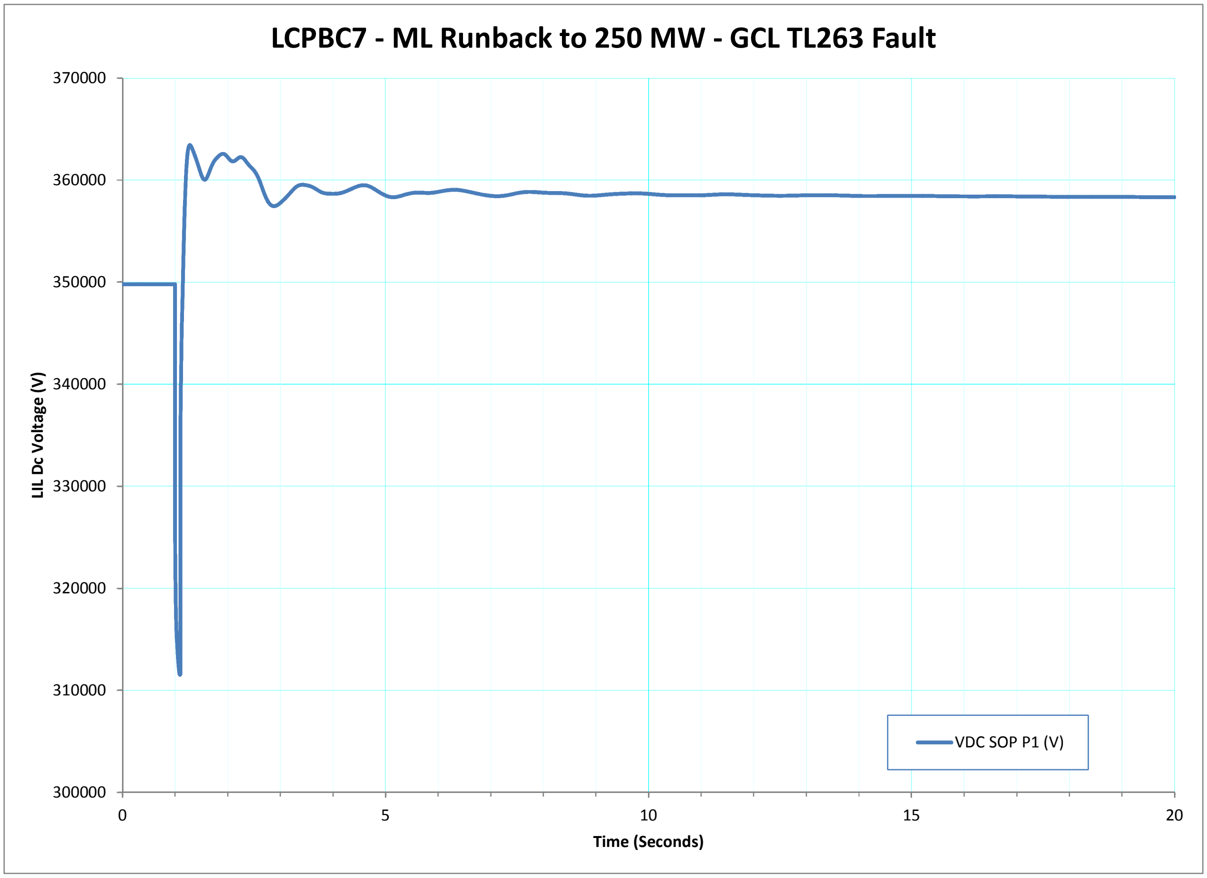


Figure 132 - LCPBC7 - ML Runback to 250 MW - GCL TL263 Fault - LIL Dc Voltage (V)

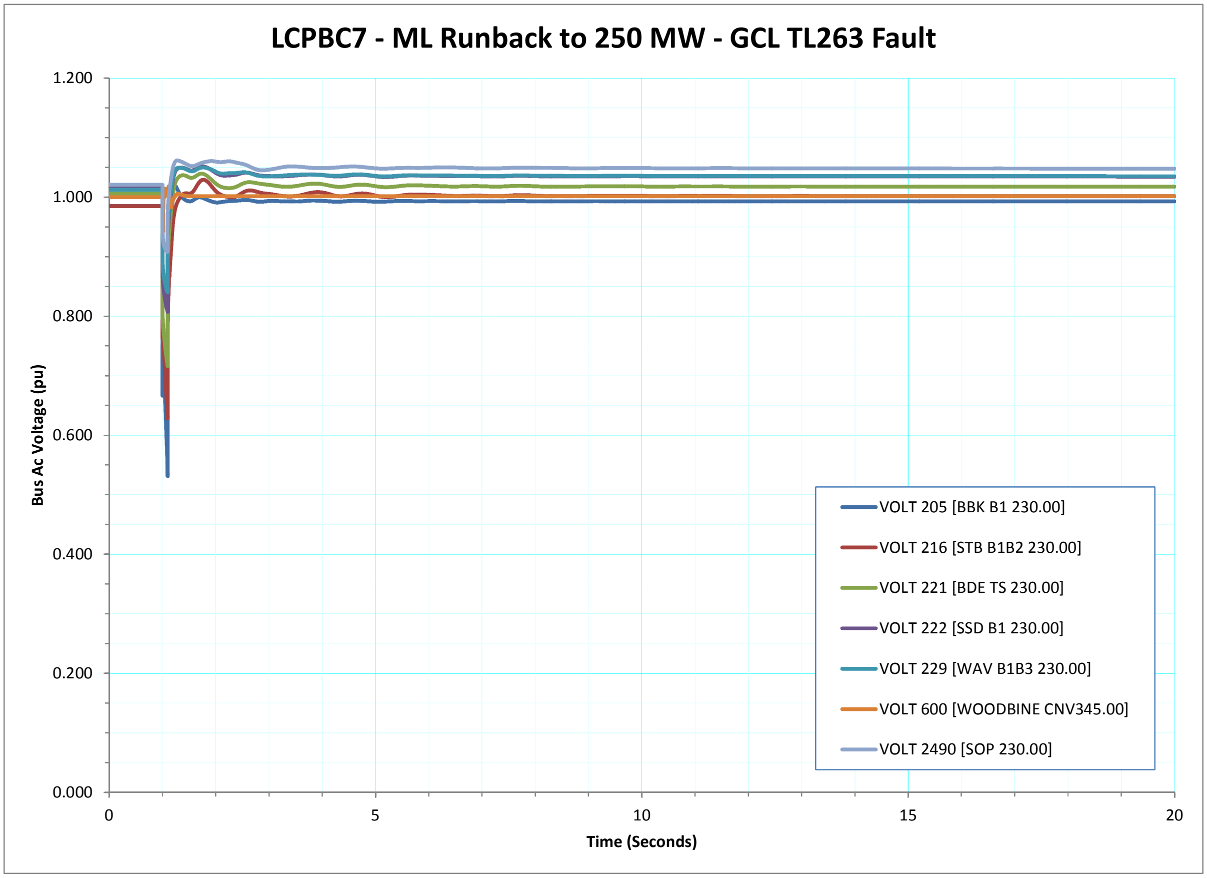


Figure 133 - LCPBC7 - ML Runback to 250 MW - GCL TL263 Fault - Bus Ac Voltage (pu)

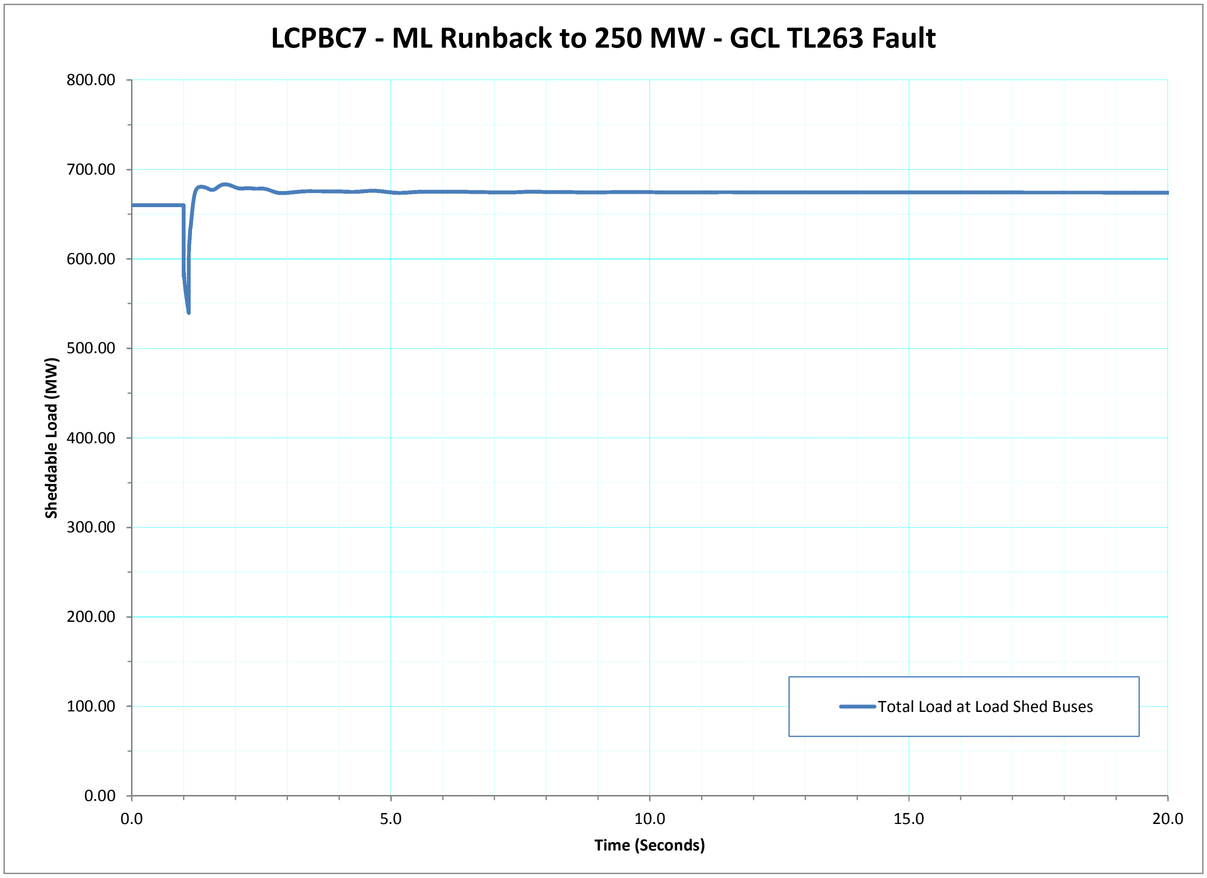


Figure 134 - LCPBC7 - ML Runback to 250 MW - GCL TL263 Fault - Sheddable Load (MW)

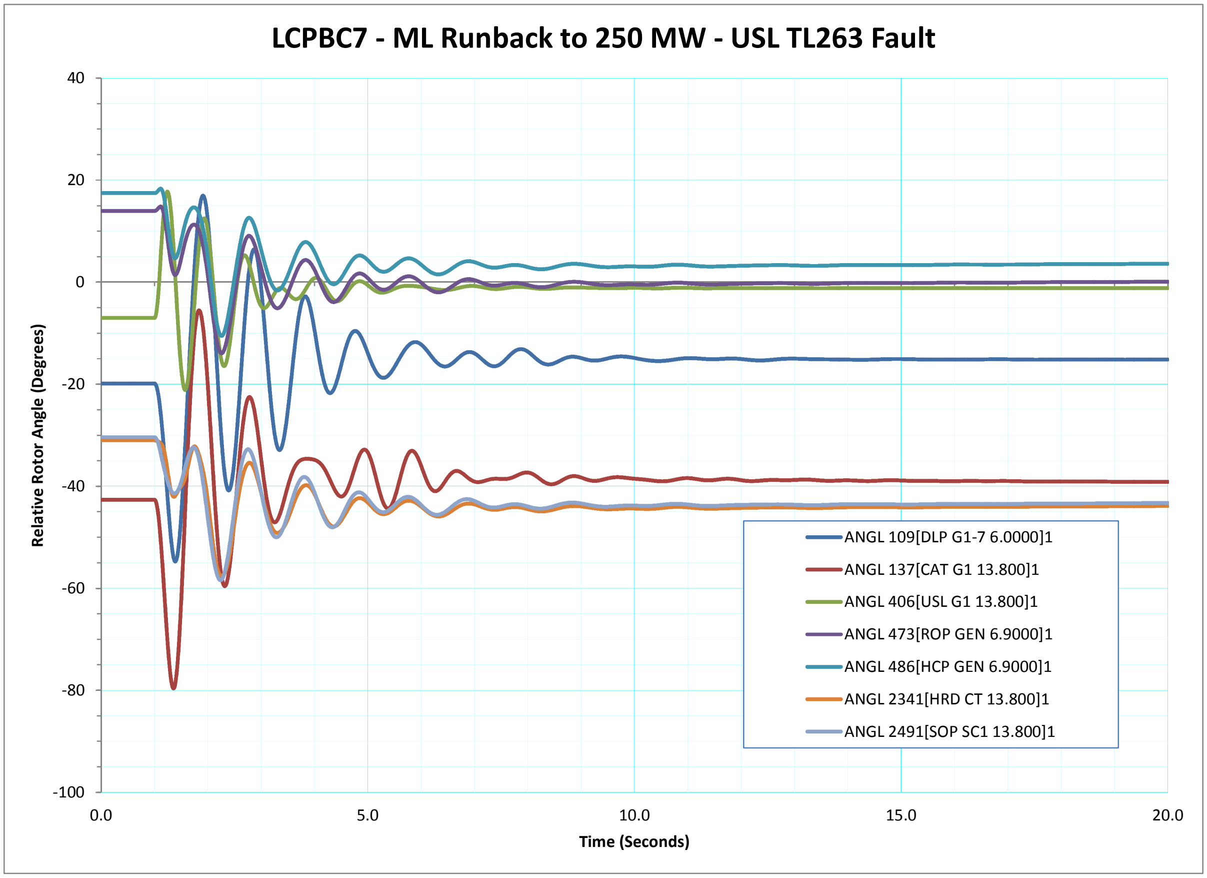


Figure 135 - LCPBC7 - ML Runback to 250 MW - USL TL263 Fault - Relative Rotor Angle (Degrees)

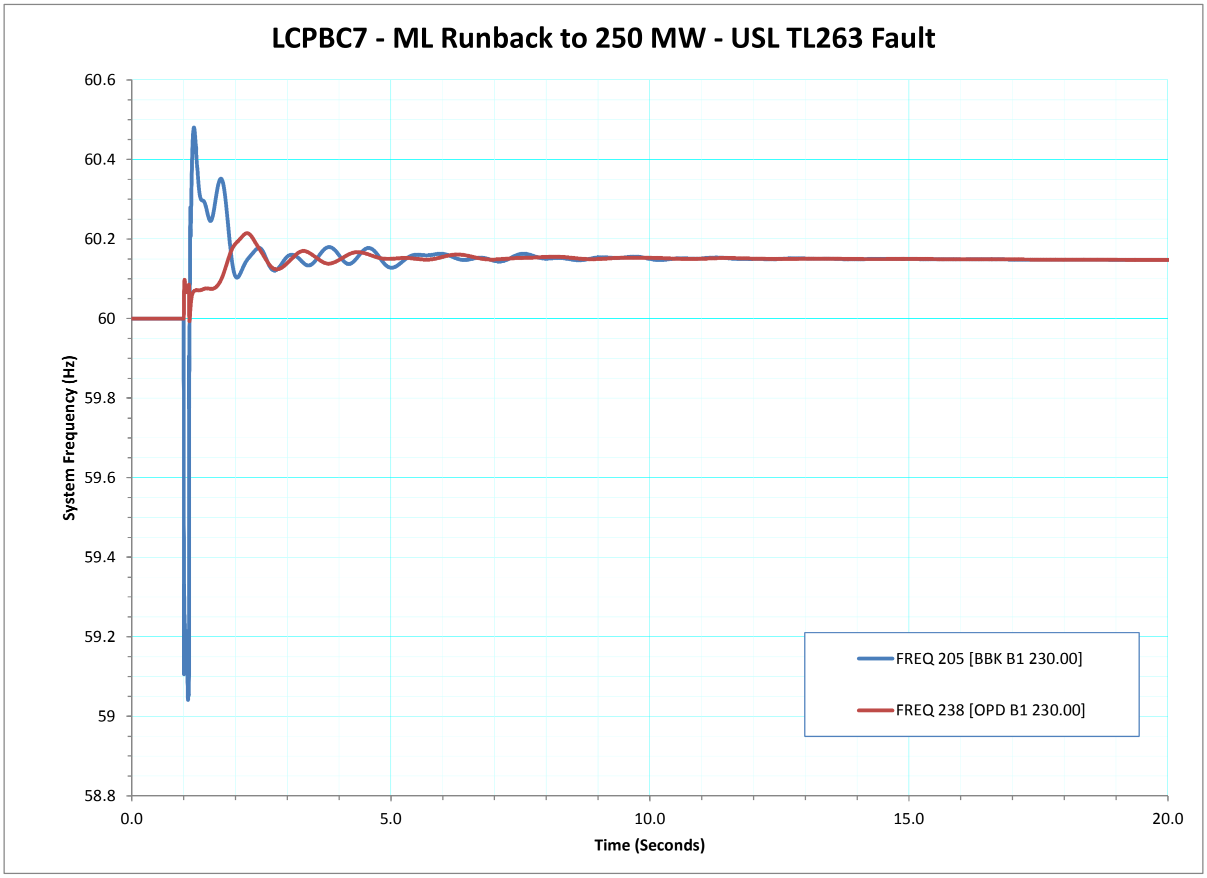


Figure 136 - LCPBC7 - ML Runback to 250 MW - USL TL263 Fault - System Frequency (Hz)

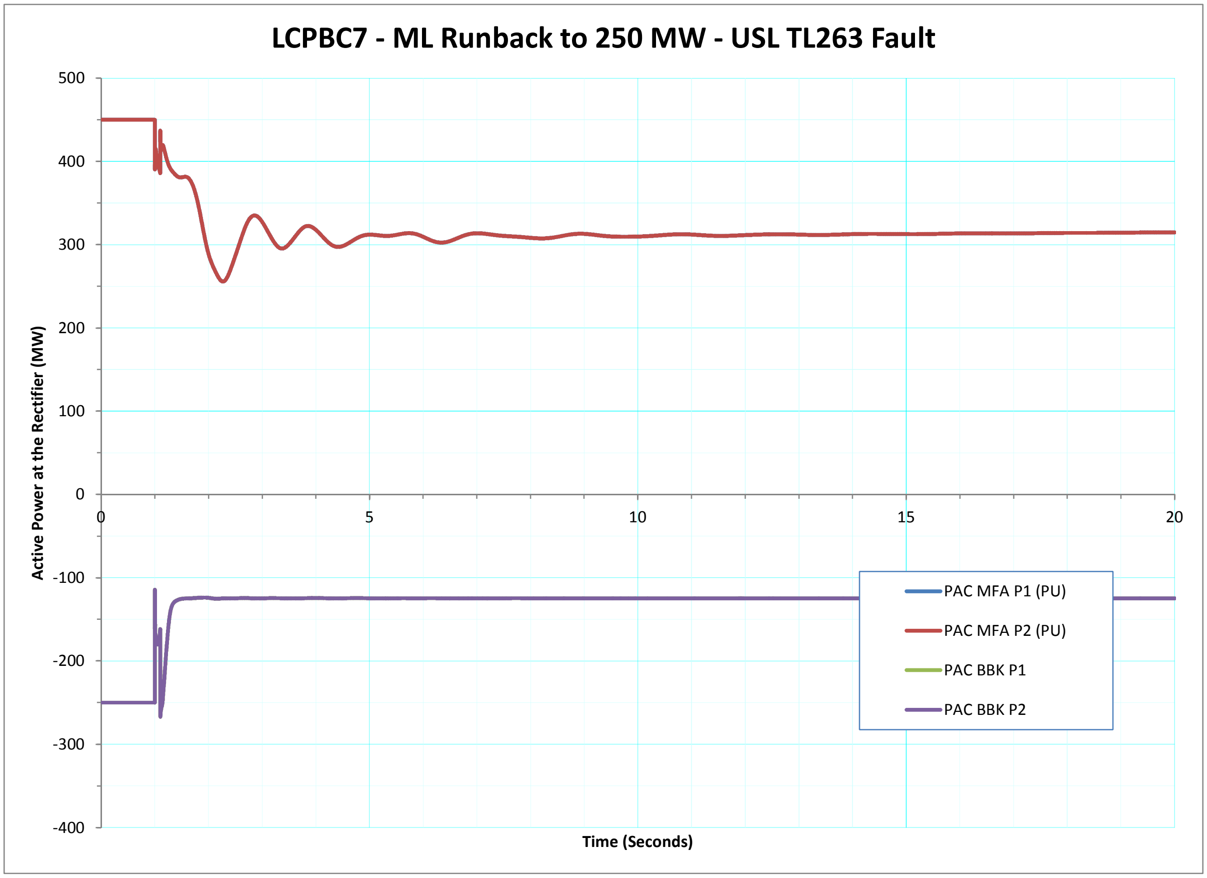


Figure 137 - LCPBC7 - ML Runback to 250 MW - USL TL263 Fault - Active Power at the Rectifier (MW)

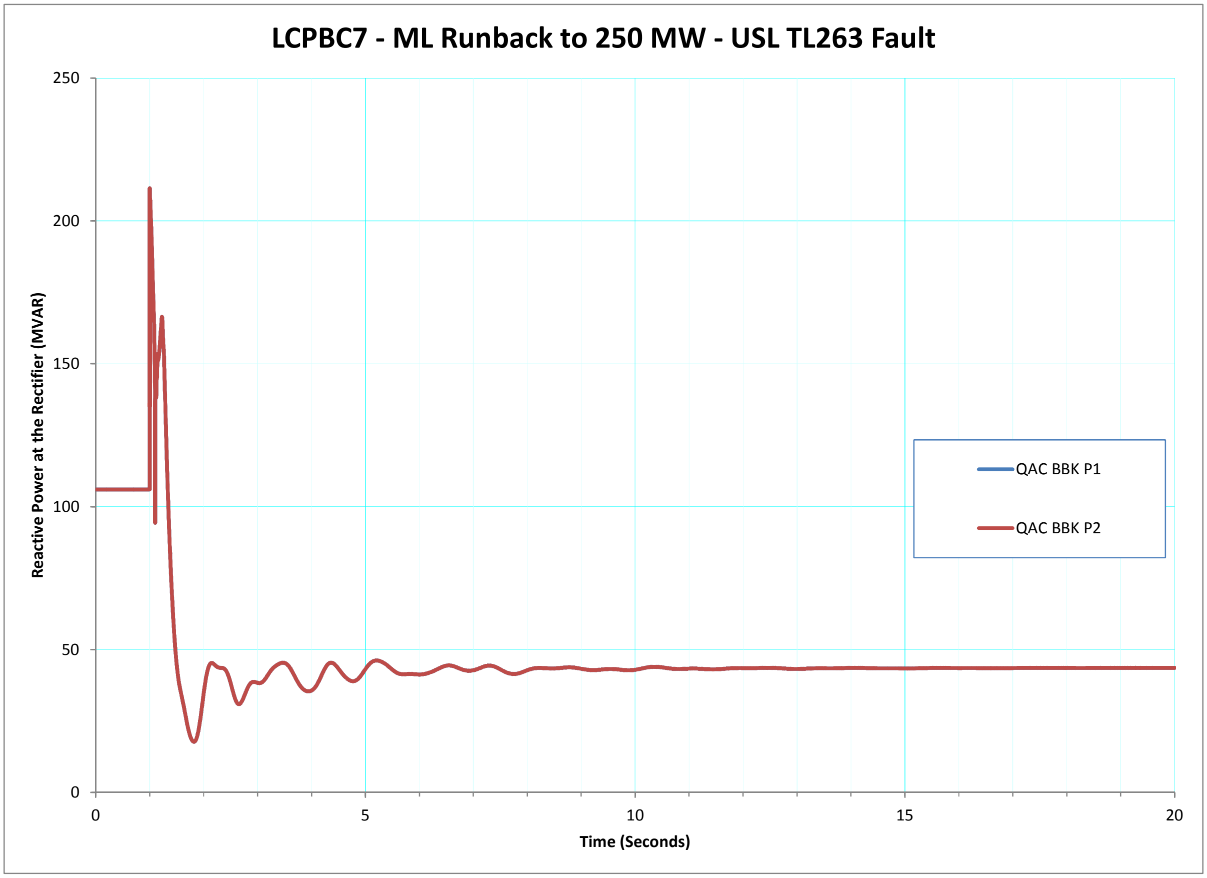


Figure 138 - LCPBC7 - ML Runback to 250 MW - USL TL263 Fault - Reactive Power at the Rectifier (MVAR)

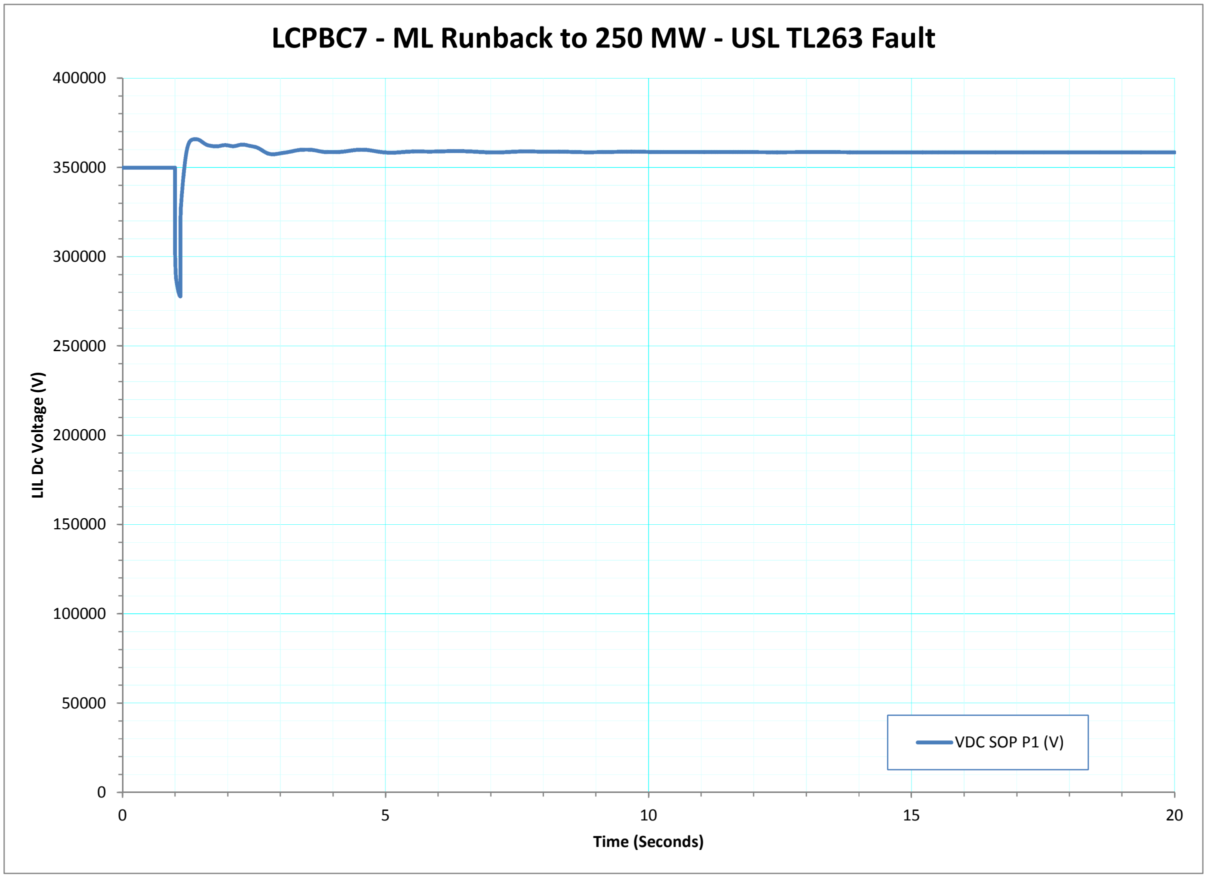


Figure 139 - LCPBC7 - ML Runback to 250 MW - USL TL263 Fault - LIL Dc Voltage (V)

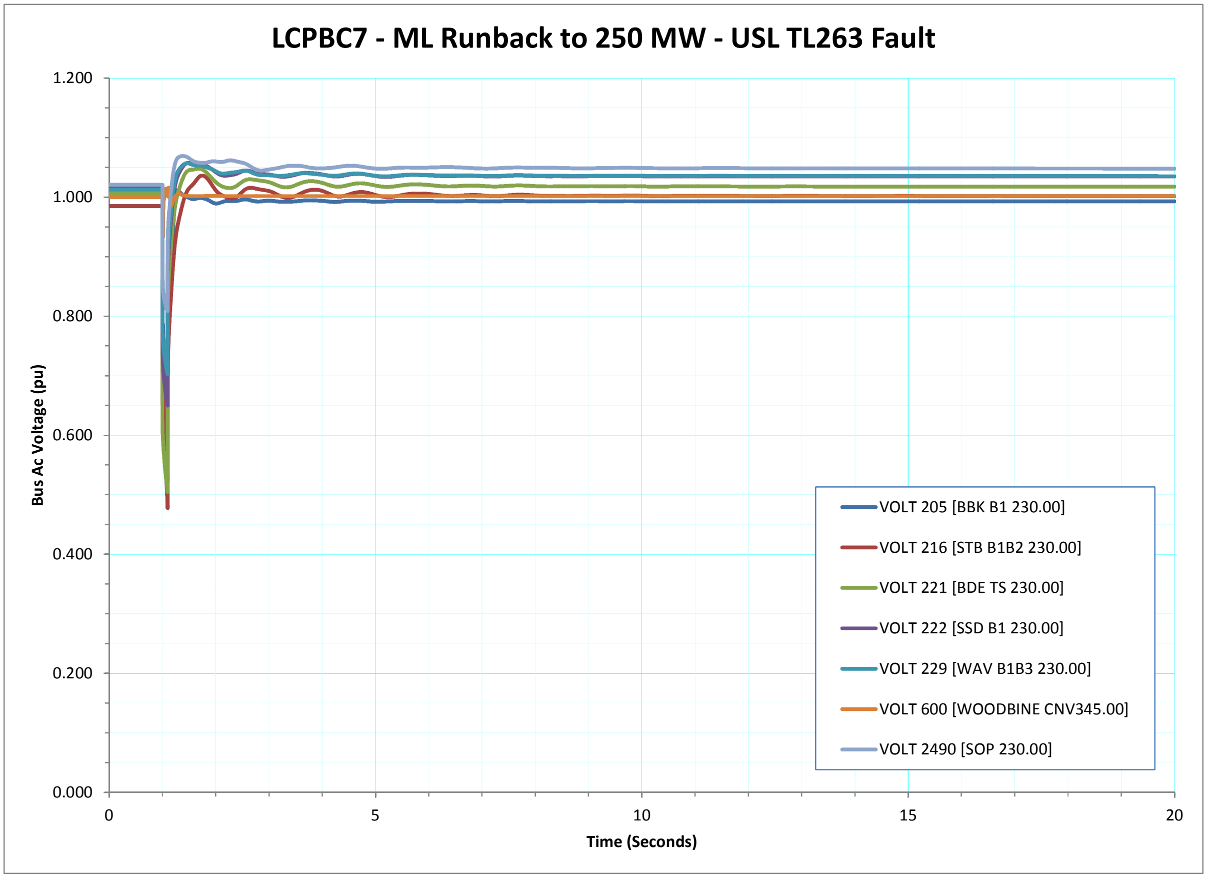


Figure 140 - LCPBC7 - ML Runback to 250 MW - USL TL263 Fault - Bus Ac Voltage (pu)

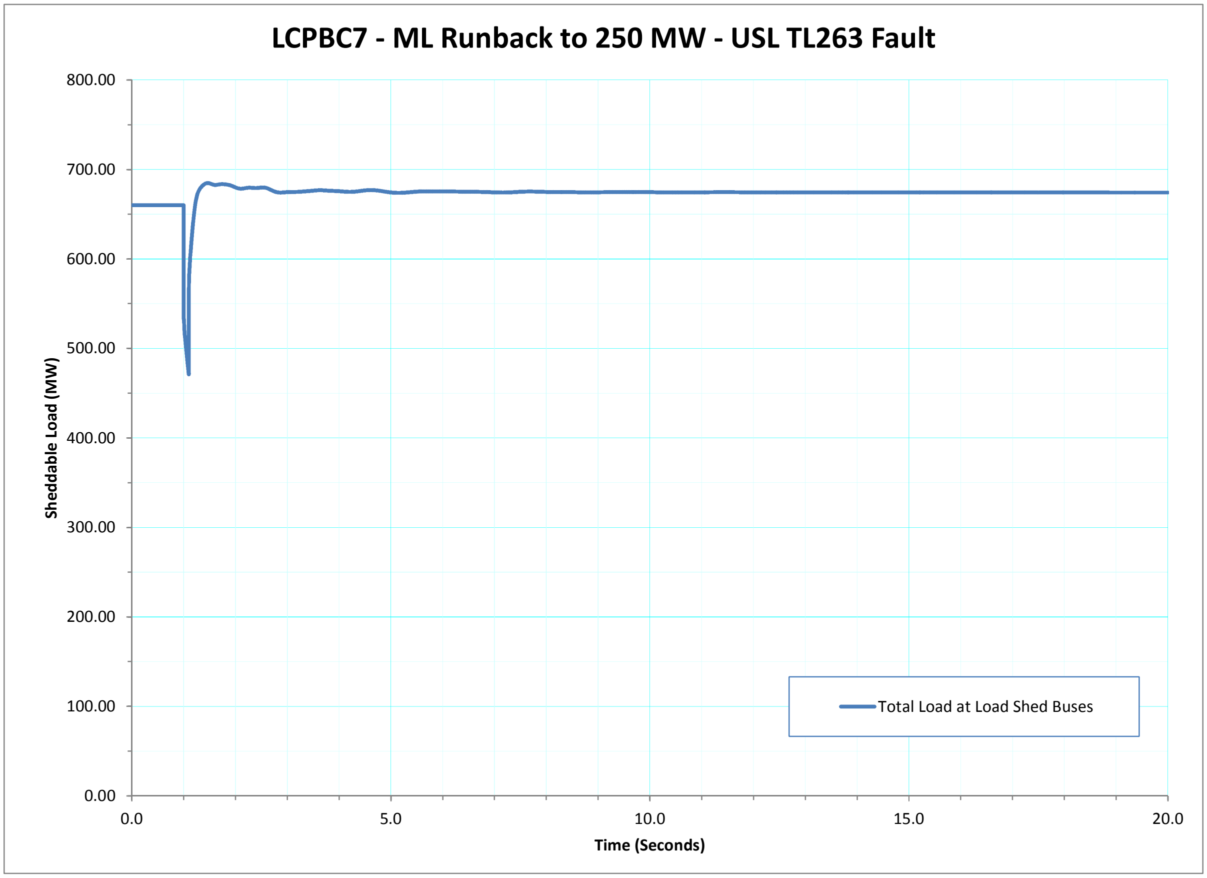


Figure 141 - LCPBC7 - ML Runback to 250 MW - USL TL263 Fault - Sheddable Load (MW)

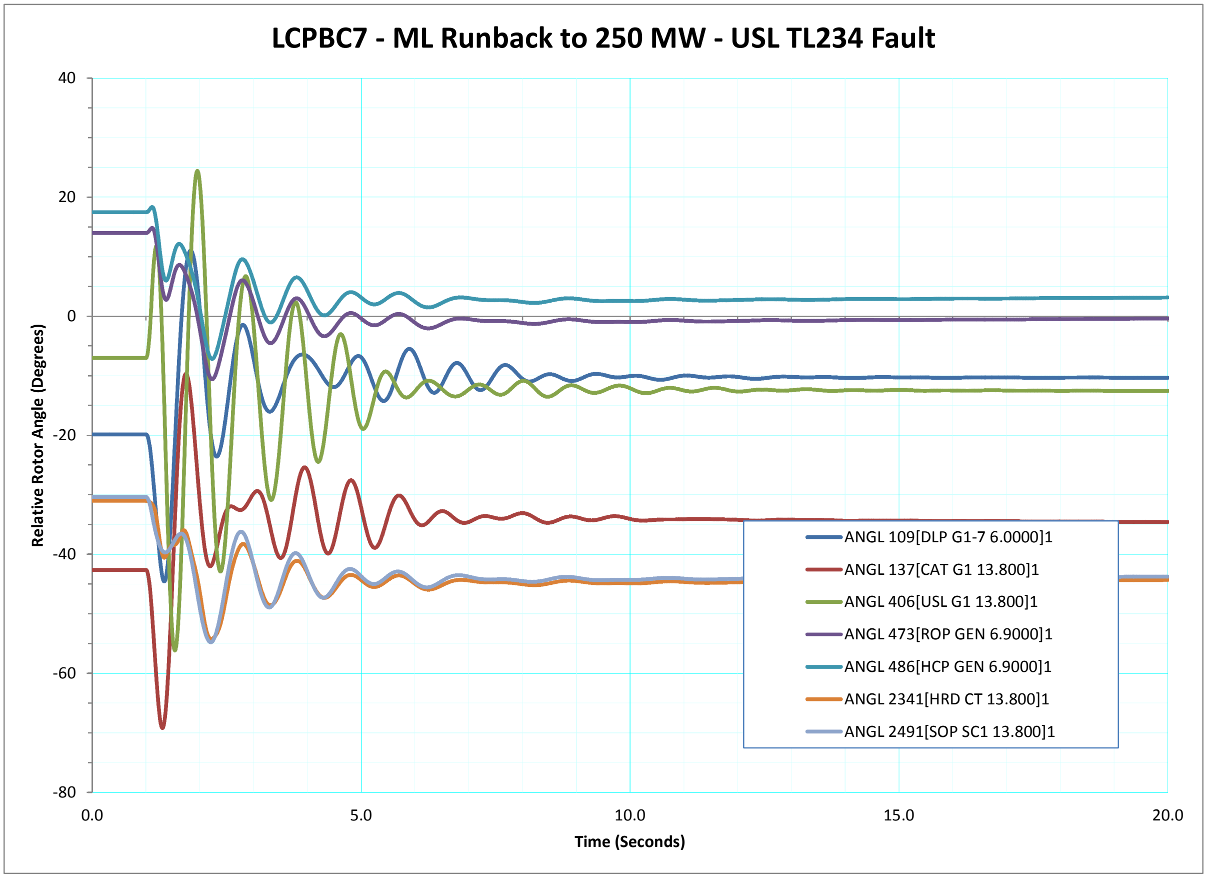


Figure 142 - LCPBC7 - ML Runback to 250 MW - USL TL234 Fault - Relative Rotor Angle (Degrees)

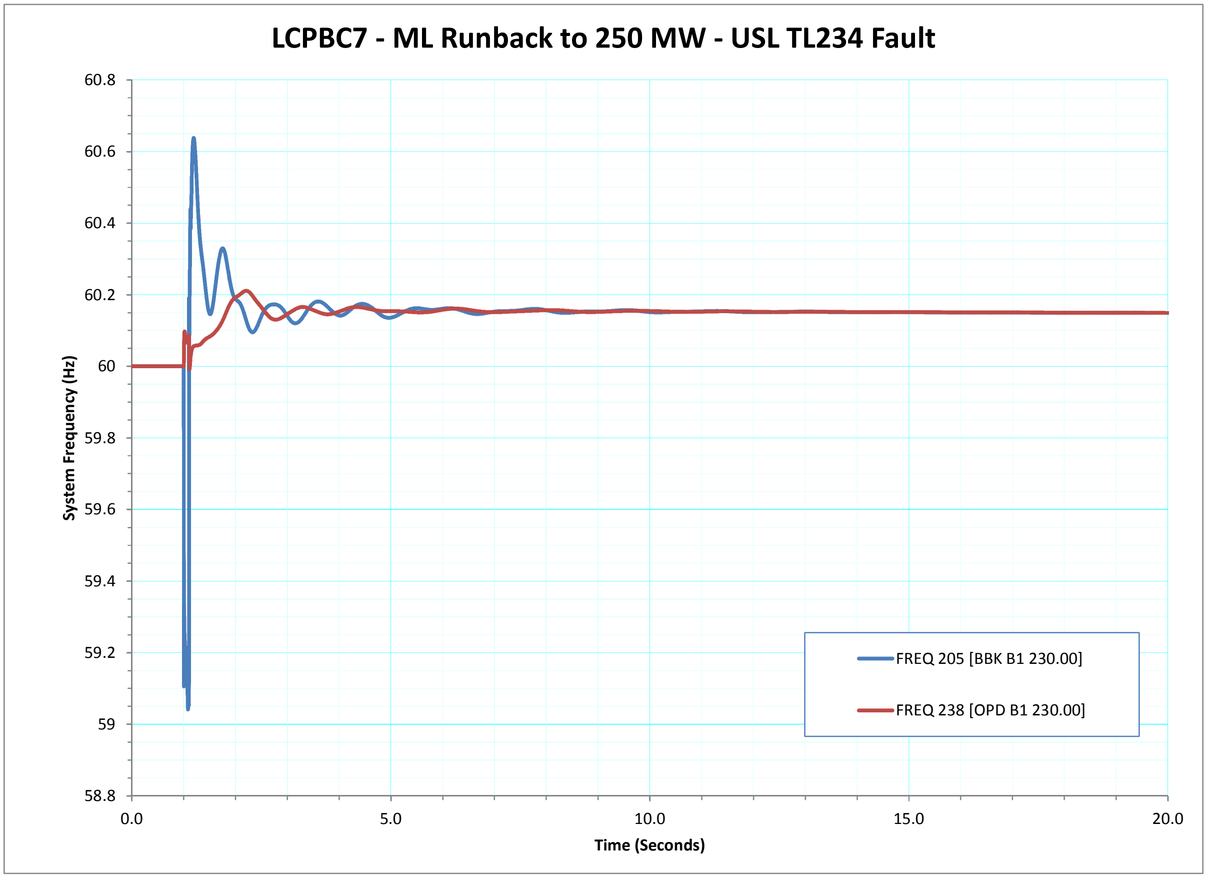


Figure 143 - LCPBC7 - ML Runback to 250 MW - USL TL234 Fault - System Frequency (Hz)

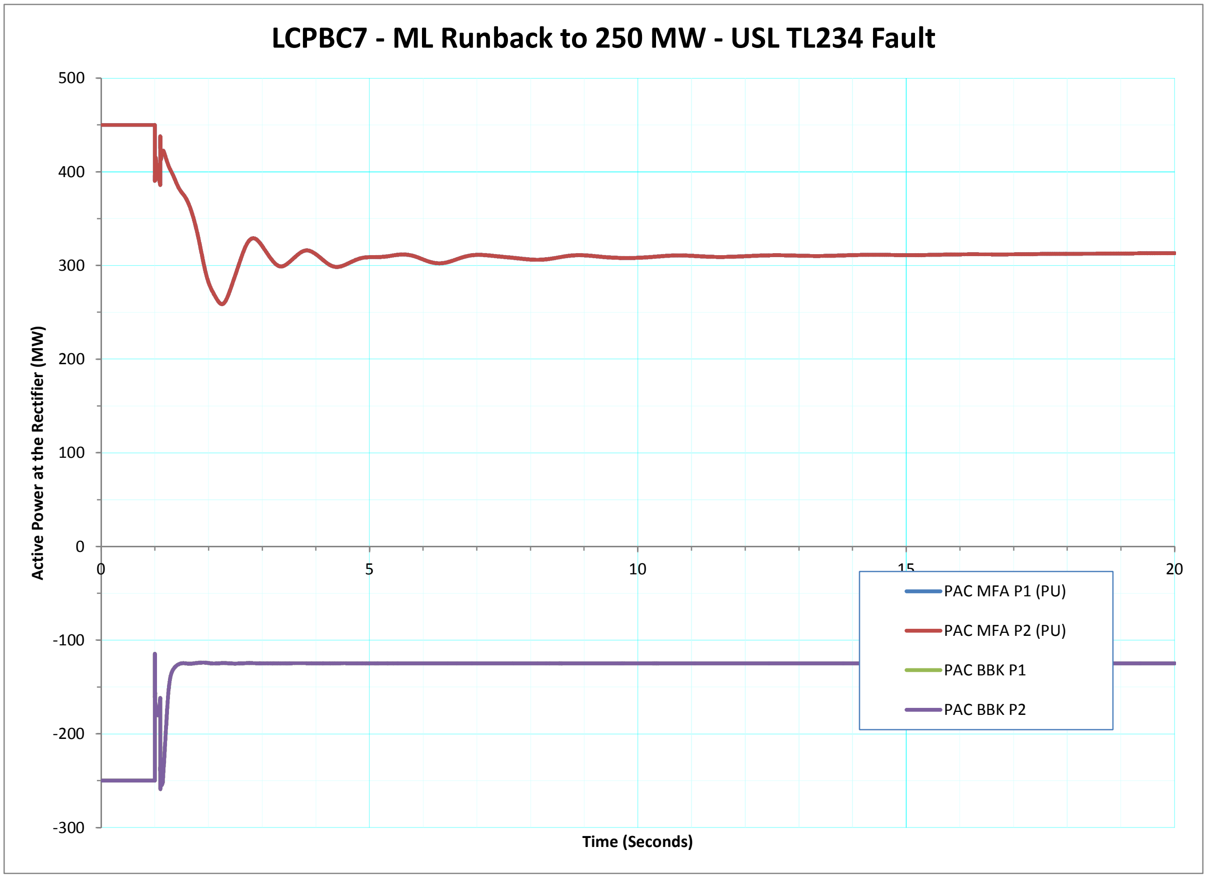


Figure 144 - LCPBC7 - ML Runback to 250 MW - USL TL234 Fault - Active Power at the Rectifier (MW)

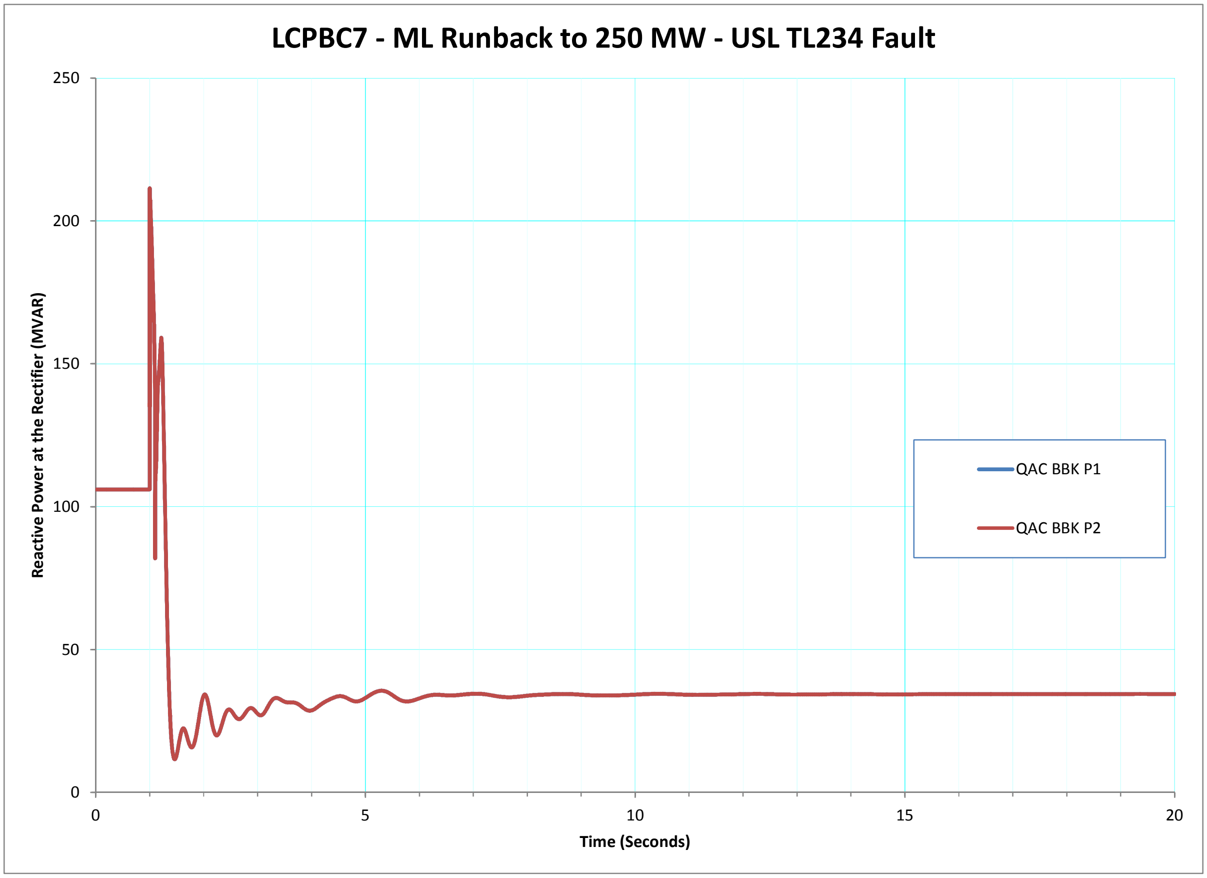


Figure 145 - LCPBC7 - ML Runback to 250 MW - USL TL234 Fault - Reactive Power at the Rectifier (MVAR)

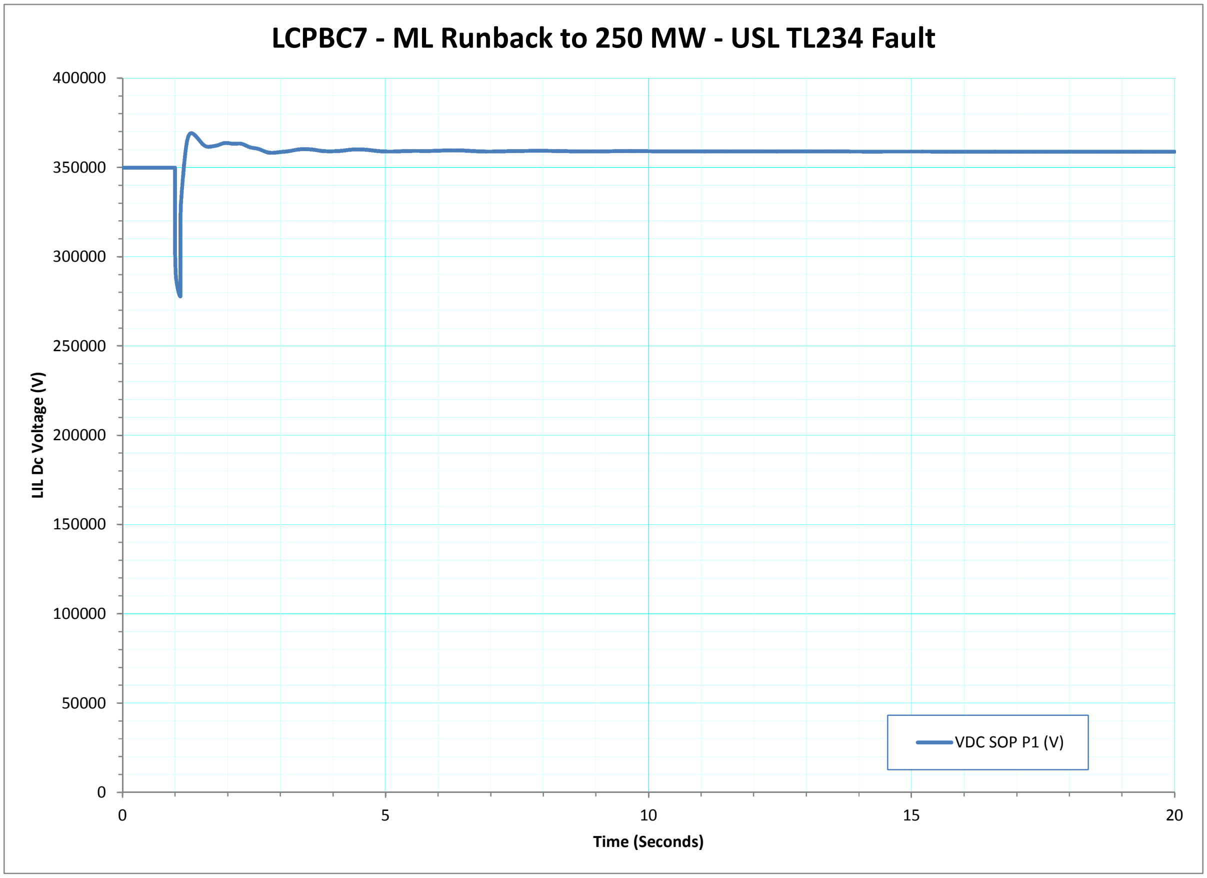


Figure 146 - LCPBC7 - ML Runback to 250 MW - USL TL234 Fault - LIL Dc Voltage (V)

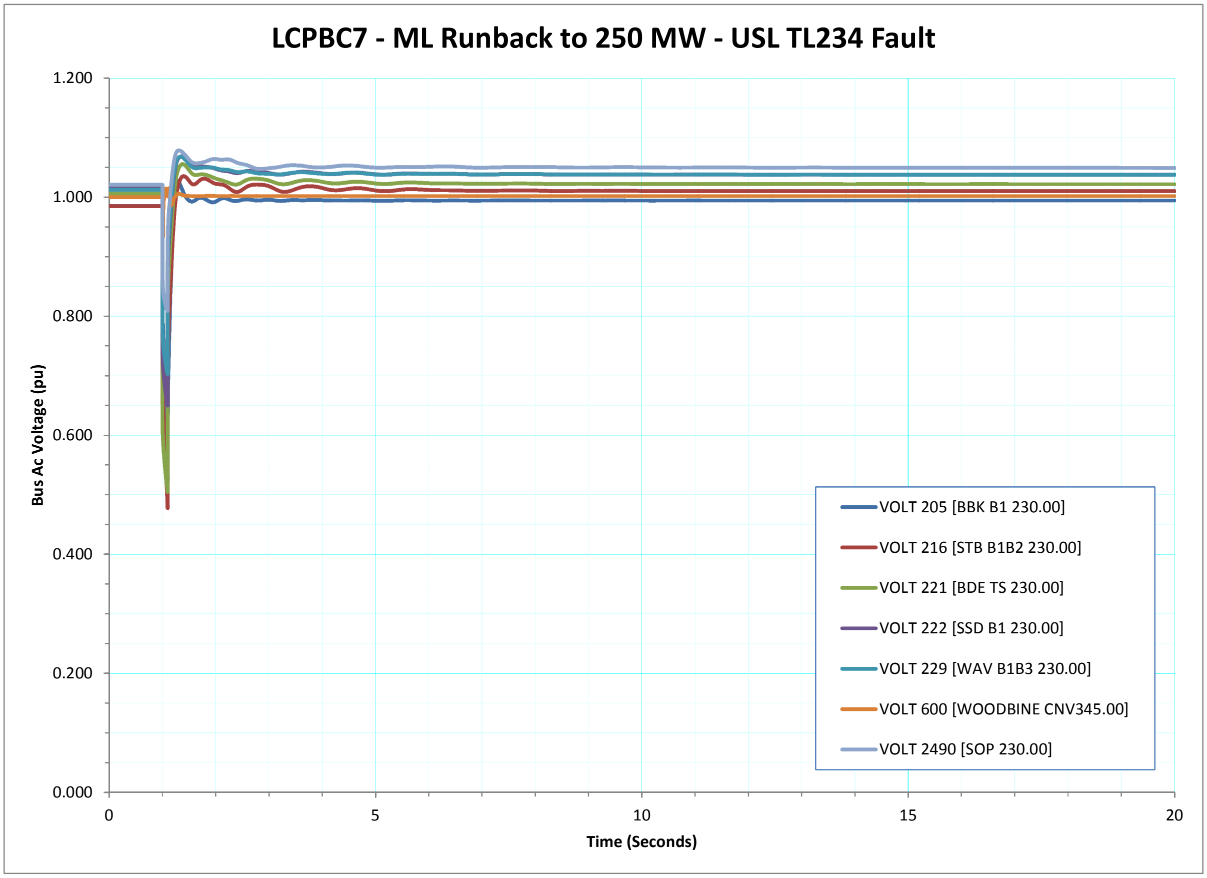


Figure 147 - LCPBC7 - ML Runback to 250 MW - USL TL234 Fault - Bus Ac Voltage (pu)

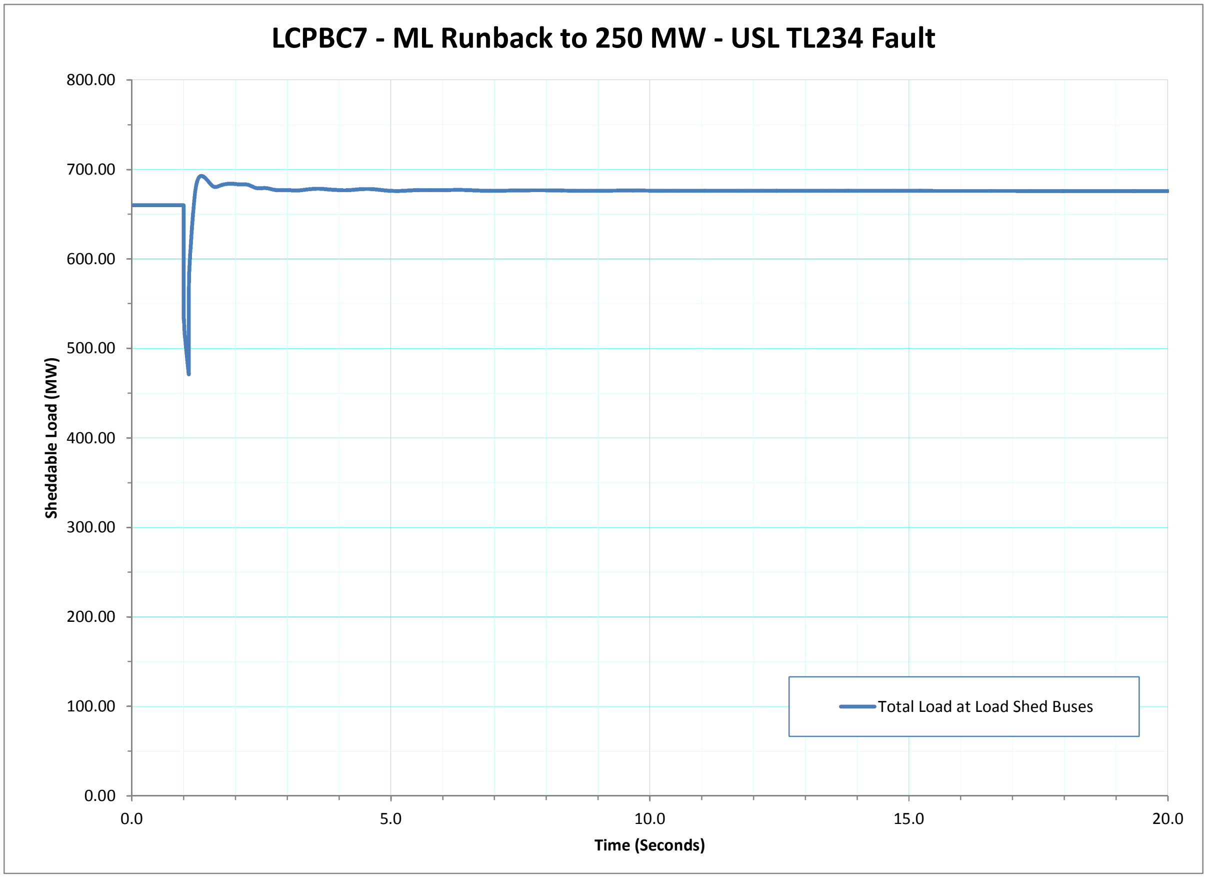


Figure 148 - LCPBC7 - ML Runback to 250 MW - USL TL234 Fault - Sheddable Load (MW)

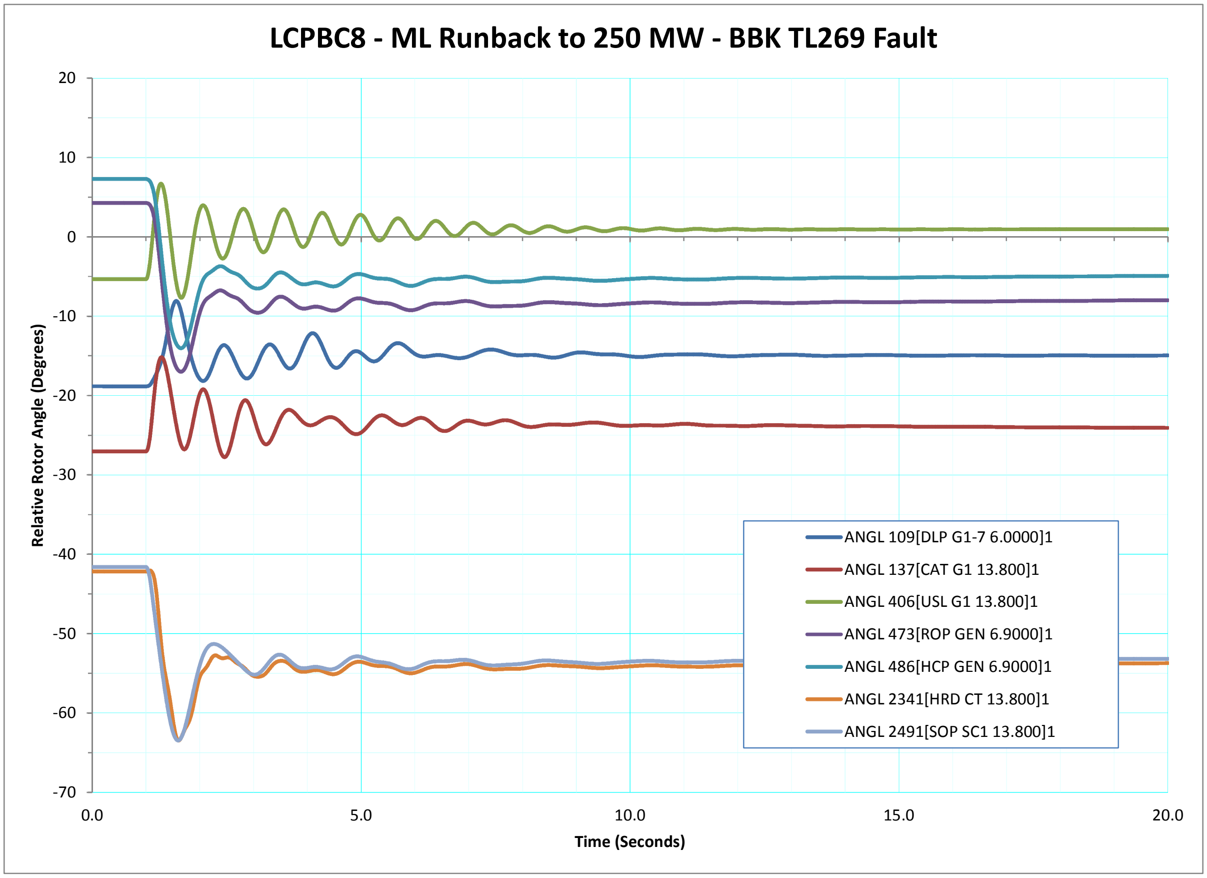


Figure 149 - LCPBC8 - ML Runback to 250 MW - BBK TL269 Fault - Relative Rotor Angle (Degrees)

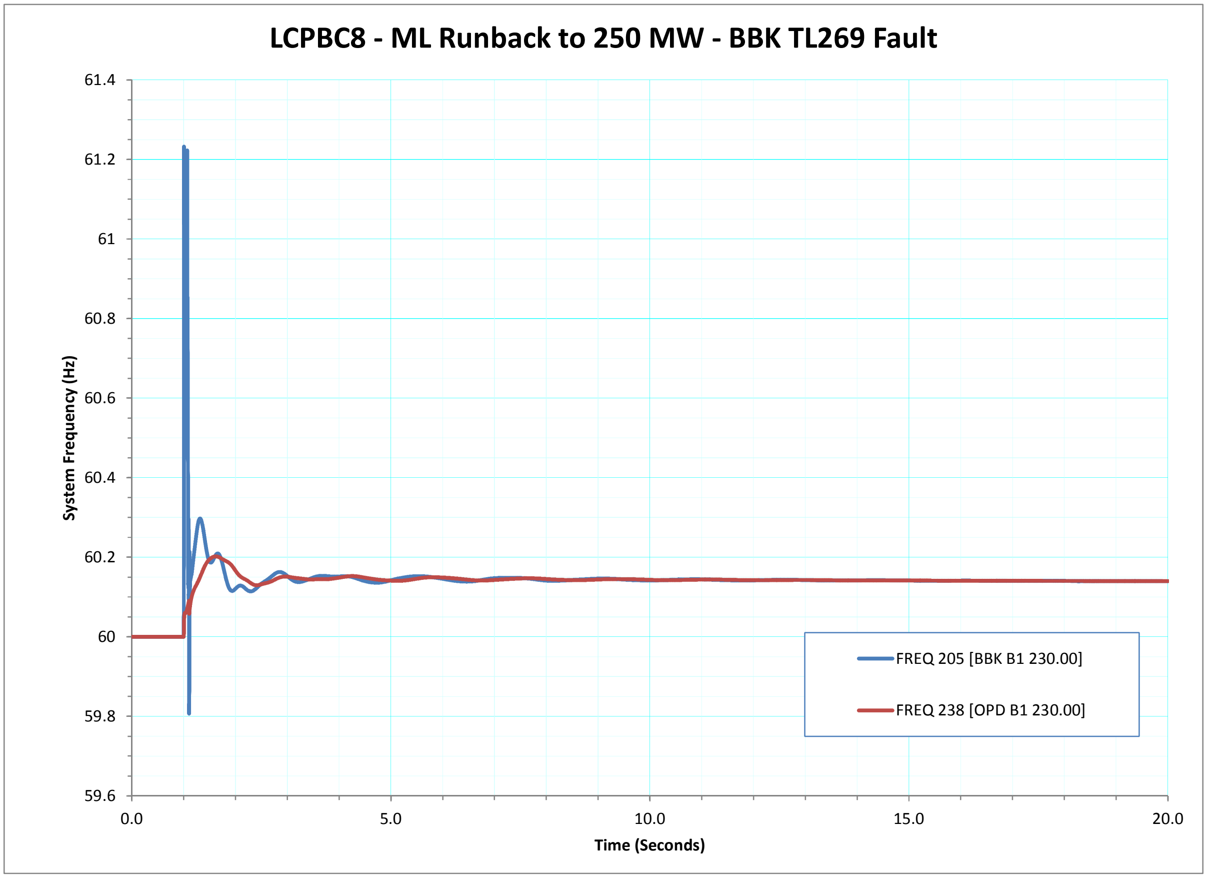


Figure 150 - LCPBC8 - ML Runback to 250 MW - BBK TL269 Fault - System Frequency (Hz)

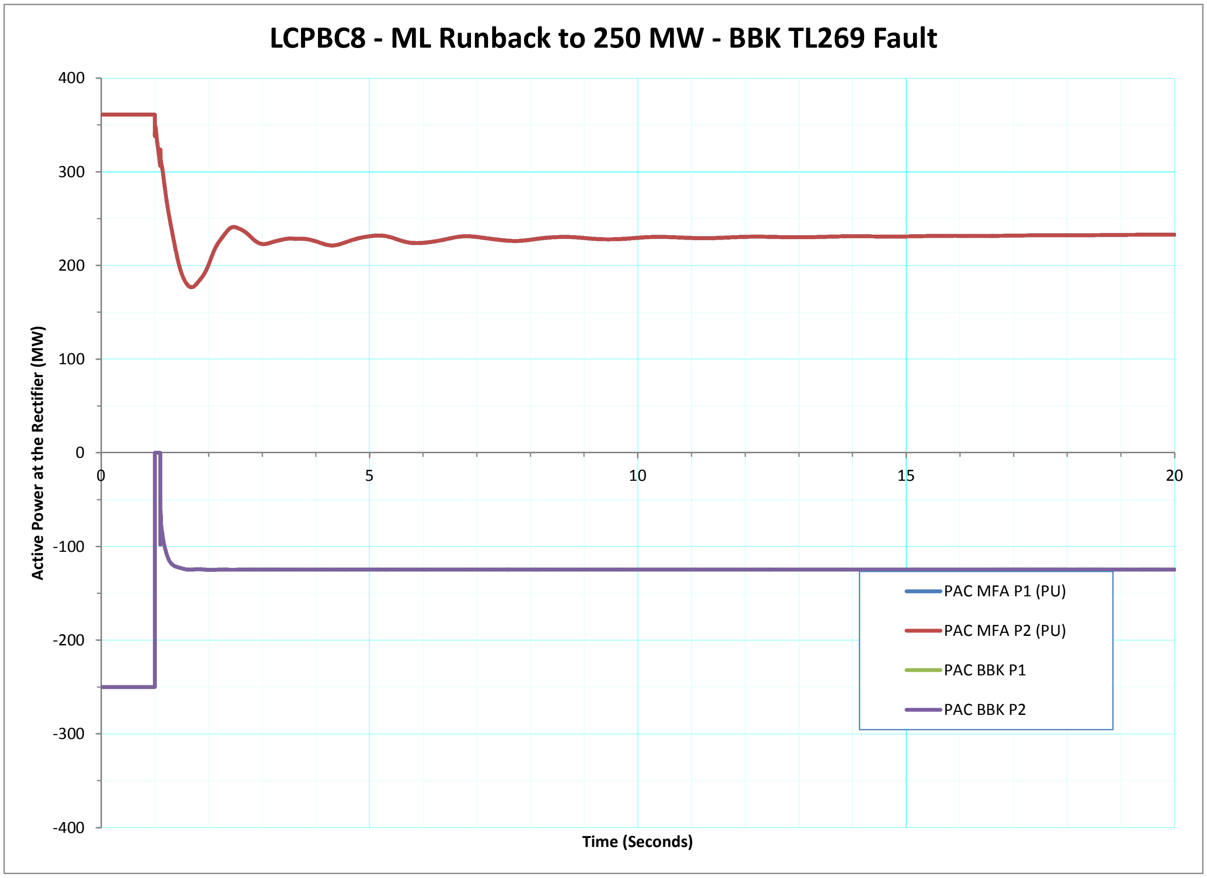


Figure 151 - LCPBC8 - ML Runback to 250 MW - BBK TL269 Fault - Active Power at the Rectifier (MW)

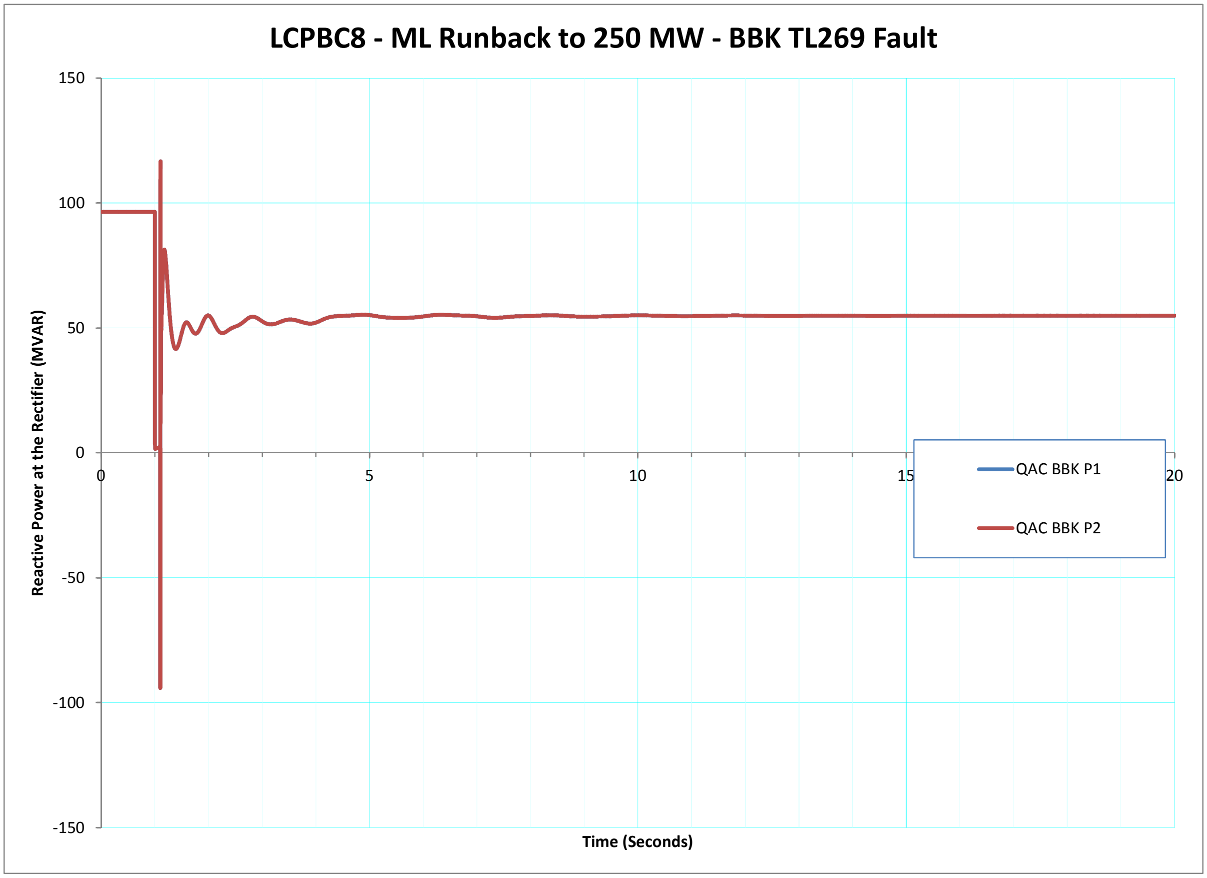


Figure 152 - LCPBC8 - ML Runback to 250 MW - BBK TL269 Fault - Reactive Power at the Rectifier (MVAR)

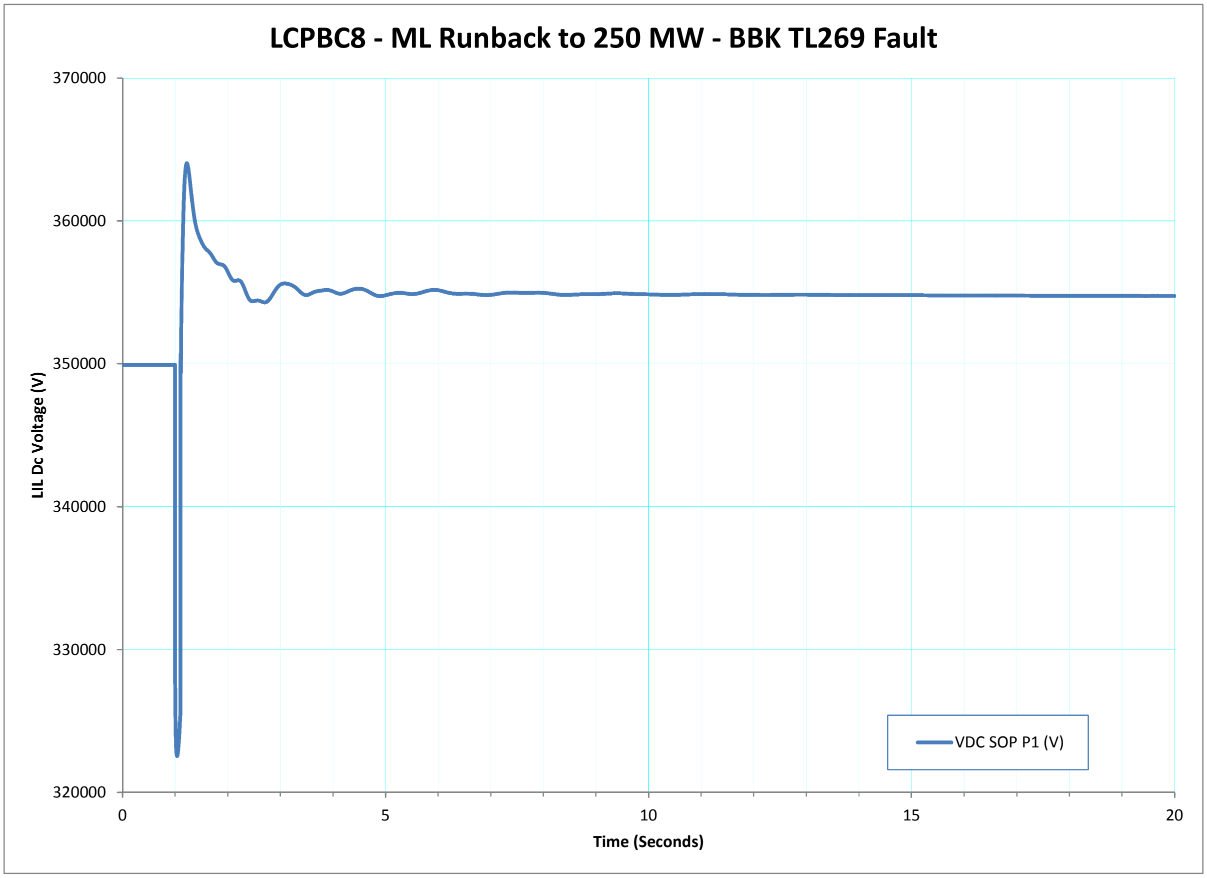


Figure 153 - LCPBC8 - ML Runback to 250 MW - BBK TL269 Fault - LIL Dc Voltage (V)

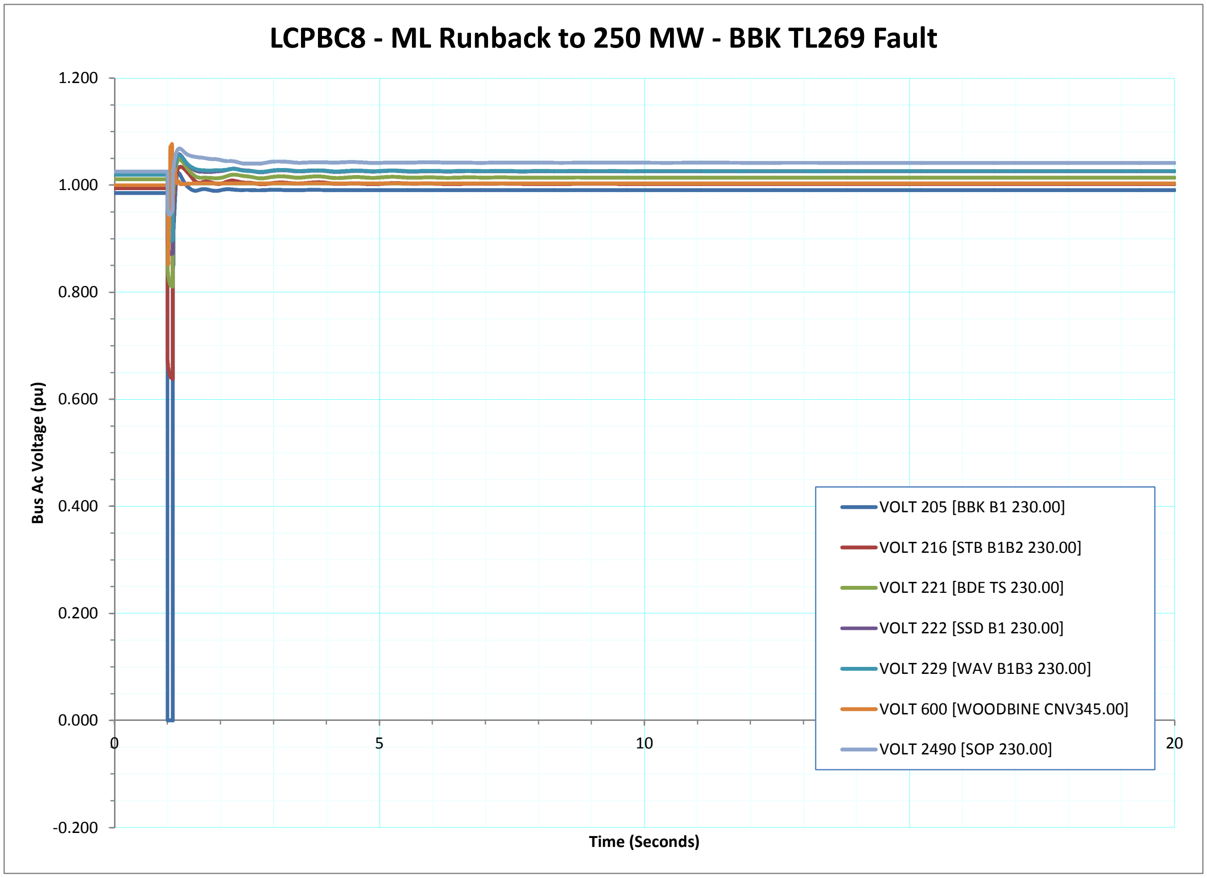


Figure 154 - LCPBC8 - ML Runback to 250 MW - BBK TL269 Fault - Bus Ac Voltage (pu)

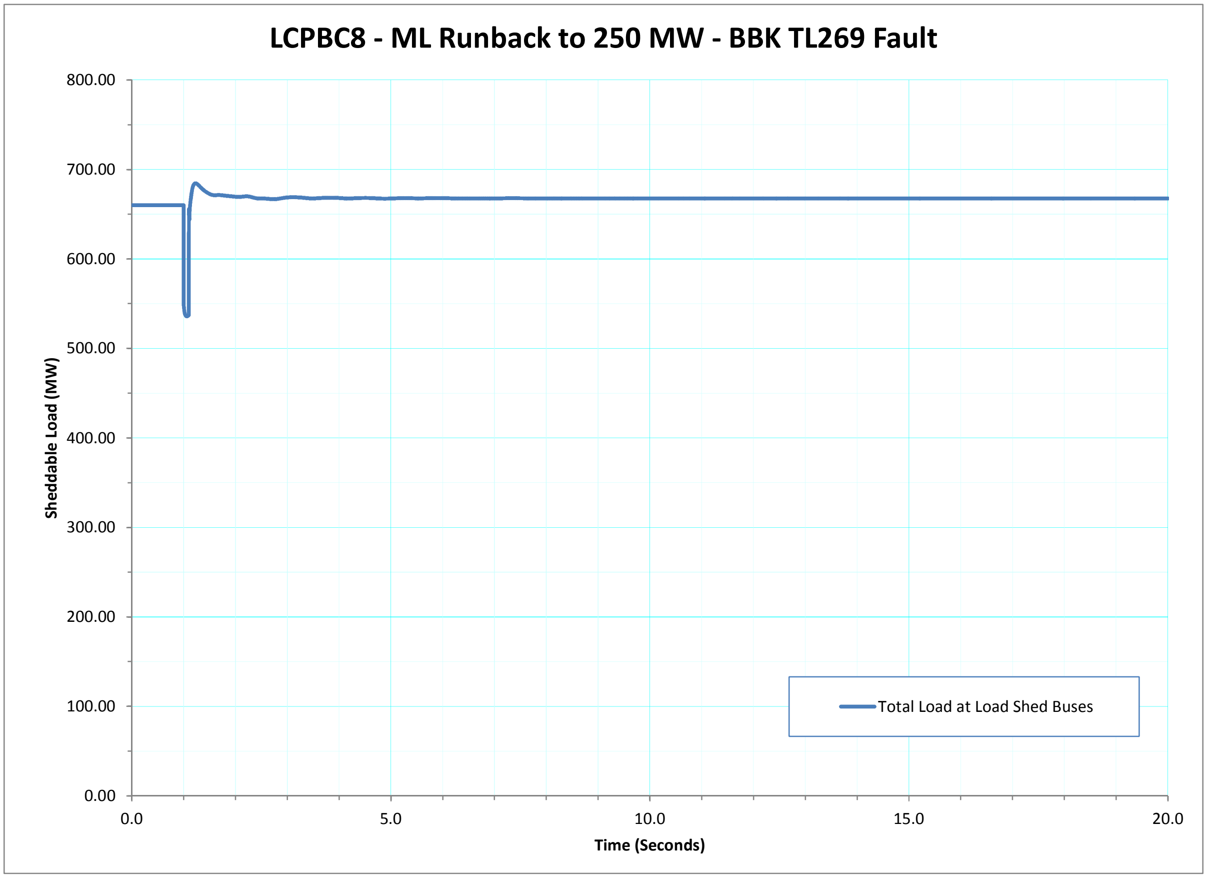


Figure 155 - LCPBC8 - ML Runback to 250 MW - BBK TL269 Fault - Sheddable Load (MW)

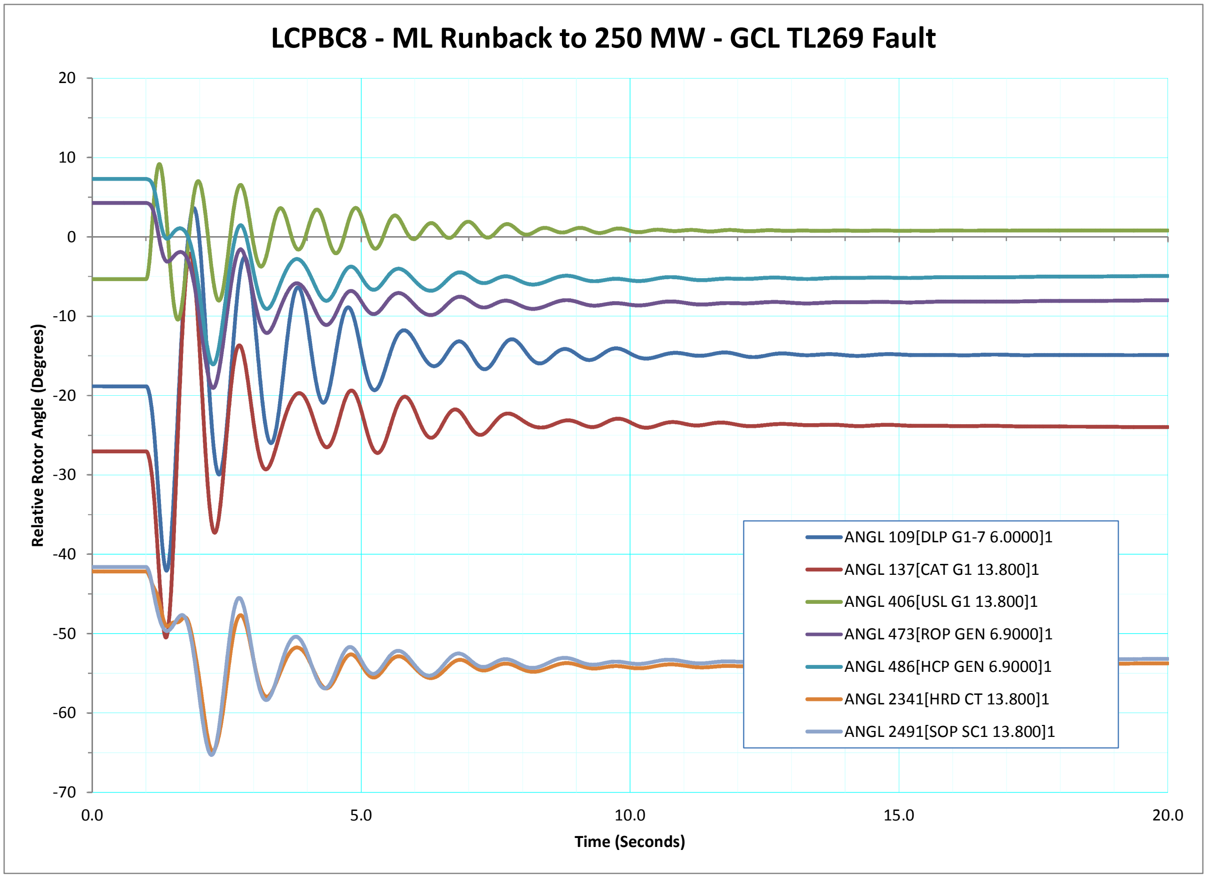


Figure 156 - LCPBC8 - ML Runback to 250 MW - GCL TL269 Fault - Relative Rotor Angle (Degrees)

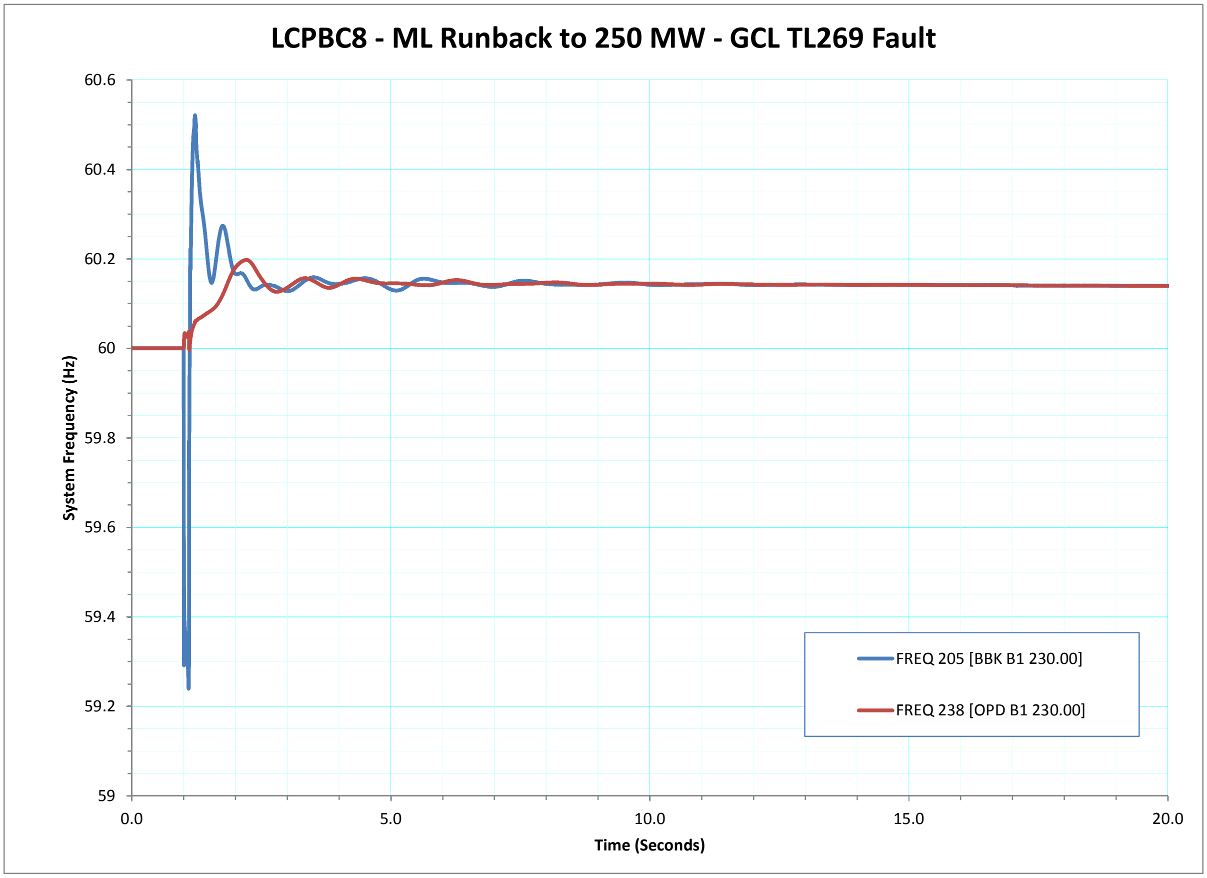


Figure 157 - LCPBC8 - ML Runback to 250 MW - GCL TL269 Fault - System Frequency (Hz)

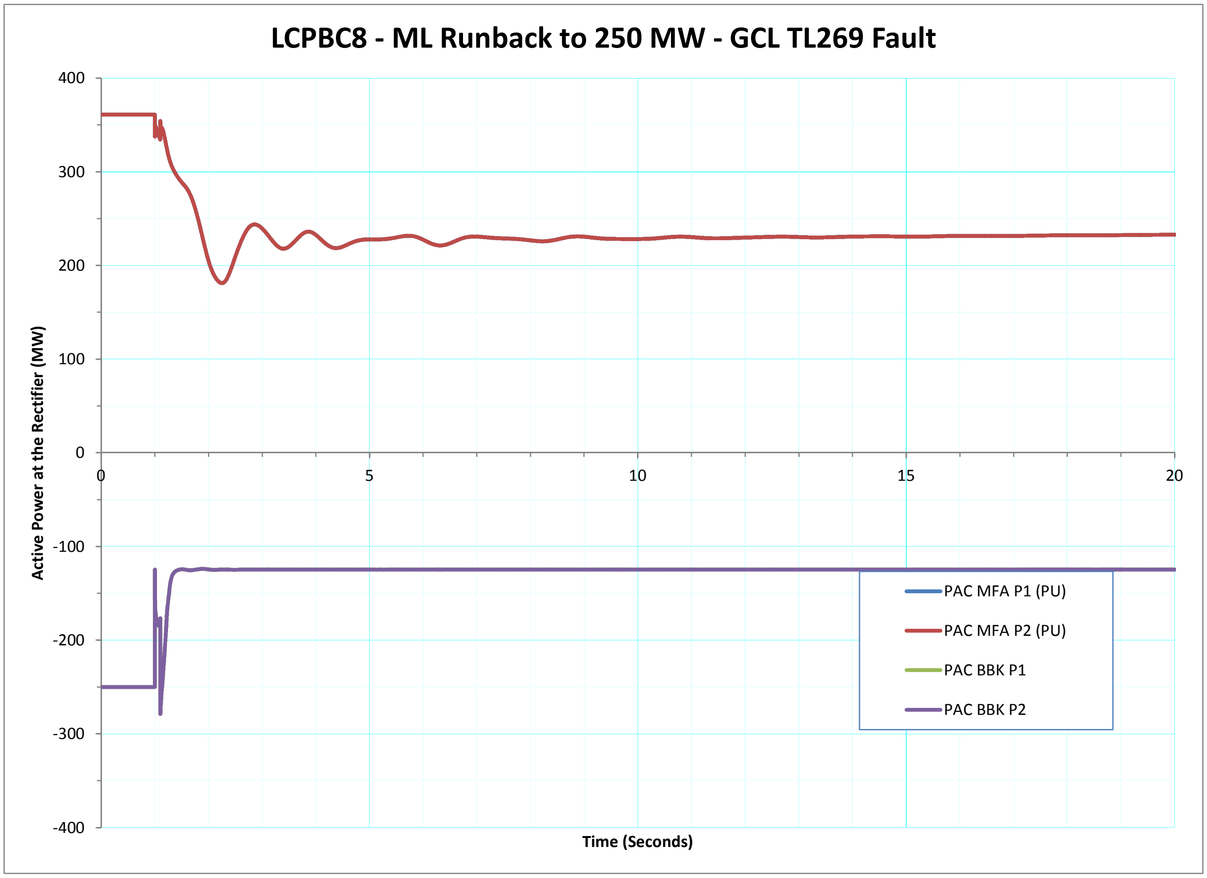


Figure 158 - LCPBC8 - ML Runback to 250 MW - GCL TL269 Fault - Active Power at the Rectifier (MW)

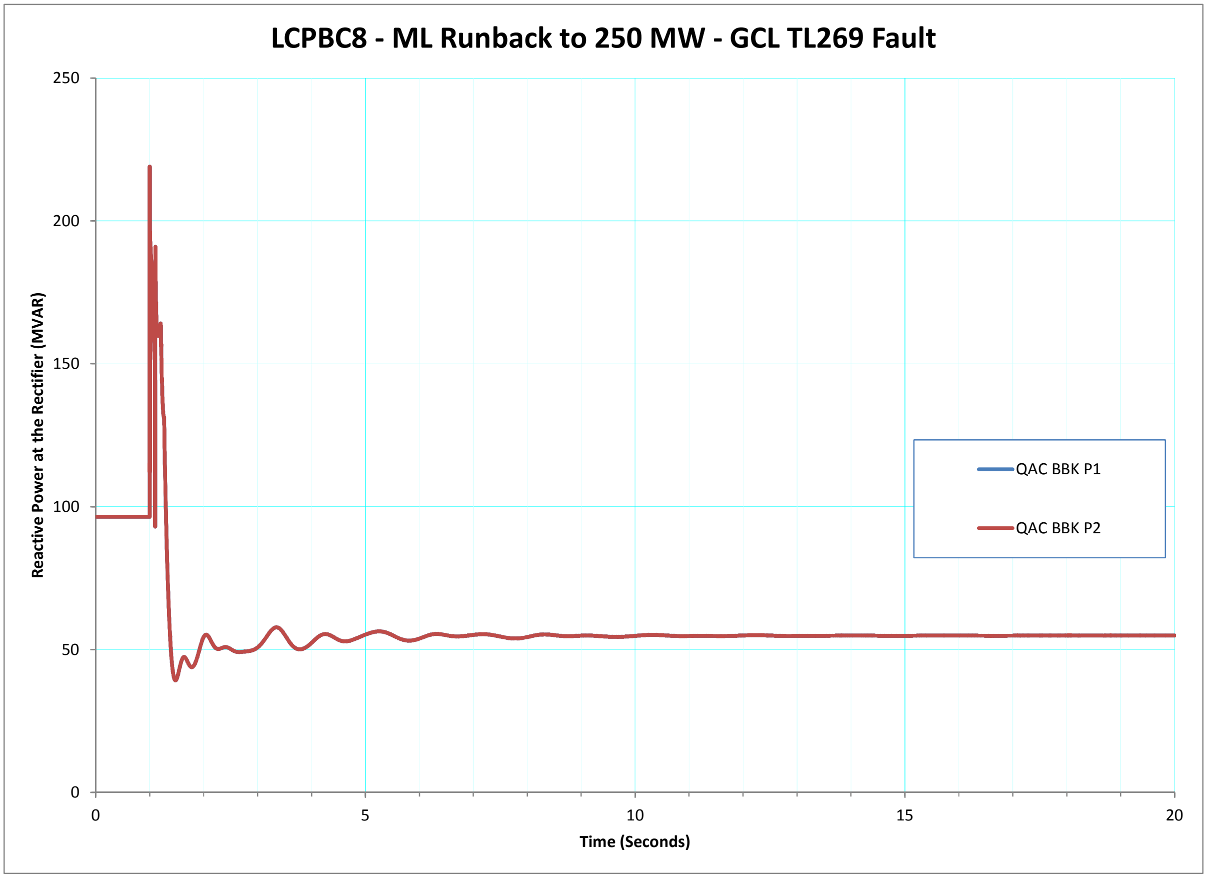


Figure 159 - LCPBC8 - ML Runback to 250 MW - GCL TL269 Fault - Reactive Power at the Rectifier (MVAR)

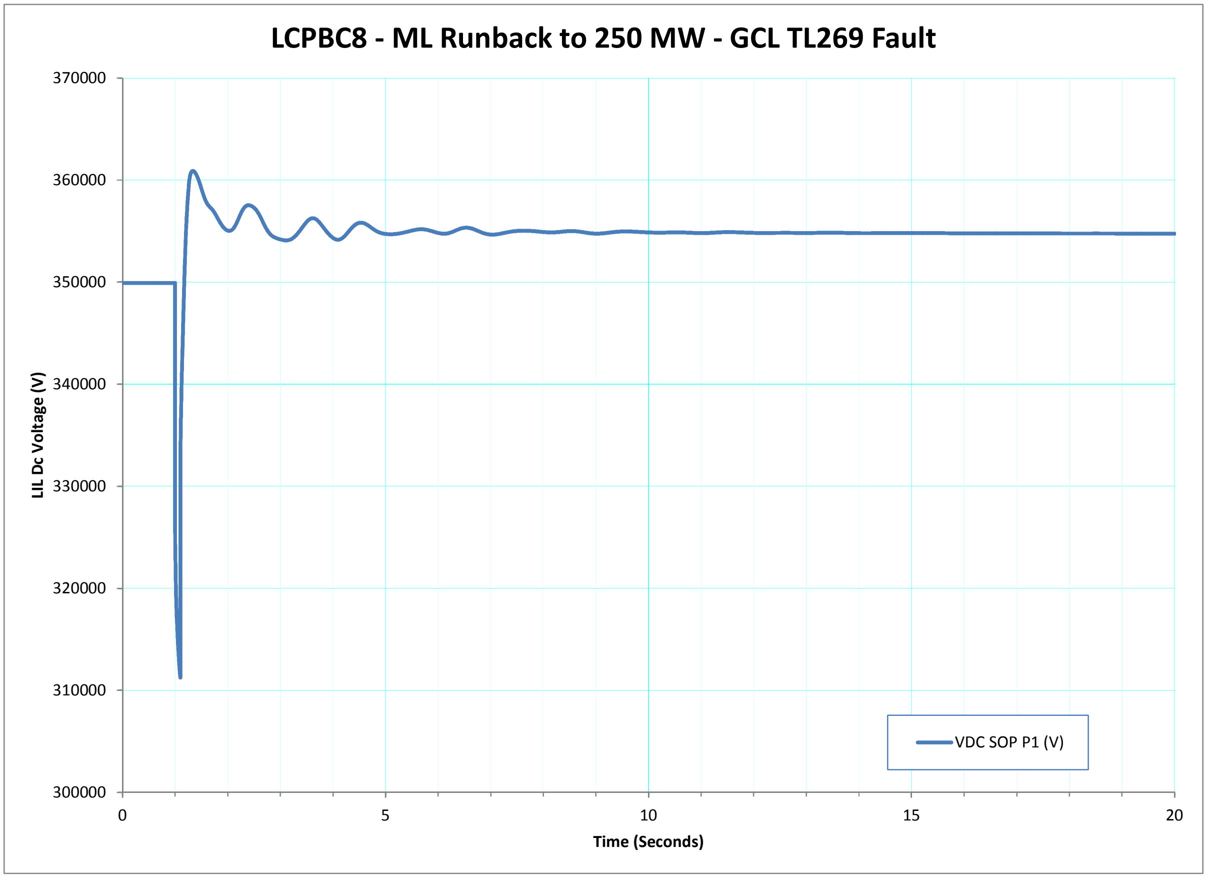


Figure 160 - LCPBC8 - ML Runback to 250 MW - GCL TL269 Fault - LIL Dc Voltage (V)

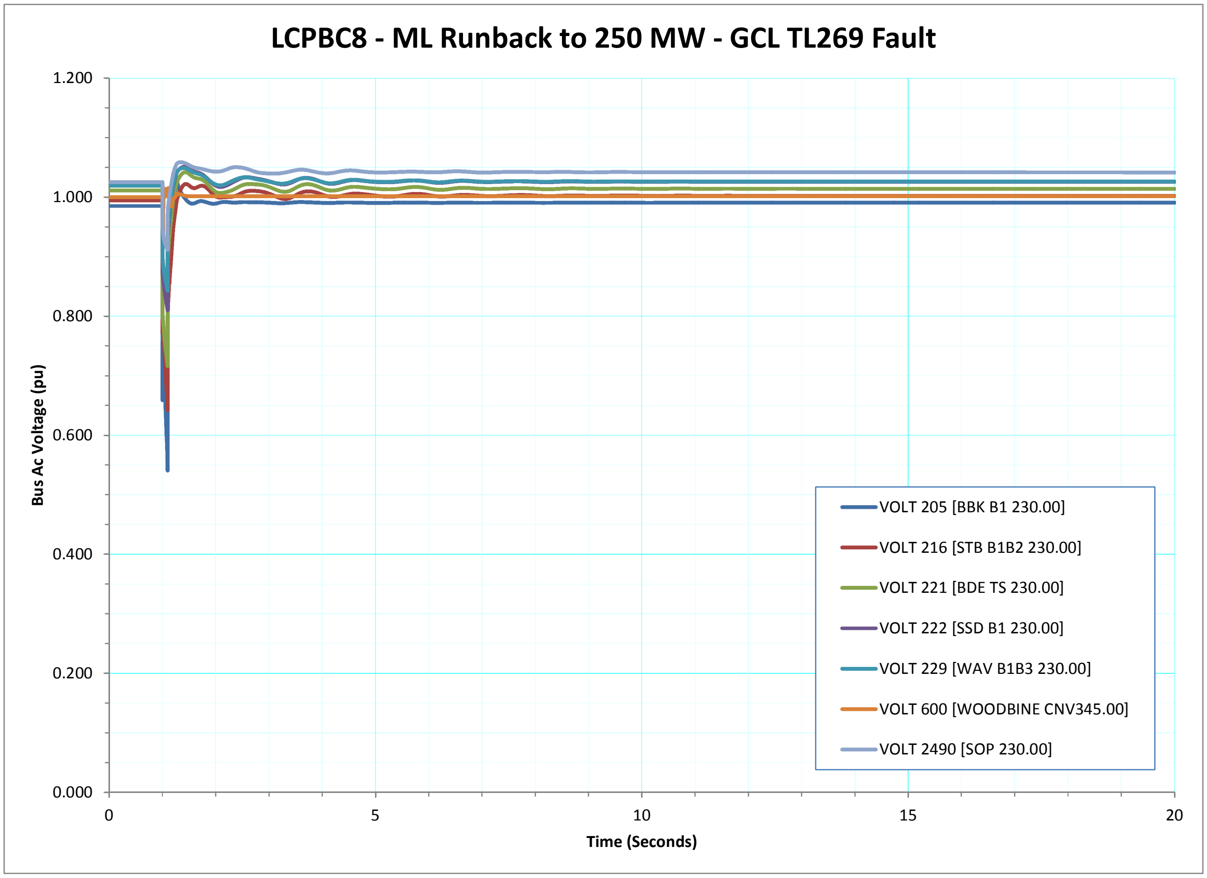


Figure 161 - LCPBC8 - ML Runback to 250 MW - GCL TL269 Fault - Bus Ac Voltage (pu)

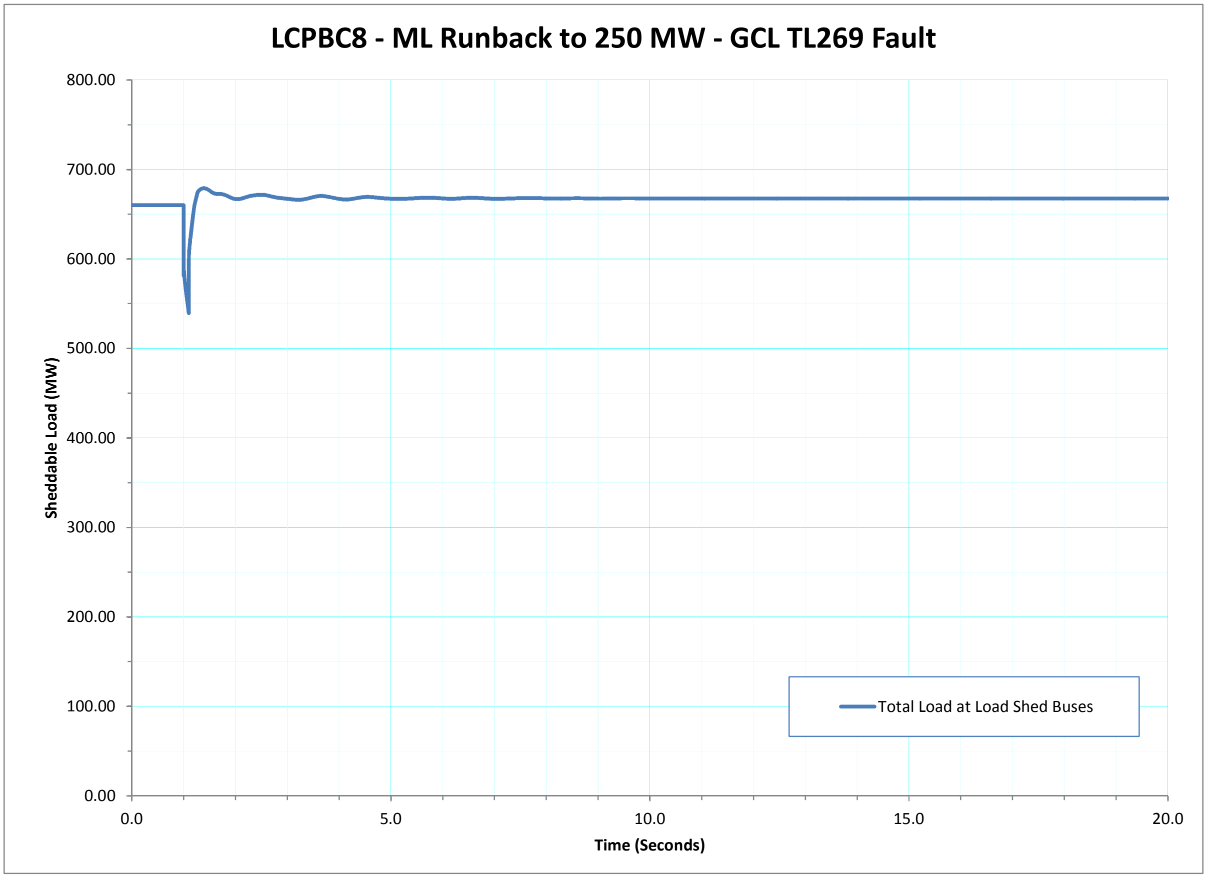


Figure 162 - LCPBC8 - ML Runback to 250 MW - GCL TL269 Fault - Sheddable Load (MW)

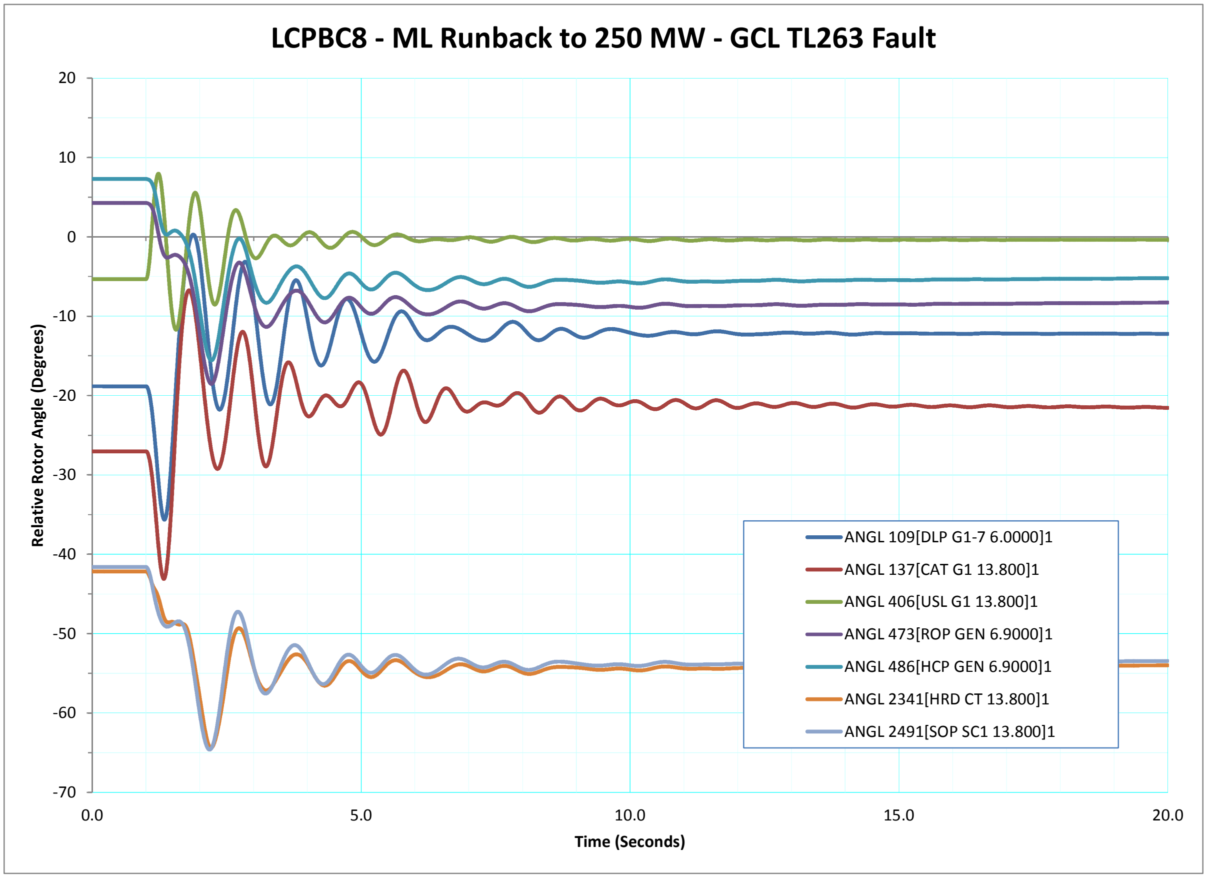


Figure 163 - LCPBC8 - ML Runback to 250 MW - GCL TL263 Fault - Relative Rotor Angle (Degrees)

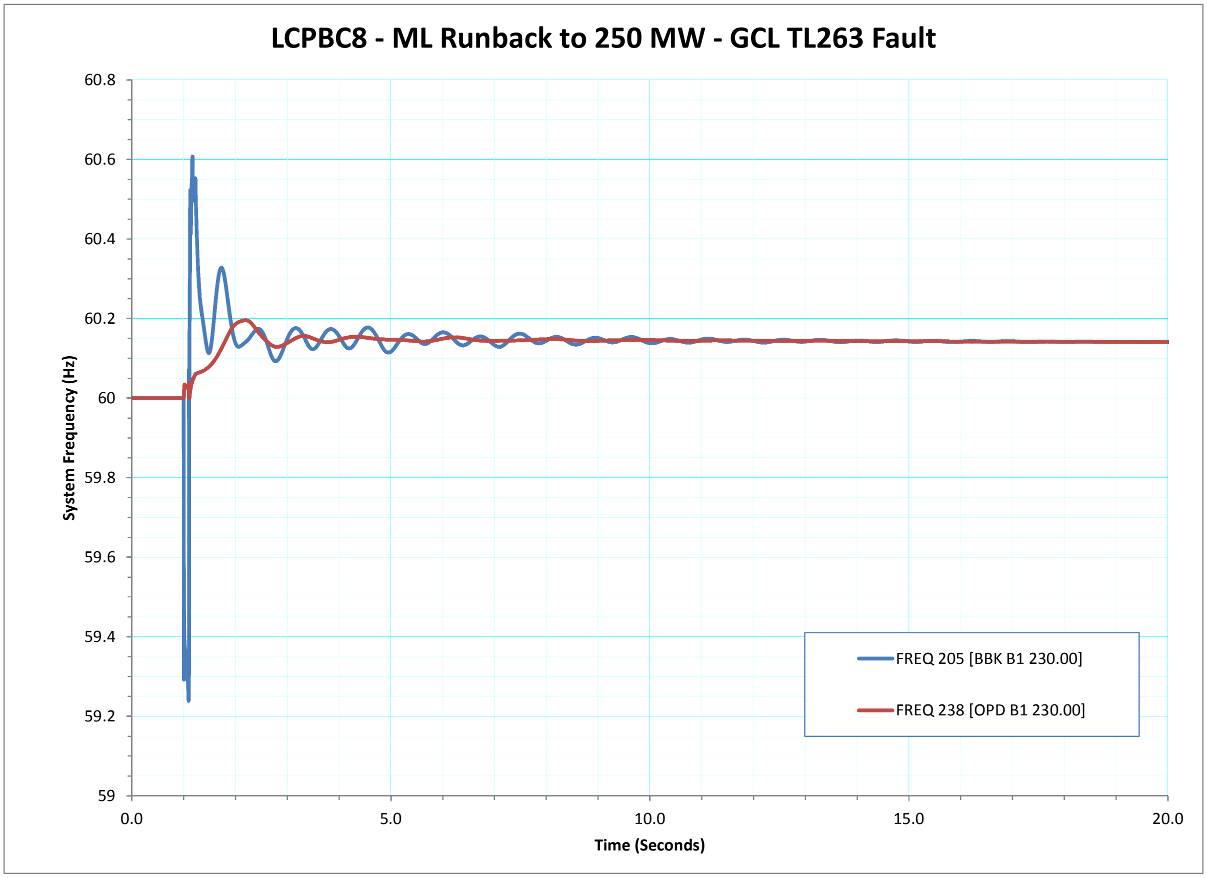


Figure 164 - LCPBC8 - ML Runback to 250 MW - GCL TL263 Fault - System Frequency (Hz)

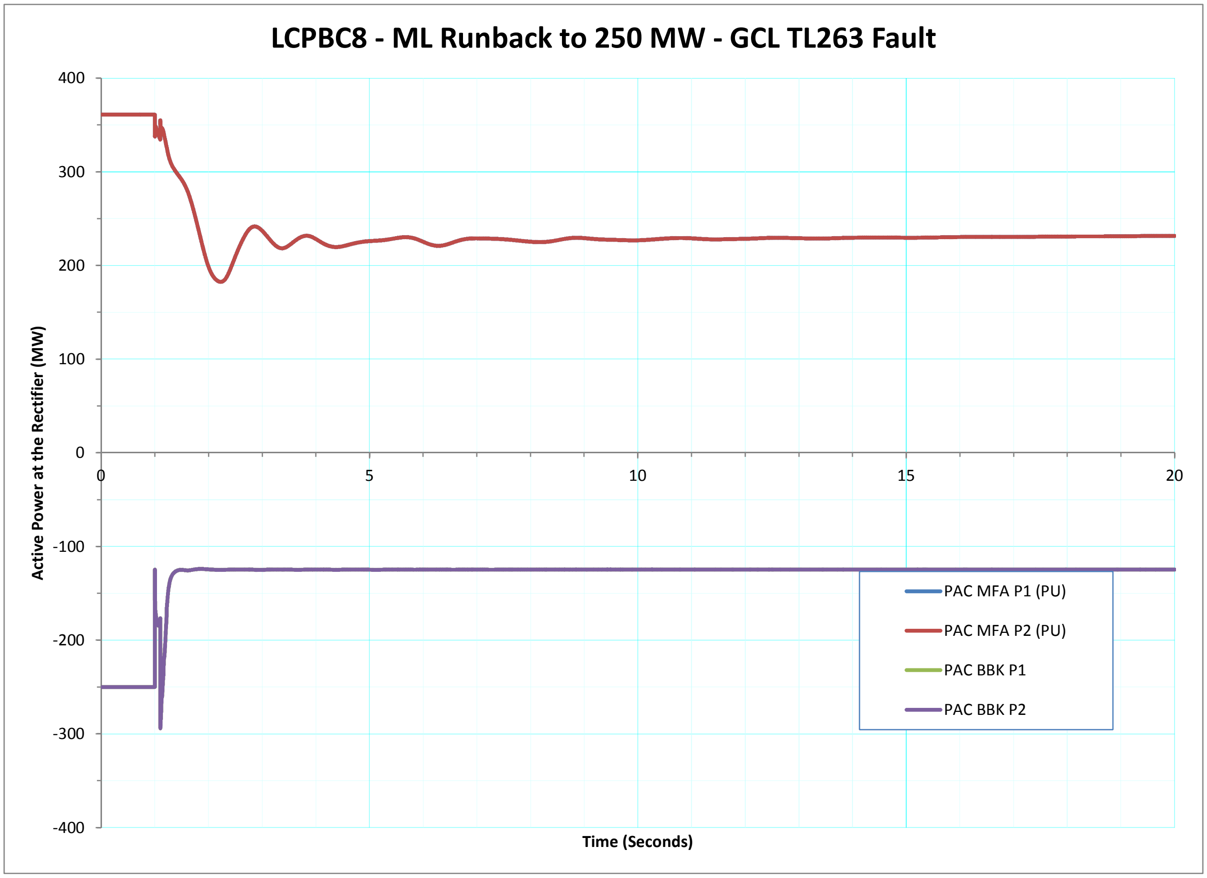


Figure 165 - LCPBC8 - ML Runback to 250 MW - GCL TL263 Fault - Active Power at the Rectifier (MW)

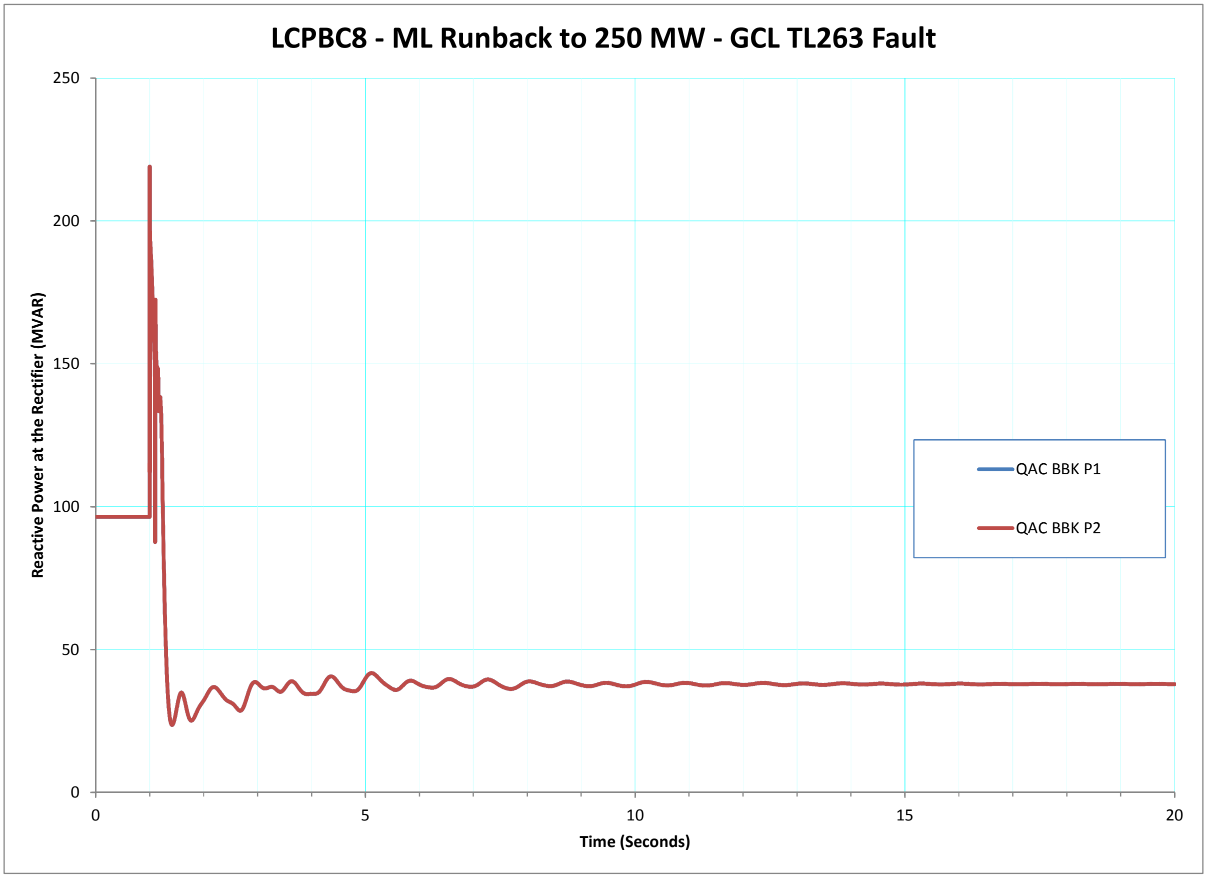


Figure 166 - LCPBC8 - ML Runback to 250 MW - GCL TL263 Fault - Reactive Power at the Rectifier (MVAR)

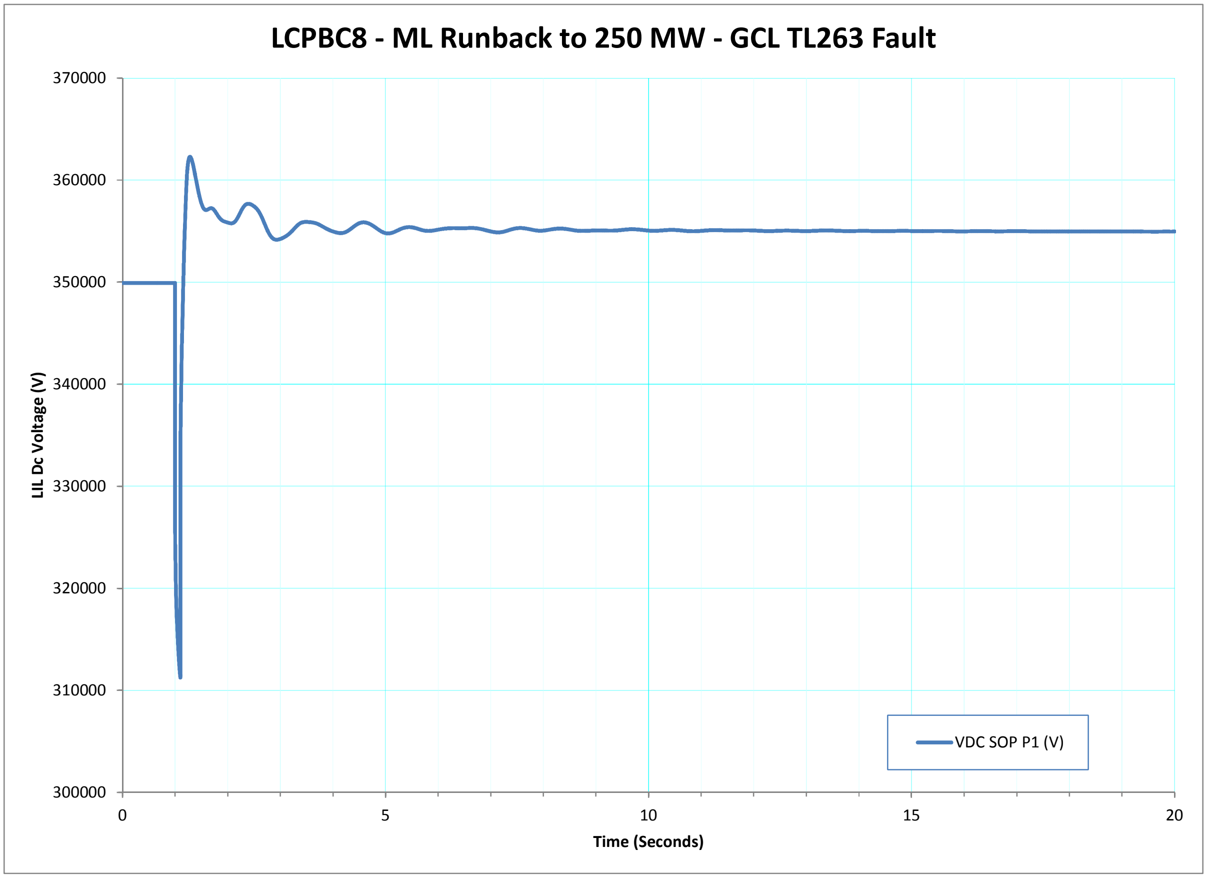


Figure 167 - LCPBC8 - ML Runback to 250 MW - GCL TL263 Fault - LIL Dc Voltage (V)

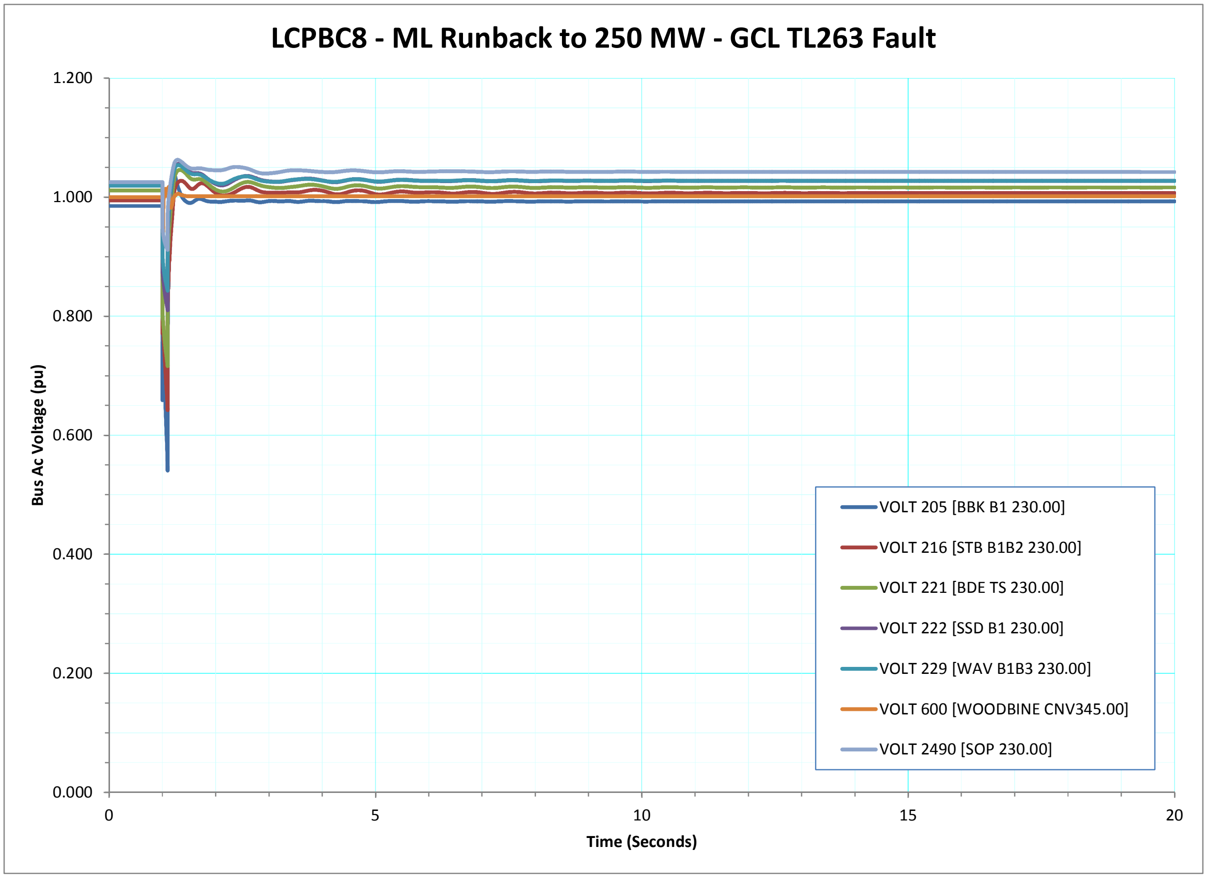


Figure 168 - LCPBC8 - ML Runback to 250 MW - GCL TL263 Fault - Bus Ac Voltage (pu)

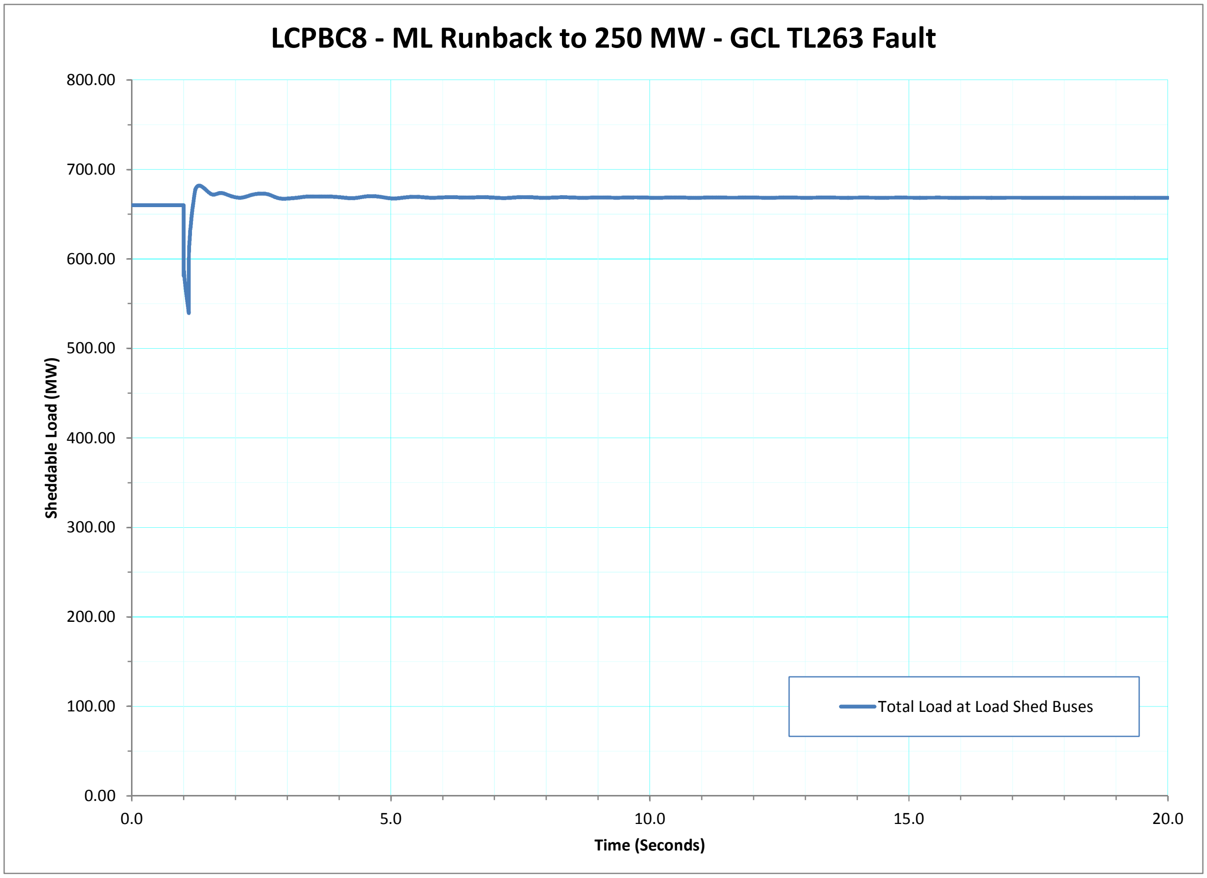


Figure 169 - LCPBC8 - ML Runback to 250 MW - GCL TL263 Fault - Sheddable Load (MW)

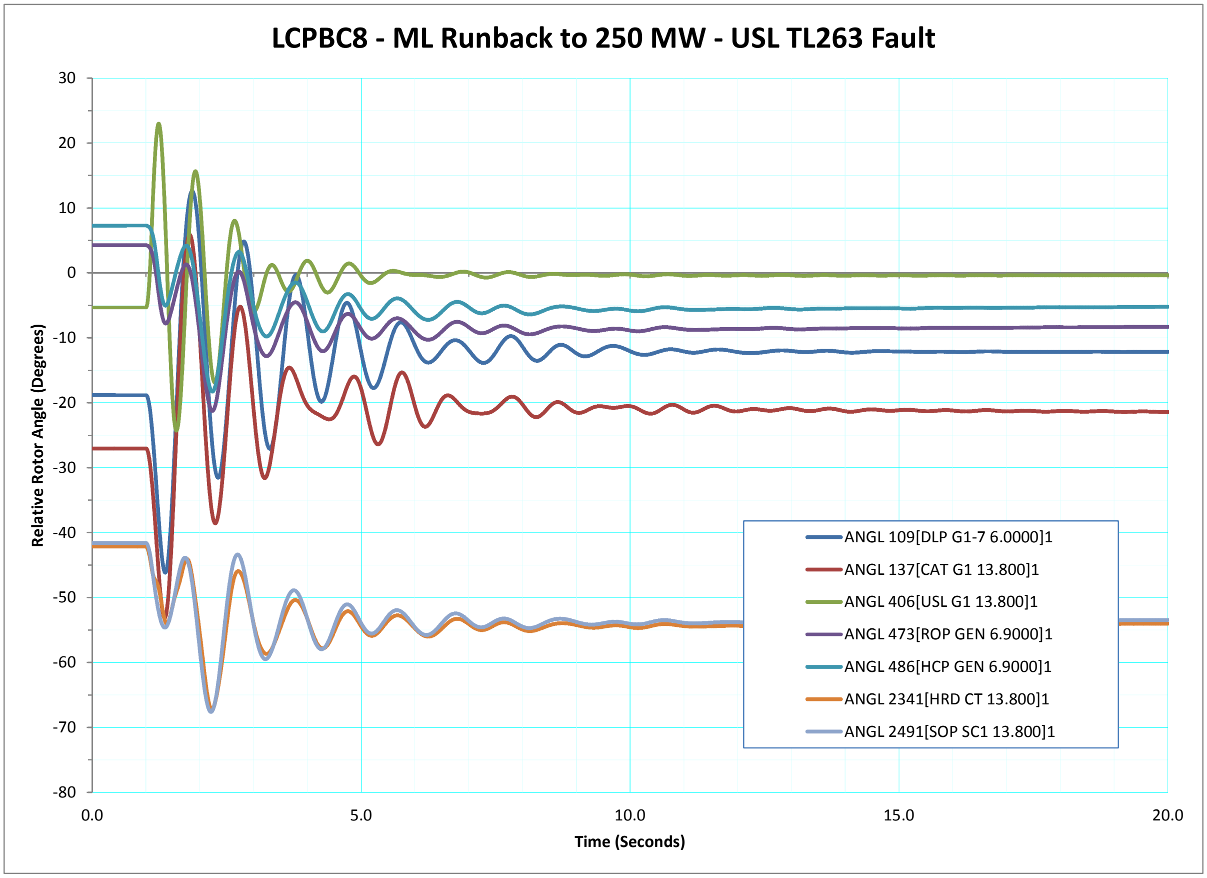


Figure 170 - LCPBC8 - ML Runback to 250 MW - USL TL263 Fault - Relative Rotor Angle (Degrees)

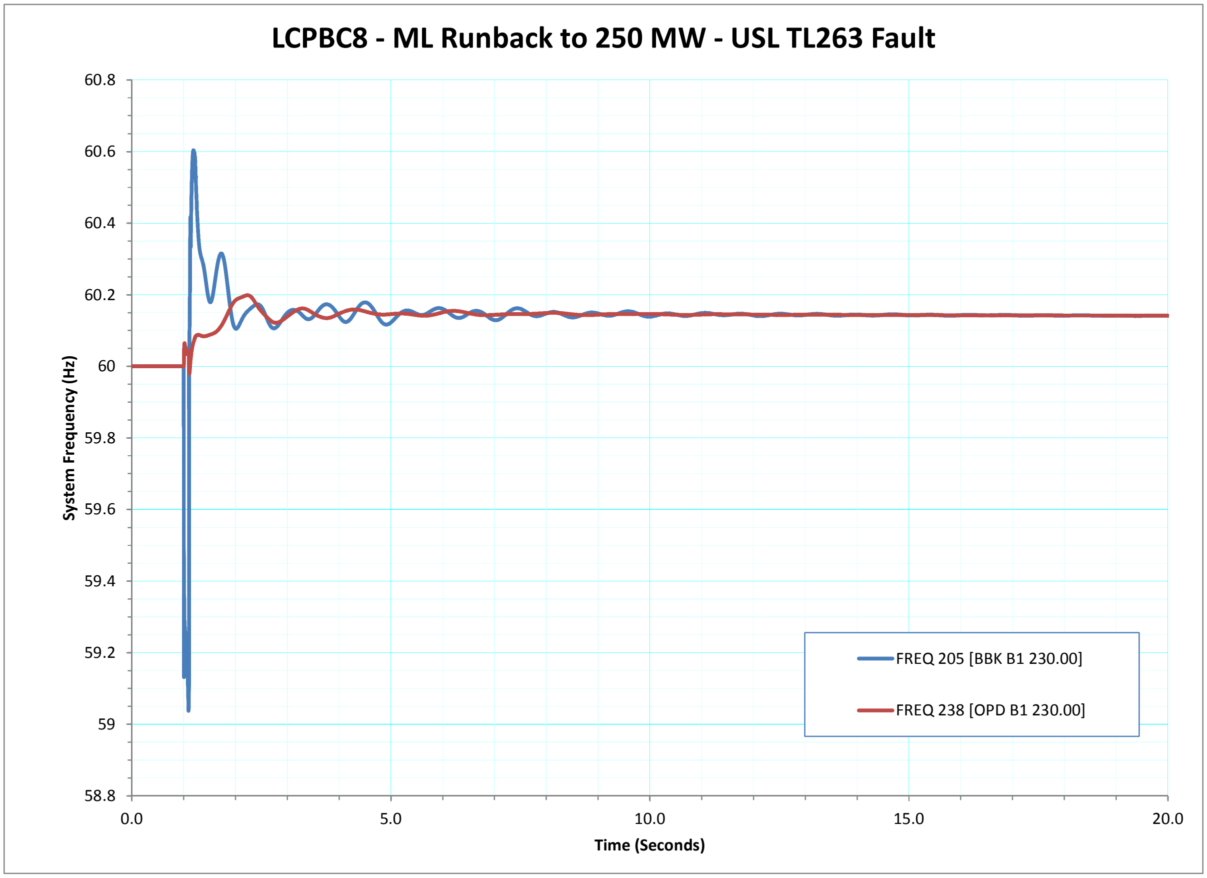


Figure 171 - LCPBC8 - ML Runback to 250 MW - USL TL263 Fault - System Frequency (Hz)

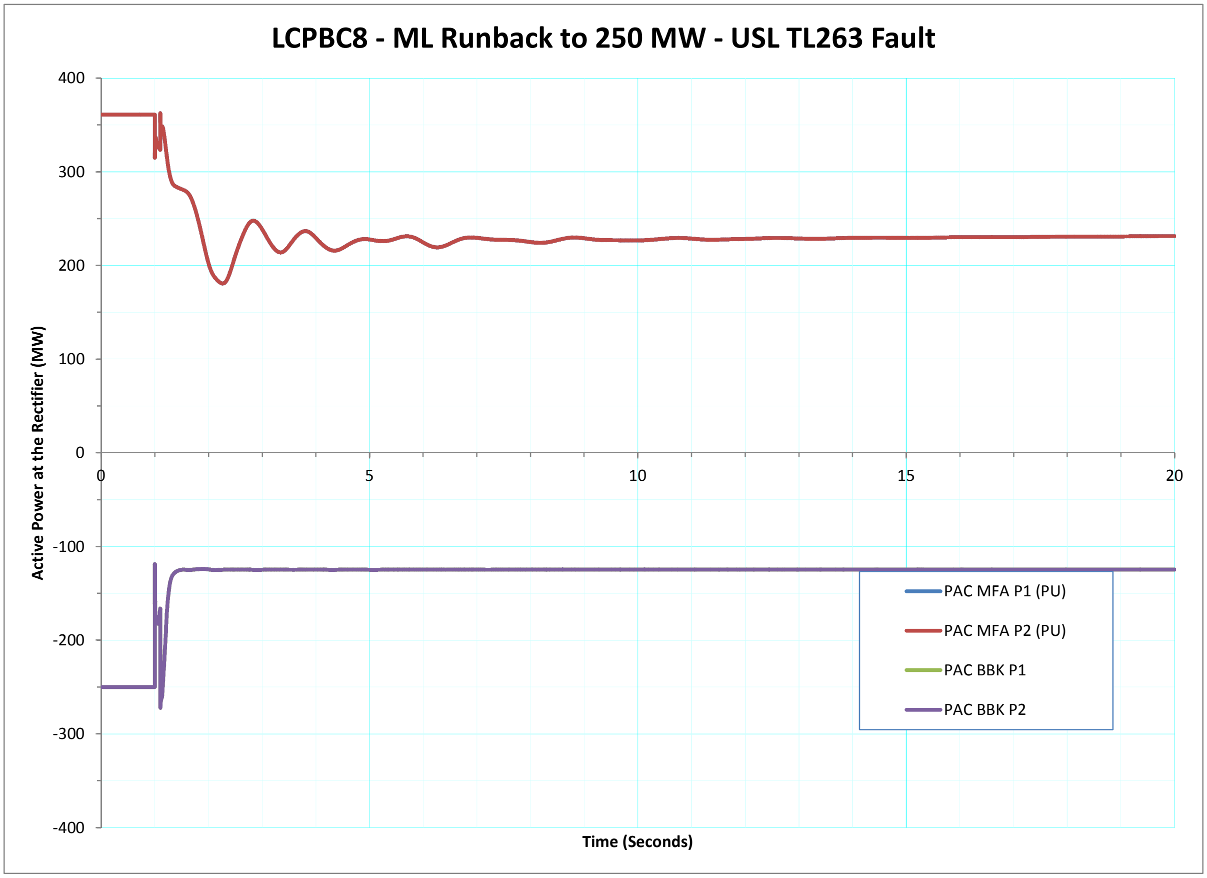


Figure 172 - LCPBC8 - ML Runback to 250 MW - USL TL263 Fault - Active Power at the Rectifier (MW)

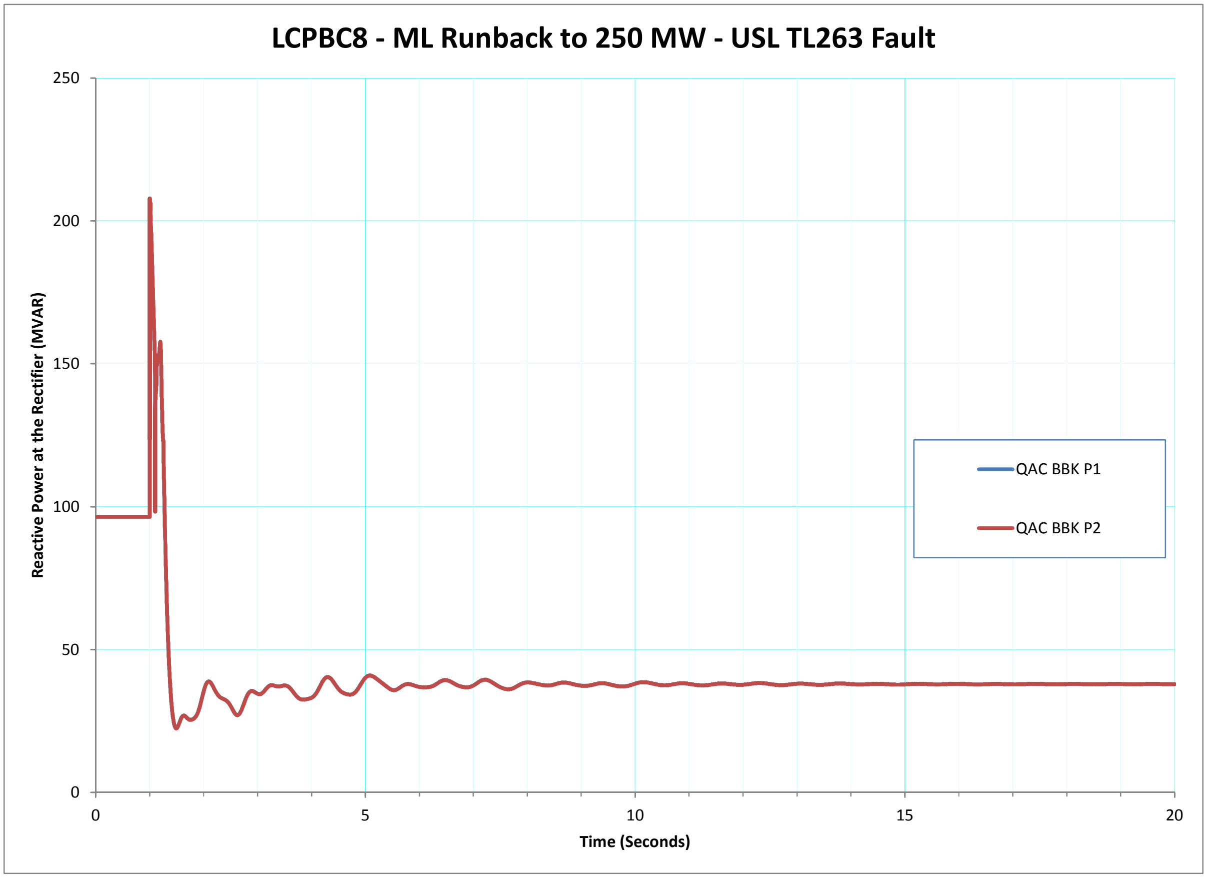


Figure 173 - LCPBC8 - ML Runback to 250 MW - USL TL263 Fault - Reactive Power at the Rectifier (MVAR)

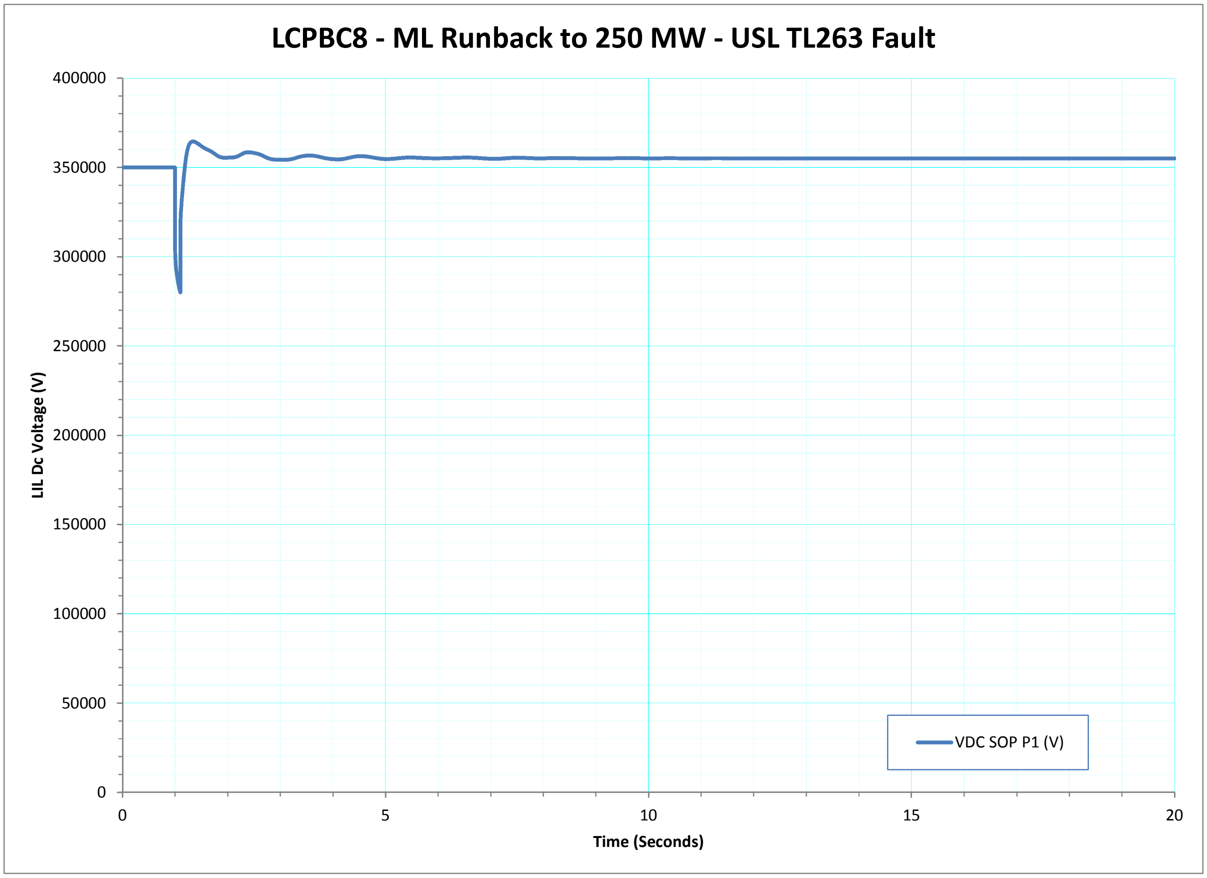


Figure 174 - LCPBC8 - ML Runback to 250 MW - USL TL263 Fault - LIL Dc Voltage (V)

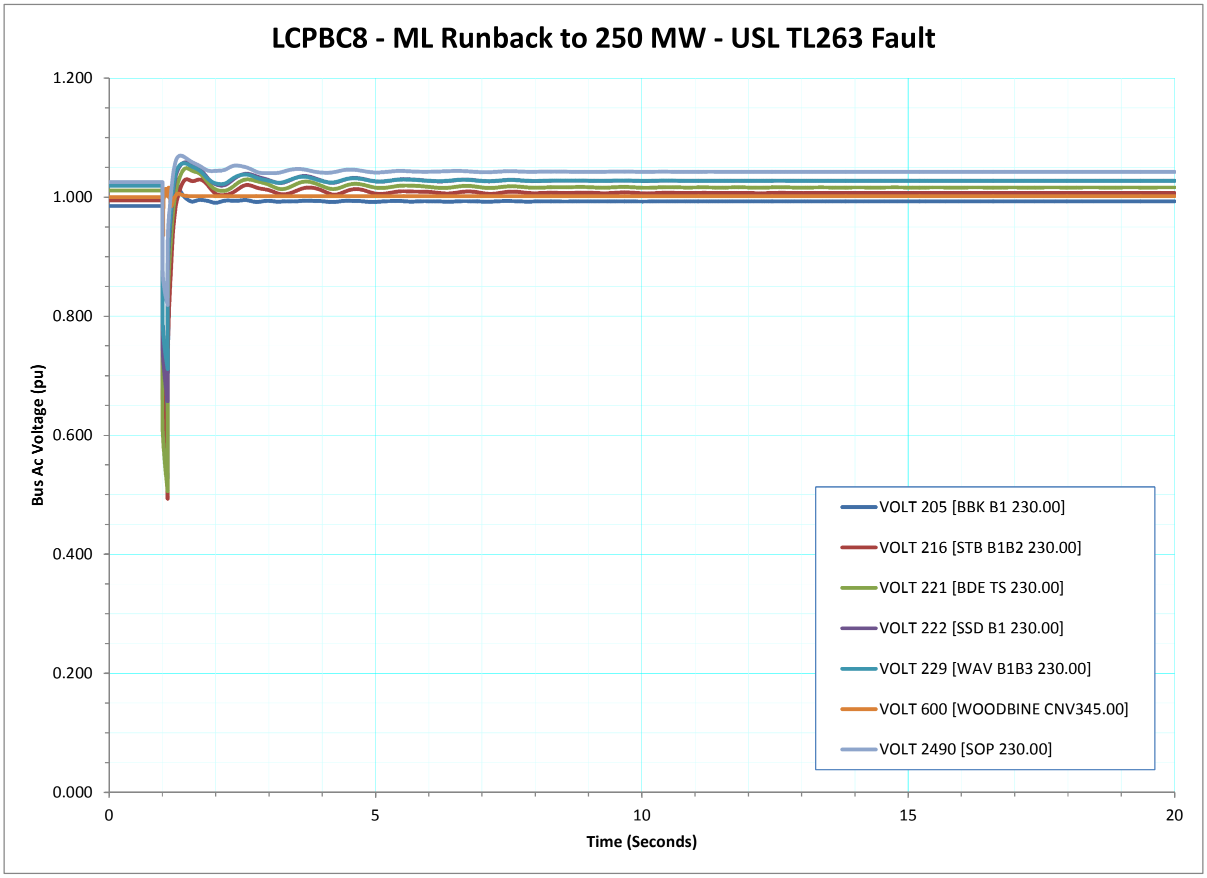


Figure 175 - LCPBC8 - ML Runback to 250 MW - USL TL263 Fault - Bus Ac Voltage (pu)

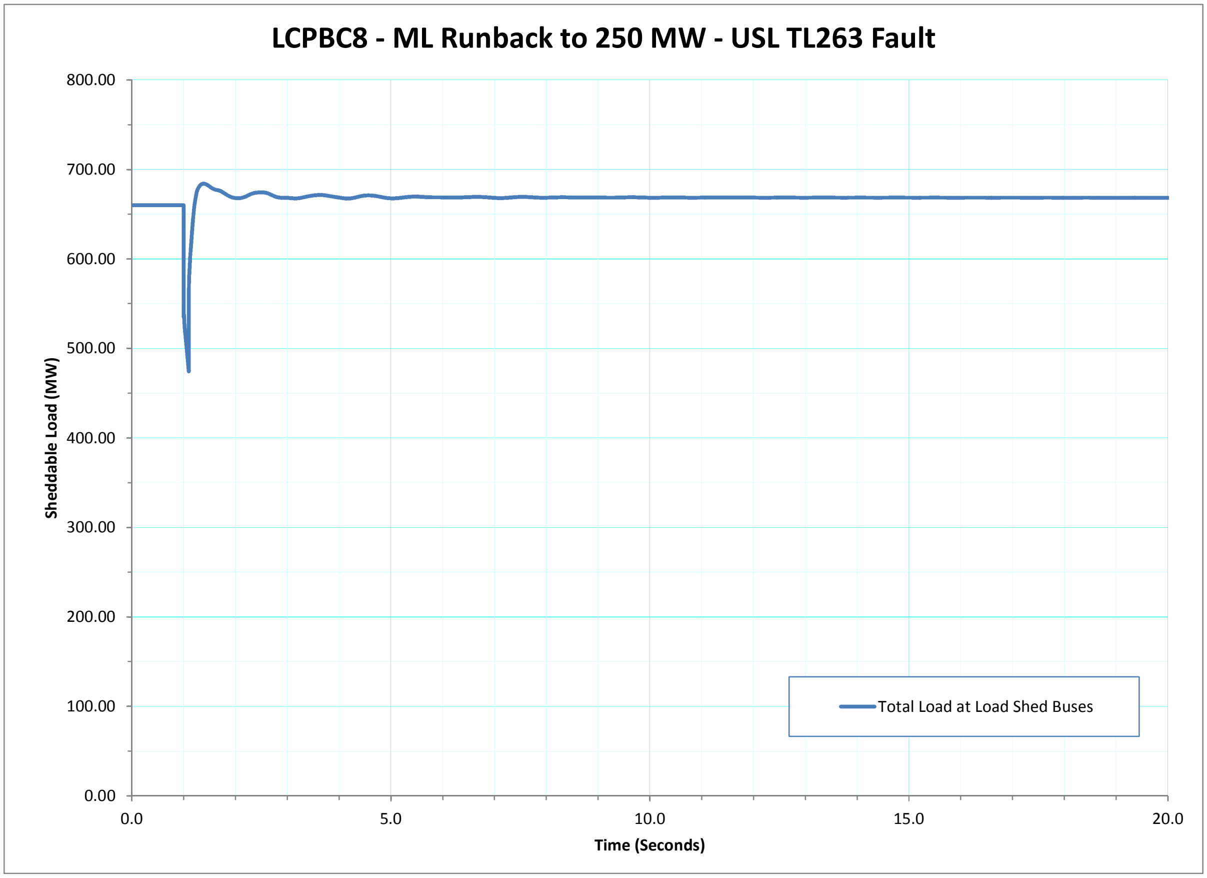


Figure 176 - LCPBC8 - ML Runback to 250 MW - USL TL263 Fault - Sheddable Load (MW)

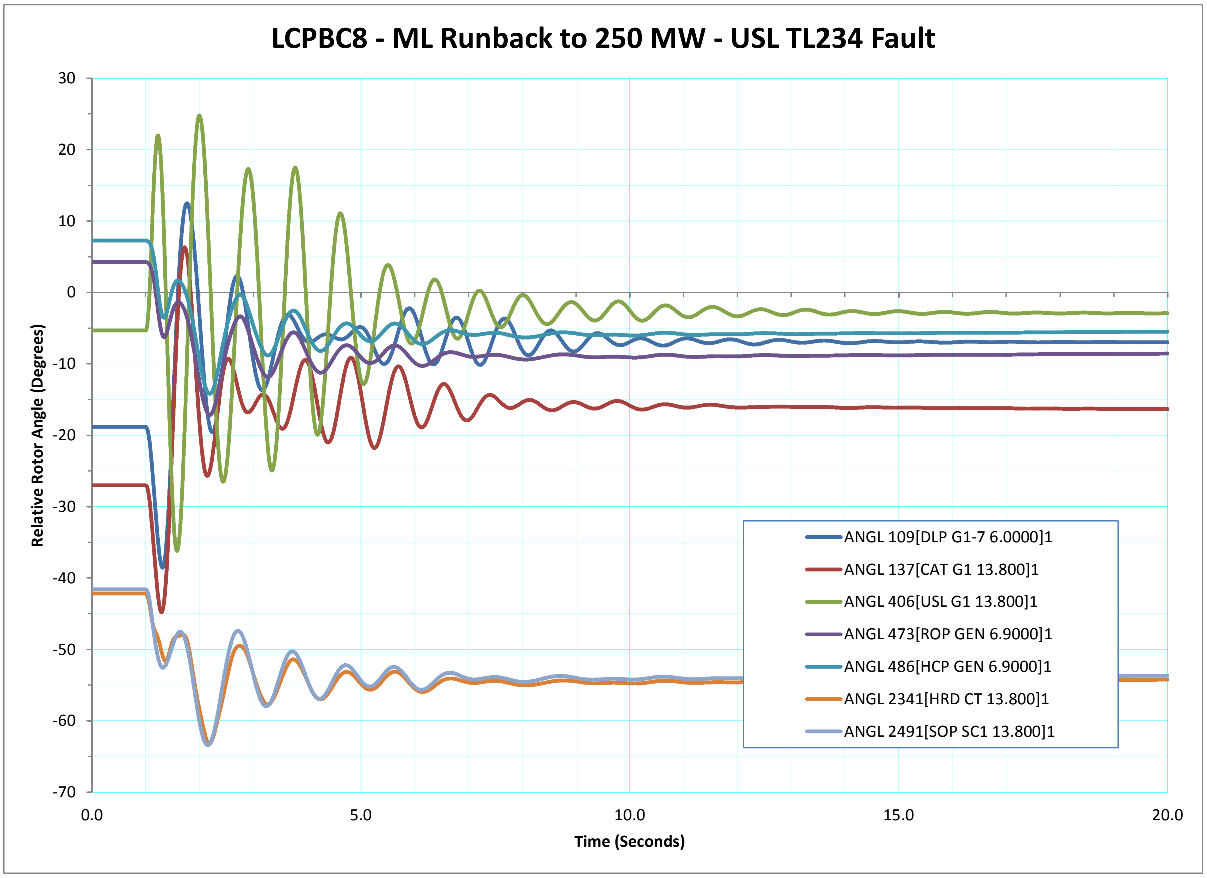


Figure 177 - LCPBC8 - ML Runback to 250 MW - USL TL234 Fault - Relative Rotor Angle (Degrees)

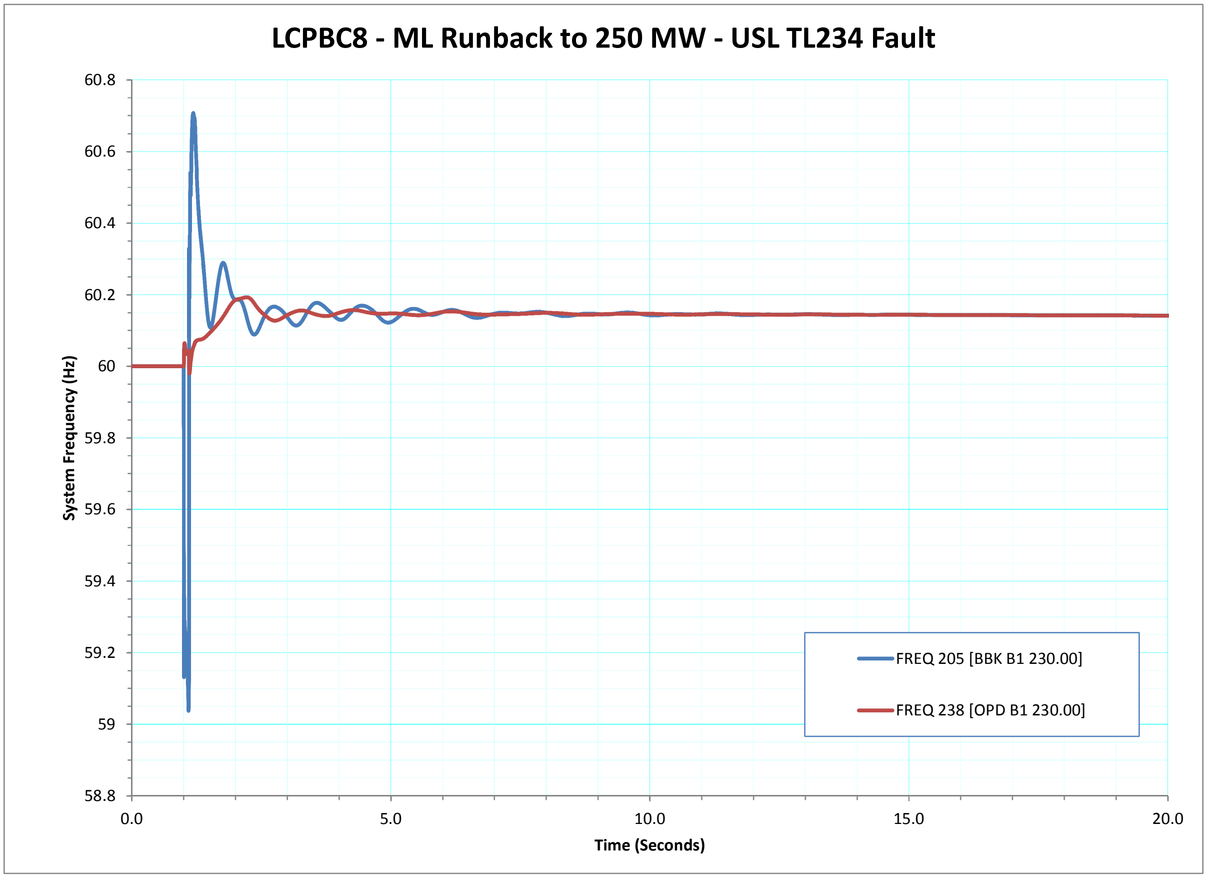


Figure 178 - LCPBC8 - ML Runback to 250 MW - USL TL234 Fault - System Frequency (Hz)

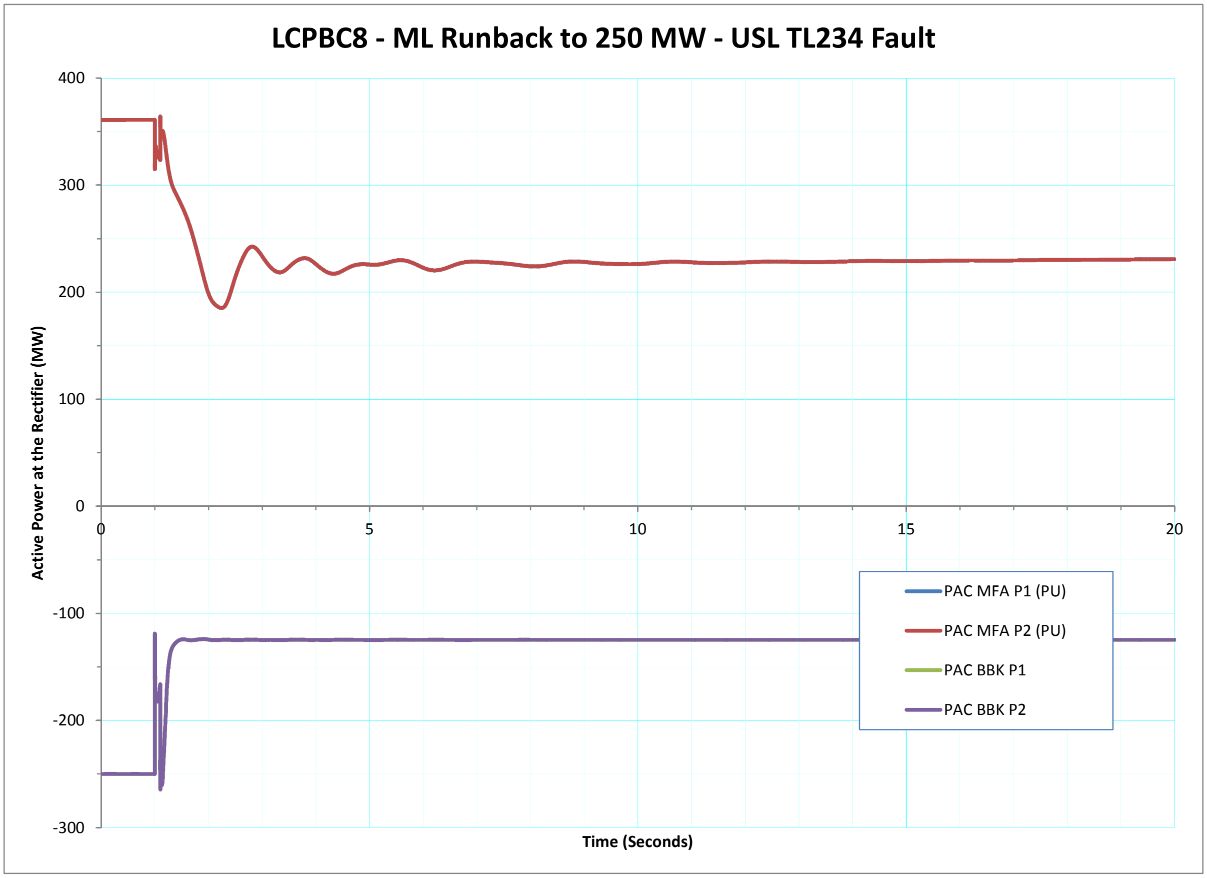


Figure 179 - LCPBC8 - ML Runback to 250 MW - USL TL234 Fault - Active Power at the Rectifier (MW)

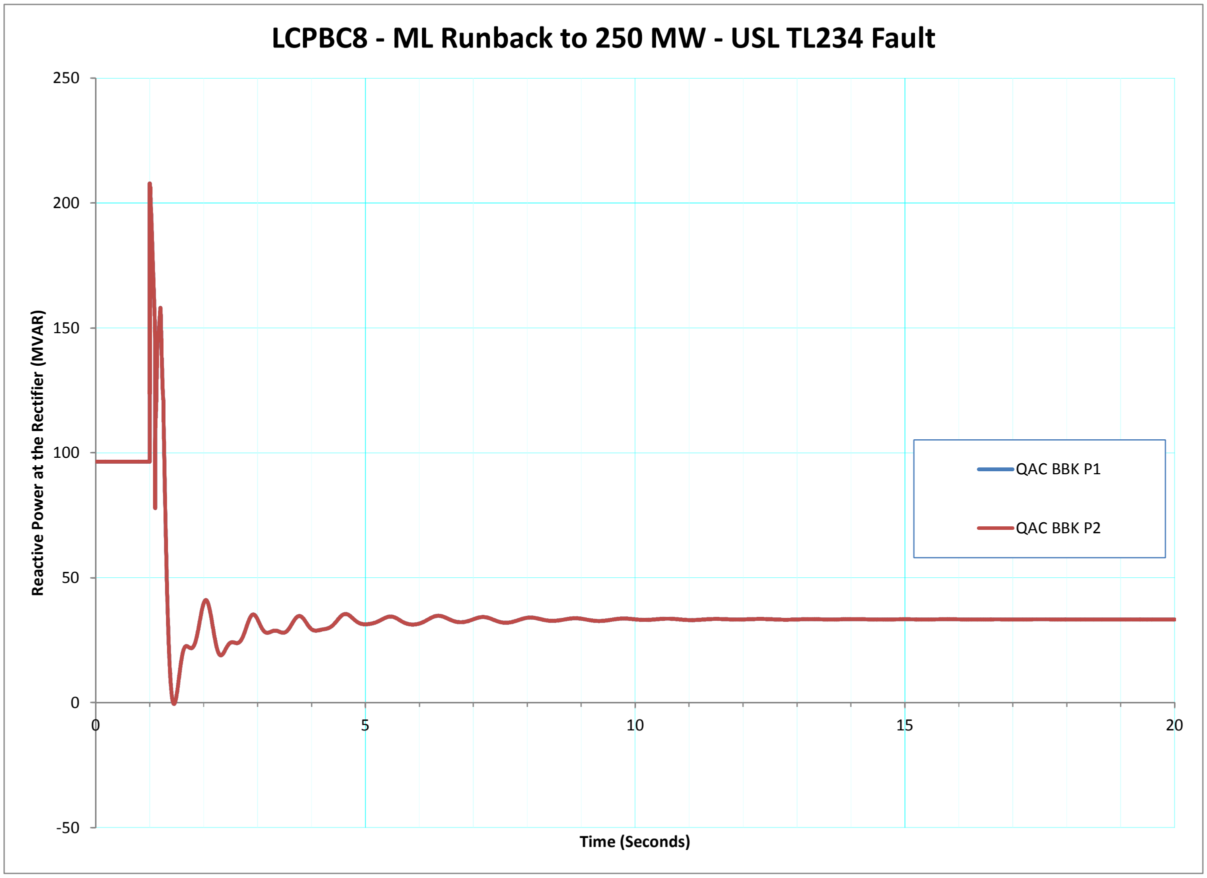


Figure 180 - LCPBC8 - ML Runback to 250 MW - USL TL234 Fault - Reactive Power at the Rectifier (MVAR)

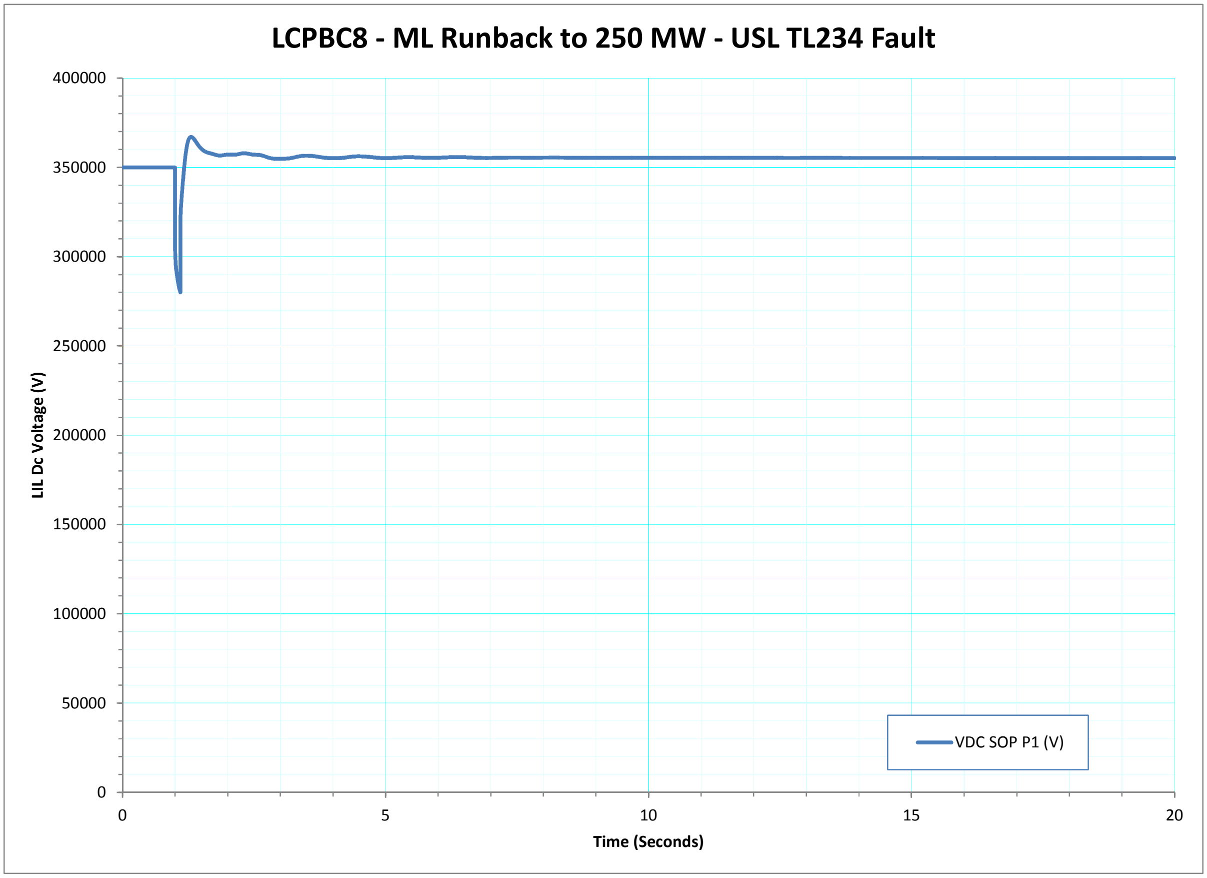


Figure 181 - LCPBC8 - ML Runback to 250 MW - USL TL234 Fault - LIL Dc Voltage (V)

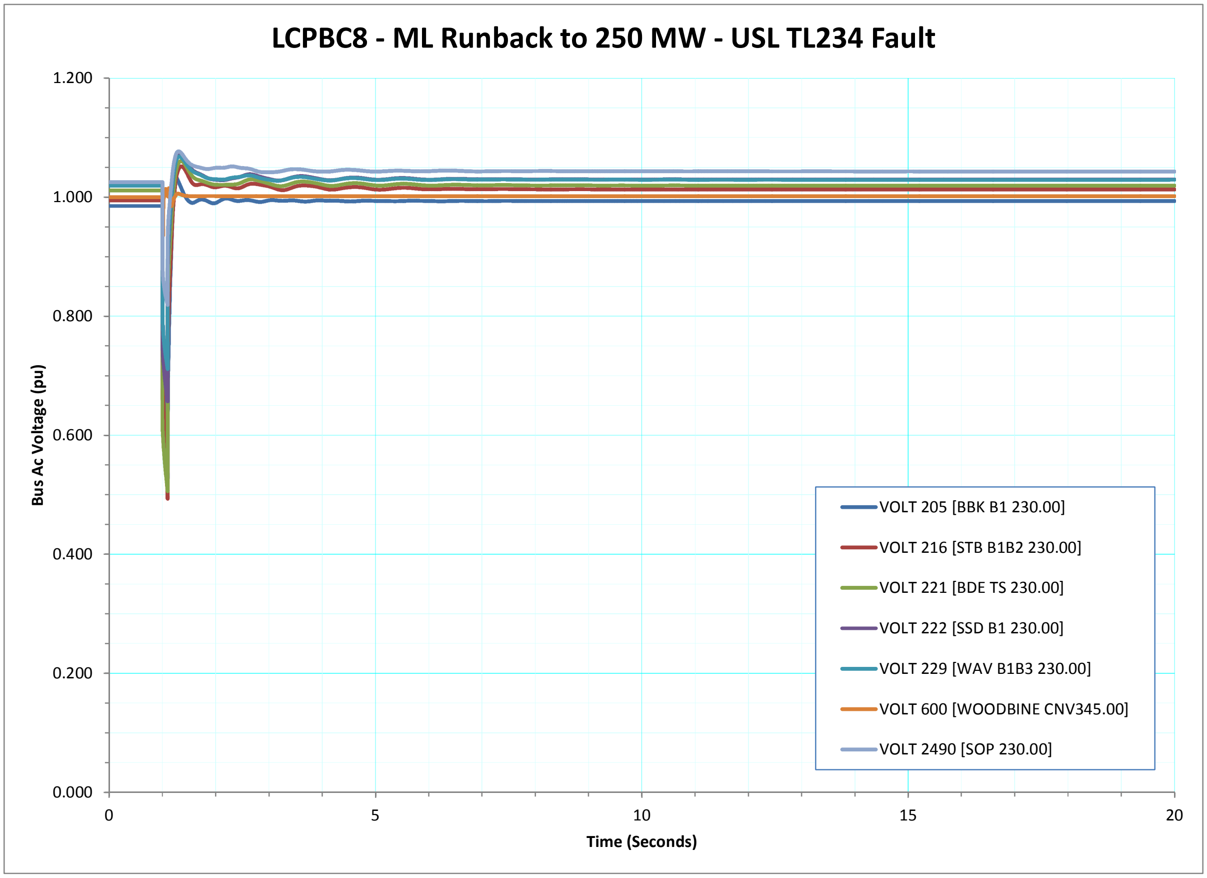


Figure 182 - LCPBC8 - ML Runback to 250 MW - USL TL234 Fault - Bus Ac Voltage (pu)

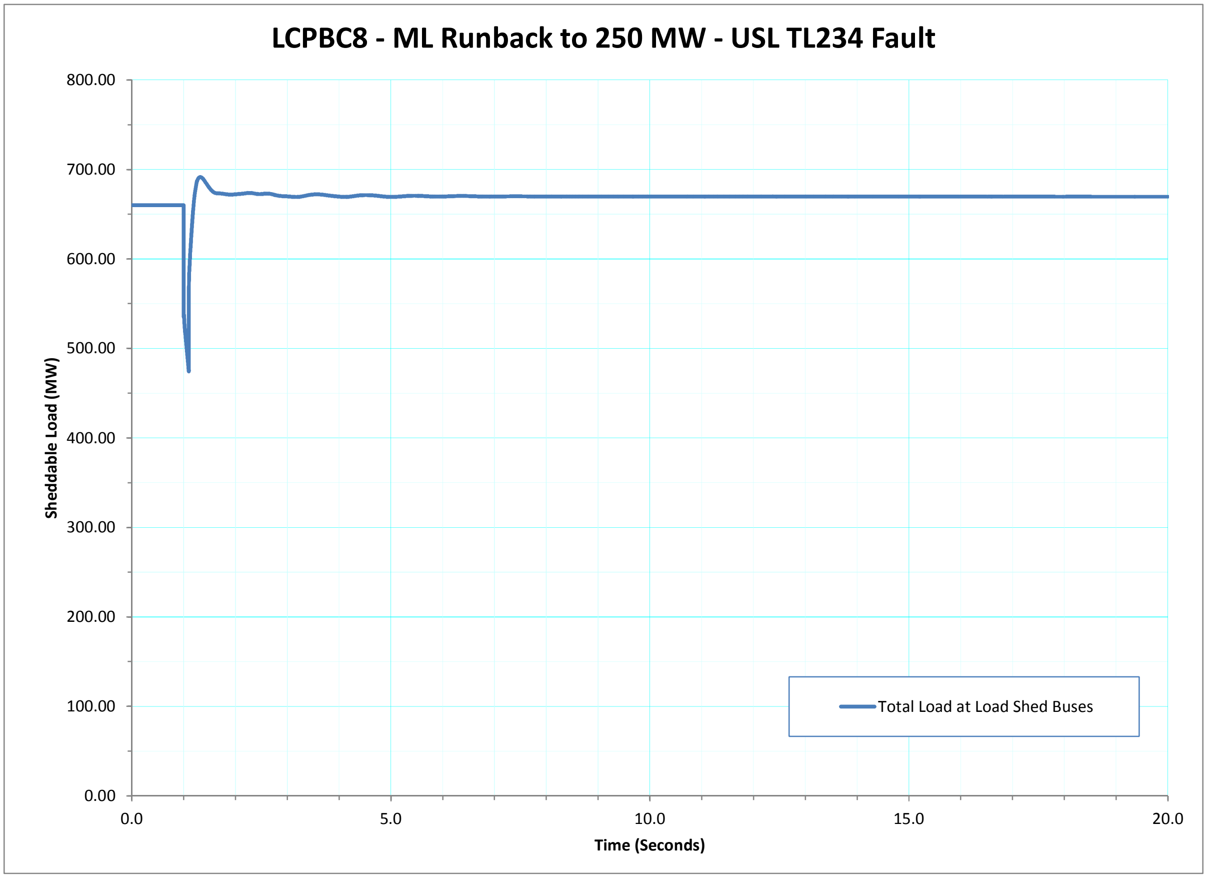


Figure 183 - LCPBC8 - ML Runback to 250 MW - USL TL234 Fault - Sheddable Load (MW)

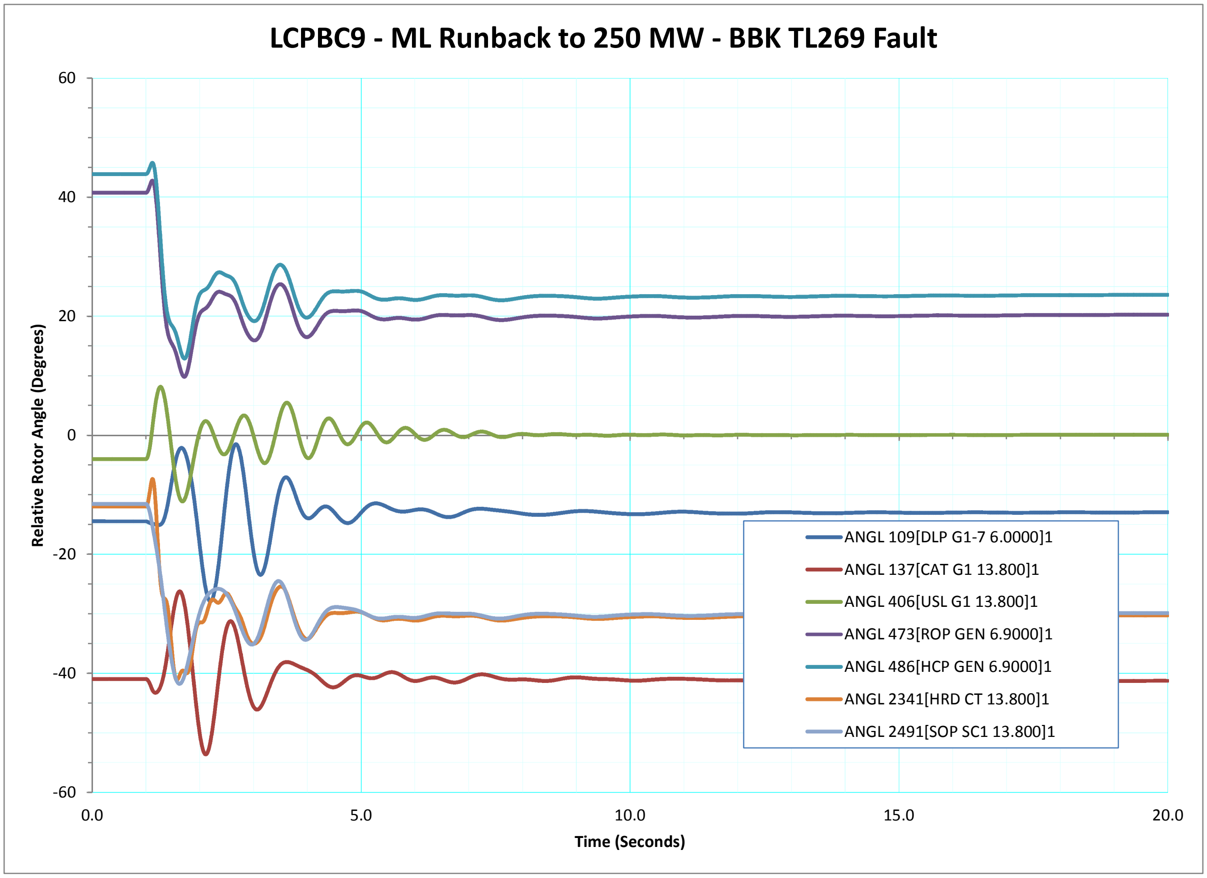


Figure 184 - LCPBC9 - ML Runback to 250 MW - BBK TL269 Fault - Relative Rotor Angle (Degrees)

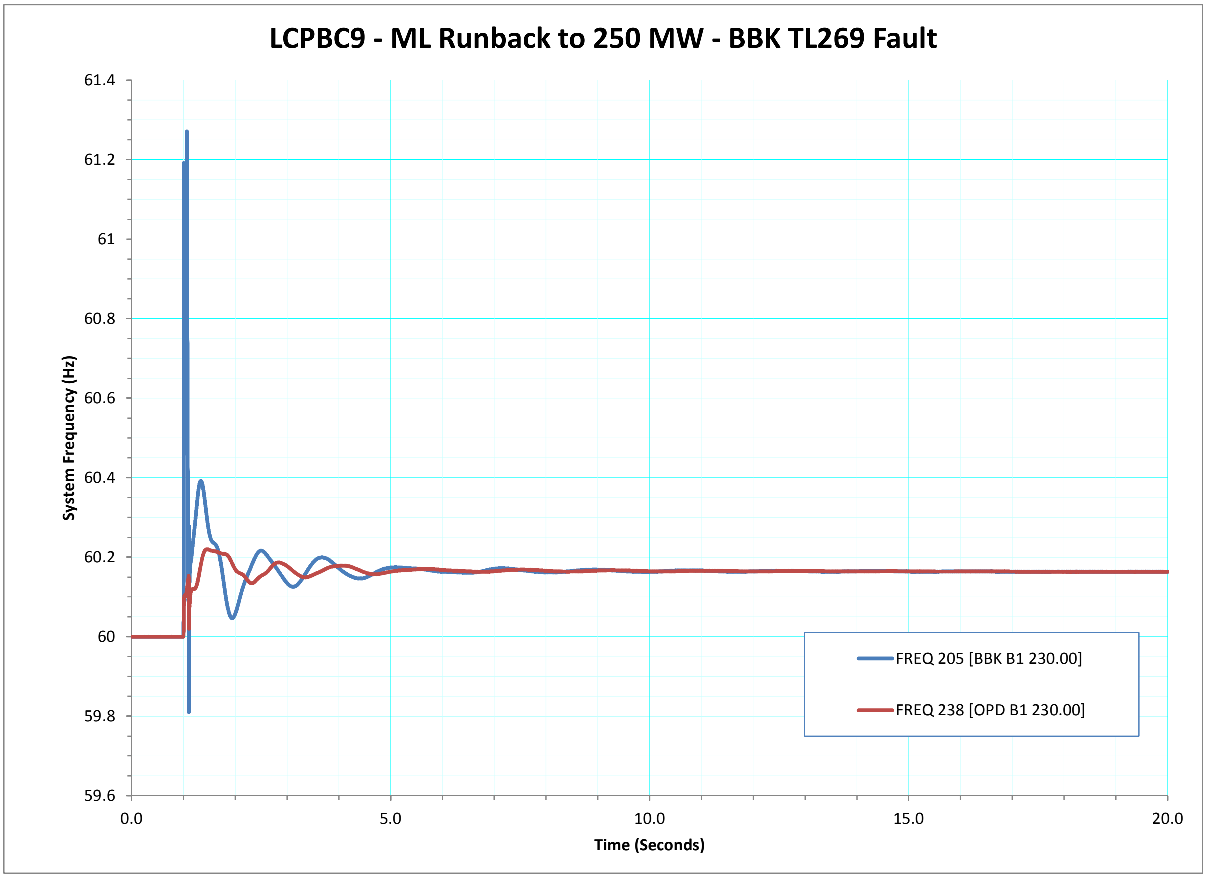


Figure 185 - LCPBC9 - ML Runback to 250 MW - BBK TL269 Fault - System Frequency (Hz)

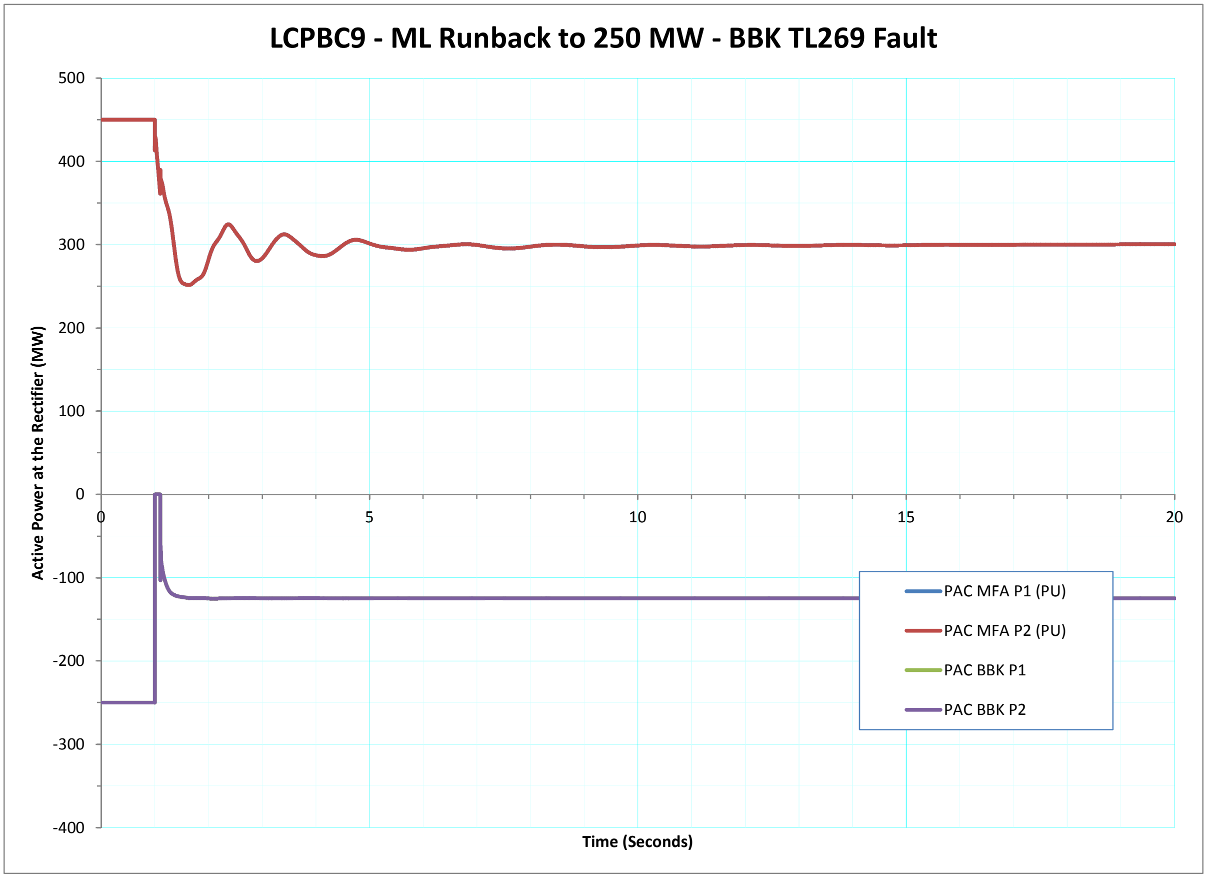


Figure 186 - LCPBC9 - ML Runback to 250 MW - BBK TL269 Fault - Active Power at the Rectifier (MW)

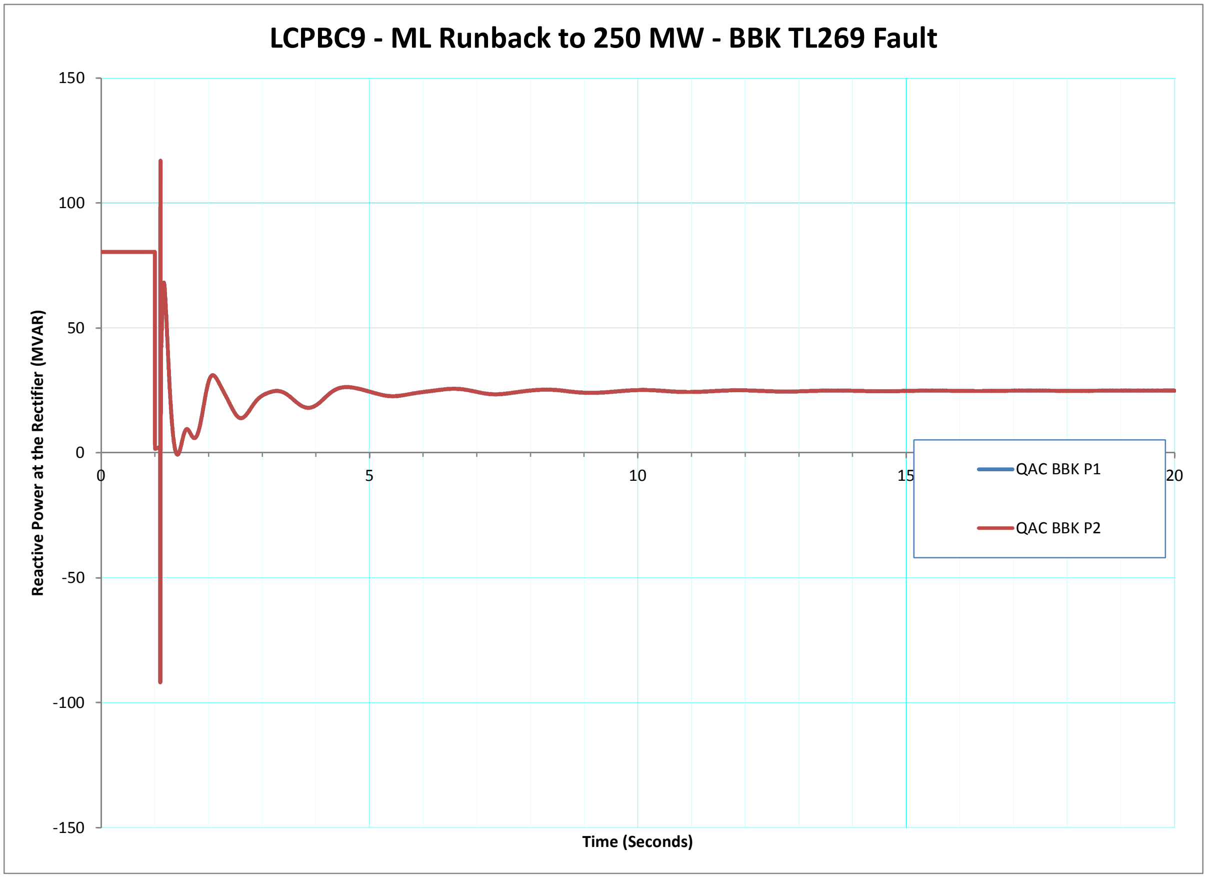


Figure 187 - LCPBC9 - ML Runback to 250 MW - BBK TL269 Fault - Reactive Power at the Rectifier (MVAR)

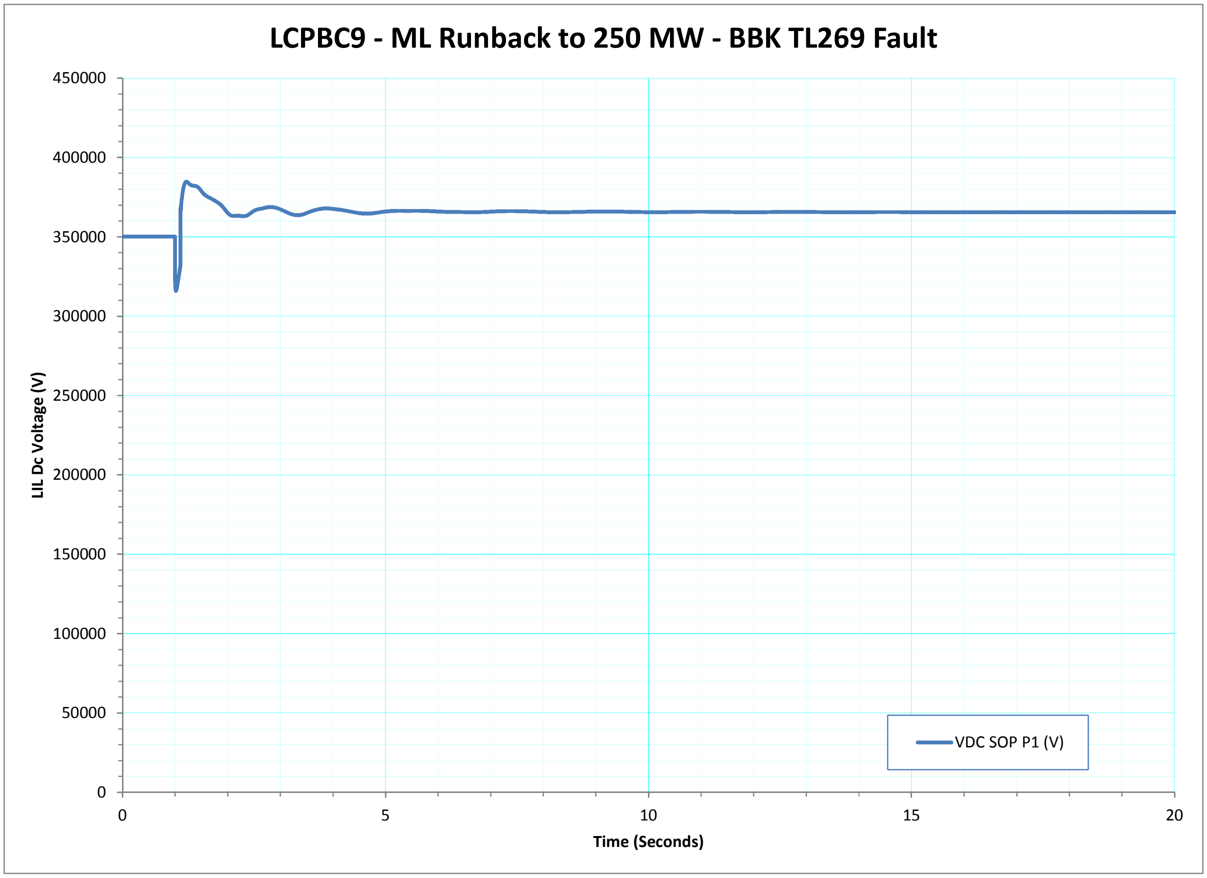


Figure 188 - LCPBC9 - ML Runback to 250 MW - BBK TL269 Fault - LIL Dc Voltage (V)

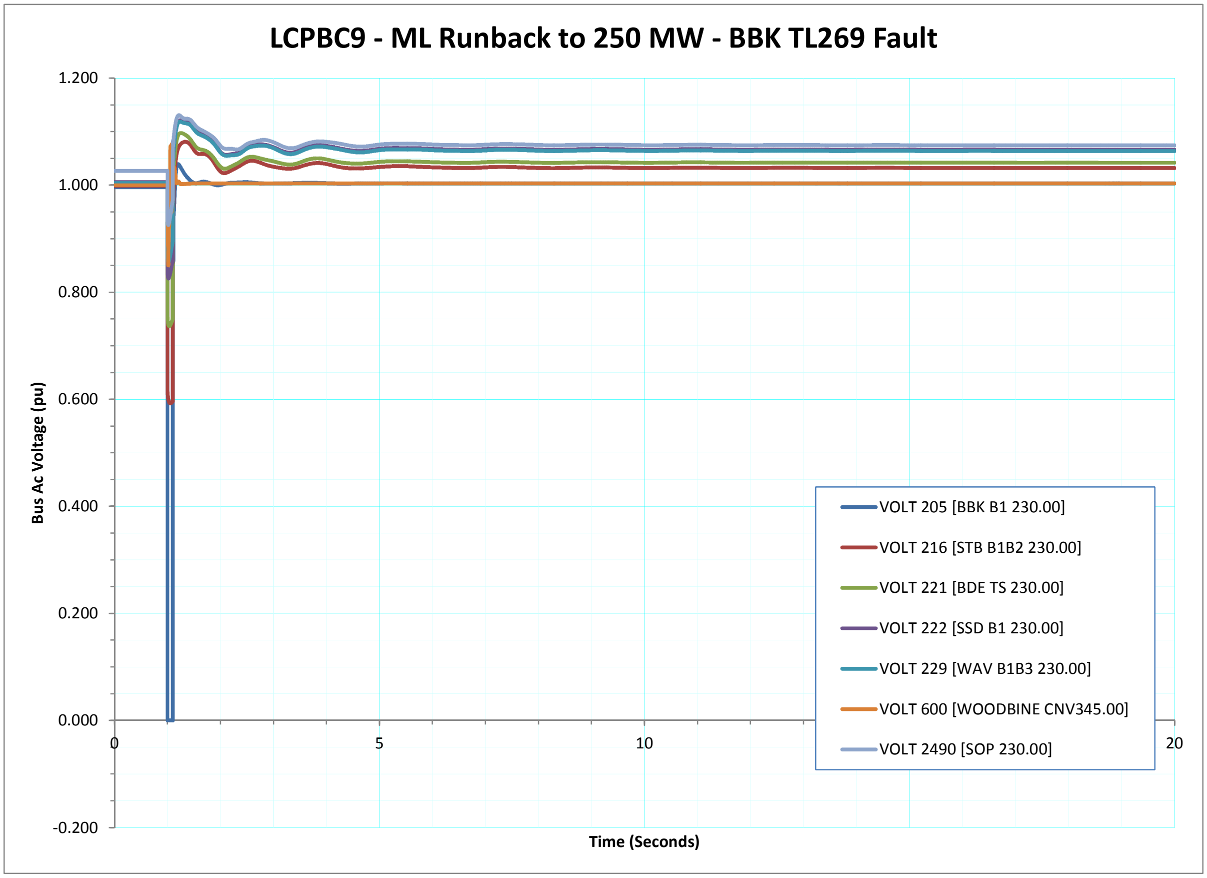


Figure 189 - LCPBC9 - ML Runback to 250 MW - BBK TL269 Fault - Bus Ac Voltage (pu)

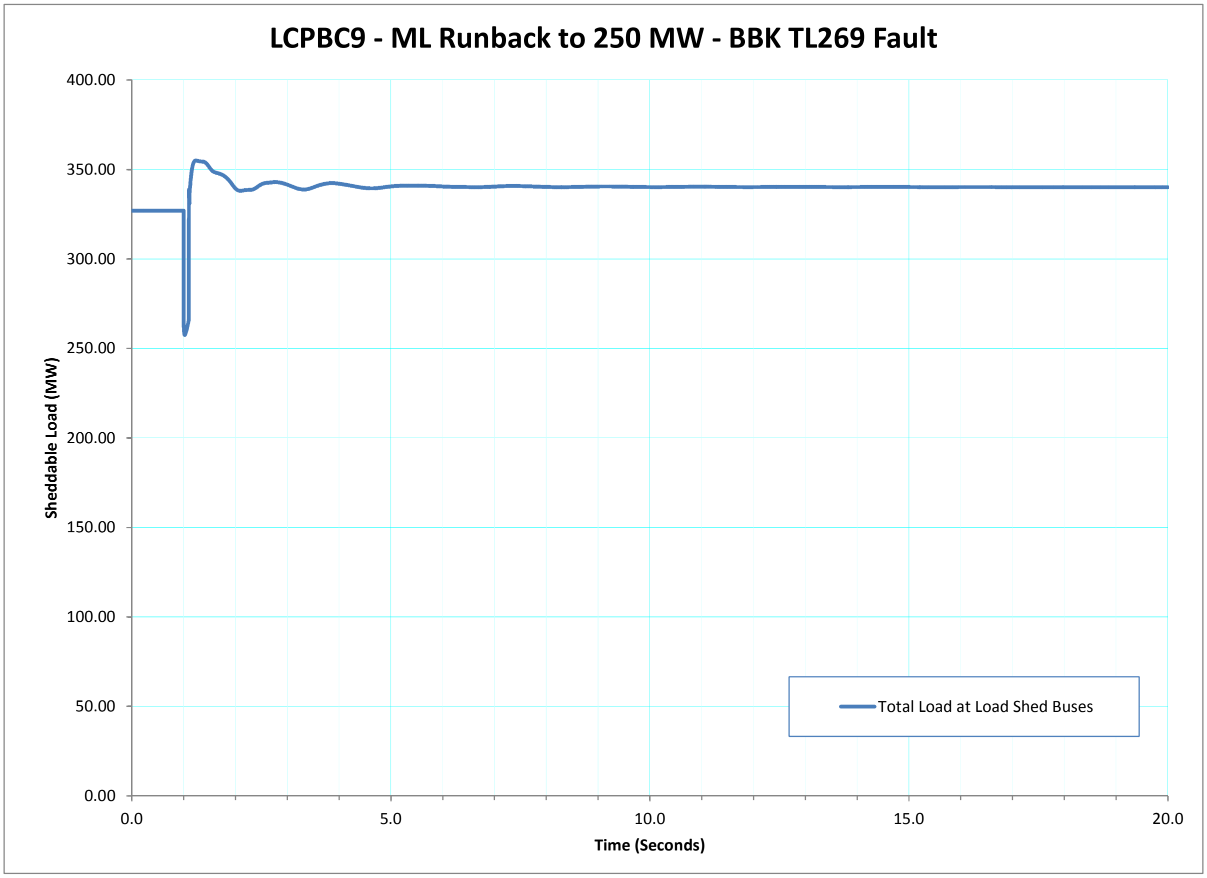

LCPBC9 - ML Runback to 250 MW - BBK TL269 Fault
Sheddable Load (MW)
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0.0
5.0
10.0
15.0
20.0
Time (Seconds)
Total Load at Load Shed Buses

Figure 190 - LCPBC9 - ML Runback to 250 MW - BBK TL269 Fault - Sheddable Load (MW)

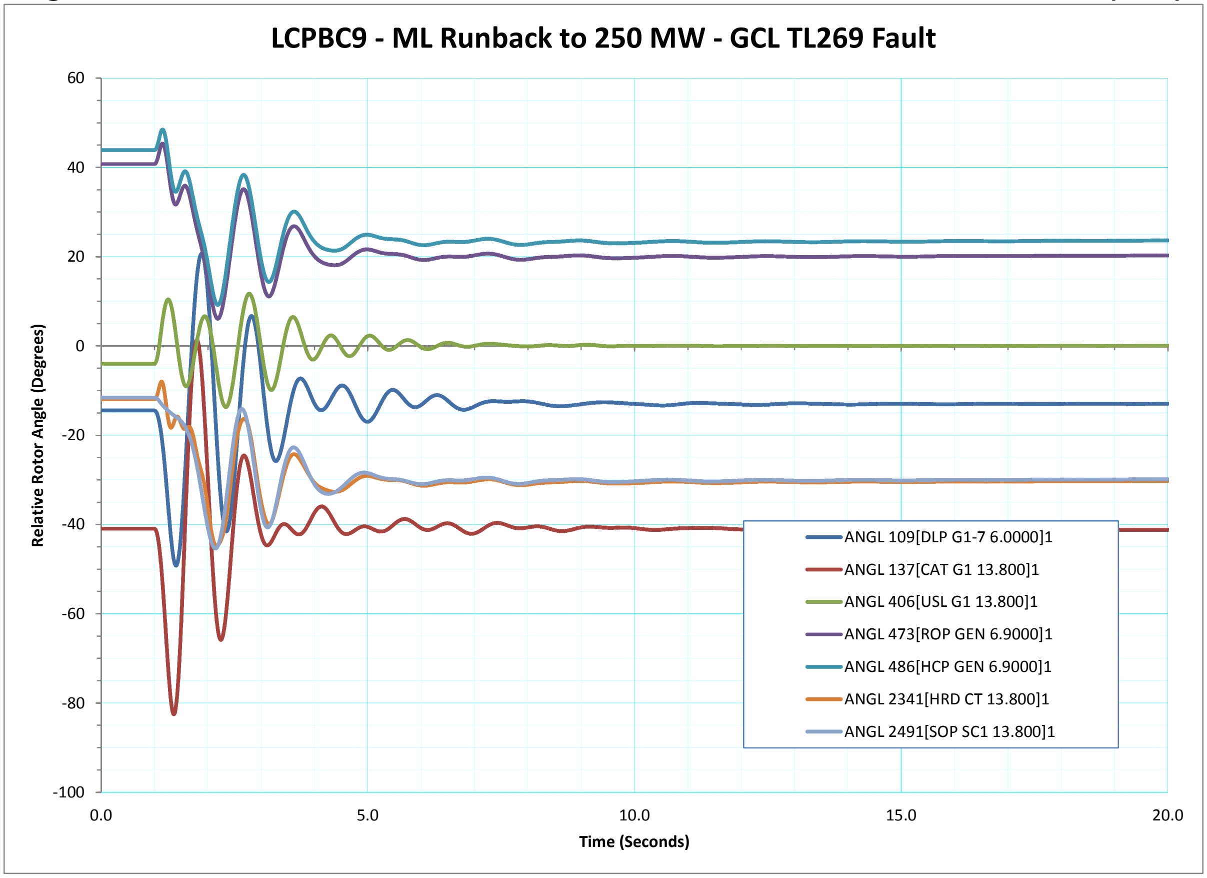


Figure 191 - LCPBC9 - ML Runback to 250 MW - GCL TL269 Fault - Relative Rotor Angle (Degrees)

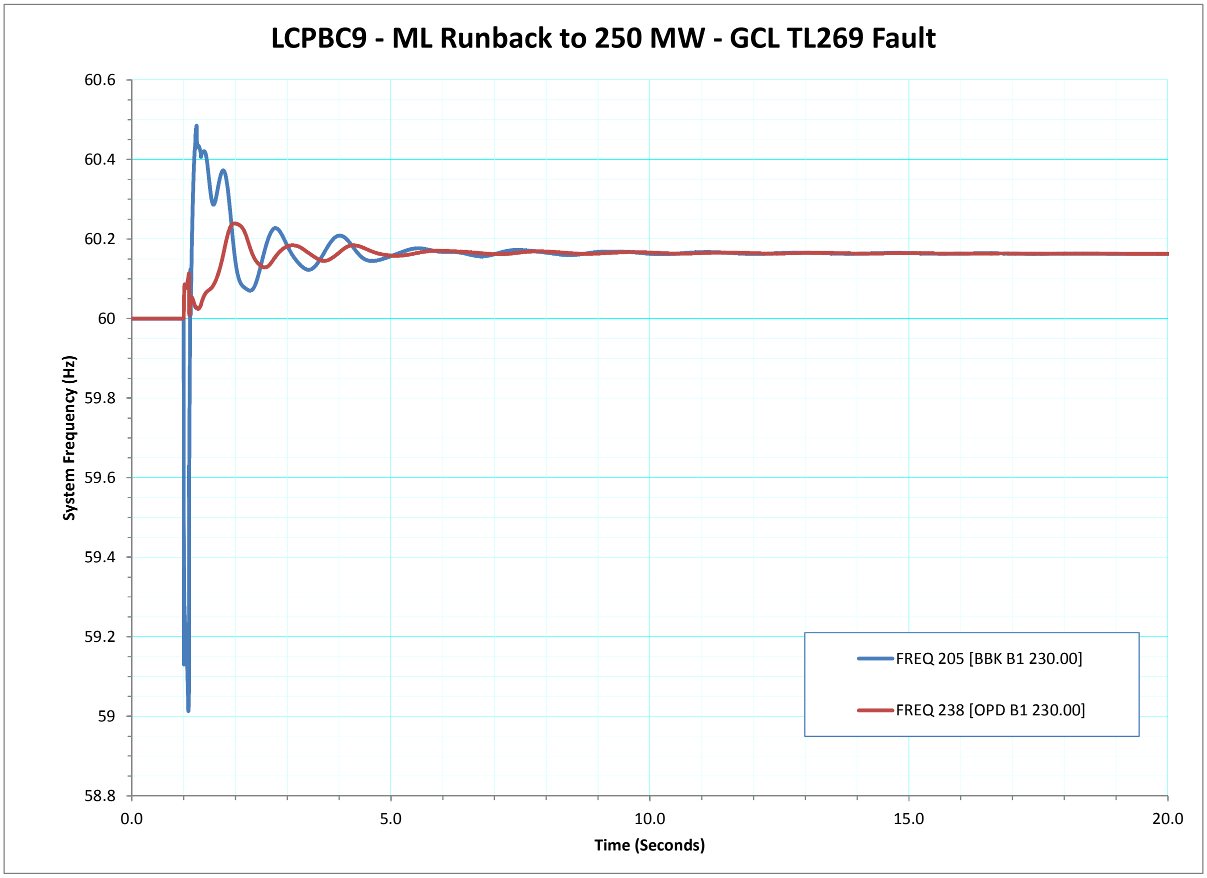


Figure 192 - LCPBC9 - ML Runback to 250 MW - GCL TL269 Fault - System Frequency (Hz)

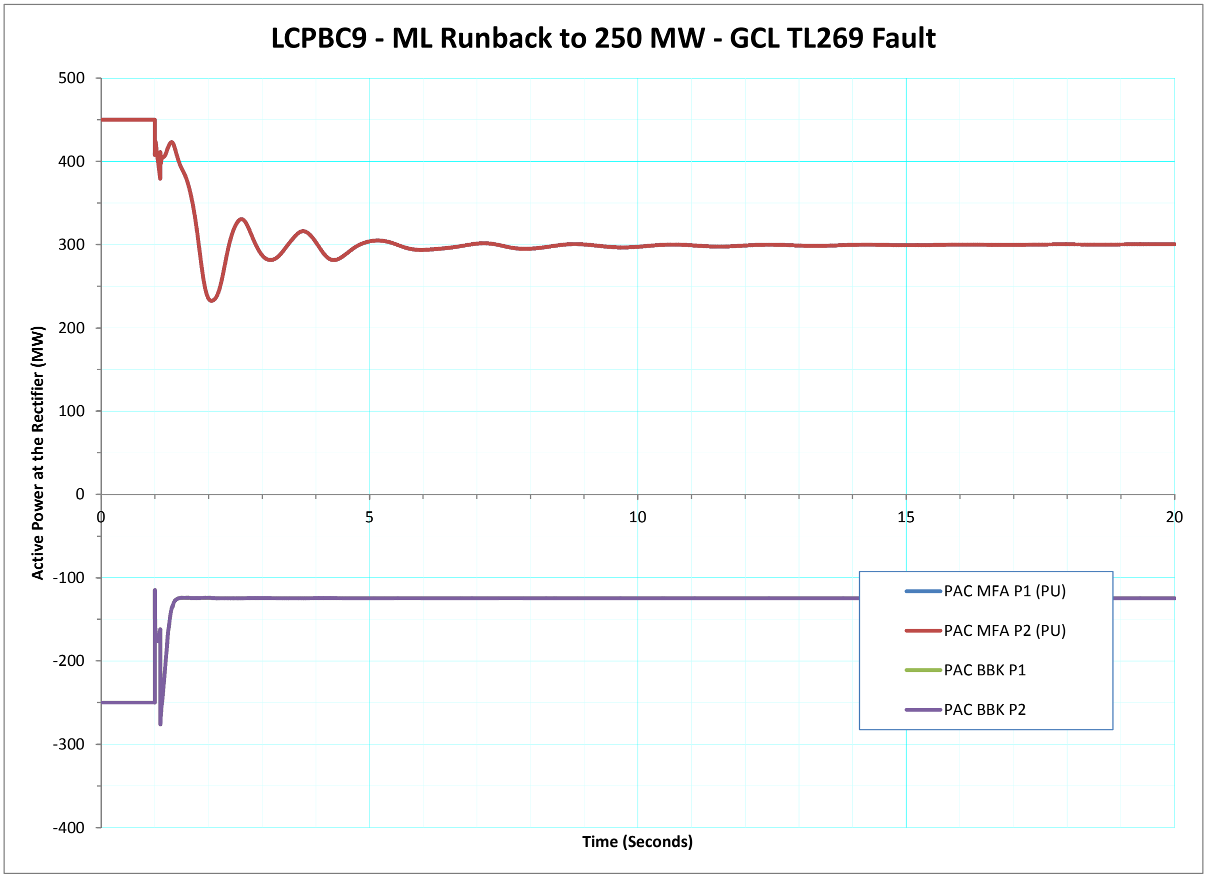


Figure 193 - LCPBC9 - ML Runback to 250 MW - GCL TL269 Fault - Active Power at the Rectifier (MW)

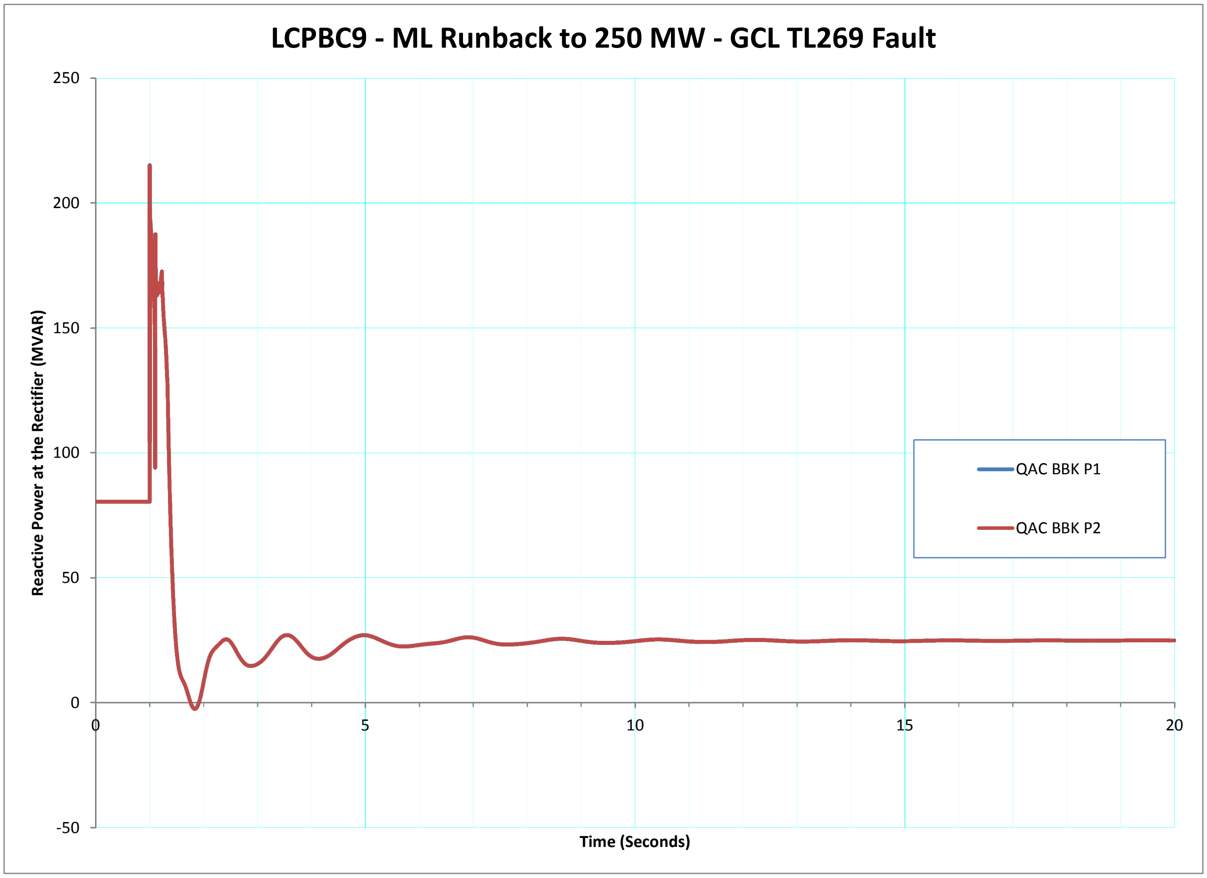


Figure 194 - LCPBC9 - ML Runback to 250 MW - GCL TL269 Fault - Reactive Power at the Rectifier (MVAR)

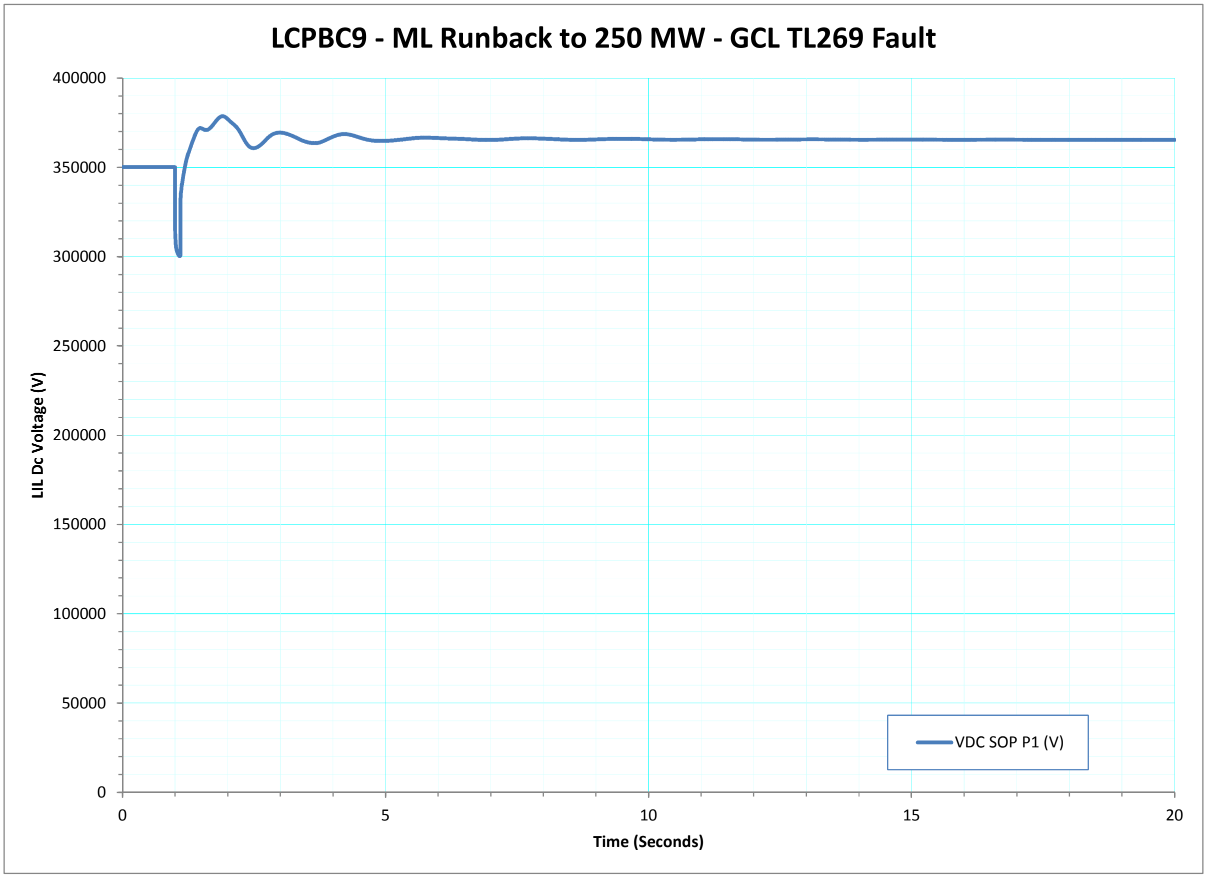


Figure 195 - LCPBC9 - ML Runback to 250 MW - GCL TL269 Fault - LIL Dc Voltage (V)

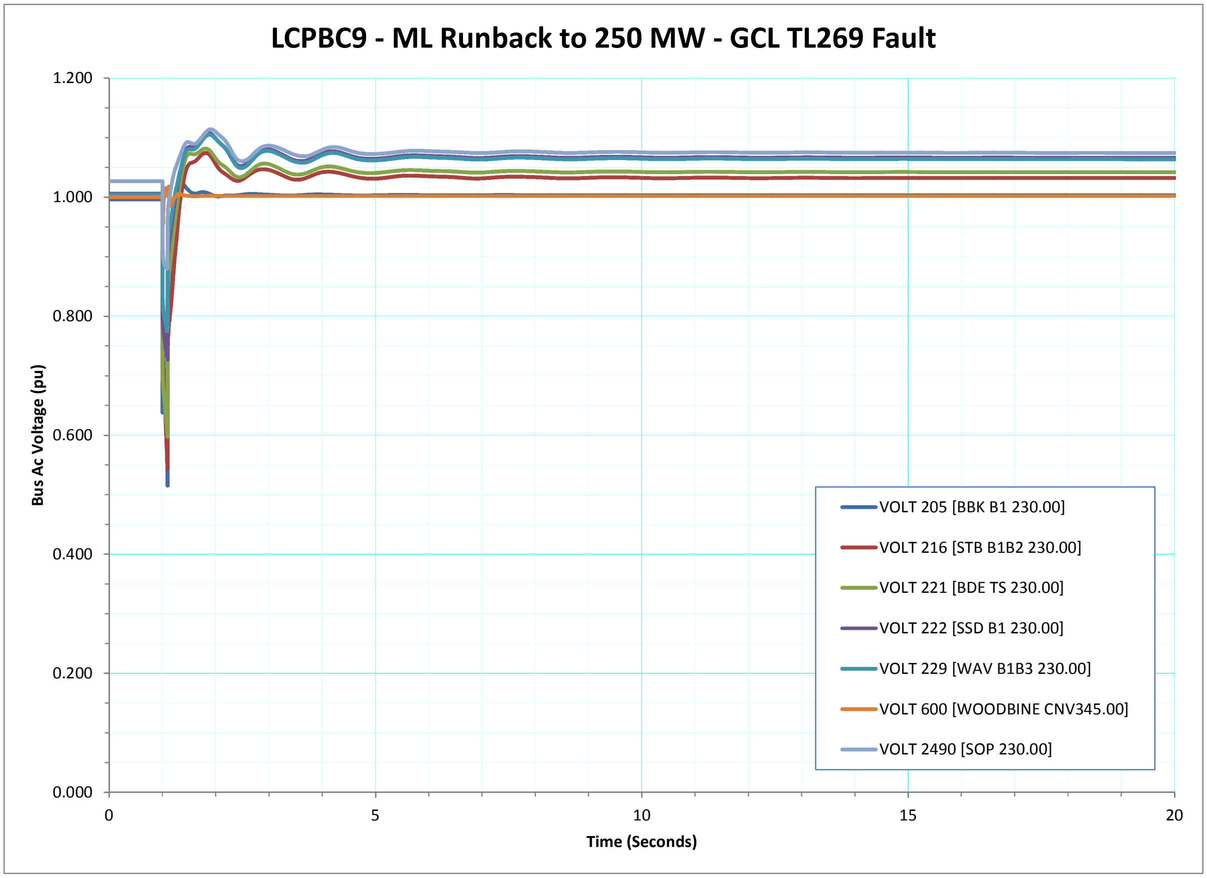


Figure 196 - LCPBC9 - ML Runback to 250 MW - GCL TL269 Fault - Bus Ac Voltage (pu)

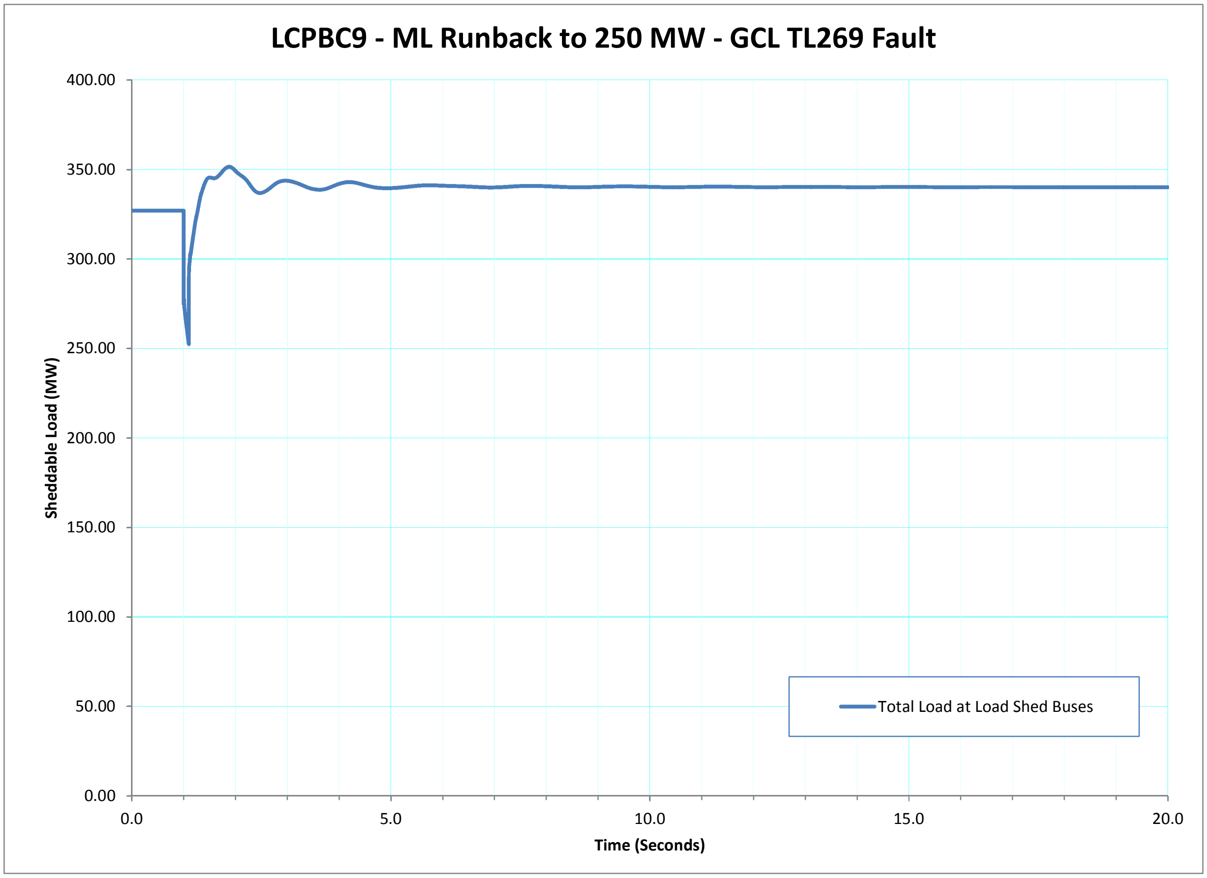


Figure 197 - LCPBC9 - ML Runback to 250 MW - GCL TL269 Fault - Sheddable Load (MW)

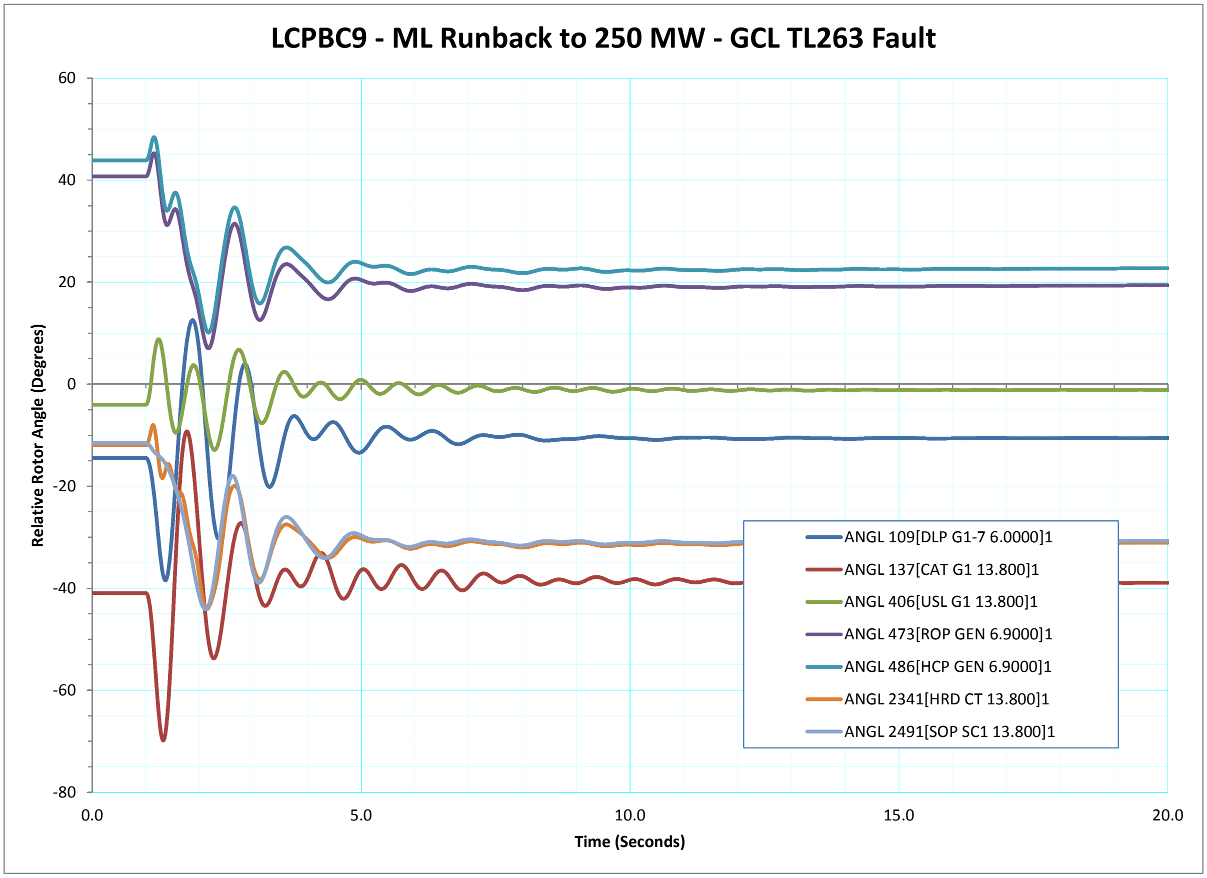


Figure 198 - LCPBC9 - ML Runback to 250 MW - GCL TL263 Fault - Relative Rotor Angle (Degrees)

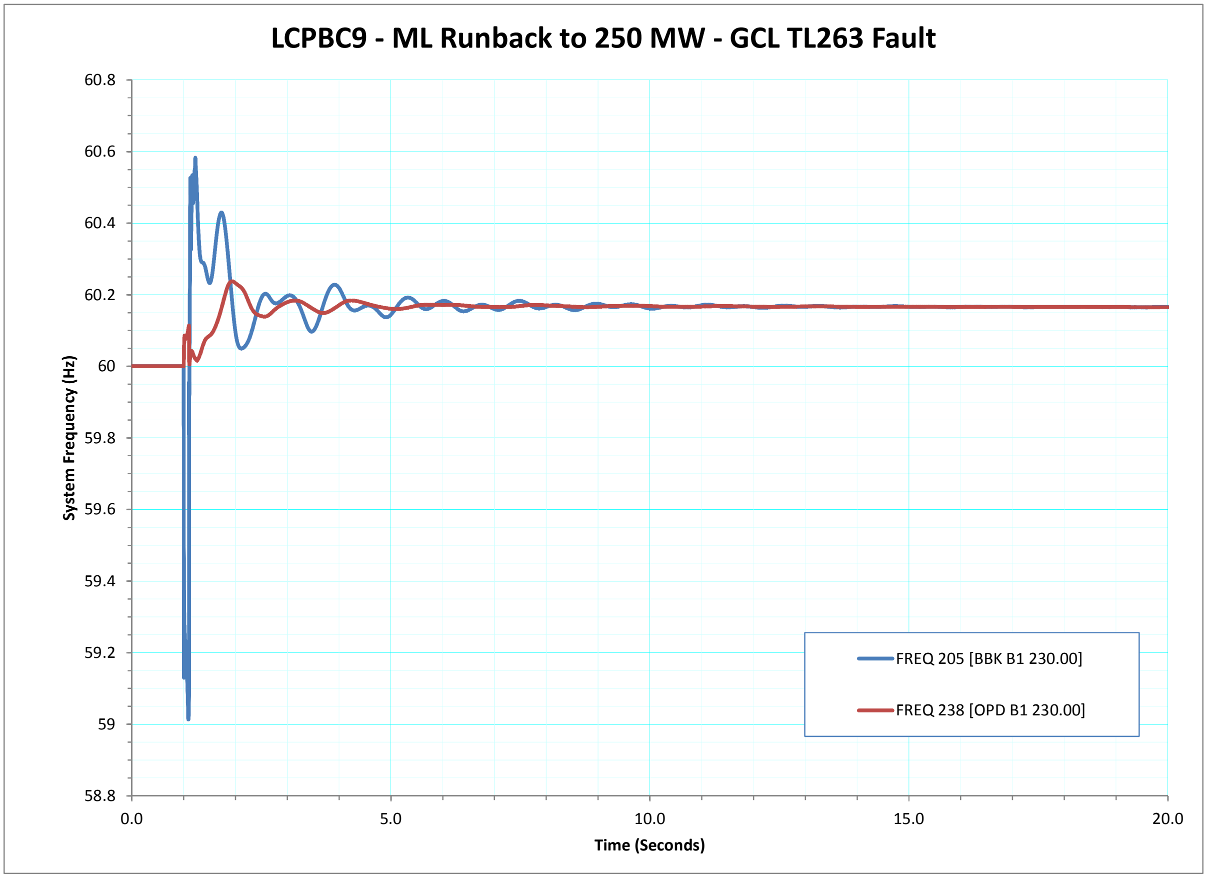


Figure 199 - LCPBC9 - ML Runback to 250 MW - GCL TL263 Fault - System Frequency (Hz)

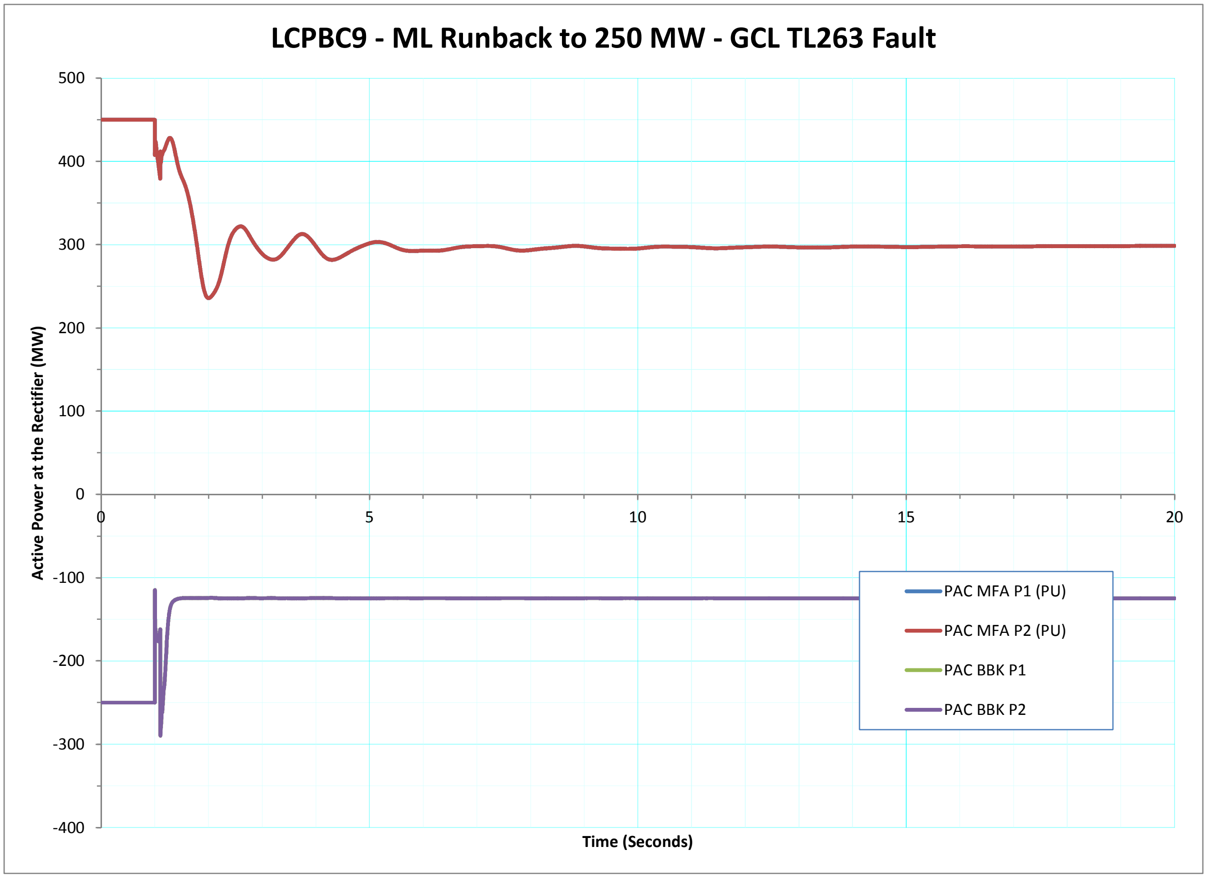


Figure 200 - LCPBC9 - ML Runback to 250 MW - GCL TL263 Fault - Active Power at the Rectifier (MW)

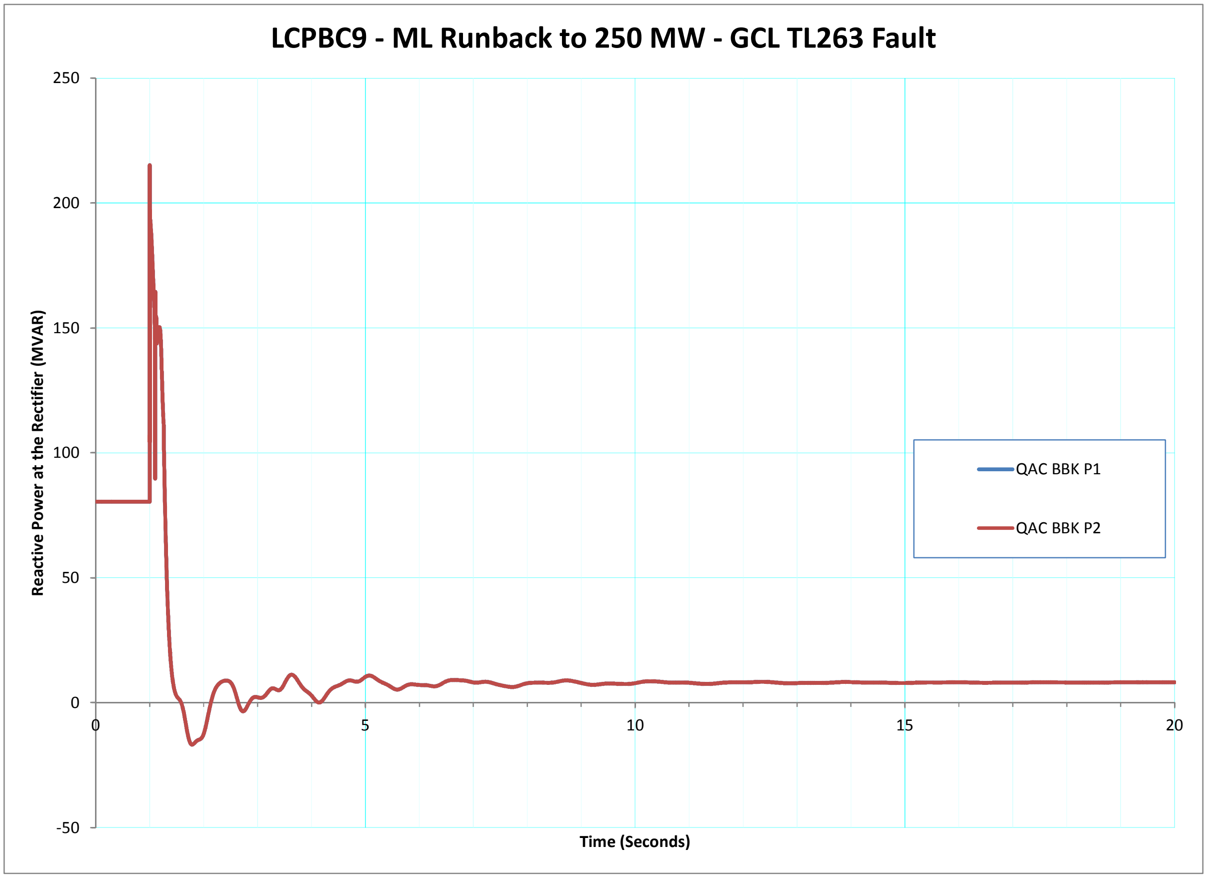


Figure 201 - LCPBC9 - ML Runback to 250 MW - GCL TL263 Fault - Reactive Power at the Rectifier (MVAR)

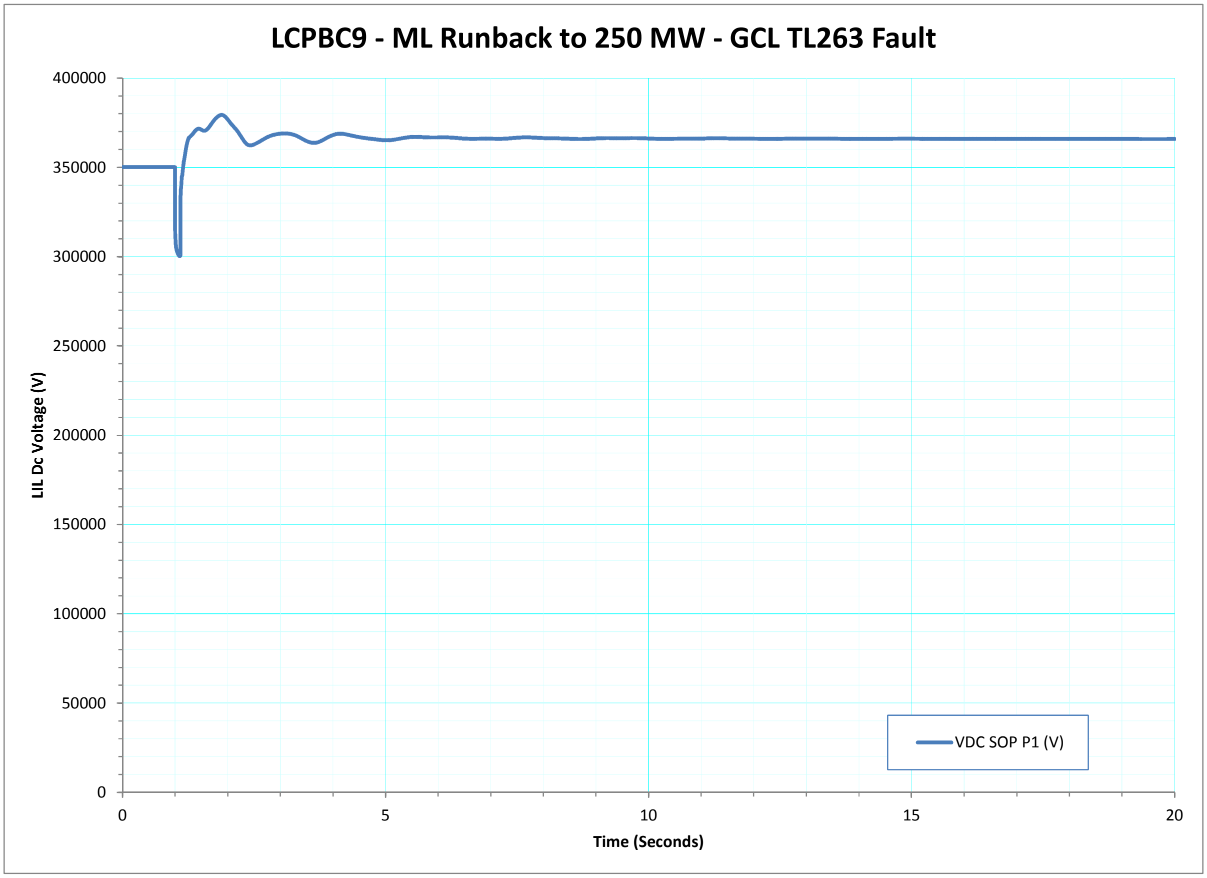


Figure 202 - LCPBC9 - ML Runback to 250 MW - GCL TL263 Fault - LIL Dc Voltage (V)

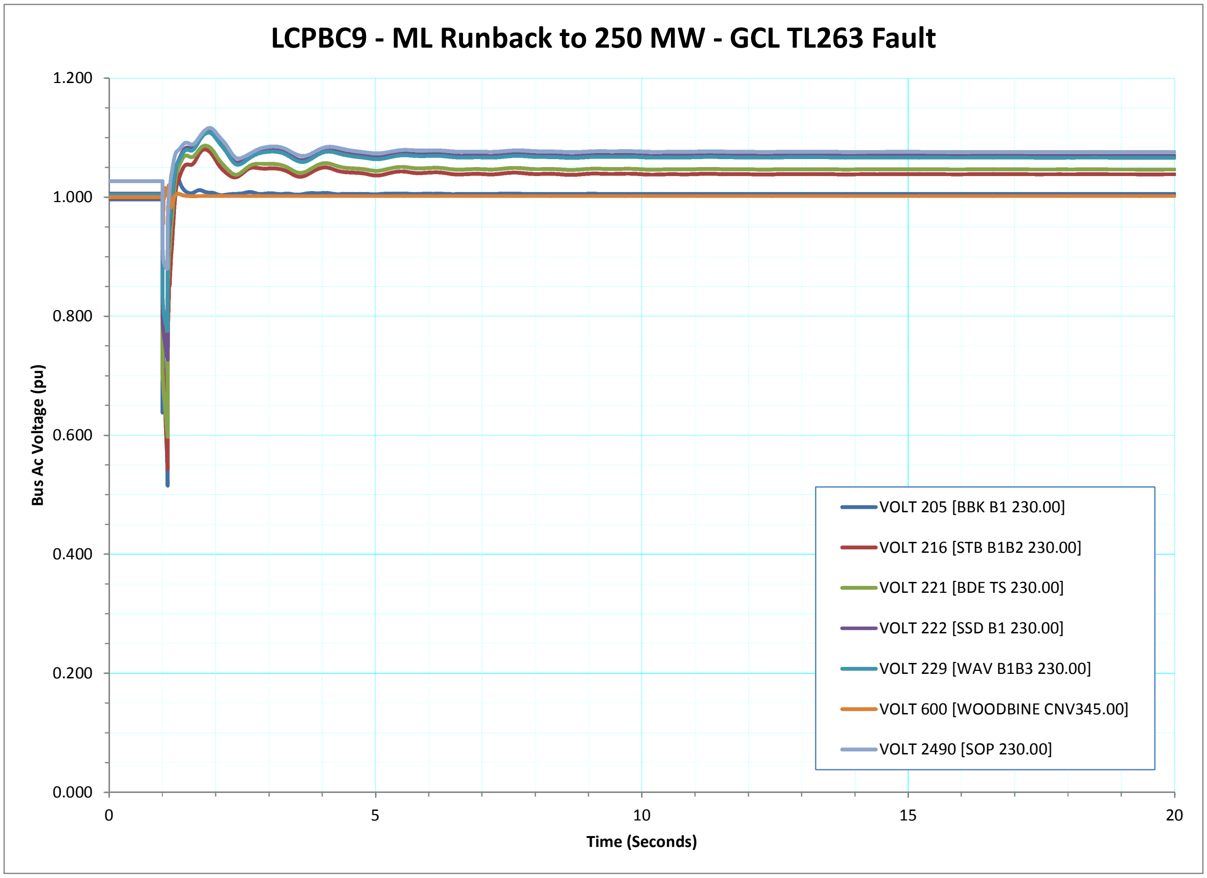


Figure 203 - LCPBC9 - ML Runback to 250 MW - GCL TL263 Fault - Bus Ac Voltage (pu)

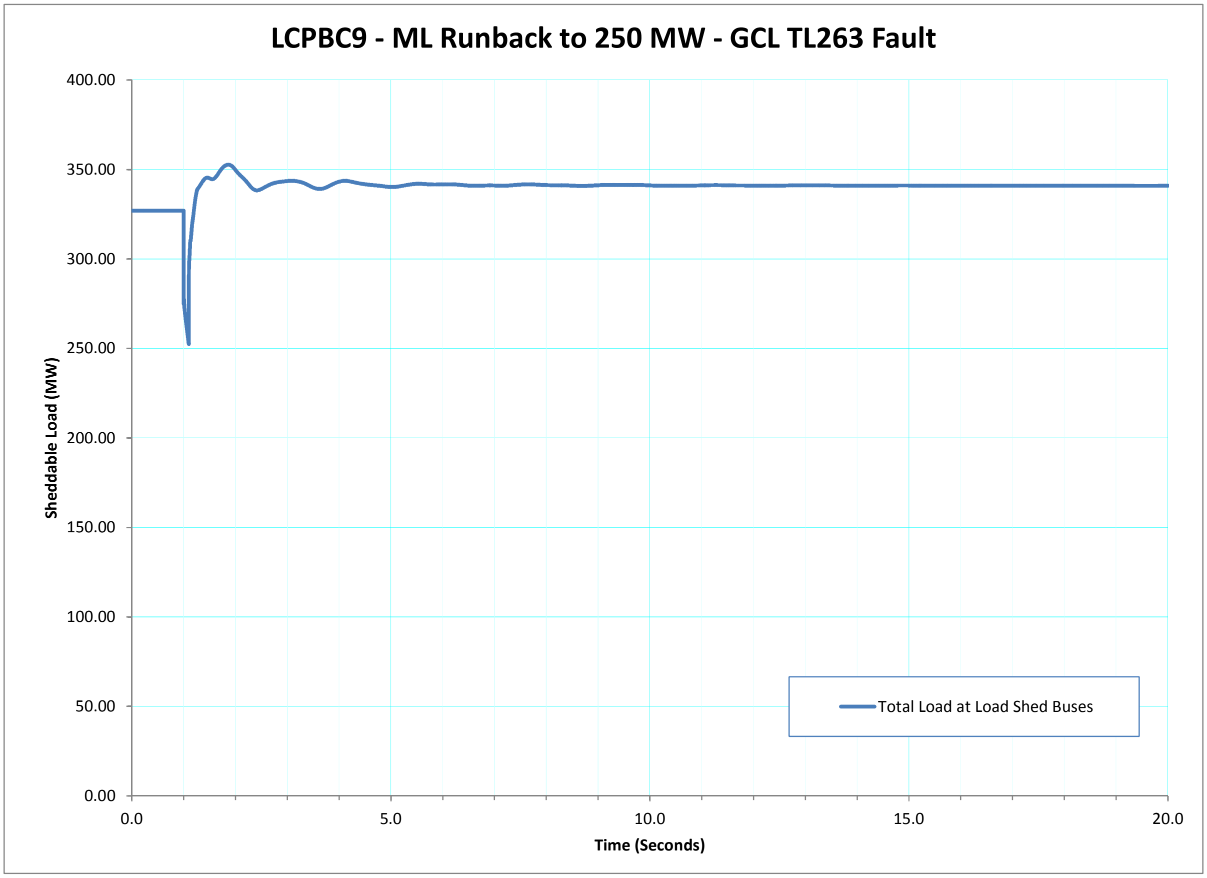


Figure 204 - LCPBC9 - ML Runback to 250 MW - GCL TL263 Fault - Sheddable Load (MW)

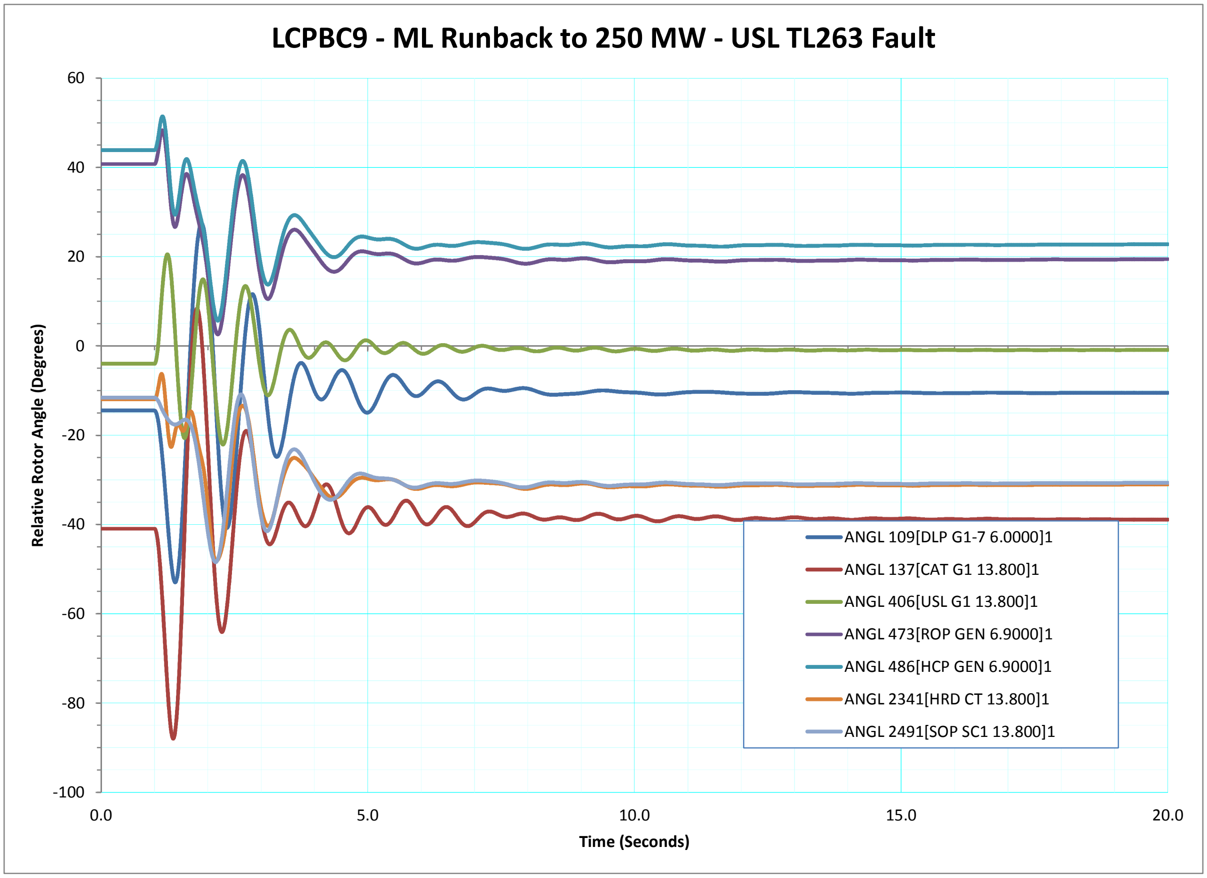


Figure 205 - LCPBC9 - ML Runback to 250 MW - USL TL263 Fault - Relative Rotor Angle (Degrees)

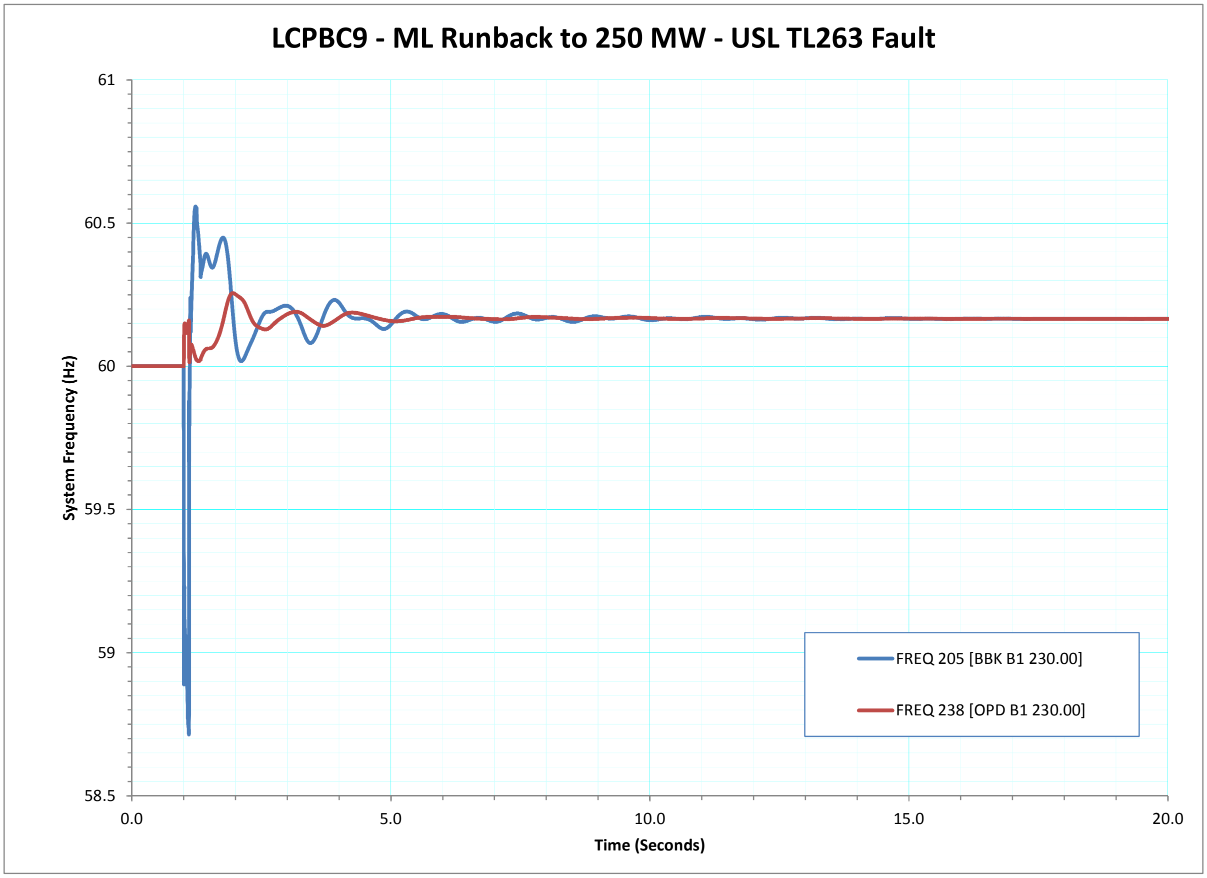


Figure 206 - LCPBC9 - ML Runback to 250 MW - USL TL263 Fault - System Frequency (Hz)

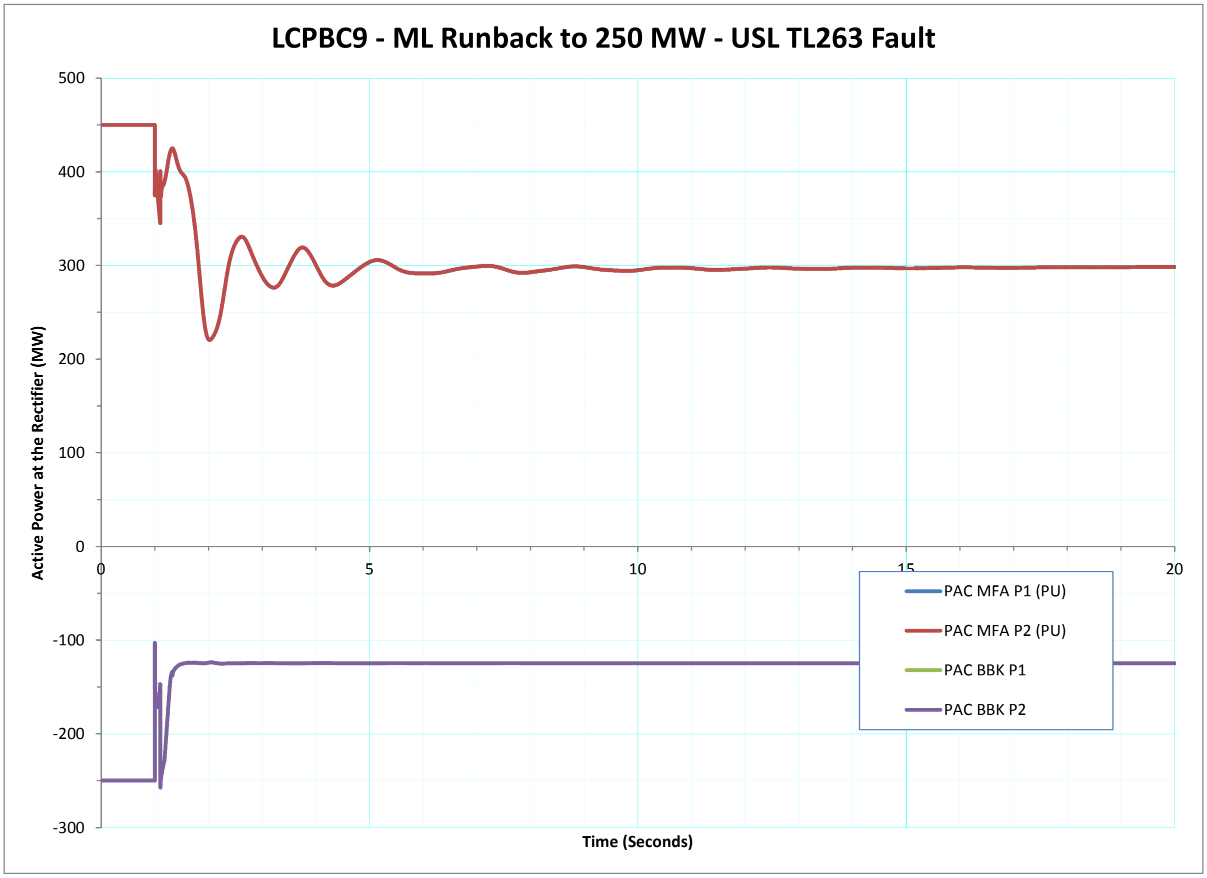


Figure 207 - LCPBC9 - ML Runback to 250 MW - USL TL263 Fault - Active Power at the Rectifier (MW)

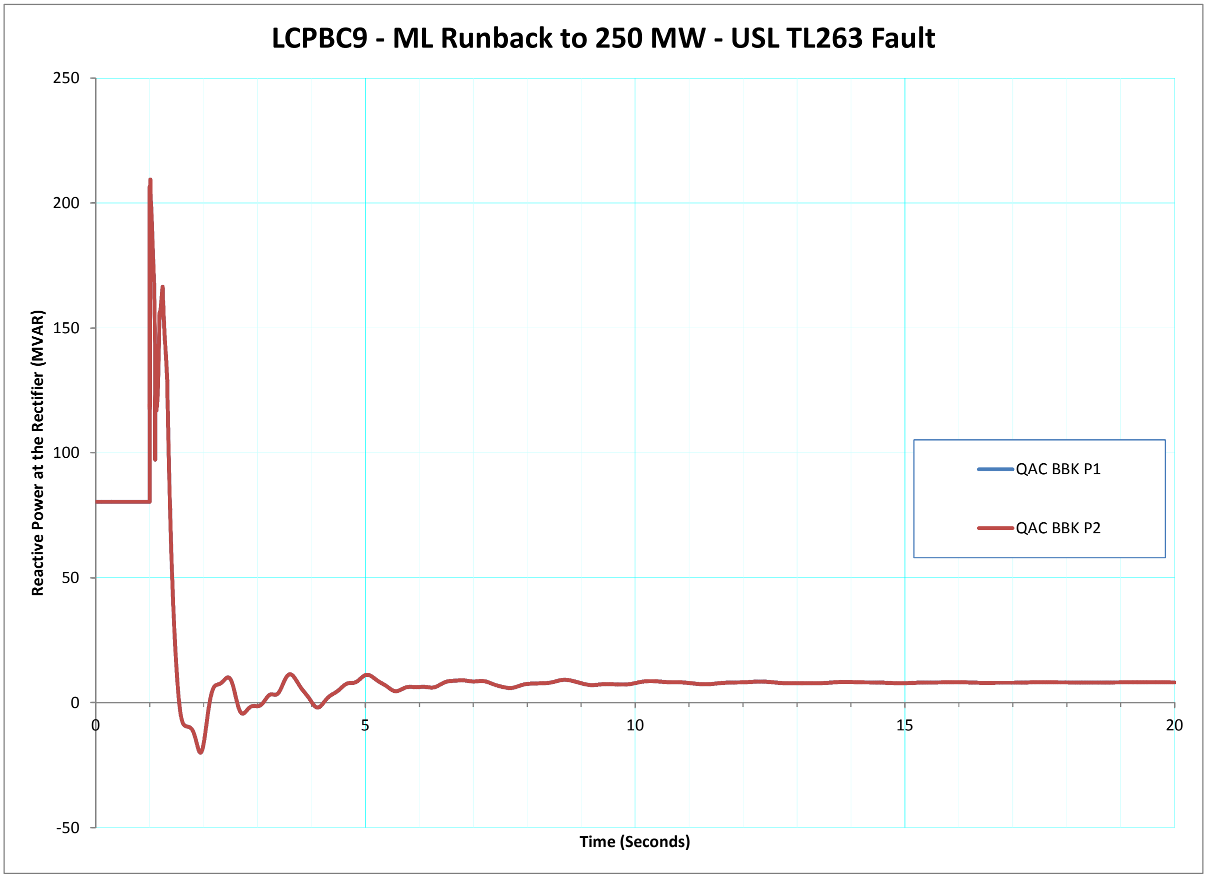


Figure 208 - LCPBC9 - ML Runback to 250 MW - USL TL263 Fault - Reactive Power at the Rectifier (MVAR)

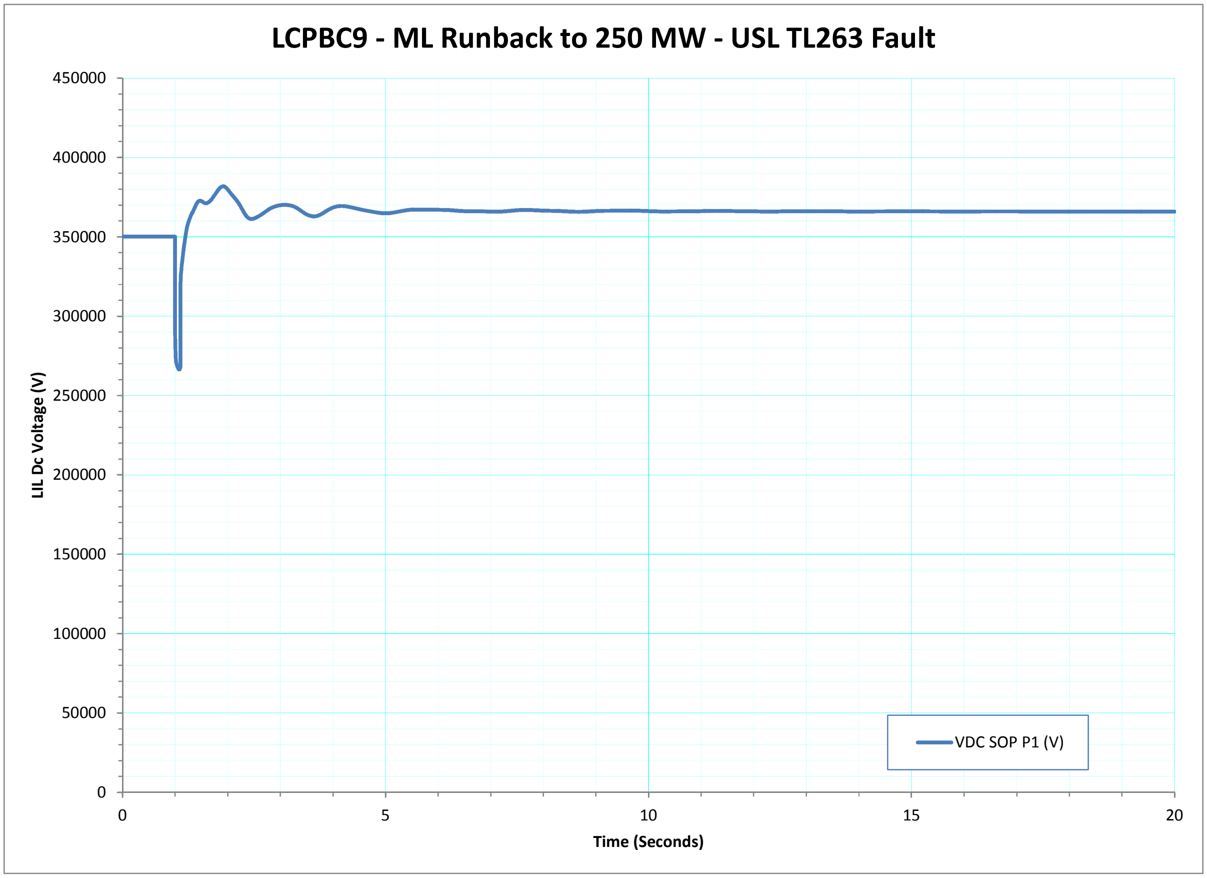


Figure 209 - LCPBC9 - ML Runback to 250 MW - USL TL263 Fault - LIL Dc Voltage (V)

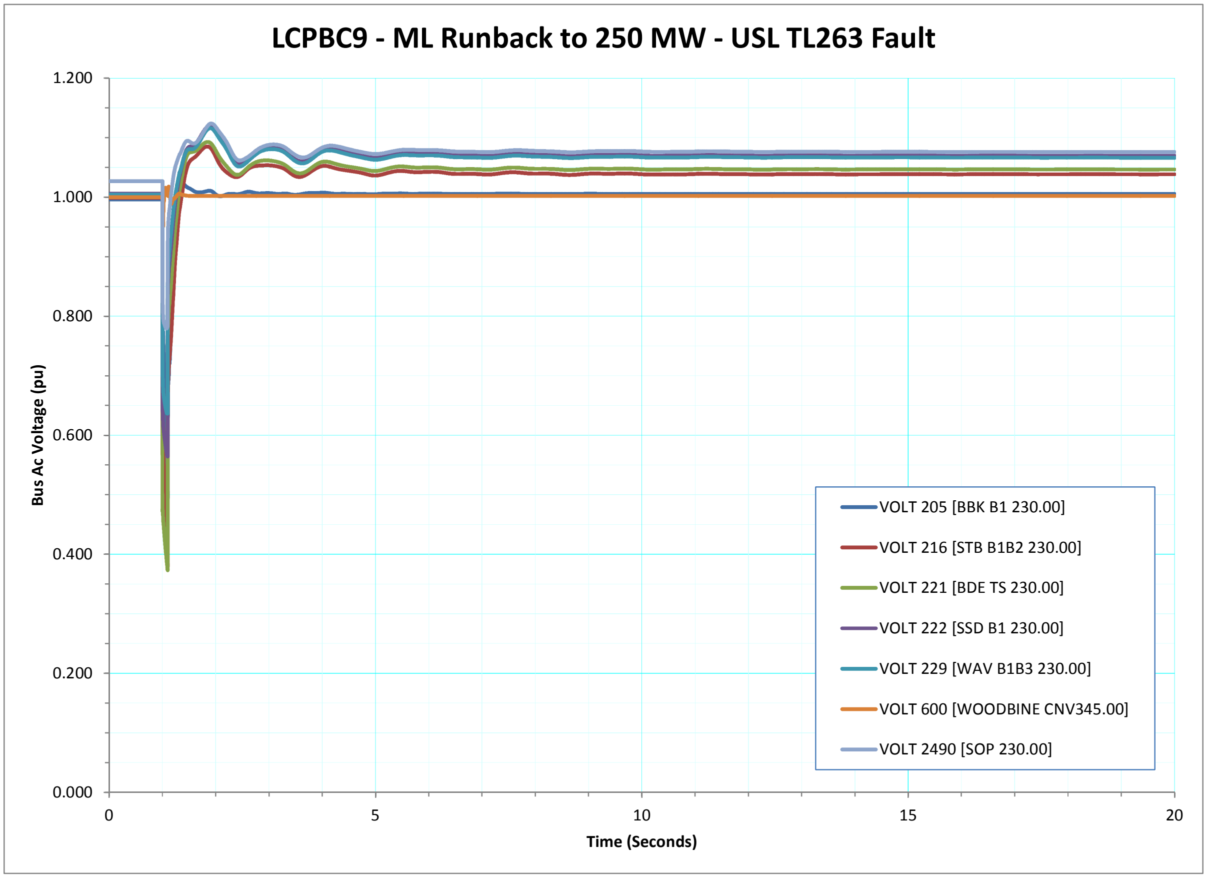


Figure 210 - LCPBC9 - ML Runback to 250 MW - USL TL263 Fault - Bus Ac Voltage (pu)

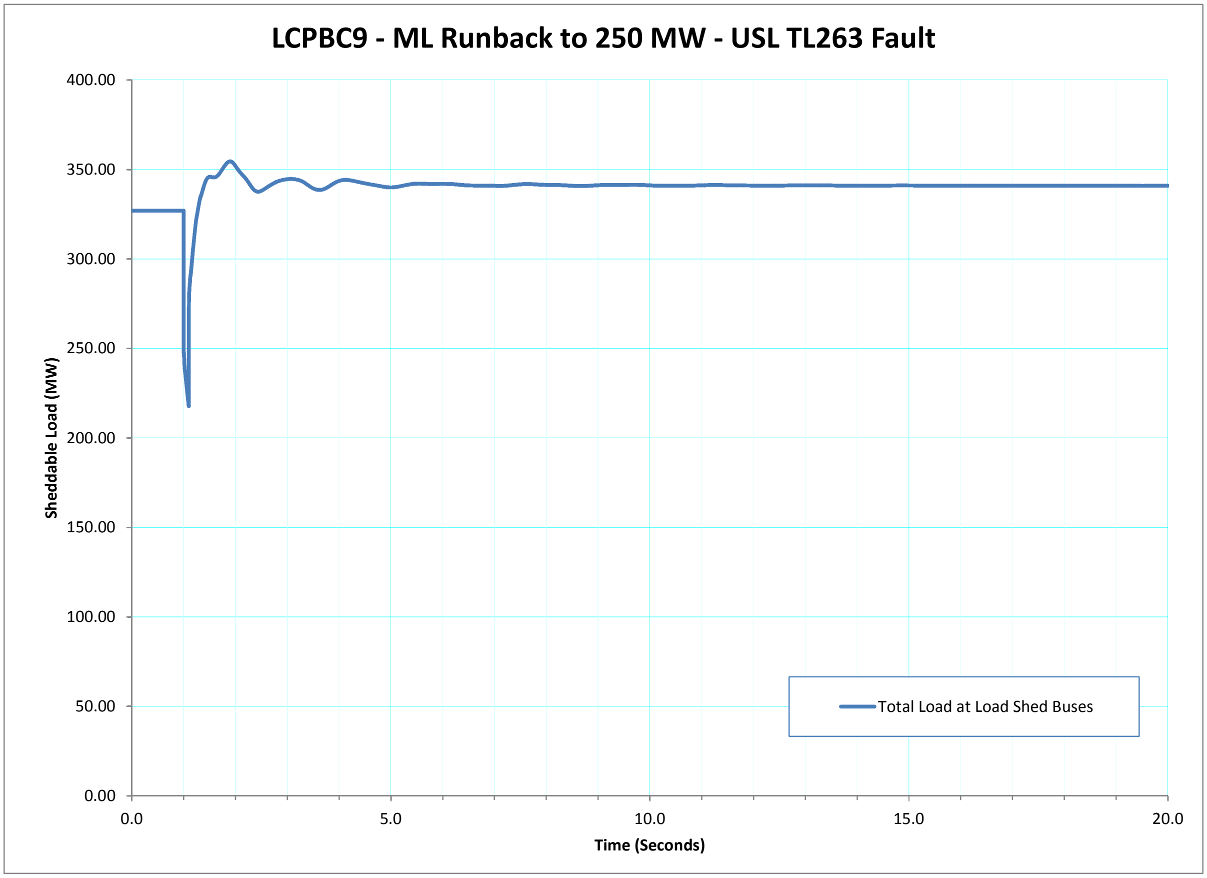


Figure 211 - LCPBC9 - ML Runback to 250 MW - USL TL263 Fault - Sheddable Load (MW)

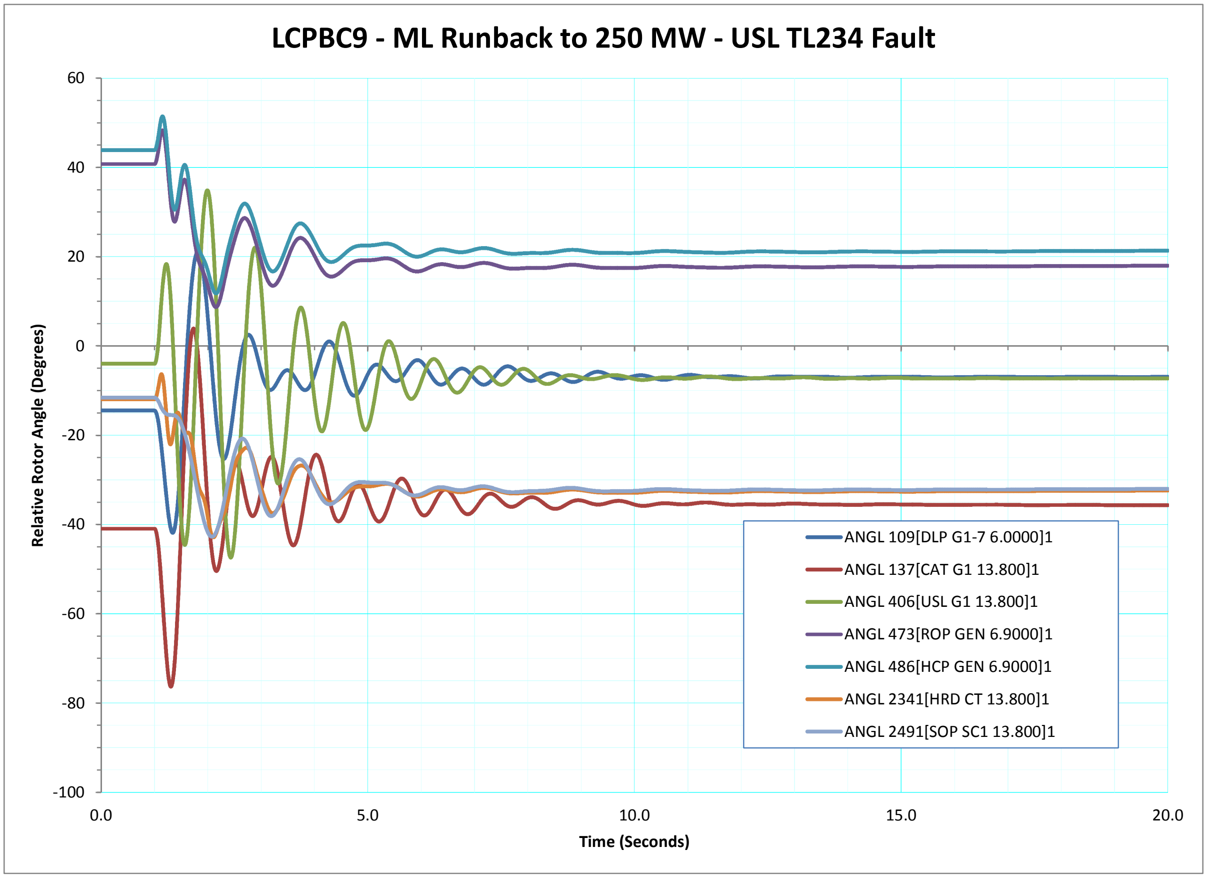


Figure 212 - LCPBC9 - ML Runback to 250 MW - USL TL234 Fault - Relative Rotor Angle (Degrees)

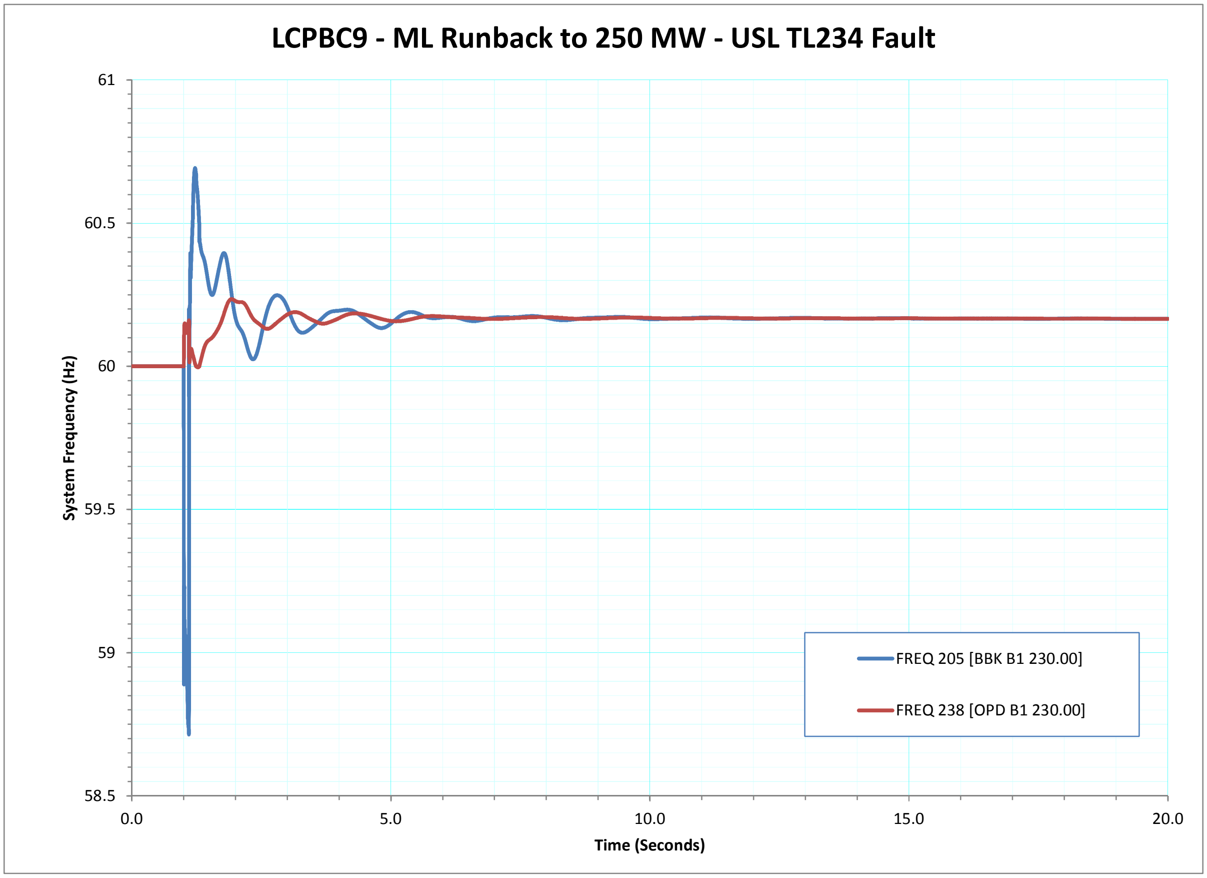


Figure 213 - LCPBC9 - ML Runback to 250 MW - USL TL234 Fault - System Frequency (Hz)

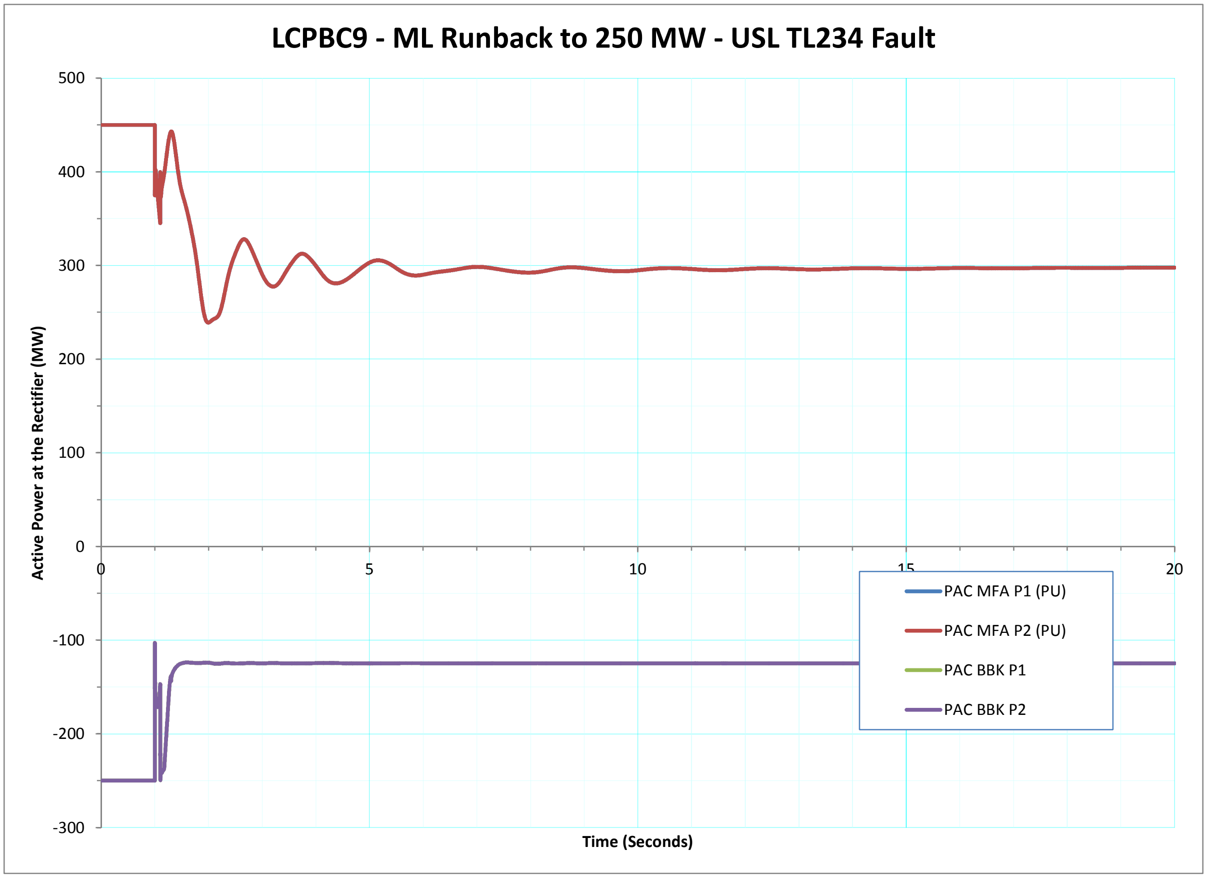


Figure 214 - LCPBC9 - ML Runback to 250 MW - USL TL234 Fault - Active Power at the Rectifier (MW)

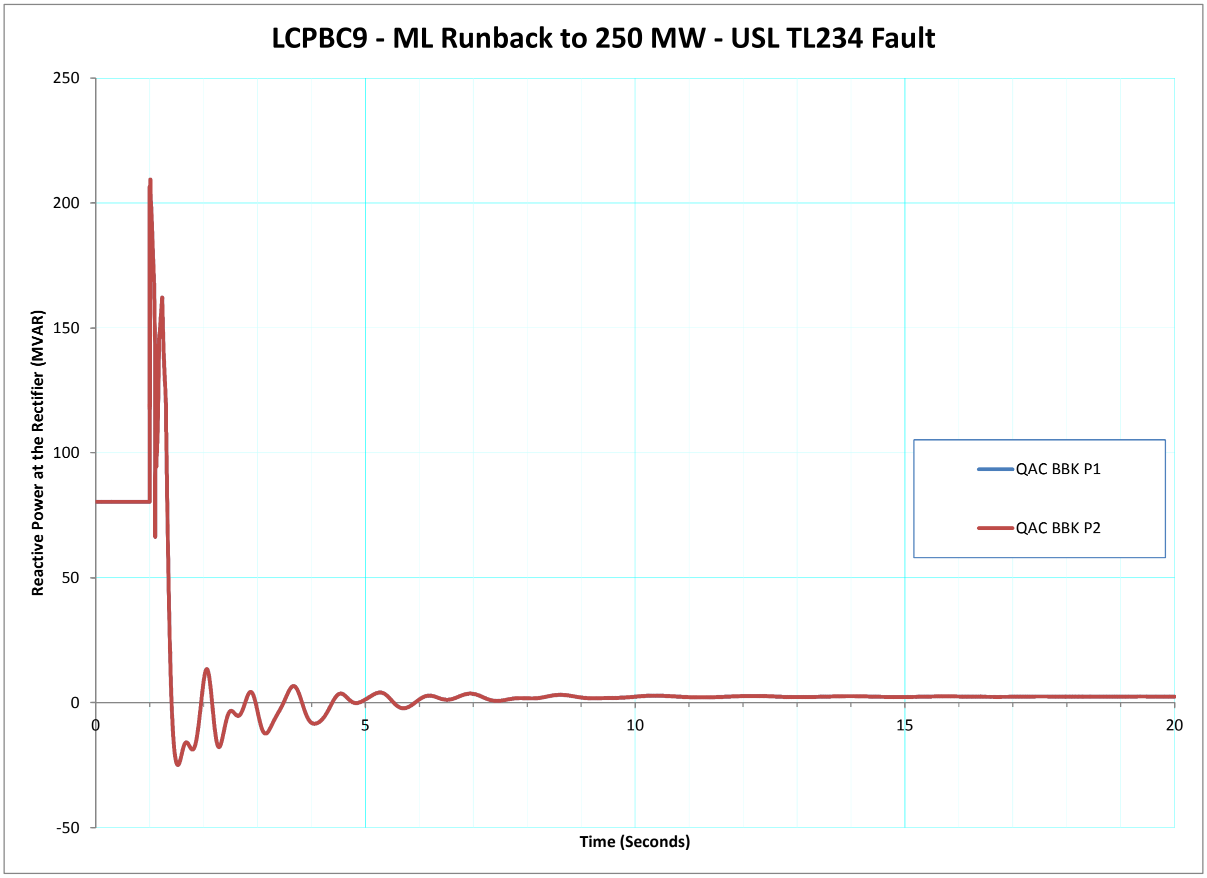


Figure 215 - LCPBC9 - ML Runback to 250 MW - USL TL234 Fault - Reactive Power at the Rectifier (MVAR)

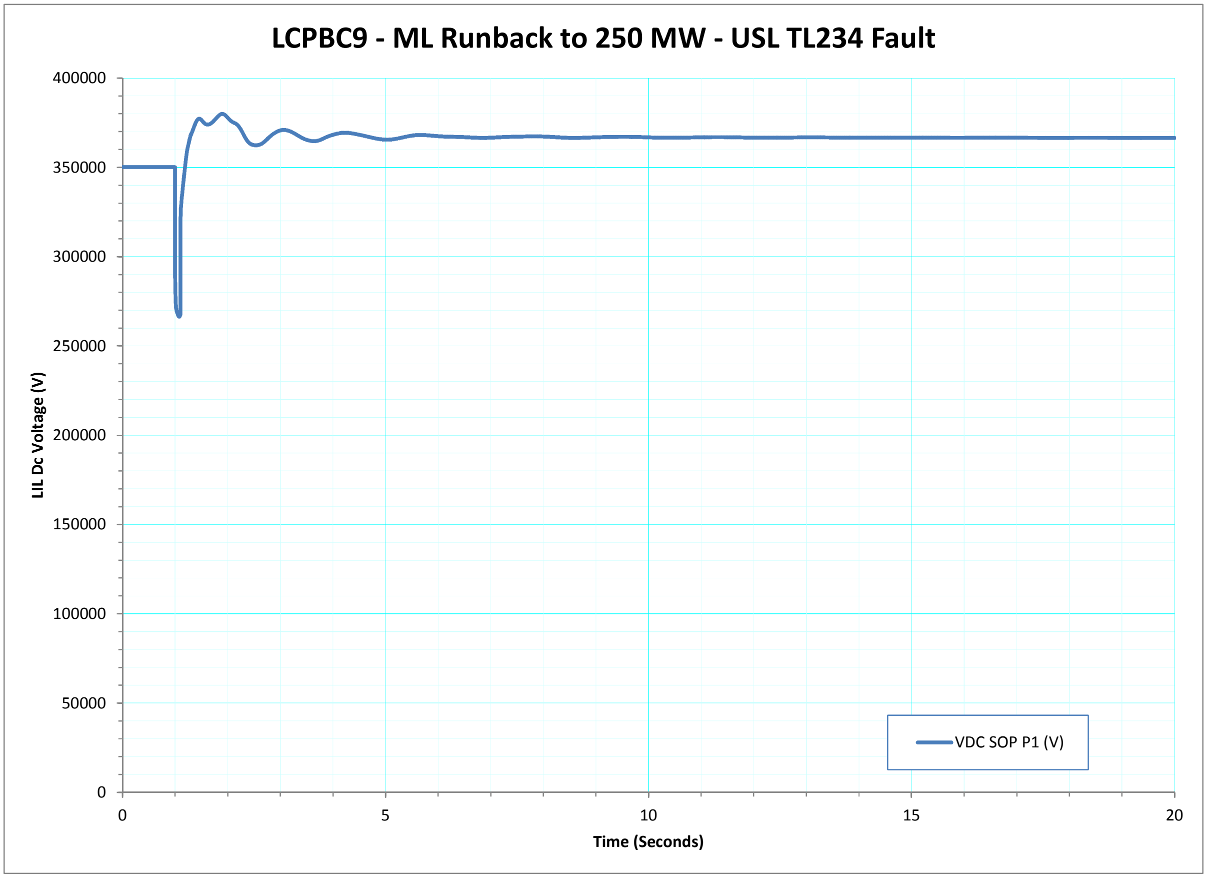


Figure 216 - LCPBC9 - ML Runback to 250 MW - USL TL234 Fault - LIL Dc Voltage (V)

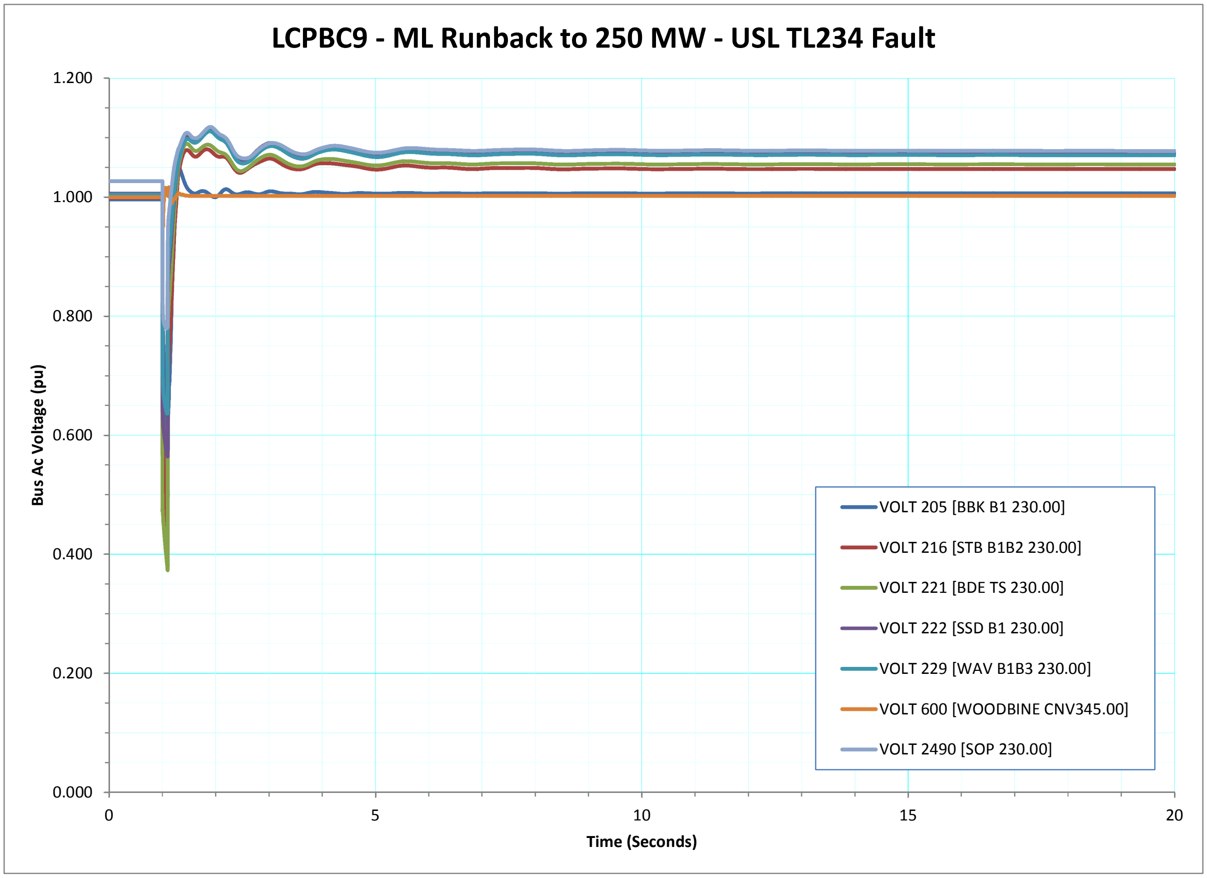


Figure 217 - LCPBC9 - ML Runback to 250 MW - USL TL234 Fault - Bus Ac Voltage (pu)

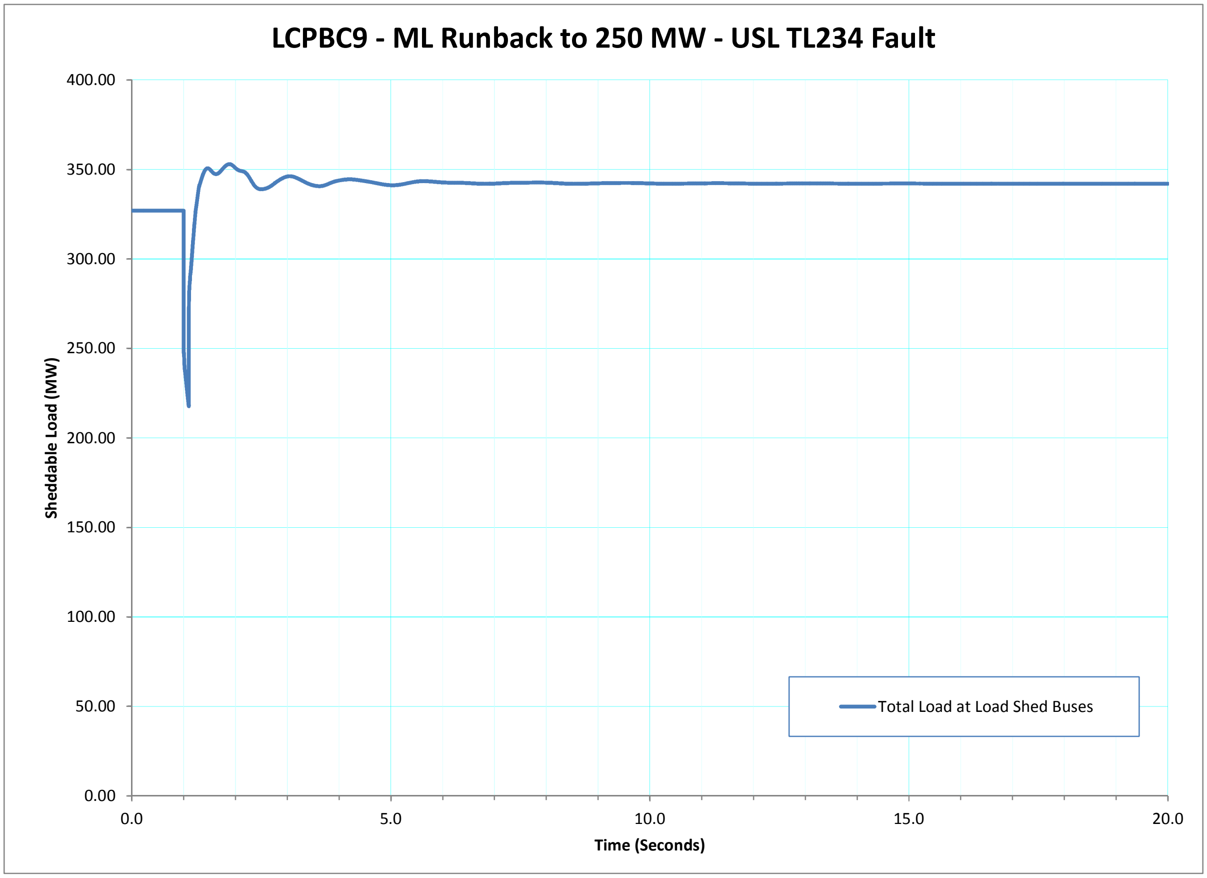


Figure 218 - LCPBC9 - ML Runback to 250 MW - USL TL234 Fault - Sheddable Load (MW)

APPENDIX D Remedial ML Curtailment for Temporary Bipole Faults

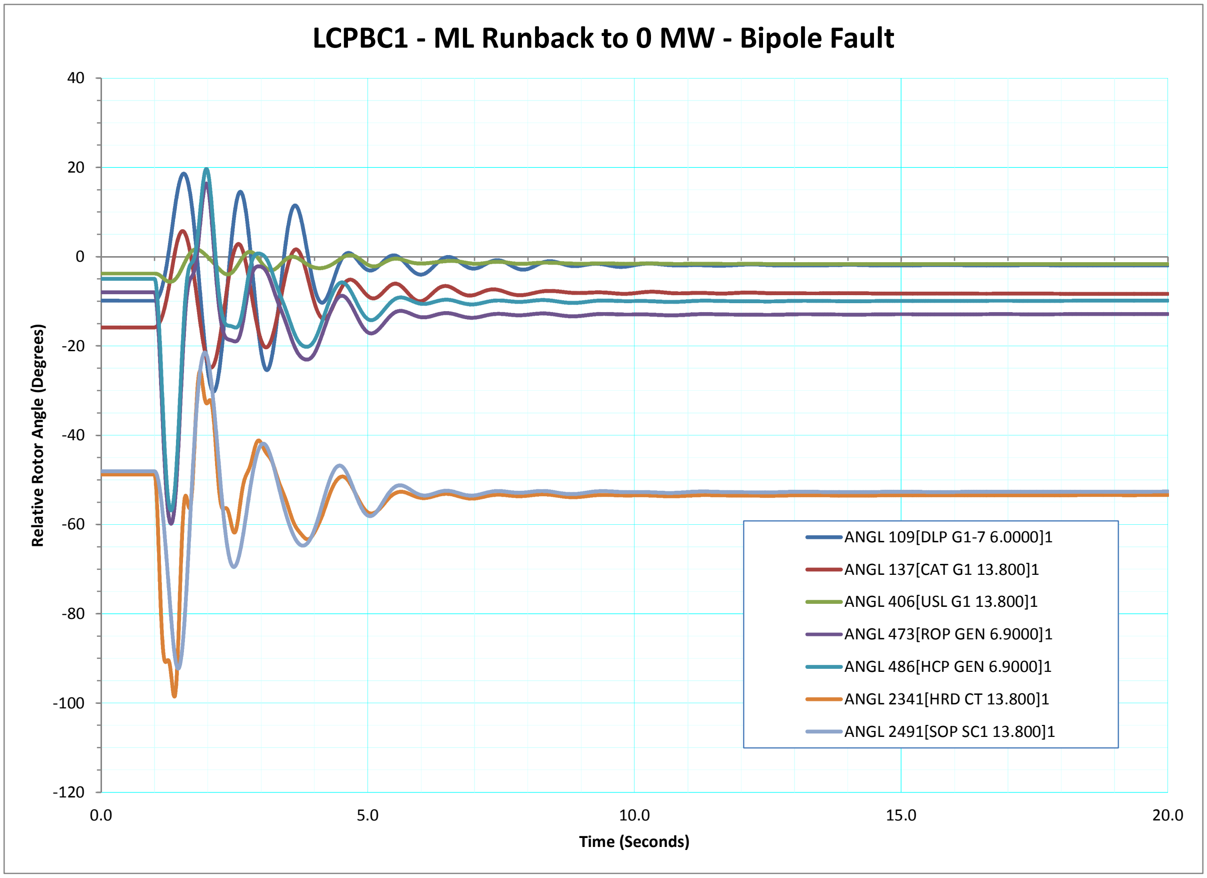


Figure 219 - LCPBC1 - ML Runback to 0 MW - Bipole Fault - Relative Rotor Angle (Degrees)

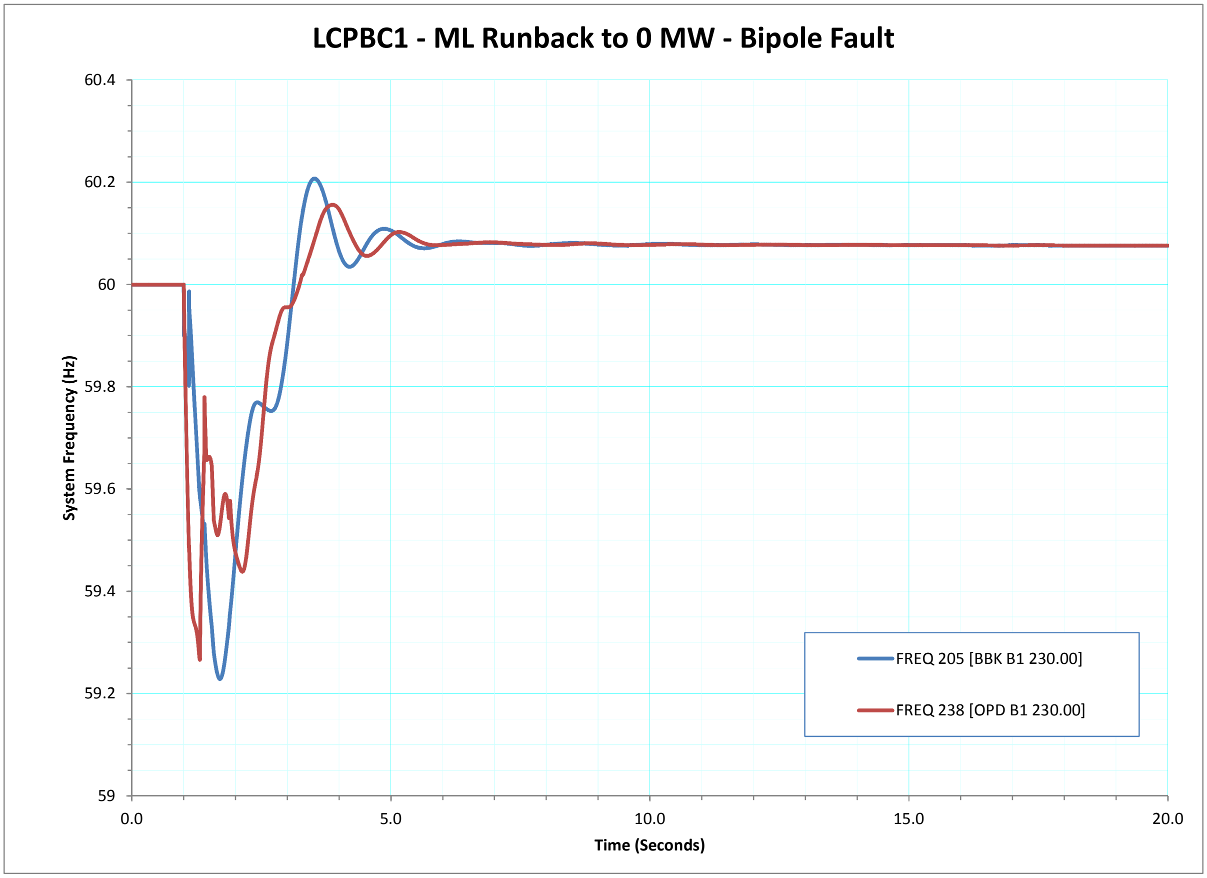


Figure 220 - LCPBC1 - ML Runback to 0 MW - Bipole Fault - System Frequency (Hz)

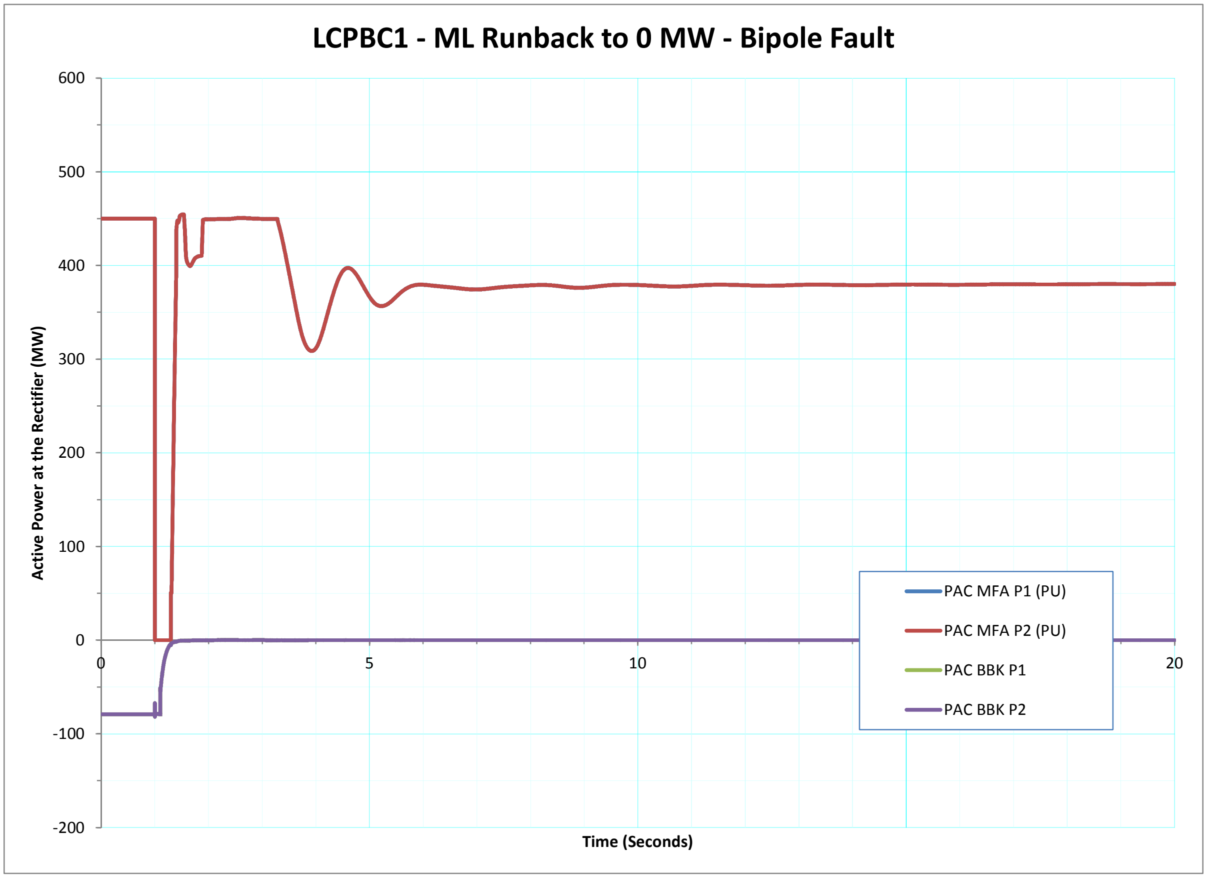


Figure 221 - LCPBC1 - ML Runback to 0 MW - Bipole Fault - Active Power at the Rectifier (MW)

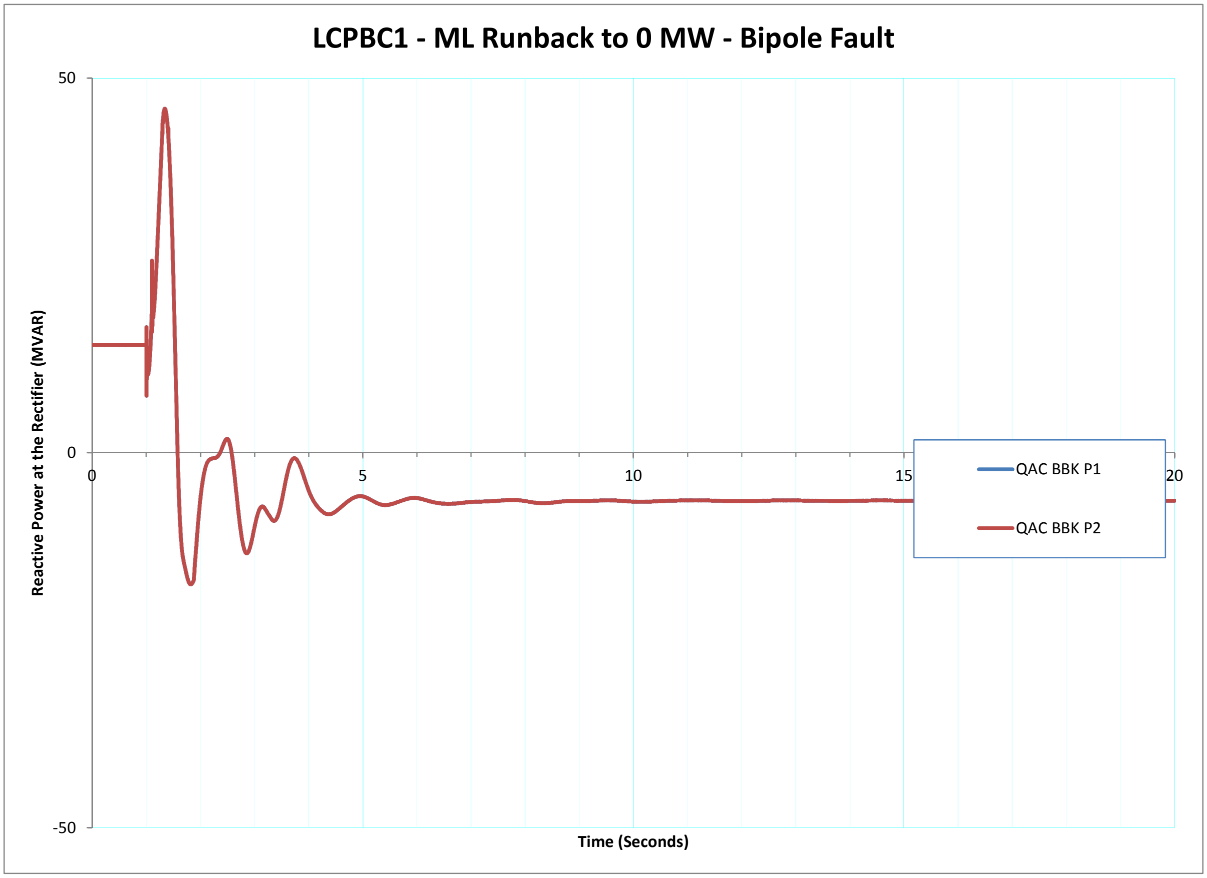


Figure 222 - LCPBC1 - ML Runback to 0 MW - Bipole Fault - Reactive Power at the Rectifier (MVAR)

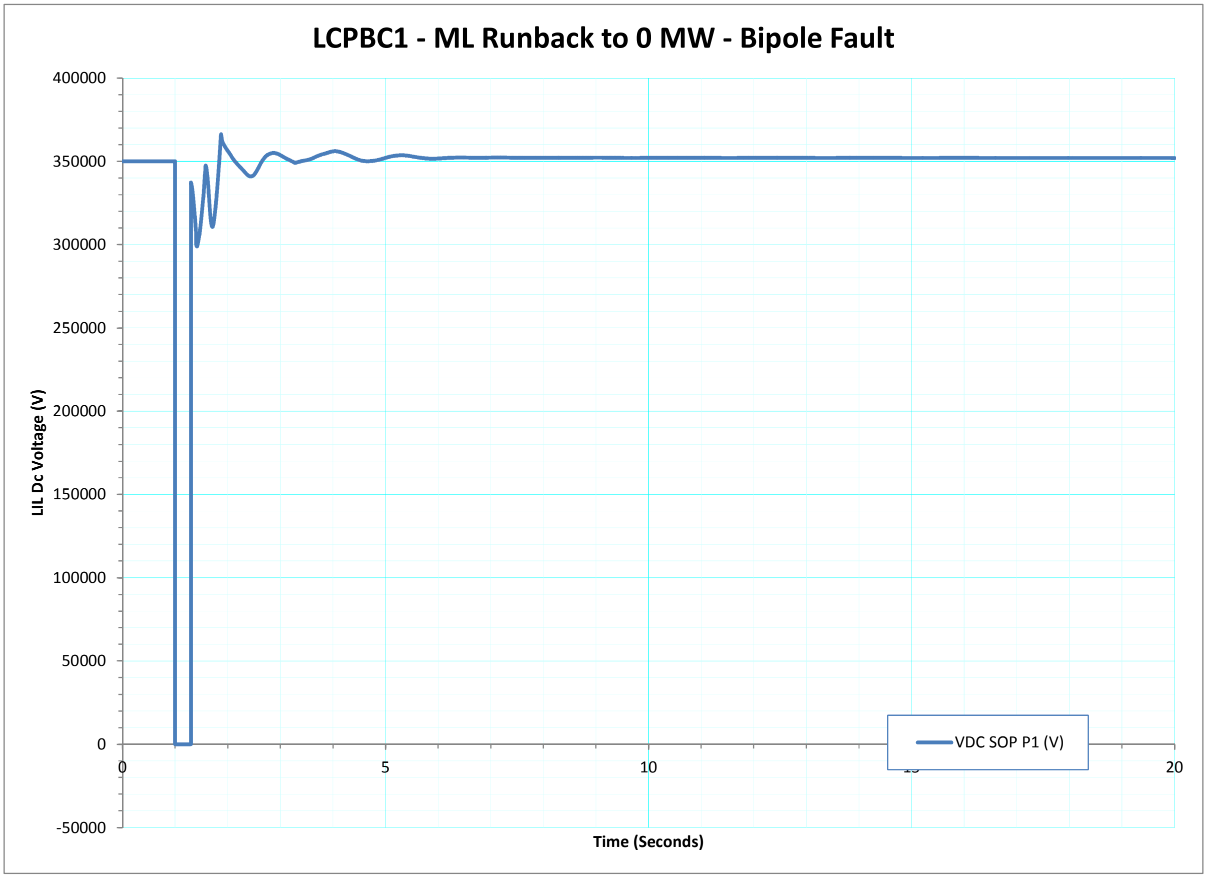


Figure 223 - LCPBC1 - ML Runback to 0 MW - Bipole Fault - LIL Dc Voltage (V)

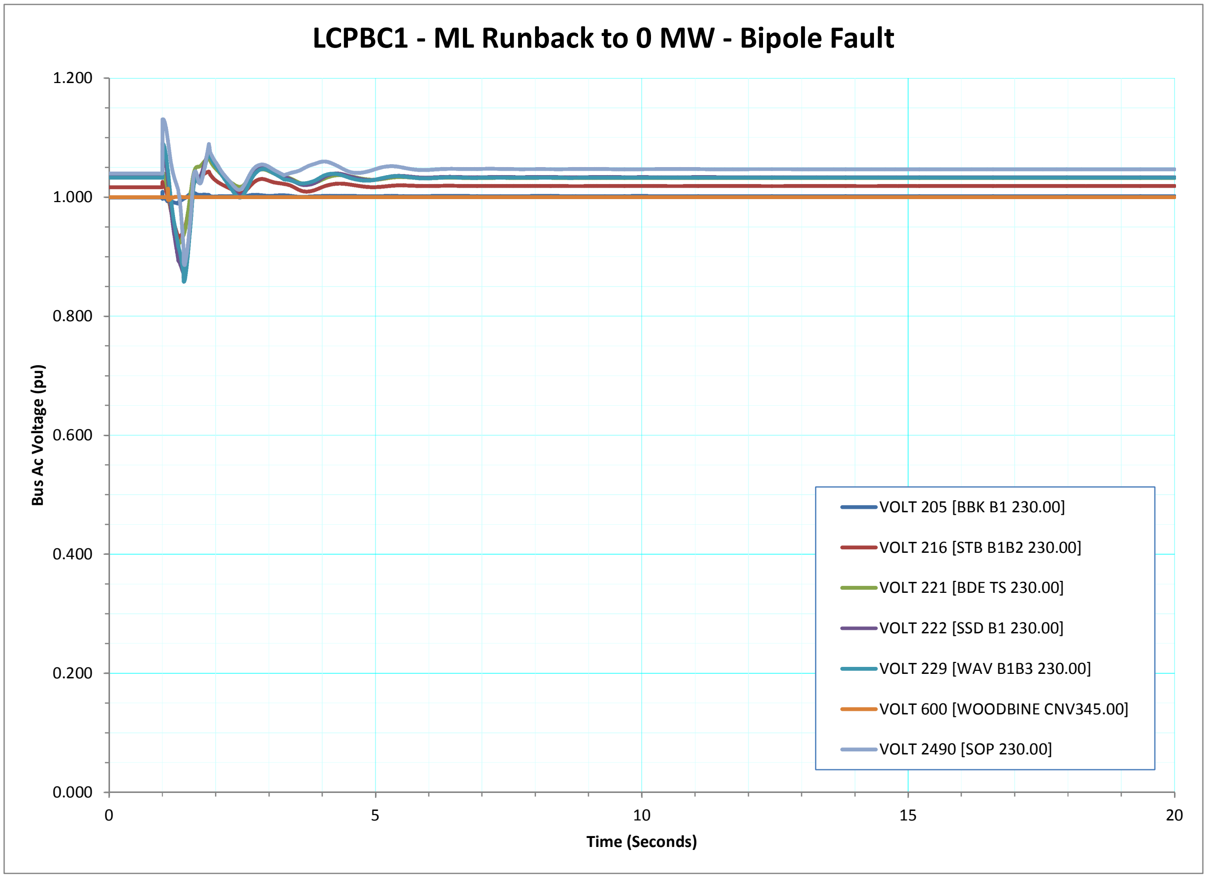


Figure 224 - LCPBC1 - ML Runback to 0 MW - Bipole Fault - Bus Ac Voltage (pu)

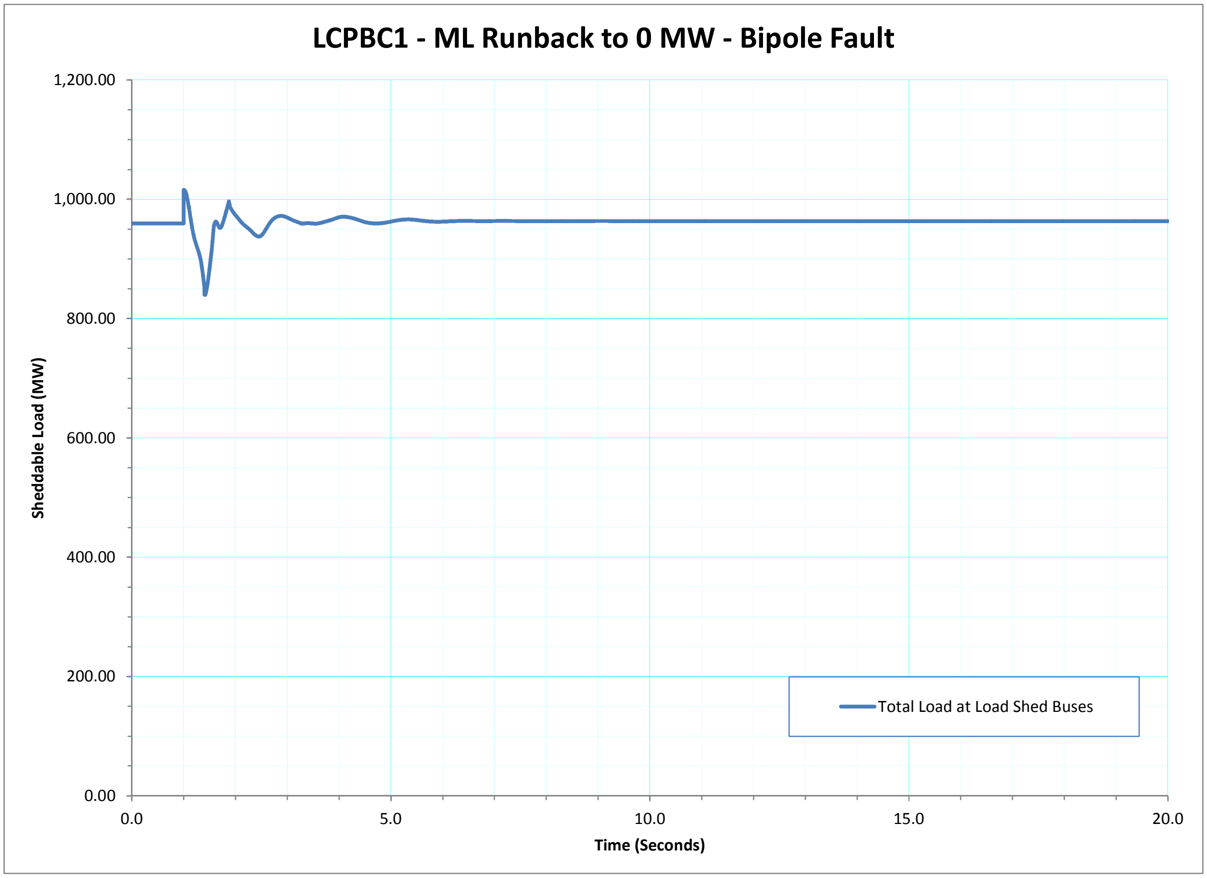


Figure 225 - LCPBC1 - ML Runback to 0 MW - Bipole Fault - Sheddable Load (MW)

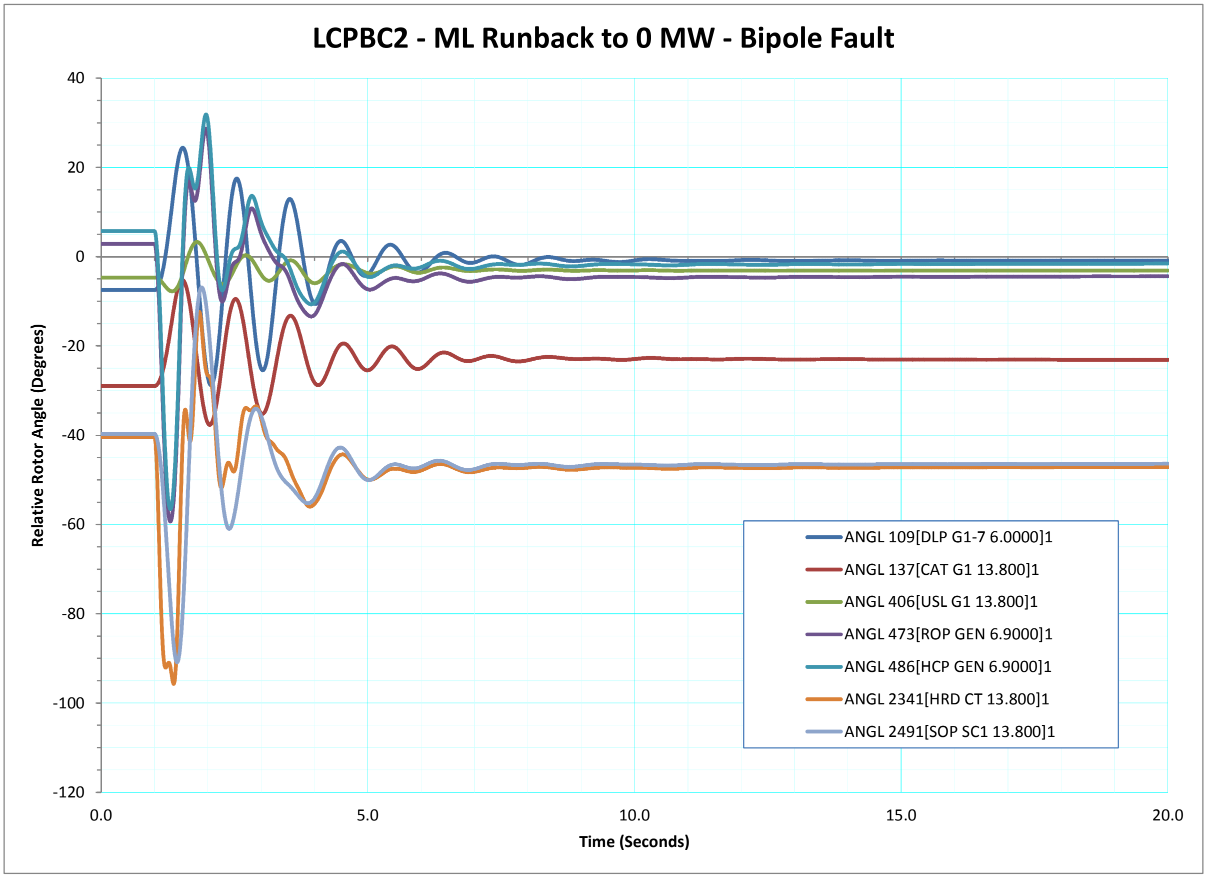


Figure 226 - LCPBC2 - ML Runback to 0 MW - Bipole Fault - Relative Rotor Angle (Degrees)

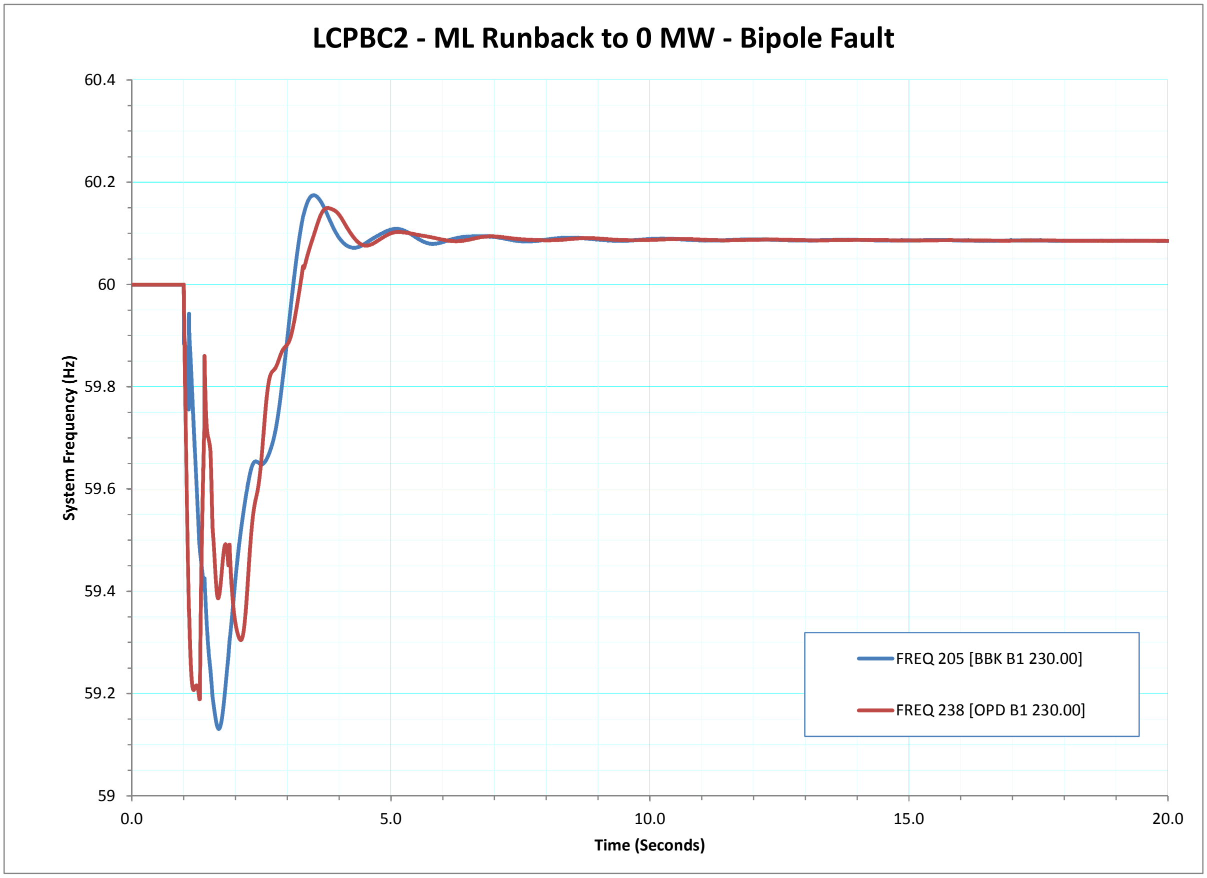


Figure 227 - LCPBC2 - ML Runback to 0 MW - Bipole Fault - System Frequency (Hz)

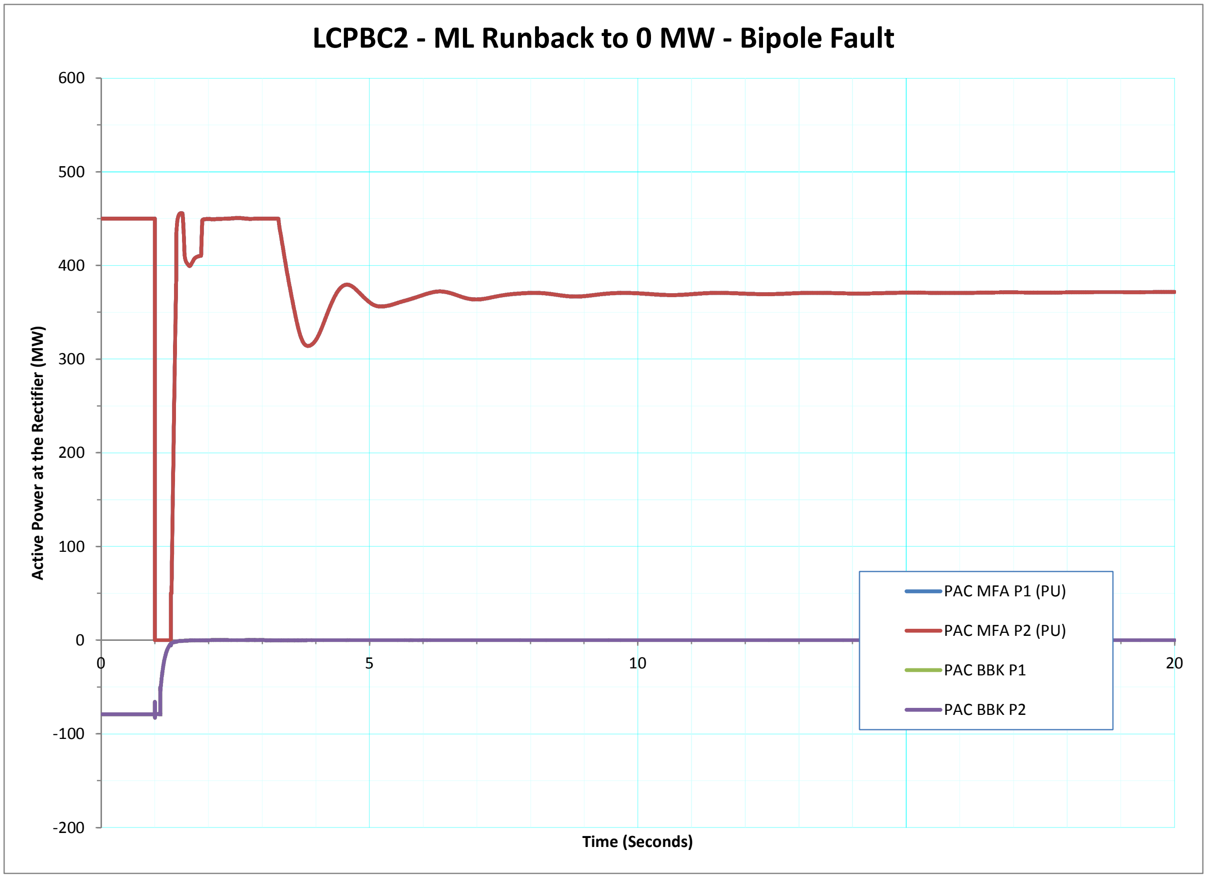


Figure 228 - LCPBC2 - ML Runback to 0 MW - Bipole Fault - Active Power at the Rectifier (MW)

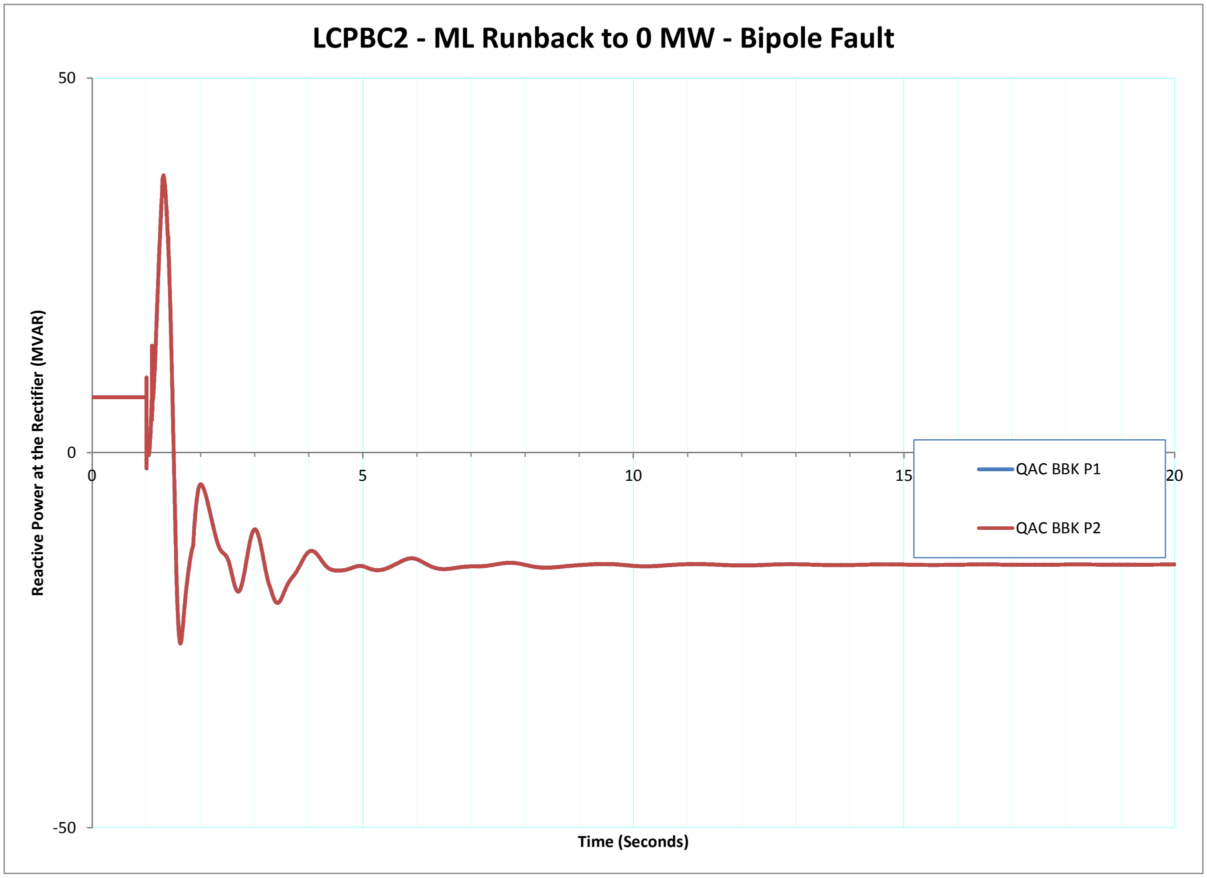


Figure 229 - LCPBC2 - ML Runback to 0 MW - Bipole Fault - Reactive Power at the Rectifier (MVAR)

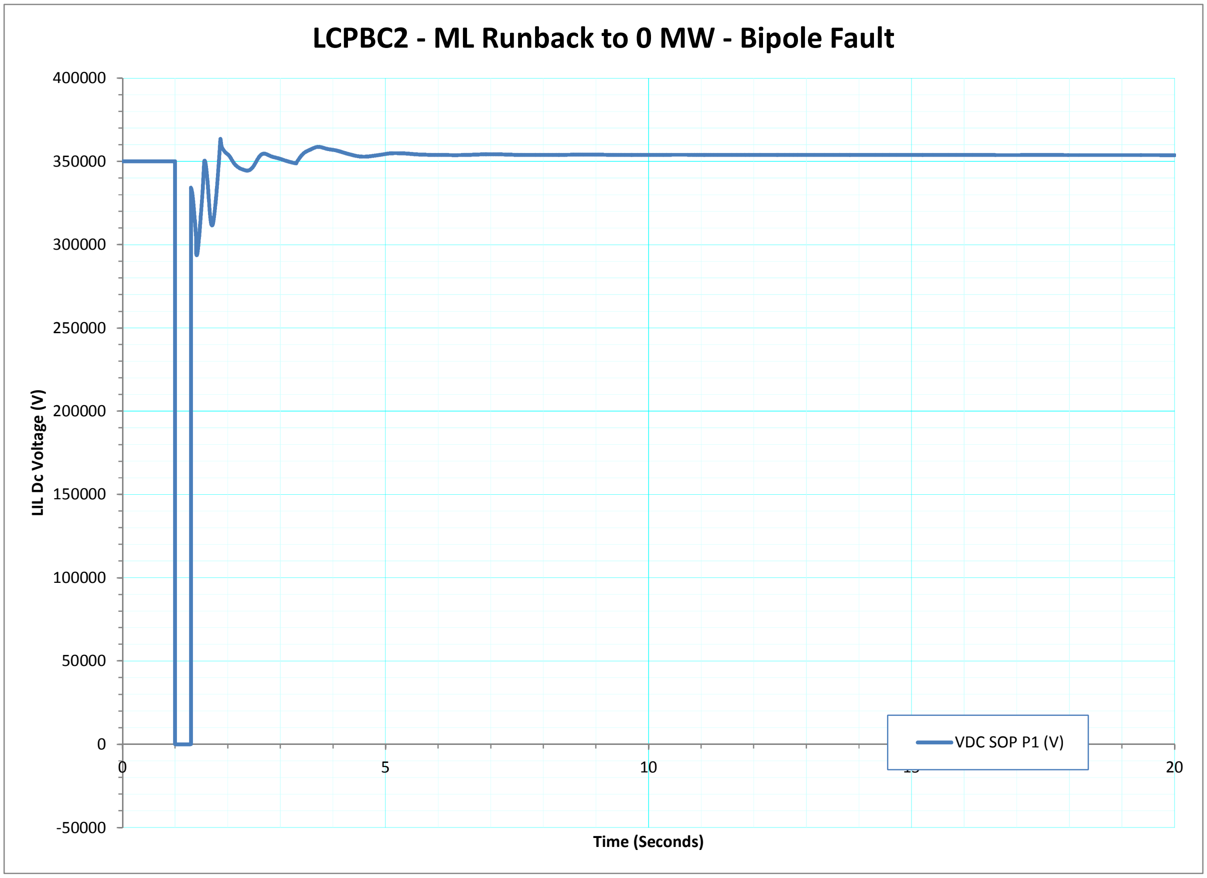


Figure 230 - LCPBC2 - ML Runback to 0 MW - Bipole Fault - LIL Dc Voltage (V)

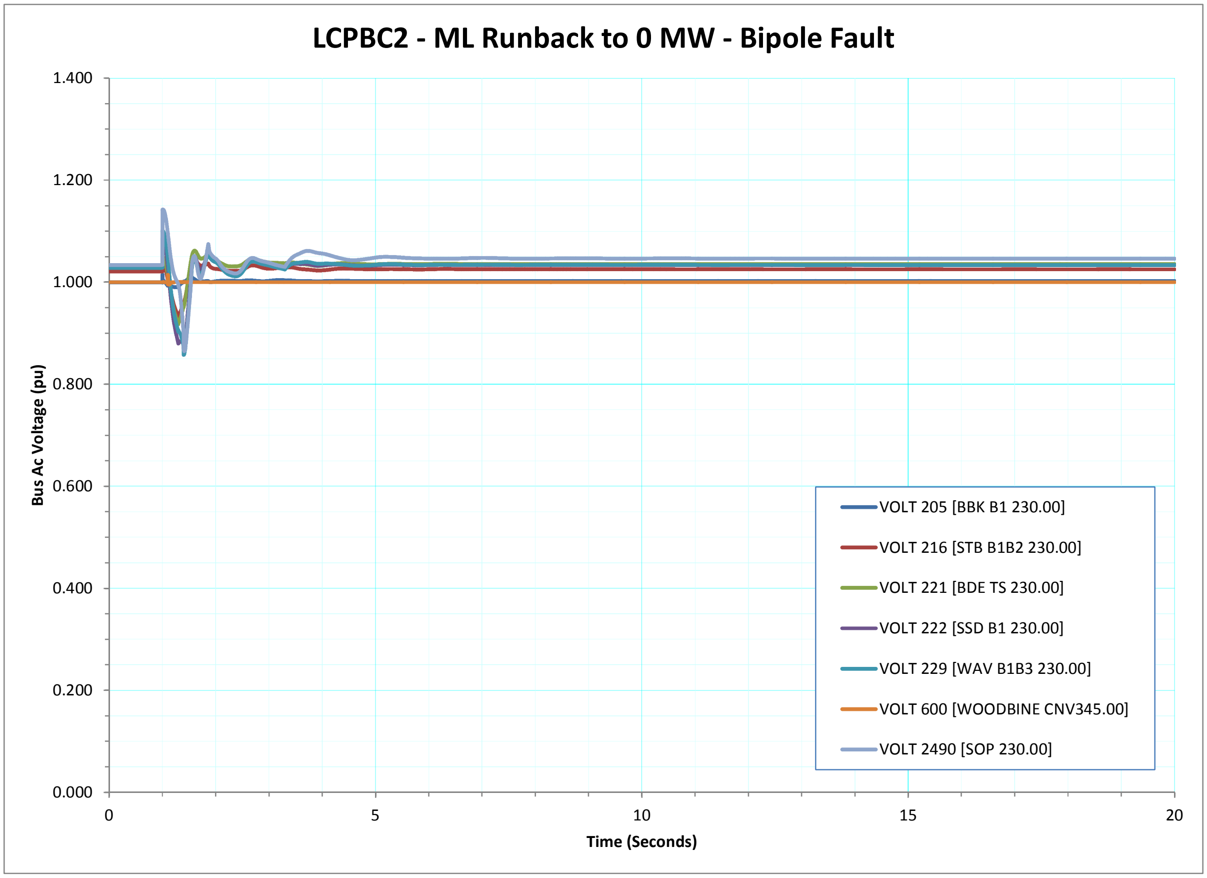


Figure 231 - LCPBC2 - ML Runback to 0 MW - Bipole Fault - Bus Ac Voltage (pu)

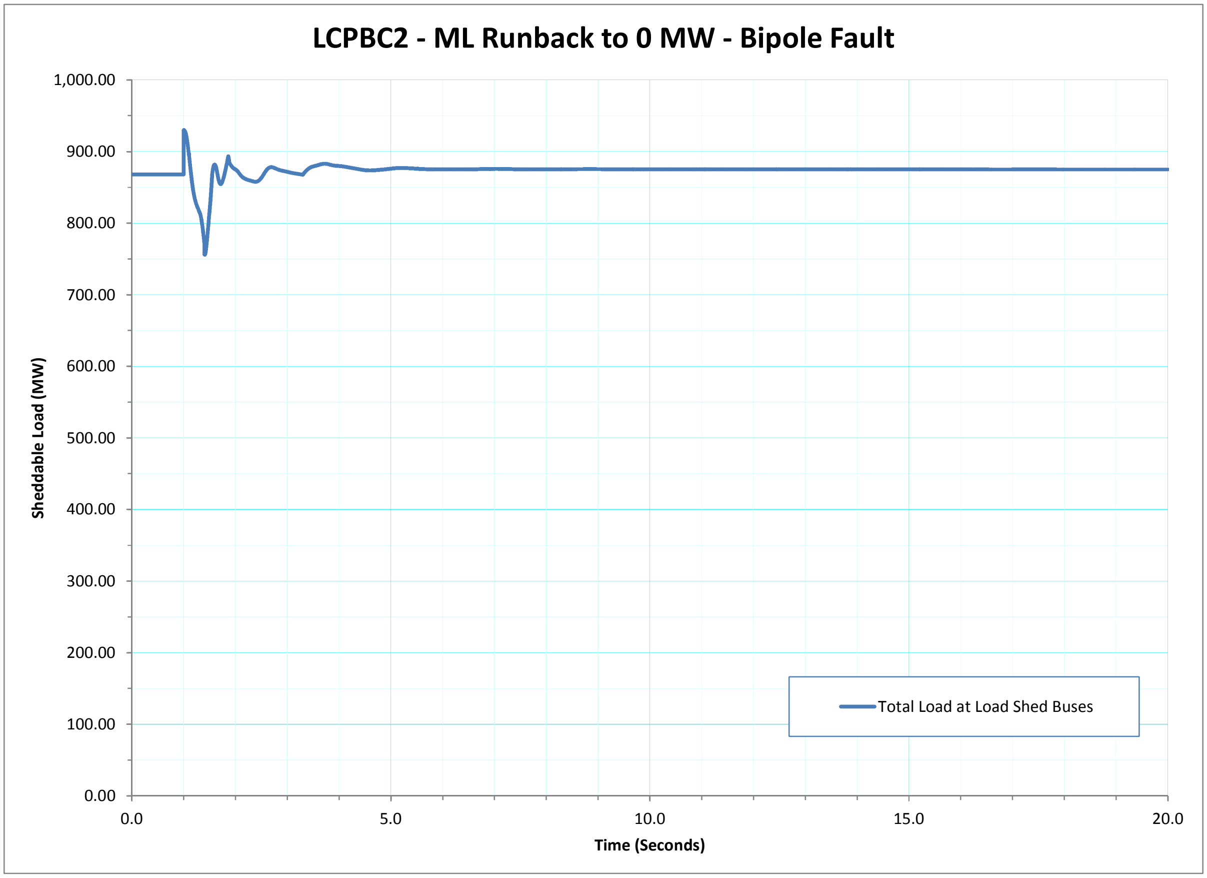


Figure 232 - LCPBC2 - ML Runback to 0 MW - Bipole Fault - Sheddable Load (MW)

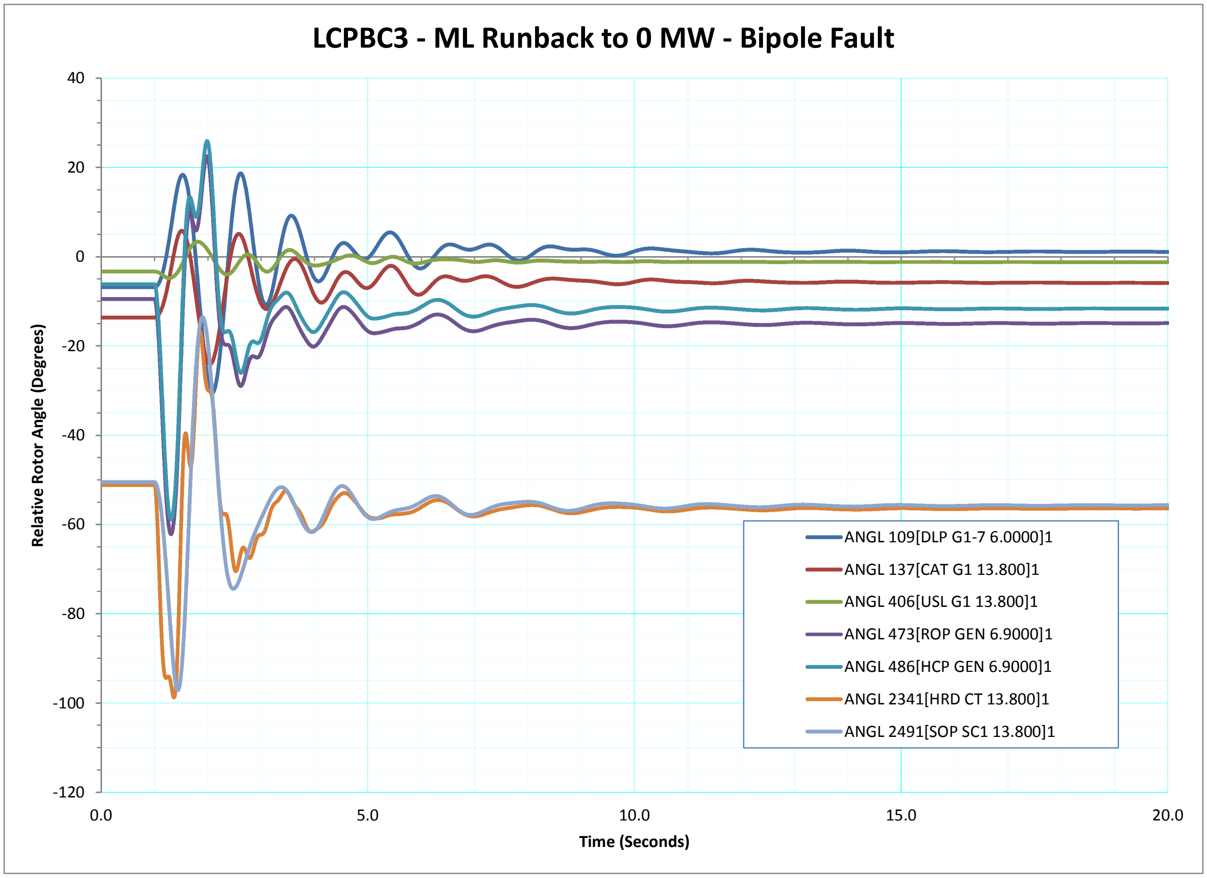


Figure 233 - LCPBC3 - ML Runback to 0 MW - Bipole Fault - Relative Rotor Angle (Degrees)

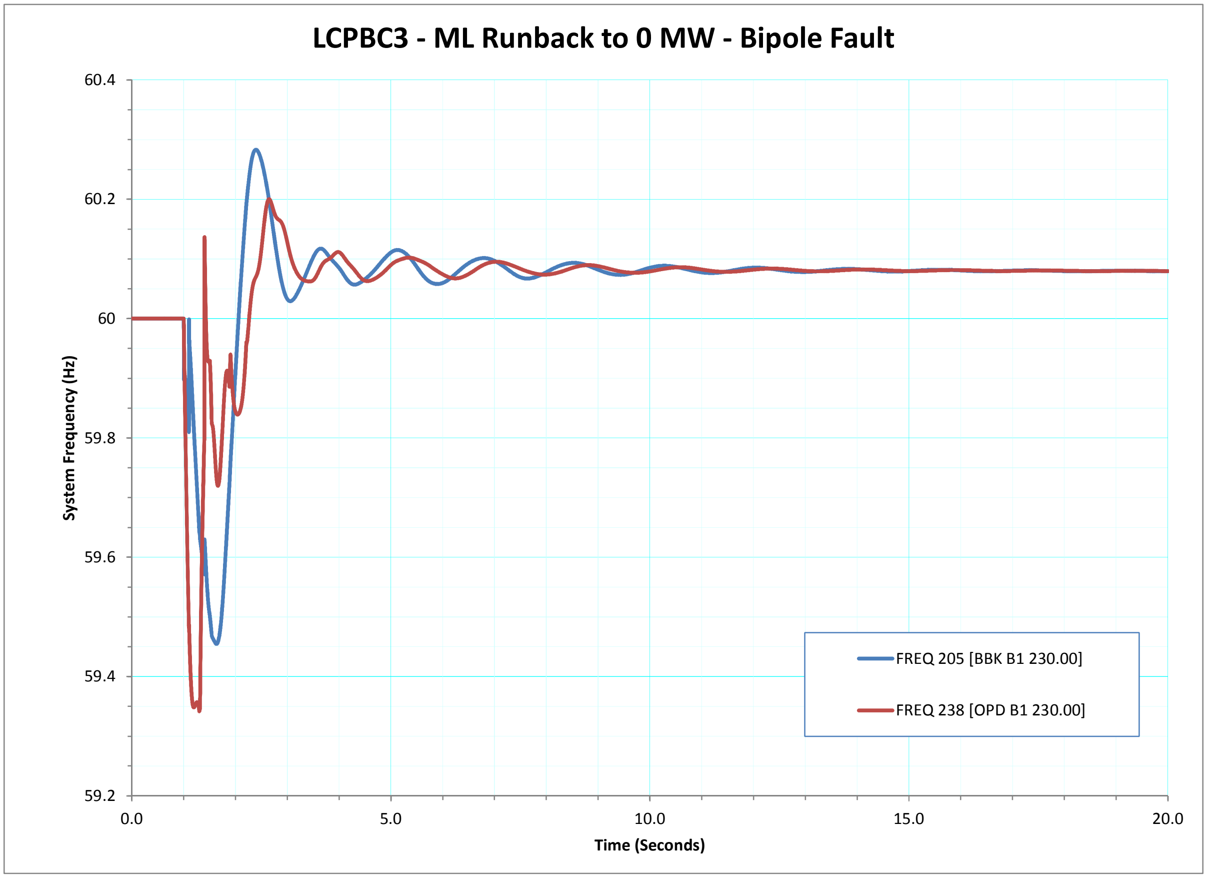


Figure 234 - LCPBC3 - ML Runback to 0 MW - Bipole Fault - System Frequency (Hz)

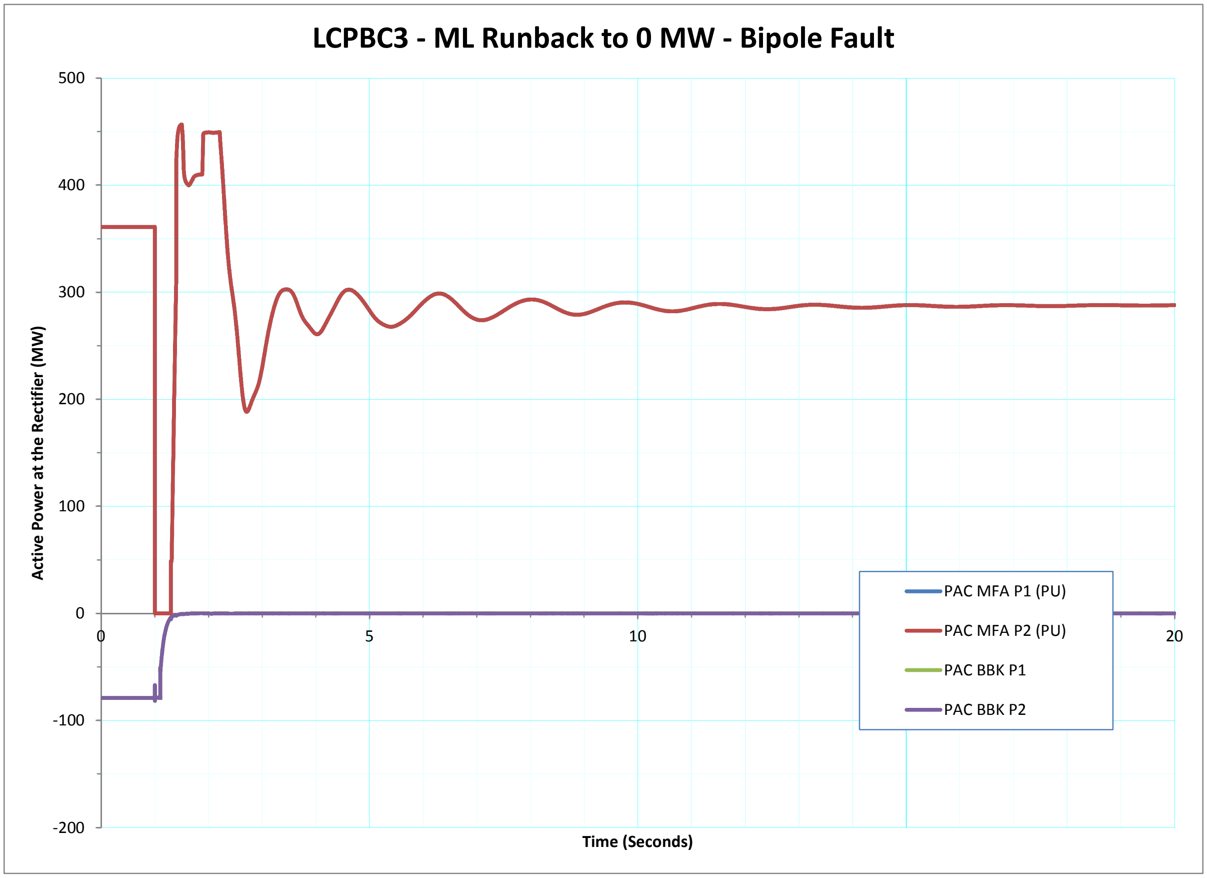


Figure 235 - LCPBC3 - ML Runback to 0 MW - Bipole Fault - Active Power at the Rectifier (MW)

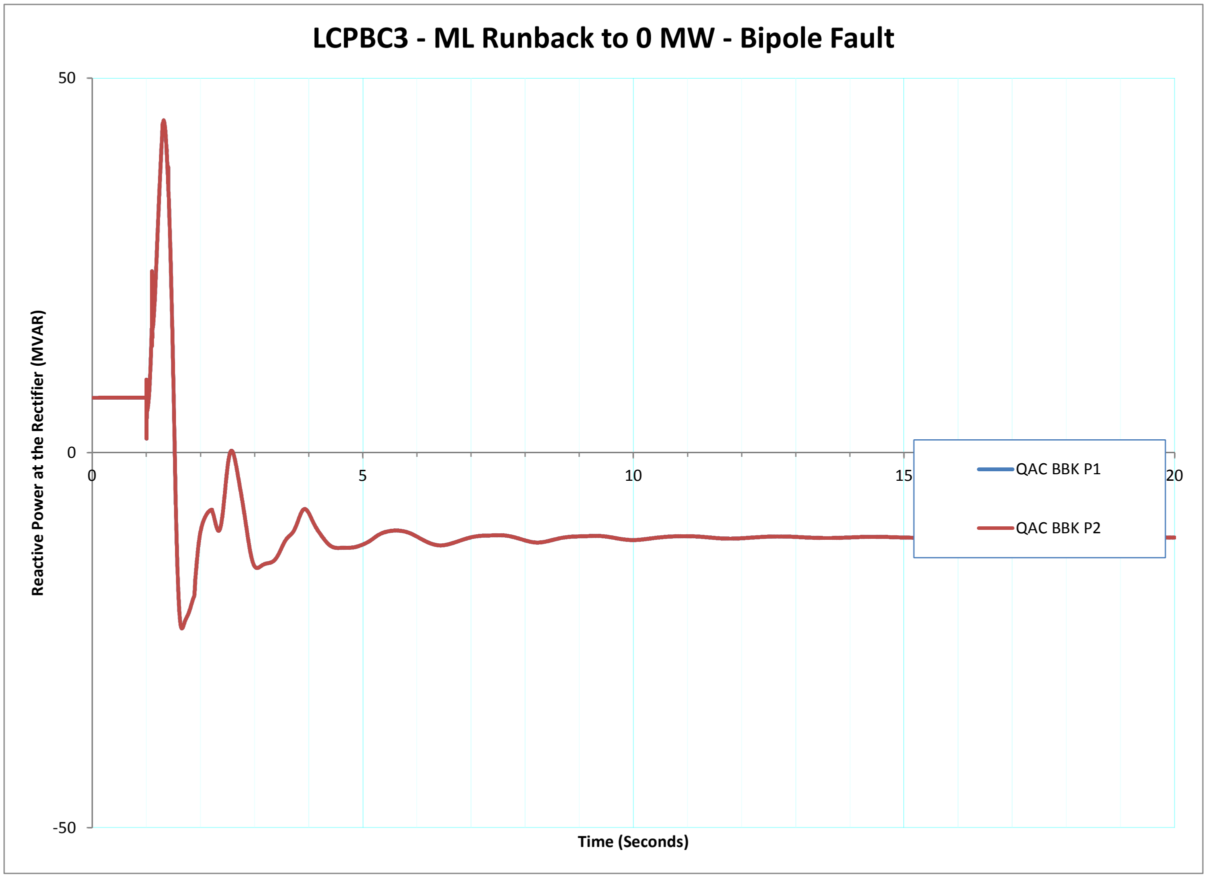


Figure 236 - LCPBC3 - ML Runback to 0 MW - Bipole Fault - Reactive Power at the Rectifier (MVAR)

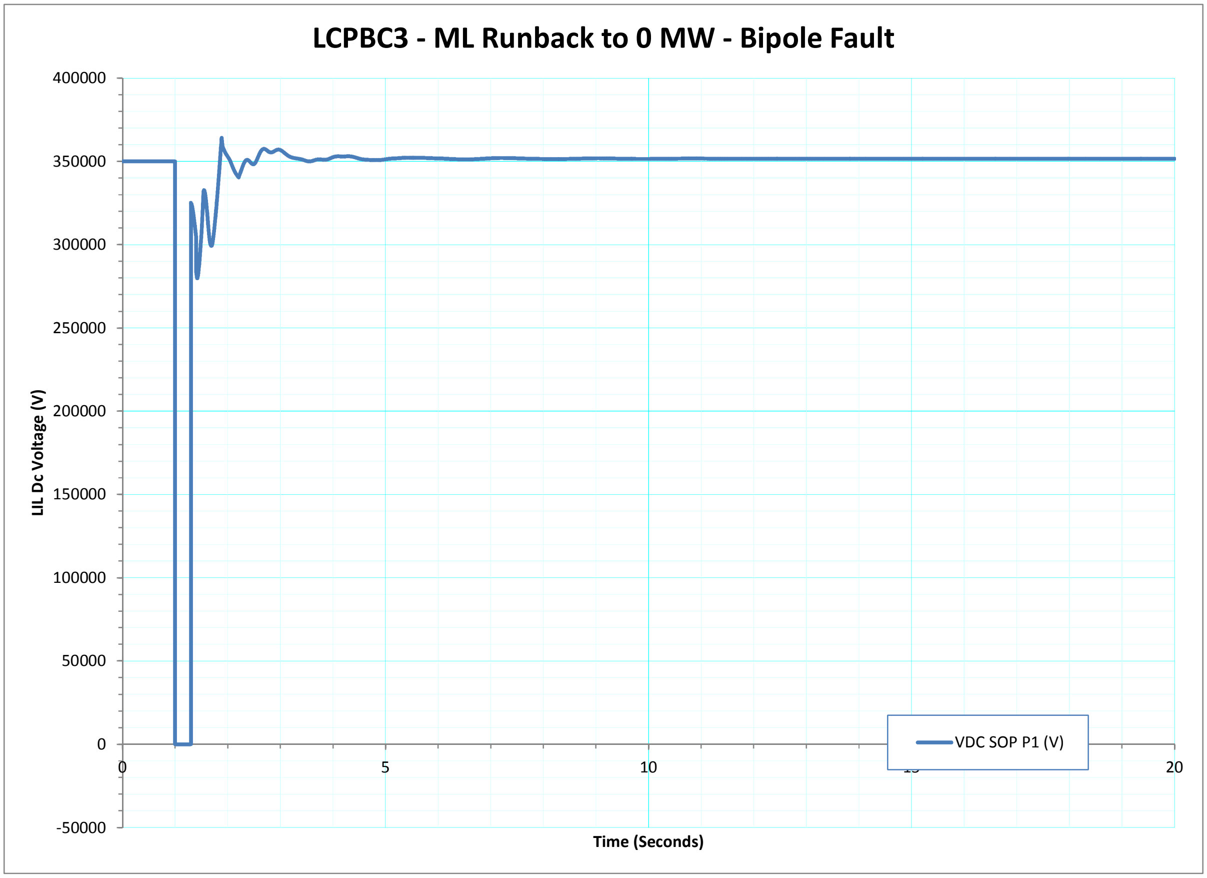


Figure 237 - LCPBC3 - ML Runback to 0 MW - Bipole Fault - LIL Dc Voltage (V)

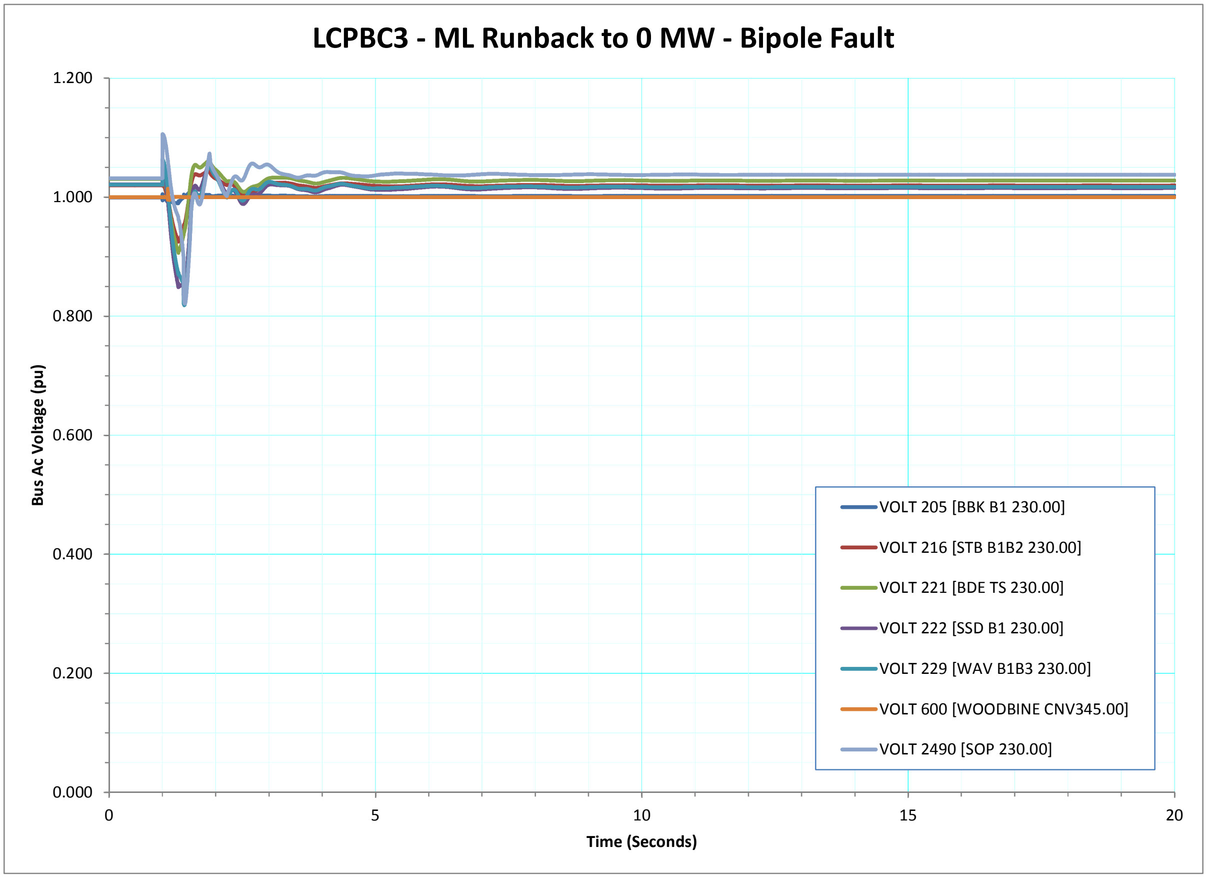


Figure 238 - LCPBC3 - ML Runback to 0 MW - Bipole Fault - Bus Ac Voltage (pu)

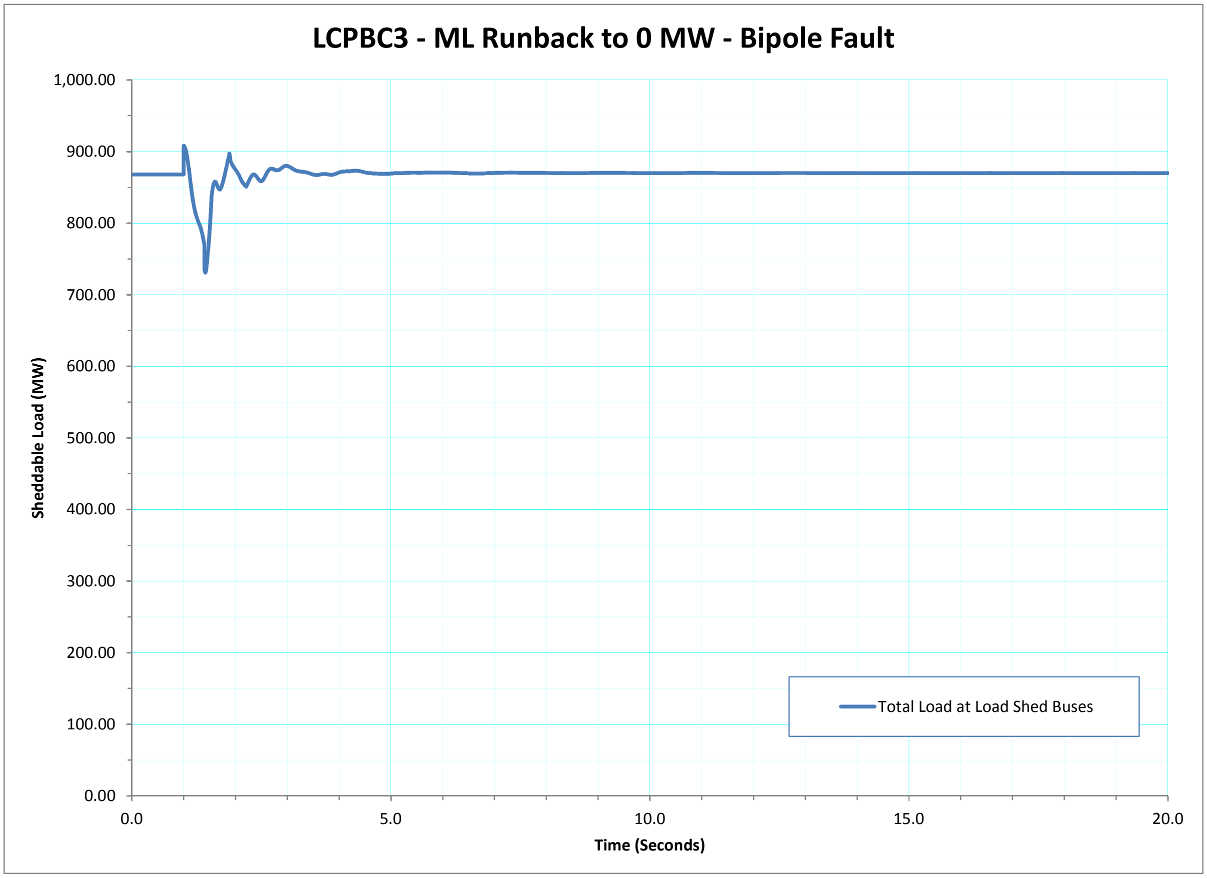


Figure 239 - LCPBC3 - ML Runback to 0 MW - Bipole Fault - Sheddable Load (MW)

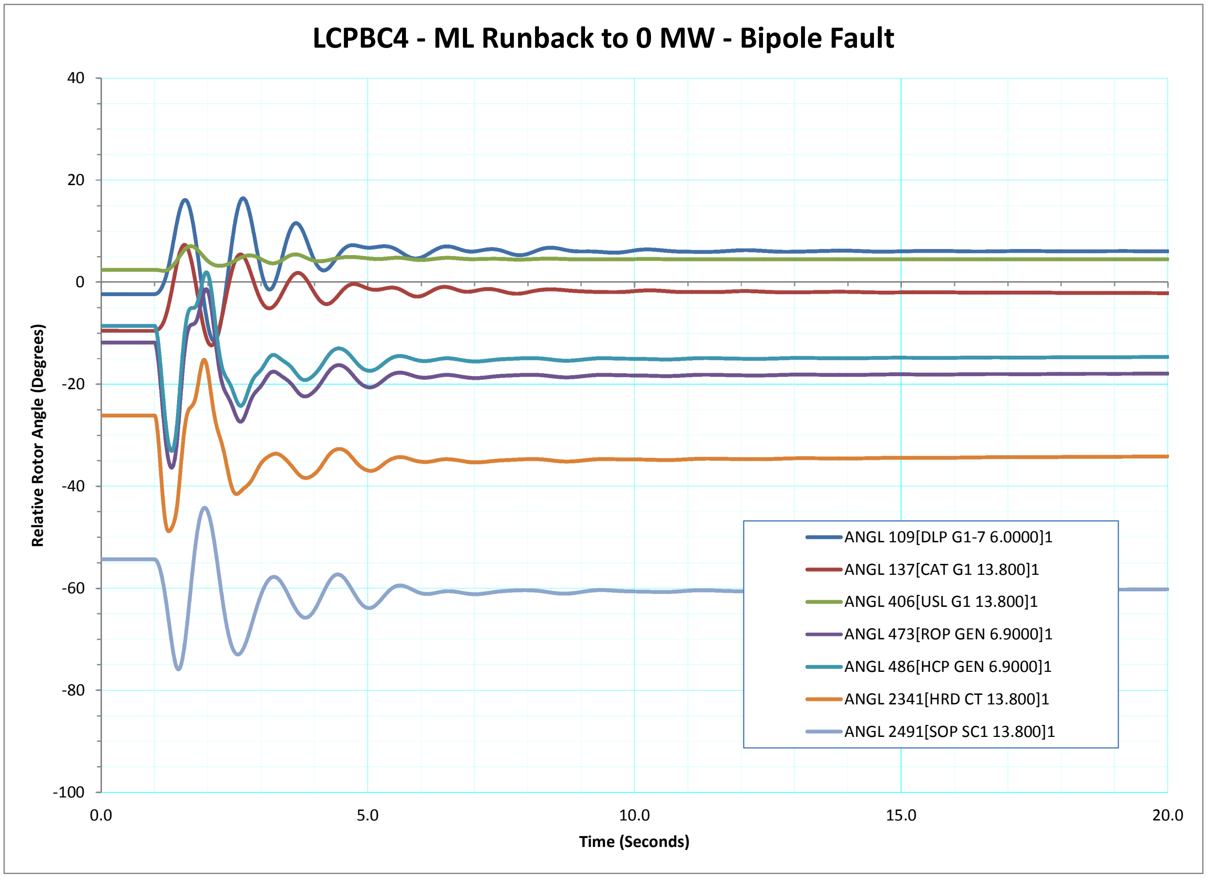


Figure 240 - LCPBC4 - ML Runback to 0 MW - Bipole Fault - Relative Rotor Angle (Degrees)

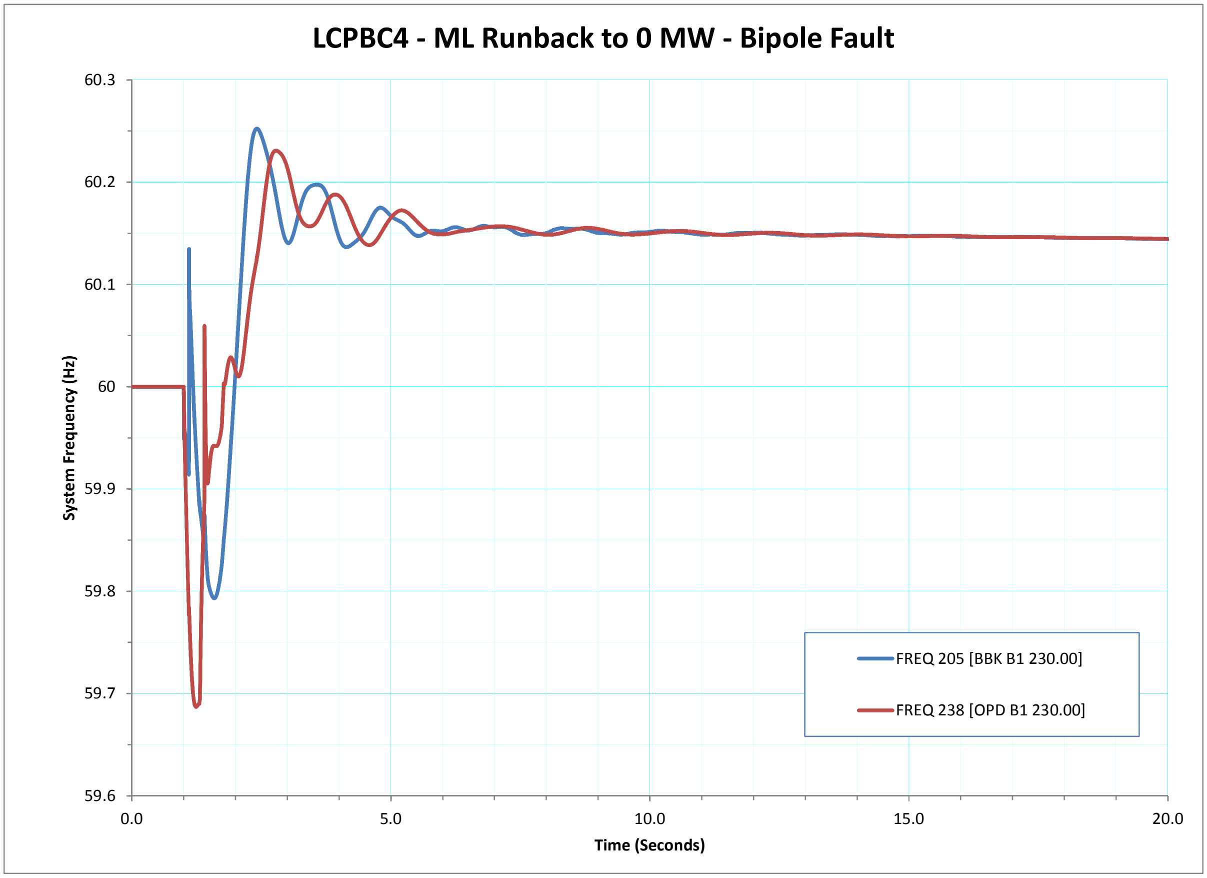


Figure 241 - LCPBC4 - ML Runback to 0 MW - Bipole Fault - System Frequency (Hz)

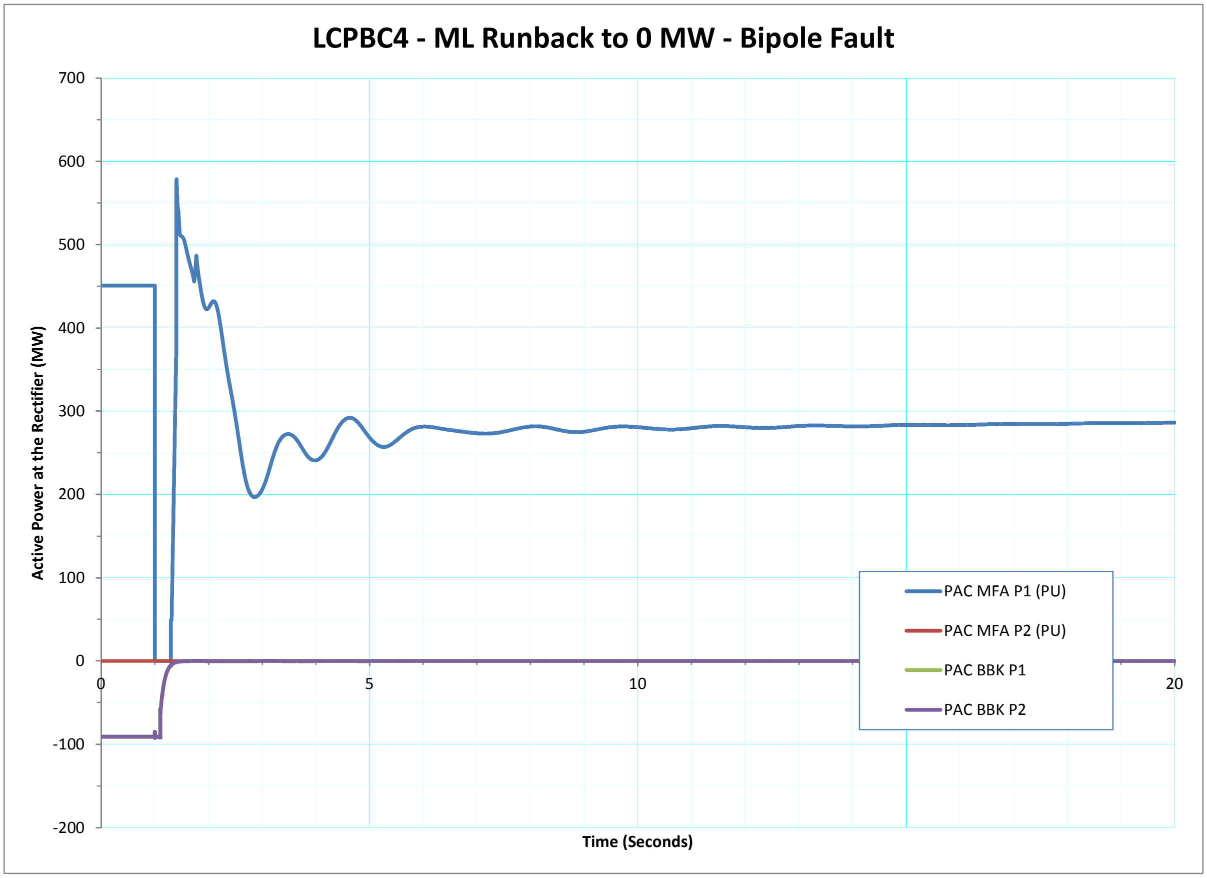


Figure 242 - LCPBC4 - ML Runback to 0 MW - Bipole Fault - Active Power at the Rectifier (MW)

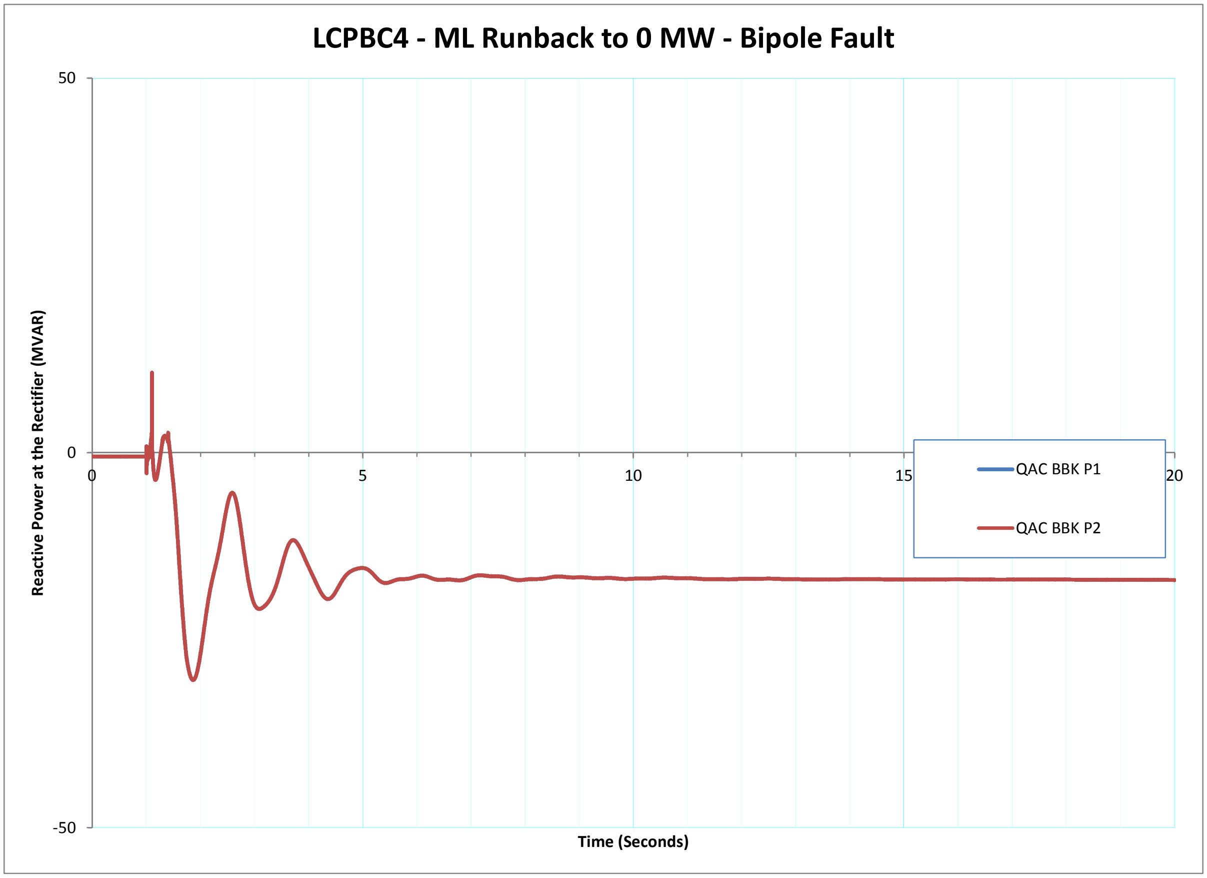


Figure 243 - LCPBC4 - ML Runback to 0 MW - Bipole Fault - Reactive Power at the Rectifier (MVAR)

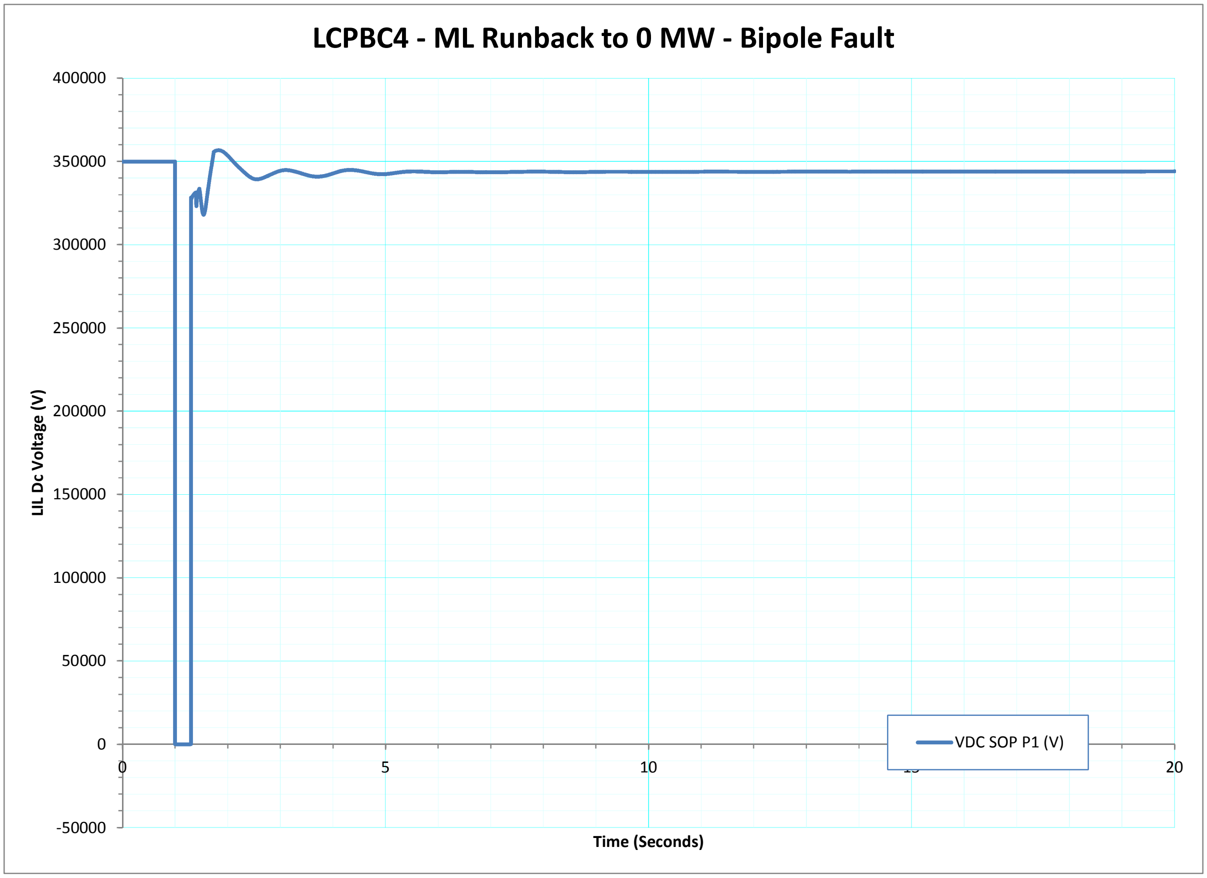


Figure 244 - LCPBC4 - ML Runback to 0 MW - Bipole Fault - LIL Dc Voltage (V)

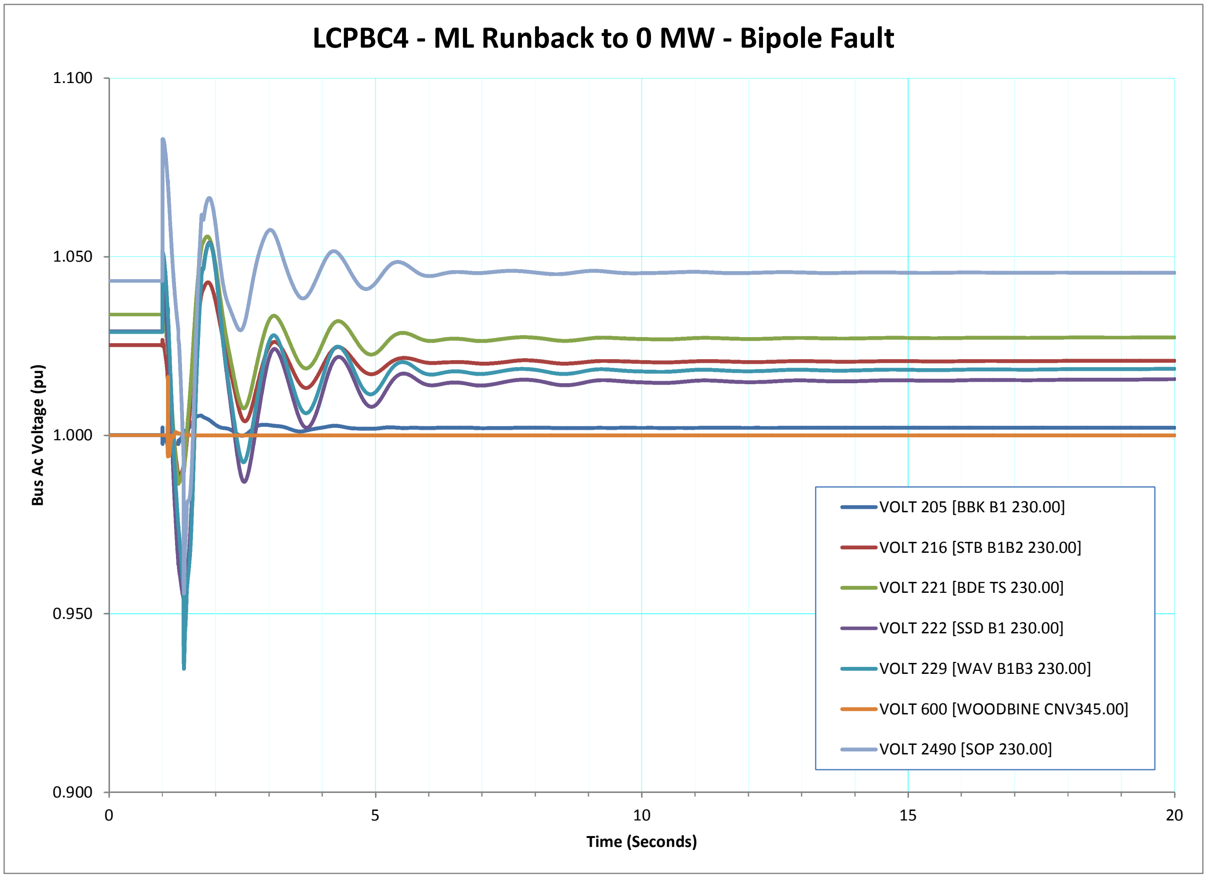


Figure 245 - LCPBC4 - ML Runback to 0 MW - Bipole Fault - Bus Ac Voltage (pu)

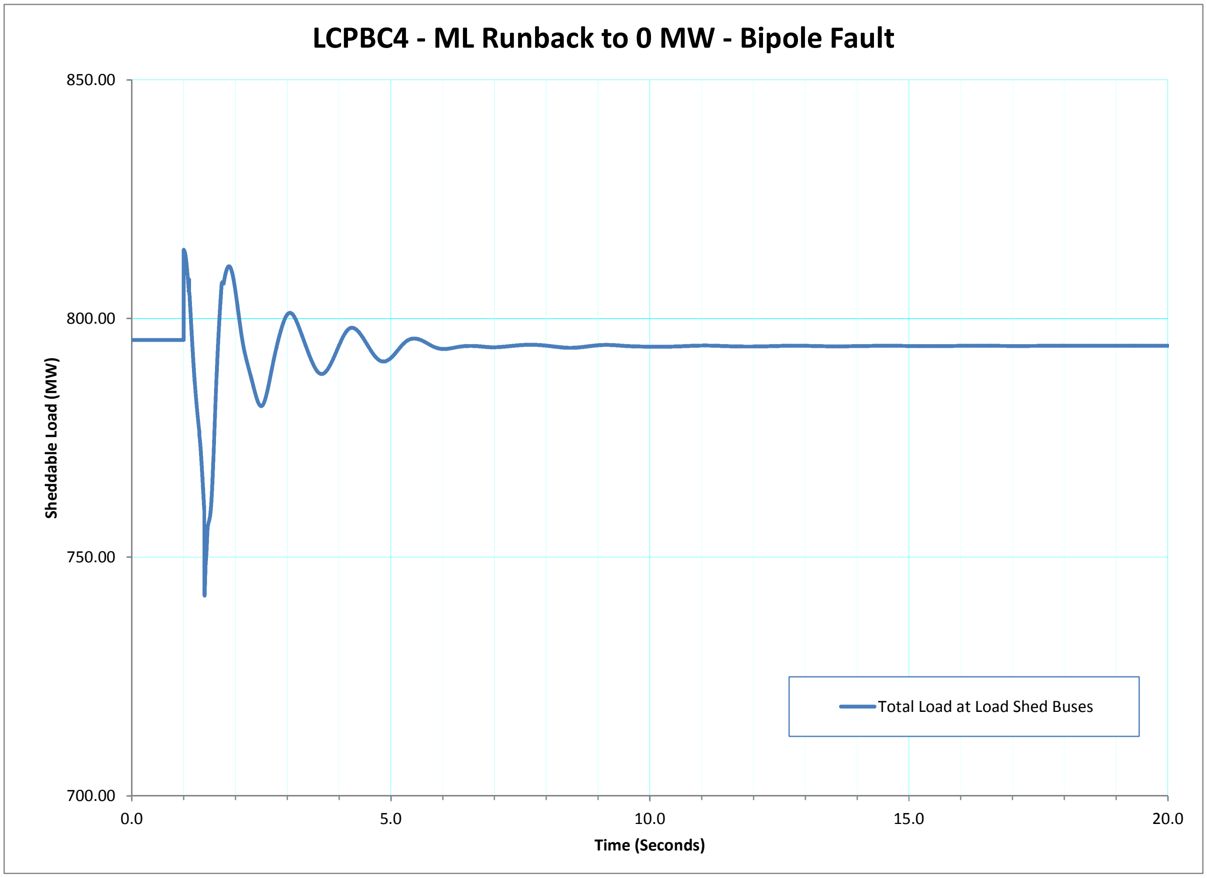


Figure 246 - LCPBC4 - ML Runback to 0 MW - Bipole Fault - Sheddable Load (MW)

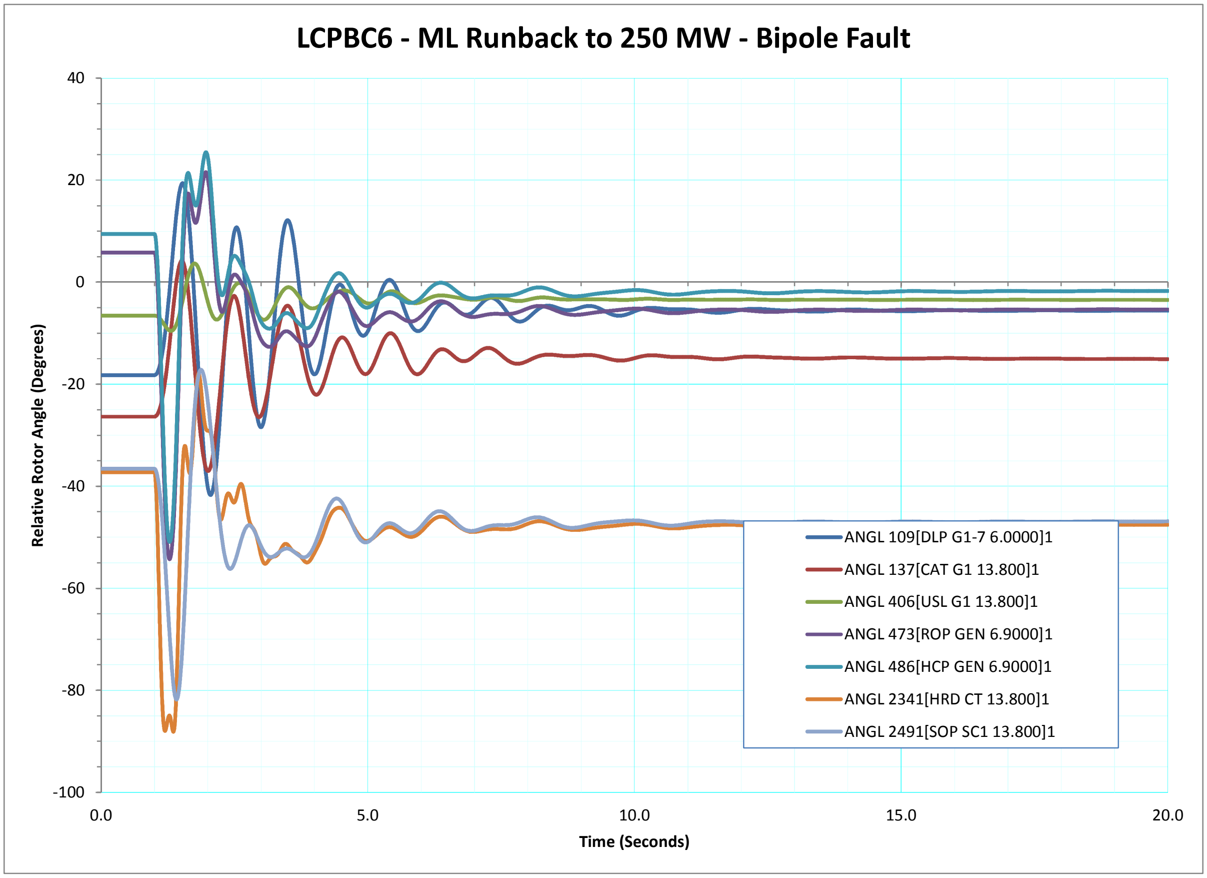


Figure 247 - LCPBC6 - ML Runback to 250 MW - Bipole Fault - Relative Rotor Angle (Degrees)

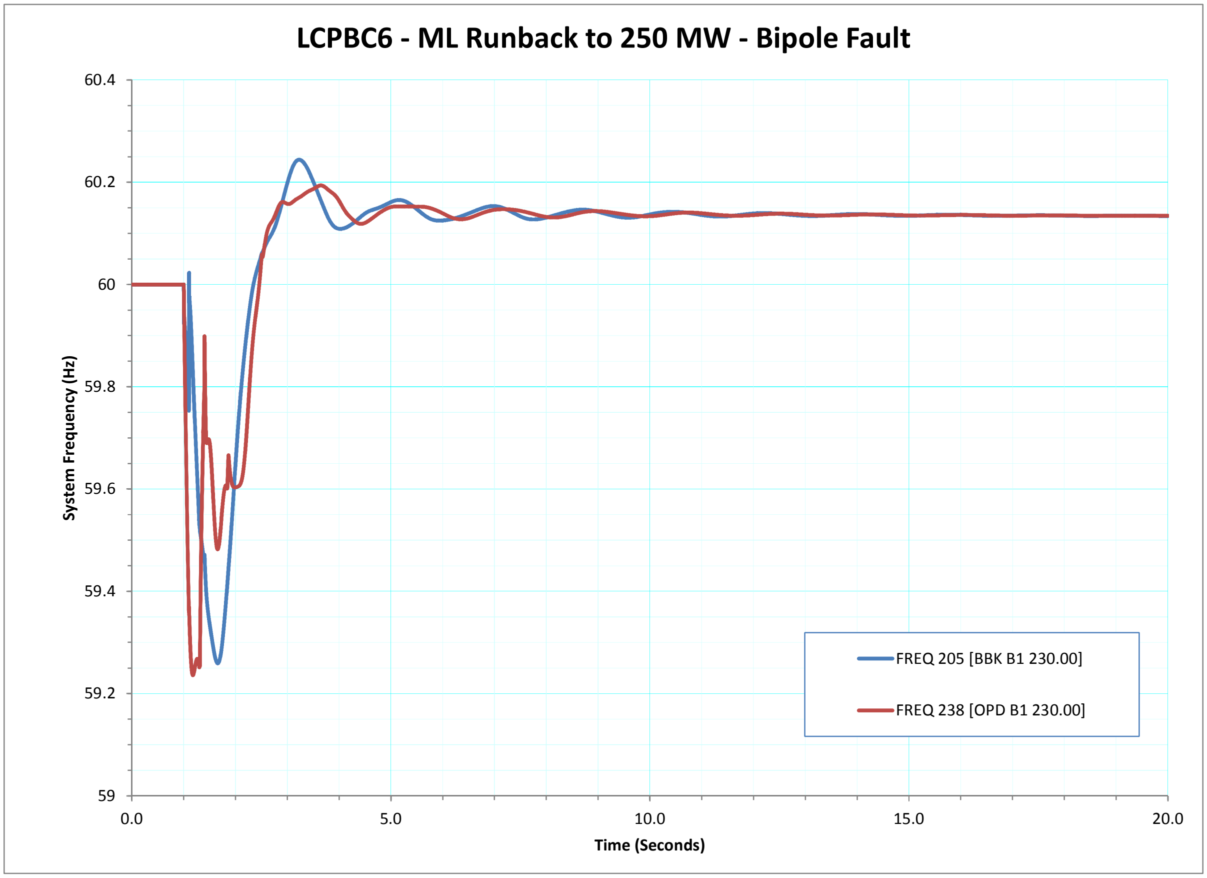


Figure 248 - LCPBC6 - ML Runback to 250 MW - Bipole Fault - System Frequency (Hz)

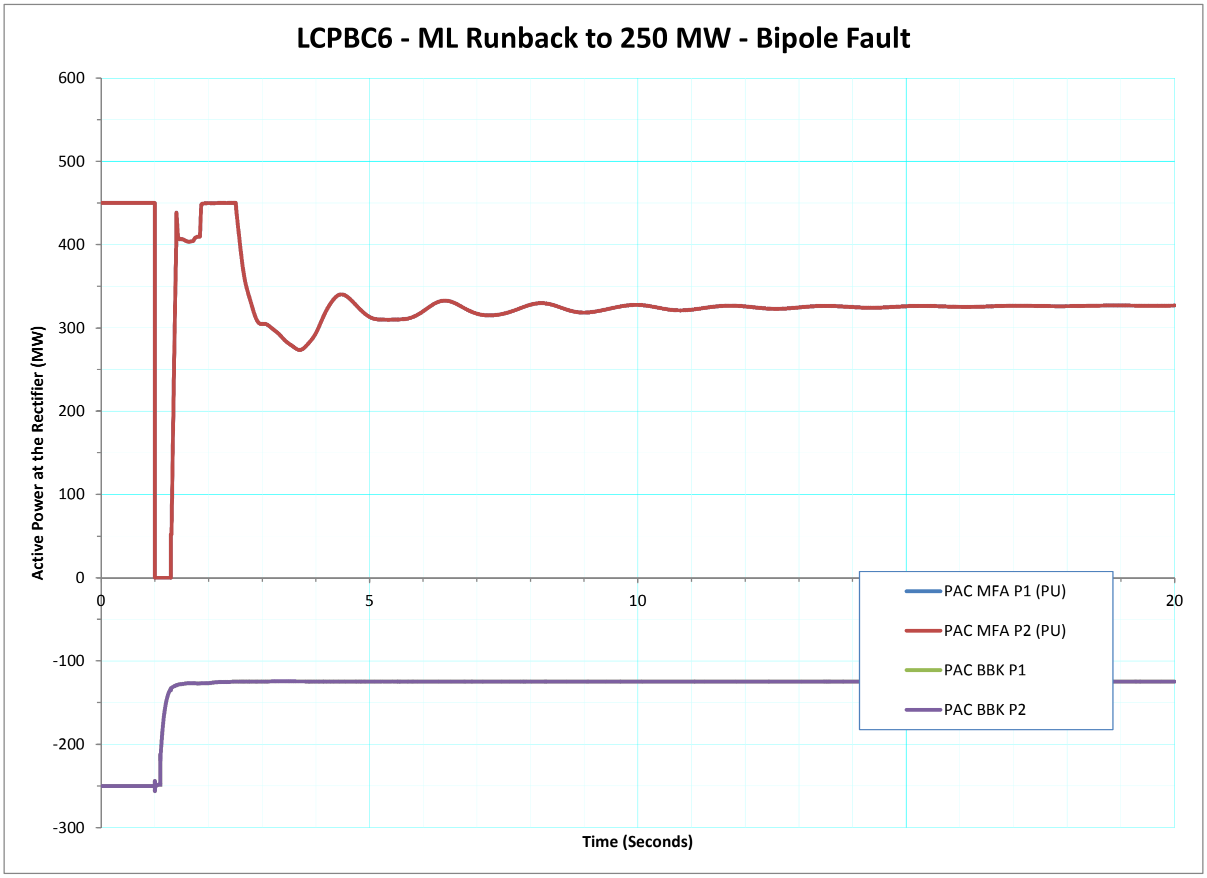


Figure 249 - LCPBC6 - ML Runback to 250 MW - Bipole Fault - Active Power at the Rectifier (MW)

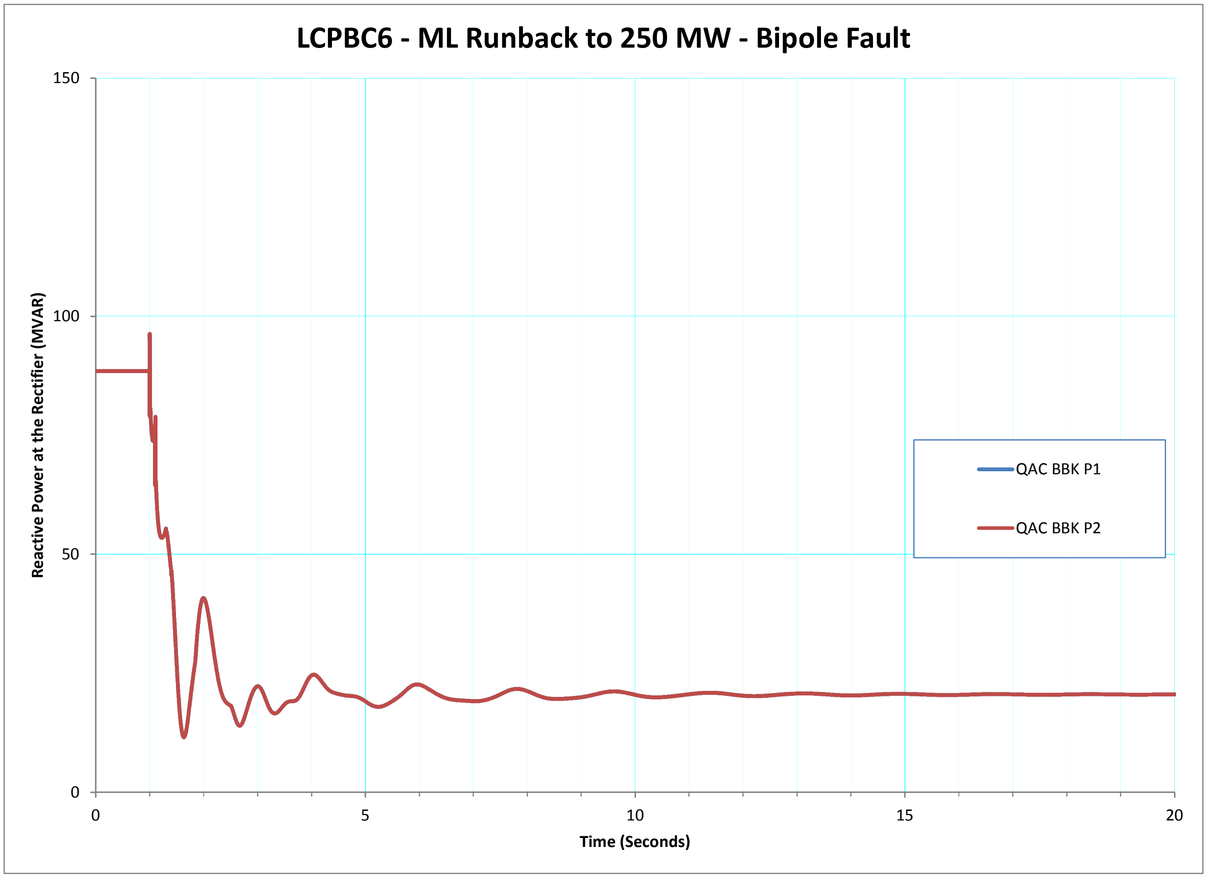


Figure 250 - LCPBC6 - ML Runback to 250 MW - Bipole Fault - Reactive Power at the Rectifier (MVAR)

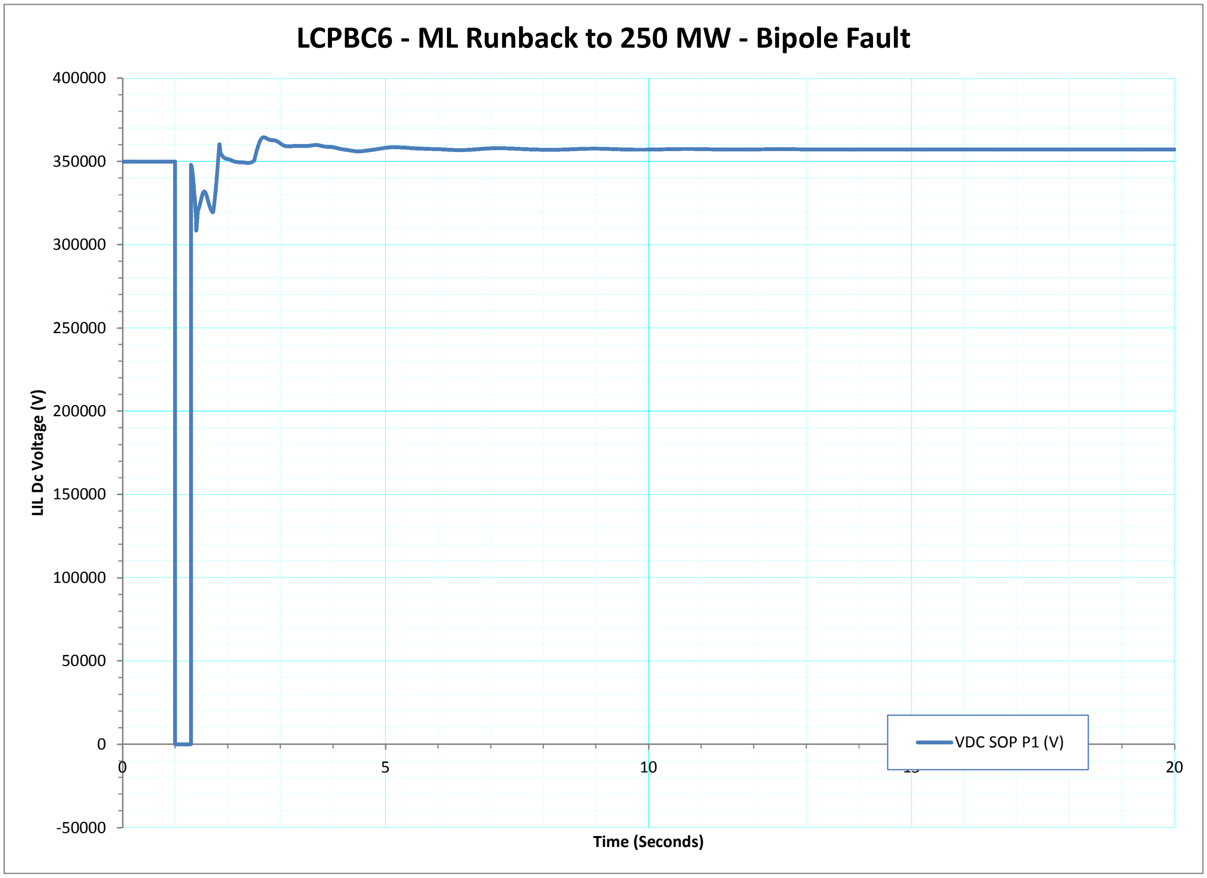


Figure 251 - LCPBC6 - ML Runback to 250 MW - Bipole Fault - LIL Dc Voltage (V)

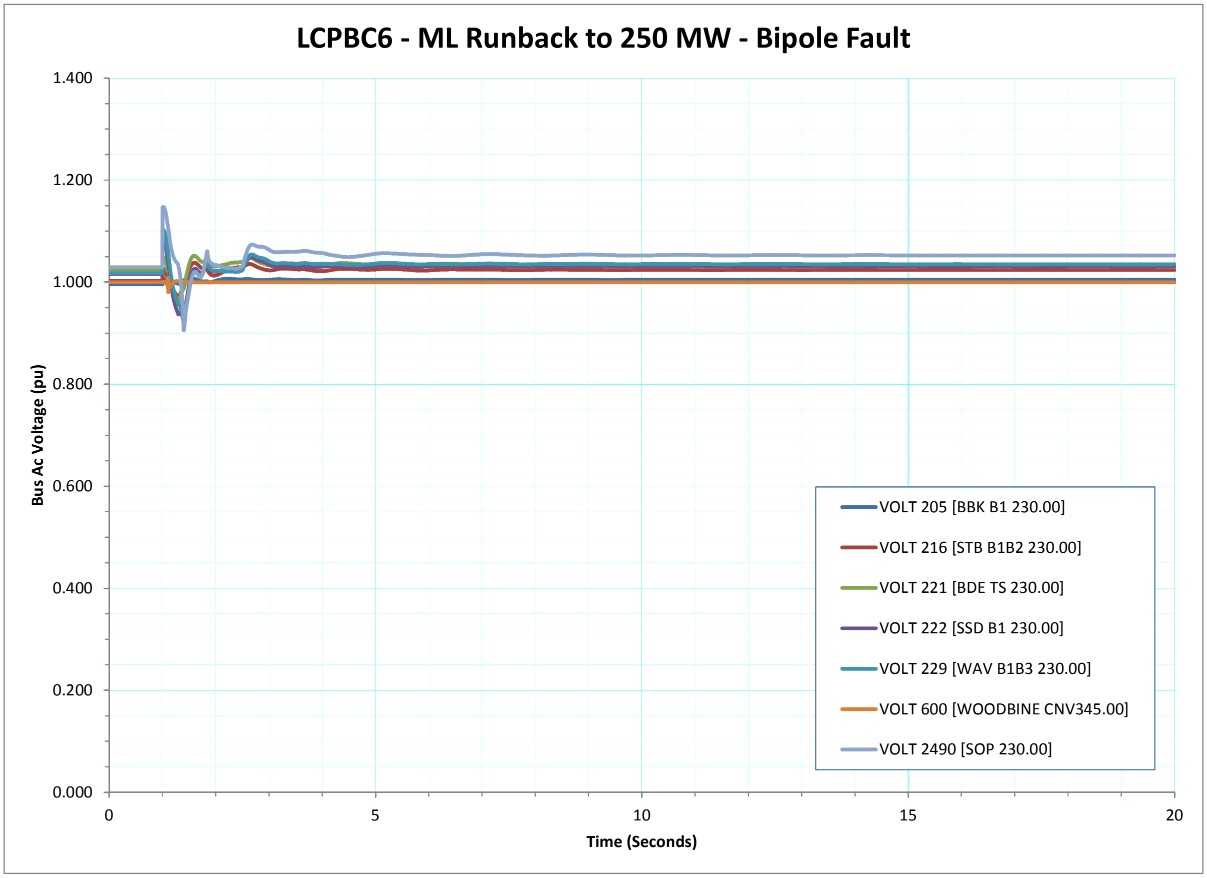


Figure 252 - LCPBC6 - ML Runback to 250 MW - Bipole Fault - Bus Ac Voltage (pu)

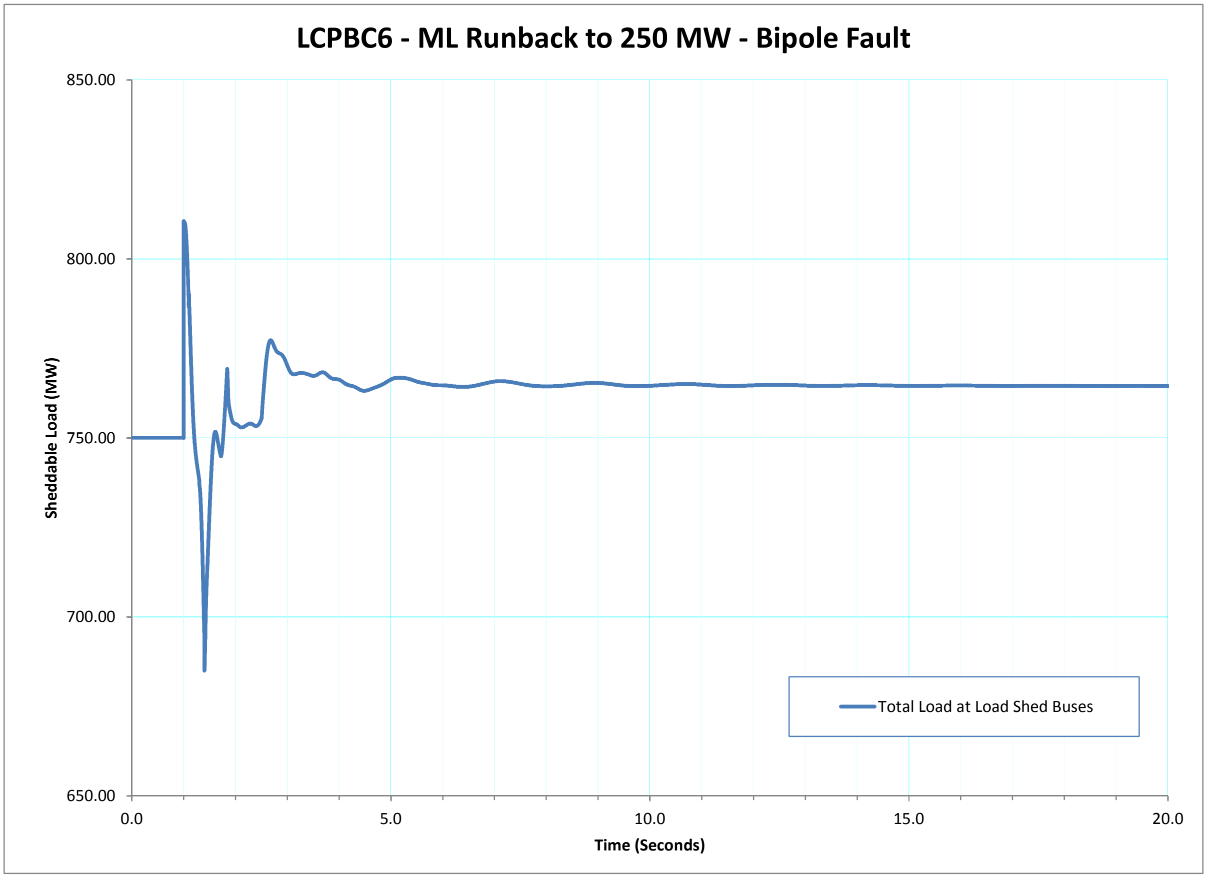


Figure 253 - LCPBC6 - ML Runback to 250 MW - Bipole Fault - Sheddable Load (MW)

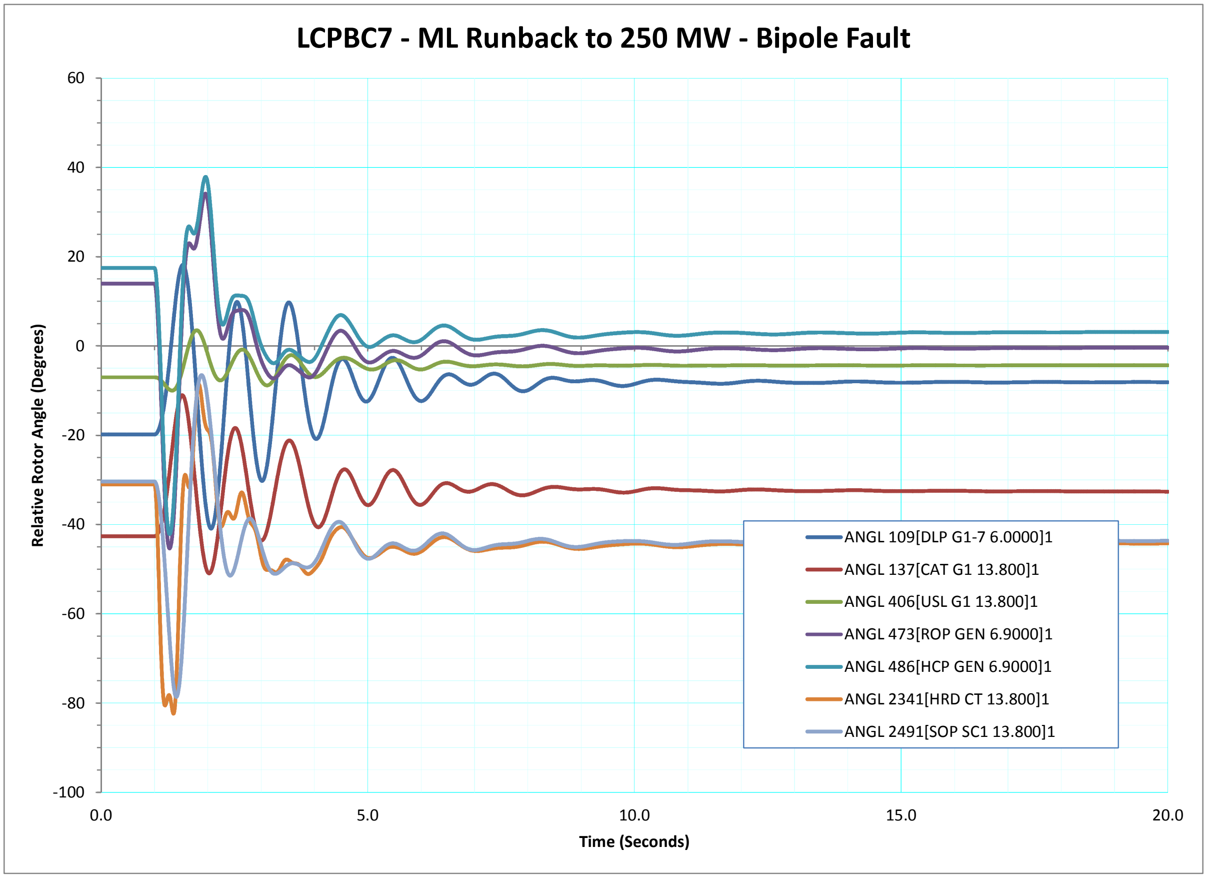


Figure 254 - LCPBC7 - ML Runback to 250 MW - Bipole Fault - Relative Rotor Angle (Degrees)

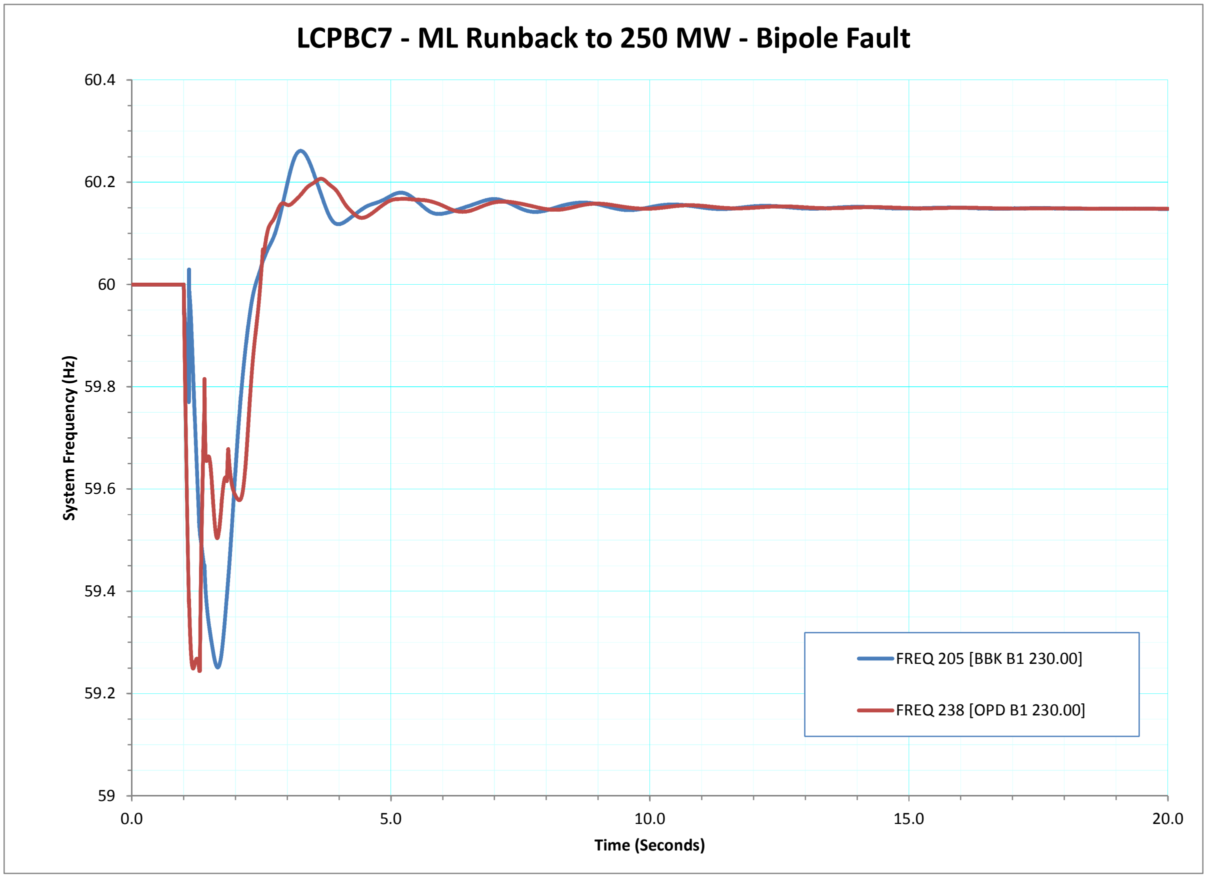


Figure 255 - LCPBC7 - ML Runback to 250 MW - Bipole Fault - System Frequency (Hz)

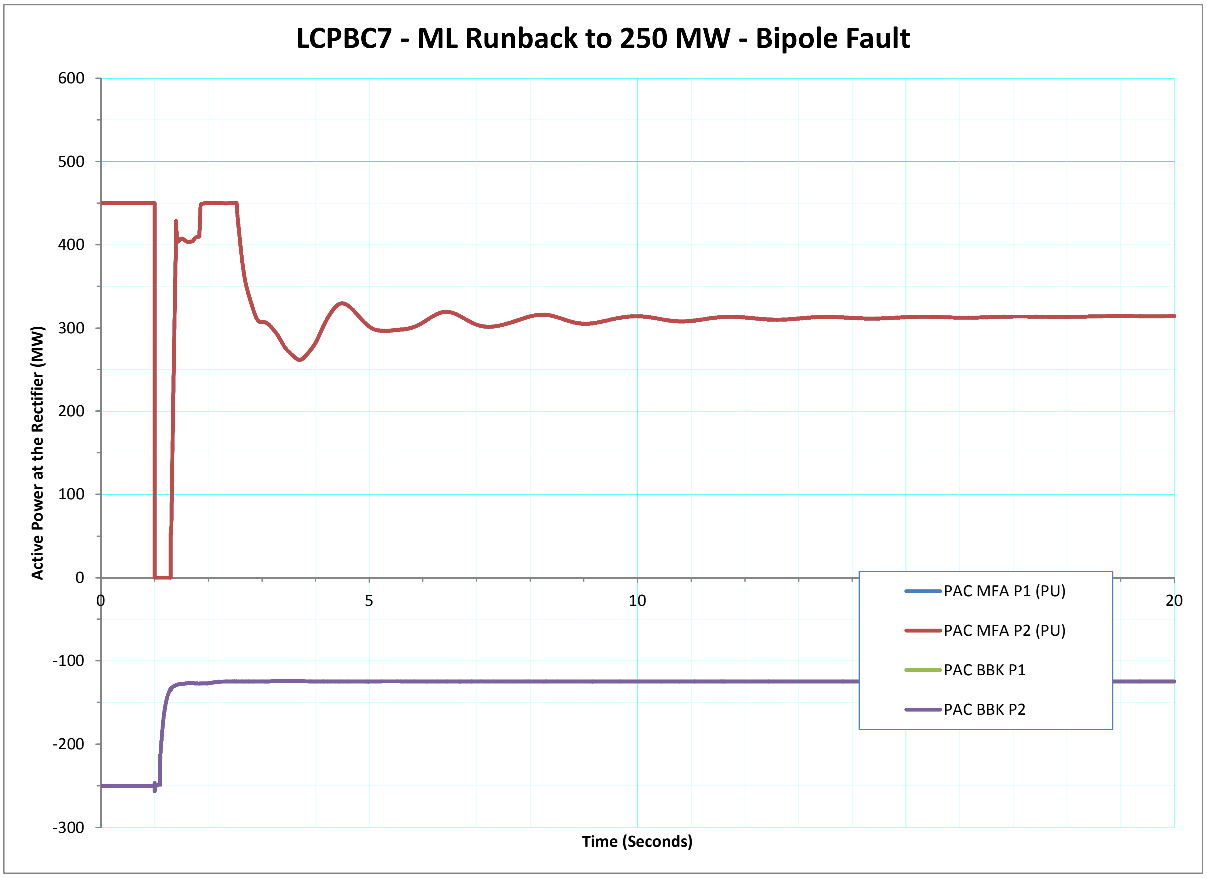


Figure 256 - LCPBC7 - ML Runback to 250 MW - Bipole Fault - Active Power at the Rectifier (MW)

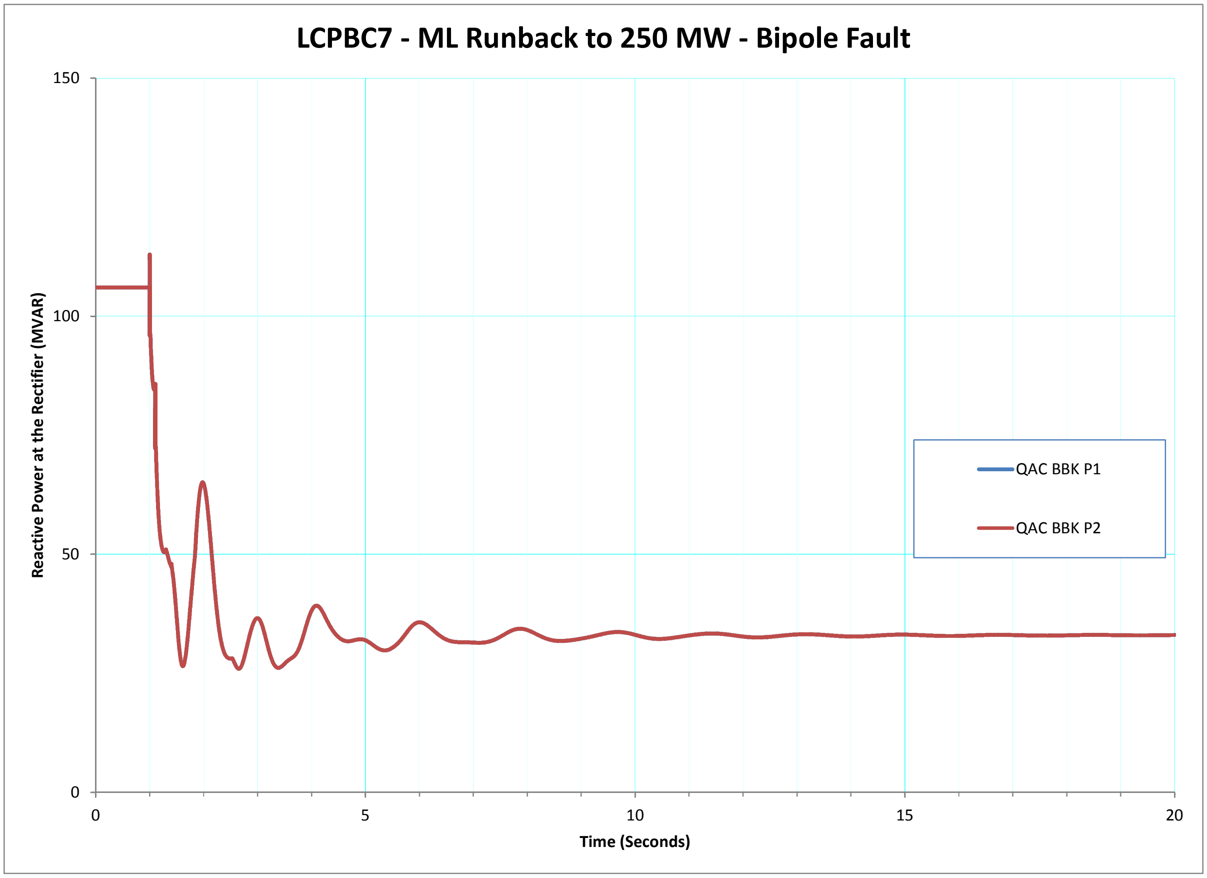


Figure 257 - LCPBC7 - ML Runback to 250 MW - Bipole Fault - Reactive Power at the Rectifier (MVAR)

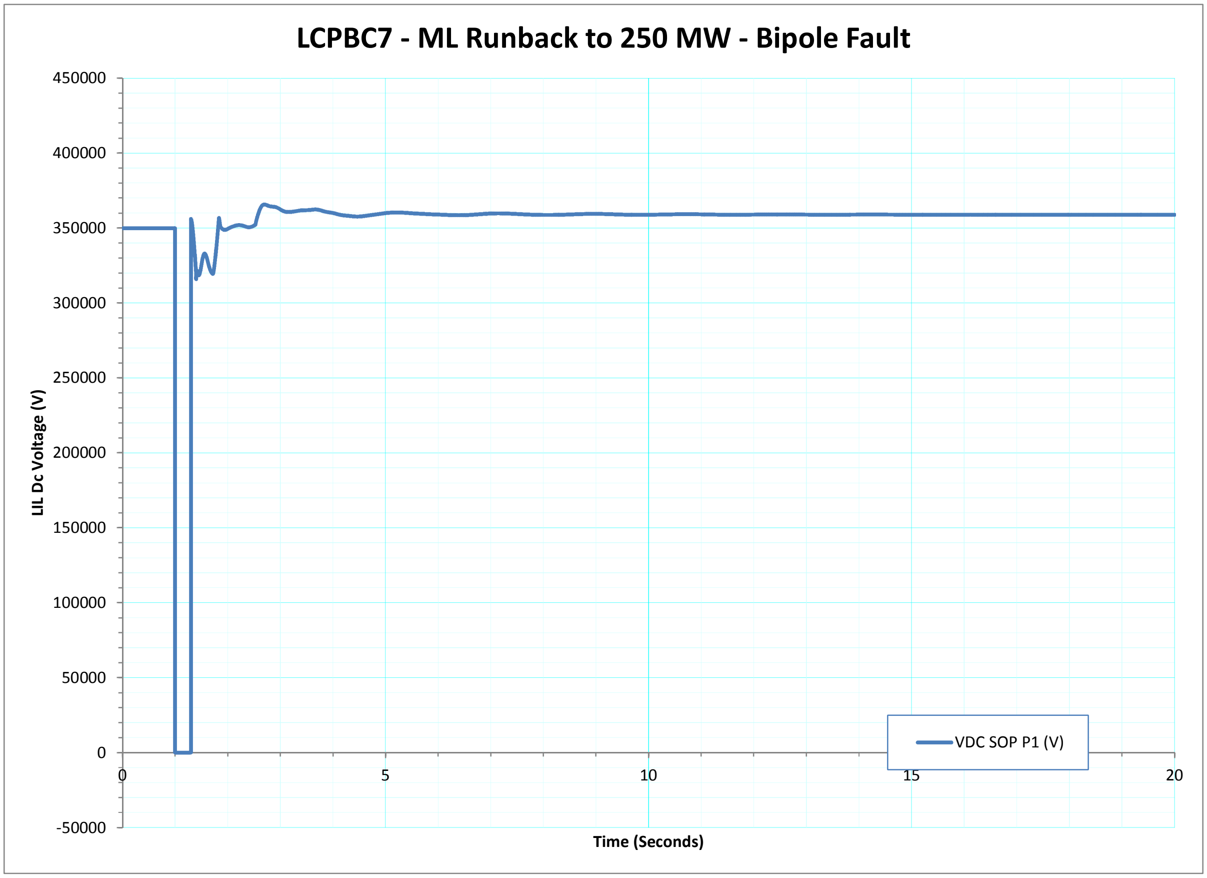


Figure 258 - LCPBC7 - ML Runback to 250 MW - Bipole Fault - LIL Dc Voltage (V)

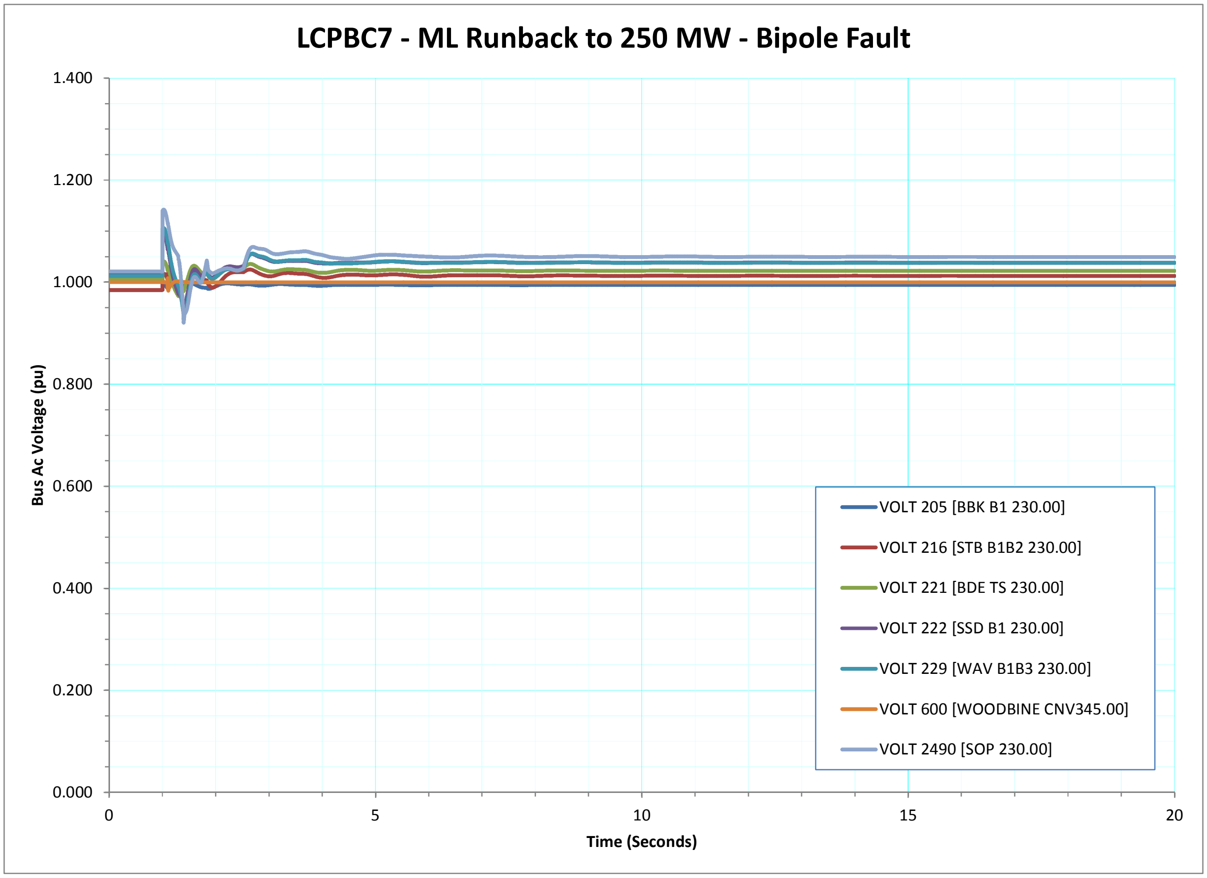


Figure 259 - LCPBC7 - ML Runback to 250 MW - Bipole Fault - Bus Ac Voltage (pu)

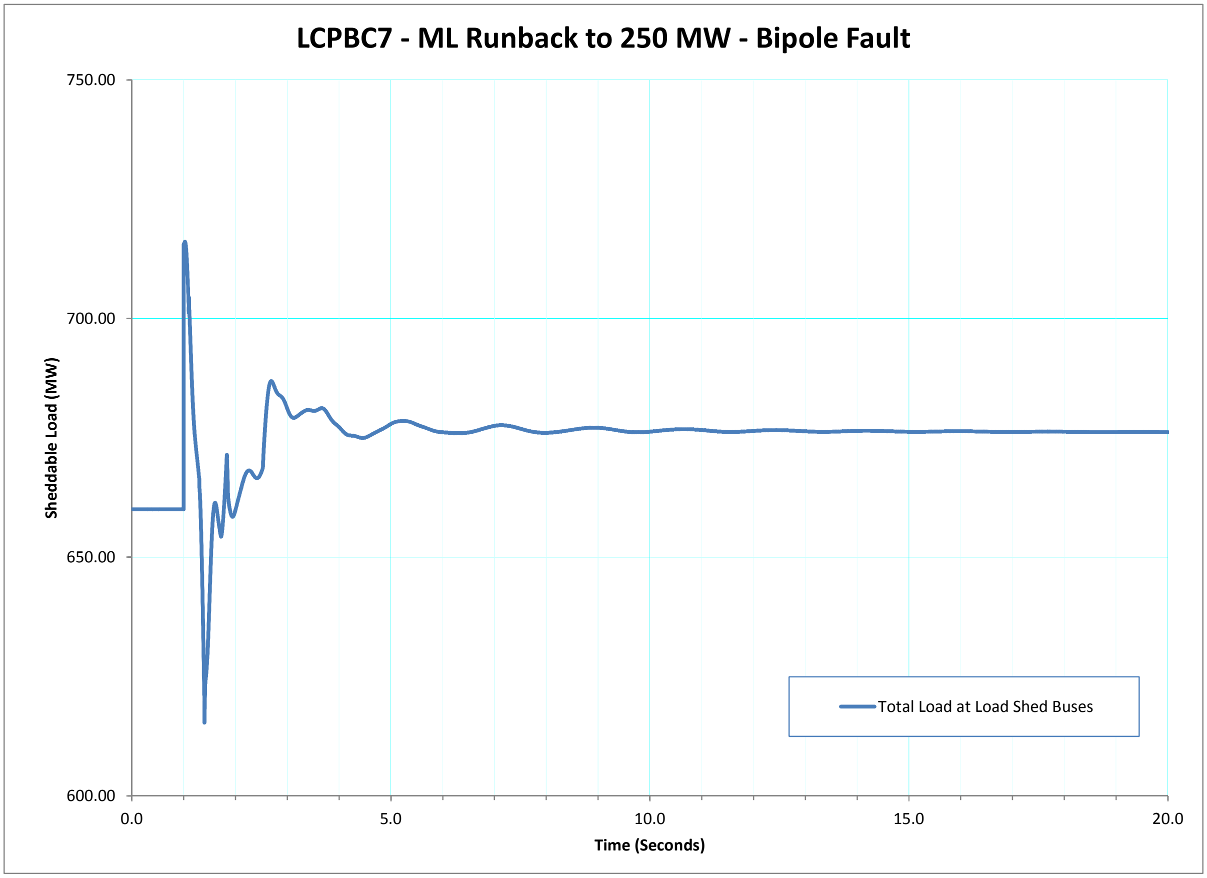


Figure 260 - LCPBC7 - ML Runback to 250 MW - Bipole Fault - Sheddable Load (MW)

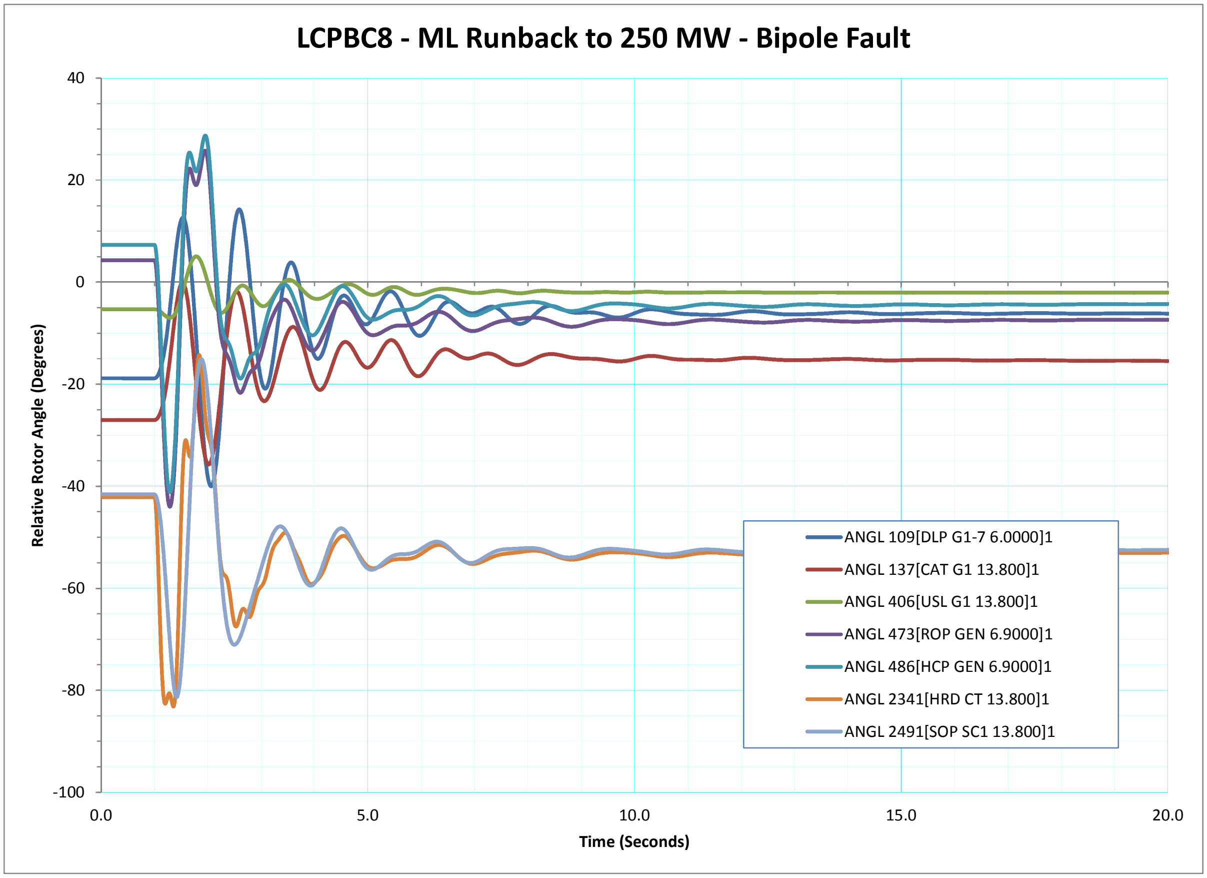


Figure 261 - LCPBC8 - ML Runback to 250 MW - Bipole Fault - Relative Rotor Angle (Degrees)

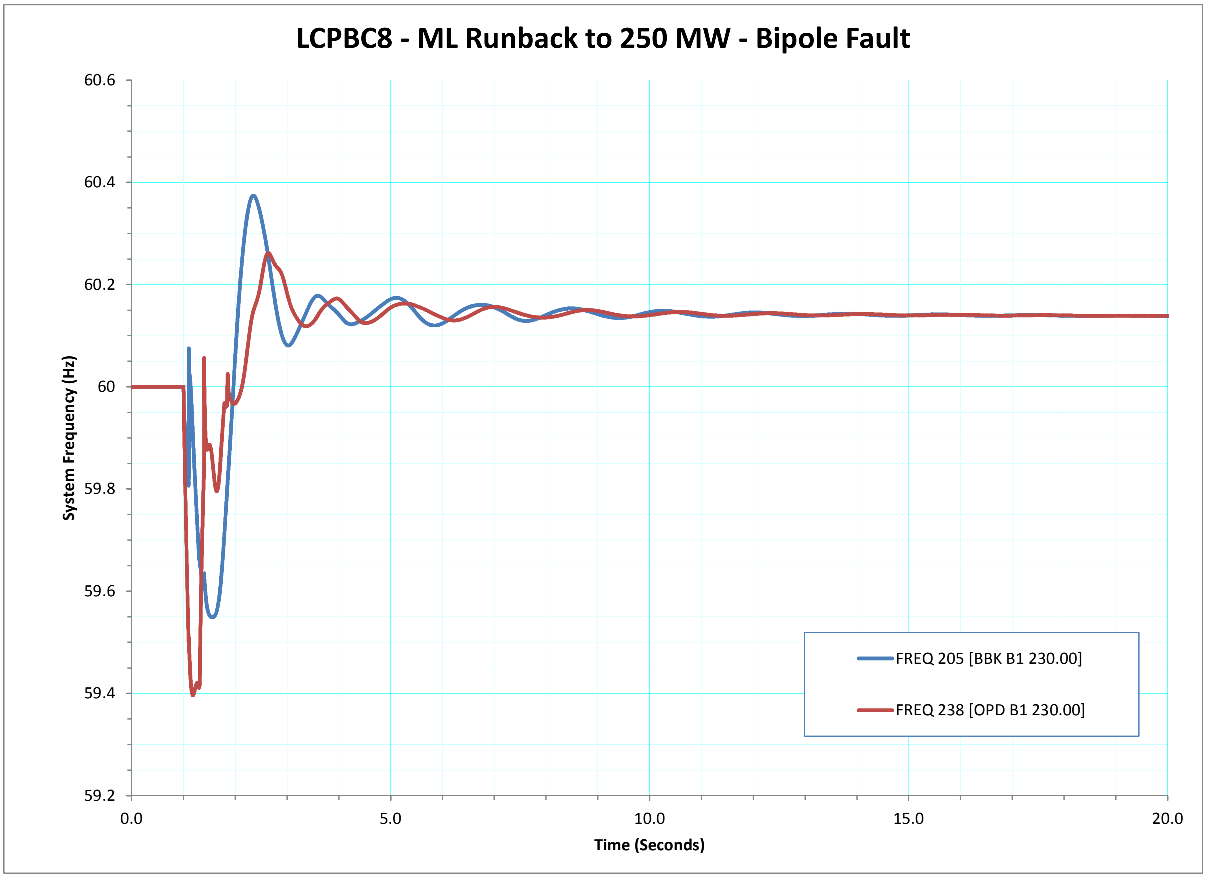


Figure 262 - LCPBC8 - ML Runback to 250 MW - Bipole Fault - System Frequency (Hz)

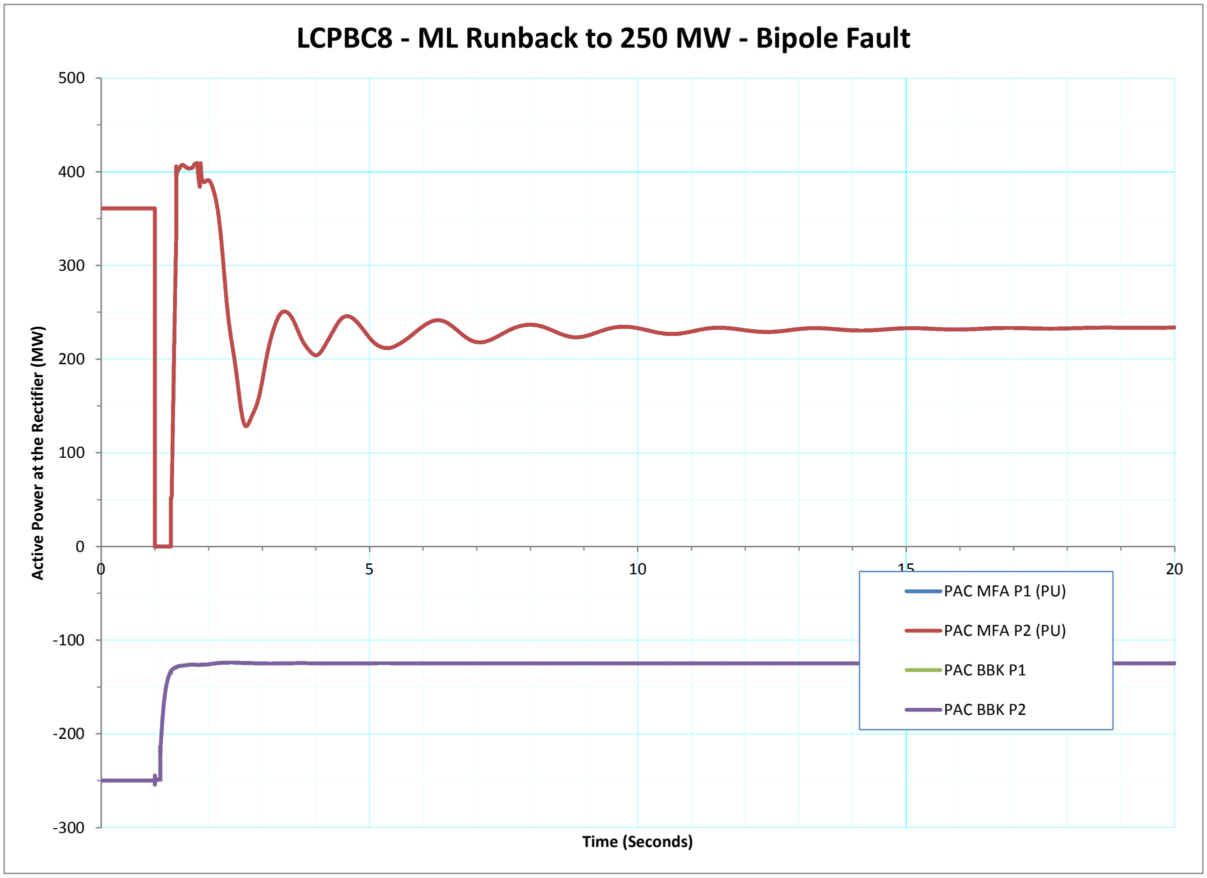


Figure 263 - LCPBC8 - ML Runback to 250 MW - Bipole Fault - Active Power at the Rectifier (MW)

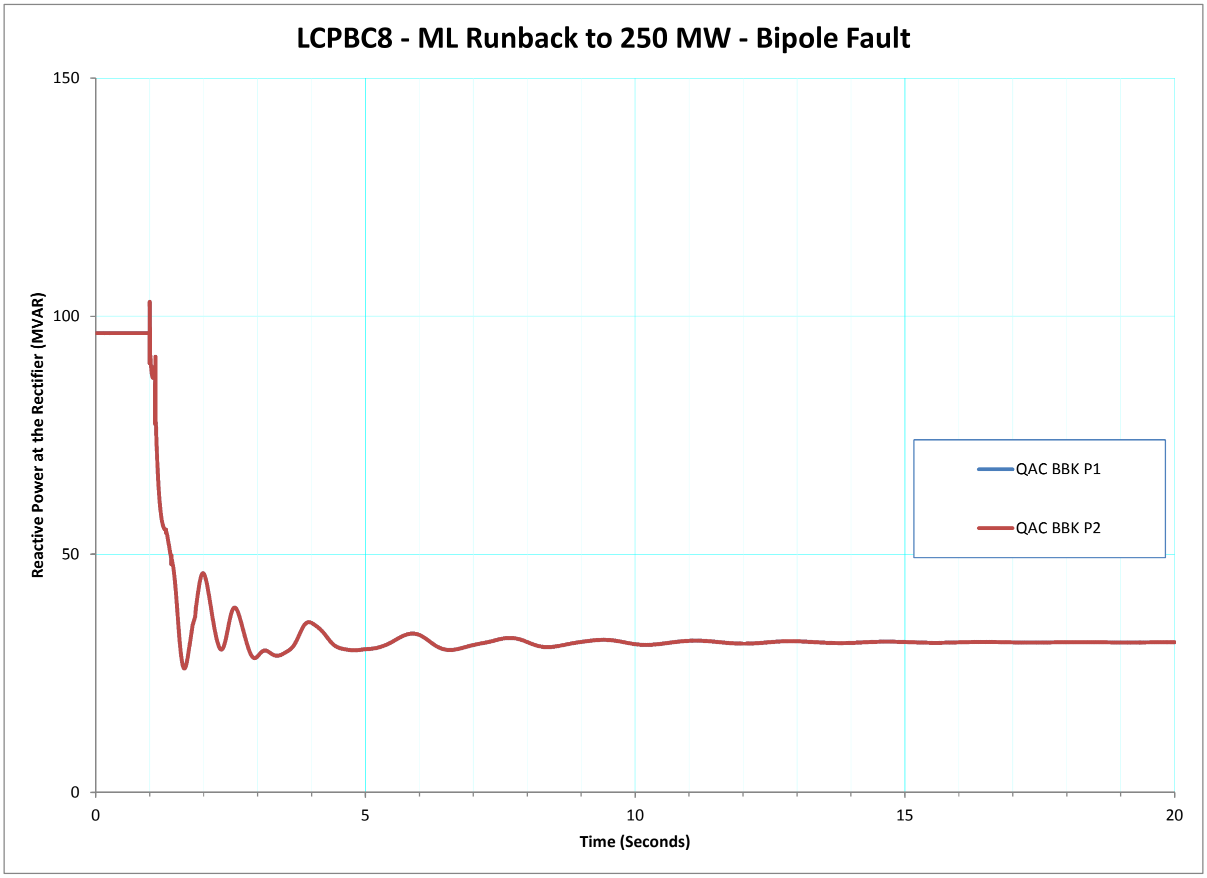


Figure 264 - LCPBC8 - ML Runback to 250 MW - Bipole Fault - Reactive Power at the Rectifier (MVAR)

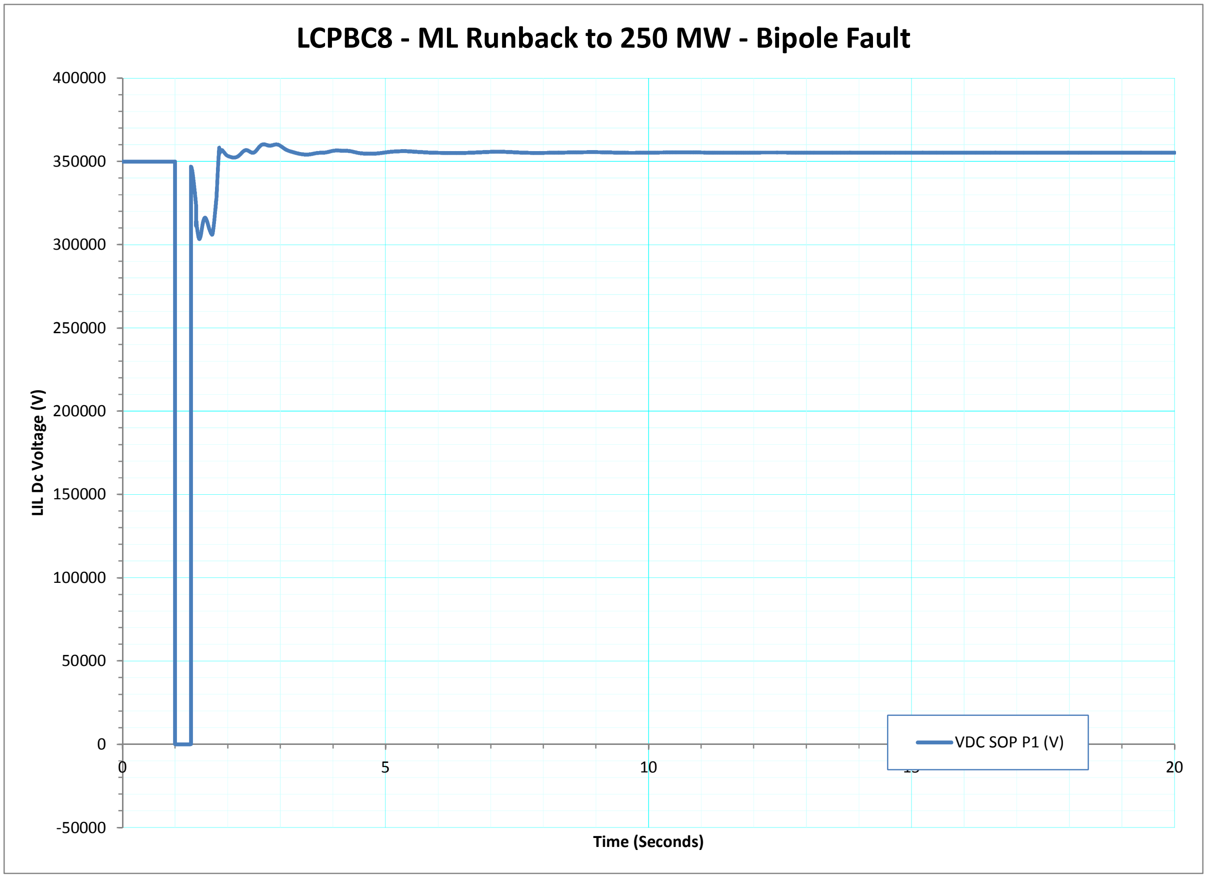


Figure 265 - LCPBC8 - ML Runback to 250 MW - Bipole Fault - LIL Dc Voltage (V)

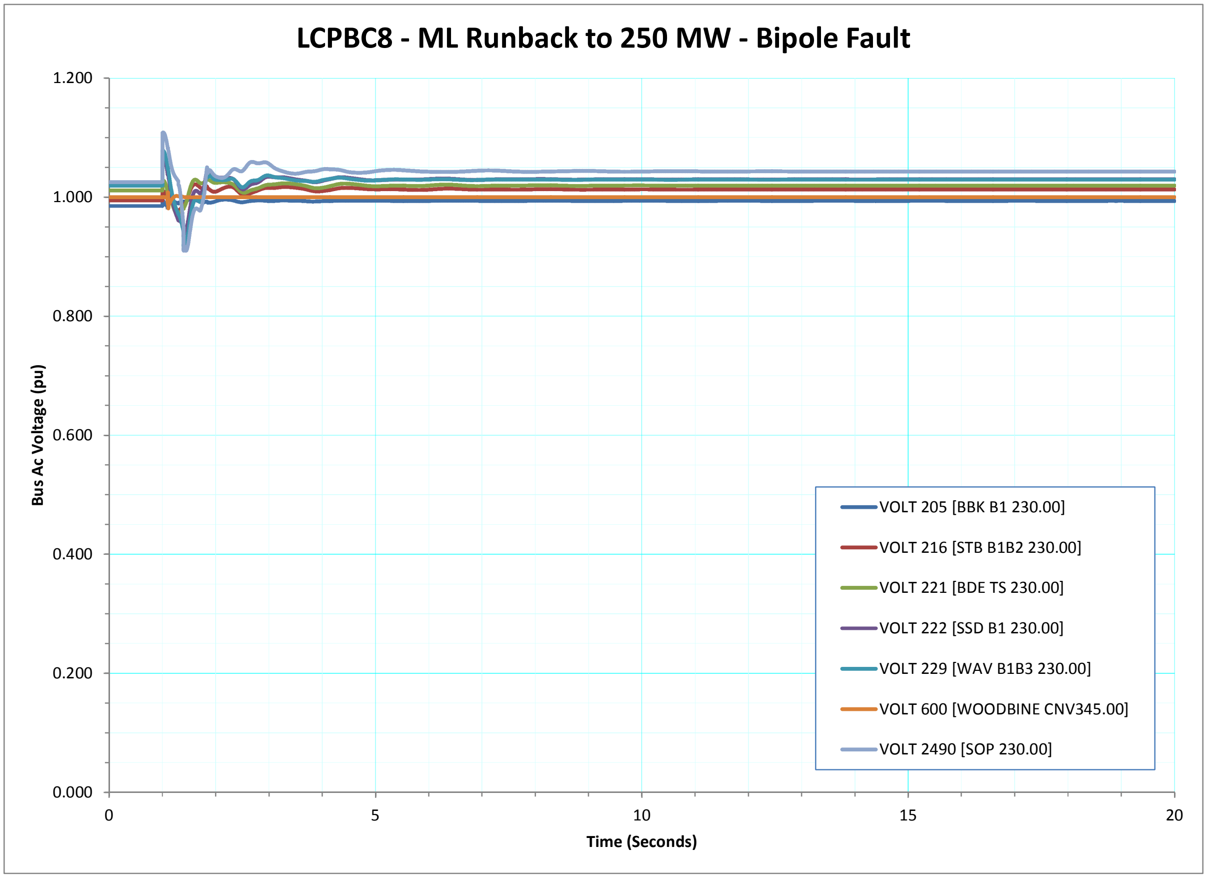


Figure 266 - LCPBC8 - ML Runback to 250 MW - Bipole Fault - Bus Ac Voltage (pu)

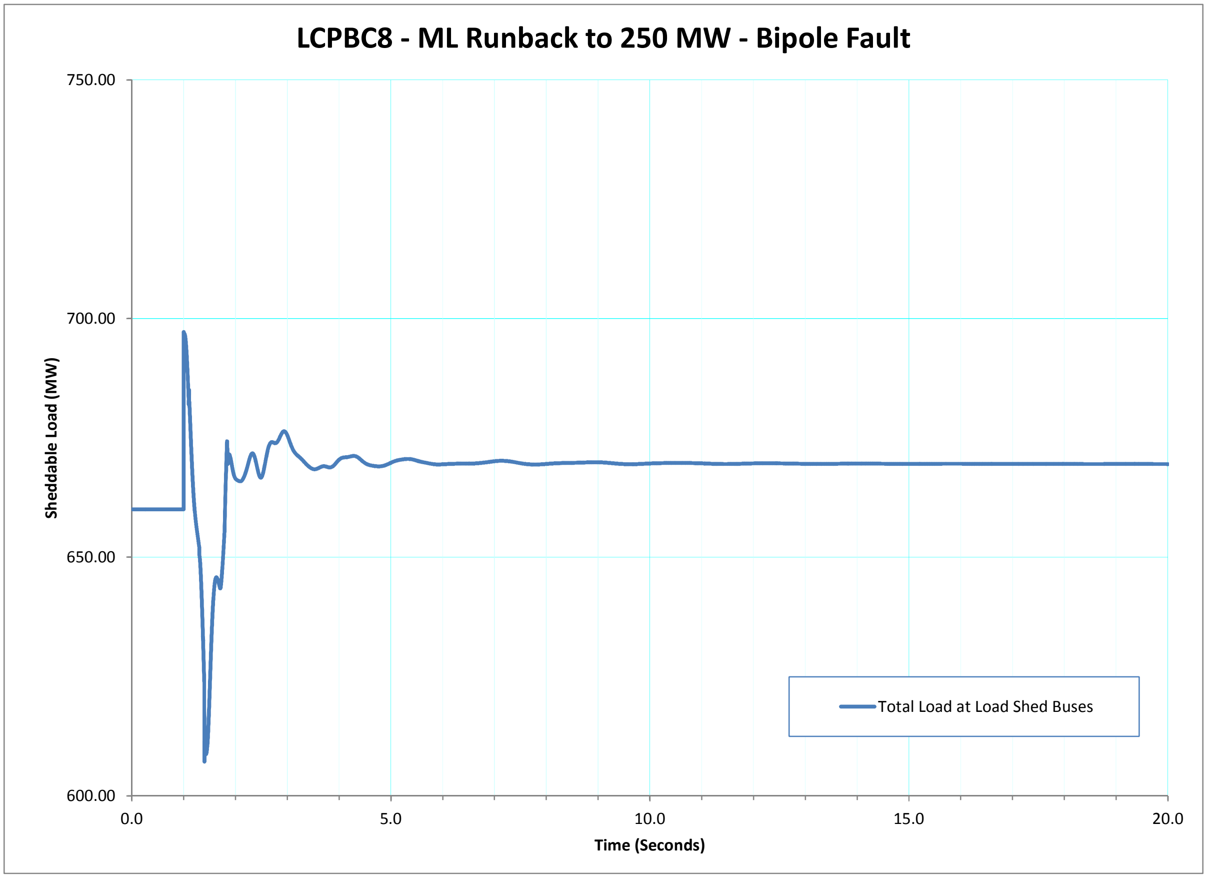


Figure 267 - LCPBC8 - ML Runback to 250 MW - Bipole Fault - Sheddable Load (MW)

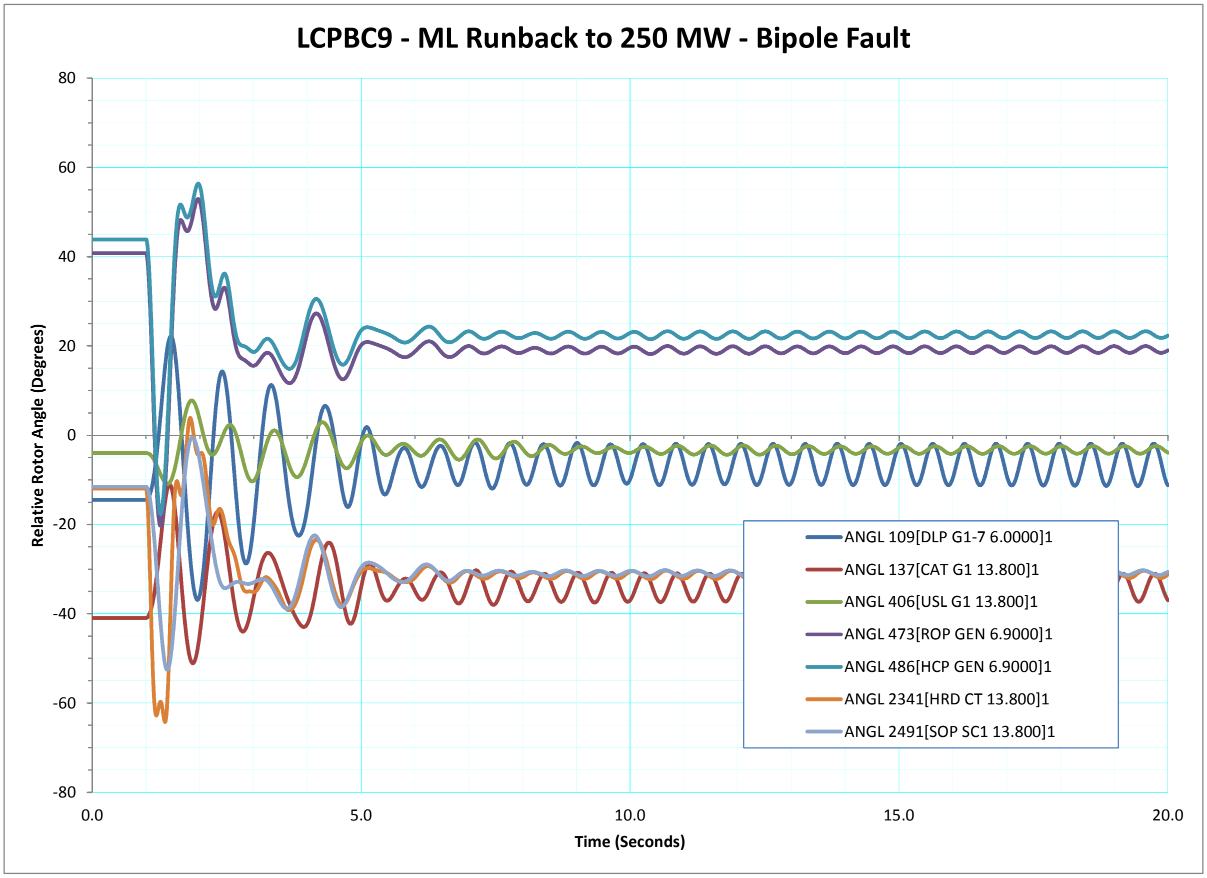


Figure 268 - LCPBC9 - ML Runback to 250 MW - Bipole Fault - Relative Rotor Angle (Degrees)

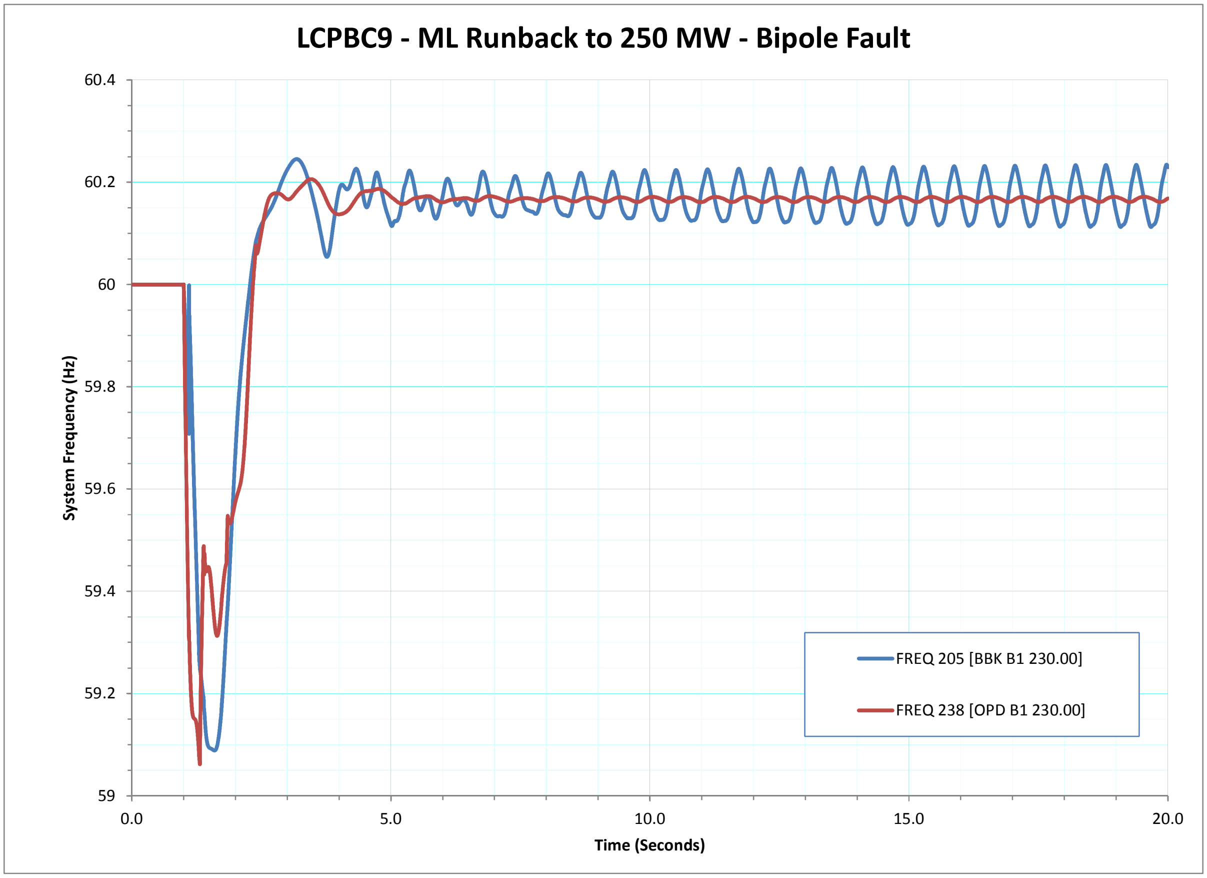


Figure 269 - LCPBC9 - ML Runback to 250 MW - Bipole Fault - System Frequency (Hz)

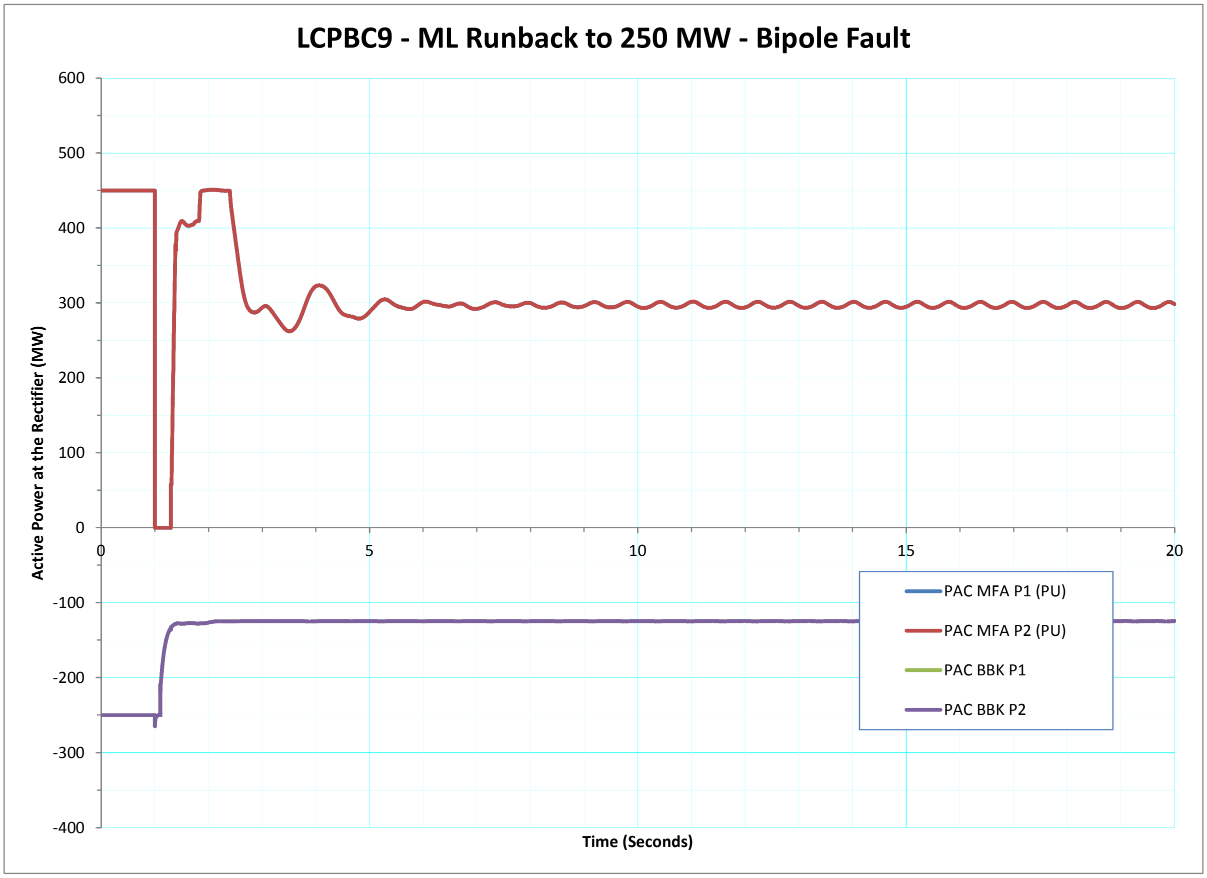


Figure 270 - LCPBC9 - ML Runback to 250 MW - Bipole Fault - Active Power at the Rectifier (MW)

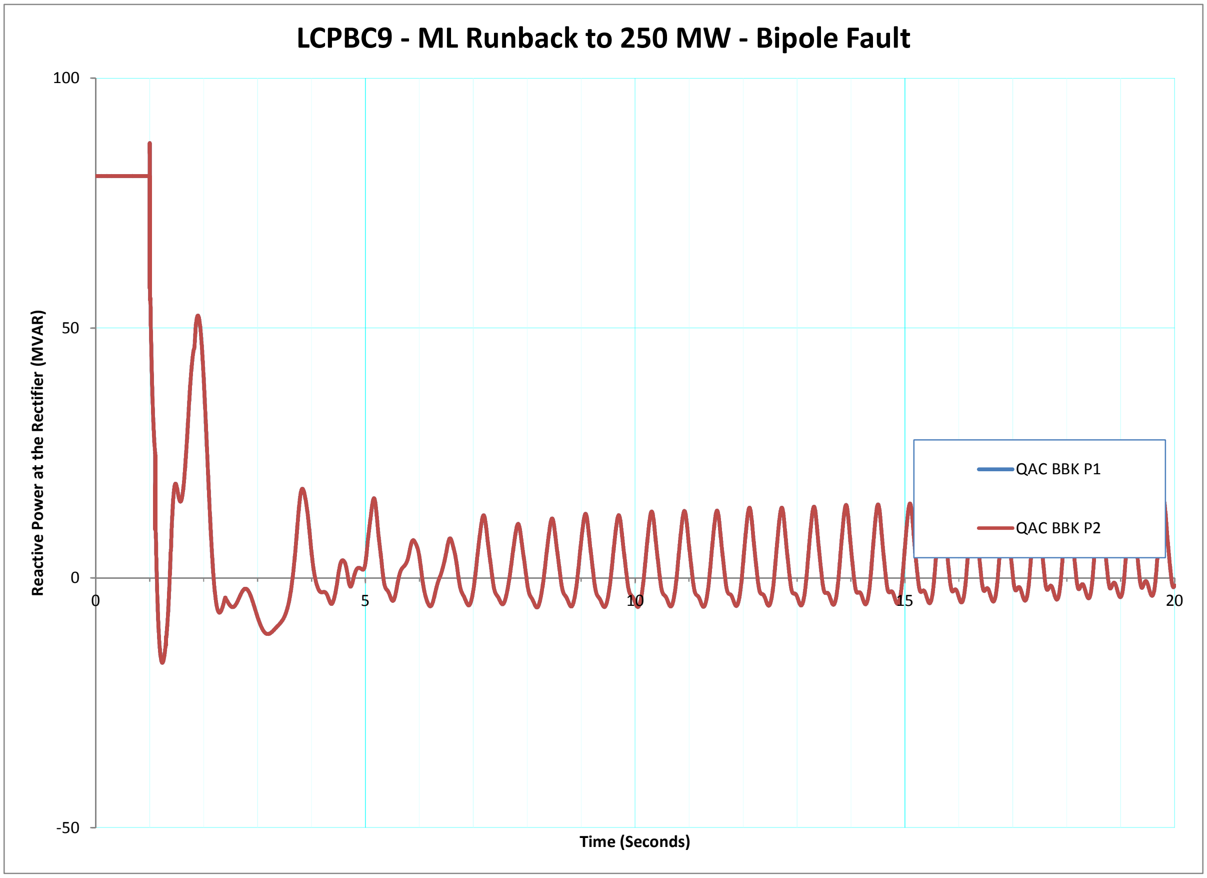


Figure 271 - LCPBC9 - ML Runback to 250 MW - Bipole Fault - Reactive Power at the Rectifier (MVAR)

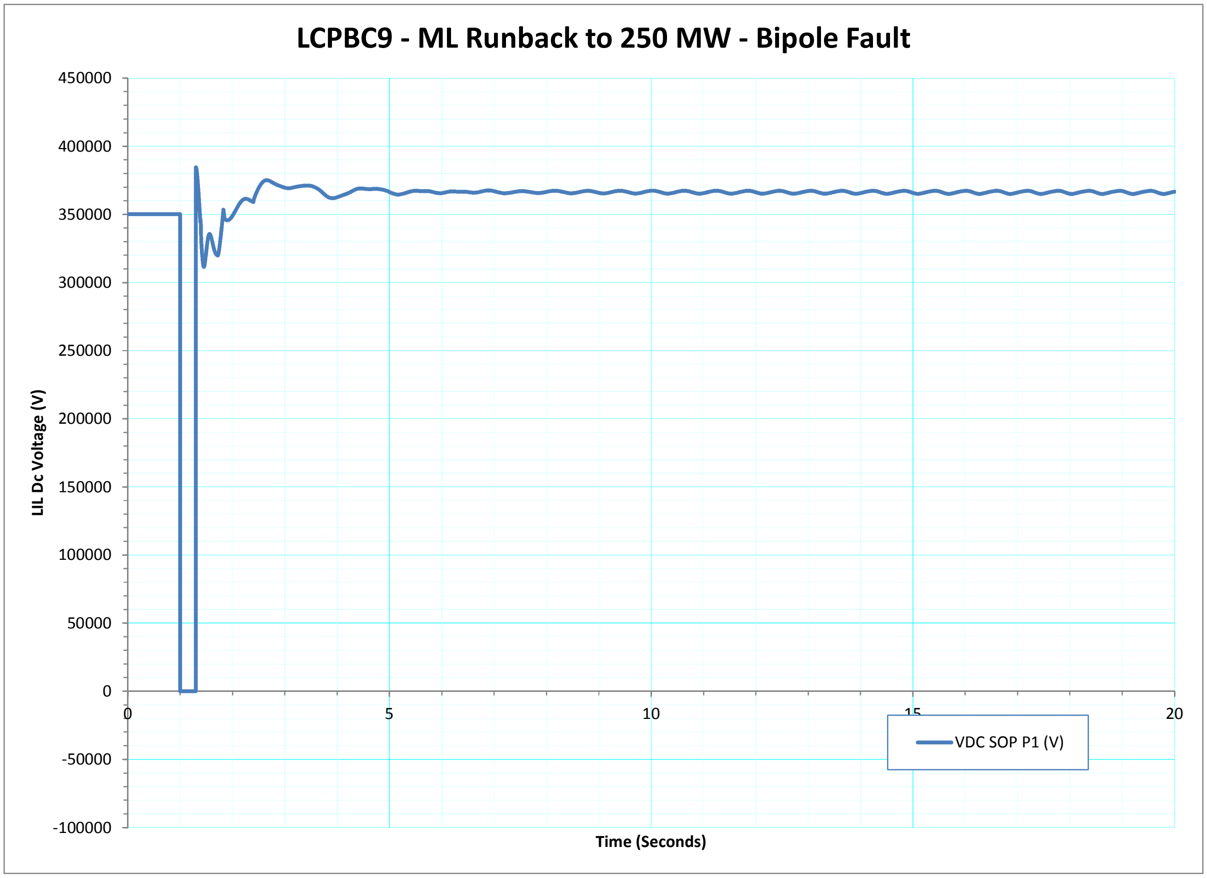


Figure 272 - LCPBC9 - ML Runback to 250 MW - Bipole Fault - LIL Dc Voltage (V)

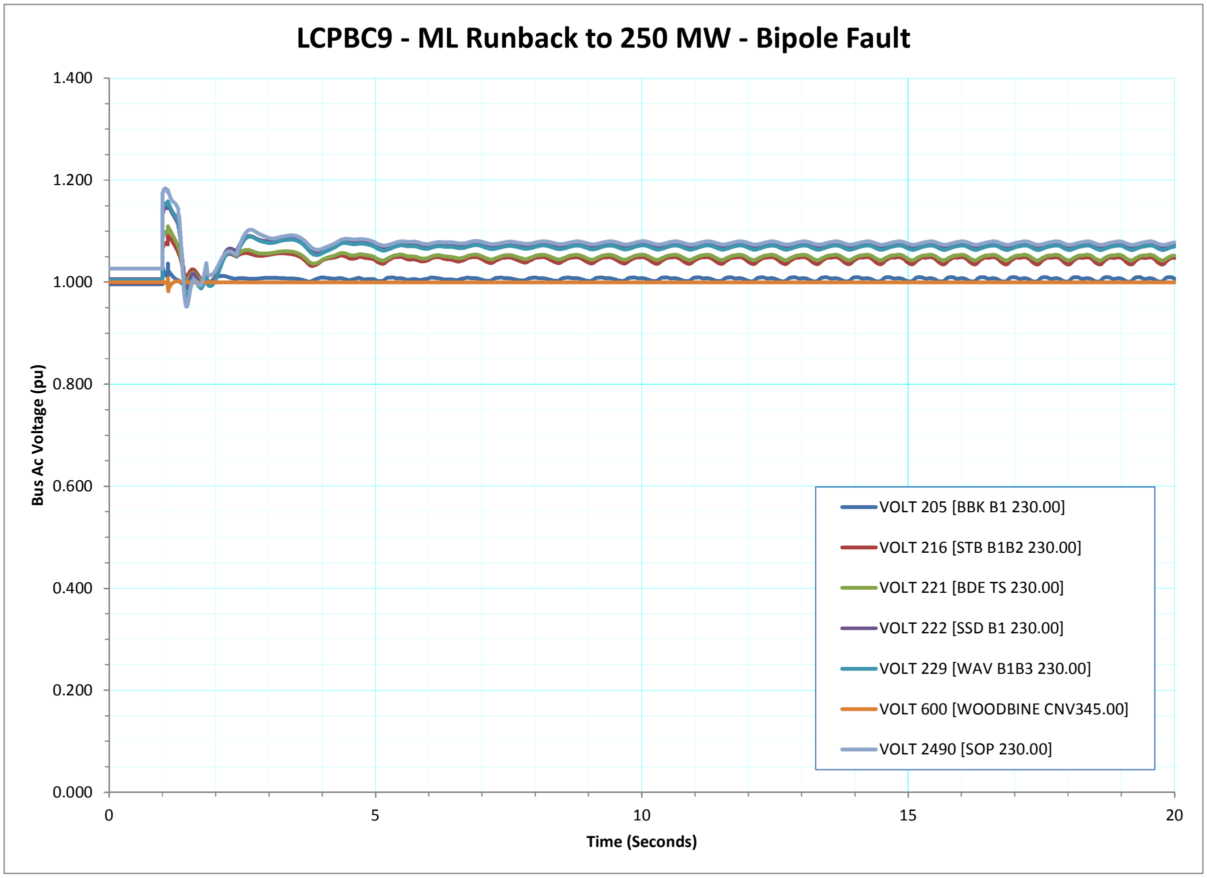


Figure 273 - LCPBC9 - ML Runback to 250 MW - Bipole Fault - Bus Ac Voltage (pu)

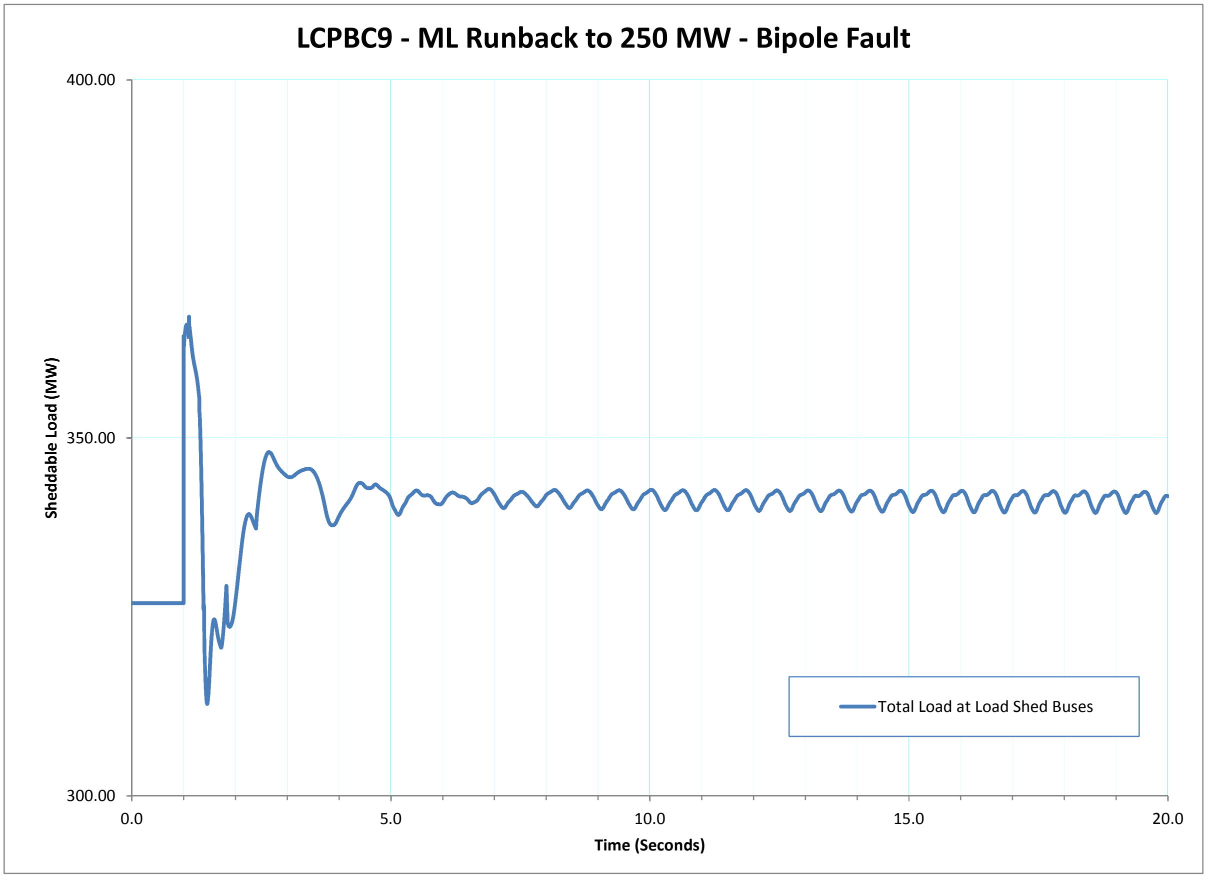


Figure 274 - LCPBC9 - ML Runback to 250 MW - Bipole Fault - Sheddable Load (MW)

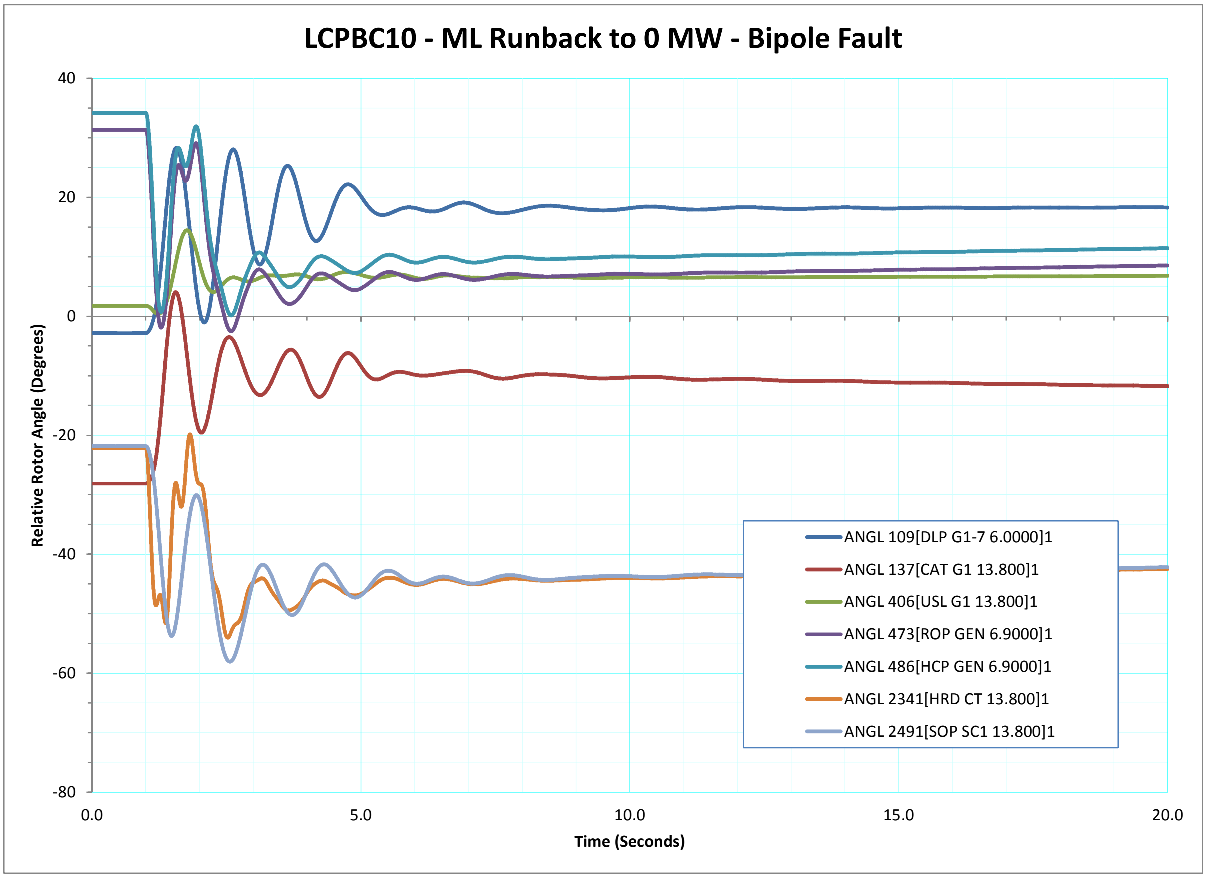


Figure 275 - LCPBC10 - ML Runback to 0 MW - Bipole Fault - Relative Rotor Angle (Degrees)

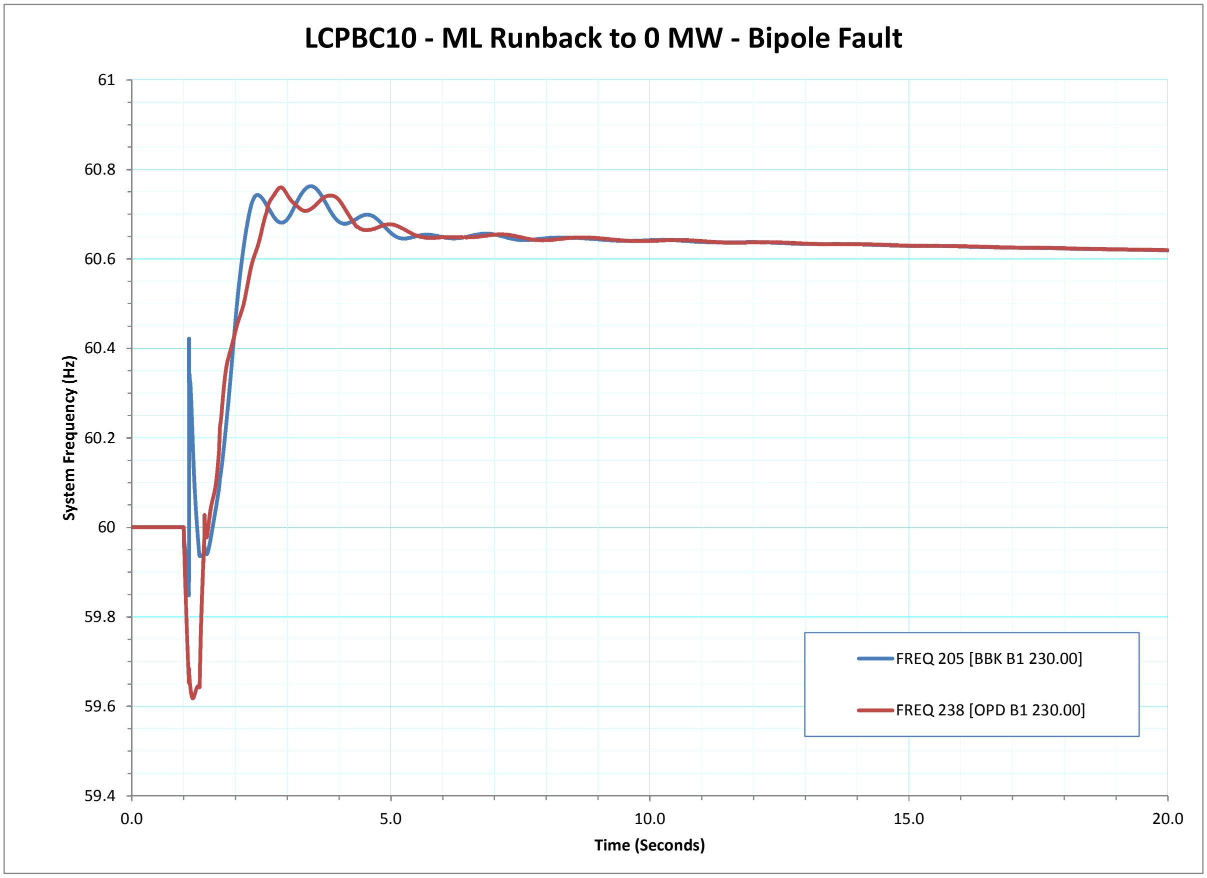


Figure 276 - LCPBC10 - ML Runback to 0 MW - Bipole Fault - System Frequency (Hz)

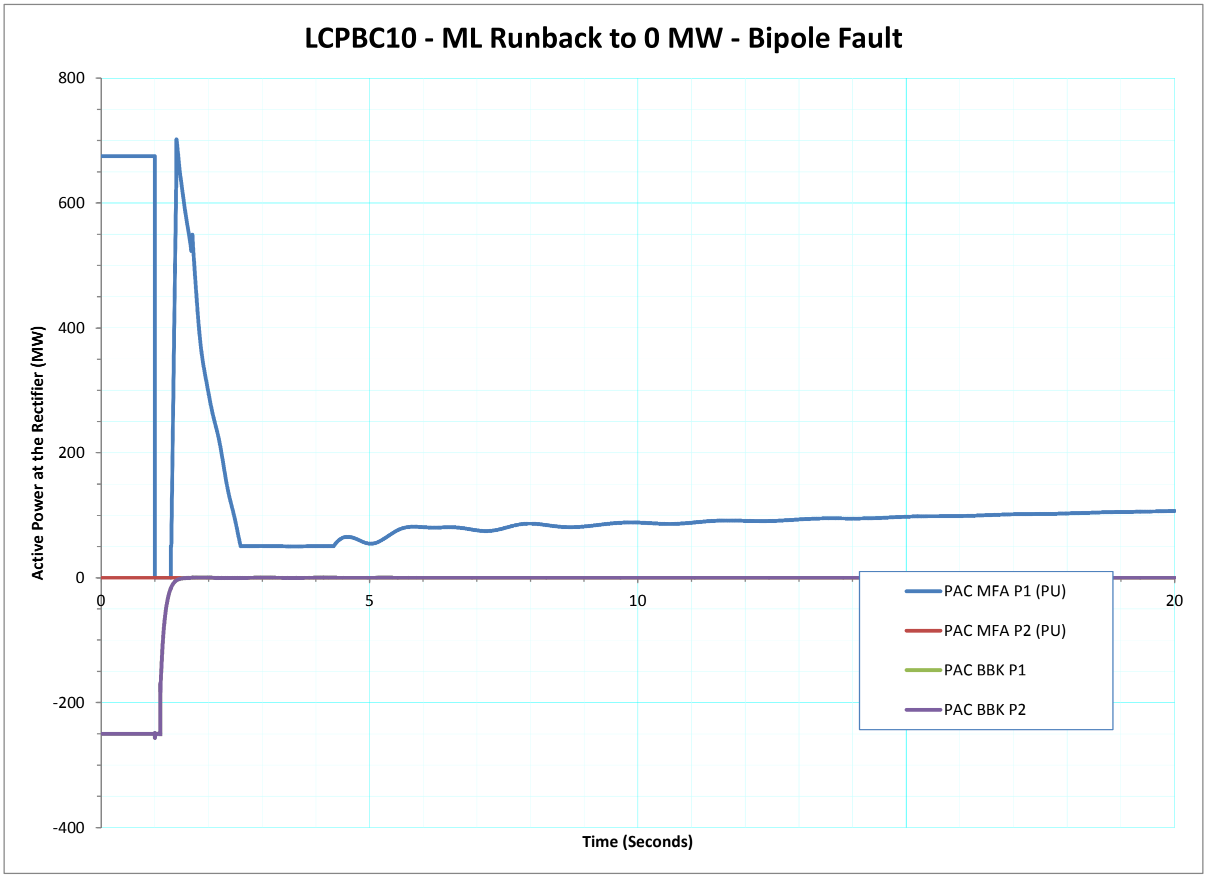


Figure 277 - LCPBC10 - ML Runback to 0 MW - Bipole Fault - Active Power at the Rectifier (MW)

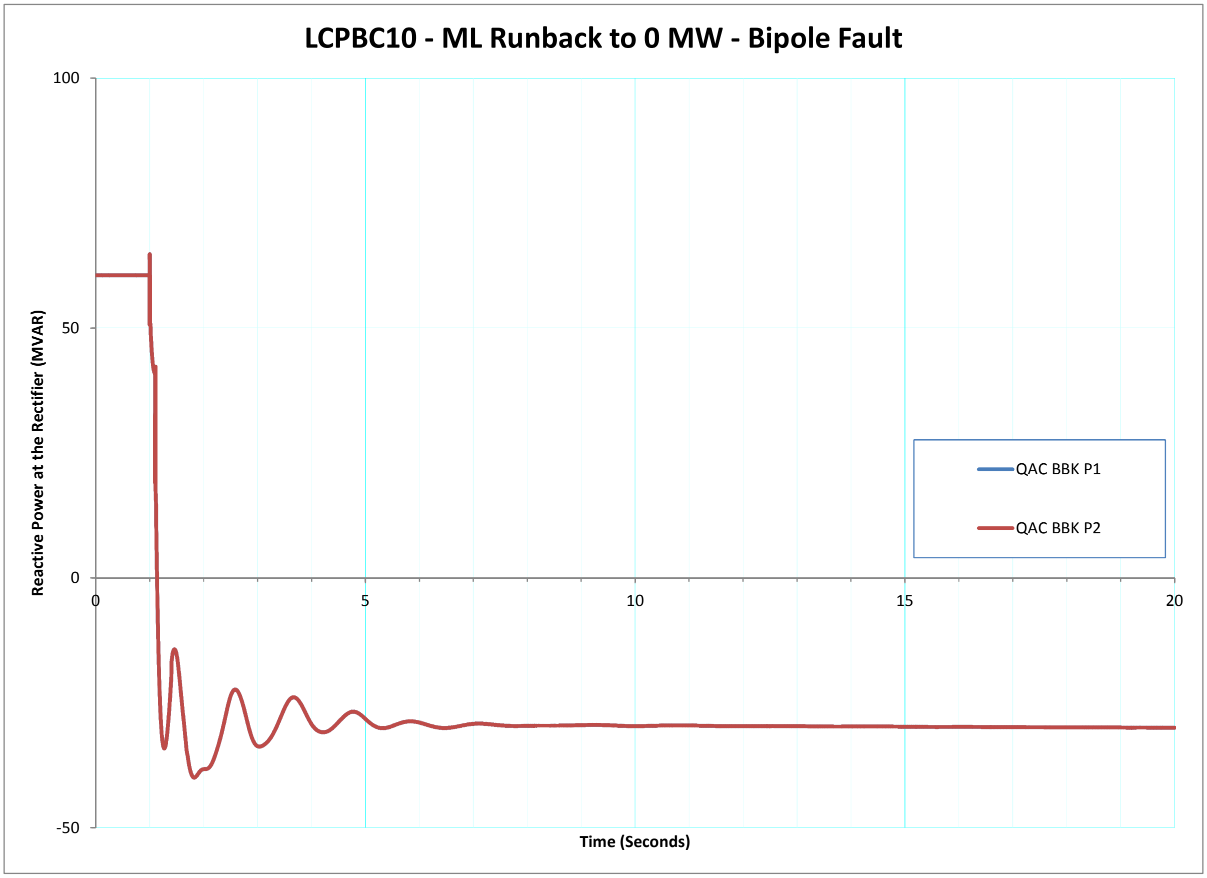


Figure 278 - LCPBC10 - ML Runback to 0 MW - Bipole Fault - Reactive Power at the Rectifier (MVAR)

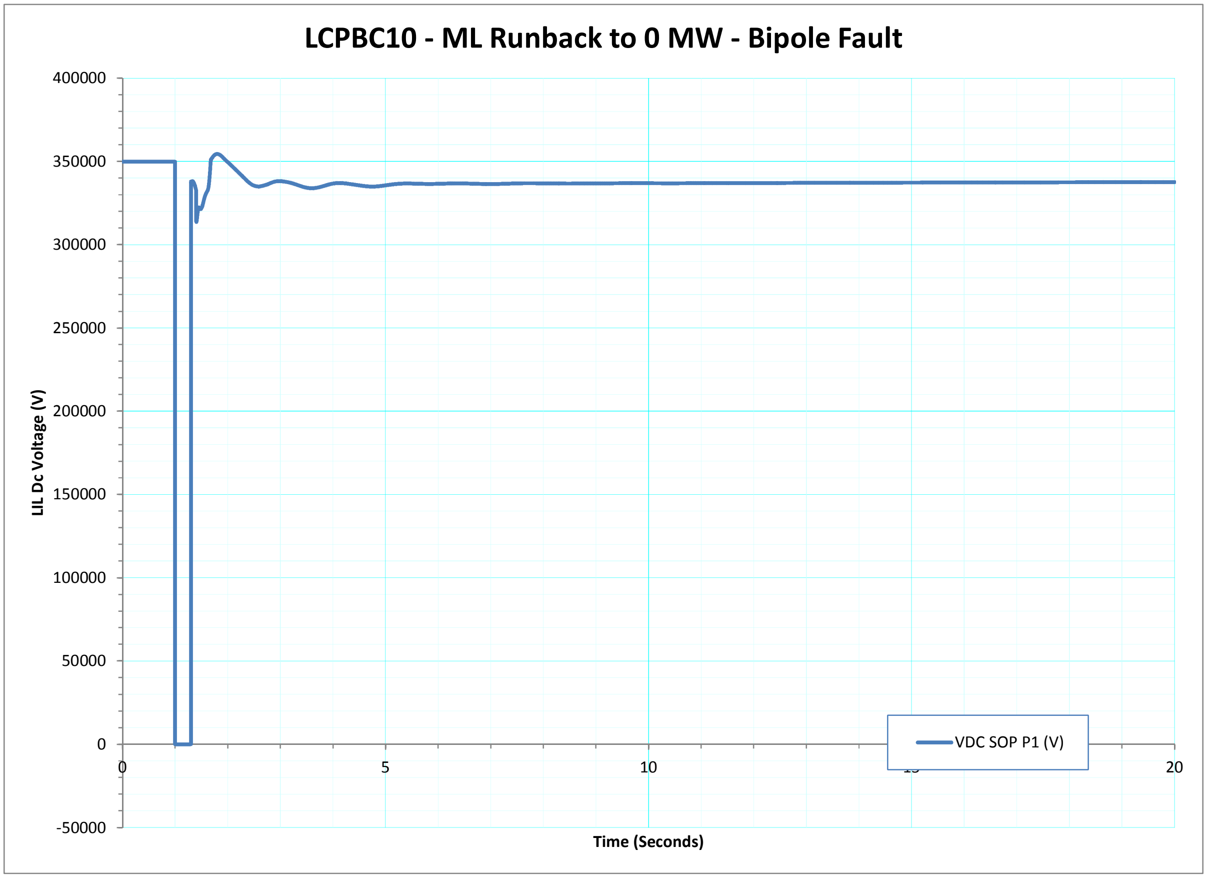


Figure 279 - LCPBC10 - ML Runback to 0 MW - Bipole Fault - LIL Dc Voltage (V)

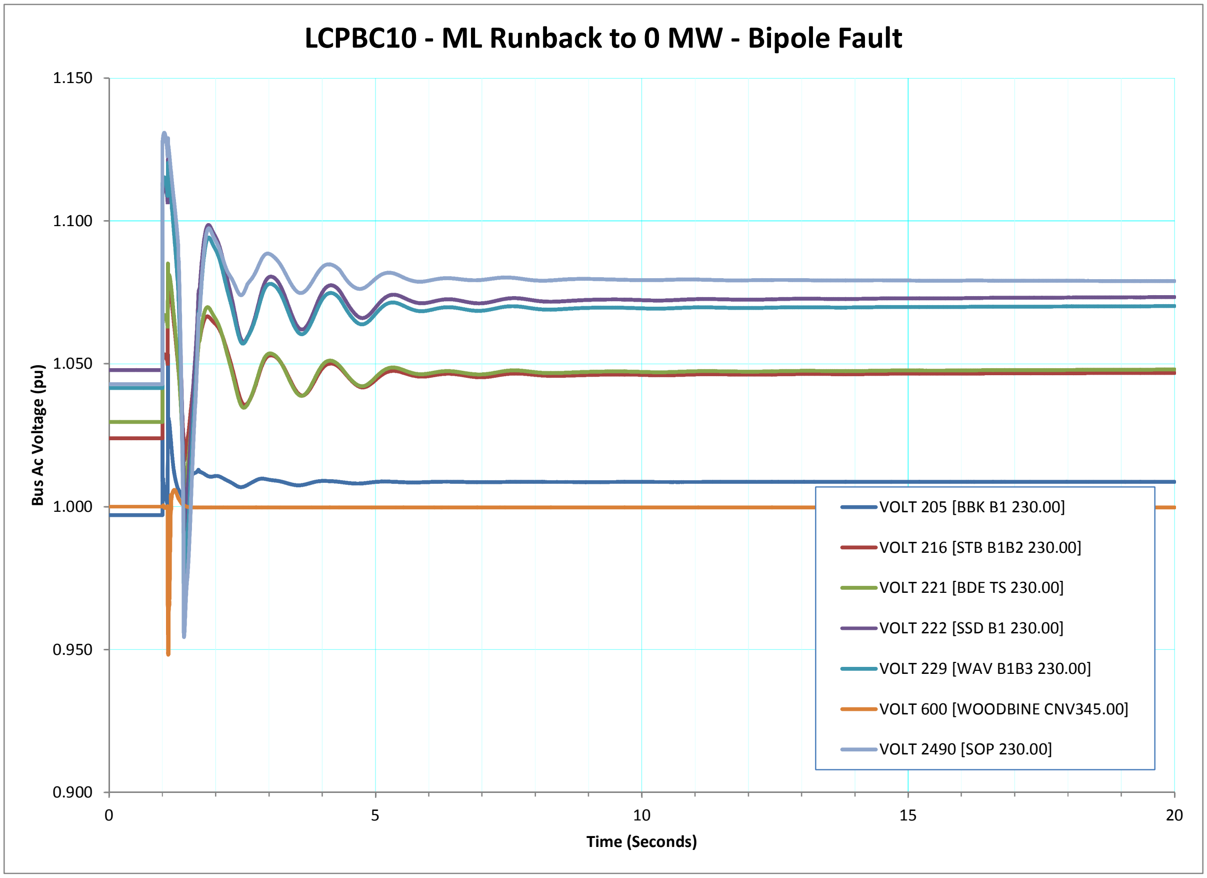


Figure 280 - LCPBC10 - ML Runback to 0 MW - Bipole Fault - Bus Ac Voltage (pu)

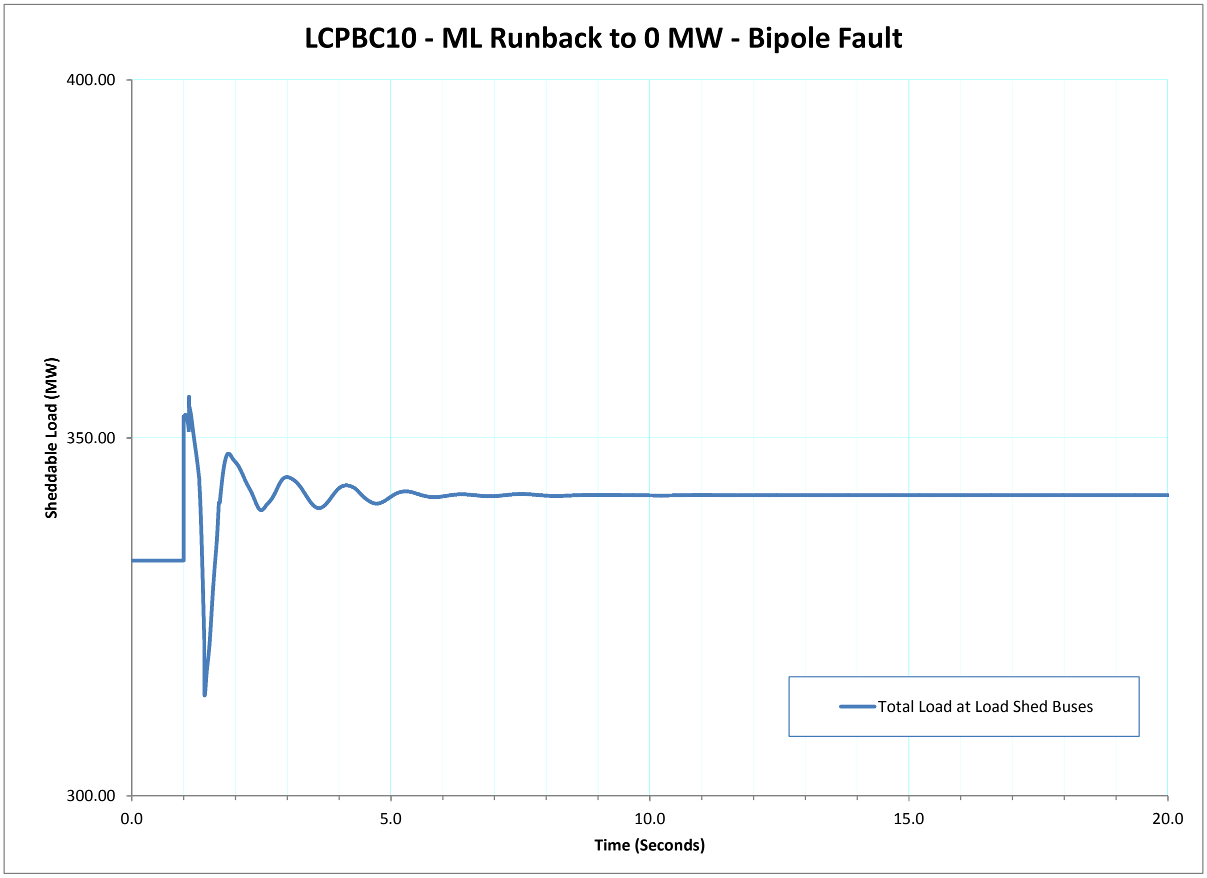


Figure 281 - LCPBC10 - ML Runback to 0 MW - Bipole Fault - Sheddable Load (MW)

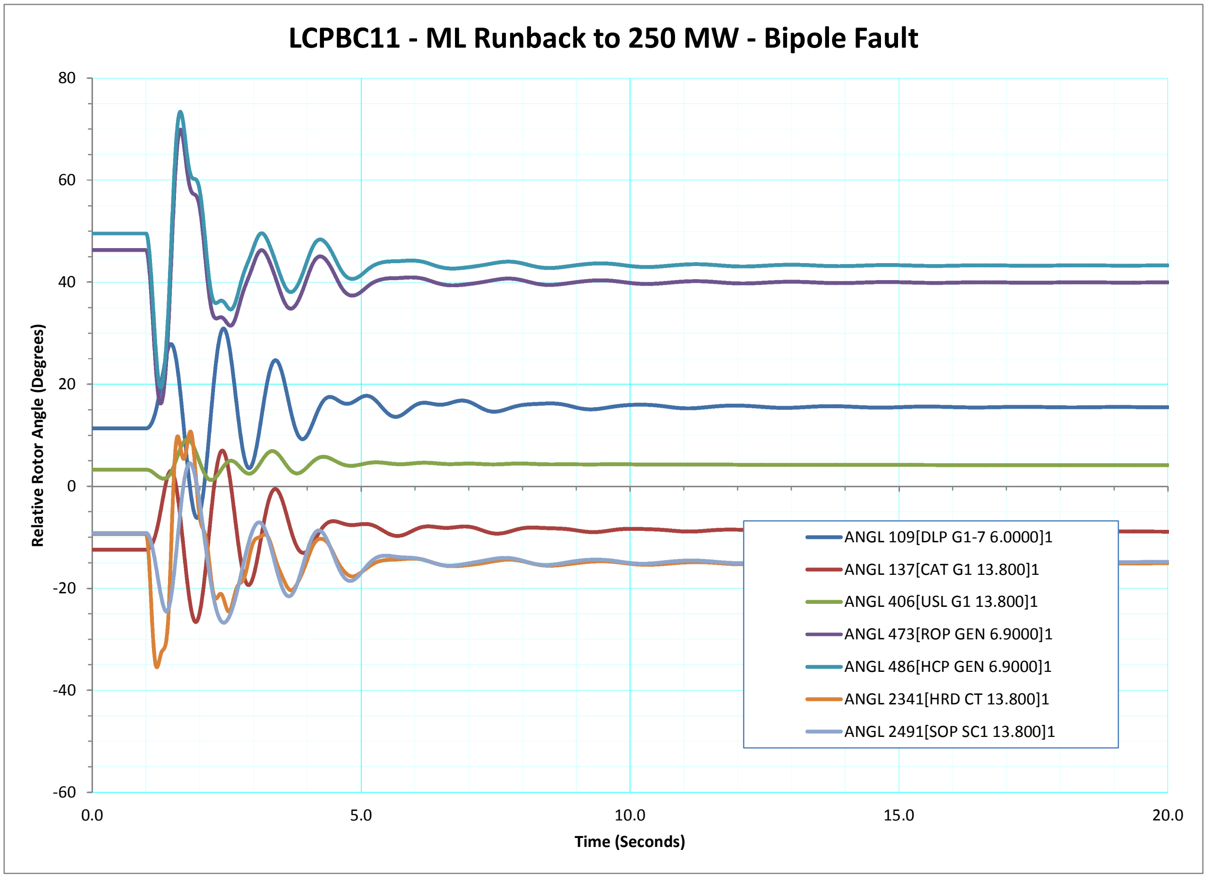


Figure 282 - LCPBC11 - ML Runback to 250 MW - Bipole Fault - Relative Rotor Angle (Degrees)

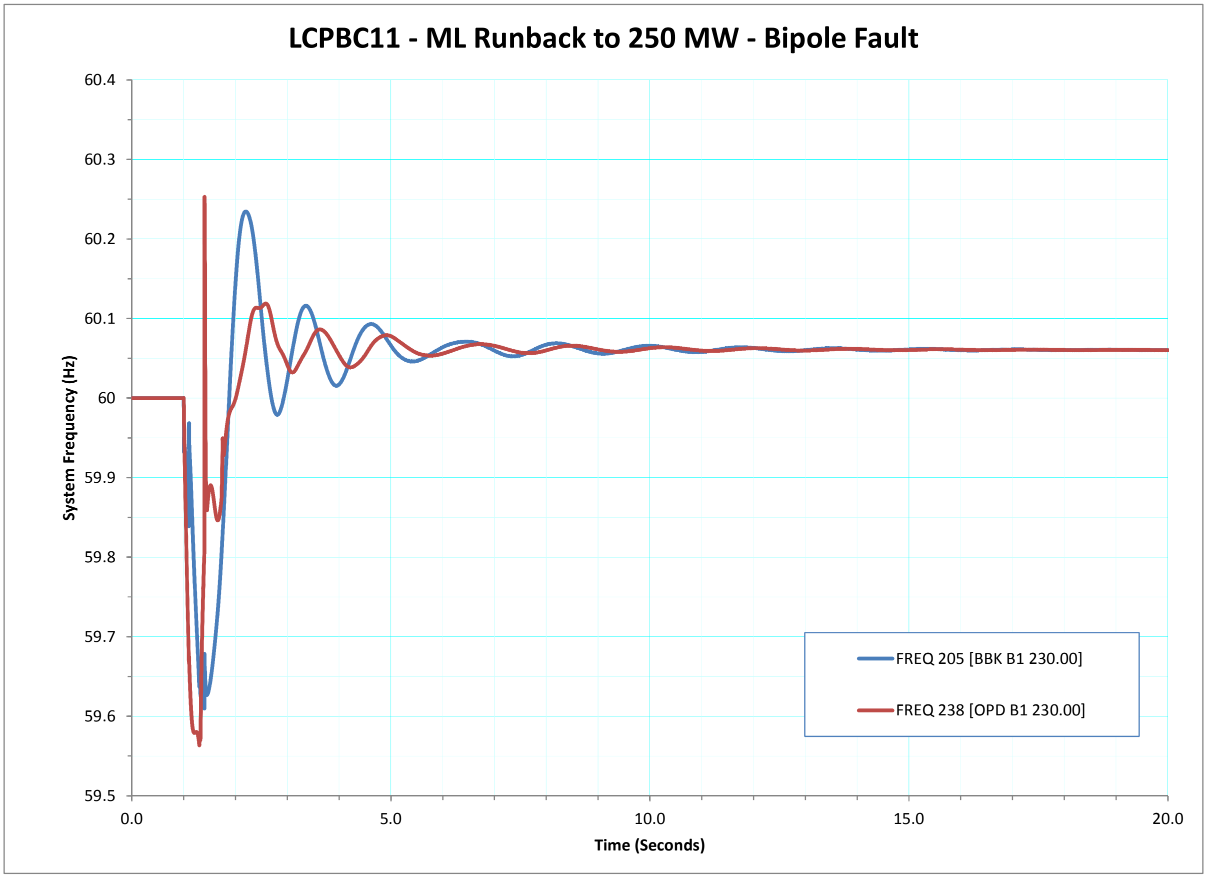


Figure 283 - LCPBC11 - ML Runback to 250 MW - Bipole Fault - System Frequency (Hz)

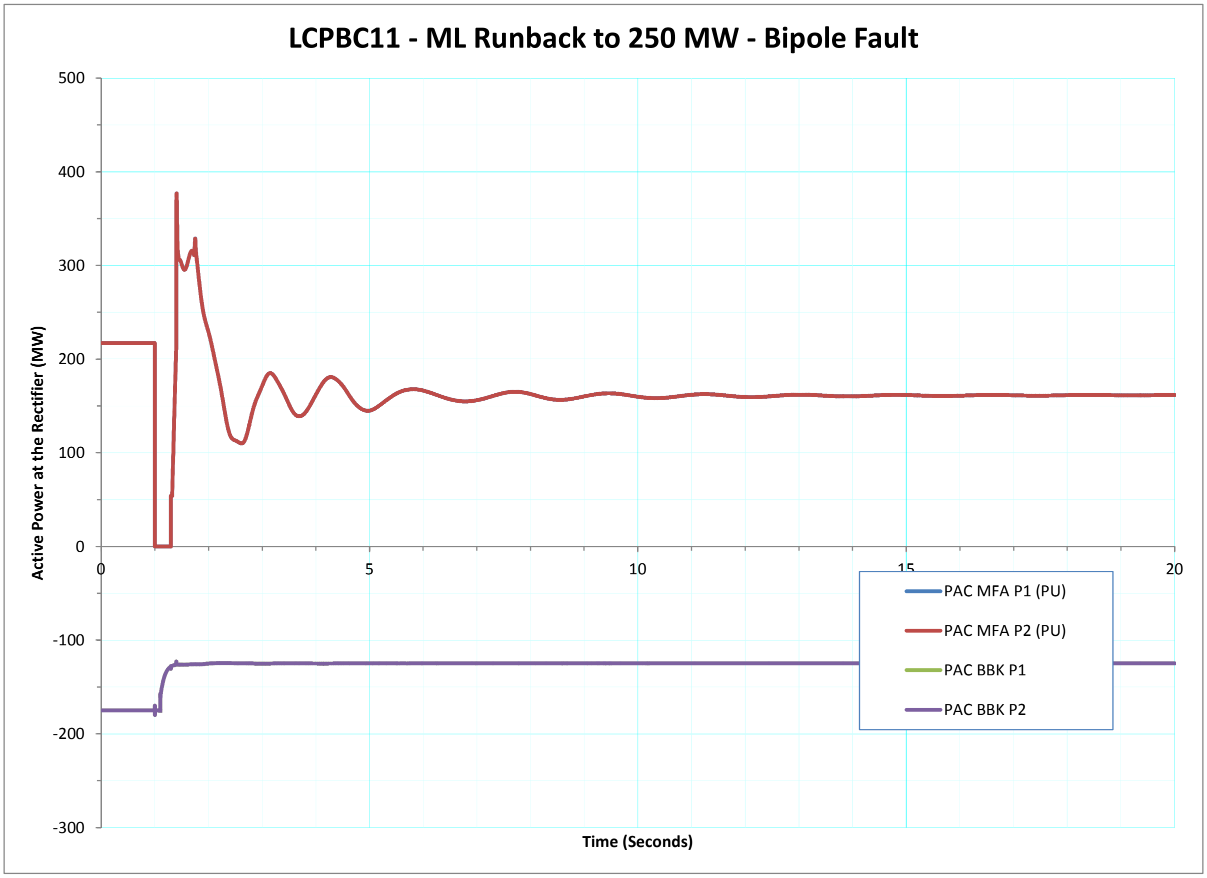


Figure 284 - LCPBC11 - ML Runback to 250 MW - Bipole Fault - Active Power at the Rectifier (MW)

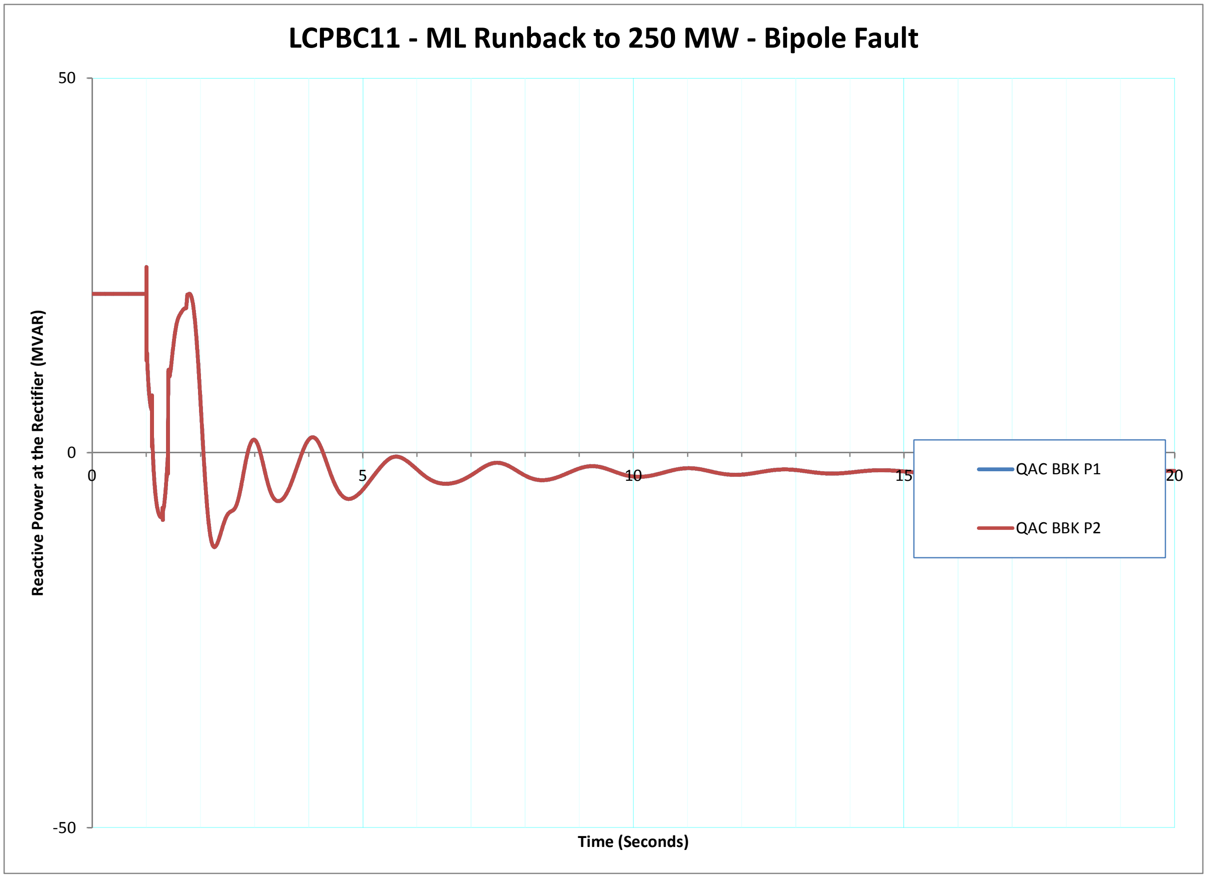


Figure 285 - LCPBC11 - ML Runback to 250 MW - Bipole Fault - Reactive Power at the Rectifier (MVAR)

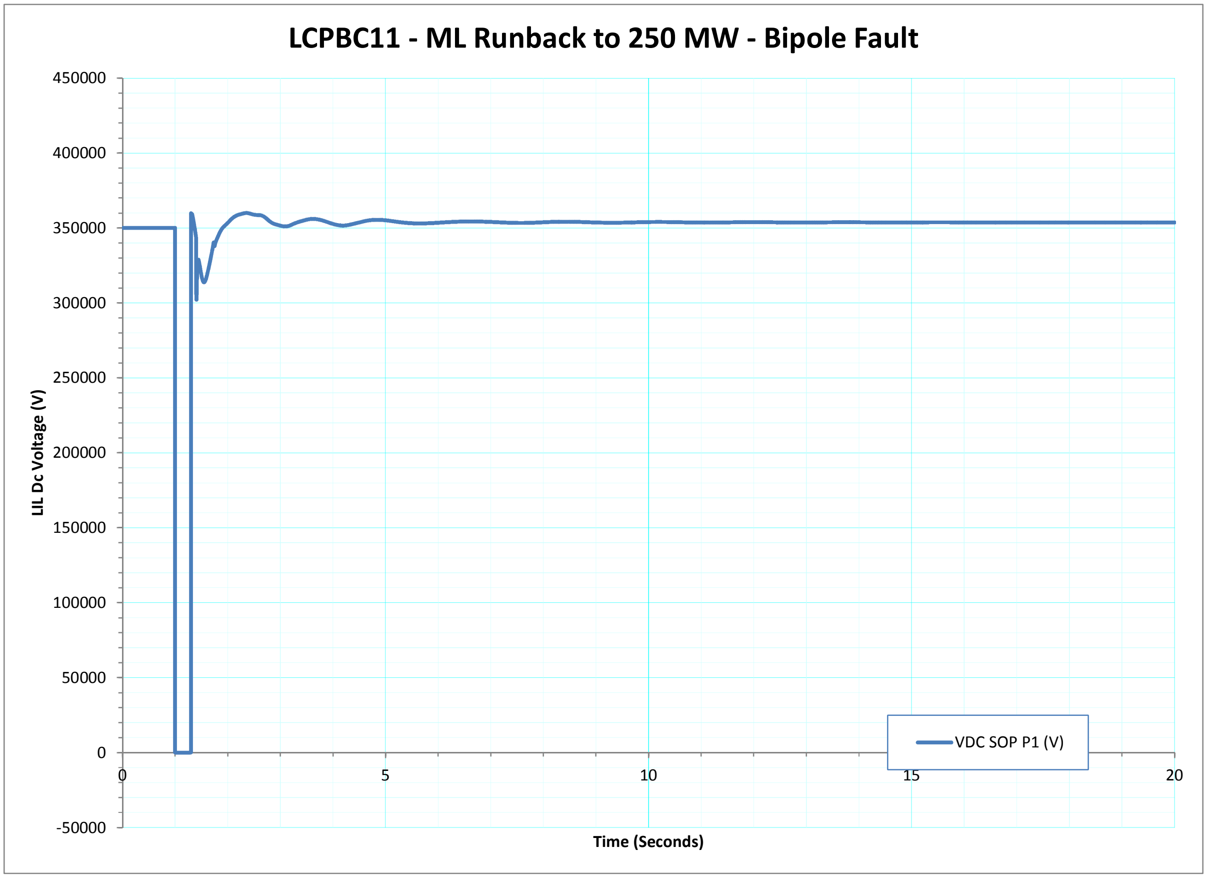


Figure 286 - LCPBC11 - ML Runback to 250 MW - Bipole Fault - LIL Dc Voltage (V)

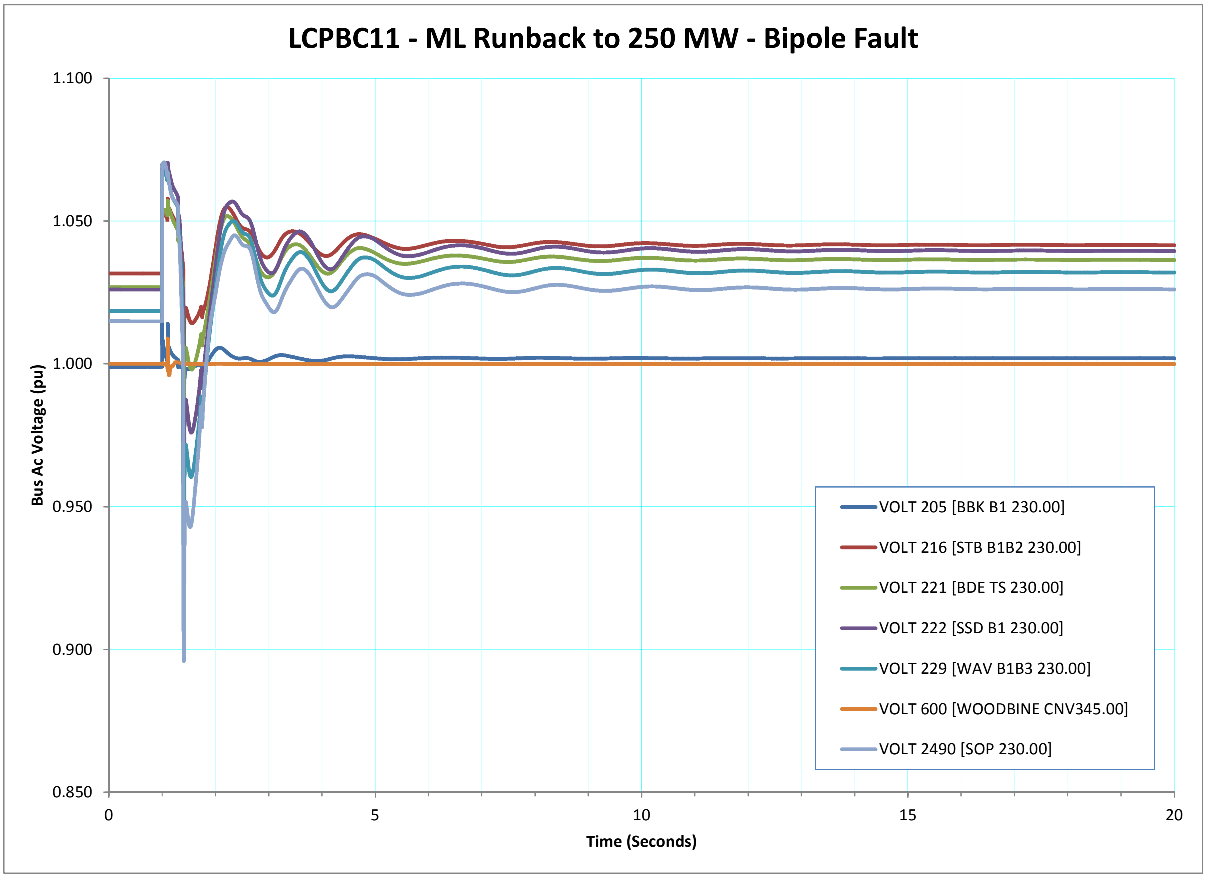


Figure 287 - LCPBC11 - ML Runback to 250 MW - Bipole Fault - Bus Ac Voltage (pu)

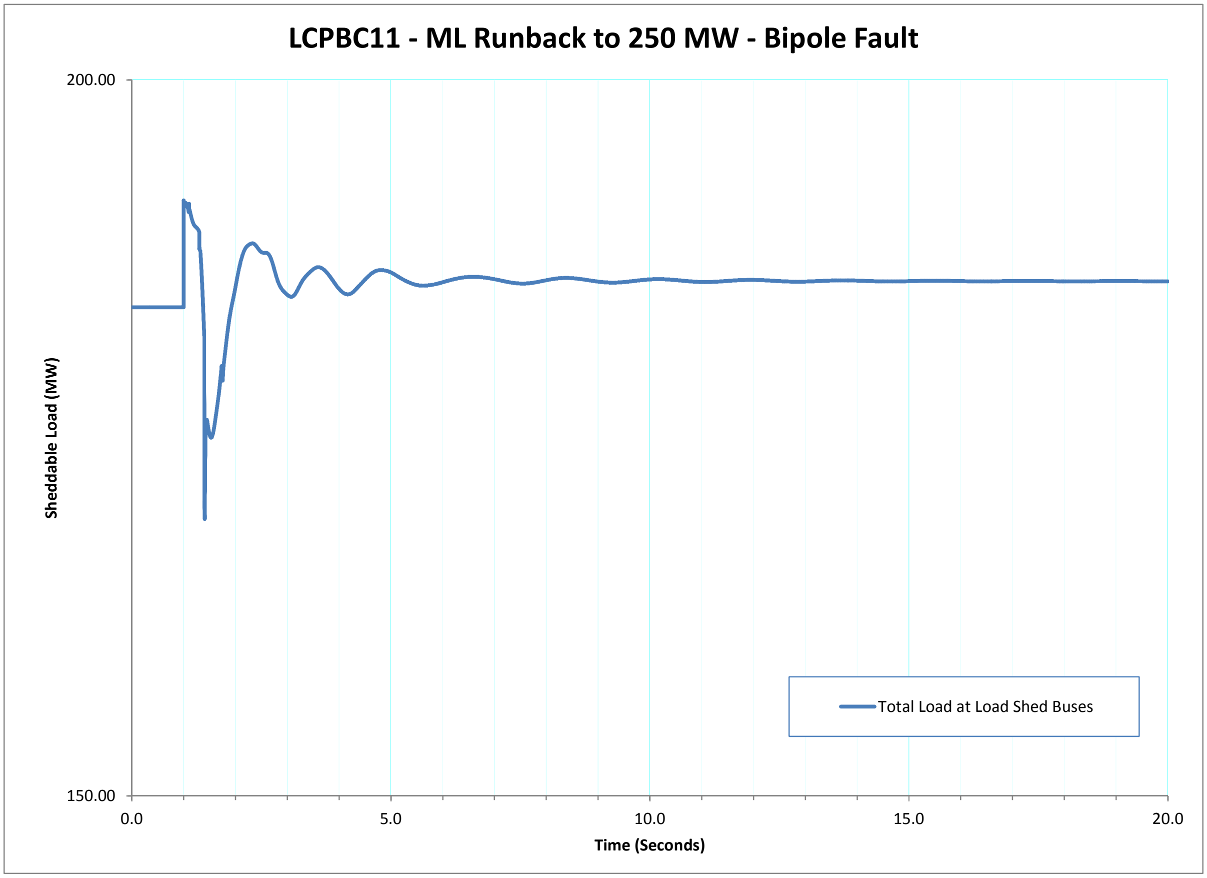


Figure 288 - LCPBC11 - ML Runback to 250 MW - Bipole Fault - Sheddable Load (MW)

APPENDIX E Remedial ML Curtailment for Permanent Pole Faults

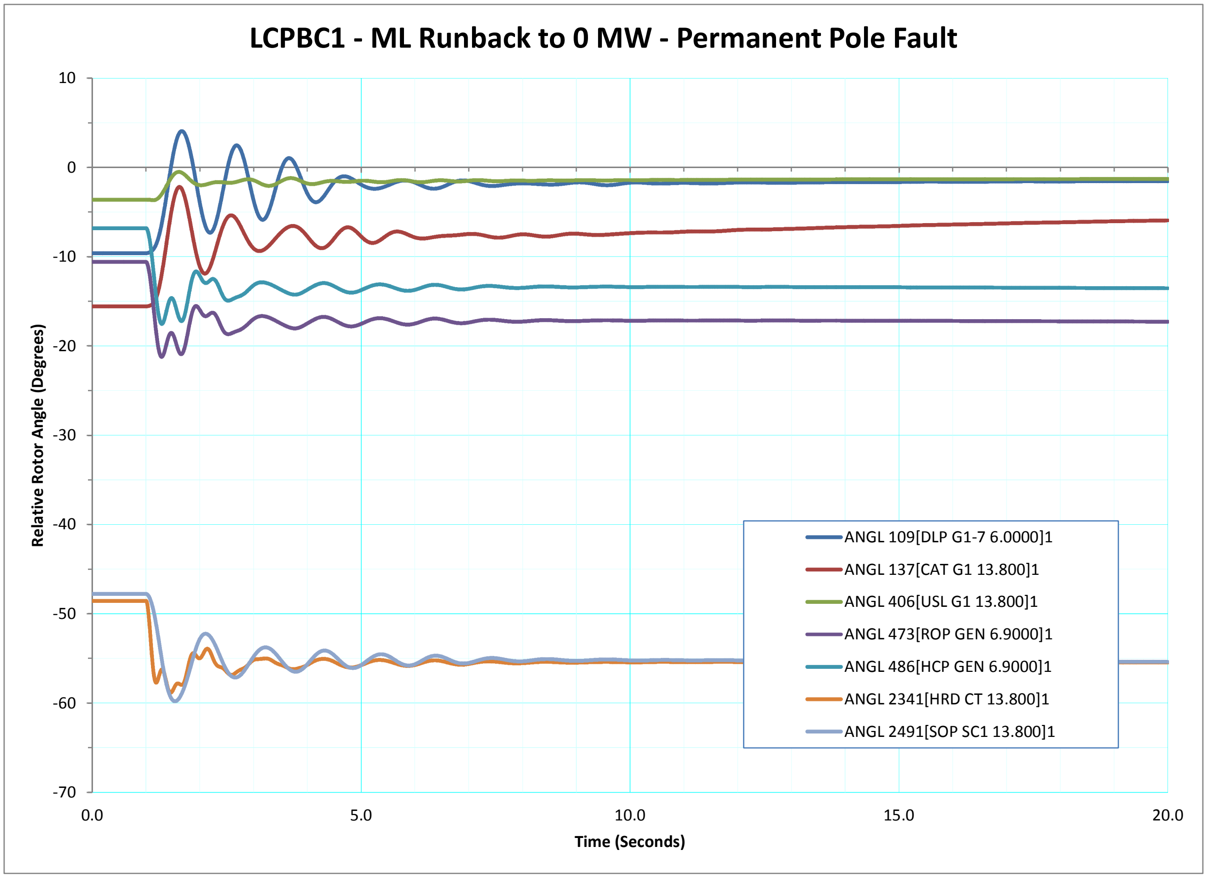


Figure 289 - LCPBC1 - ML Runback to 0 MW - Permanent Pole Fault - Relative Rotor Angle (Degrees)

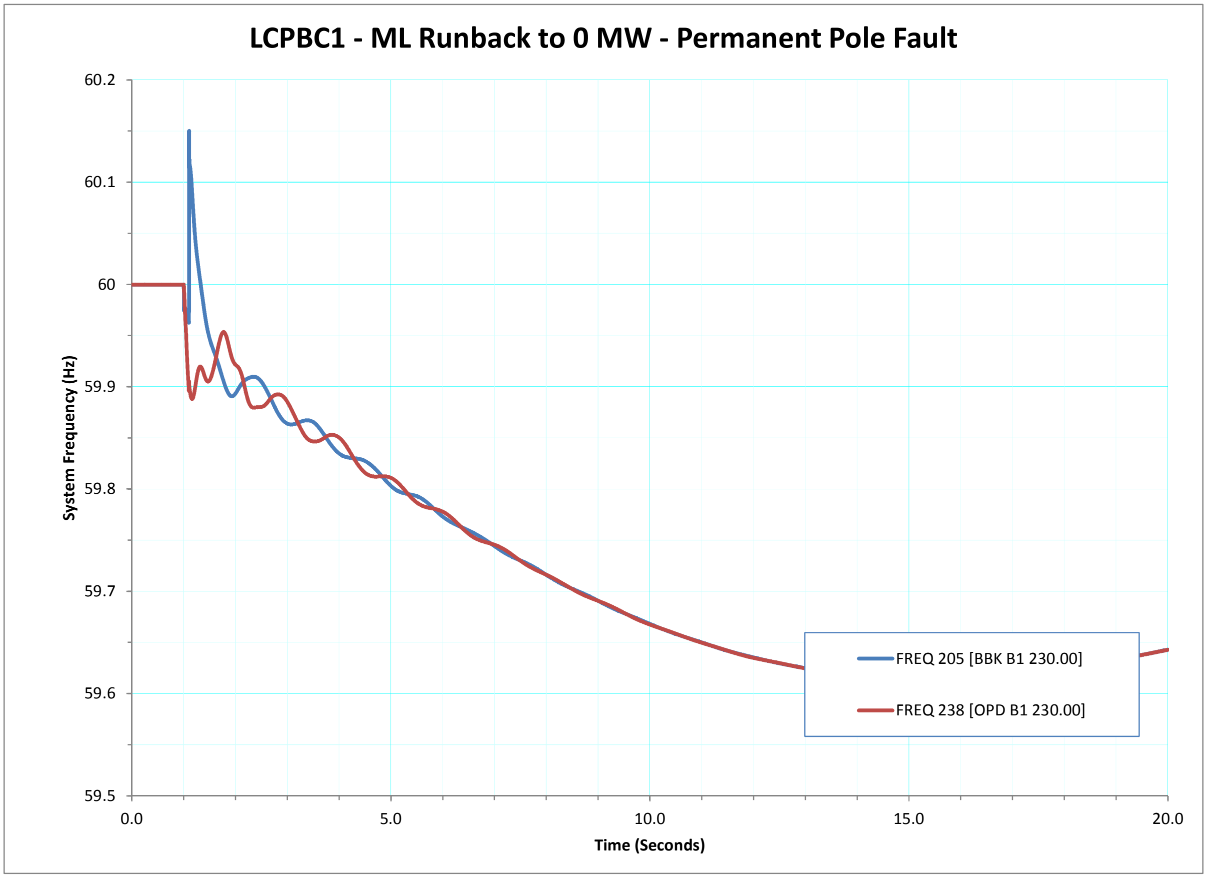


Figure 290 - LCPBC1 - ML Runback to 0 MW - Permanent Pole Fault - System Frequency (Hz)

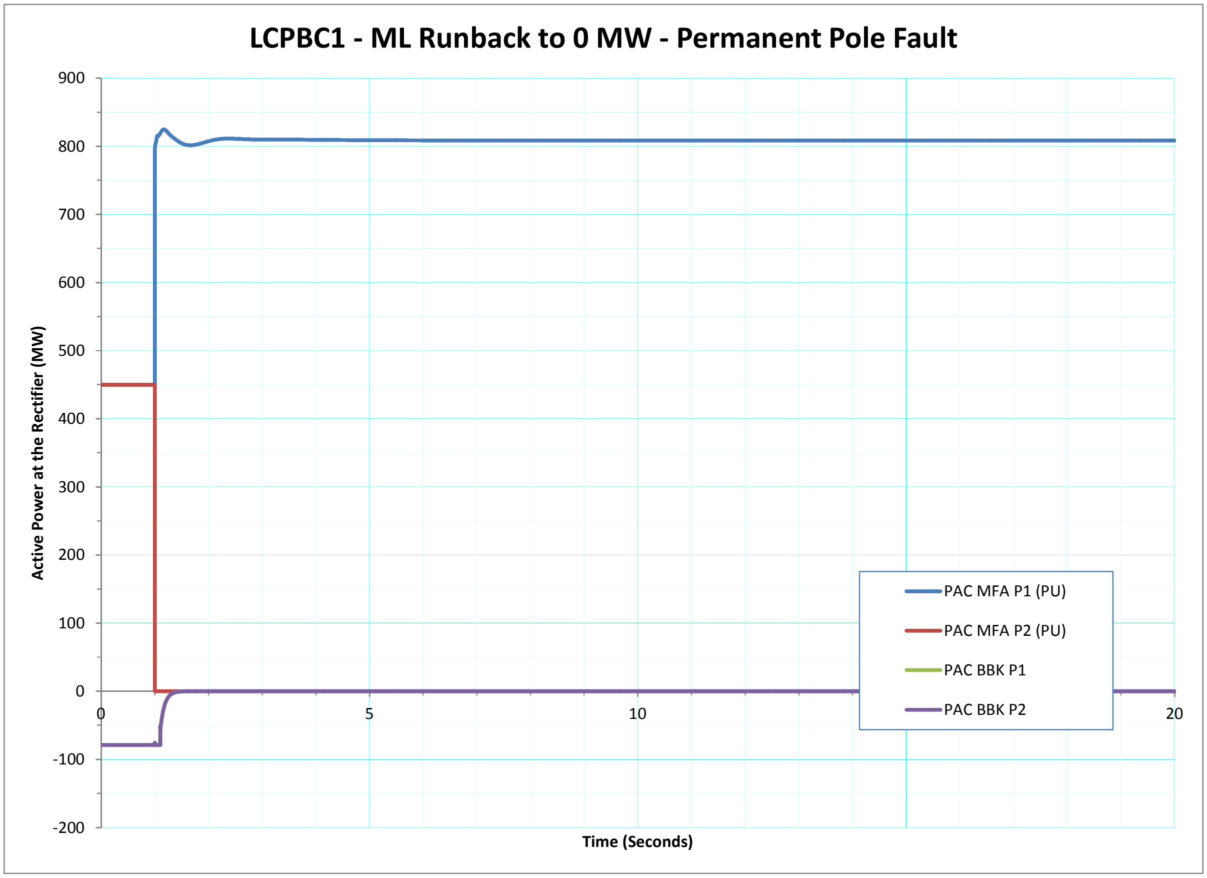


Figure 291 - LCPBC1 - ML Runback to 0 MW - Permanent Pole Fault - Active Power at the Rectifier (MW)

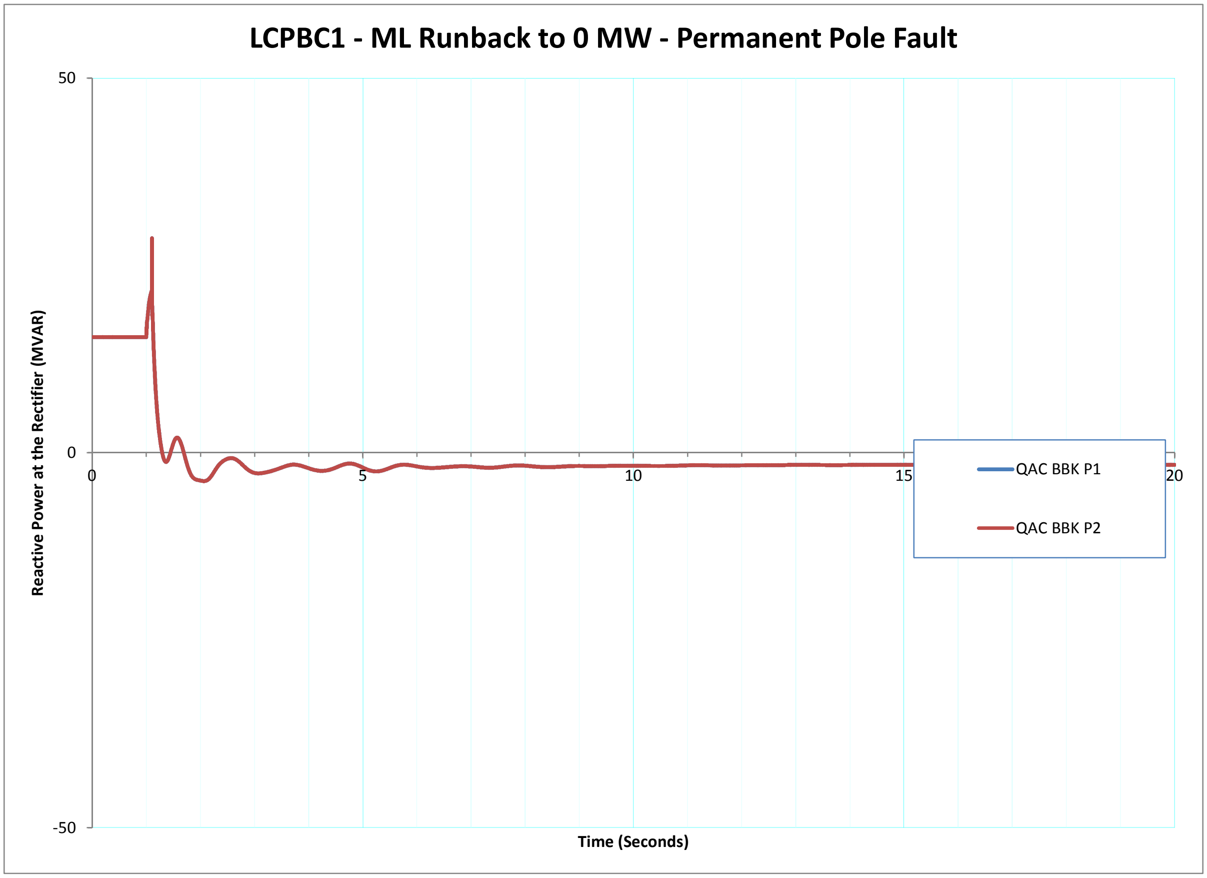


Figure 292 - LCPBC1 - ML Runback to 0 MW - Permanent Pole Fault - Reactive Power at the Rectifier (MVAR)

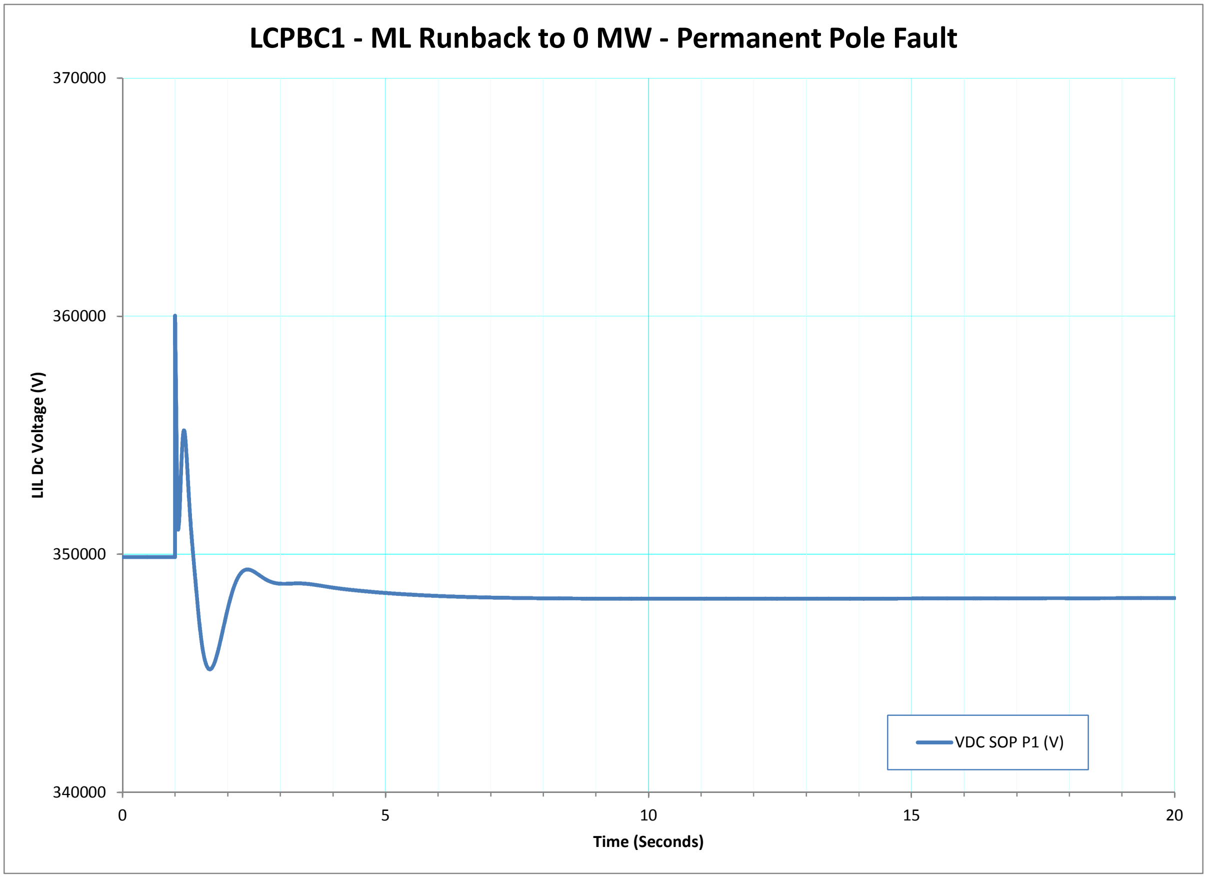


Figure 293 - LCPBC1 - ML Runback to 0 MW - Permanent Pole Fault - LIL Dc Voltage (V)

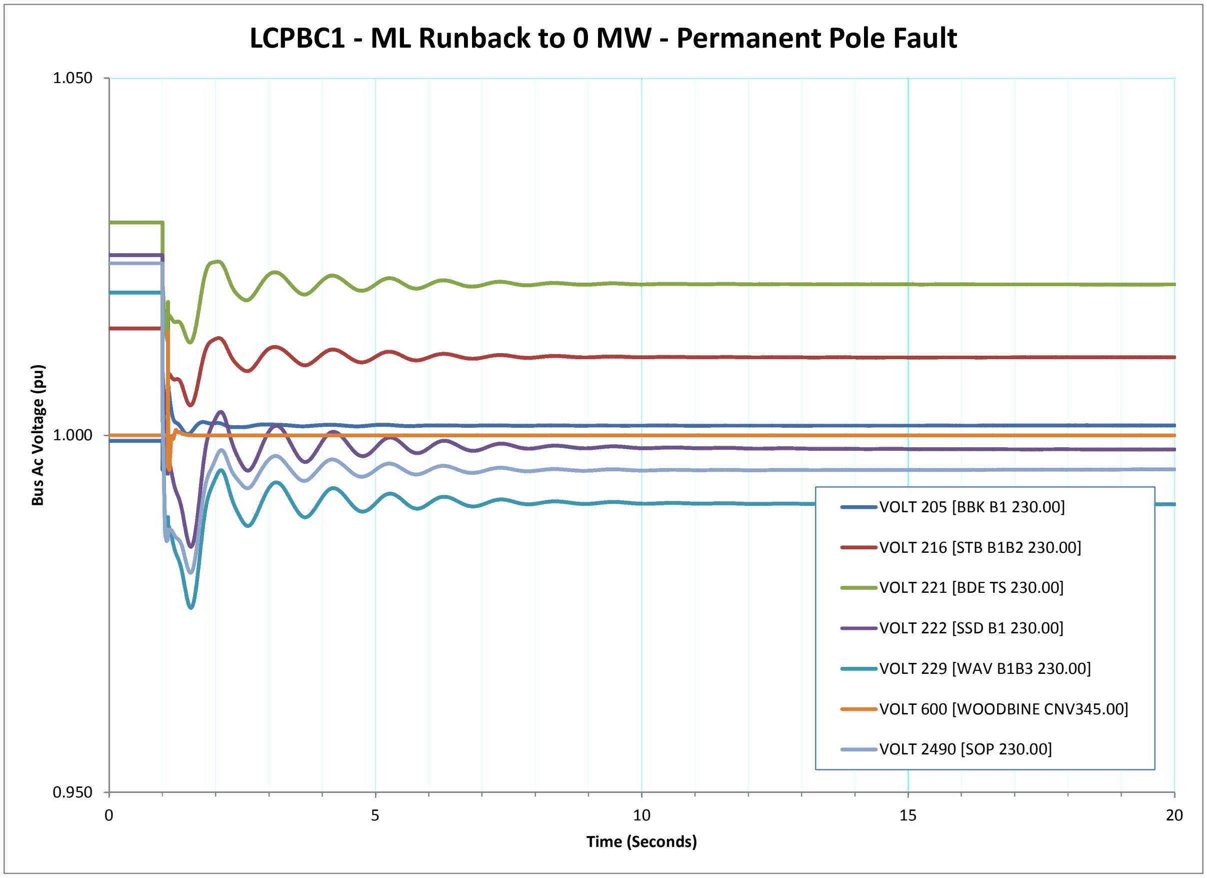


Figure 294 - LCPBC1 - ML Runback to 0 MW - Permanent Pole Fault - Bus Ac Voltage (pu)

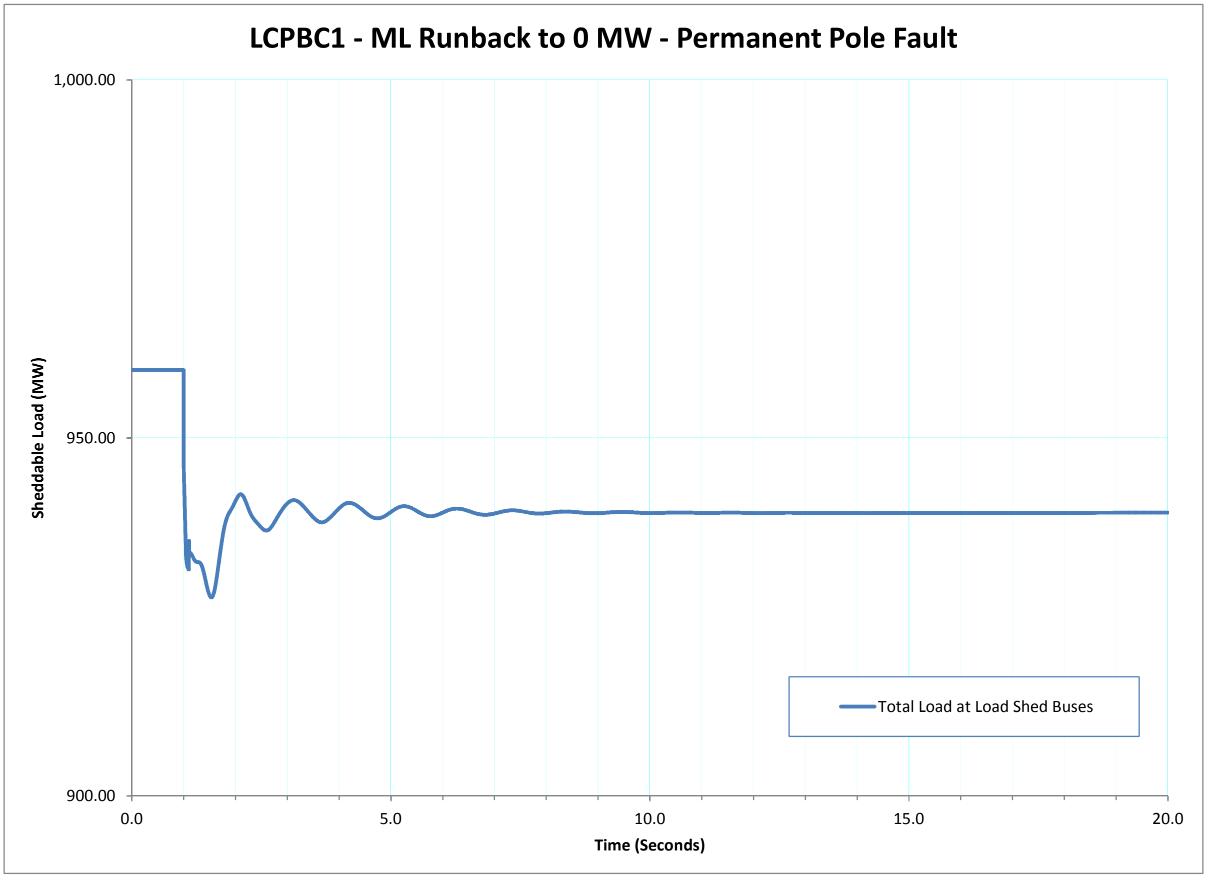


Figure 295 - LCPBC1 - ML Runback to 0 MW - Permanent Pole Fault - Sheddable Load (MW)

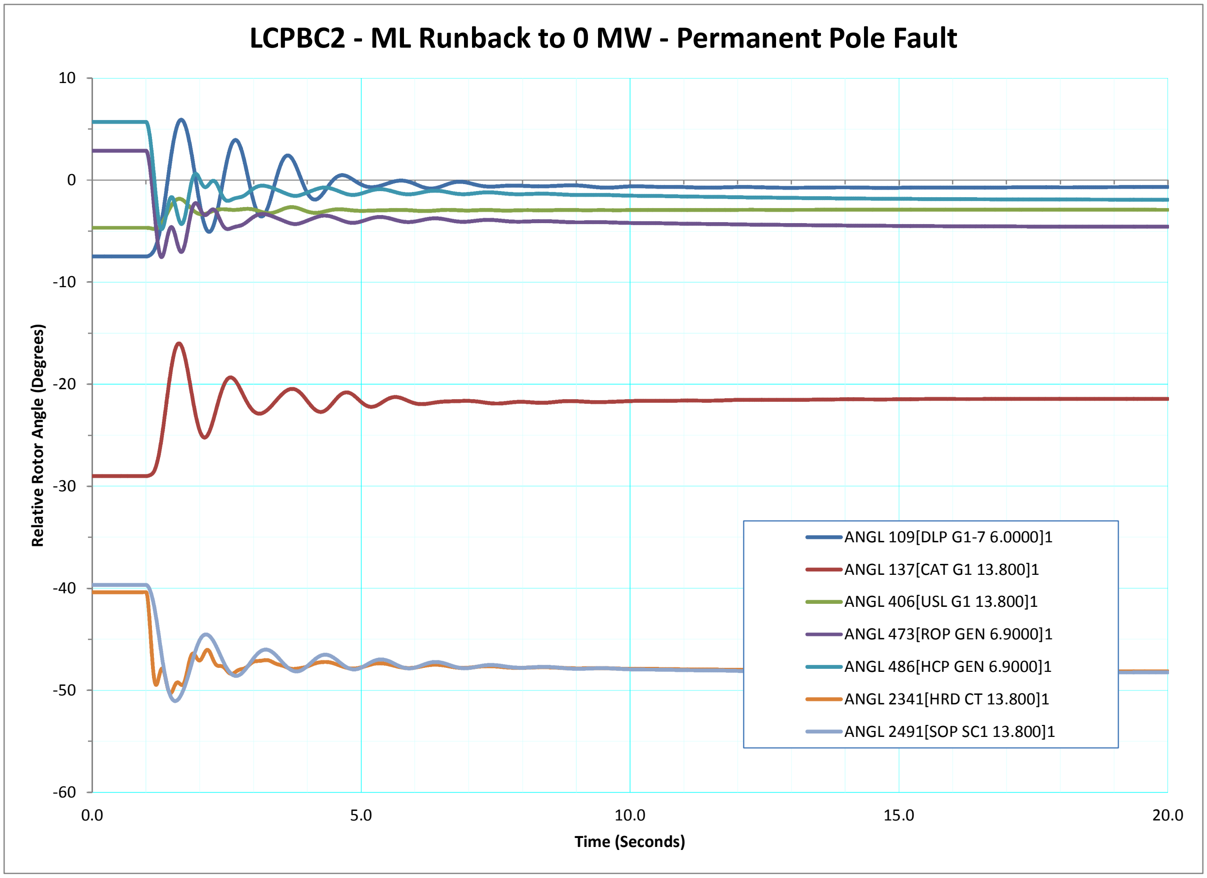


Figure 296 - LCPBC2 - ML Runback to 0 MW - Permanent Pole Fault - Relative Rotor Angle (Degrees)

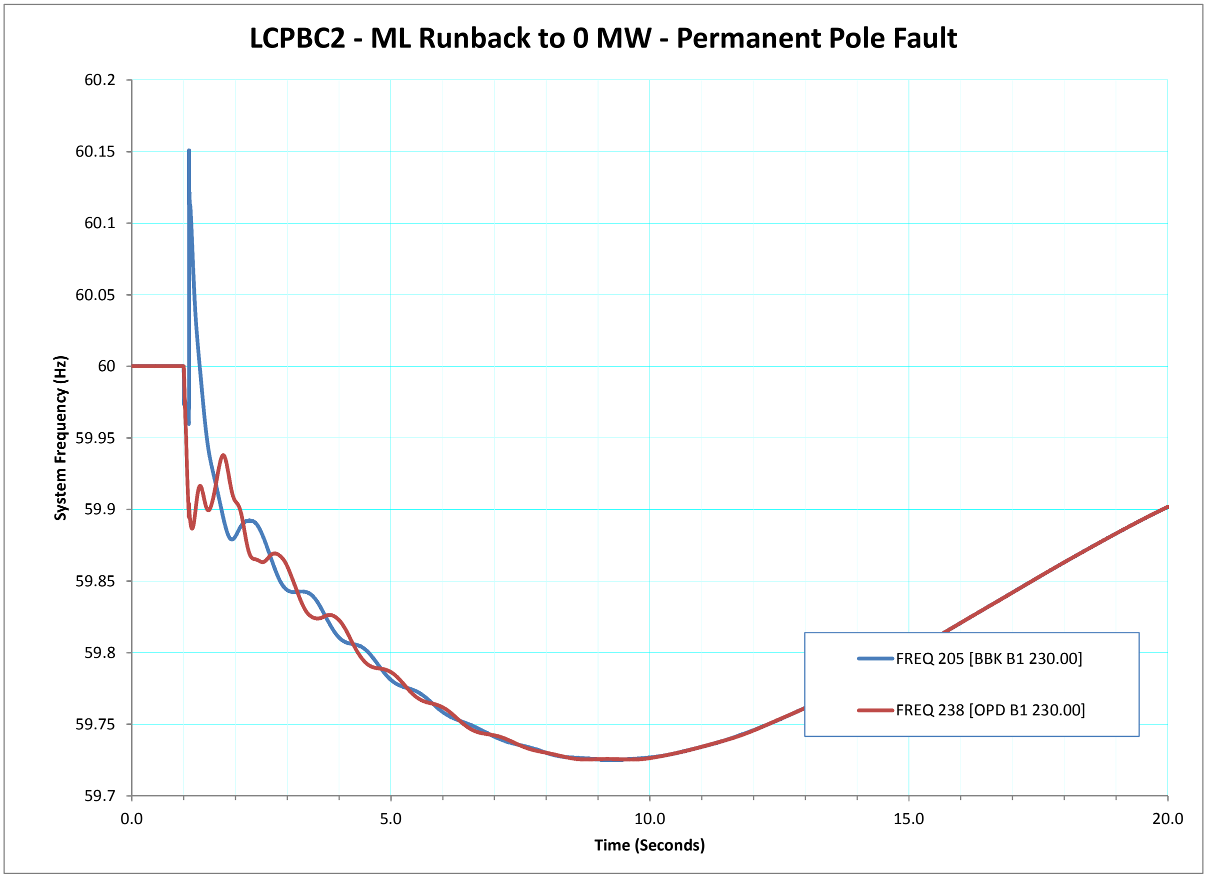


Figure 297 - LCPBC2 - ML Runback to 0 MW - Permanent Pole Fault - System Frequency (Hz)

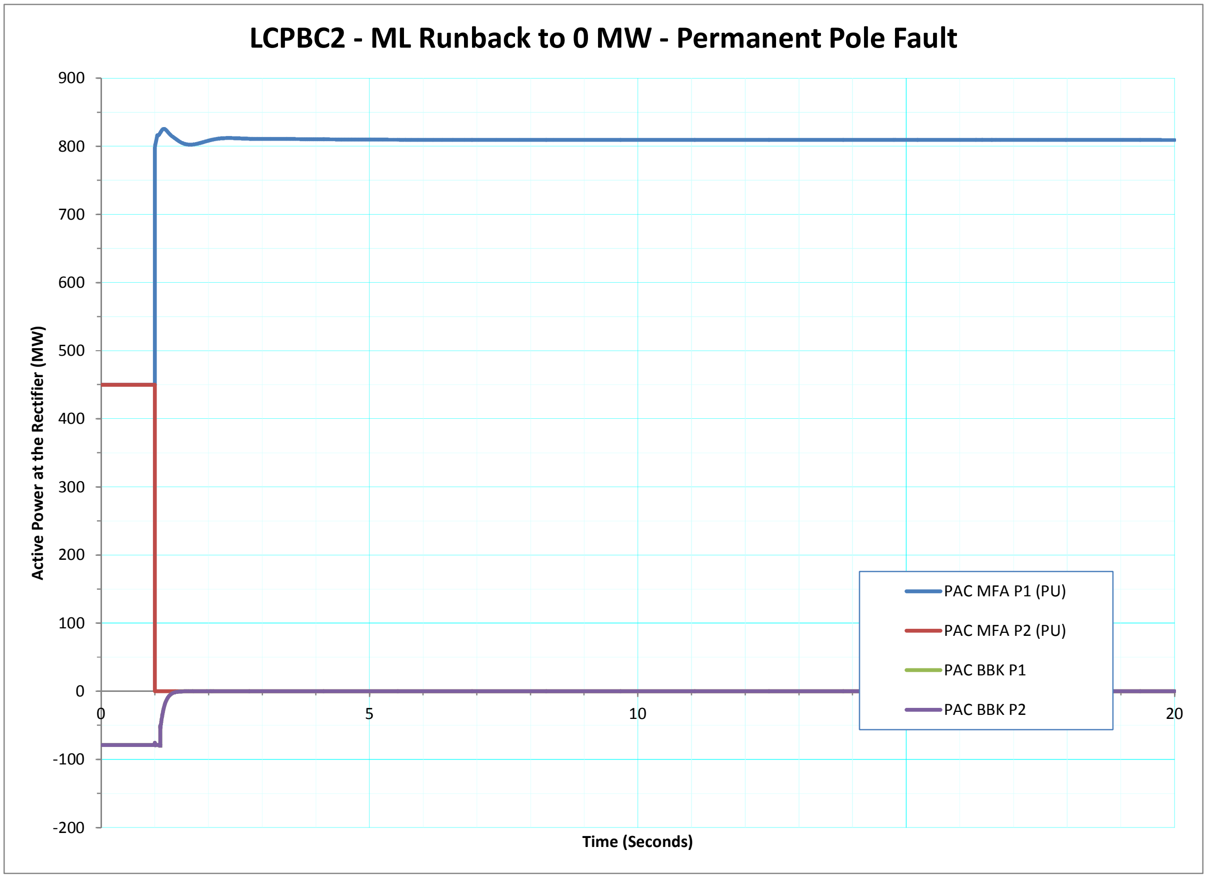


Figure 298 - LCPBC2 - ML Runback to 0 MW - Permanent Pole Fault - Active Power at the Rectifier (MW)

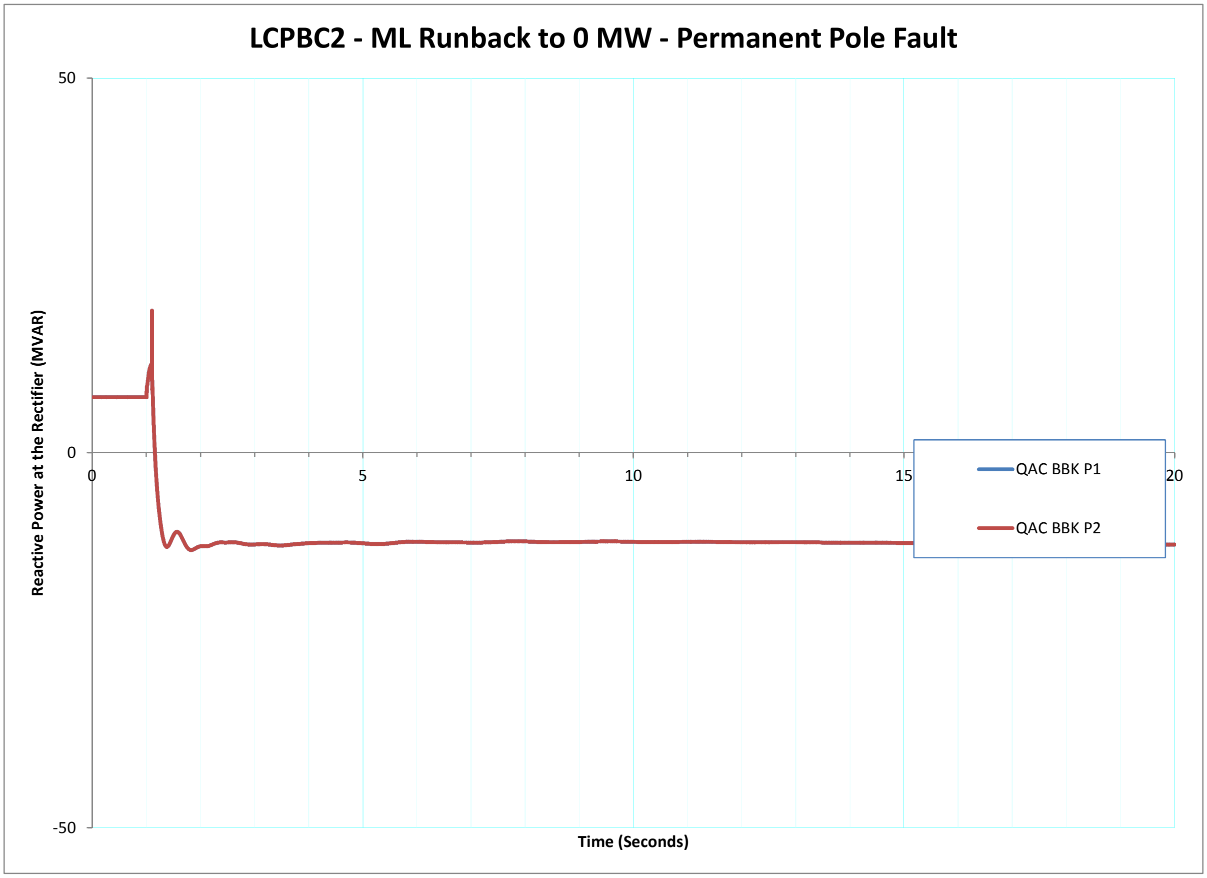


Figure 299 - LCPBC2 - ML Runback to 0 MW - Permanent Pole Fault - Reactive Power at the Rectifier (MVAR)

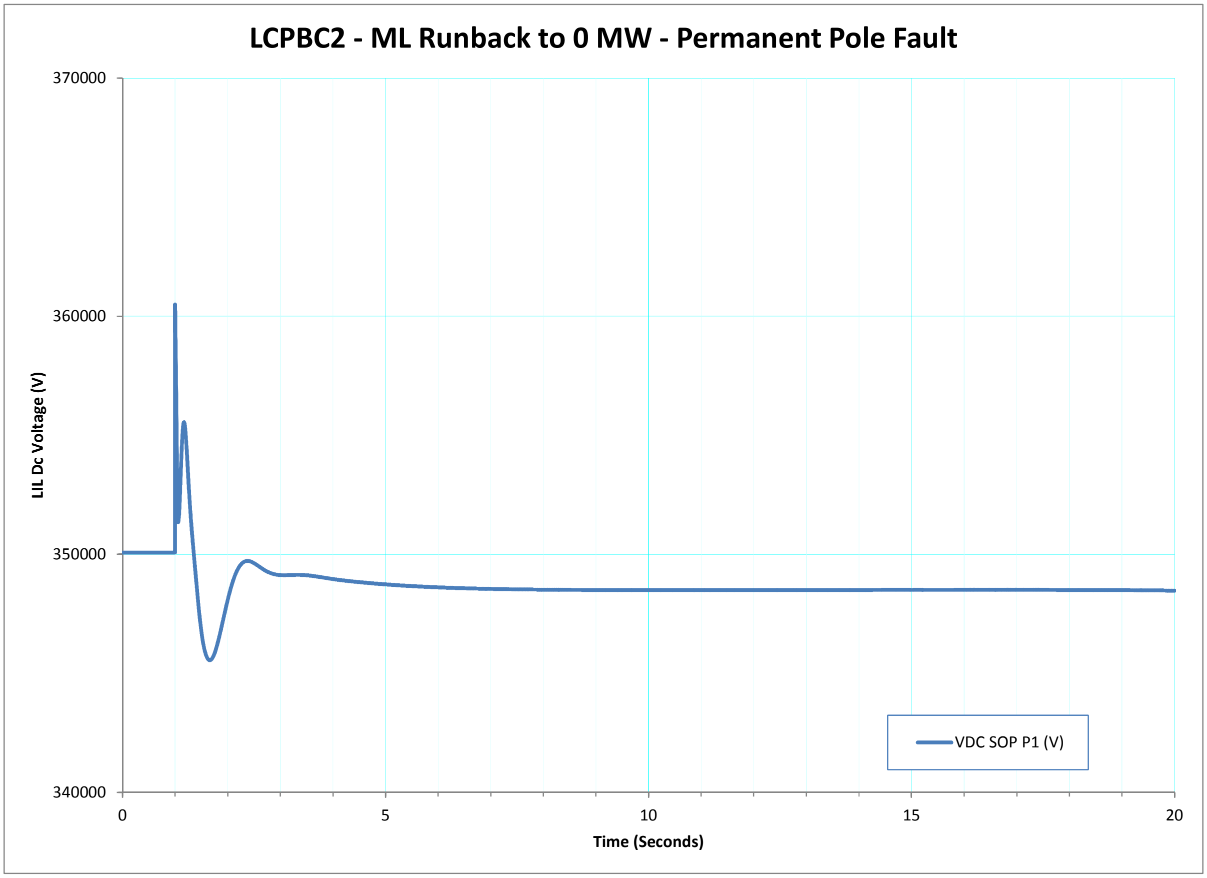


Figure 300 - LCPBC2 - ML Runback to 0 MW - Permanent Pole Fault - LIL Dc Voltage (V)

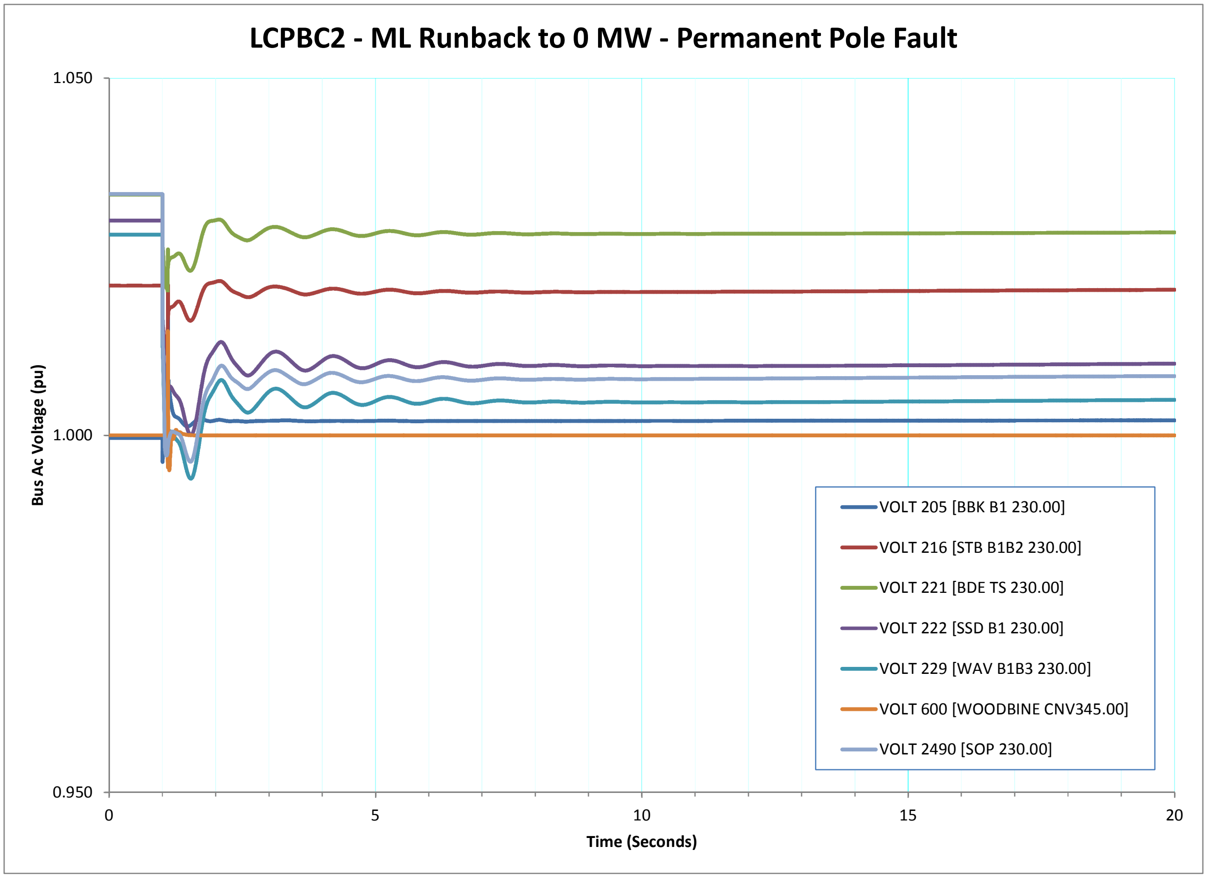


Figure 301 - LCPBC2 - ML Runback to 0 MW - Permanent Pole Fault - Bus Ac Voltage (pu)

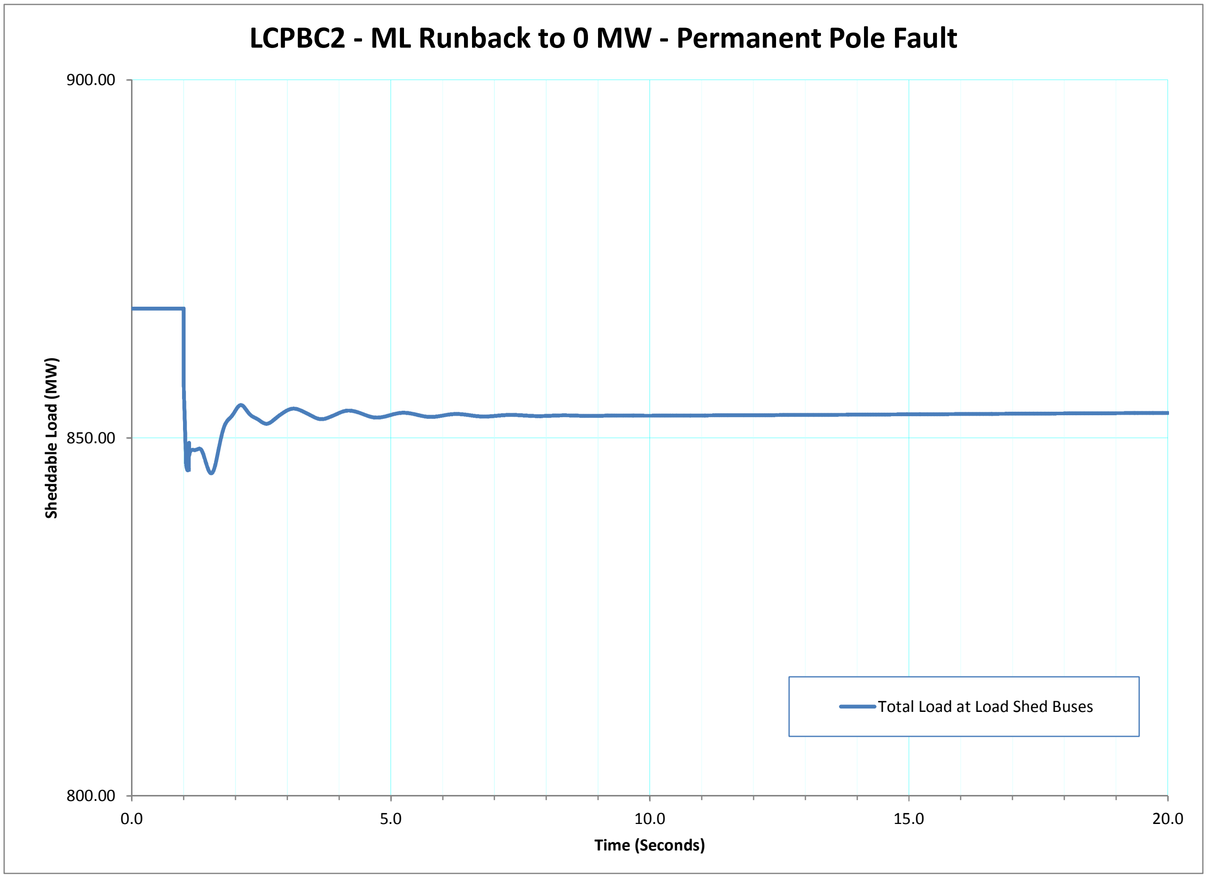


Figure 302 - LCPBC2 - ML Runback to 0 MW - Permanent Pole Fault - Sheddable Load (MW)

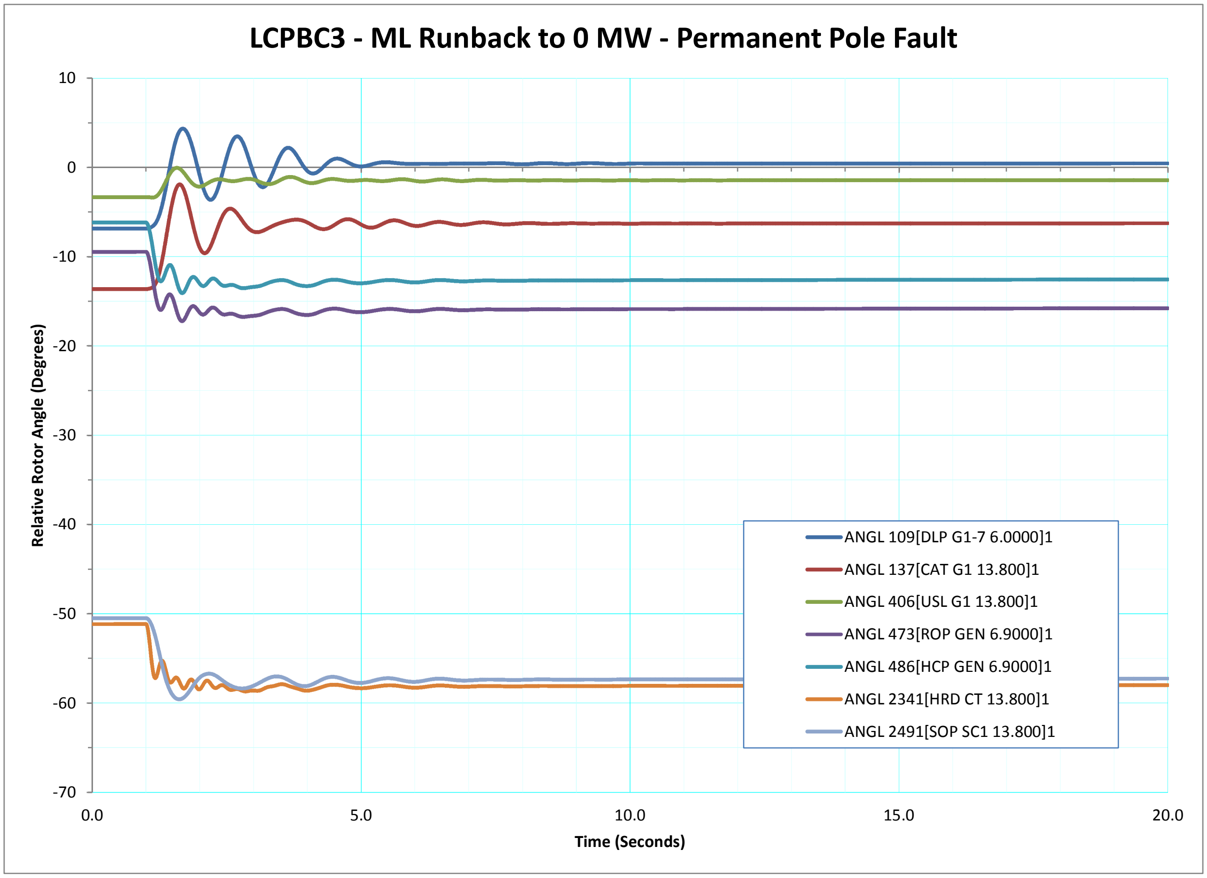


Figure 303 - LCPBC3 - ML Runback to 0 MW - Permanent Pole Fault - Relative Rotor Angle (Degrees)

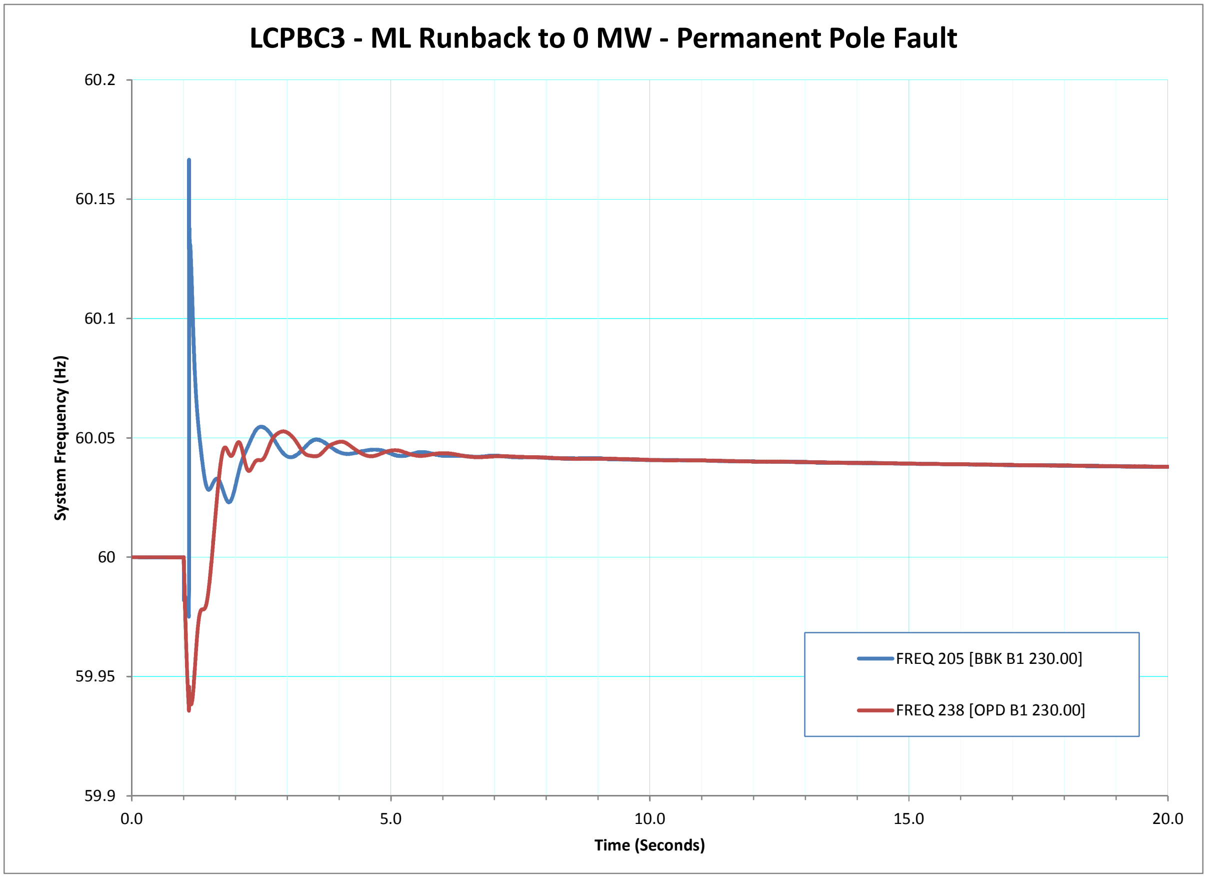


Figure 304 - LCPBC3 - ML Runback to 0 MW - Permanent Pole Fault - System Frequency (Hz)

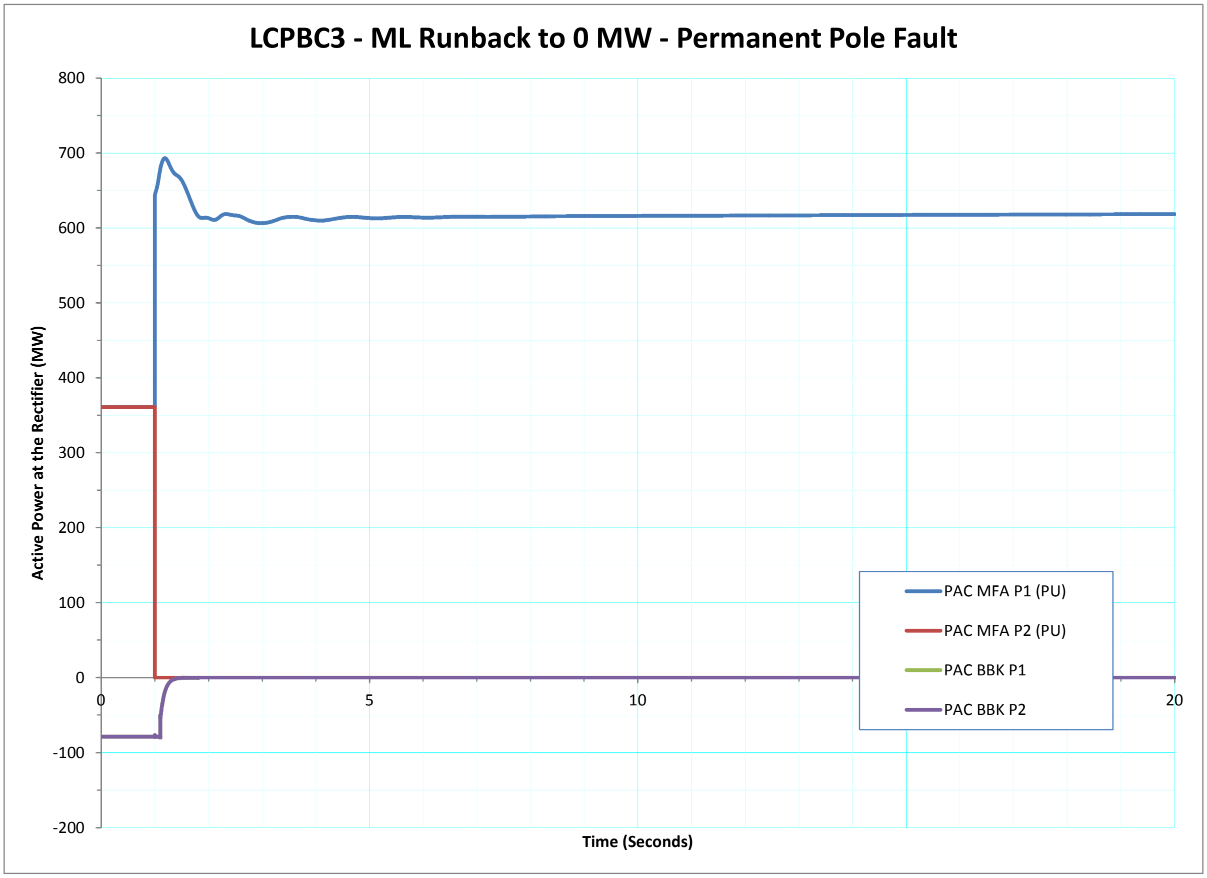


Figure 305 - LCPBC3 - ML Runback to 0 MW - Permanent Pole Fault - Active Power at the Rectifier (MW)

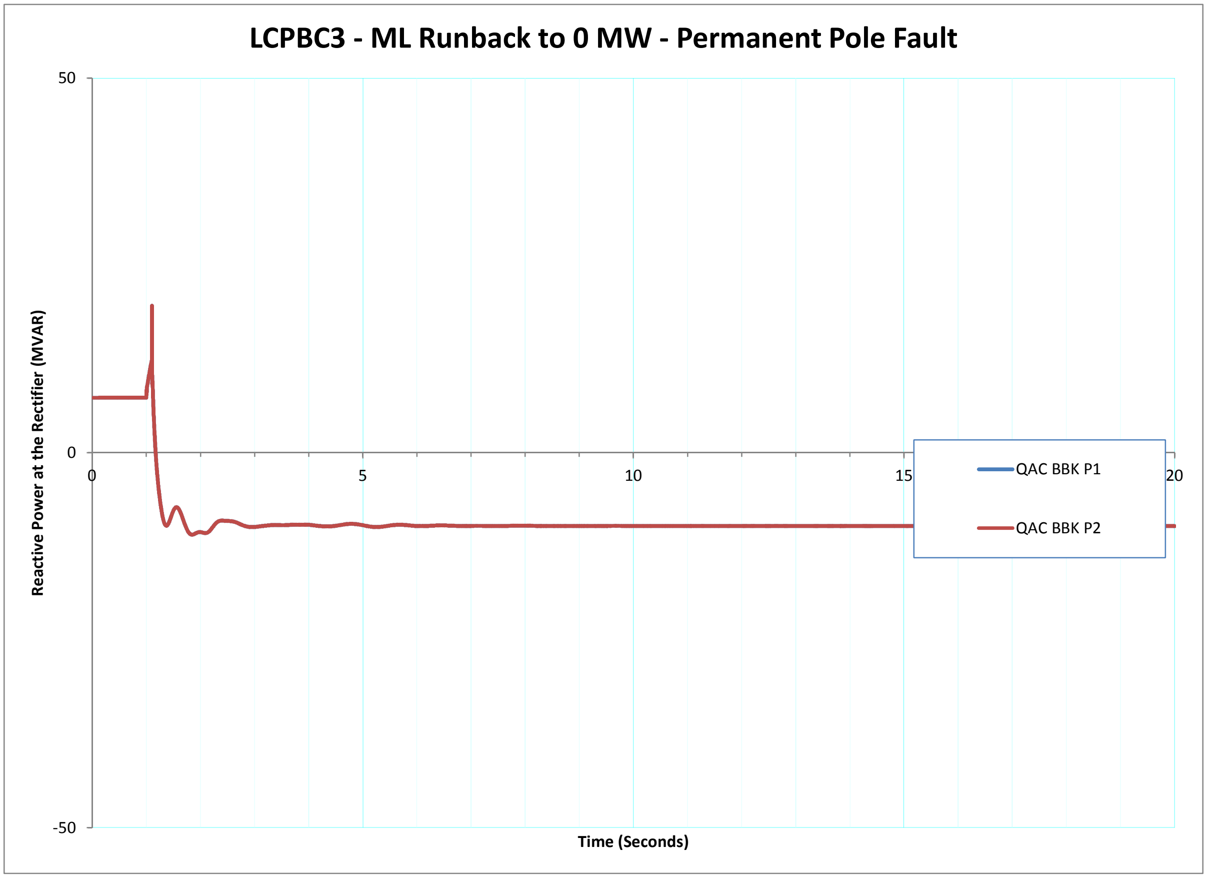


Figure 306 - LCPBC3 - ML Runback to 0 MW - Permanent Pole Fault - Reactive Power at the Rectifier (MVAR)

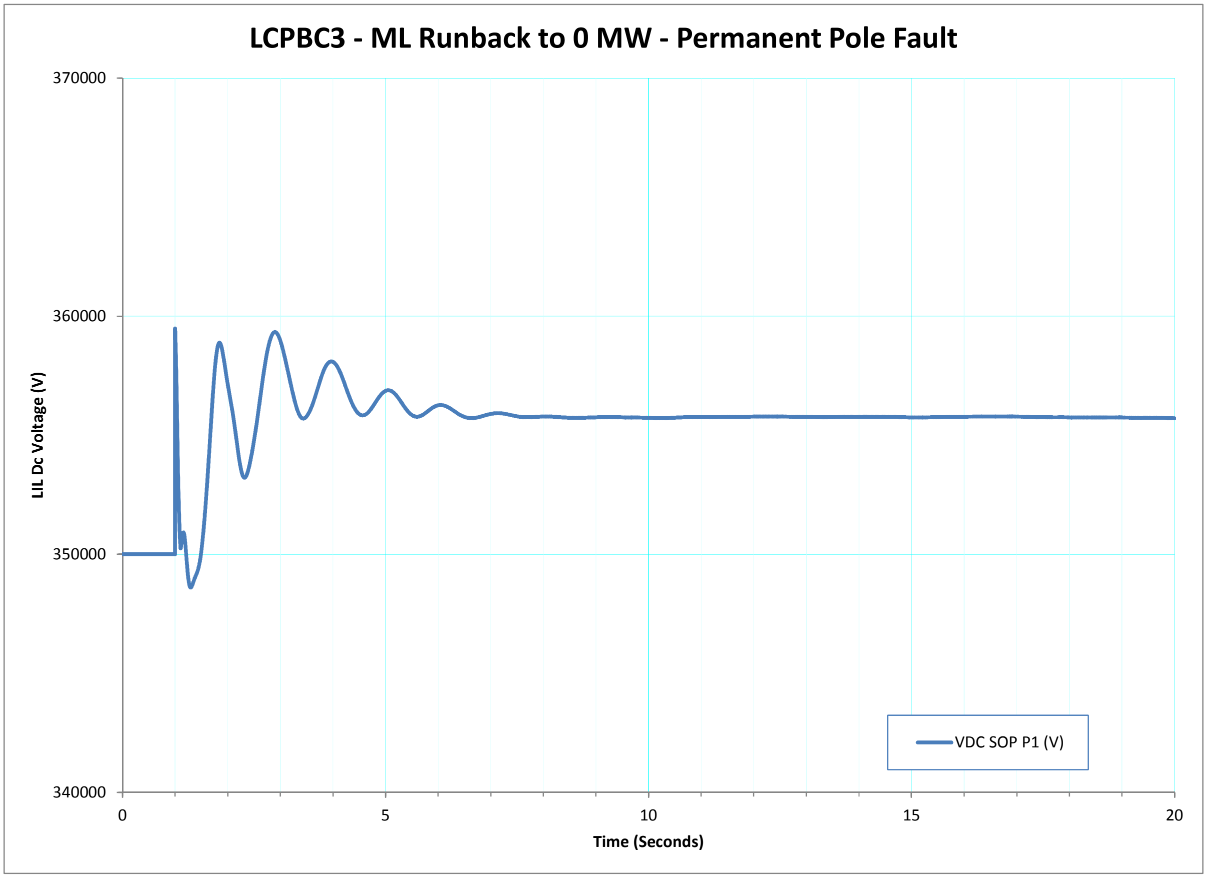


Figure 307 - LCPBC3 - ML Runback to 0 MW - Permanent Pole Fault - LIL Dc Voltage (V)

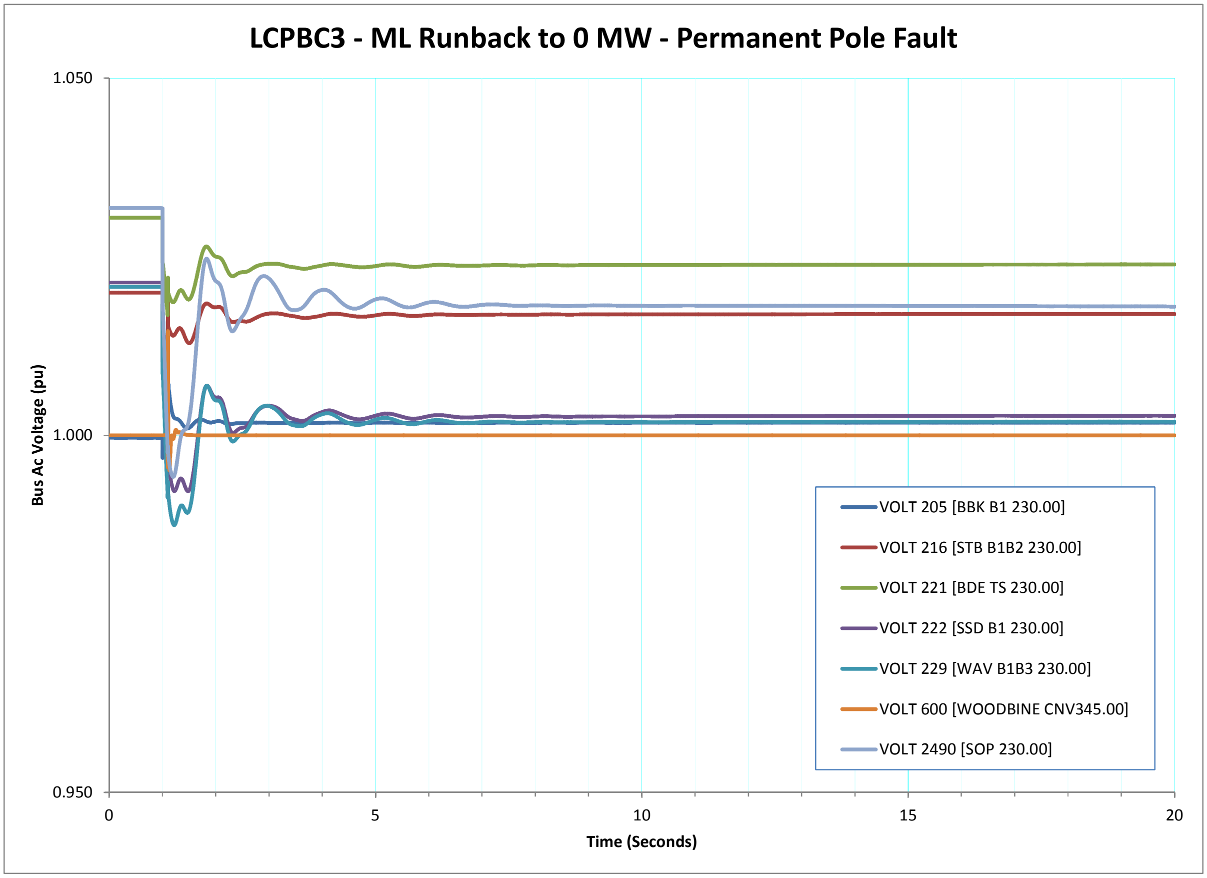


Figure 308 - LCPBC3 - ML Runback to 0 MW - Permanent Pole Fault - Bus Ac Voltage (pu)

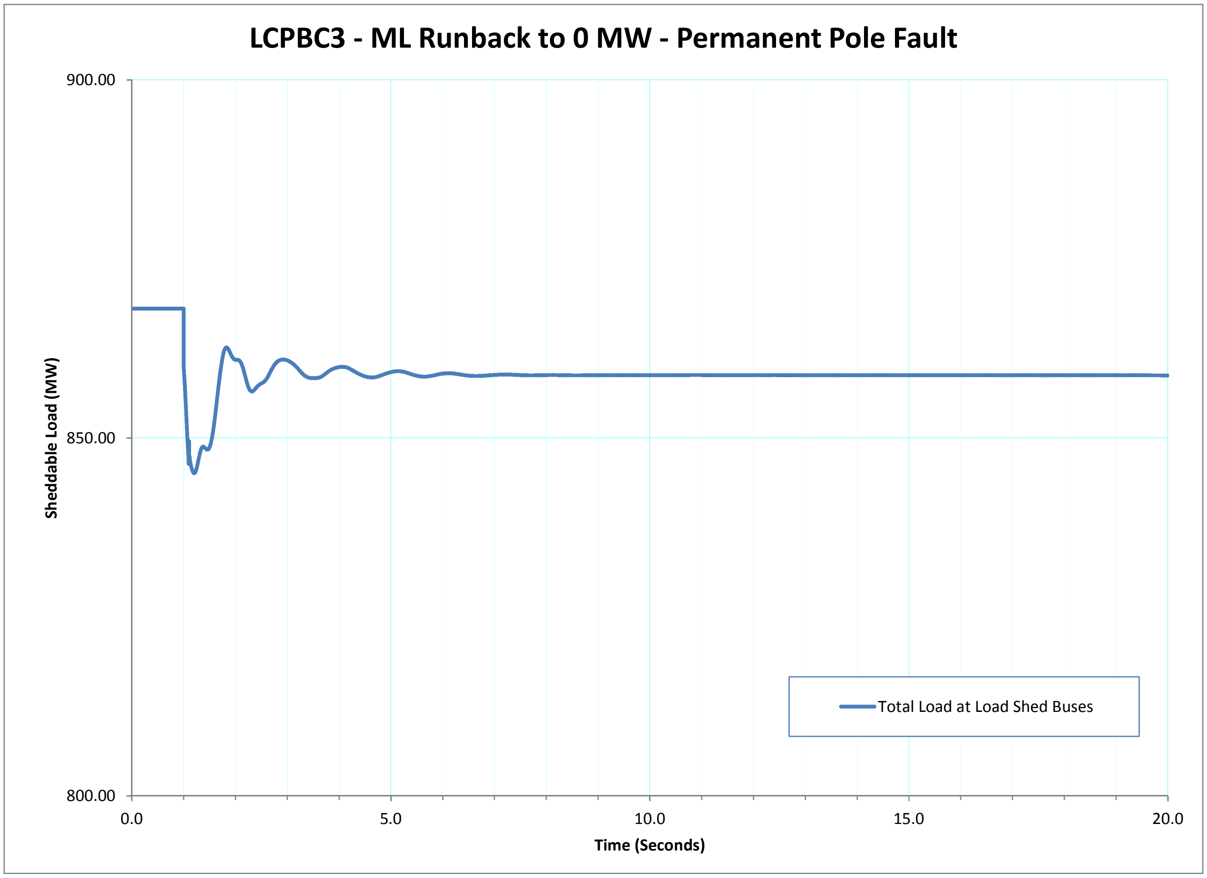


Figure 309 - LCPBC3 - ML Runback to 0 MW - Permanent Pole Fault - Sheddable Load (MW)

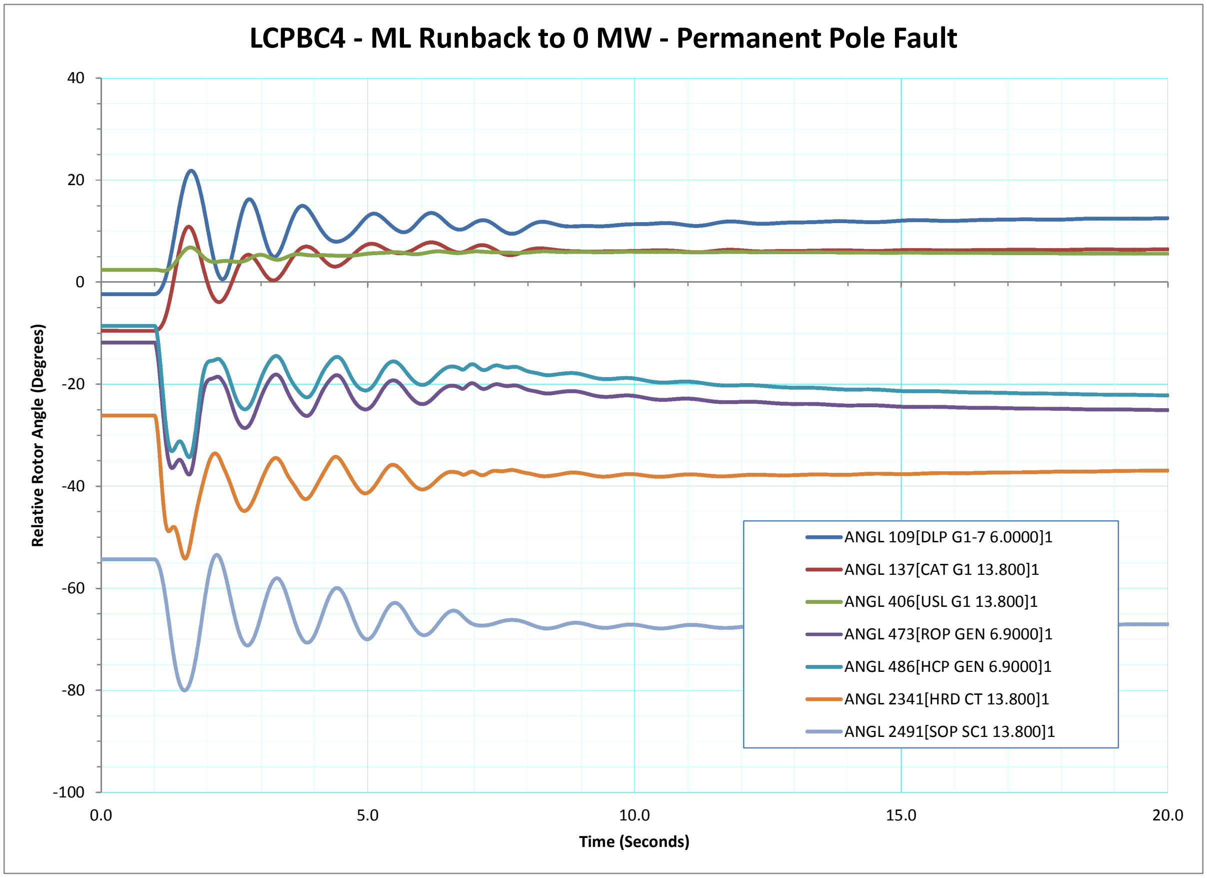


Figure 310 - LCPBC4 - ML Runback to 0 MW - Permanent Pole Fault - Relative Rotor Angle (Degrees)

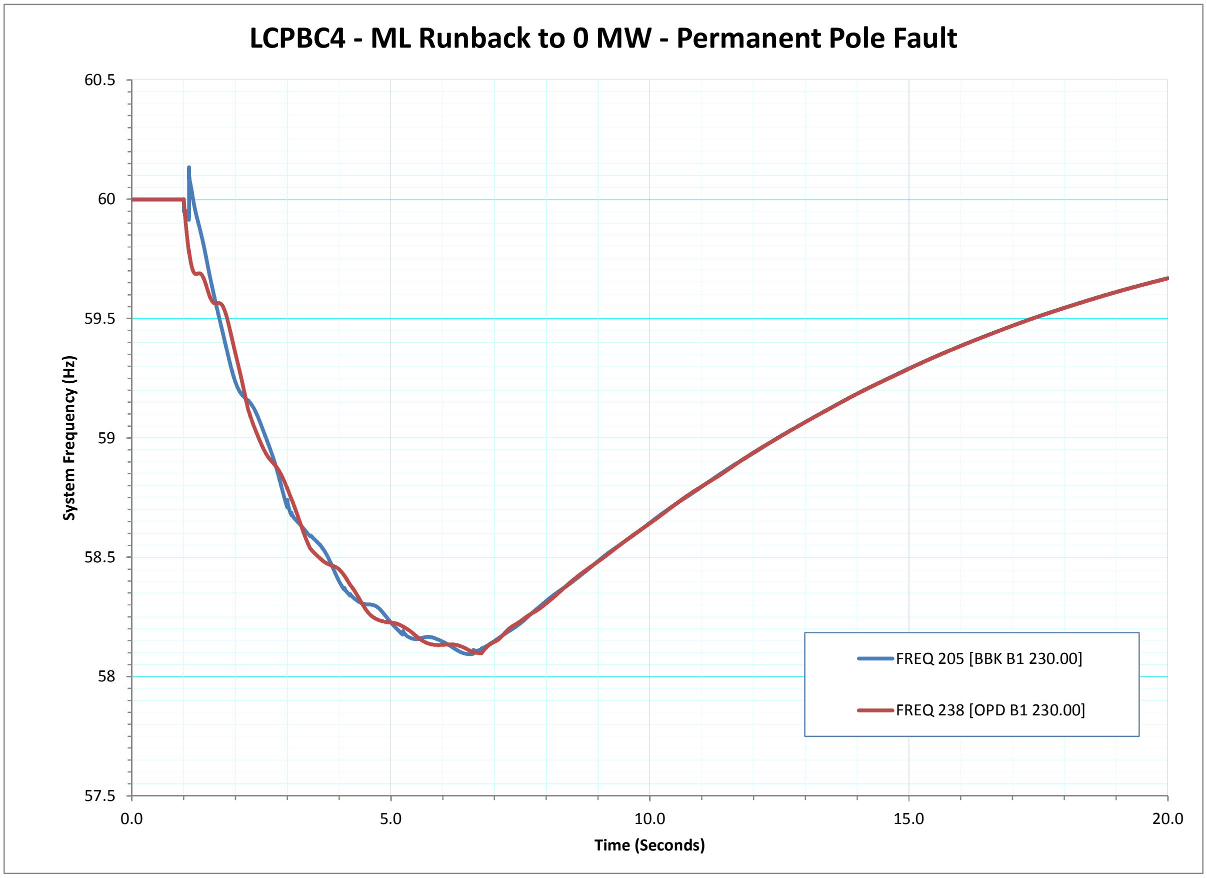


Figure 311 - LCPBC4 - ML Runback to 0 MW - Permanent Pole Fault - System Frequency (Hz)

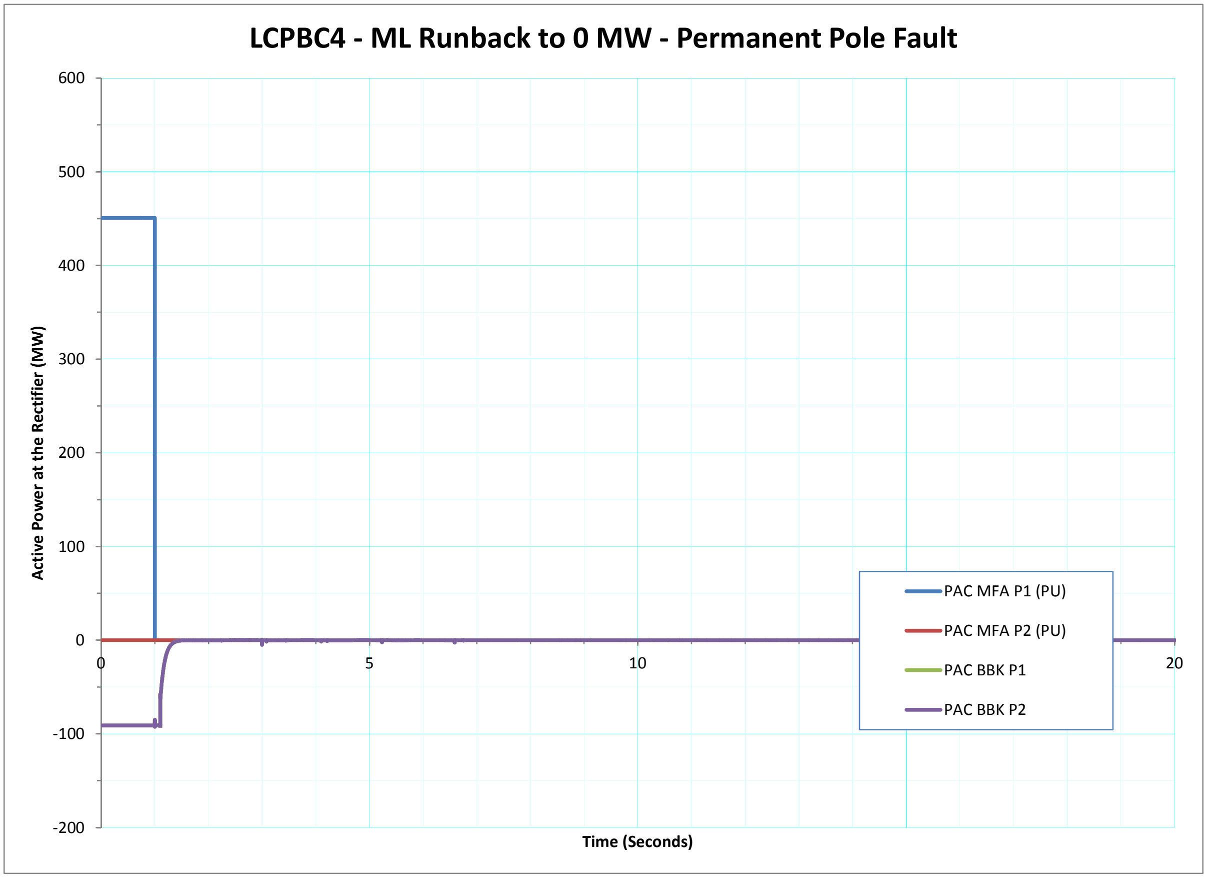


Figure 312 - LCPBC4 - ML Runback to 0 MW - Permanent Pole Fault - Active Power at the Rectifier (MW)

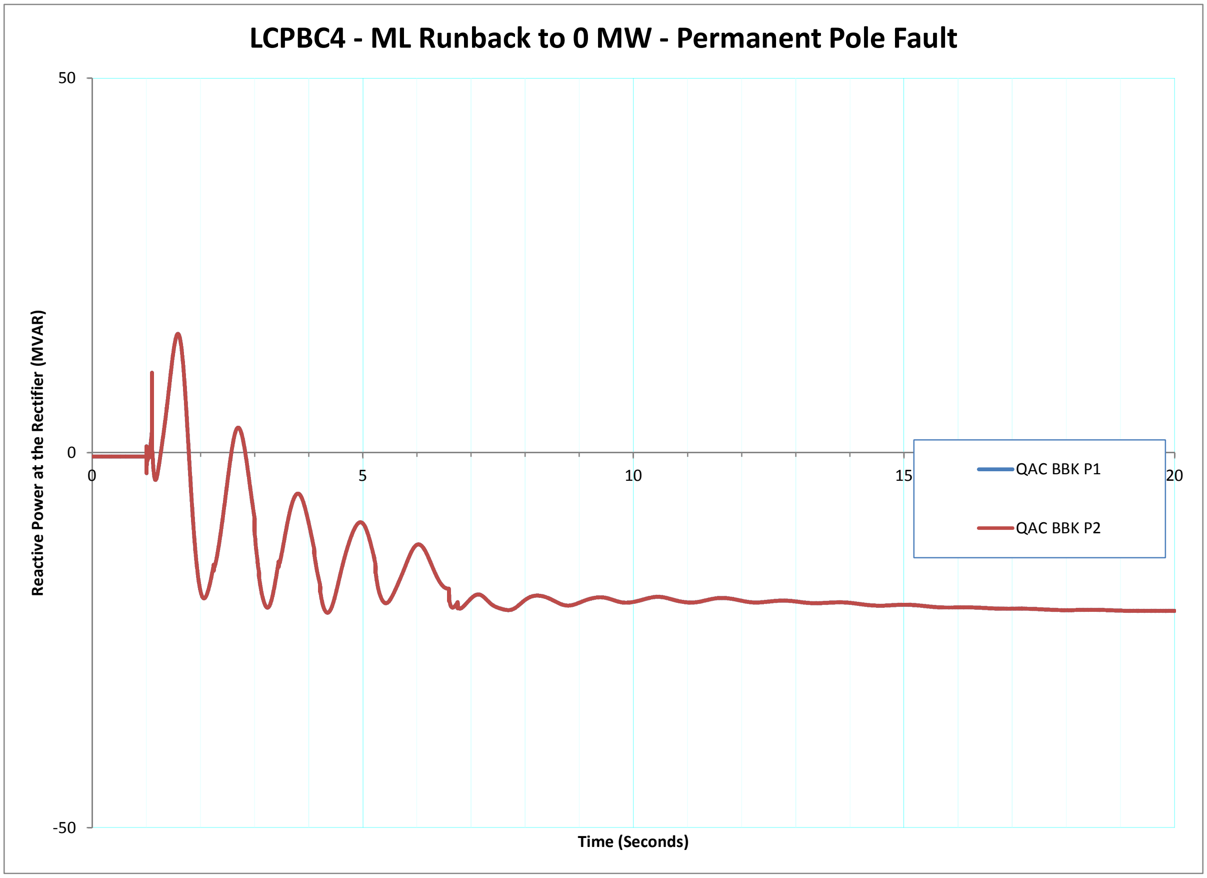


Figure 313 - LCPBC4 - ML Runback to 0 MW - Permanent Pole Fault - Reactive Power at the Rectifier (MVAR)

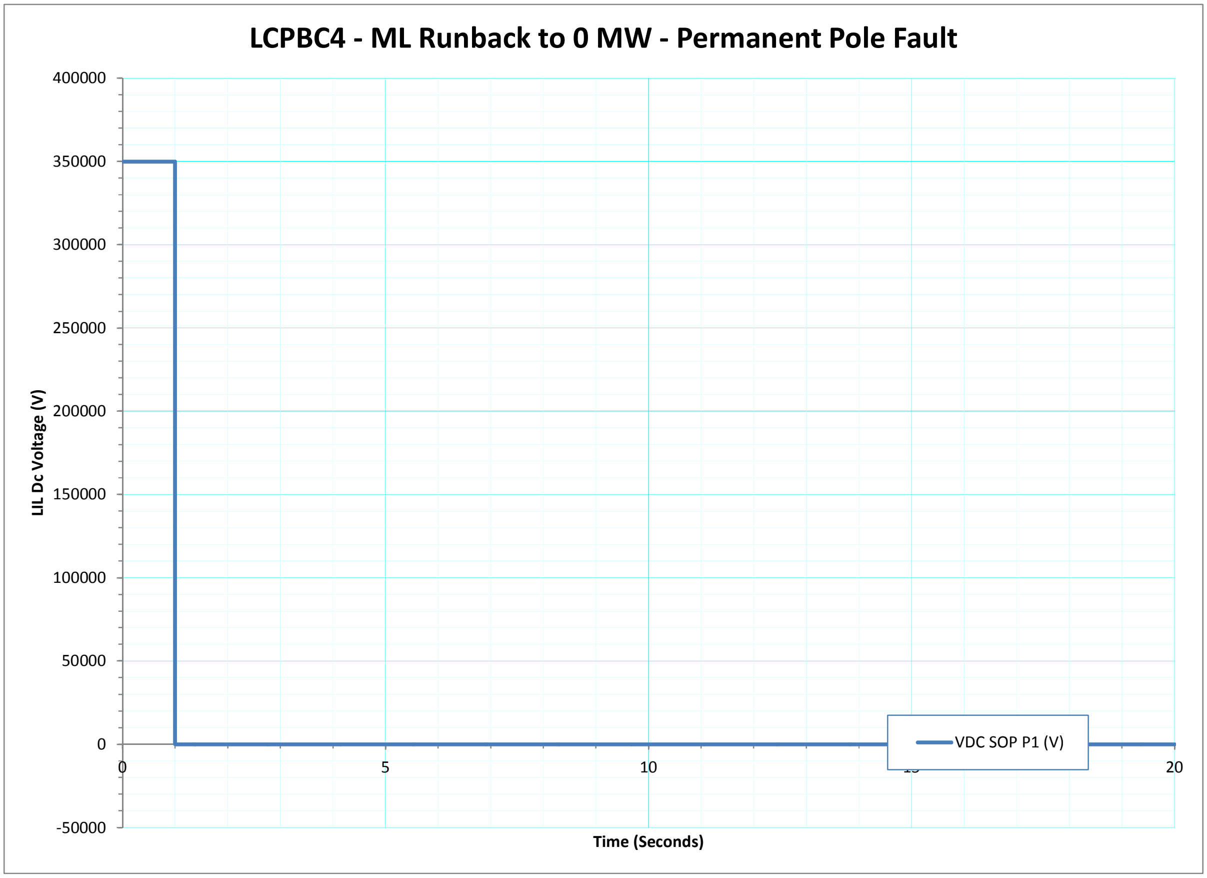


Figure 314 - LCPBC4 - ML Runback to 0 MW - Permanent Pole Fault - LIL Dc Voltage (V)

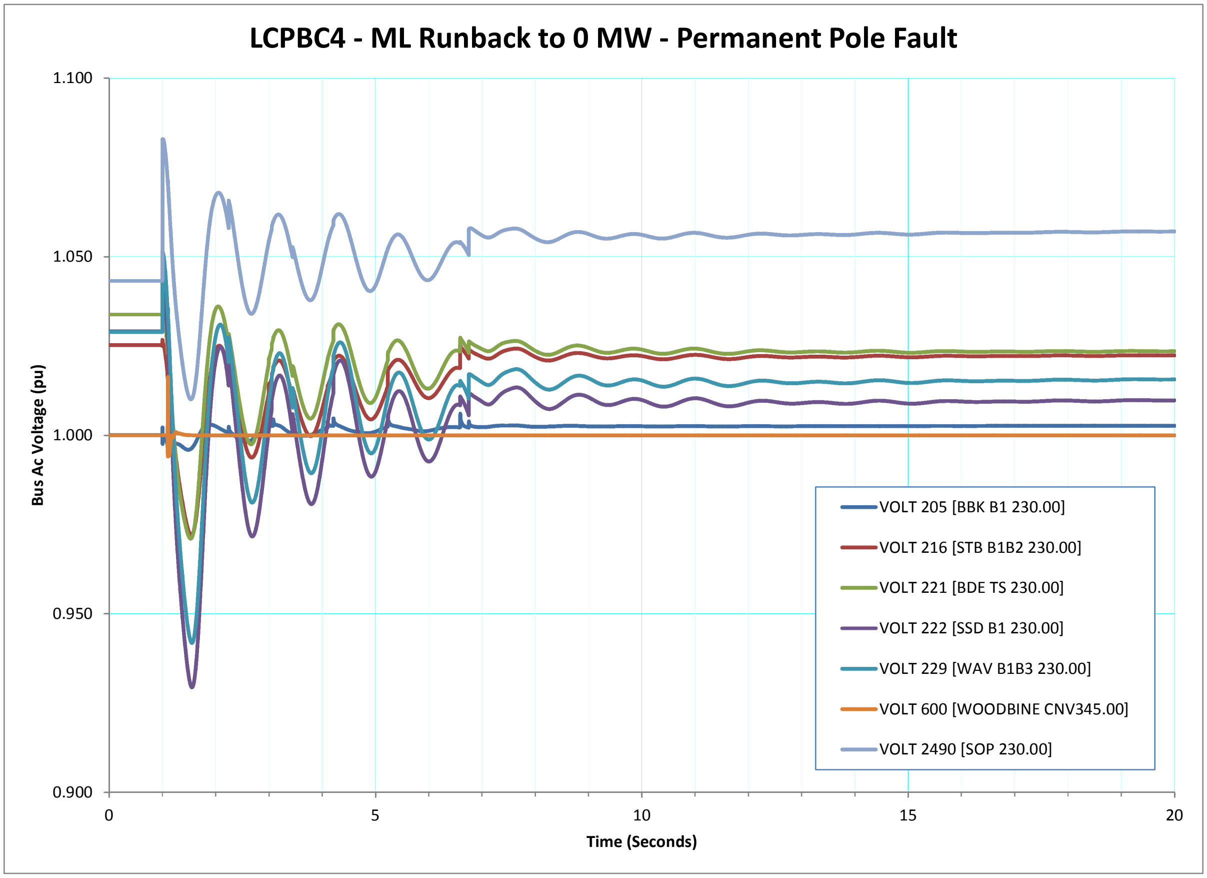


Figure 315 - LCPBC4 - ML Runback to 0 MW - Permanent Pole Fault - Bus Ac Voltage (pu)

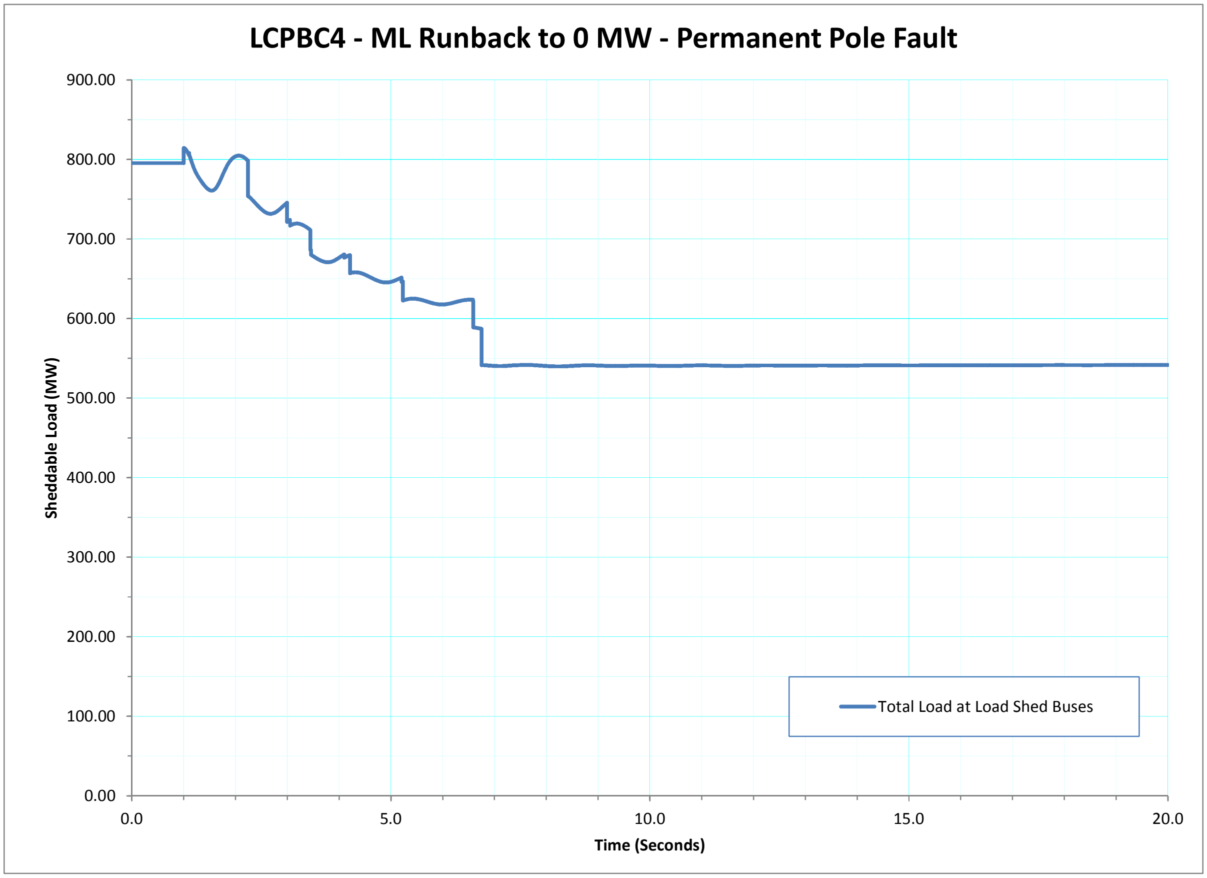


Figure 316 - LCPBC4 - ML Runback to 0 MW - Permanent Pole Fault - Sheddable Load (MW)

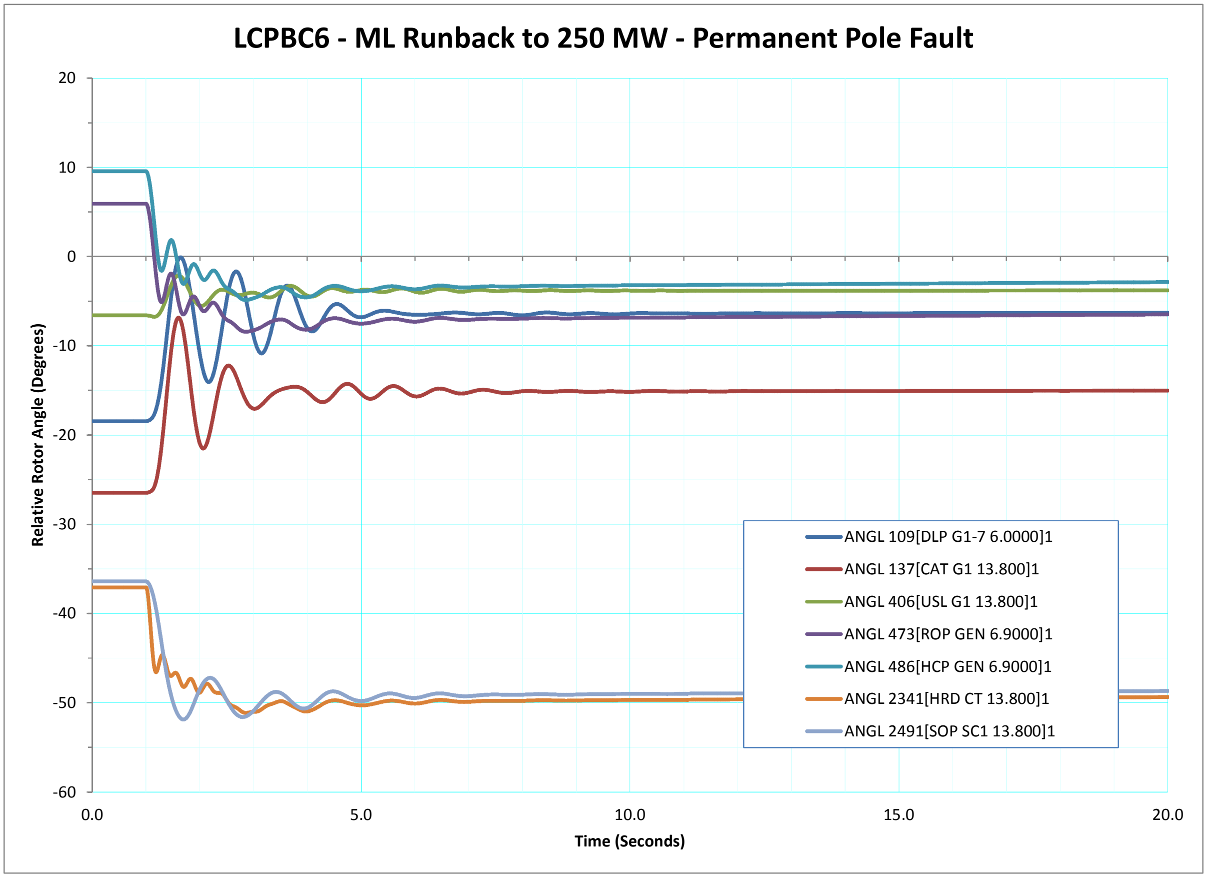


Figure 317 - LCPBC6 - ML Runback to 250 MW - Permanent Pole Fault - Relative Rotor Angle (Degrees)

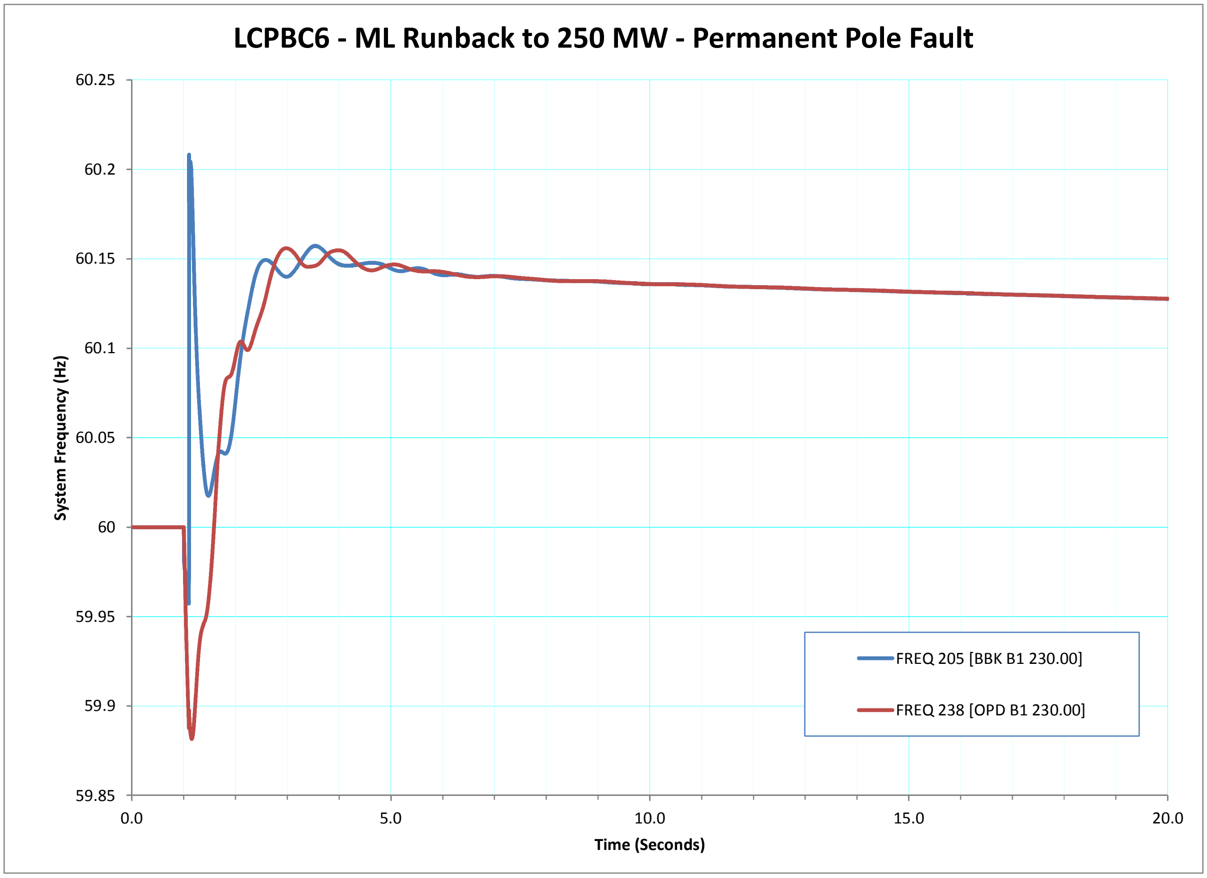


Figure 318 - LCPBC6 - ML Runback to 250 MW - Permanent Pole Fault - System Frequency (Hz)

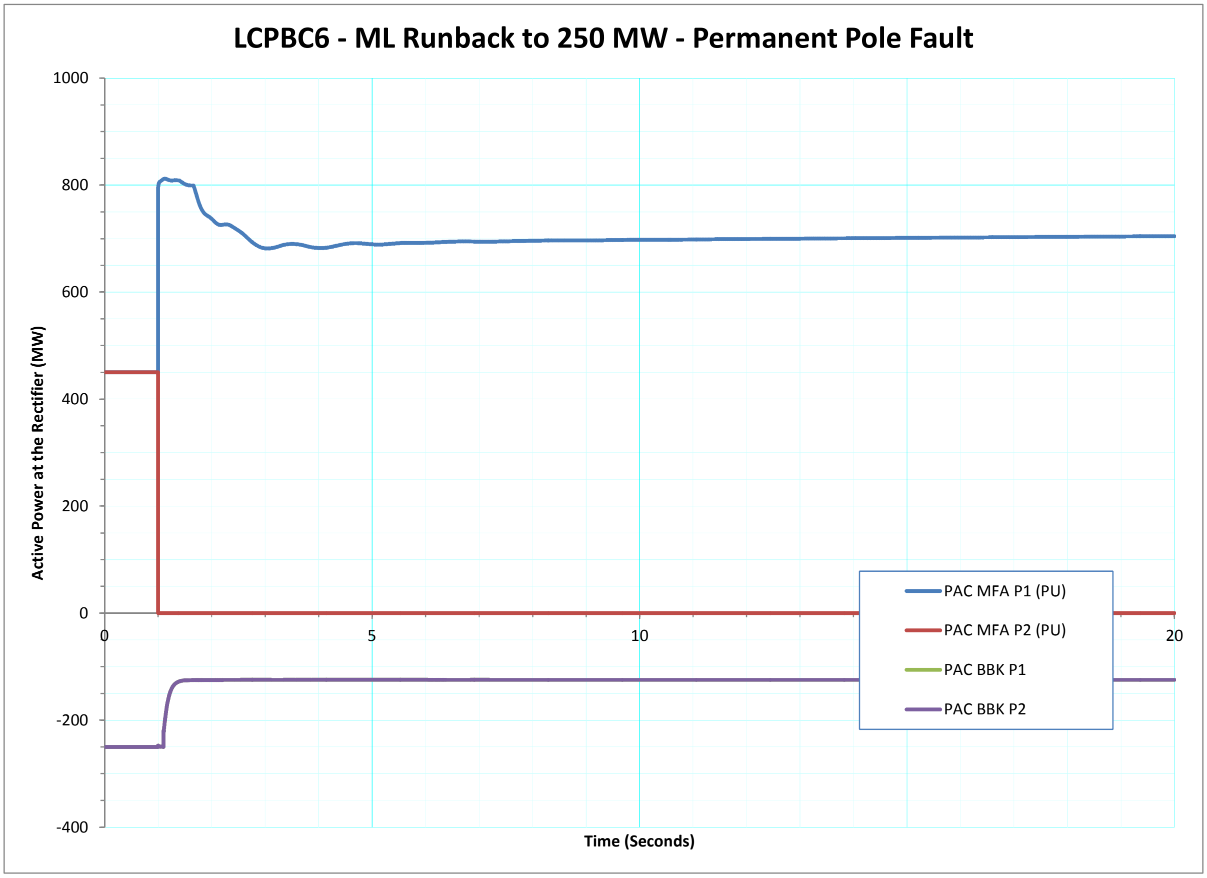


Figure 319 - LCPBC6 - ML Runback to 250 MW - Permanent Pole Fault - Active Power at the Rectifier (MW)

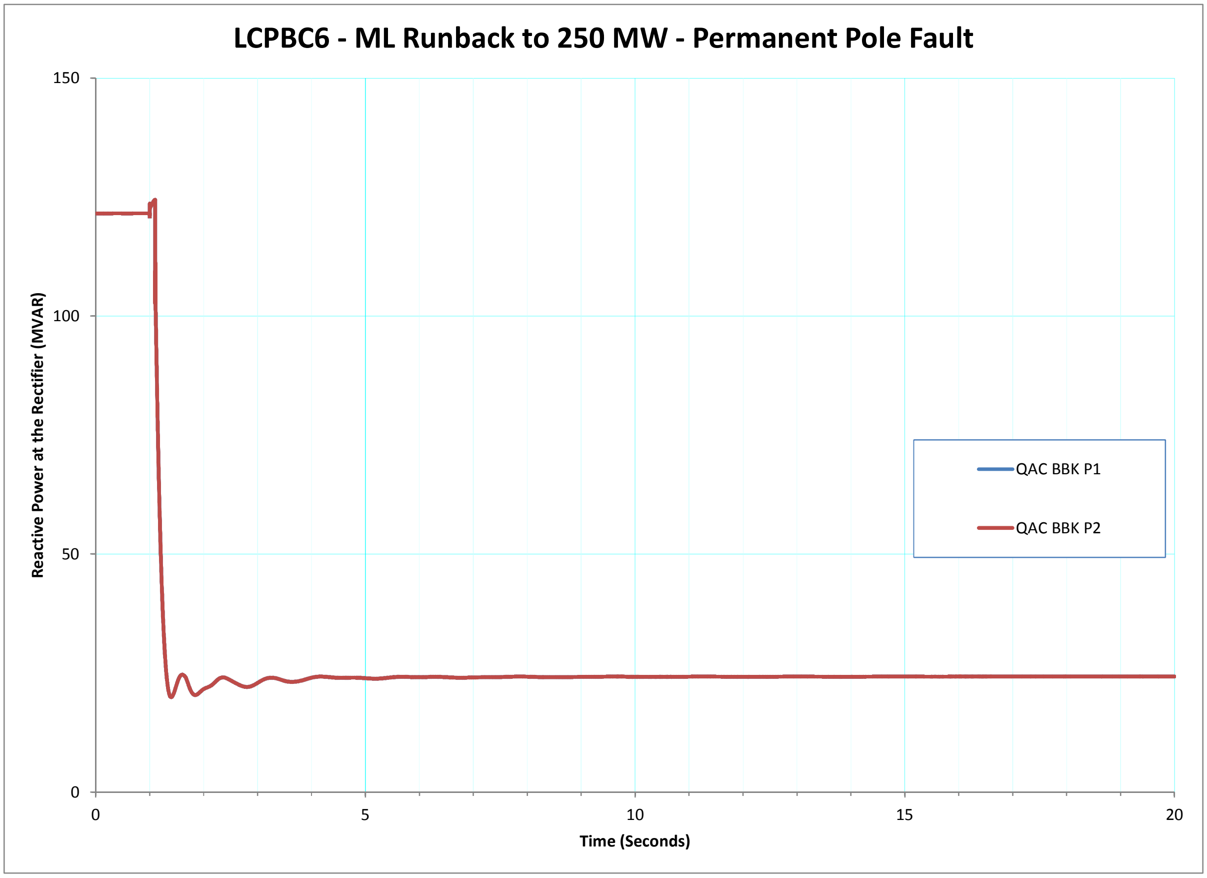


Figure 320 - LCPBC6 - ML Runback to 250 MW - Permanent Pole Fault - Reactive Power at the Rectifier (MVAR)

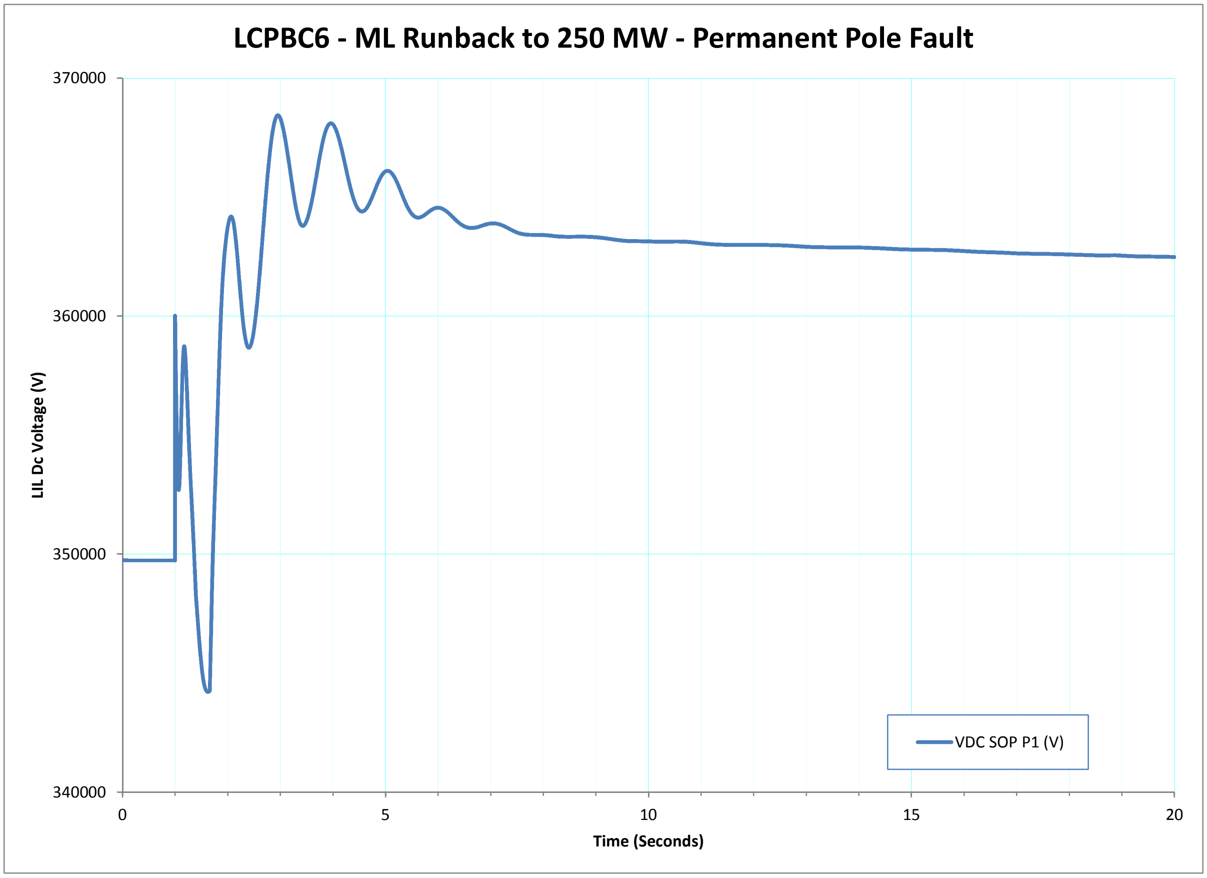


Figure 321 - LCPBC6 - ML Runback to 250 MW - Permanent Pole Fault - LIL Dc Voltage (V)

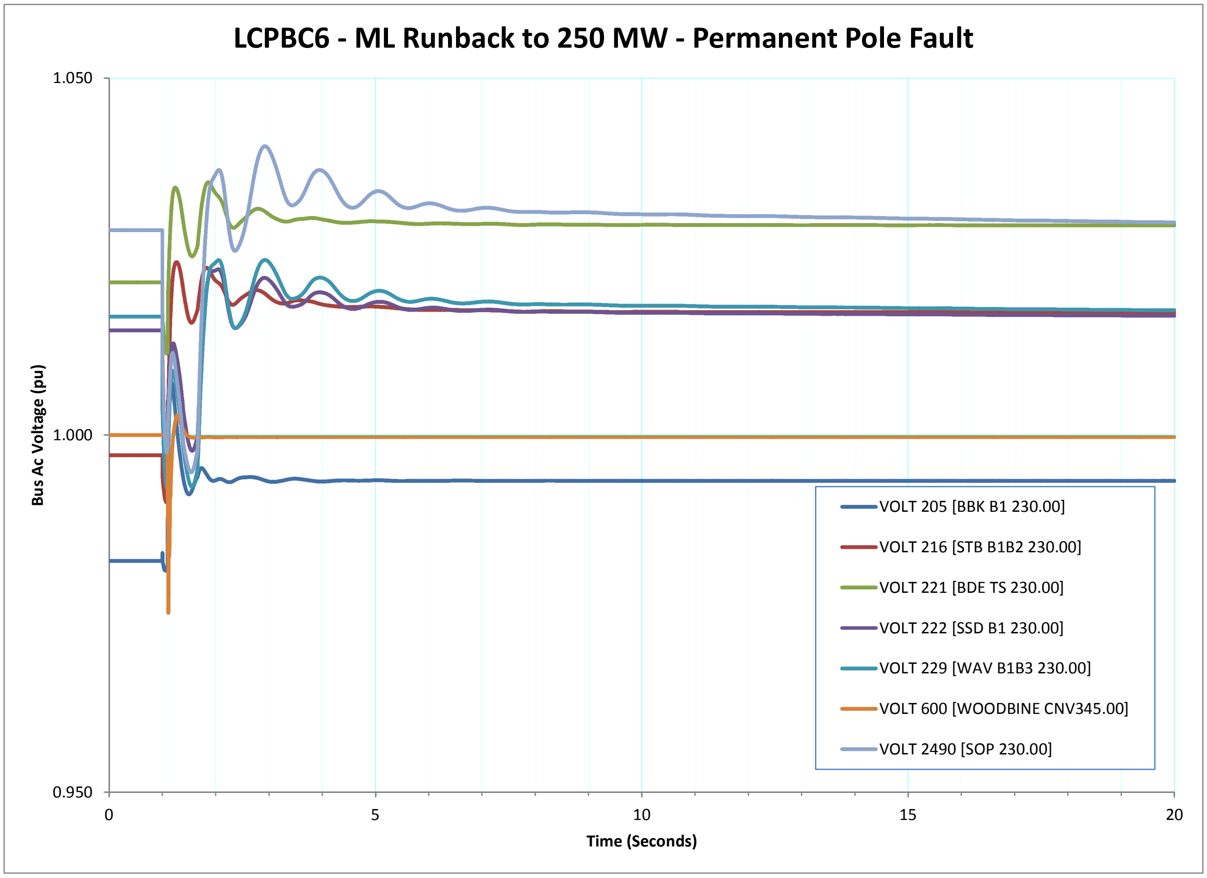


Figure 322 - LCPBC6 - ML Runback to 250 MW - Permanent Pole Fault - Bus Ac Voltage (pu)

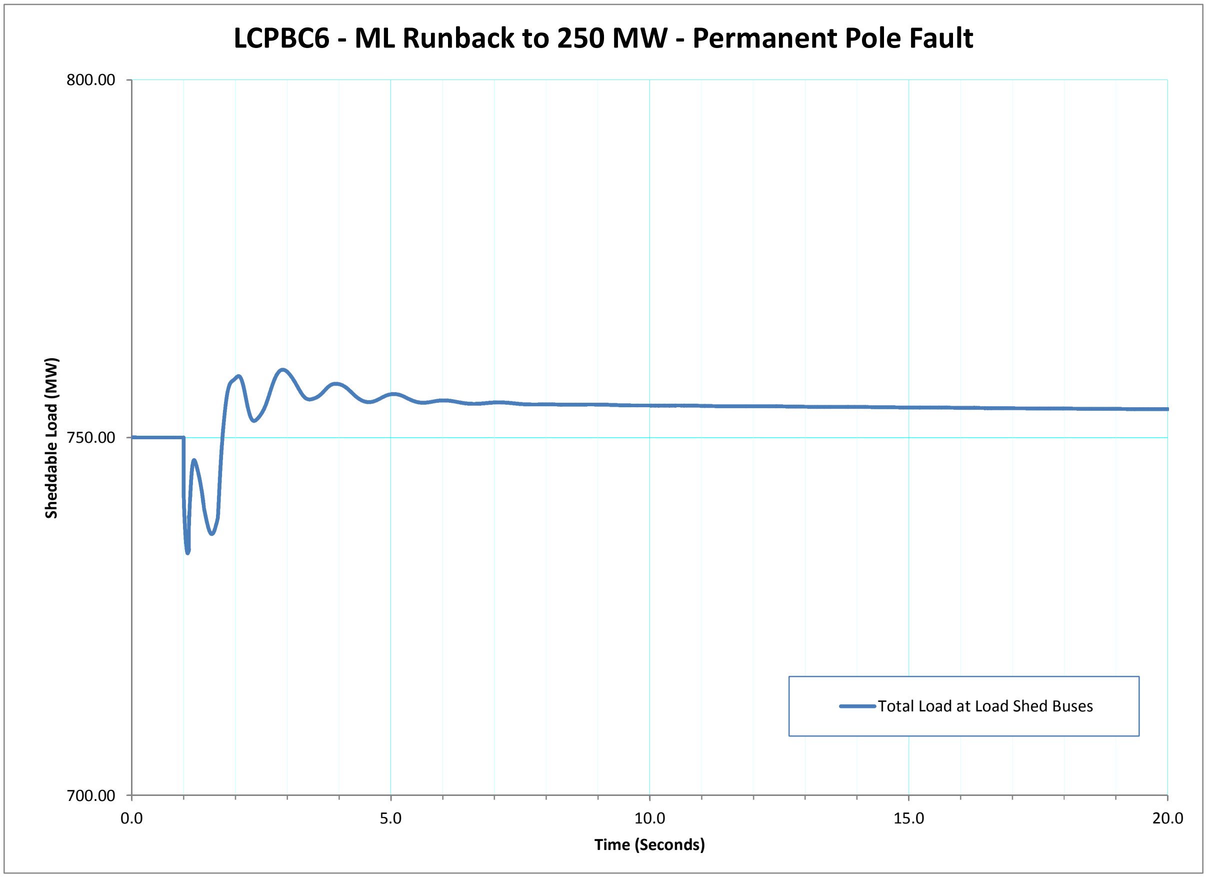


Figure 323 - LCPBC6 - ML Runback to 250 MW - Permanent Pole Fault - Sheddable Load (MW)

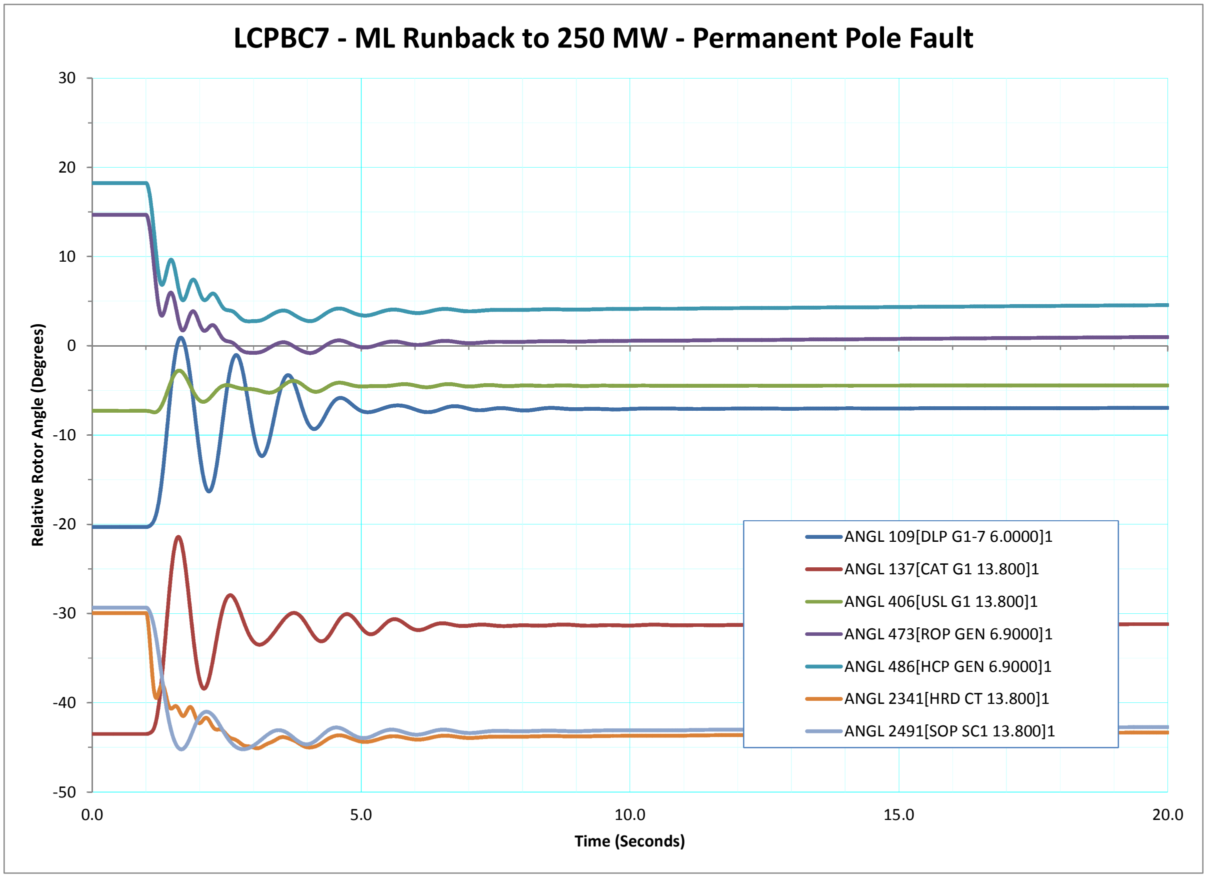


Figure 324 - LCPBC7 - ML Runback to 250 MW - Permanent Pole Fault - Relative Rotor Angle (Degrees)

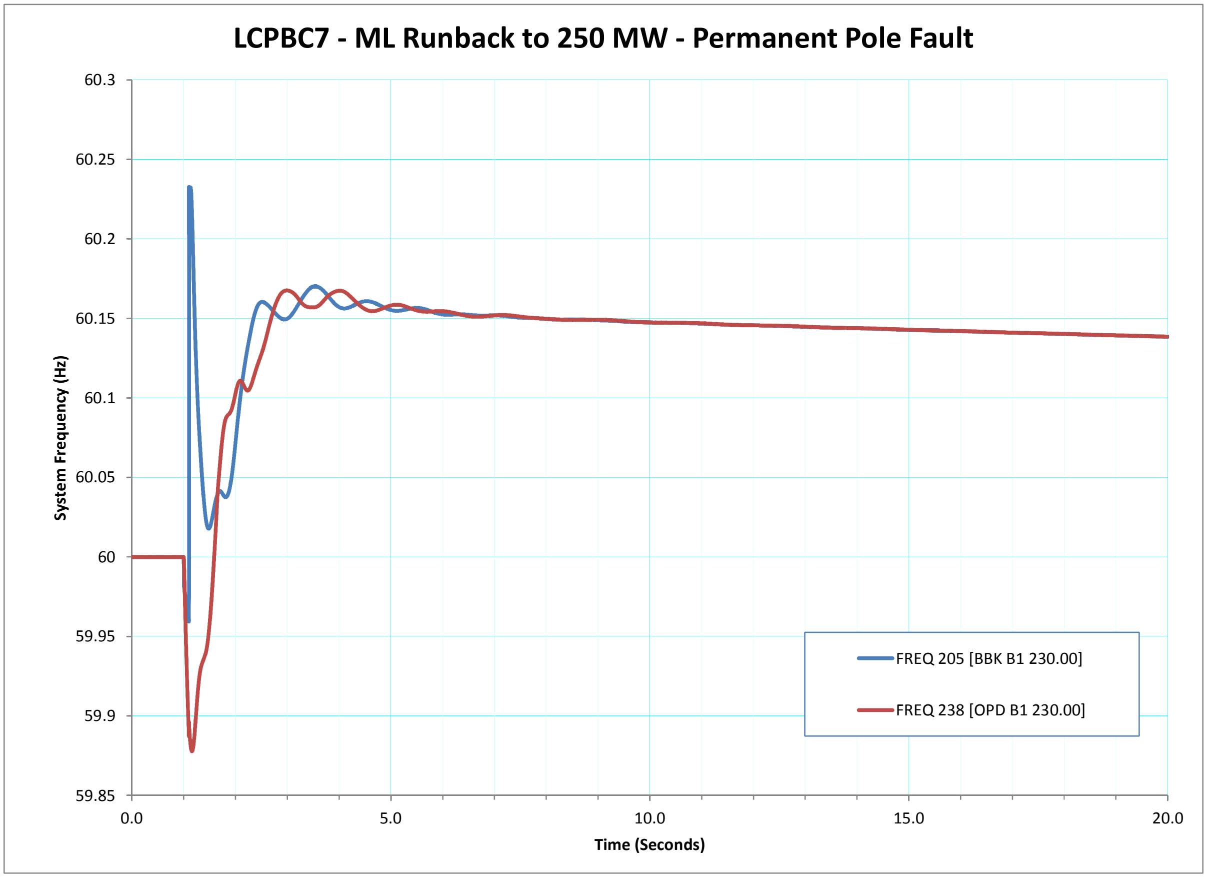


Figure 325 - LCPBC7 - ML Runback to 250 MW - Permanent Pole Fault - System Frequency (Hz)

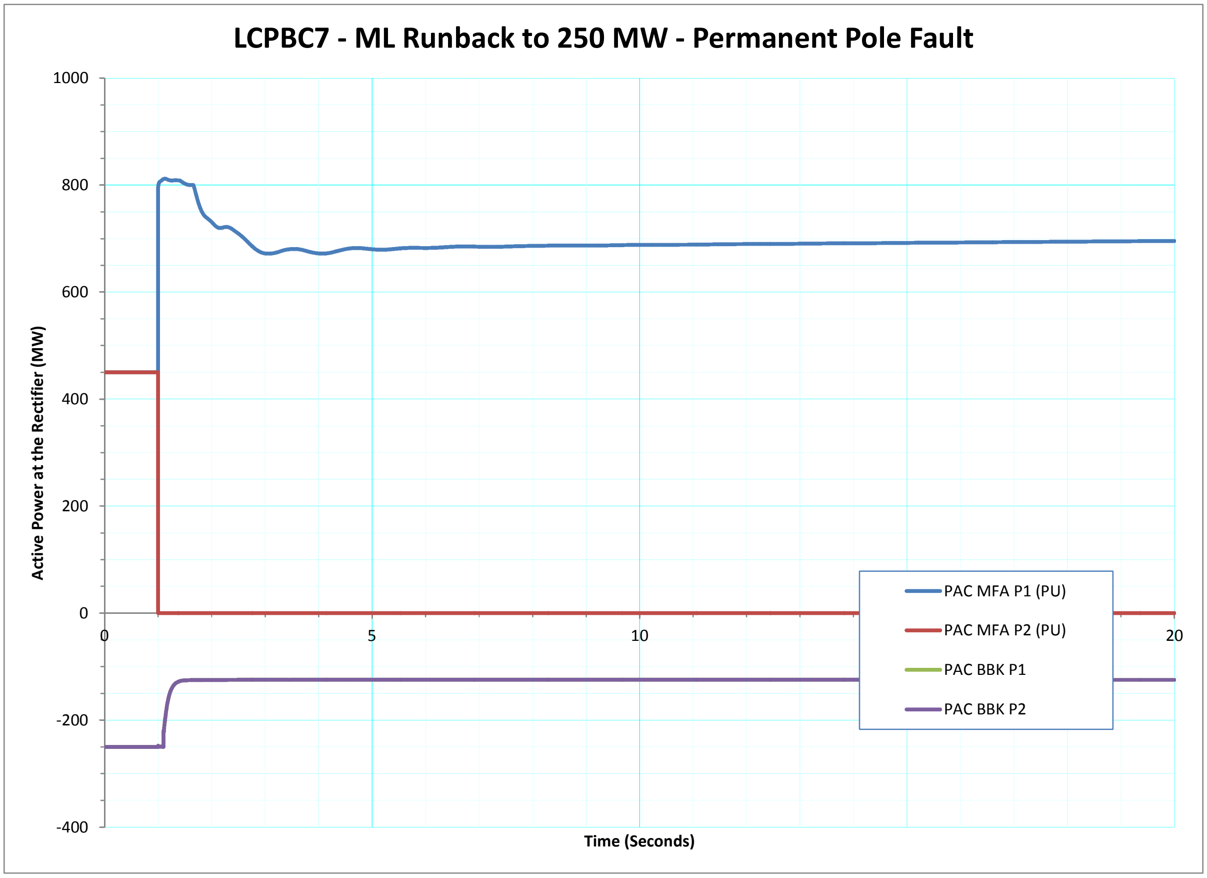


Figure 326 - LCPBC7 - ML Runback to 250 MW - Permanent Pole Fault - Active Power at the Rectifier (MW)

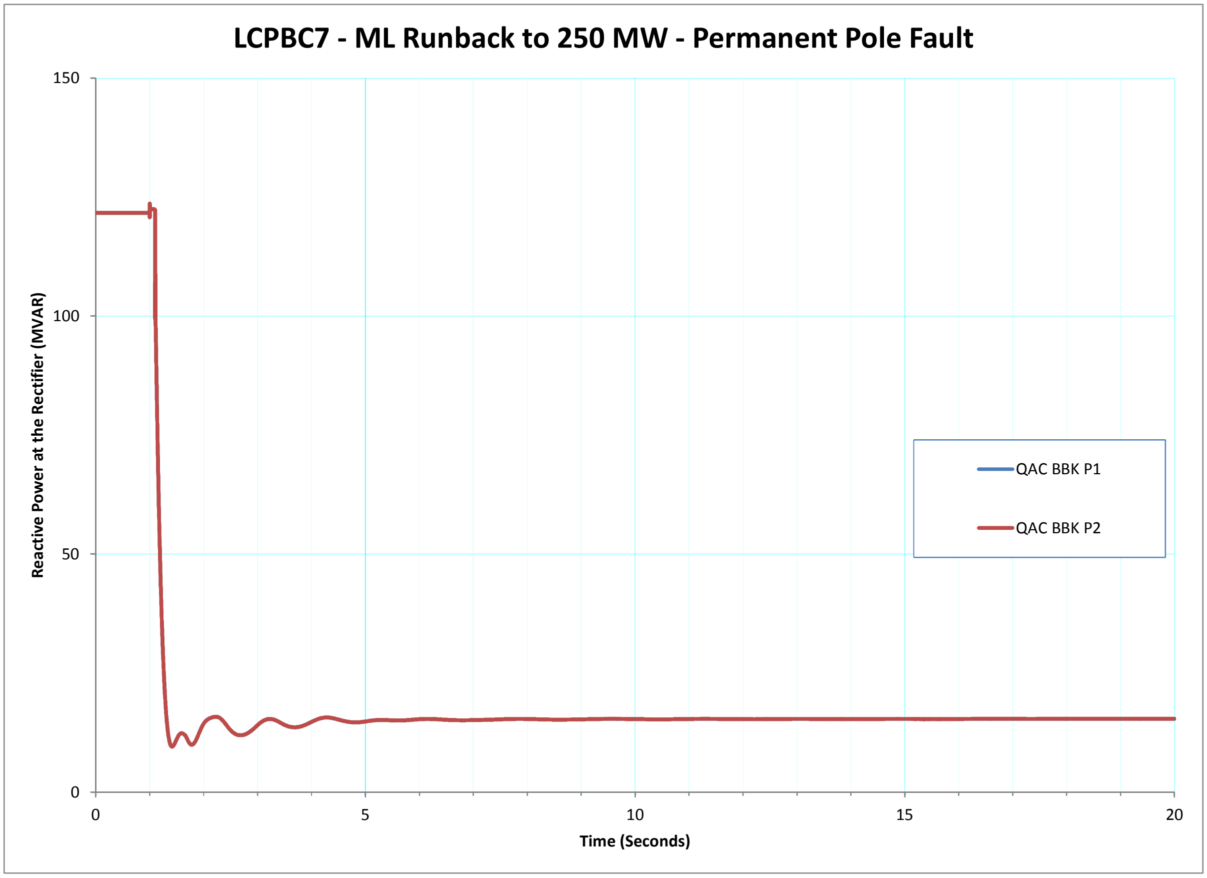


Figure 327 - LCPBC7 - ML Runback to 250 MW - Permanent Pole Fault - Reactive Power at the Rectifier (MVAR)

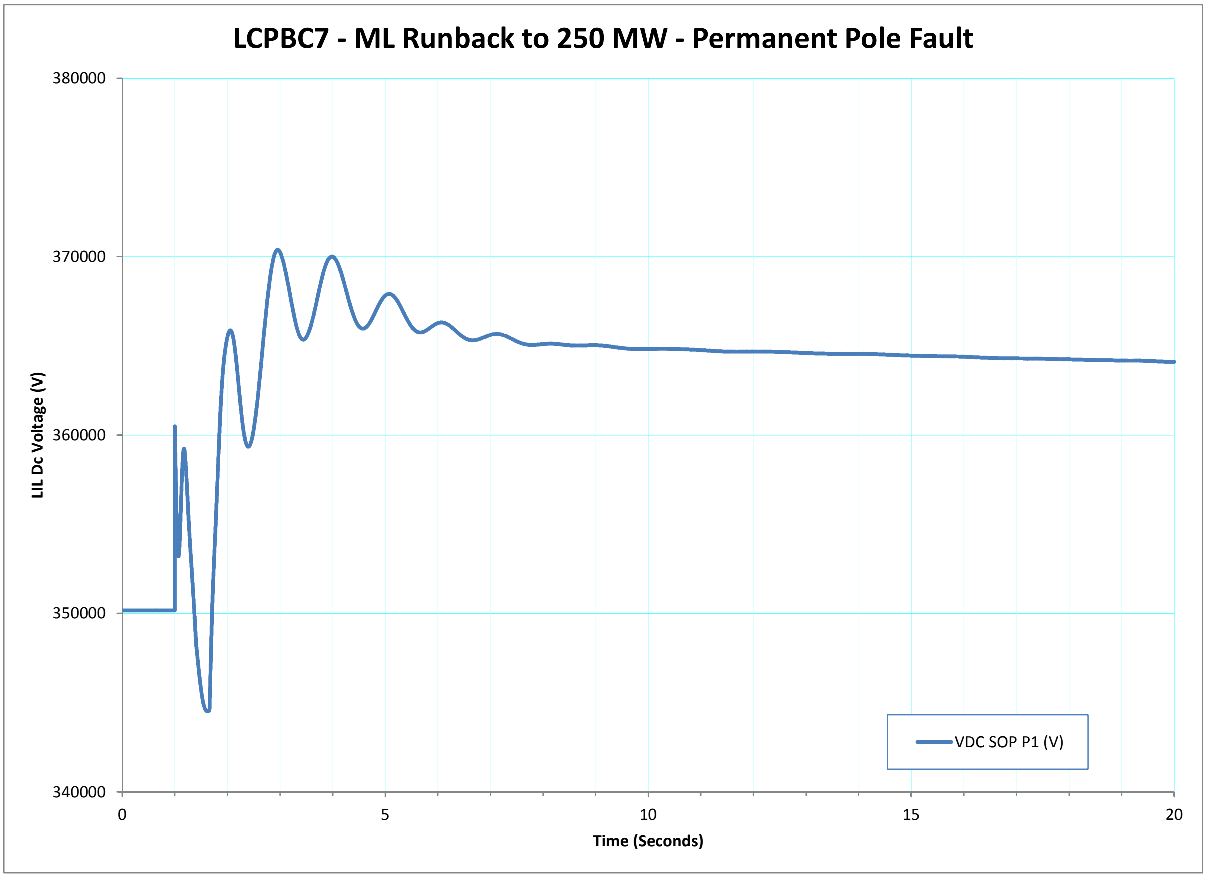


Figure 328 - LCPBC7 - ML Runback to 250 MW - Permanent Pole Fault - LIL Dc Voltage (V)

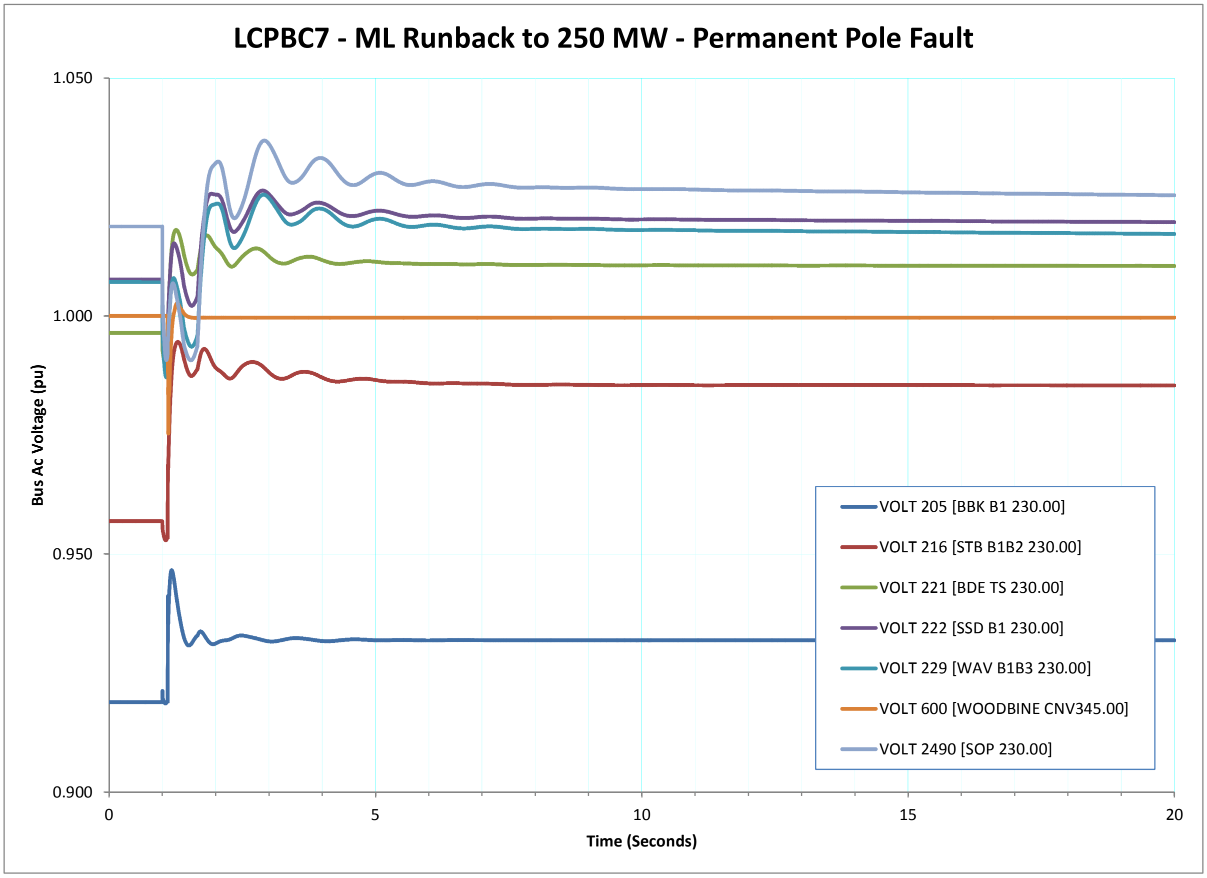


Figure 329 - LCPBC7 - ML Runback to 250 MW - Permanent Pole Fault - Bus Ac Voltage (pu)

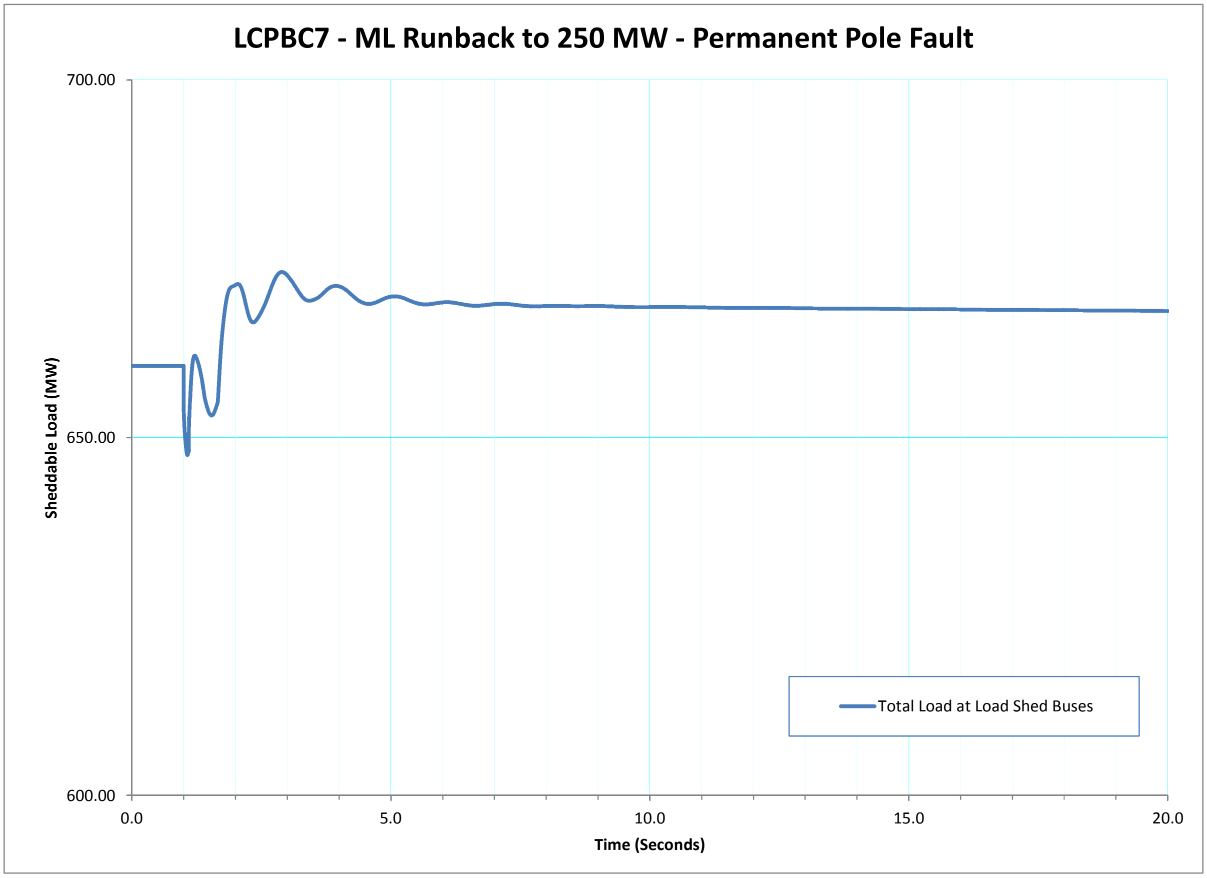


Figure 330 - LCPBC7 - ML Runback to 250 MW - Permanent Pole Fault - Sheddable Load (MW)

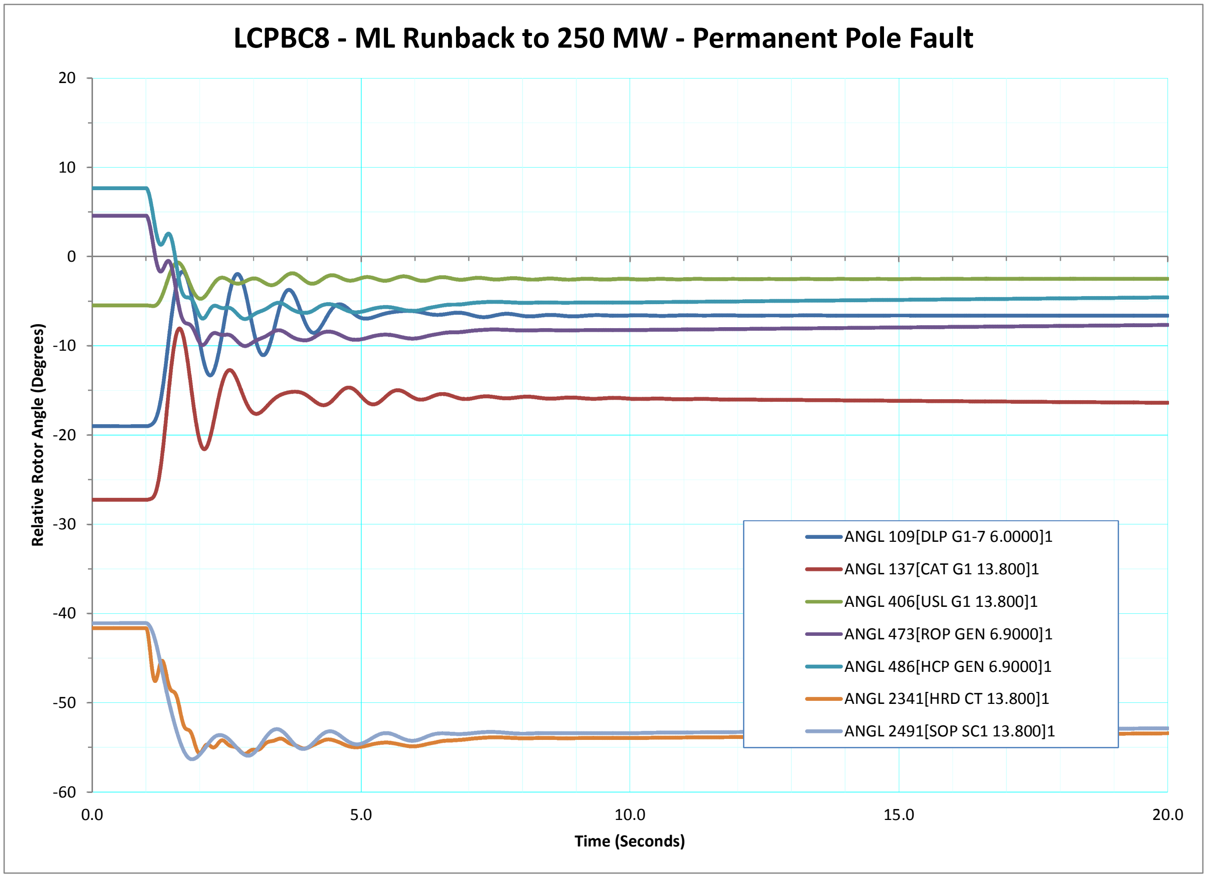


Figure 331 - LCPBC8 - ML Runback to 250 MW - Permanent Pole Fault - Relative Rotor Angle (Degrees)

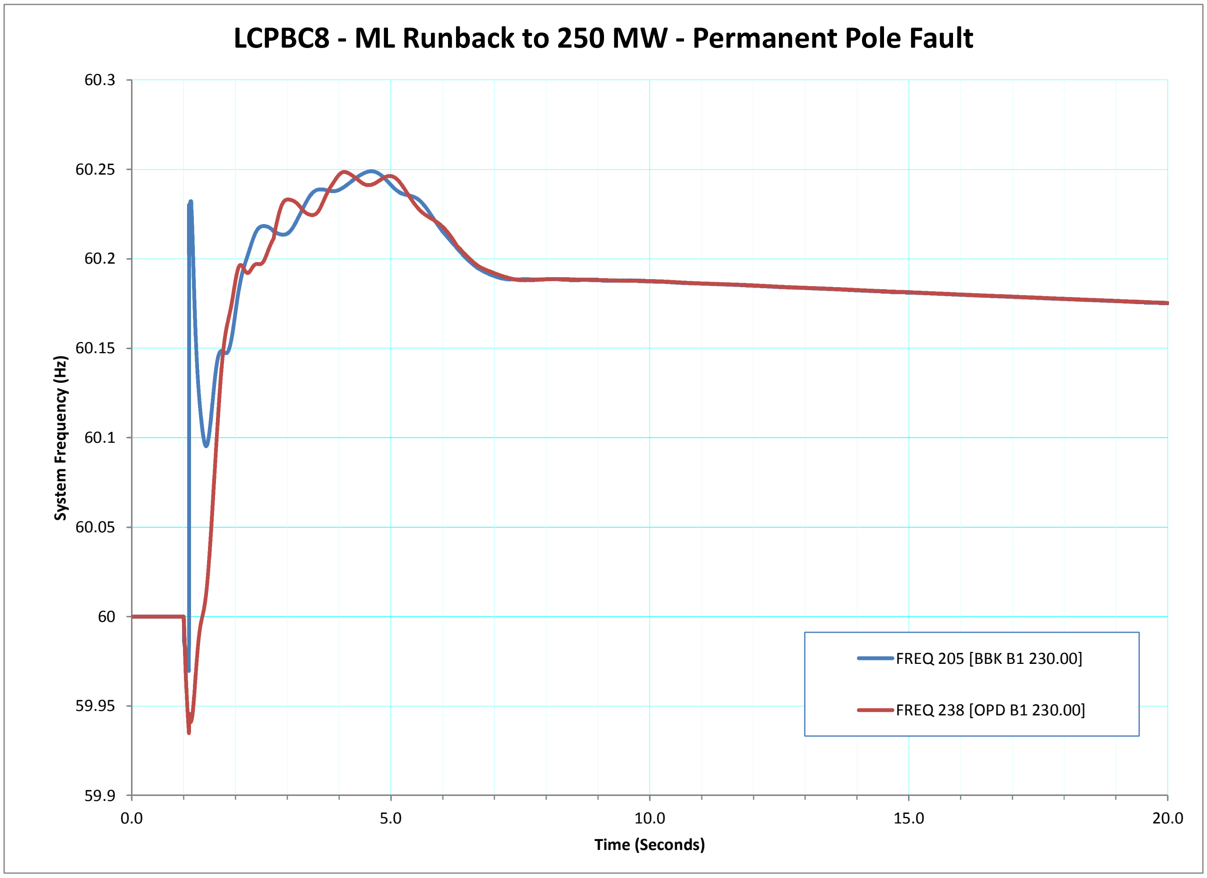


Figure 332 - LCPBC8 - ML Runback to 250 MW - Permanent Pole Fault - System Frequency (Hz)

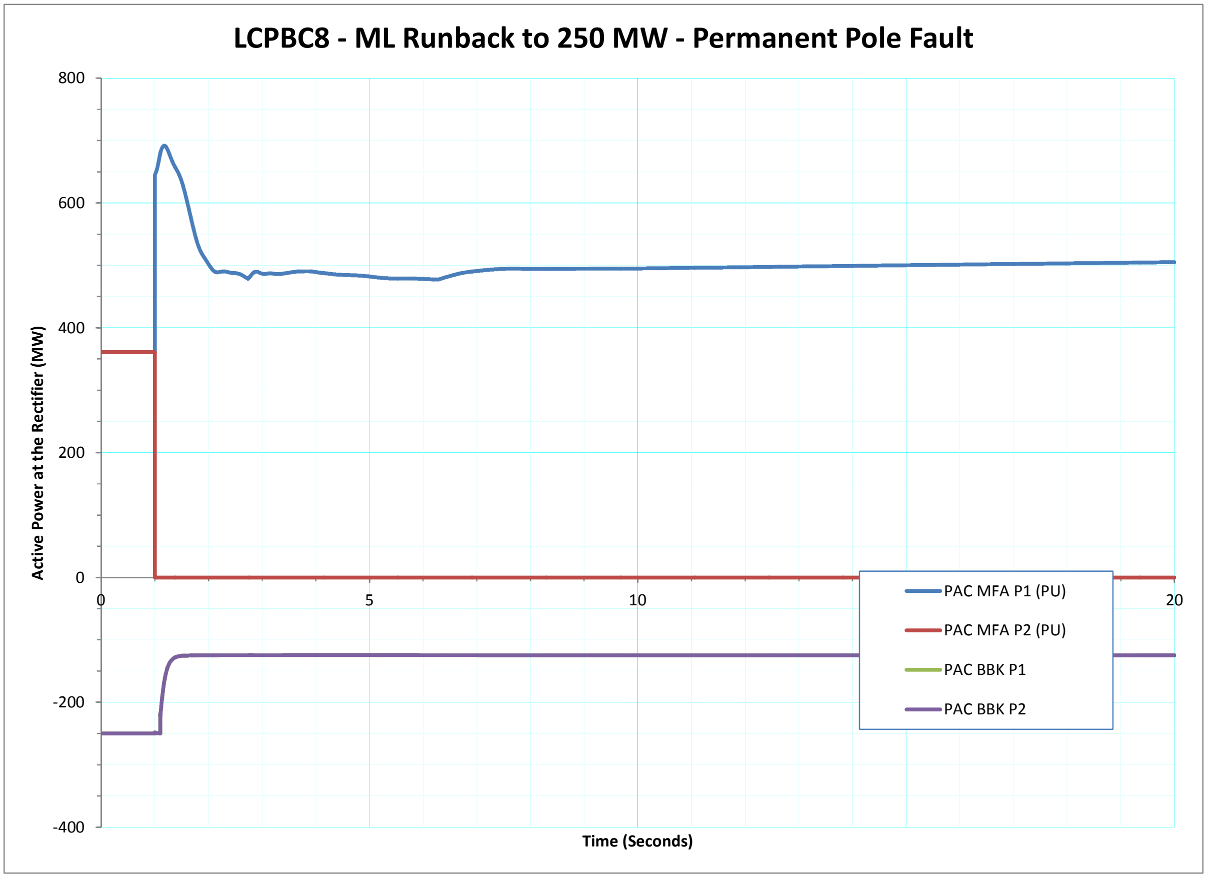


Figure 333 - LCPBC8 - ML Runback to 250 MW - Permanent Pole Fault - Active Power at the Rectifier (MW)

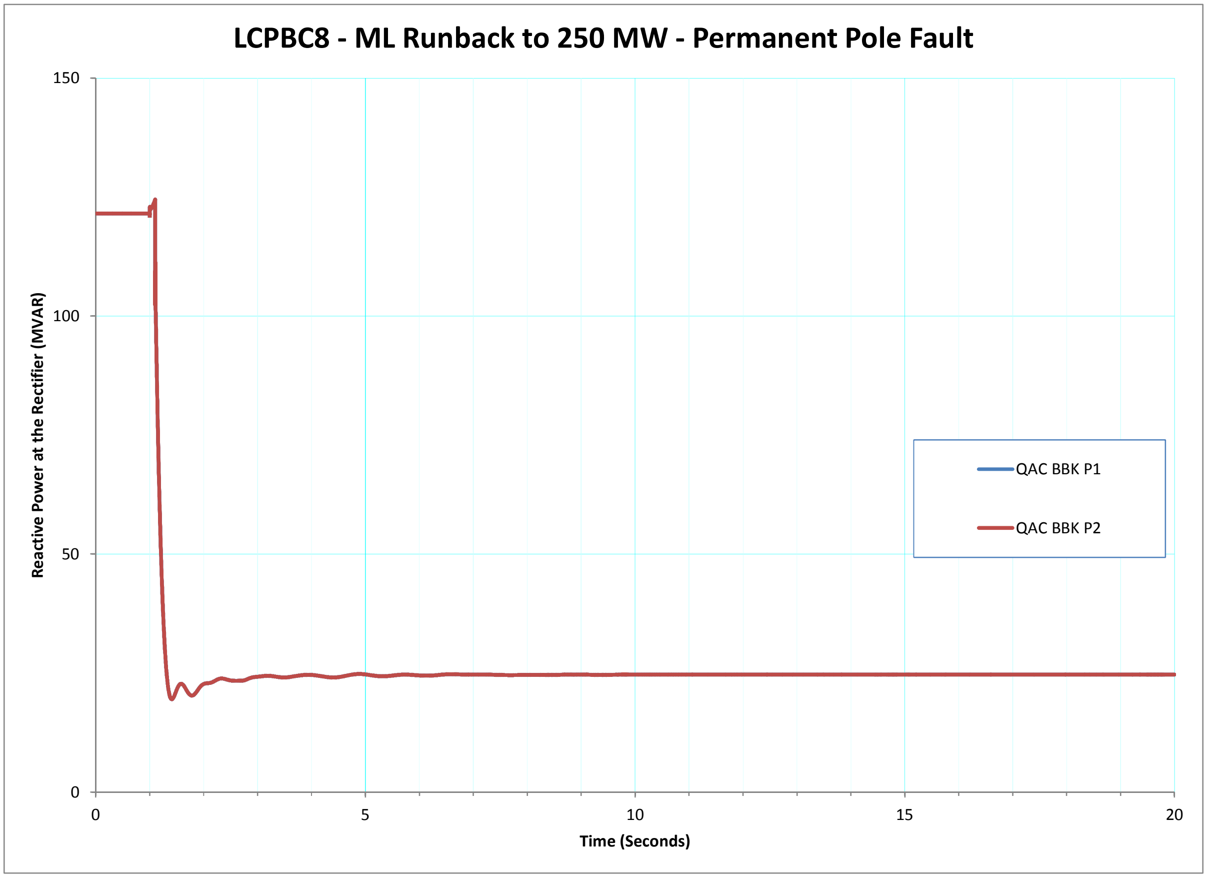


Figure 334 - LCPBC8 - ML Runback to 250 MW - Permanent Pole Fault - Reactive Power at the Rectifier (MVAR)

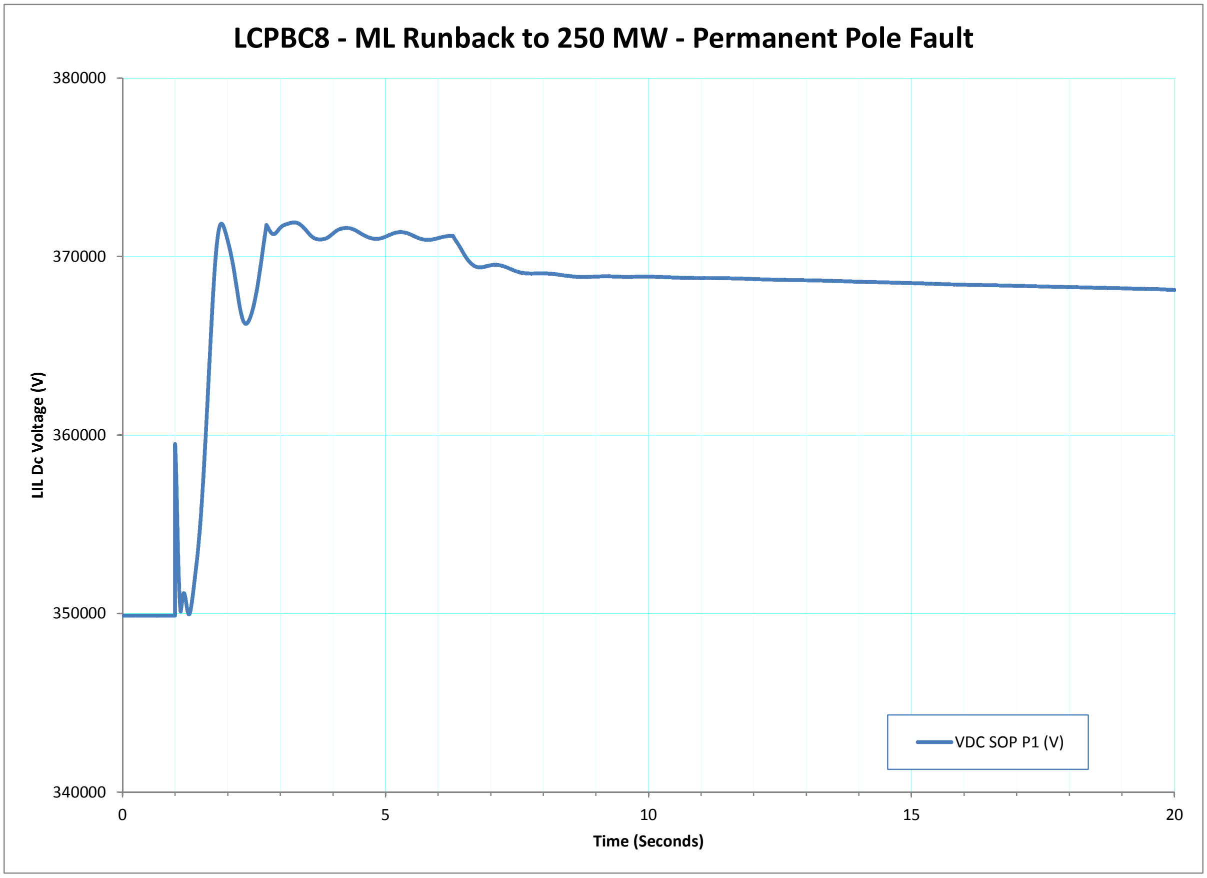


Figure 335 - LCPBC8 - ML Runback to 250 MW - Permanent Pole Fault - LIL Dc Voltage (V)

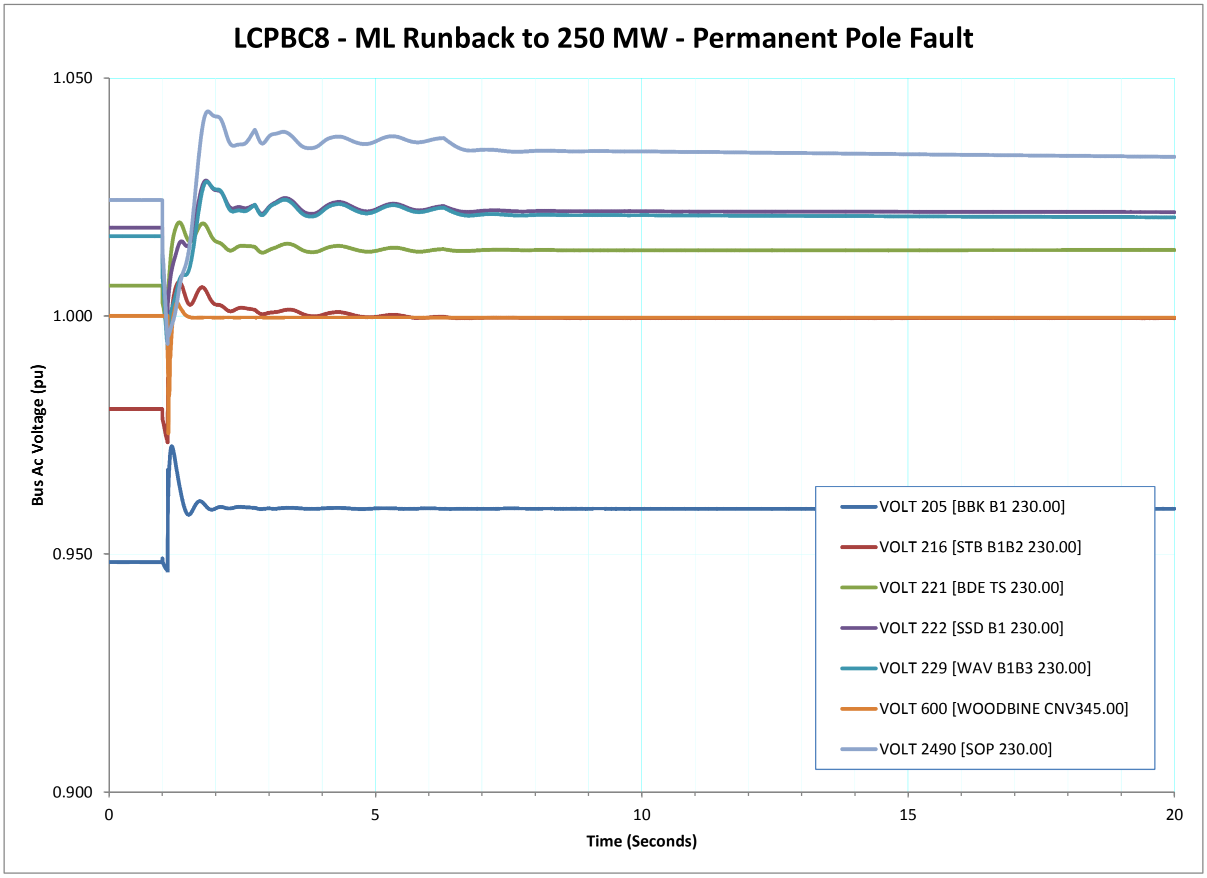


Figure 336 - LCPBC8 - ML Runback to 250 MW - Permanent Pole Fault - Bus Ac Voltage (pu)

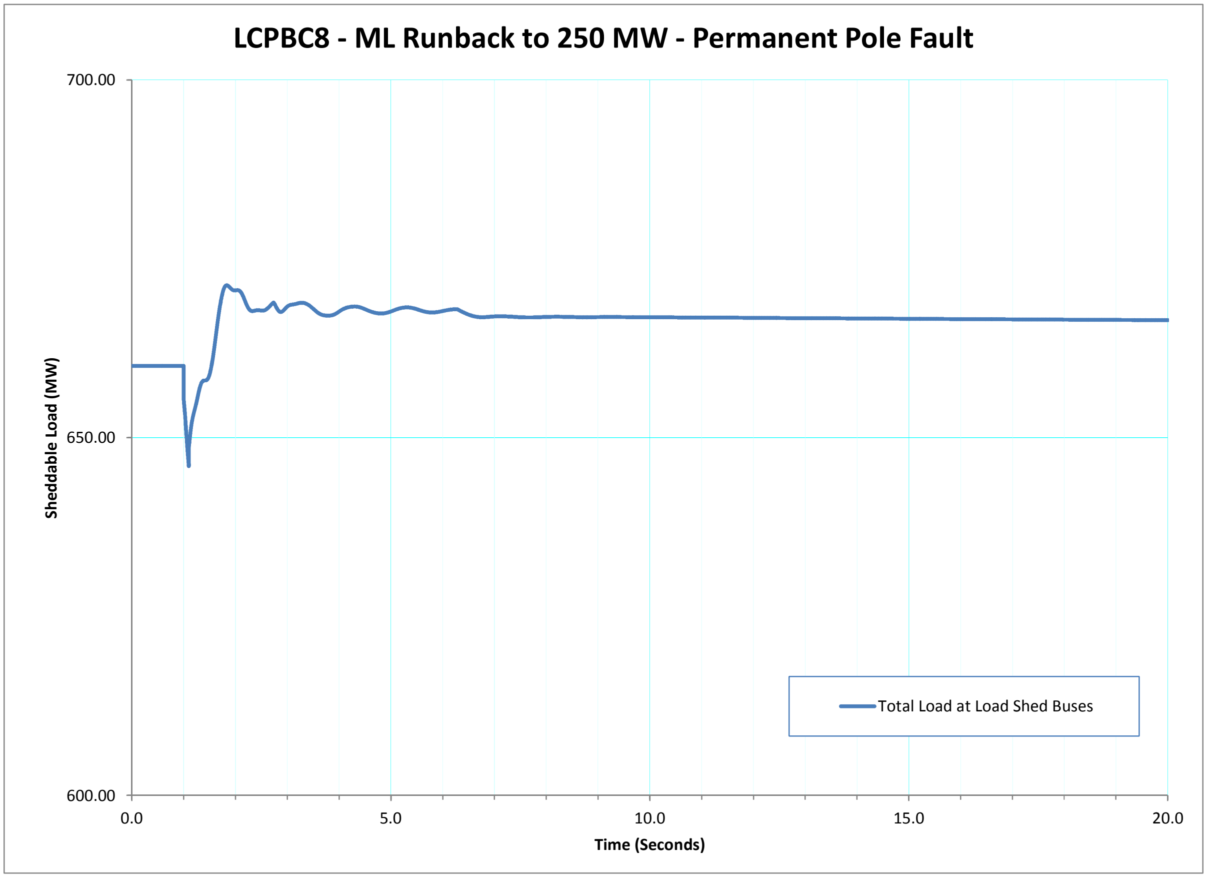


Figure 337 - LCPBC8 - ML Runback to 250 MW - Permanent Pole Fault - Sheddable Load (MW)

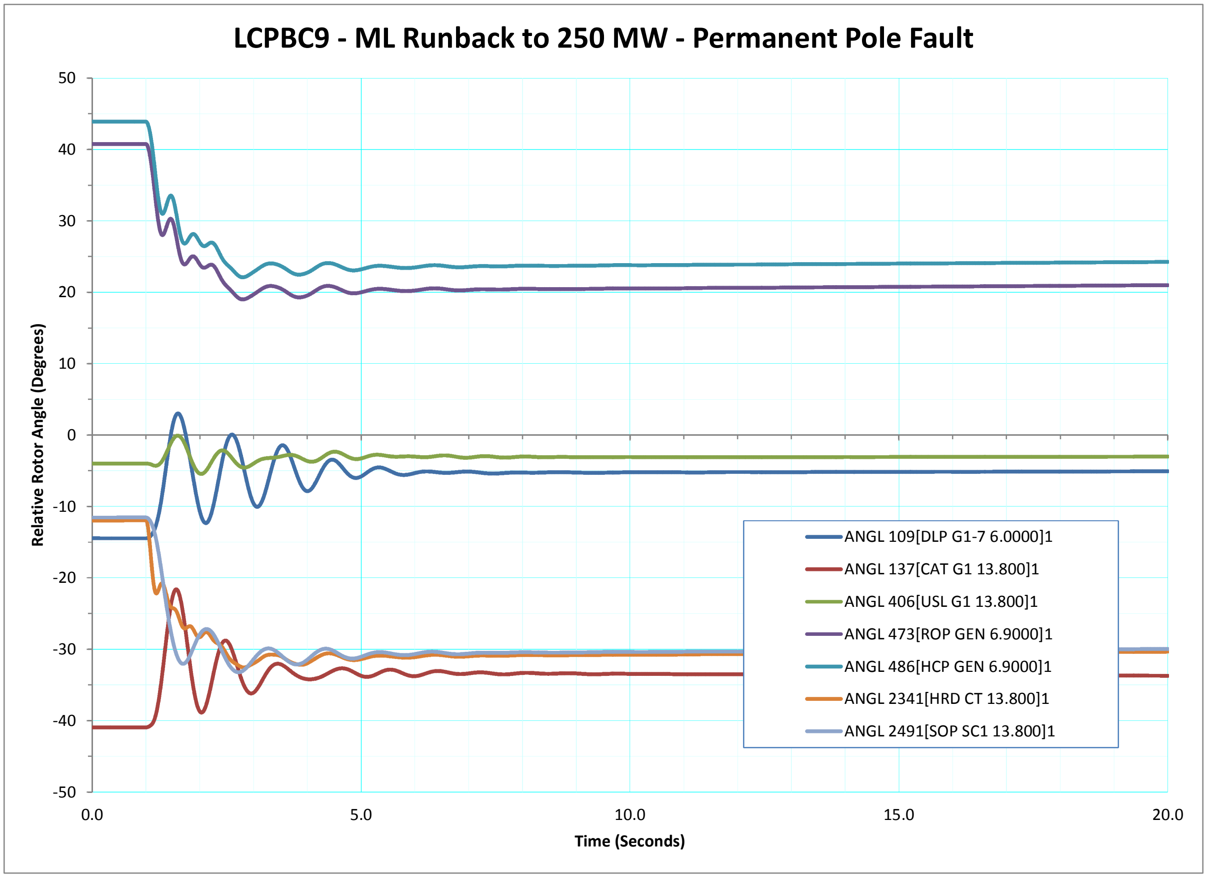


Figure 338 - LCPBC9 - ML Runback to 250 MW - Permanent Pole Fault - Relative Rotor Angle (Degrees)

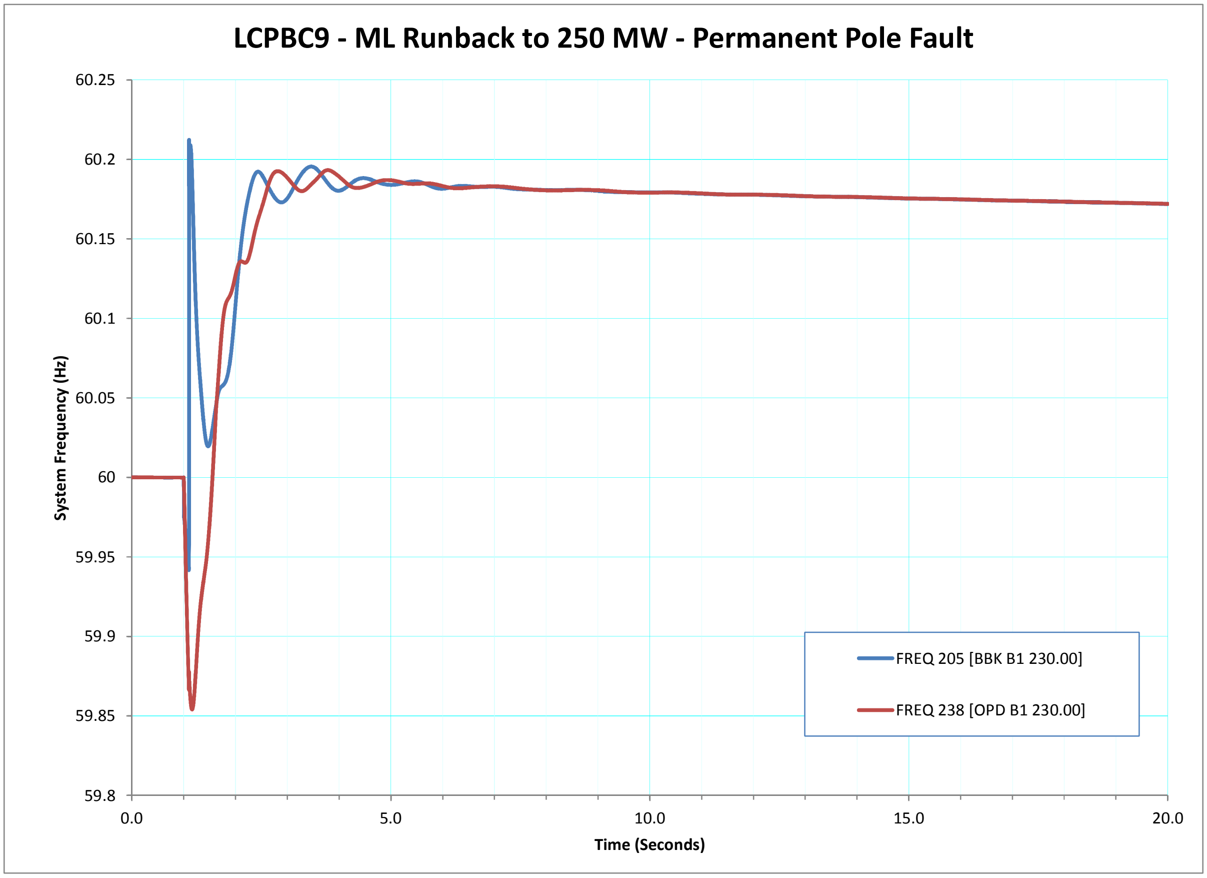


Figure 339 - LCPBC9 - ML Runback to 250 MW - Permanent Pole Fault - System Frequency (Hz)

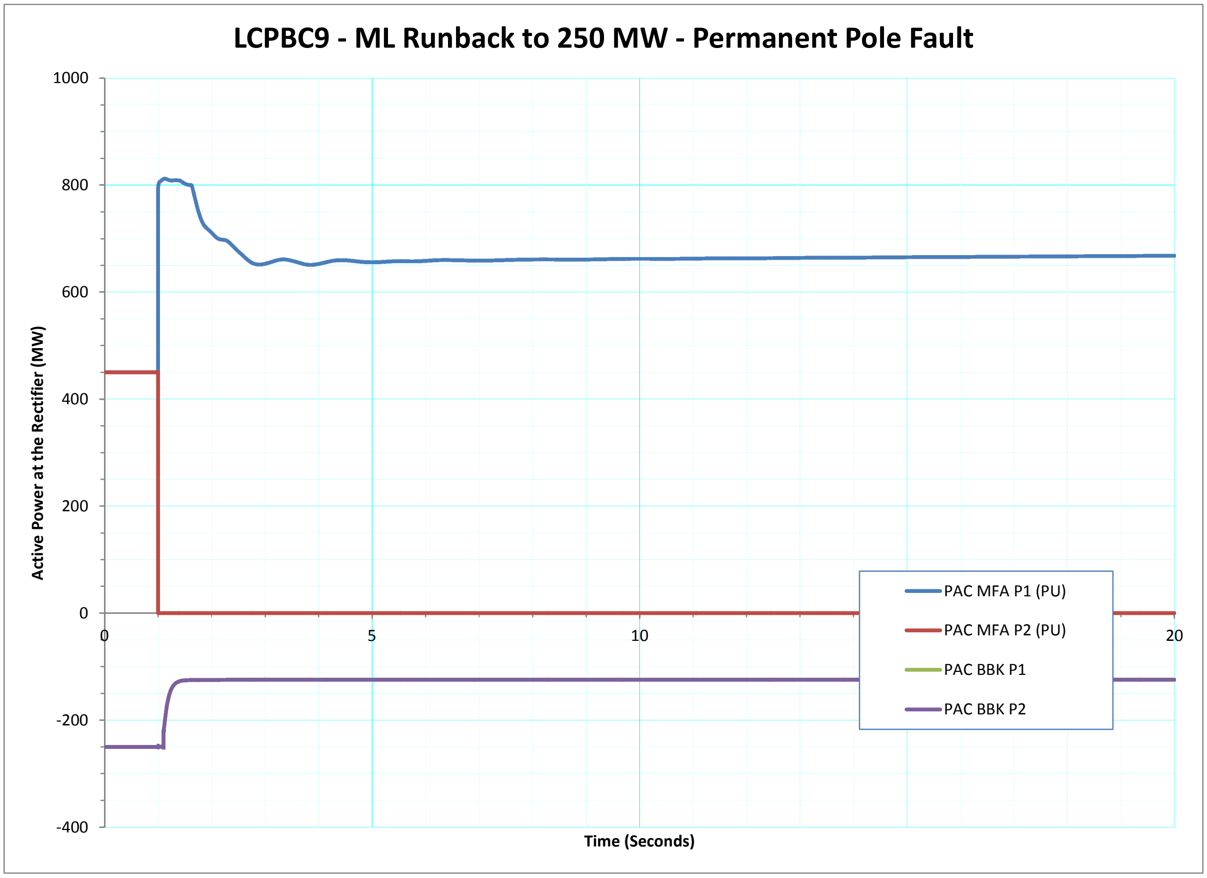


Figure 340 - LCPBC9 - ML Runback to 250 MW - Permanent Pole Fault - Active Power at the Rectifier (MW)

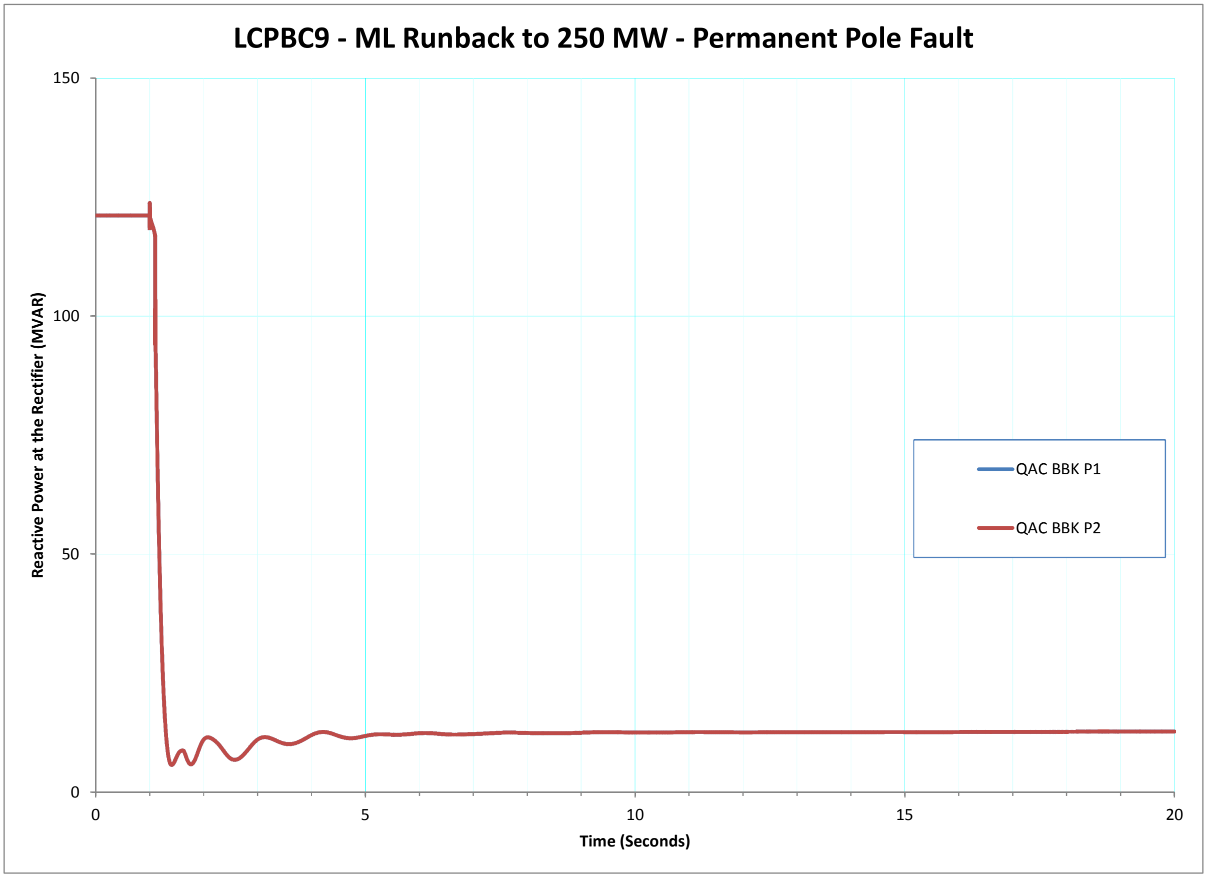


Figure 341 - LCPBC9 - ML Runback to 250 MW - Permanent Pole Fault - Reactive Power at the Rectifier (MVAR)

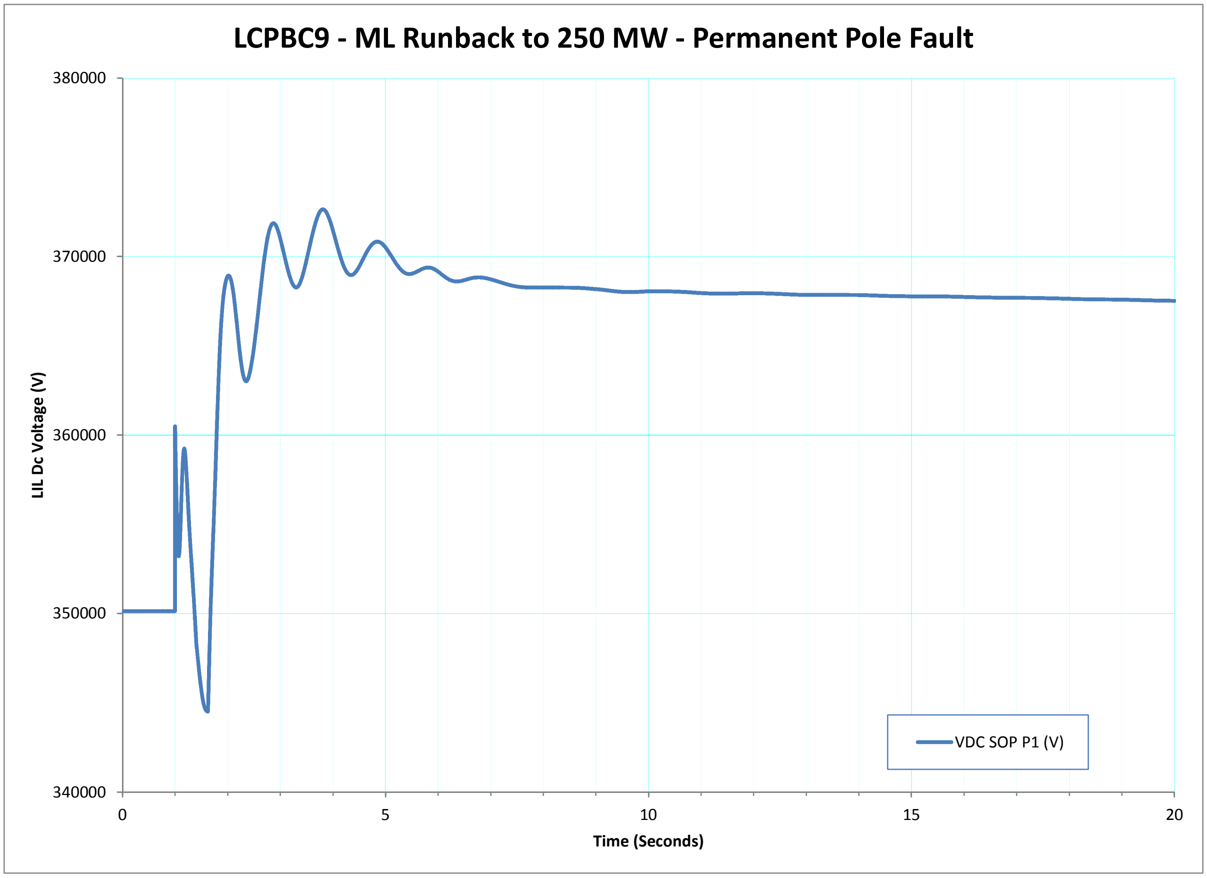


Figure 342 - LCPBC9 - ML Runback to 250 MW - Permanent Pole Fault - LIL Dc Voltage (V)

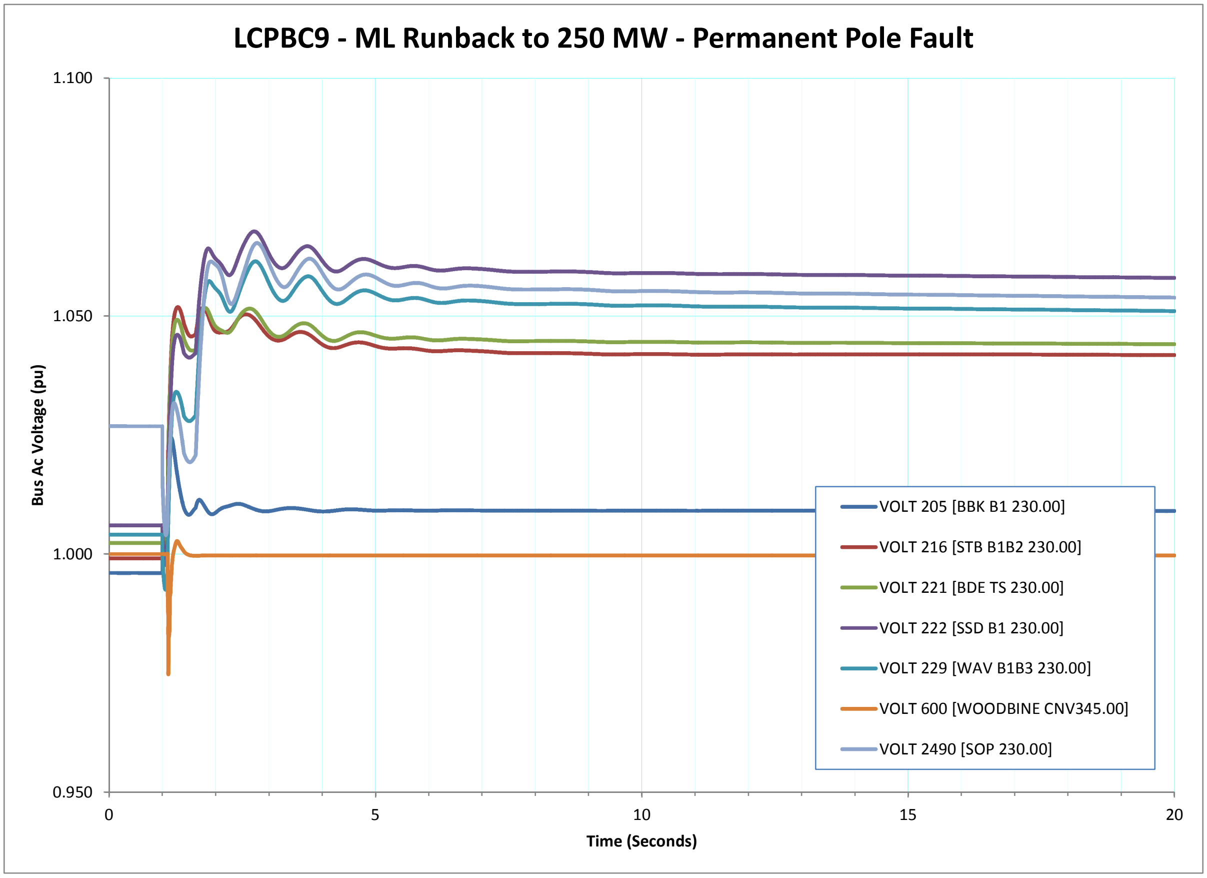


Figure 343 - LCPBC9 - ML Runback to 250 MW - Permanent Pole Fault - Bus Ac Voltage (pu)

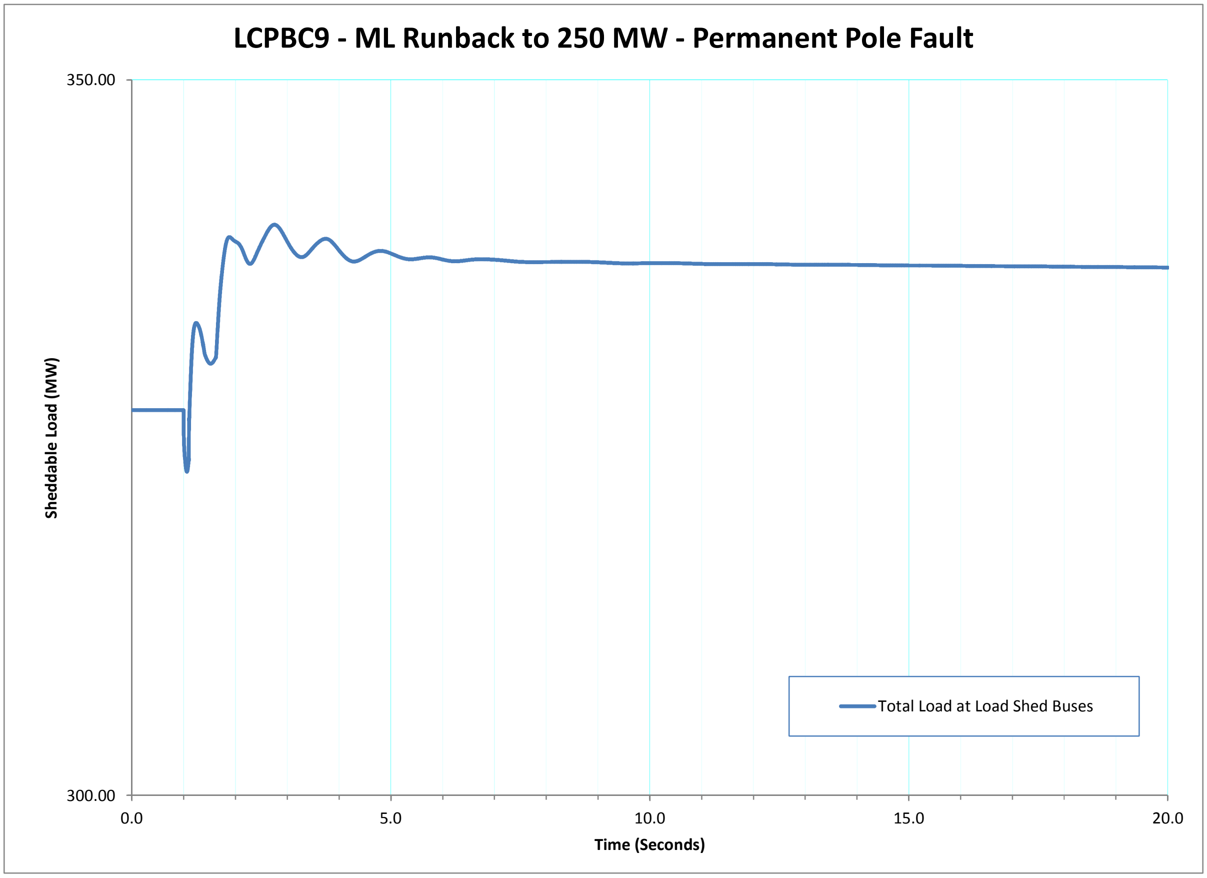


Figure 344 - LCPBC9 - ML Runback to 250 MW - Permanent Pole Fault - Sheddable Load (MW)

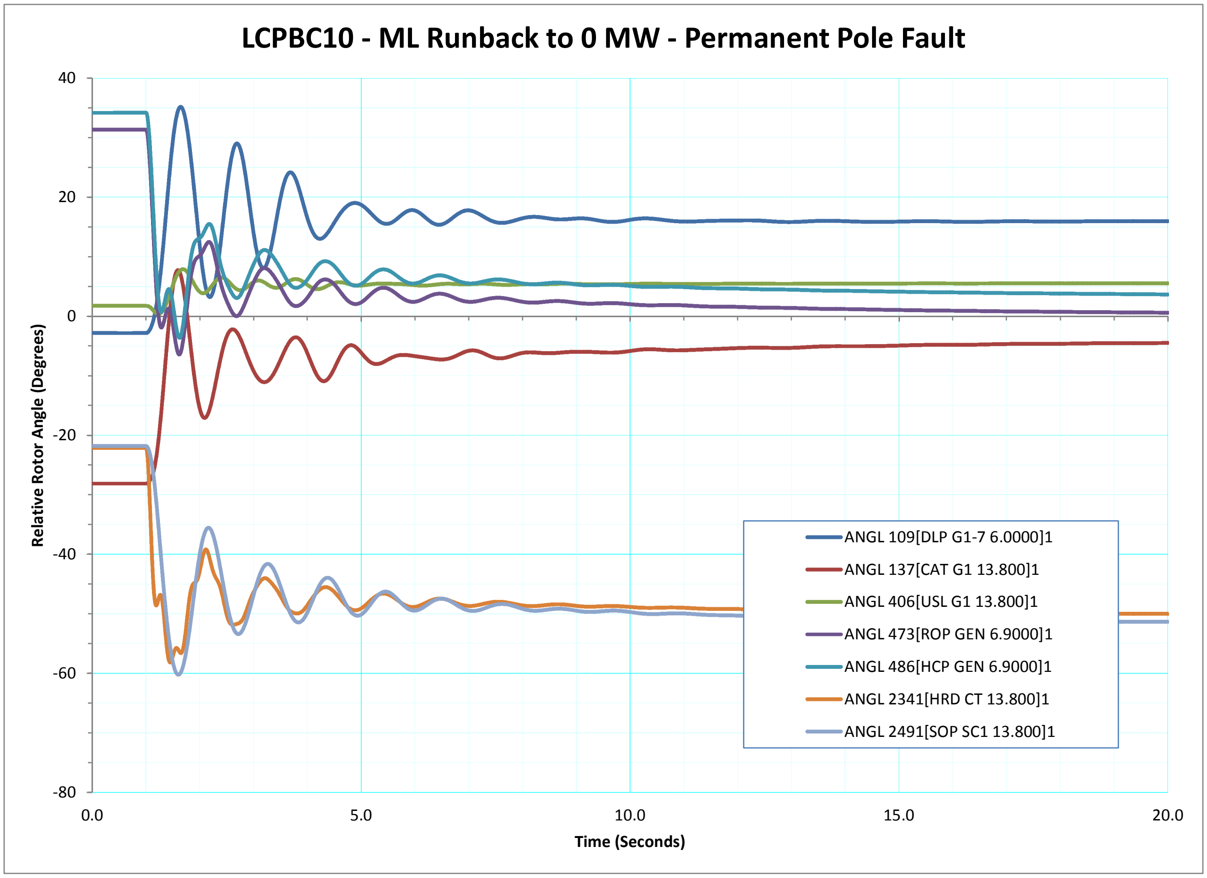


Figure 345 - LCPBC10 - ML Runback to 0 MW - Permanent Pole Fault - Relative Rotor Angle (Degrees)

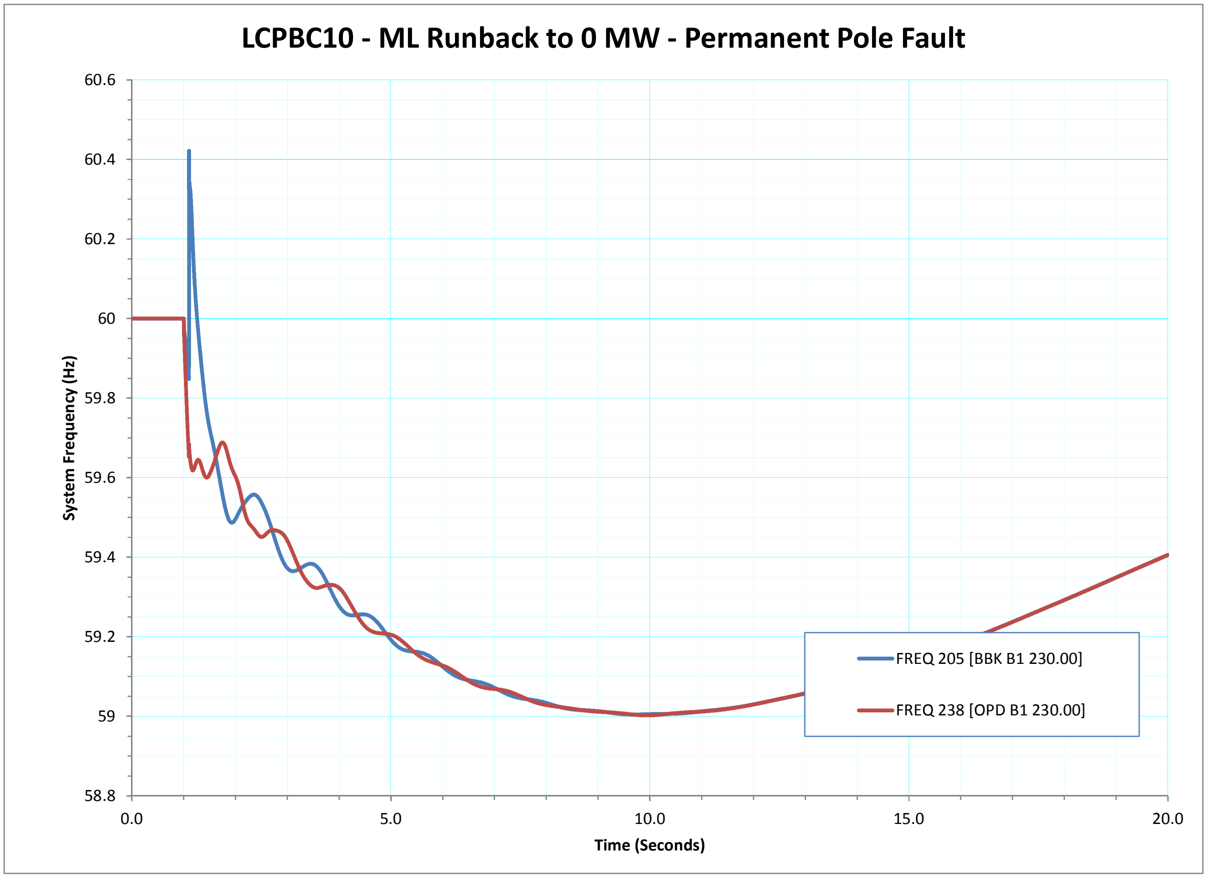


Figure 346 - LCPBC10 - ML Runback to 0 MW - Permanent Pole Fault - System Frequency (Hz)

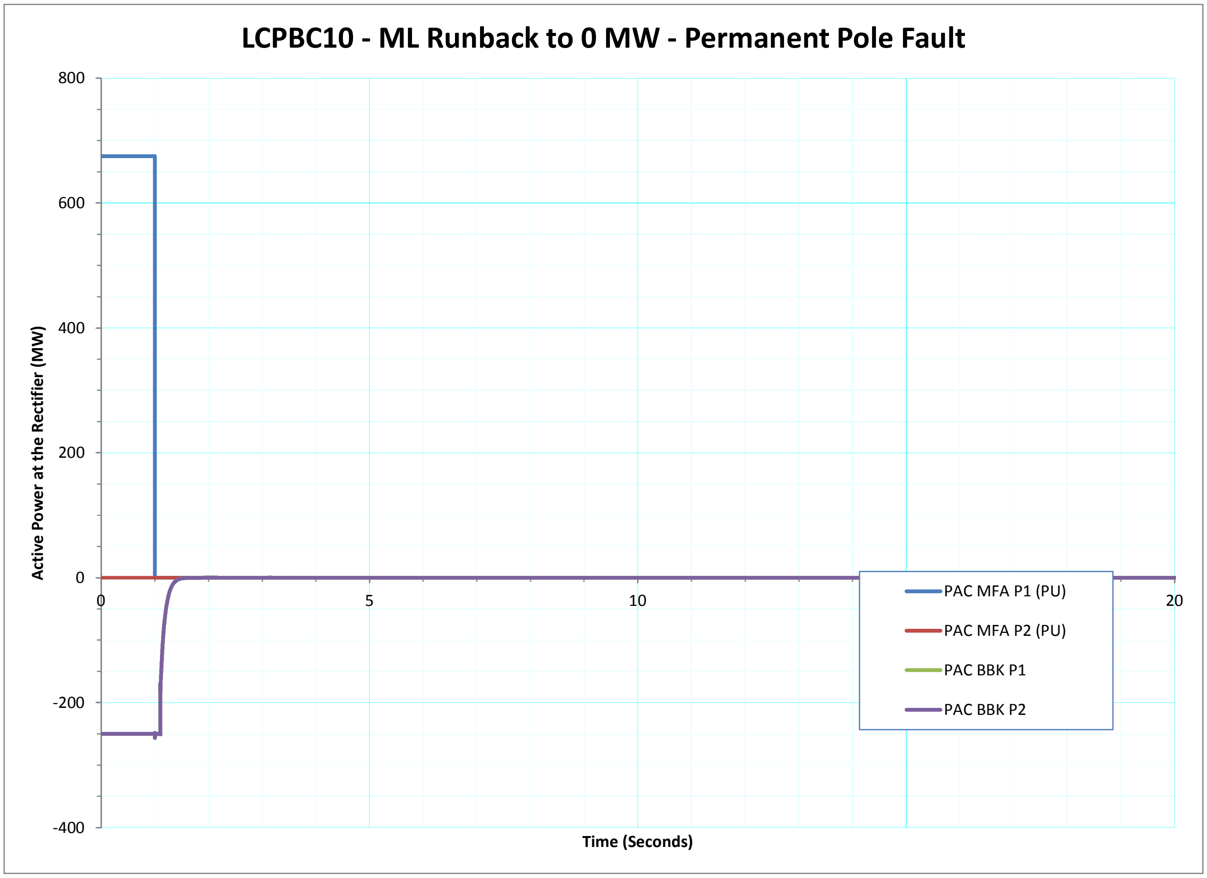


Figure 347 - LCPBC10 - ML Runback to 0 MW - Permanent Pole Fault - Active Power at the Rectifier (MW)

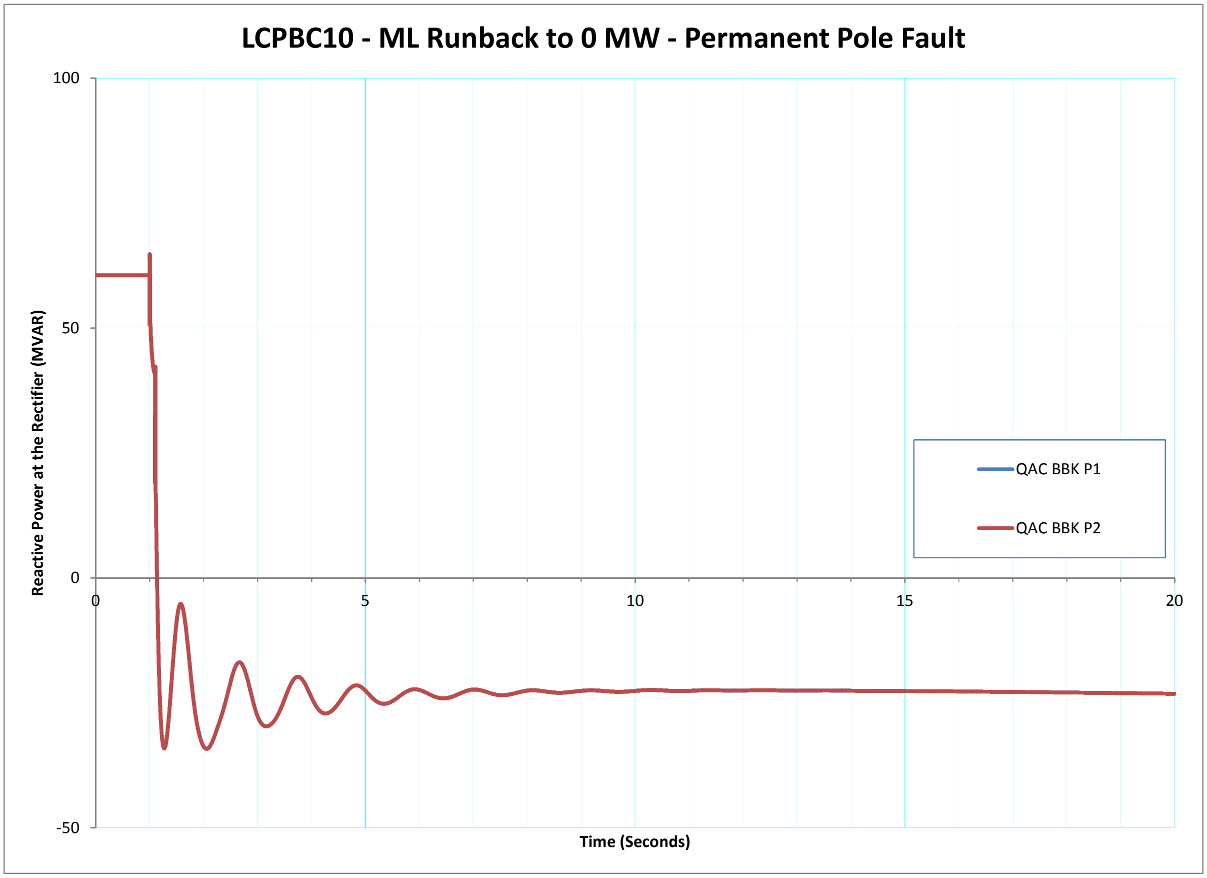


Figure 348 - LCPBC10 - ML Runback to 0 MW - Permanent Pole Fault - Reactive Power at the Rectifier (MVAR)

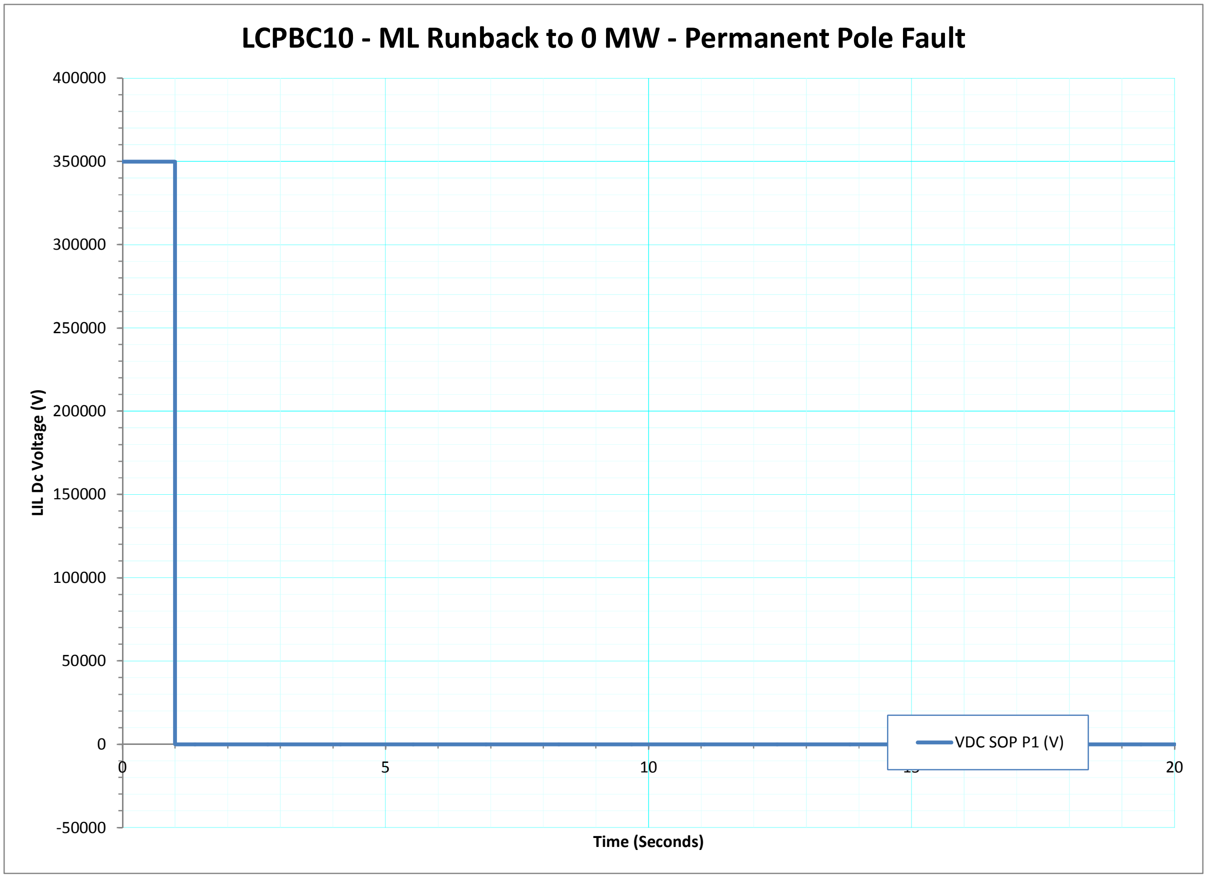


Figure 349 - LCPBC10 - ML Runback to 0 MW - Permanent Pole Fault - LIL Dc Voltage (V)

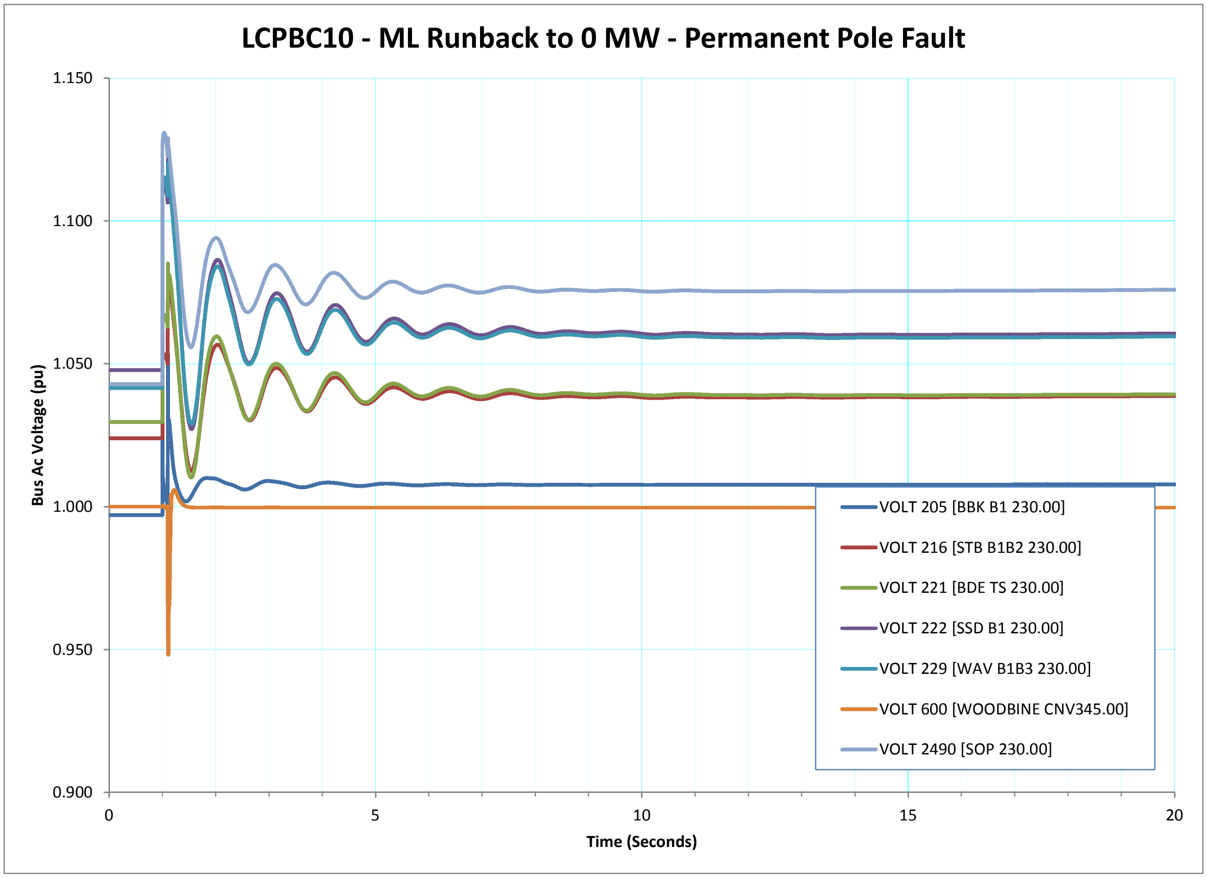


Figure 350 - LCPBC10 - ML Runback to 0 MW - Permanent Pole Fault - Bus Ac Voltage (pu)

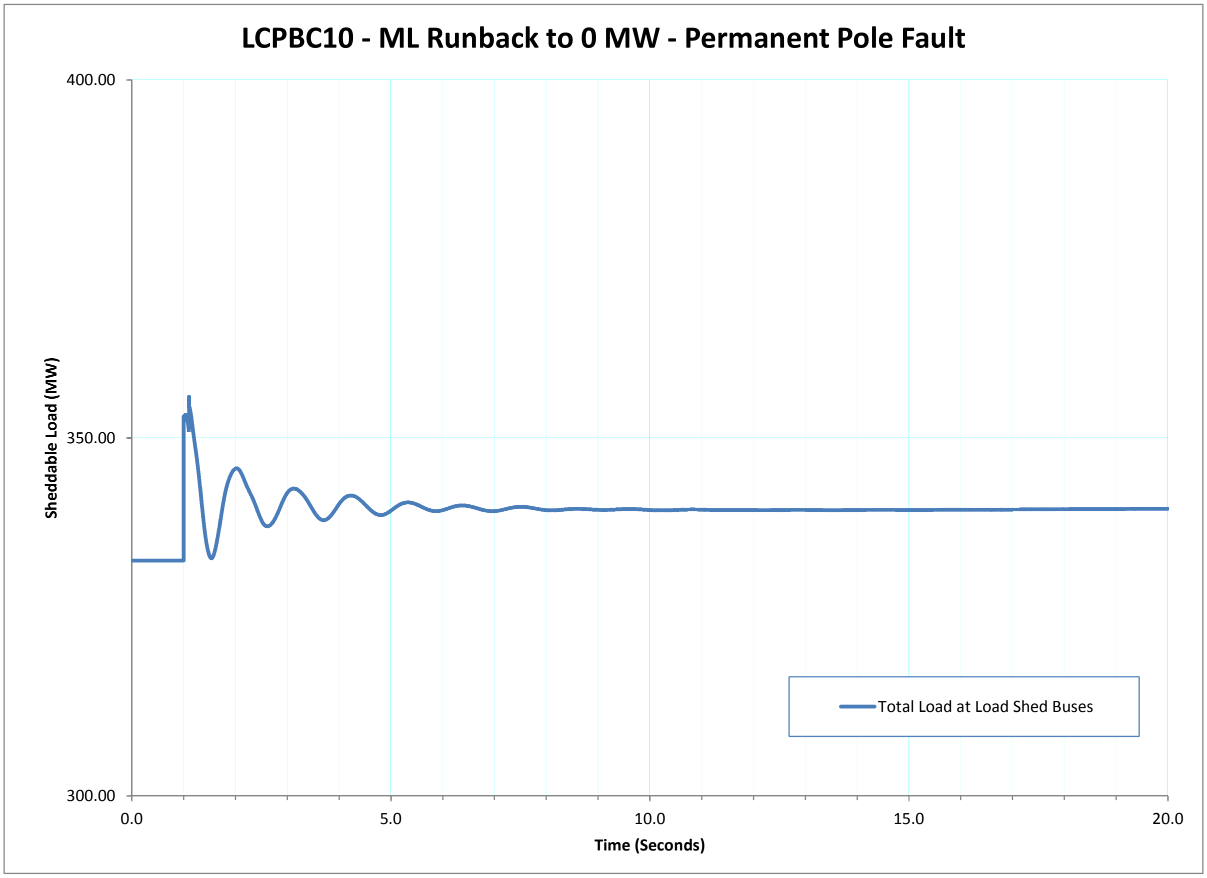


Figure 351 - LCPBC10 - ML Runback to 0 MW - Permanent Pole Fault - Sheddable Load (MW)

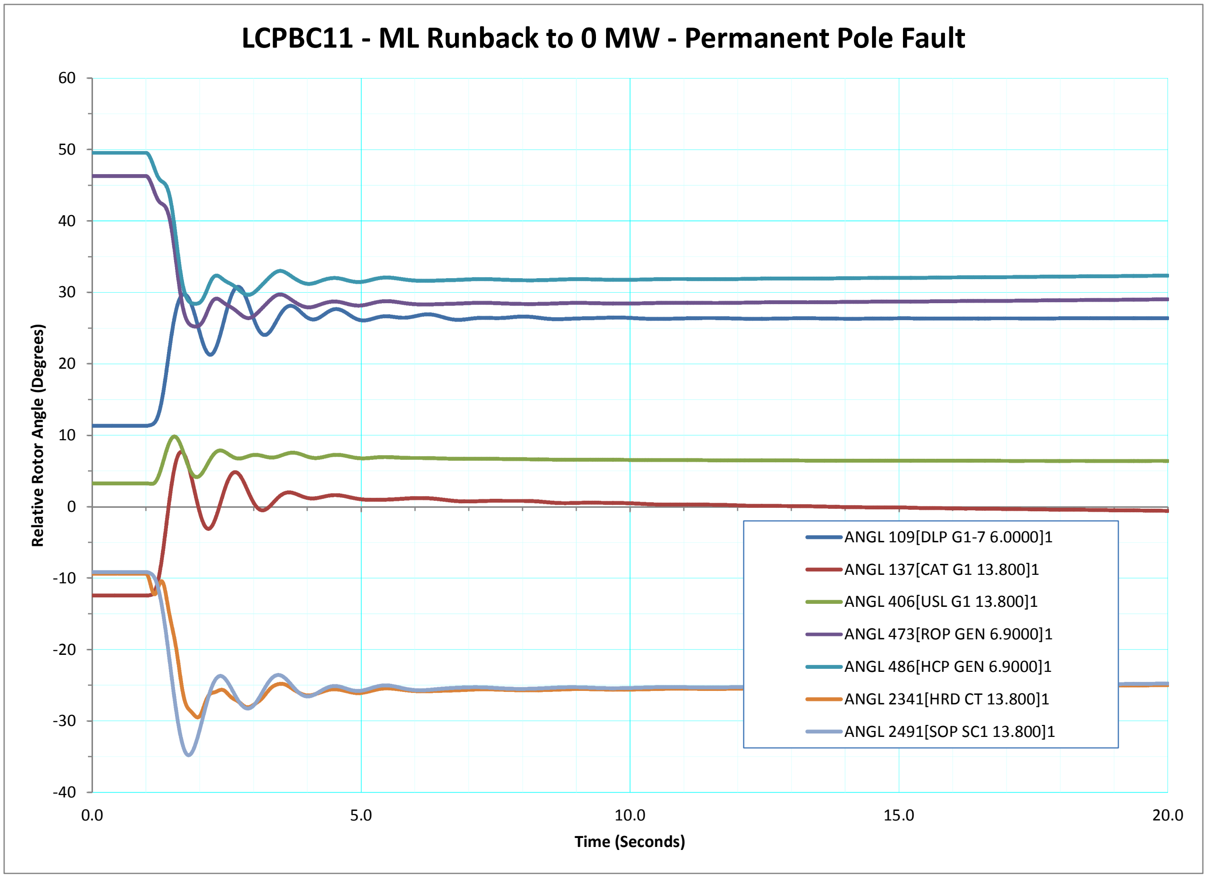


Figure 352 - LCPBC11 - ML Runback to 0 MW - Permanent Pole Fault - Relative Rotor Angle (Degrees)

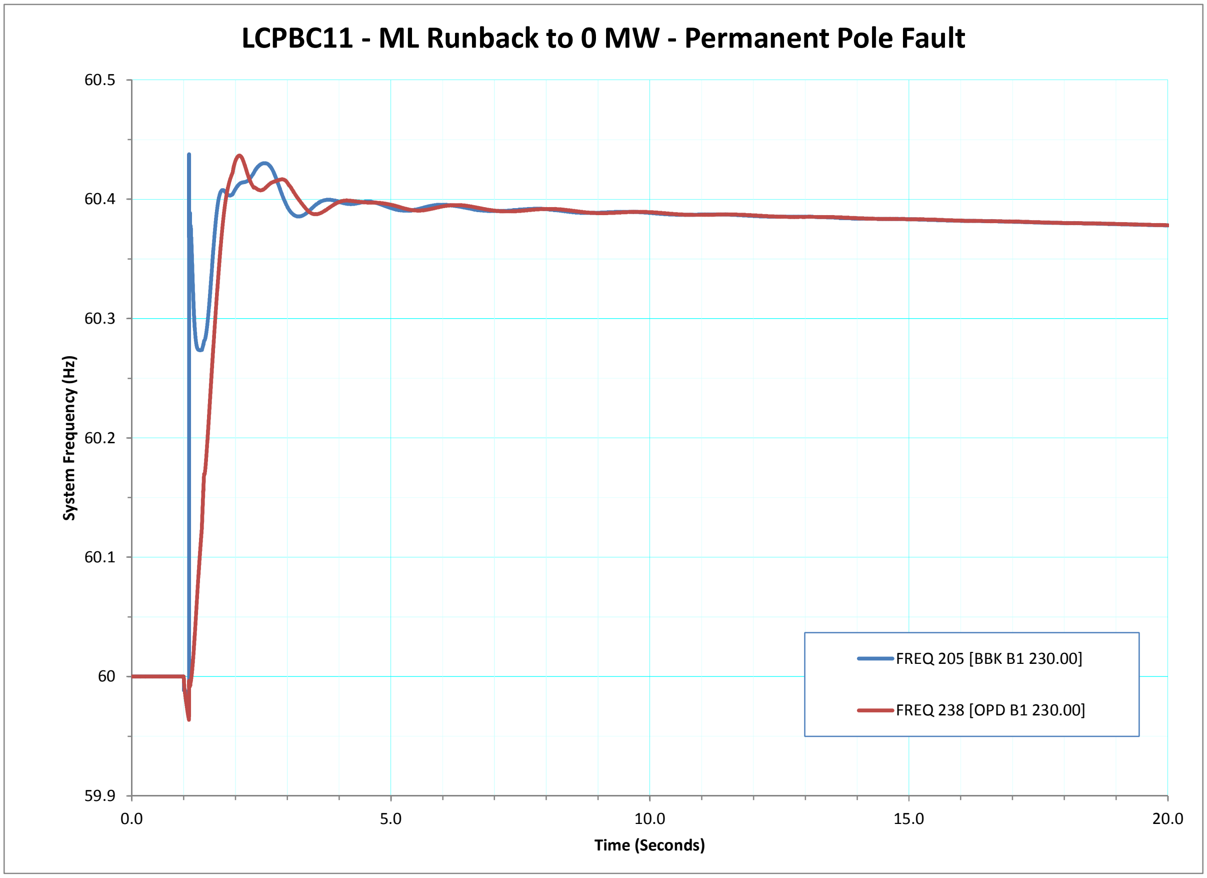


Figure 353 - LCPBC11 - ML Runback to 0 MW - Permanent Pole Fault - System Frequency (Hz)

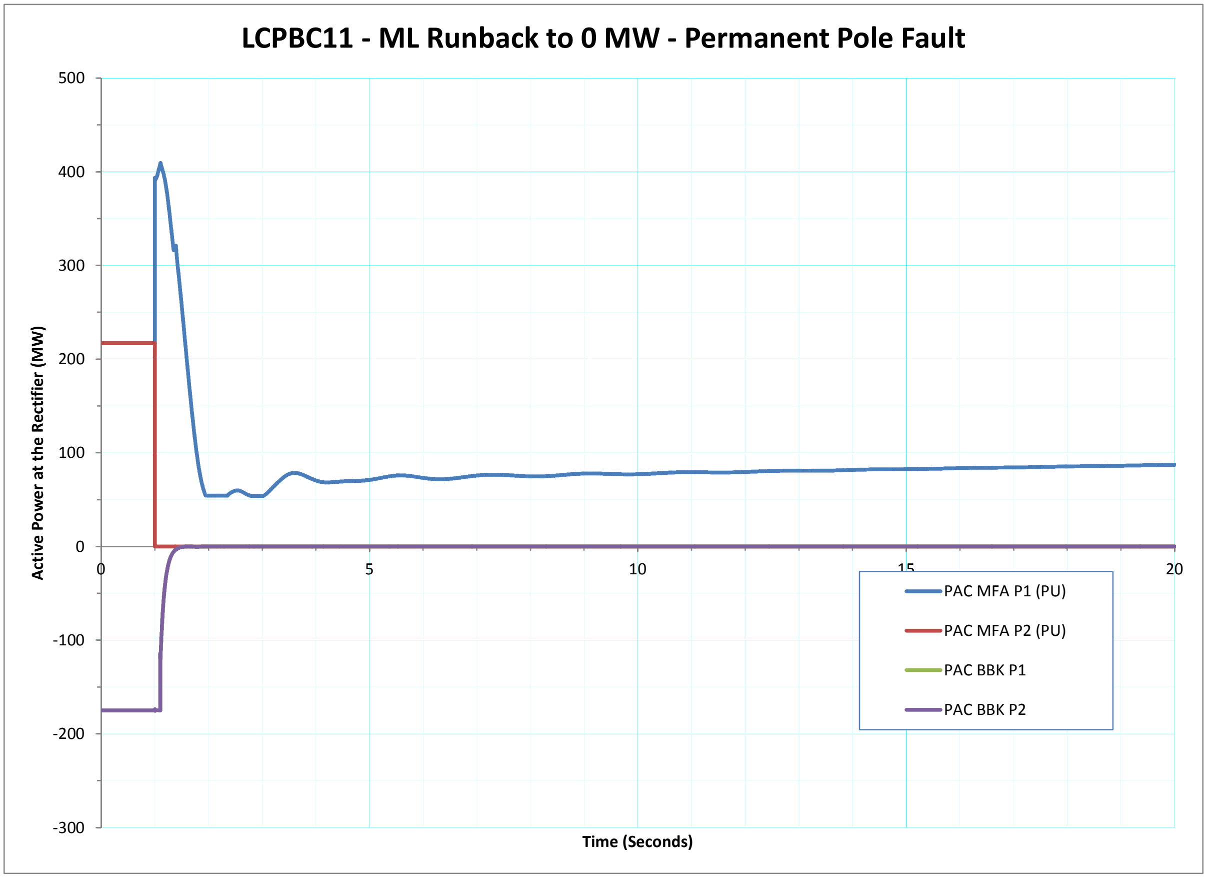


Figure 354 - LCPBC11 - ML Runback to 0 MW - Permanent Pole Fault - Active Power at the Rectifier (MW)

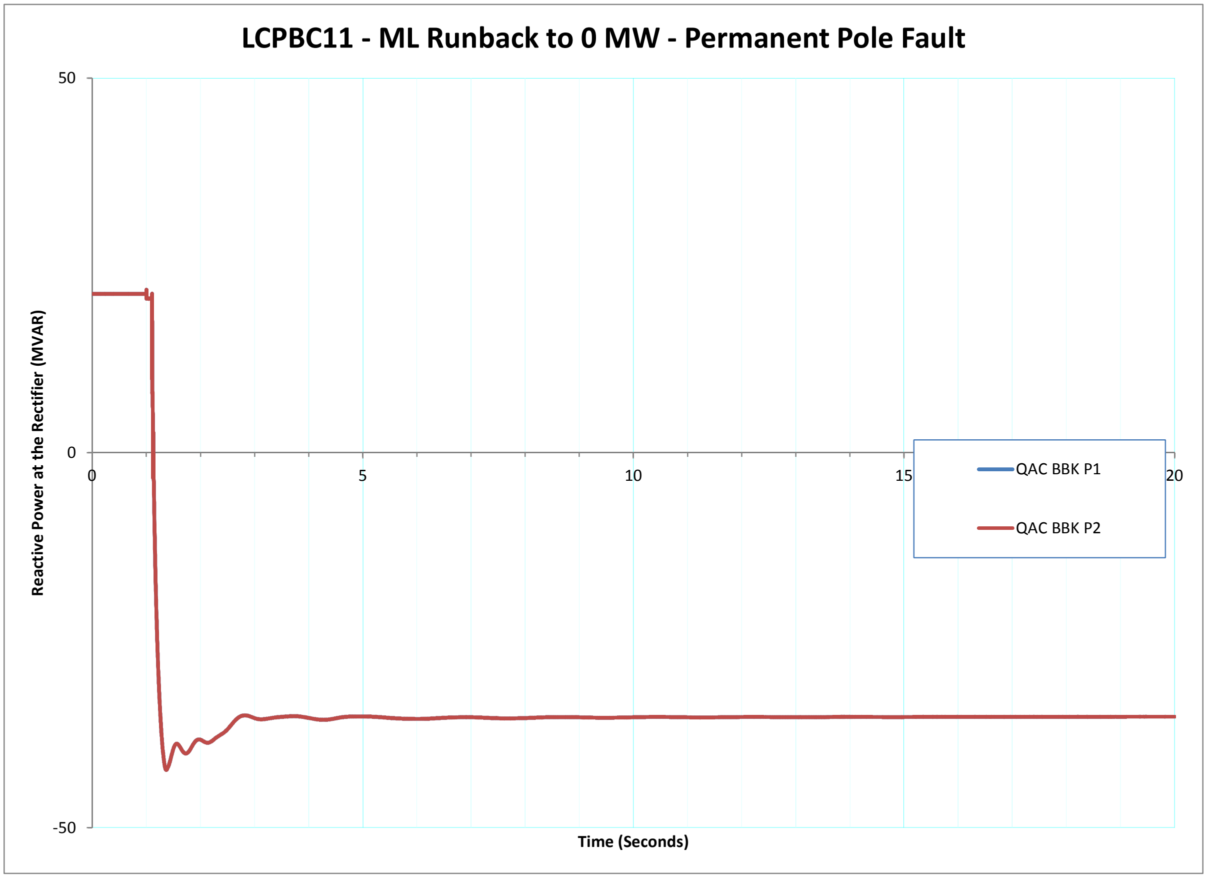


Figure 355 - LCPBC11 - ML Runback to 0 MW - Permanent Pole Fault - Reactive Power at the Rectifier (MVAR)

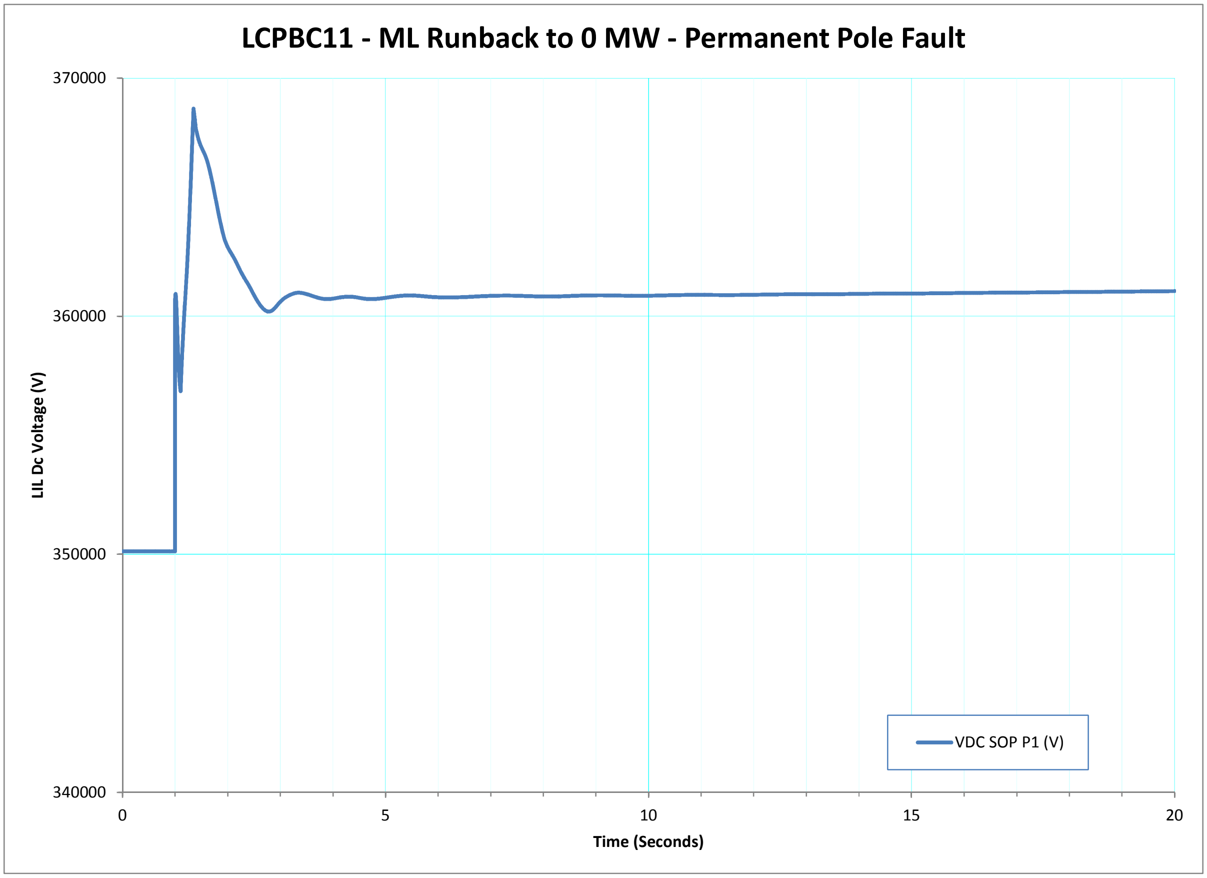


Figure 356 - LCPBC11 - ML Runback to 0 MW - Permanent Pole Fault - LIL Dc Voltage (V)

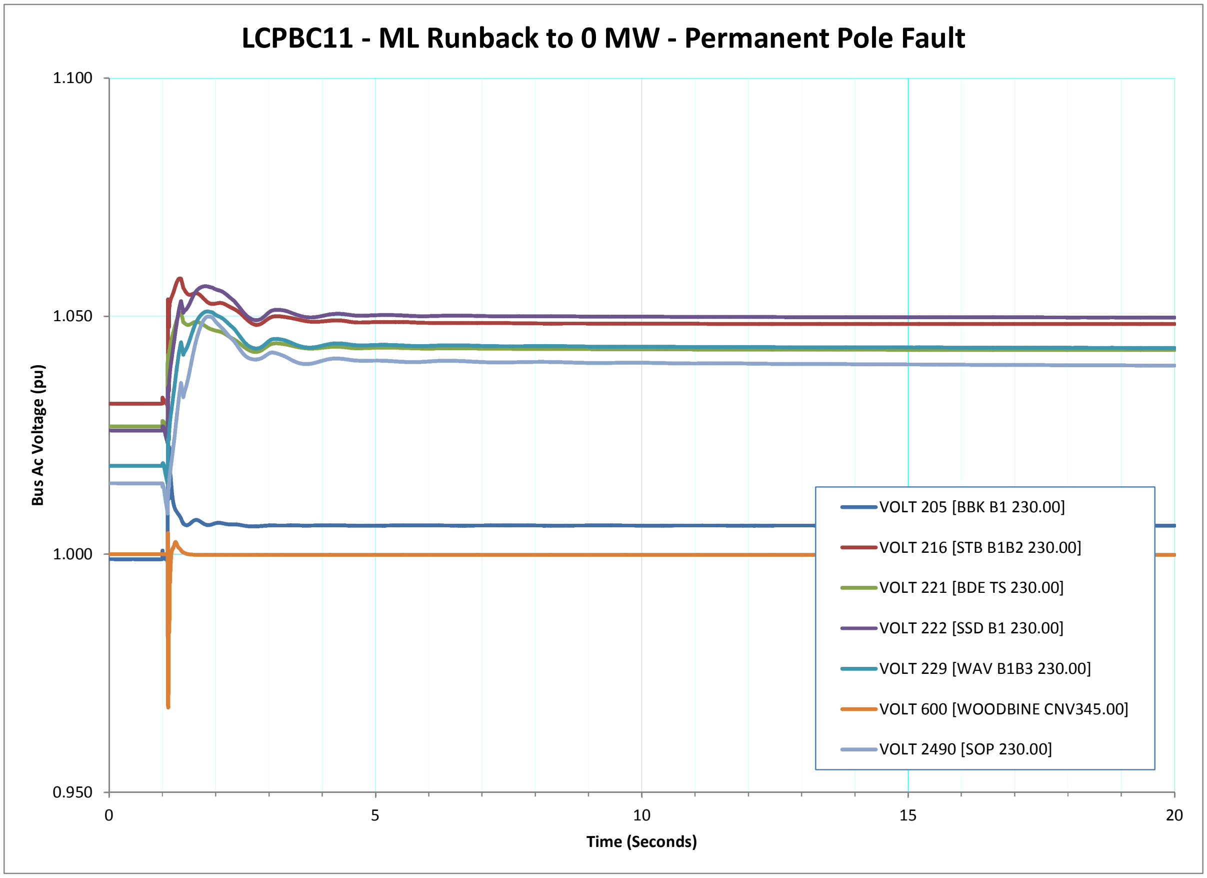


Figure 357 - LCPBC11 - ML Runback to 0 MW - Permanent Pole Fault - Bus Ac Voltage (pu)

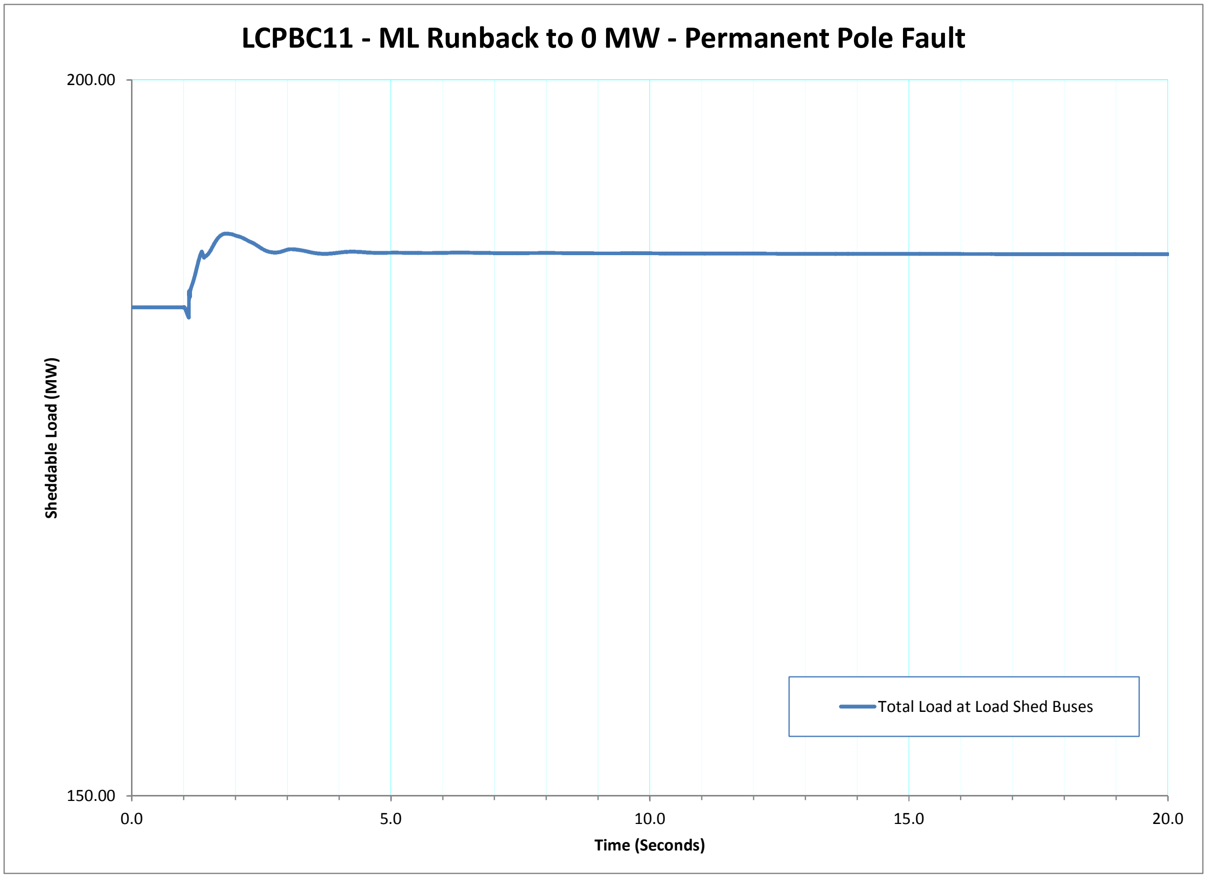


Figure 358 - LCPBC11 - ML Runback to 0 MW - Permanent Pole Fault - Sheddable Load (MW)

APPENDIX F Remedial ML Curtailment for Loss of Island Generation

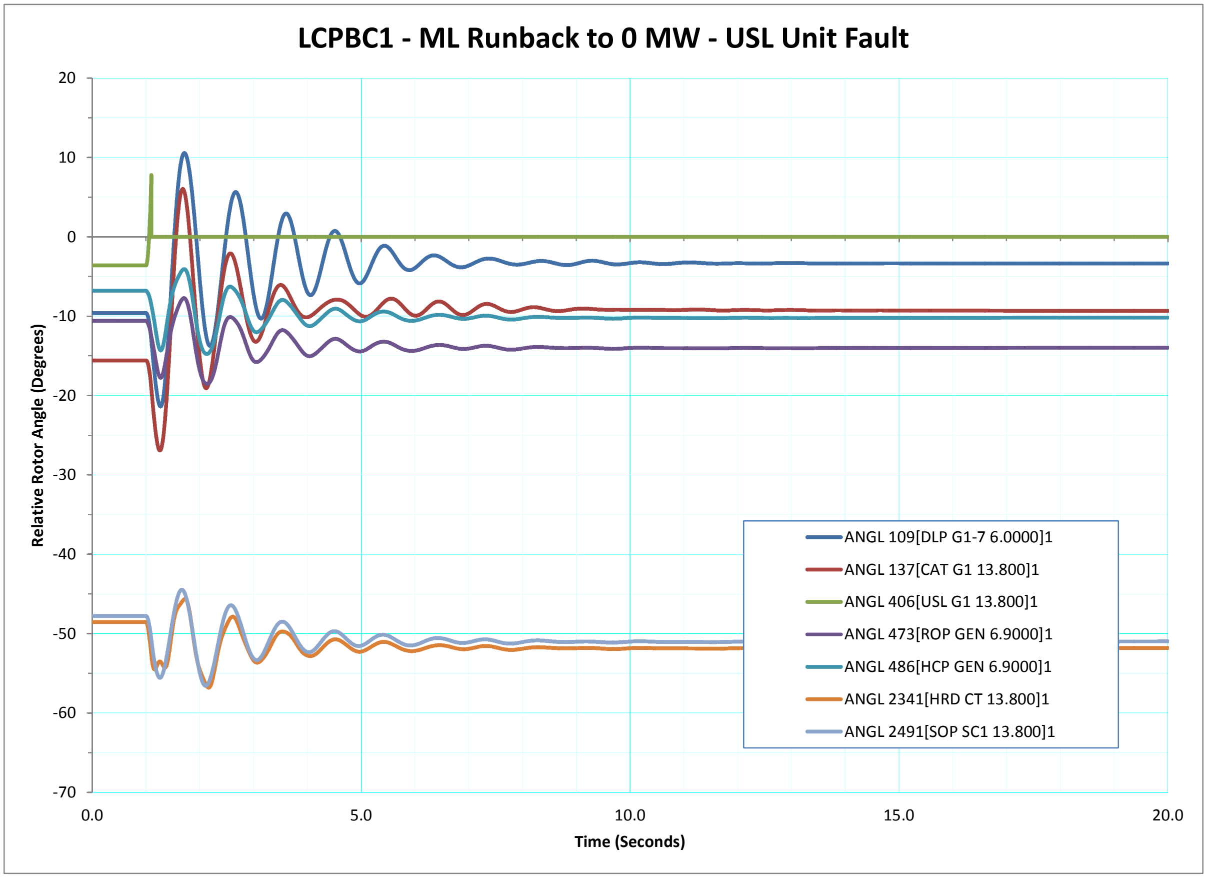


Figure 359 - LCPBC1 - ML Runback to 0 MW - USL Unit Fault - Relative Rotor Angle (Degrees)

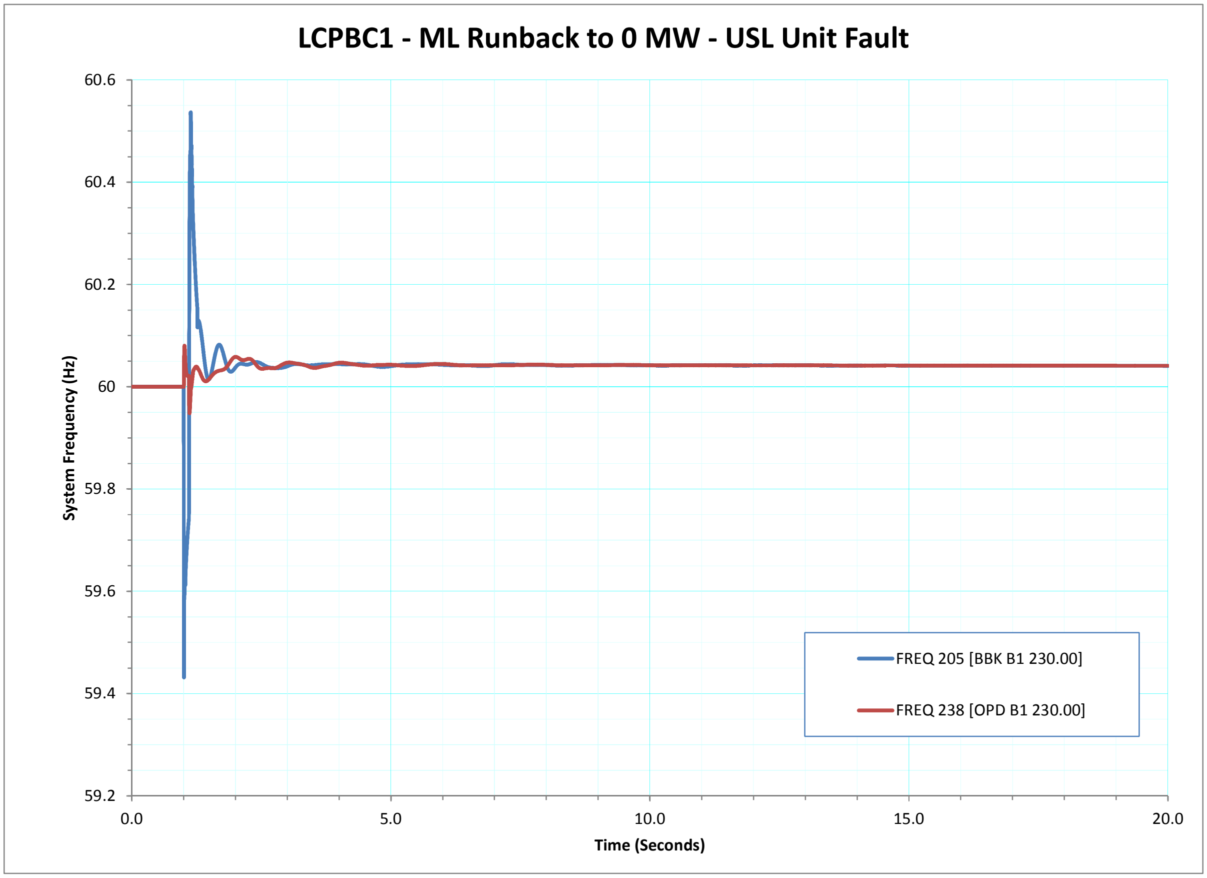


Figure 360 - LCPBC1 - ML Runback to 0 MW - USL Unit Fault - System Frequency (Hz)

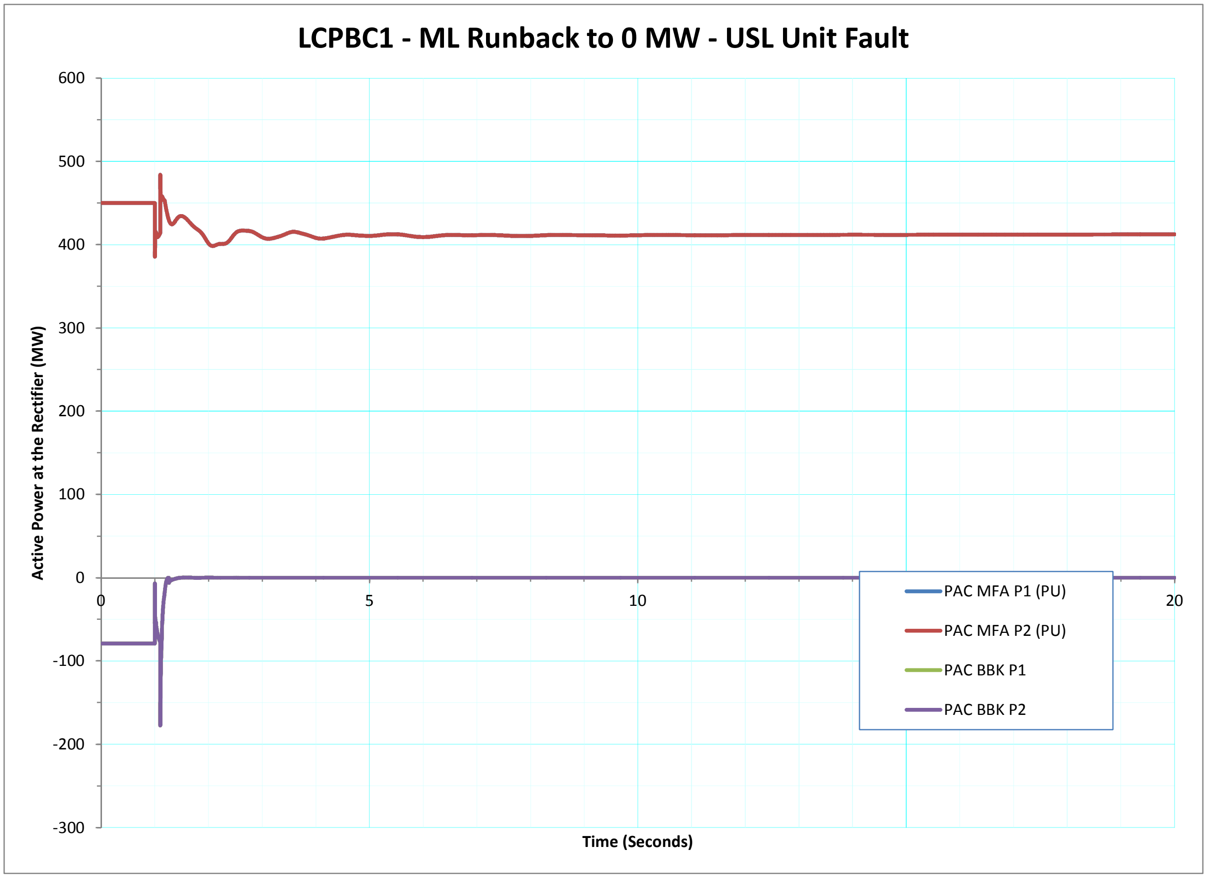


Figure 361 - LCPBC1 - ML Runback to 0 MW - USL Unit Fault - Active Power at the Rectifier (MW)

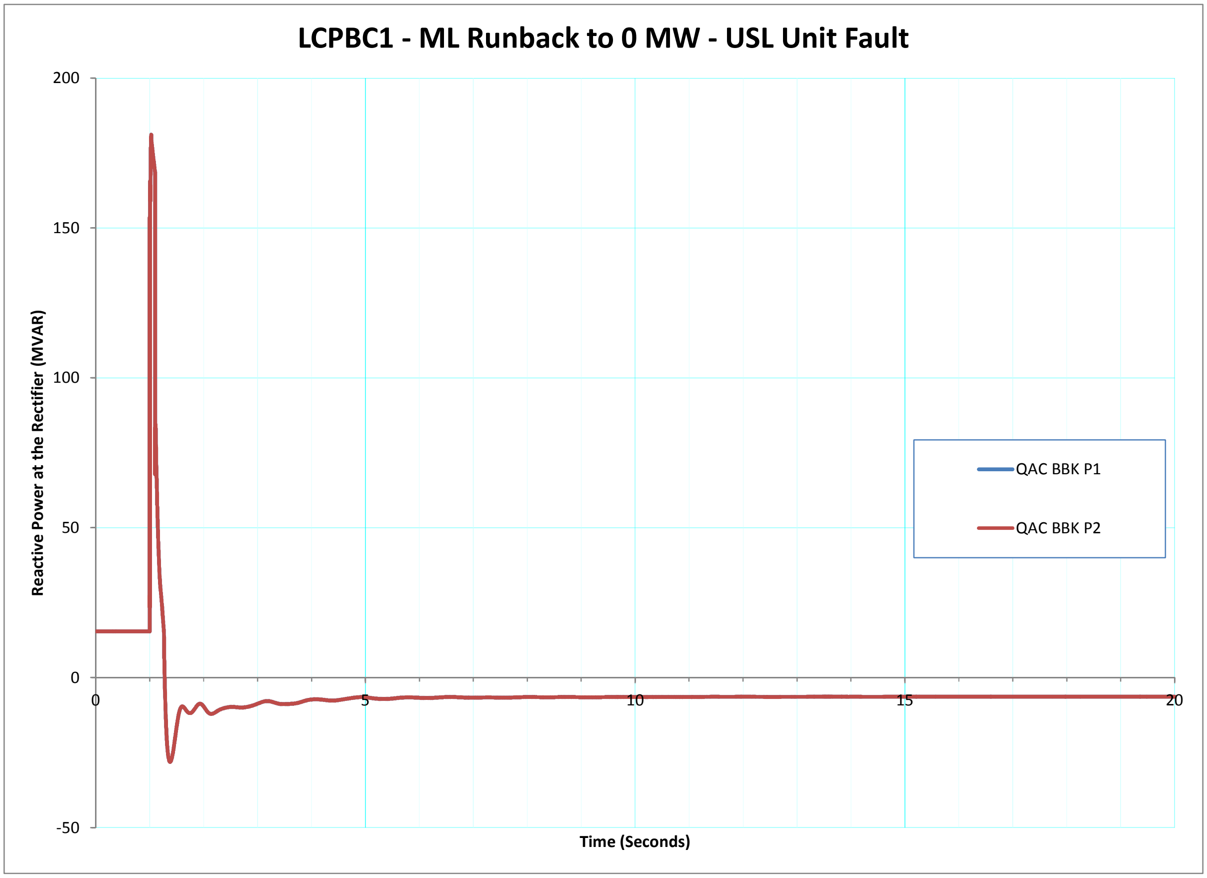


Figure 362 - LCPBC1 - ML Runback to 0 MW - USL Unit Fault - Reactive Power at the Rectifier (MVAR)

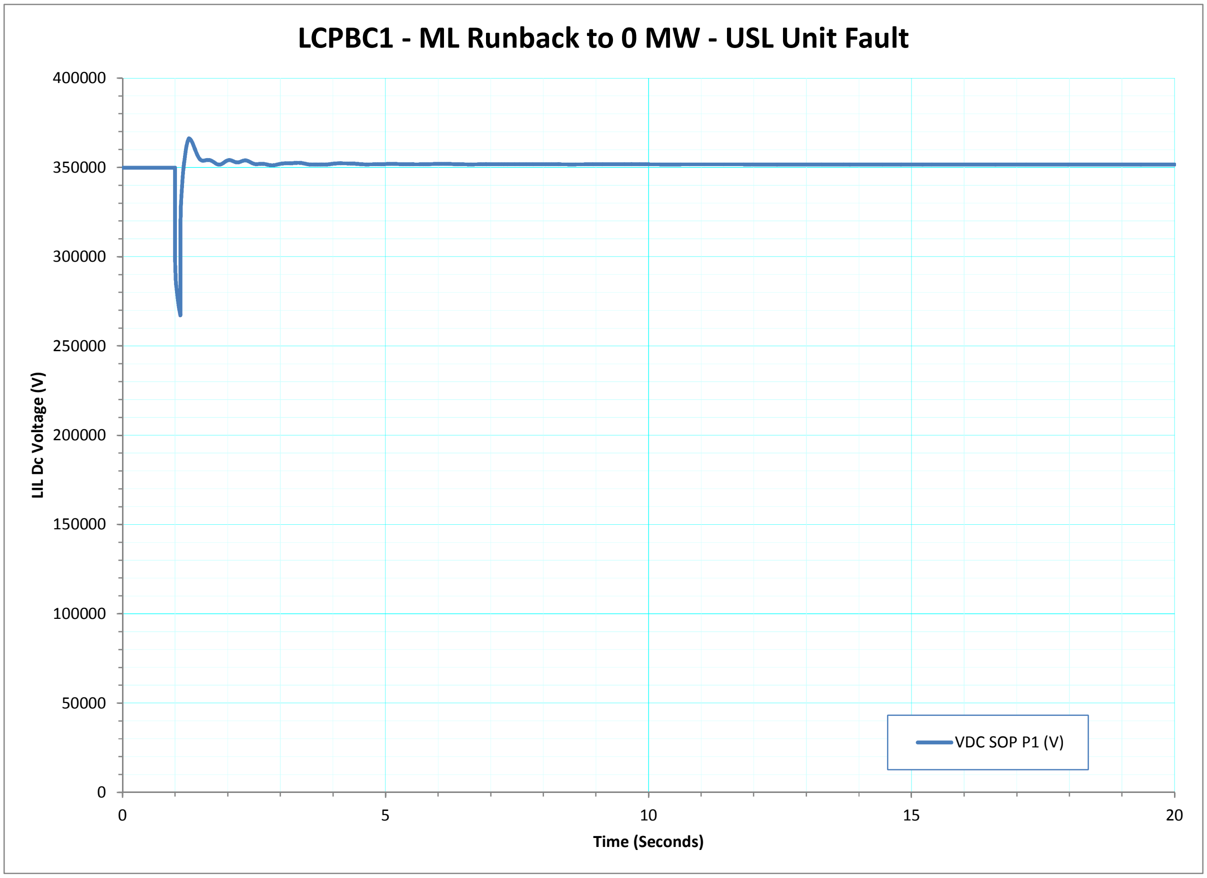


Figure 363 - LCPBC1 - ML Runback to 0 MW - USL Unit Fault - LIL Dc Voltage (V)

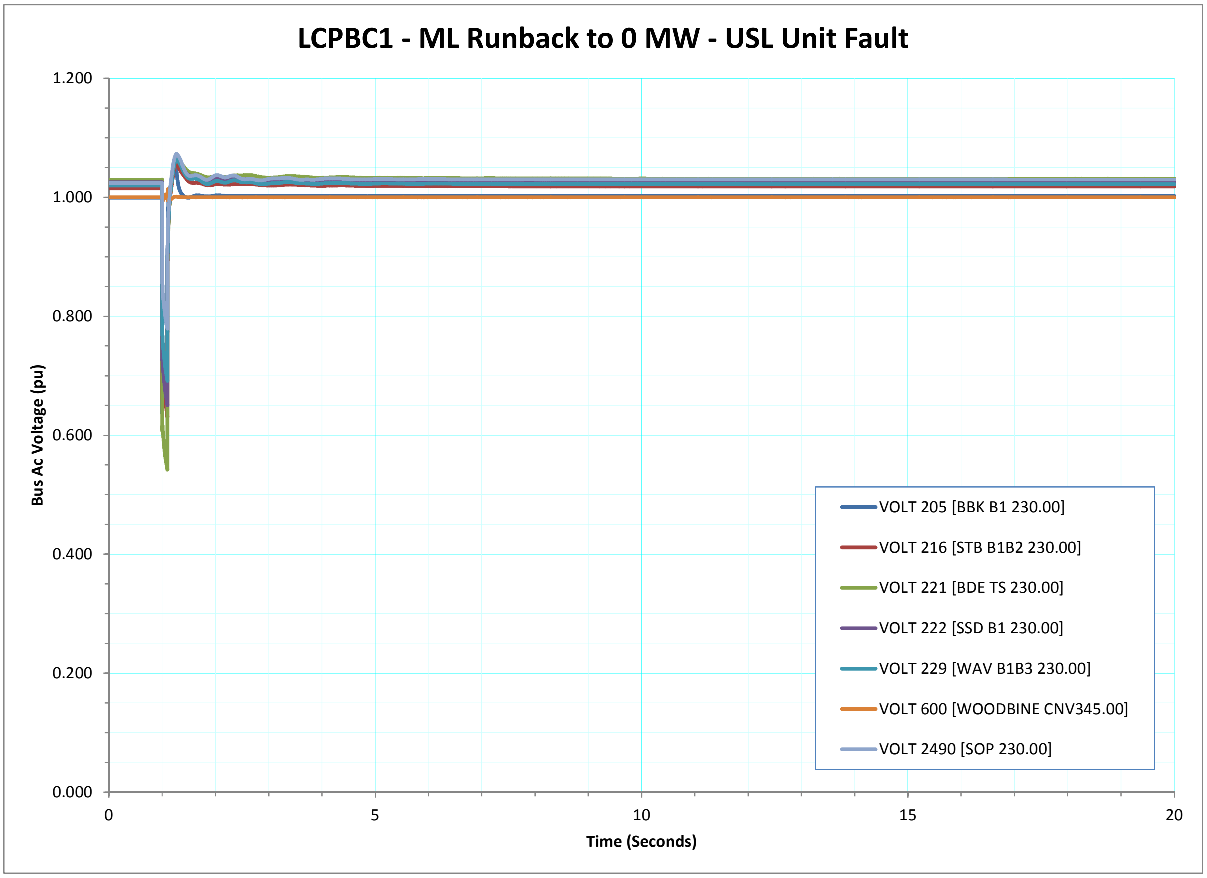


Figure 364 - LCPBC1 - ML Runback to 0 MW - USL Unit Fault - Bus Ac Voltage (pu)

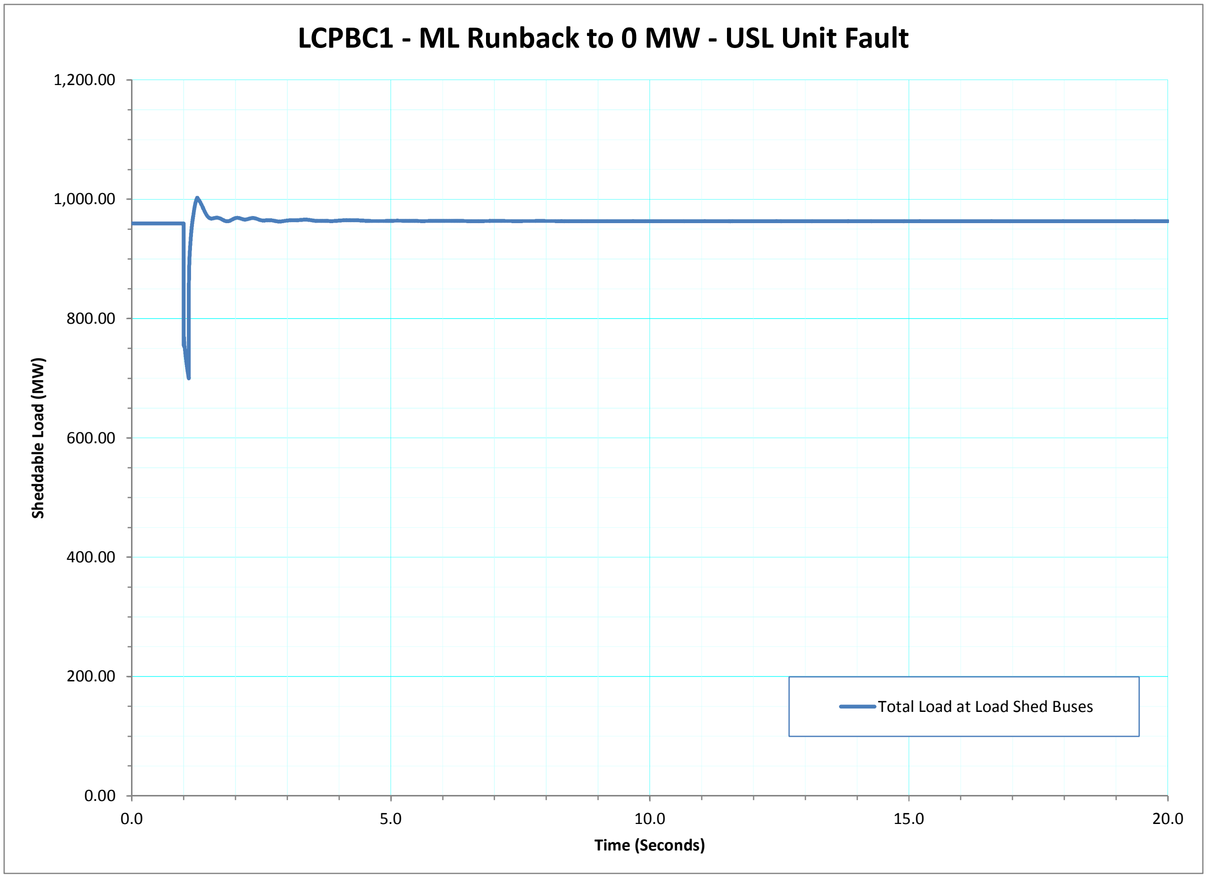


Figure 365 - LCPBC1 - ML Runback to 0 MW - USL Unit Fault - Sheddable Load (MW)

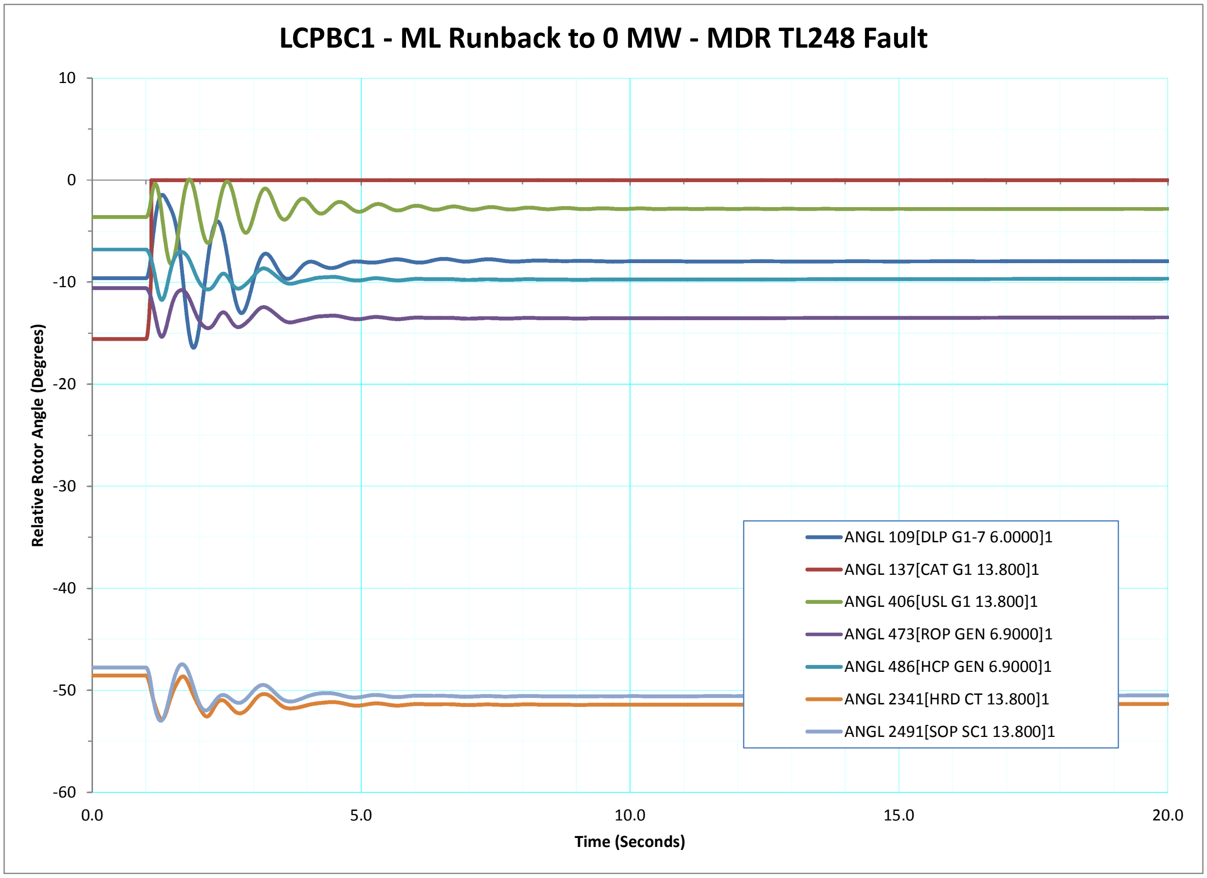


Figure 366 - LCPBC1 - ML Runback to 0 MW - MDR TL248 Fault - Relative Rotor Angle (Degrees)

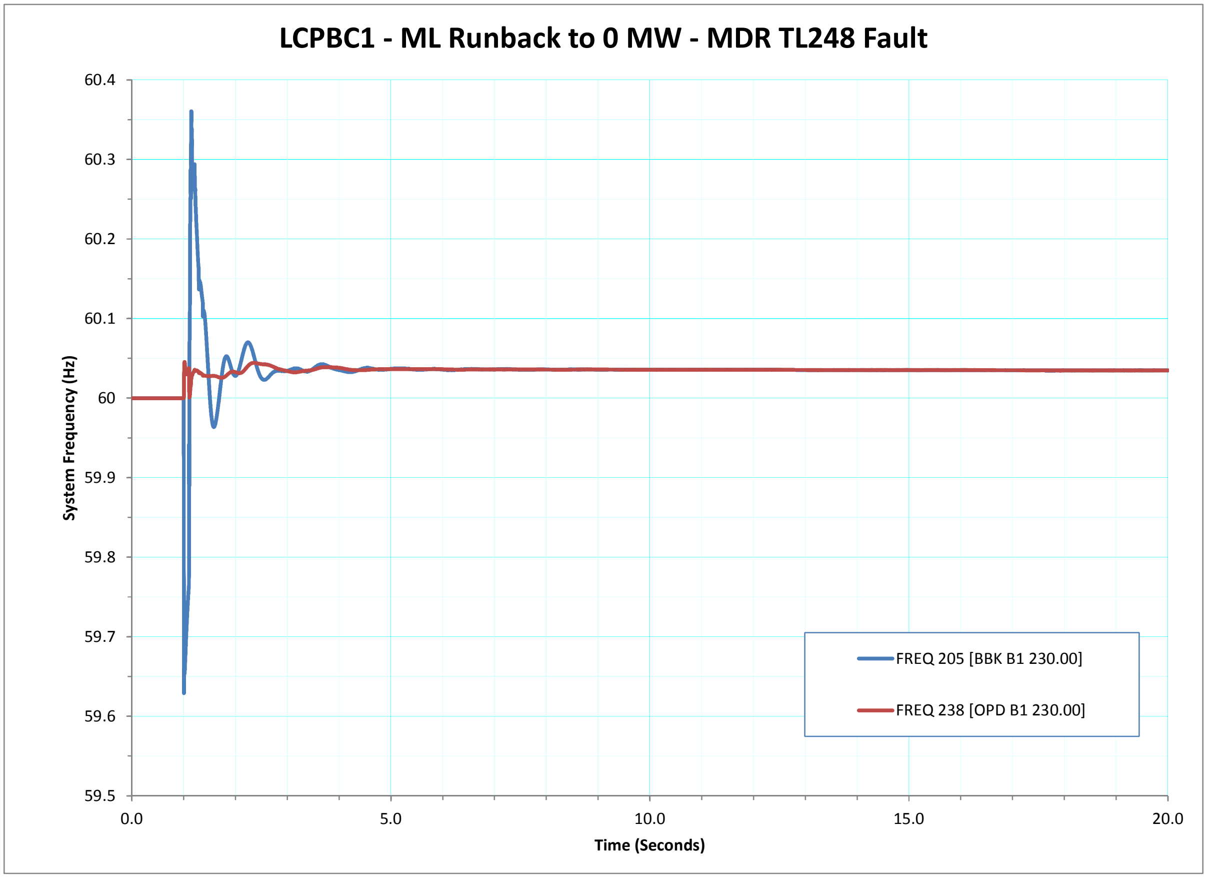


Figure 367 - LCPBC1 - ML Runback to 0 MW - MDR TL248 Fault - System Frequency (Hz)

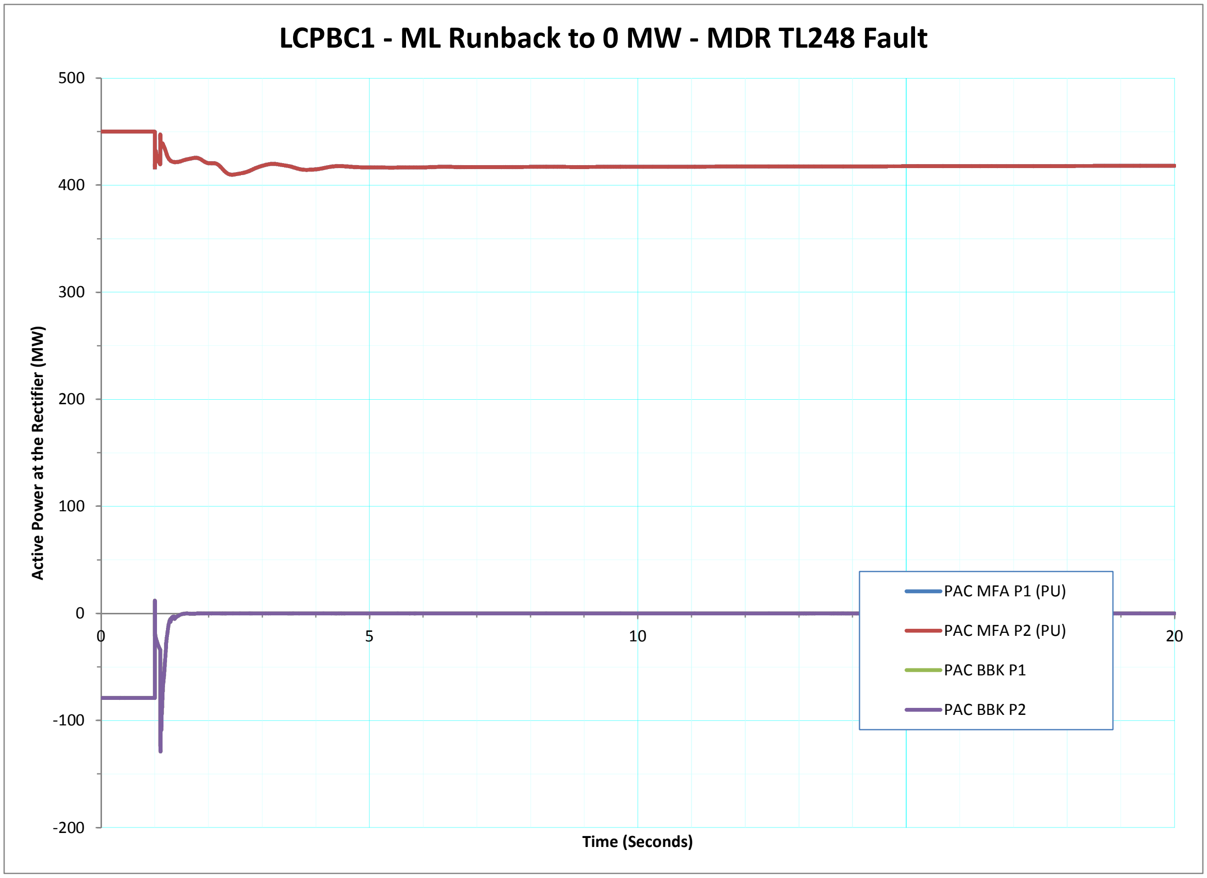


Figure 368 - LCPBC1 - ML Runback to 0 MW - MDR TL248 Fault - Active Power at the Rectifier (MW)

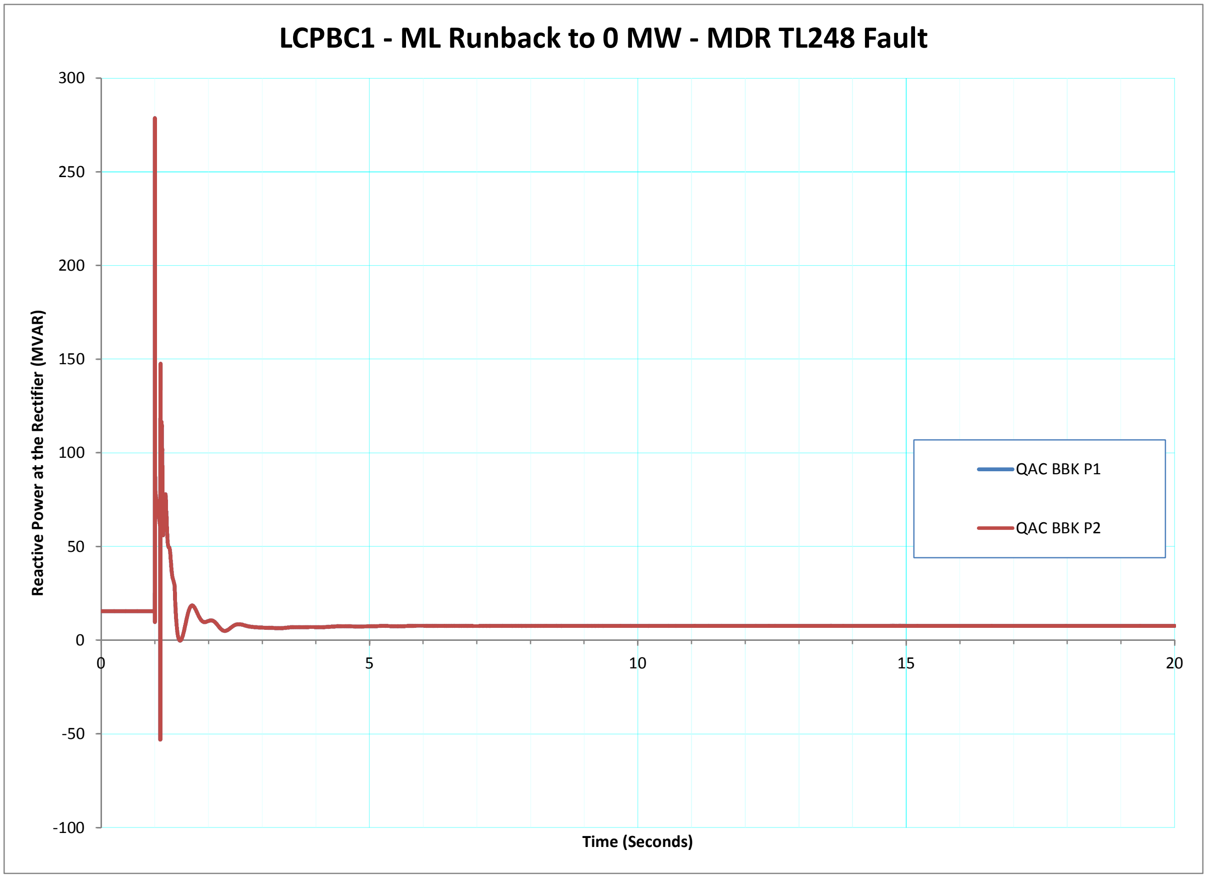


Figure 369 - LCPBC1 - ML Runback to 0 MW - MDR TL248 Fault - Reactive Power at the Rectifier (MVAR)

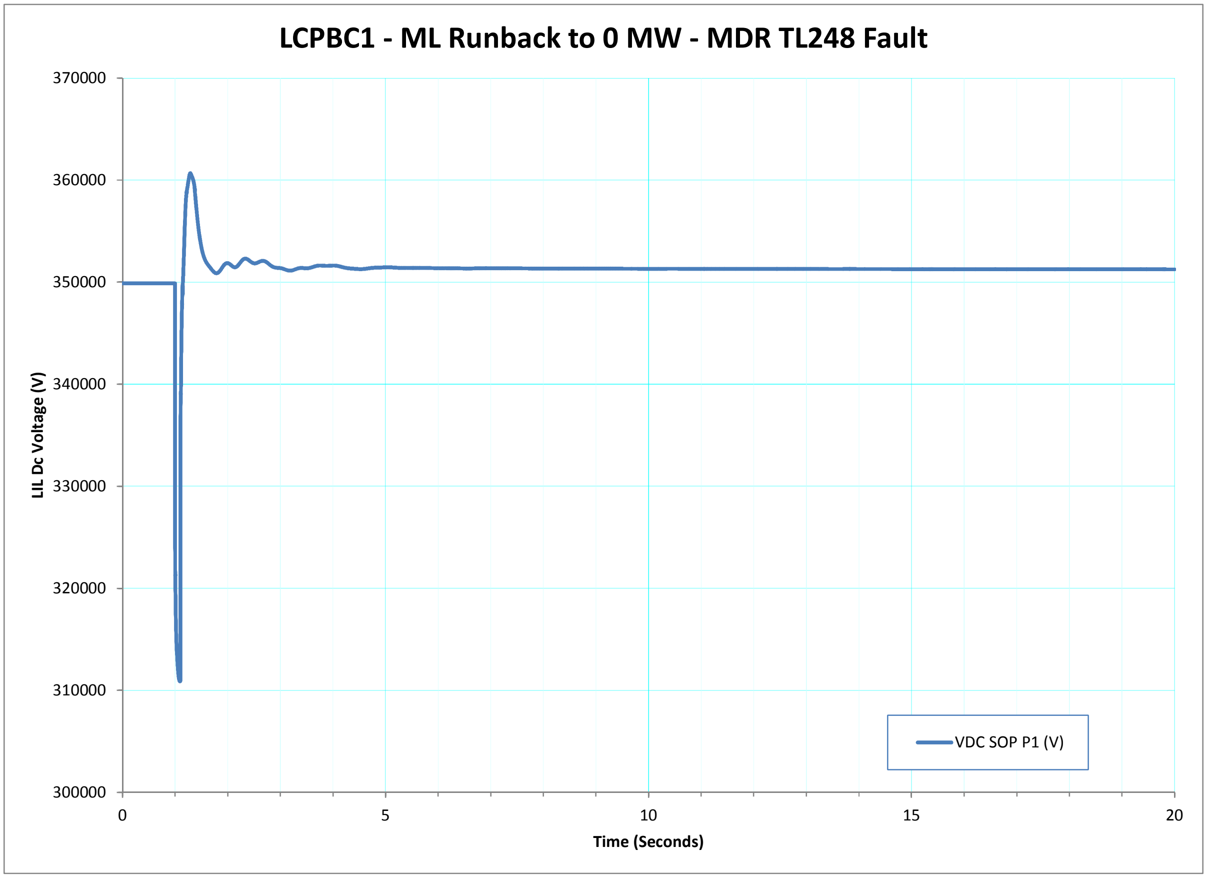


Figure 370 - LCPBC1 - ML Runback to 0 MW - MDR TL248 Fault - LIL Dc Voltage (V)

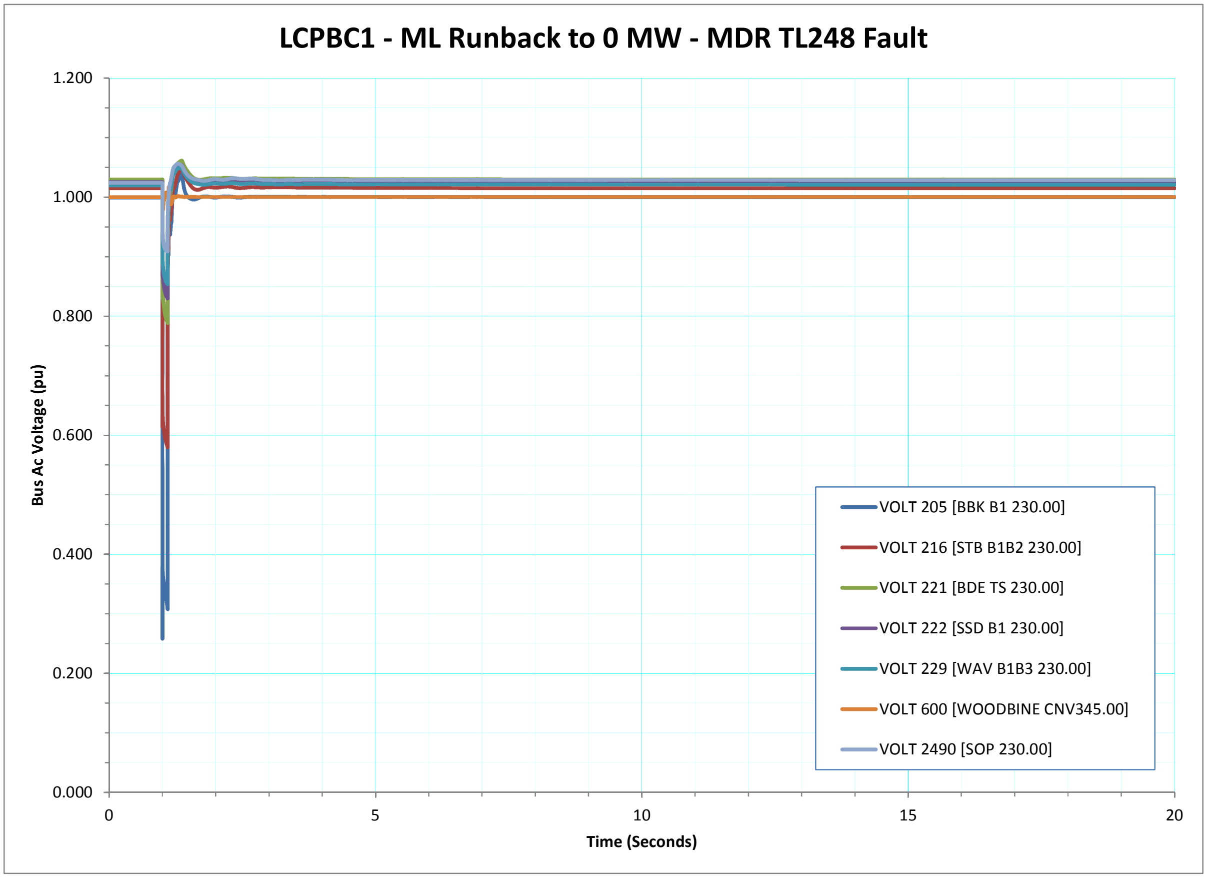


Figure 371 - LCPBC1 - ML Runback to 0 MW - MDR TL248 Fault - Bus Ac Voltage (pu)

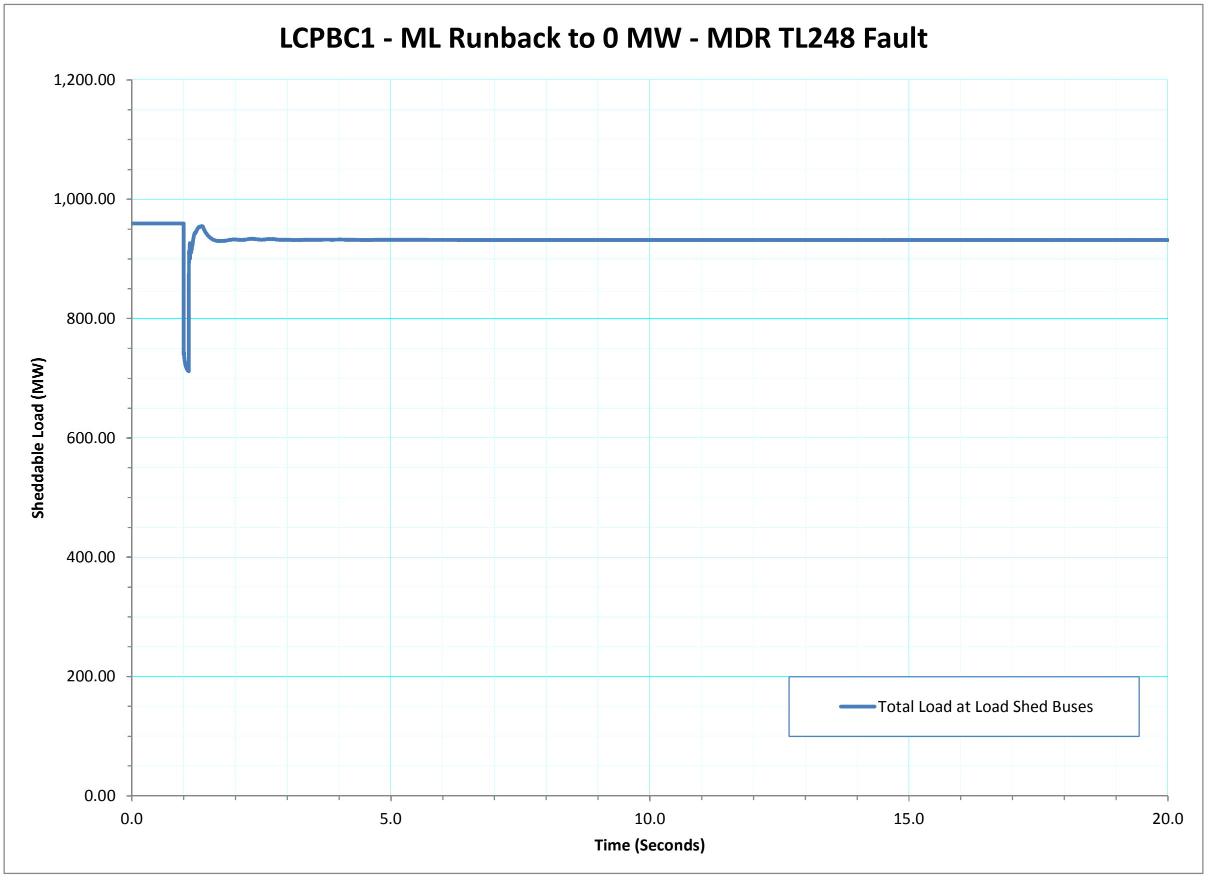


Figure 372 - LCPBC1 - ML Runback to 0 MW - MDR TL248 Fault - Sheddable Load (MW)

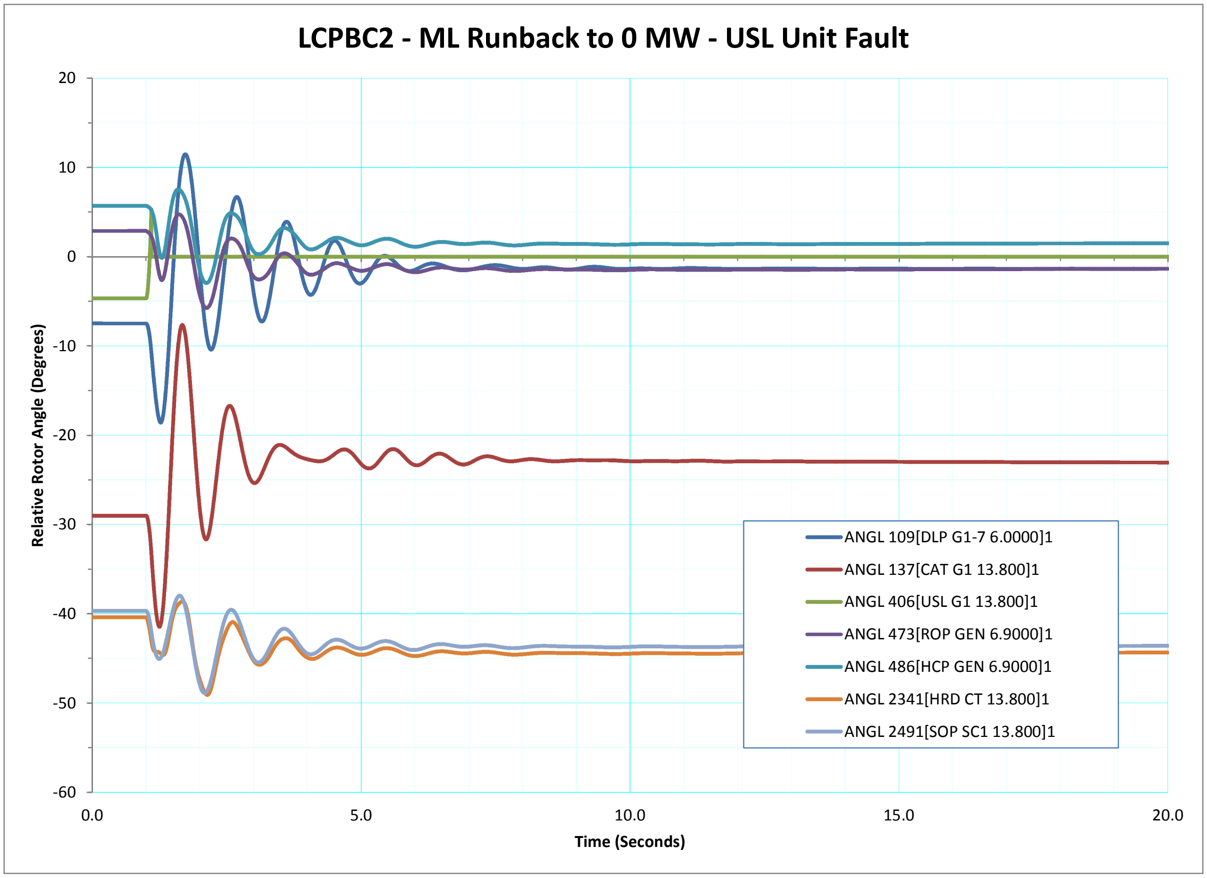


Figure 373 - LCPBC2 - ML Runback to 0 MW - USL Unit Fault - Relative Rotor Angle (Degrees)

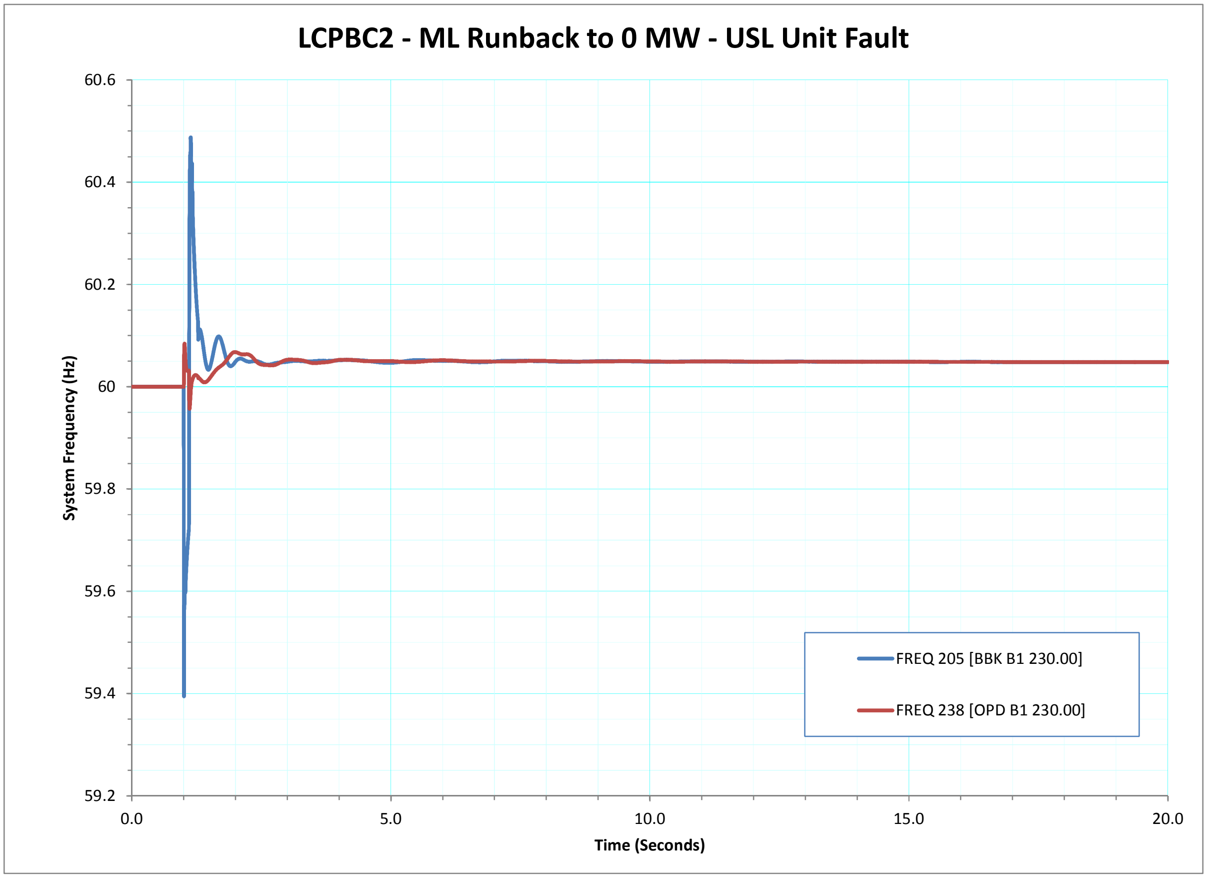


Figure 374 - LCPBC2 - ML Runback to 0 MW - USL Unit Fault - System Frequency (Hz)

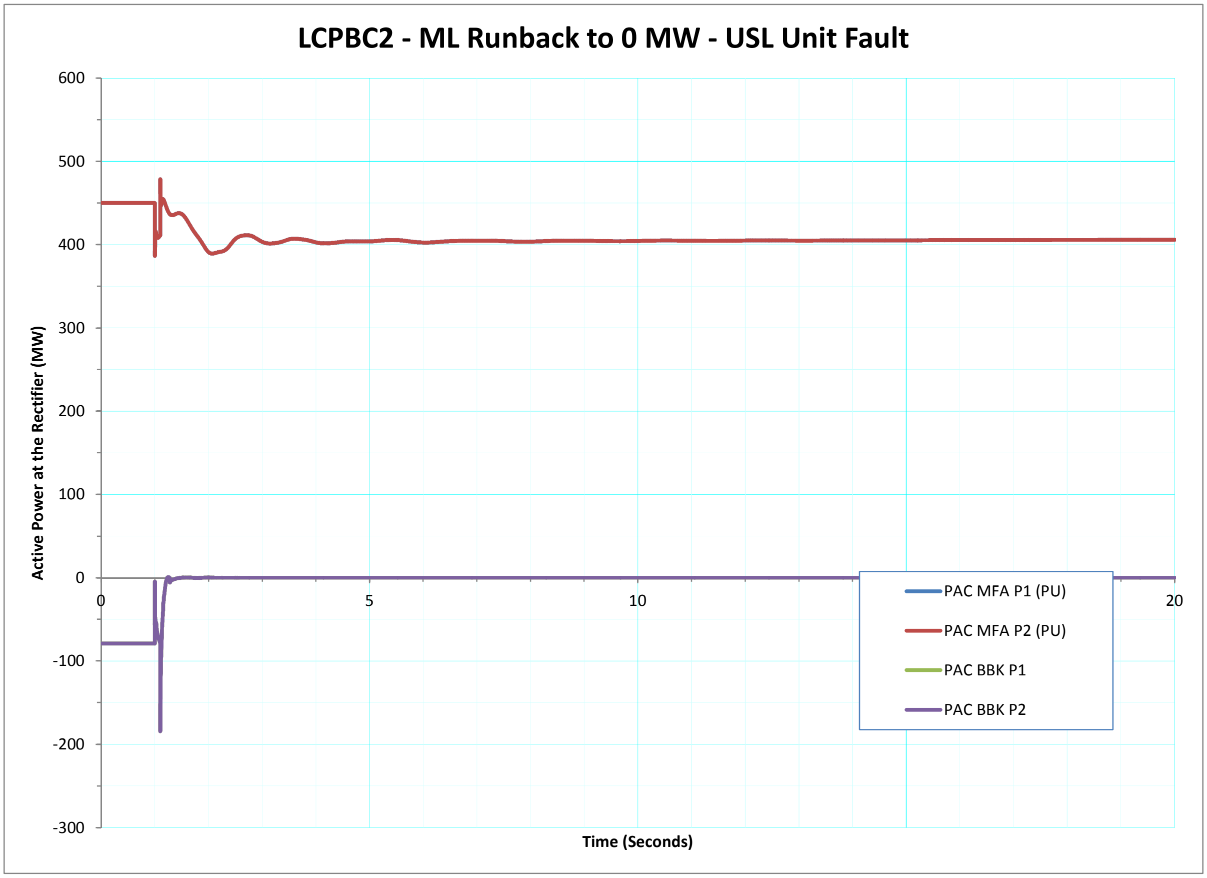


Figure 375 - LCPBC2 - ML Runback to 0 MW - USL Unit Fault - Active Power at the Rectifier (MW)

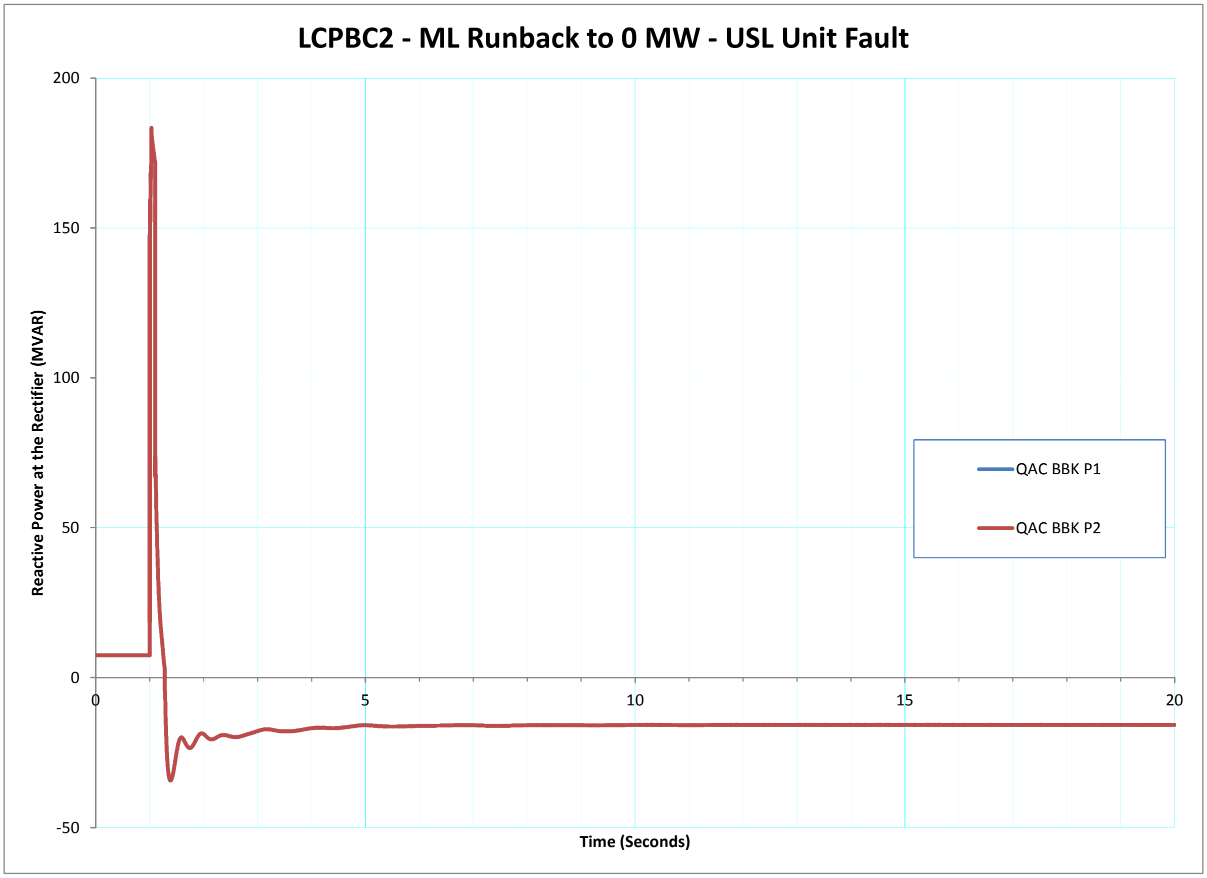


Figure 376 - LCPBC2 - ML Runback to 0 MW - USL Unit Fault - Reactive Power at the Rectifier (MVAR)

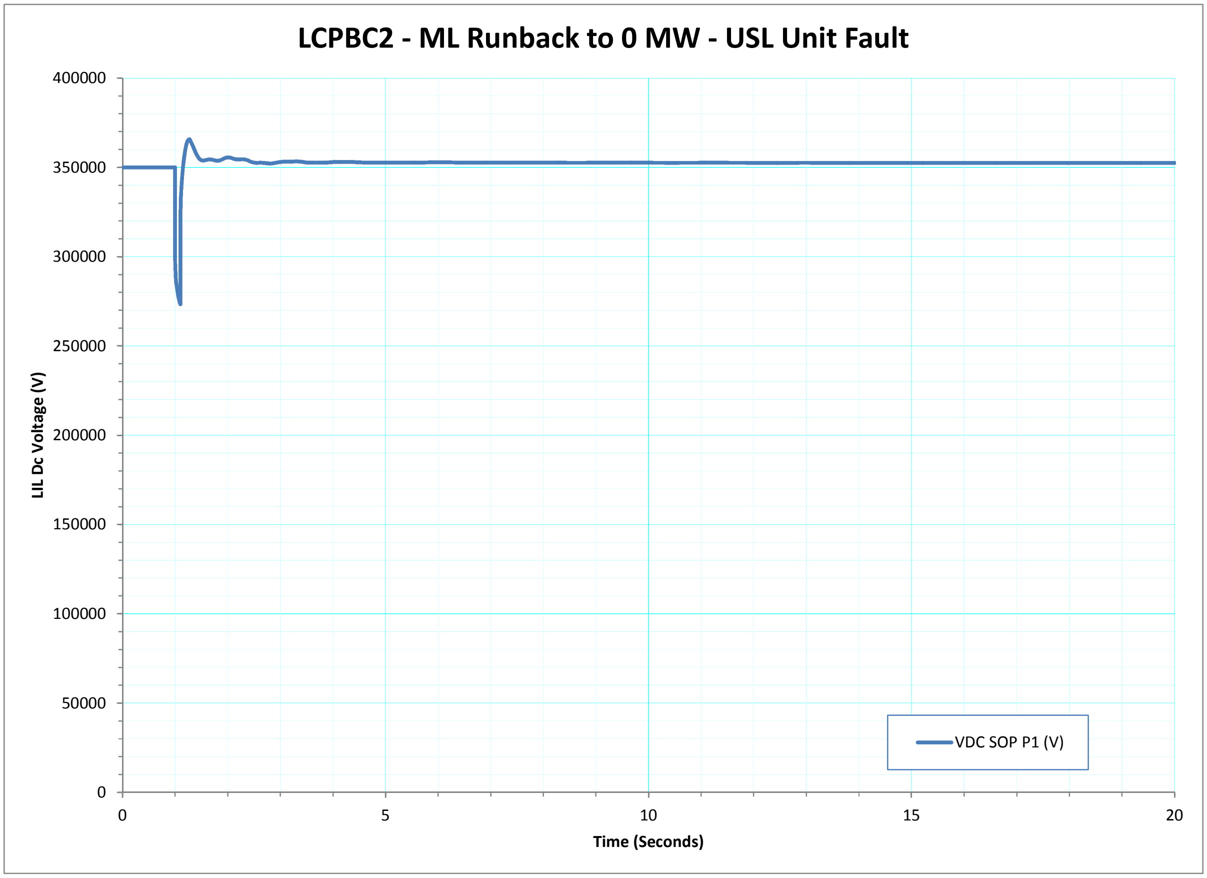


Figure 377 - LCPBC2 - ML Runback to 0 MW - USL Unit Fault - LIL Dc Voltage (V)

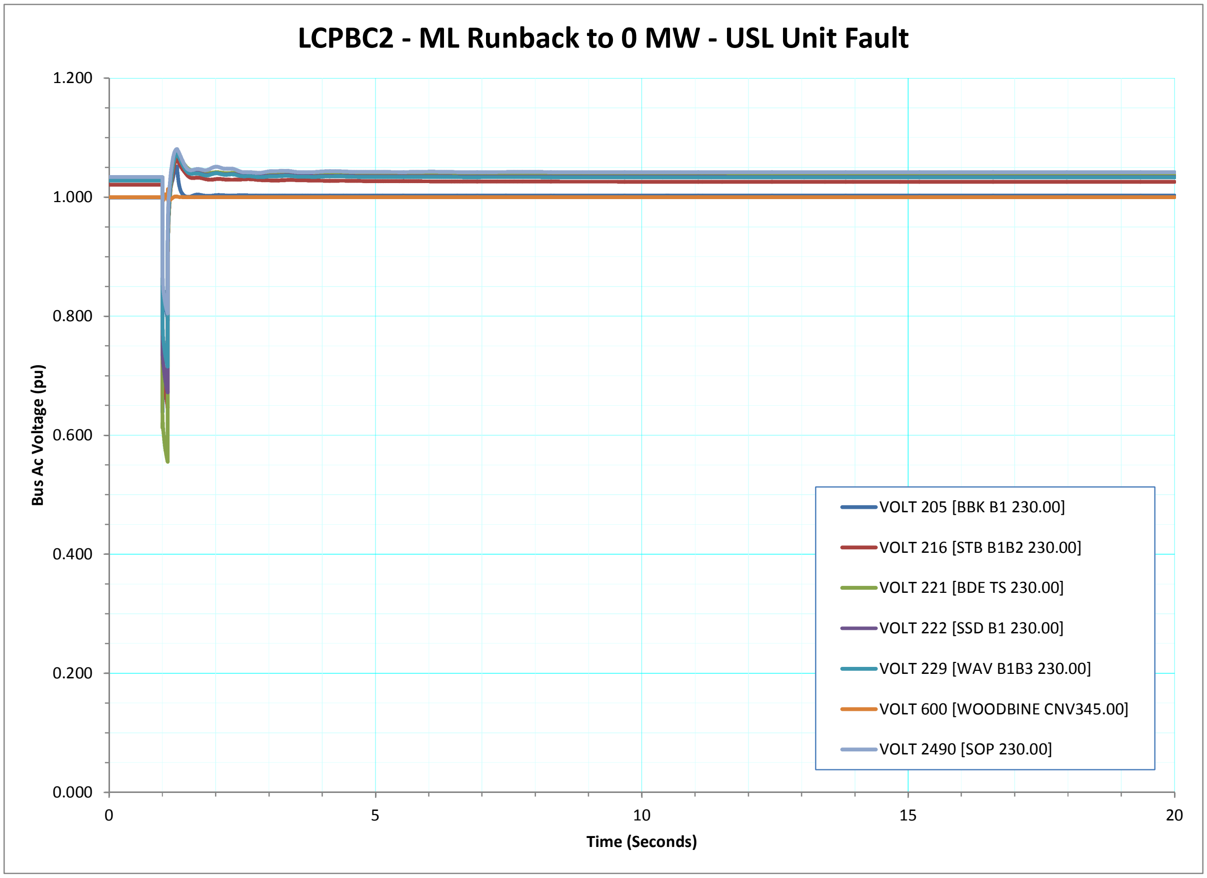


Figure 378 - LCPBC2 - ML Runback to 0 MW - USL Unit Fault - Bus Ac Voltage (pu)

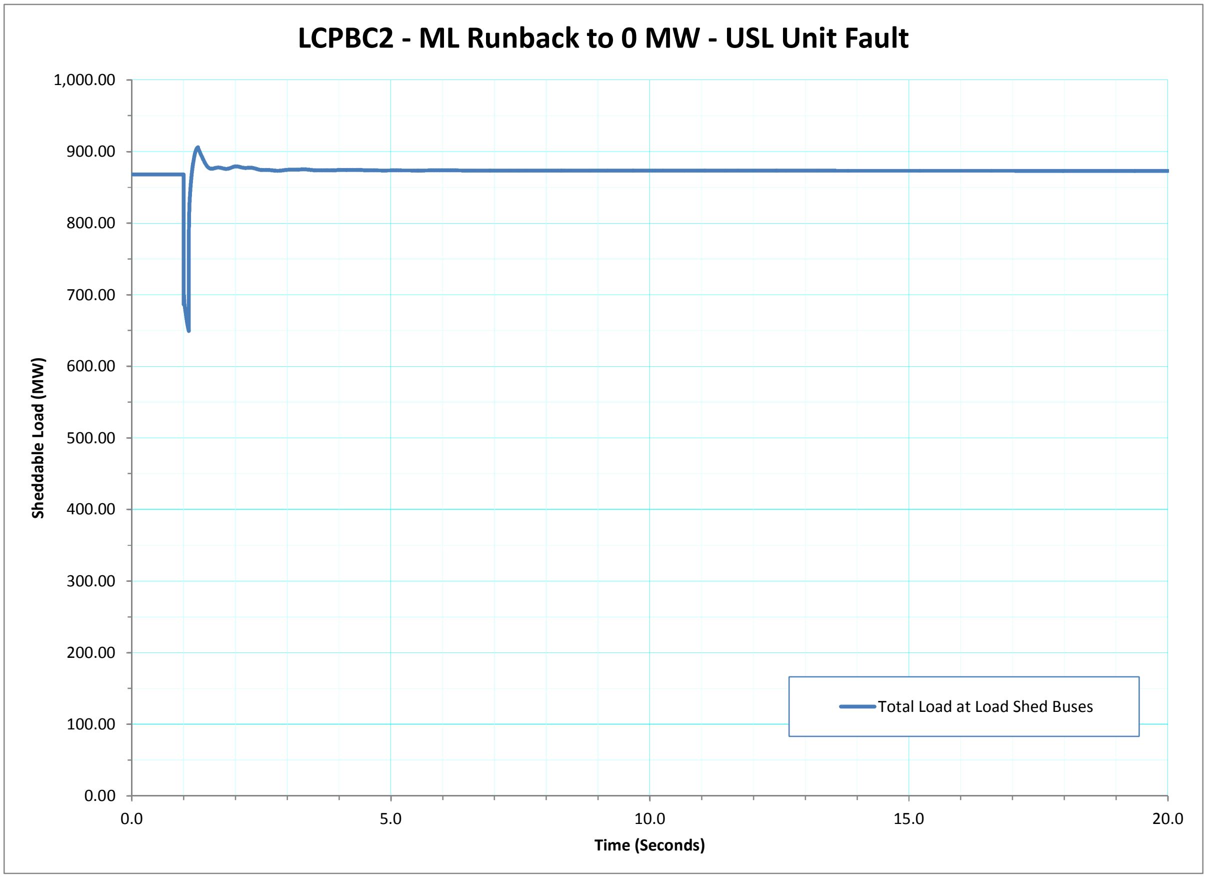


Figure 379 - LCPBC2 - ML Runback to 0 MW - USL Unit Fault - Sheddable Load (MW)

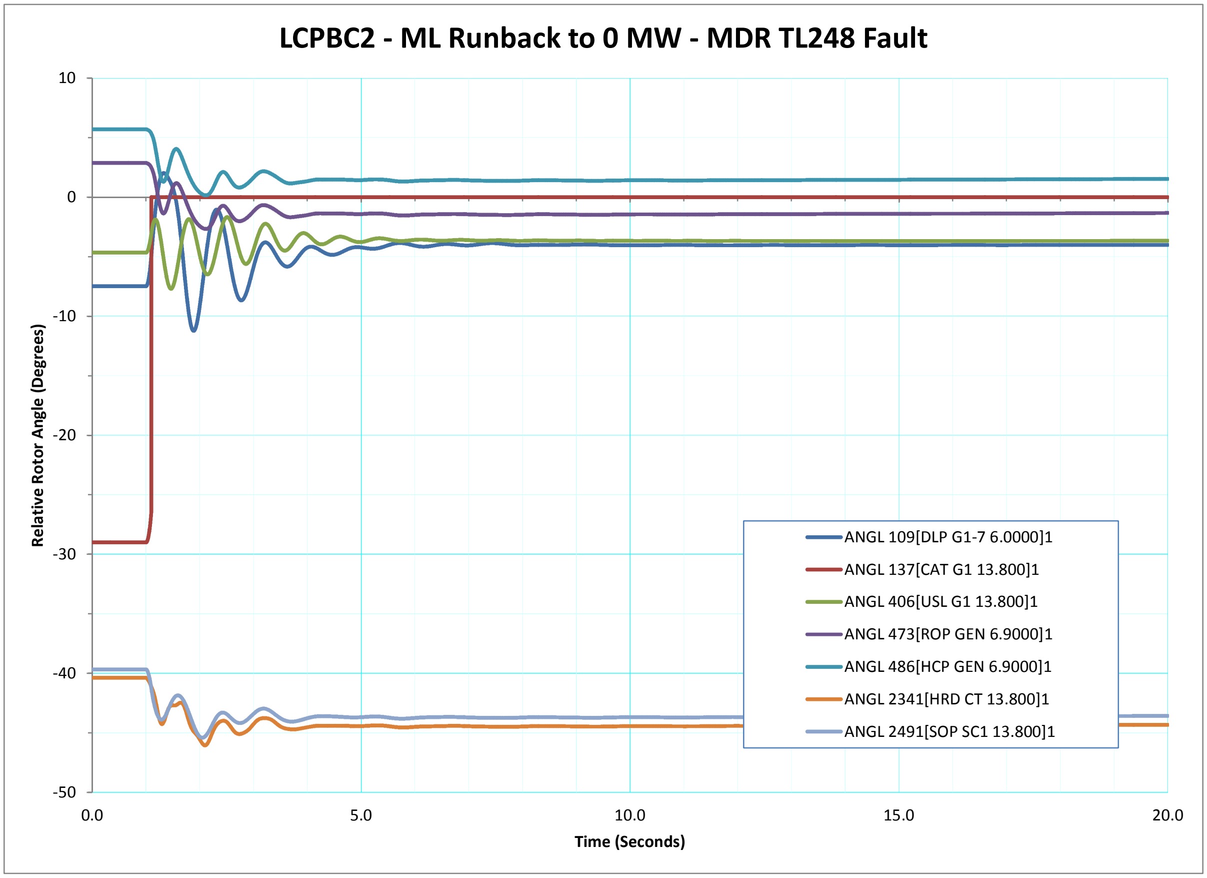


Figure 380 - LCPBC2 - ML Runback to 0 MW - MDR TL248 Fault - Relative Rotor Angle (Degrees)

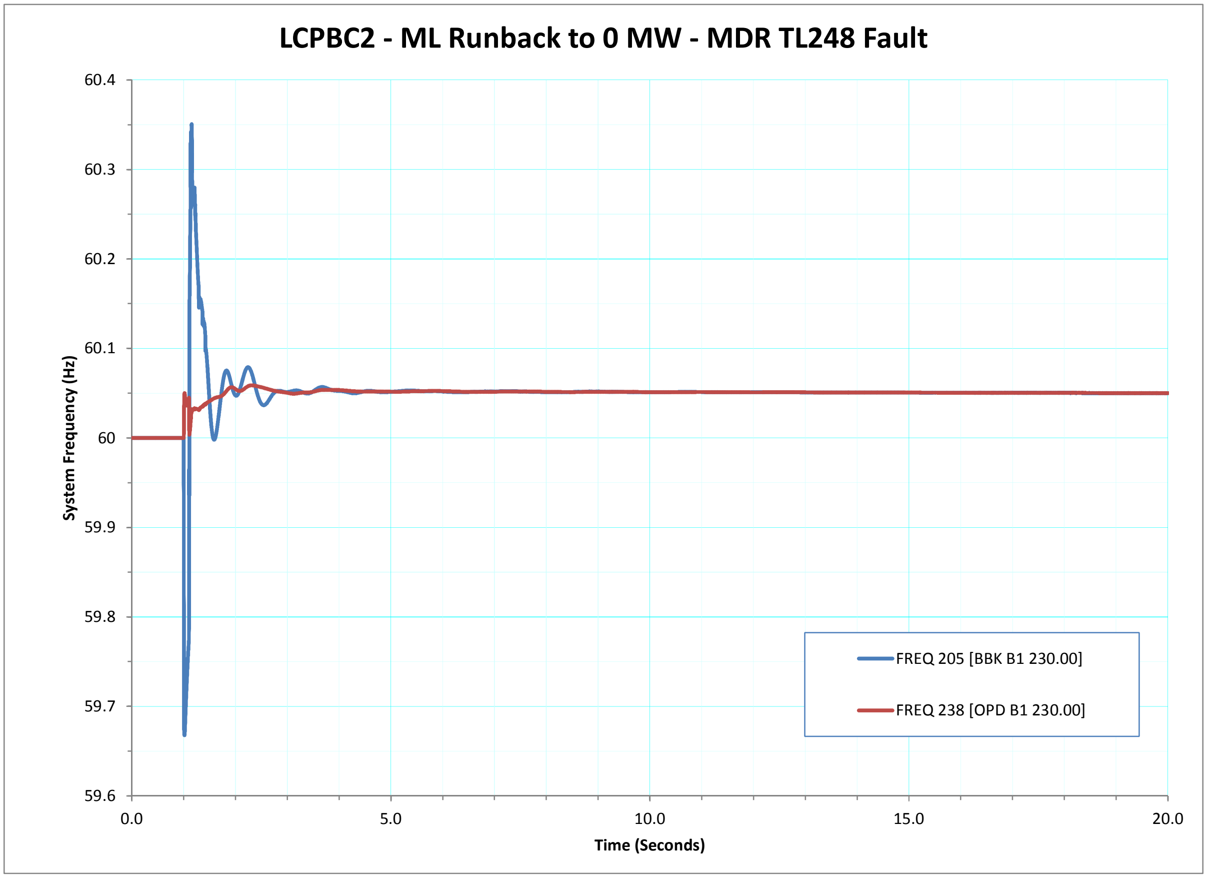


Figure 381 - LCPBC2 - ML Runback to 0 MW - MDR TL248 Fault - System Frequency (Hz)

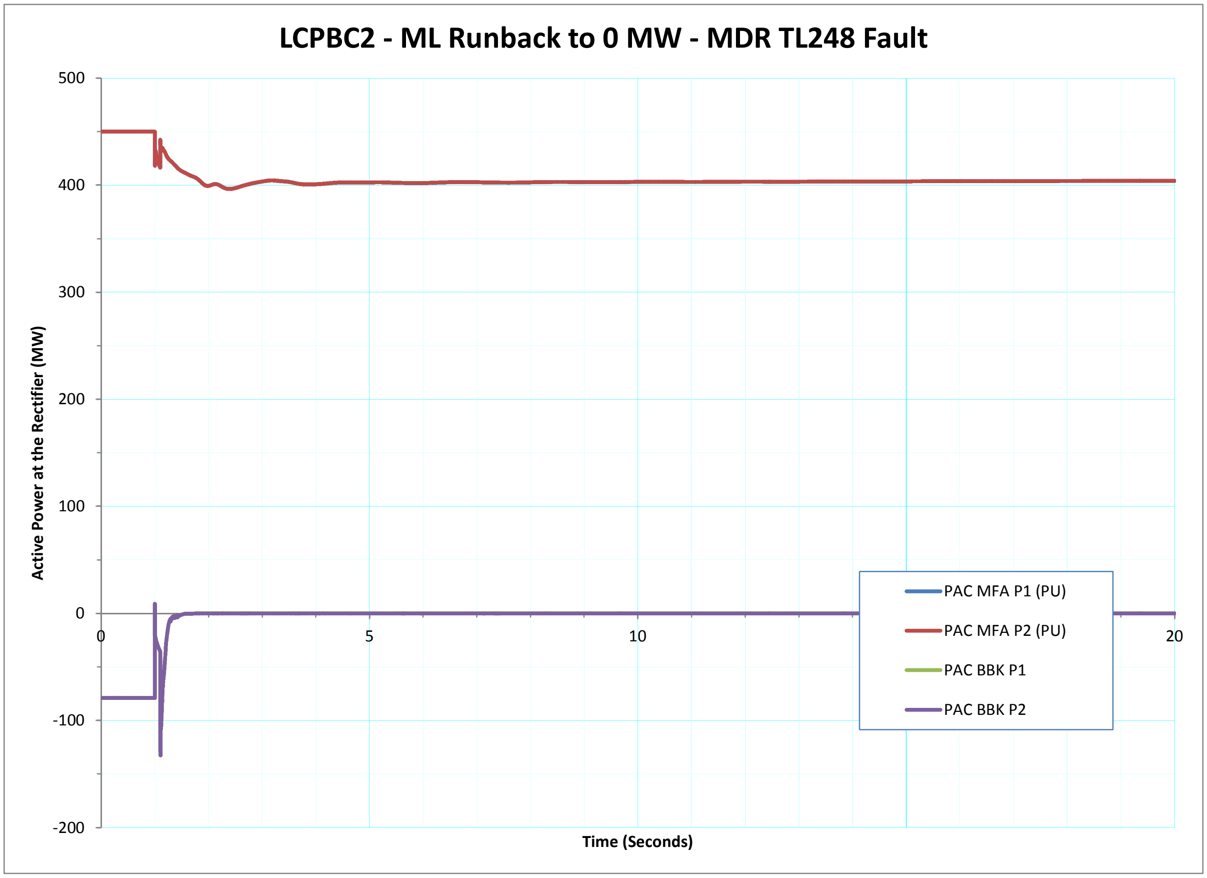


Figure 382 - LCPBC2 - ML Runback to 0 MW - MDR TL248 Fault - Active Power at the Rectifier (MW)

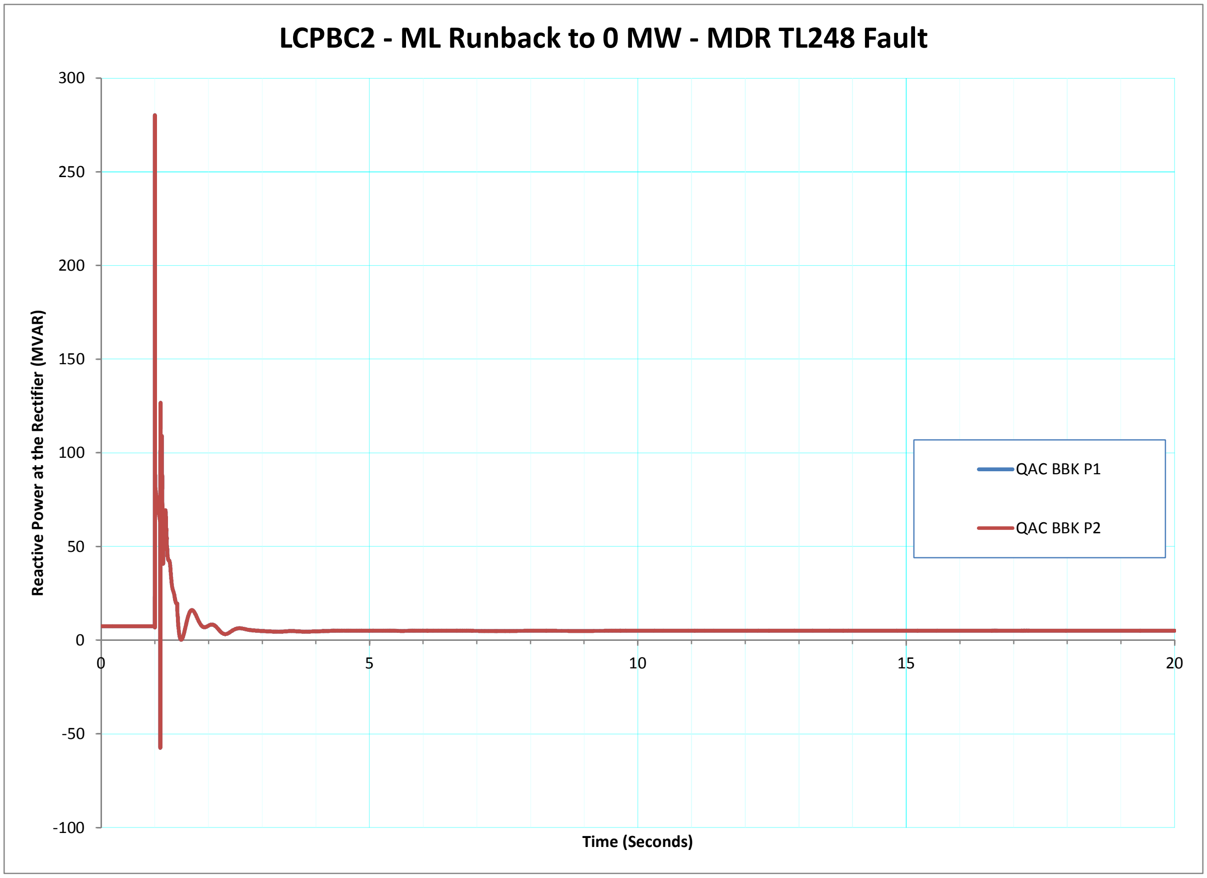


Figure 383 - LCPBC2 - ML Runback to 0 MW - MDR TL248 Fault - Reactive Power at the Rectifier (MVAR)

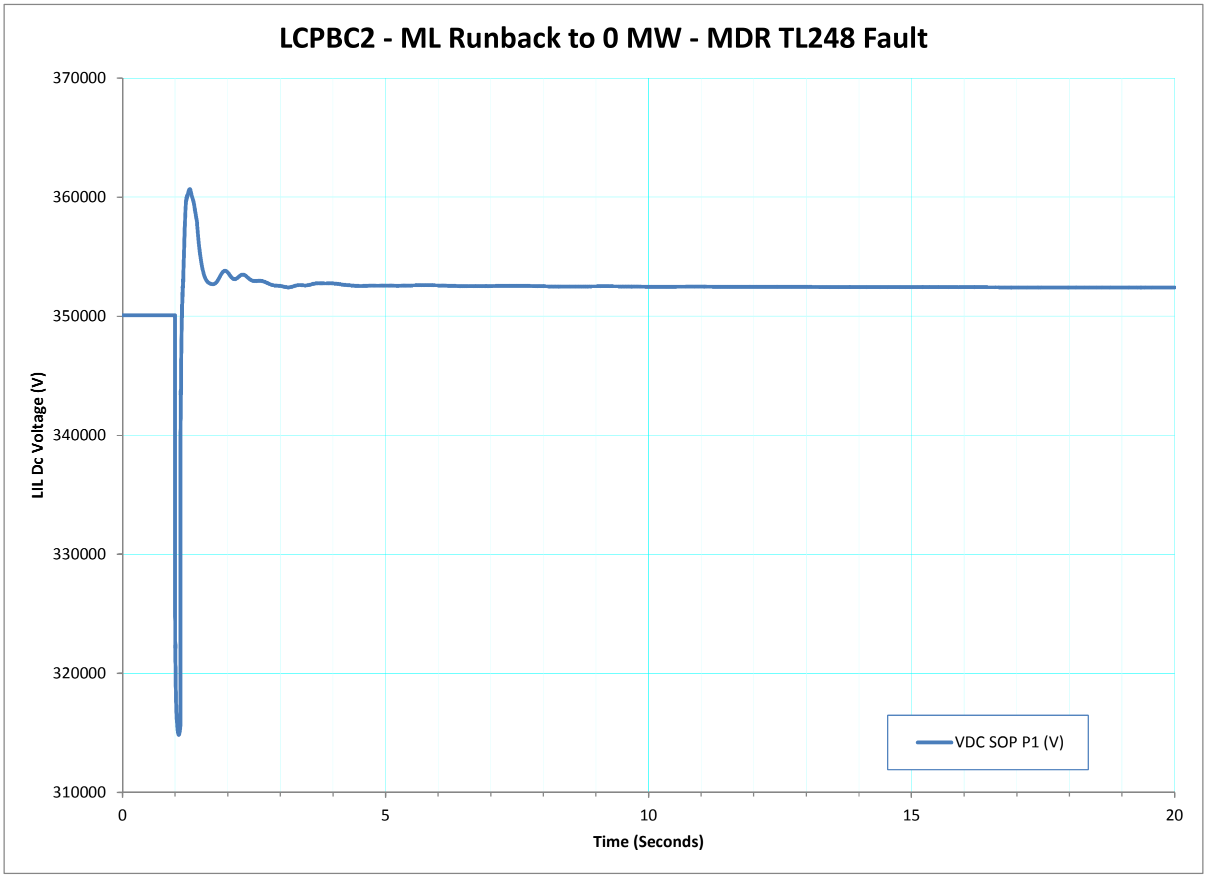


Figure 384 - LCPBC2 - ML Runback to 0 MW - MDR TL248 Fault - LIL Dc Voltage (V)

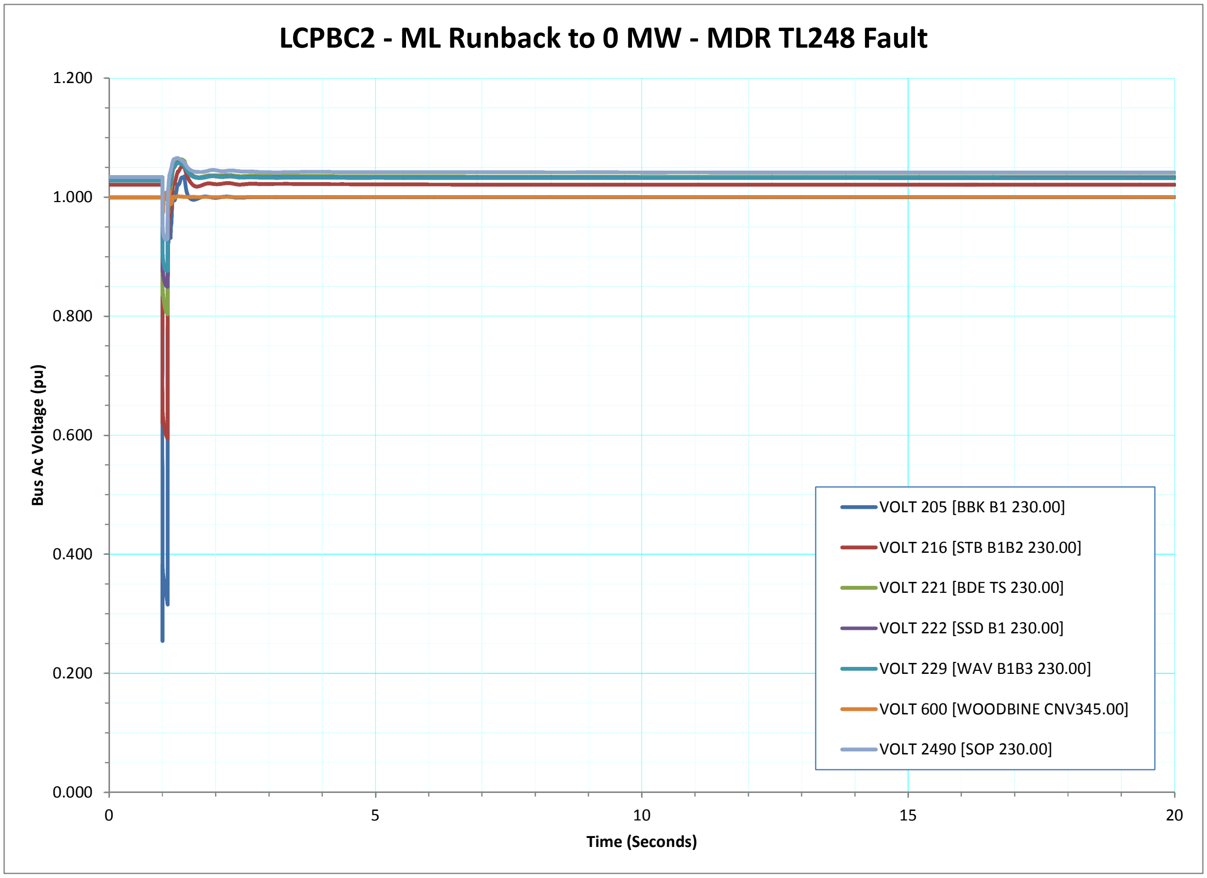


Figure 385 - LCPBC2 - ML Runback to 0 MW - MDR TL248 Fault - Bus Ac Voltage (pu)

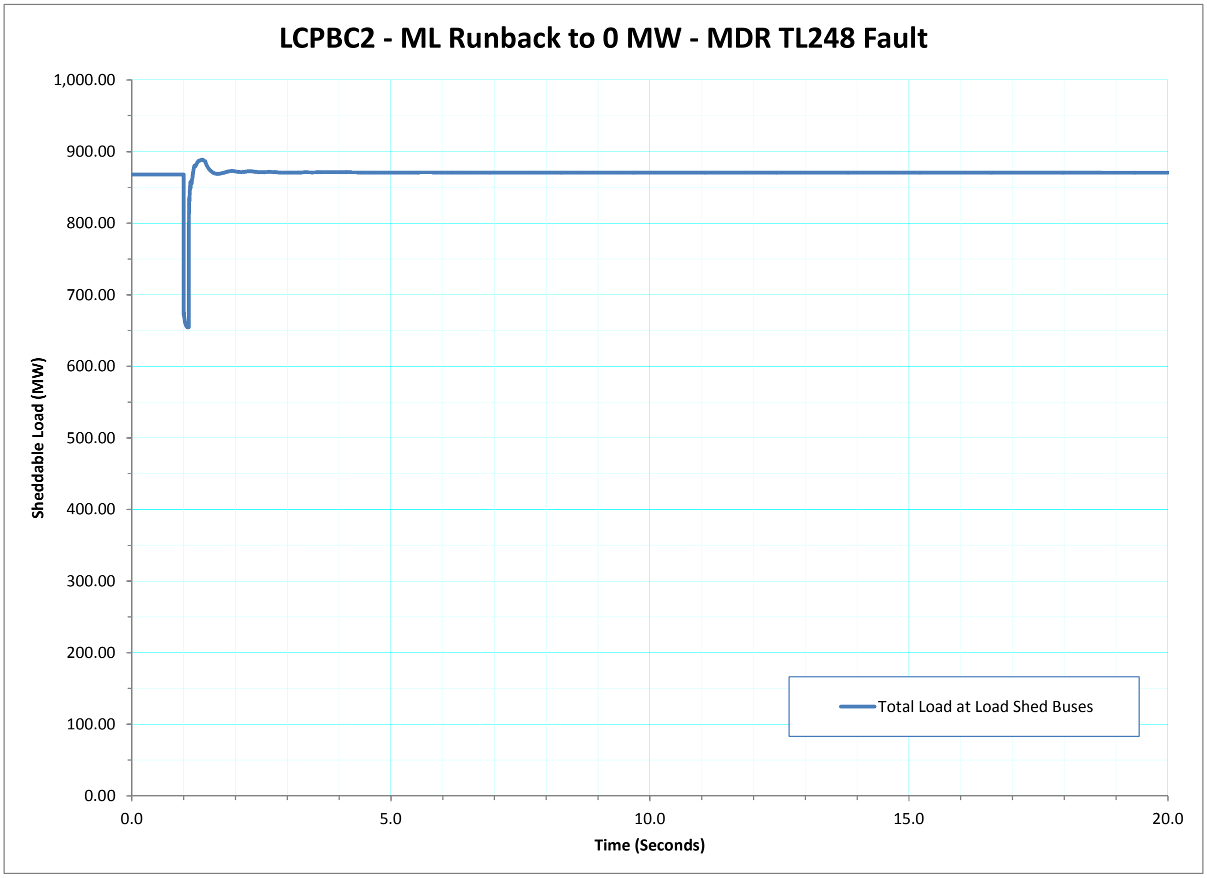


Figure 386 - LCPBC2 - ML Runback to 0 MW - MDR TL248 Fault - Sheddable Load (MW)

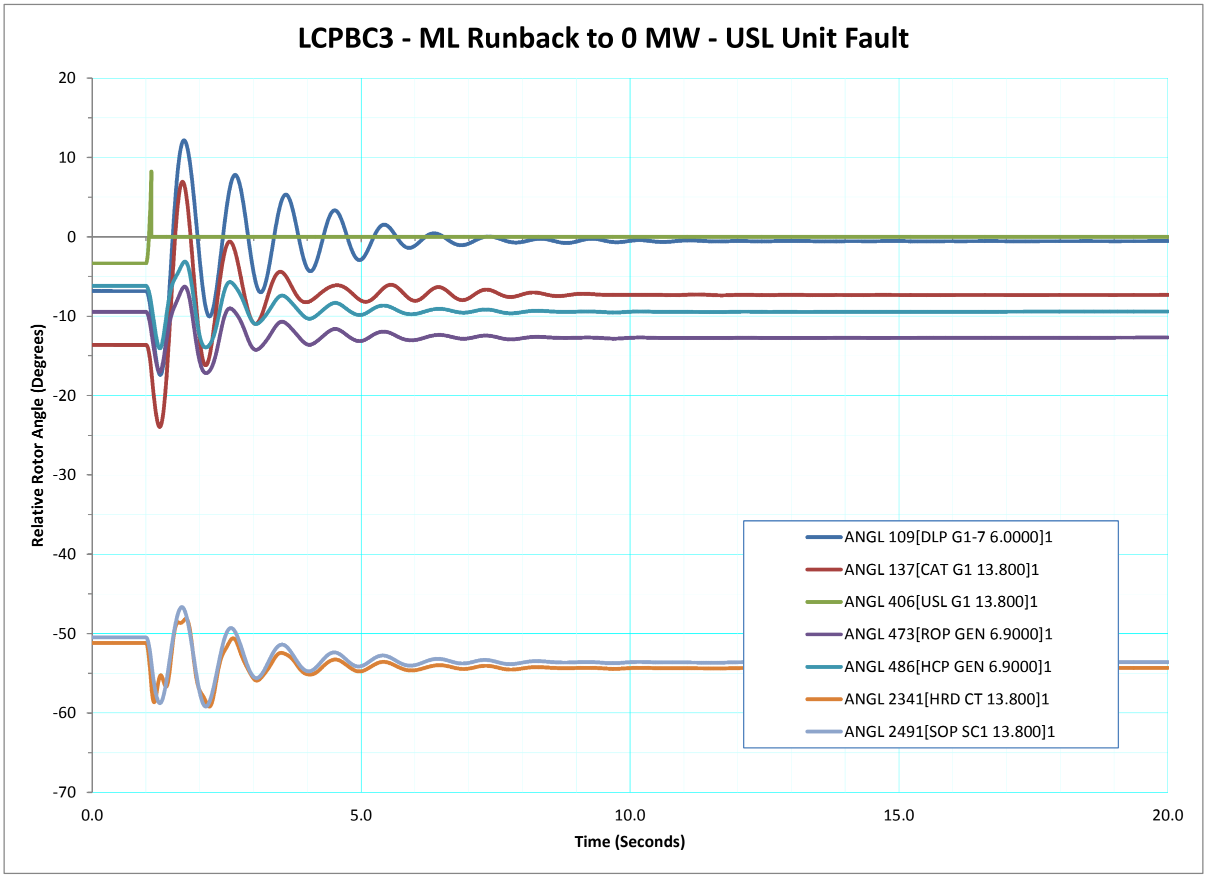


Figure 387 - LCPBC3 - ML Runback to 0 MW - USL Unit Fault - Relative Rotor Angle (Degrees)

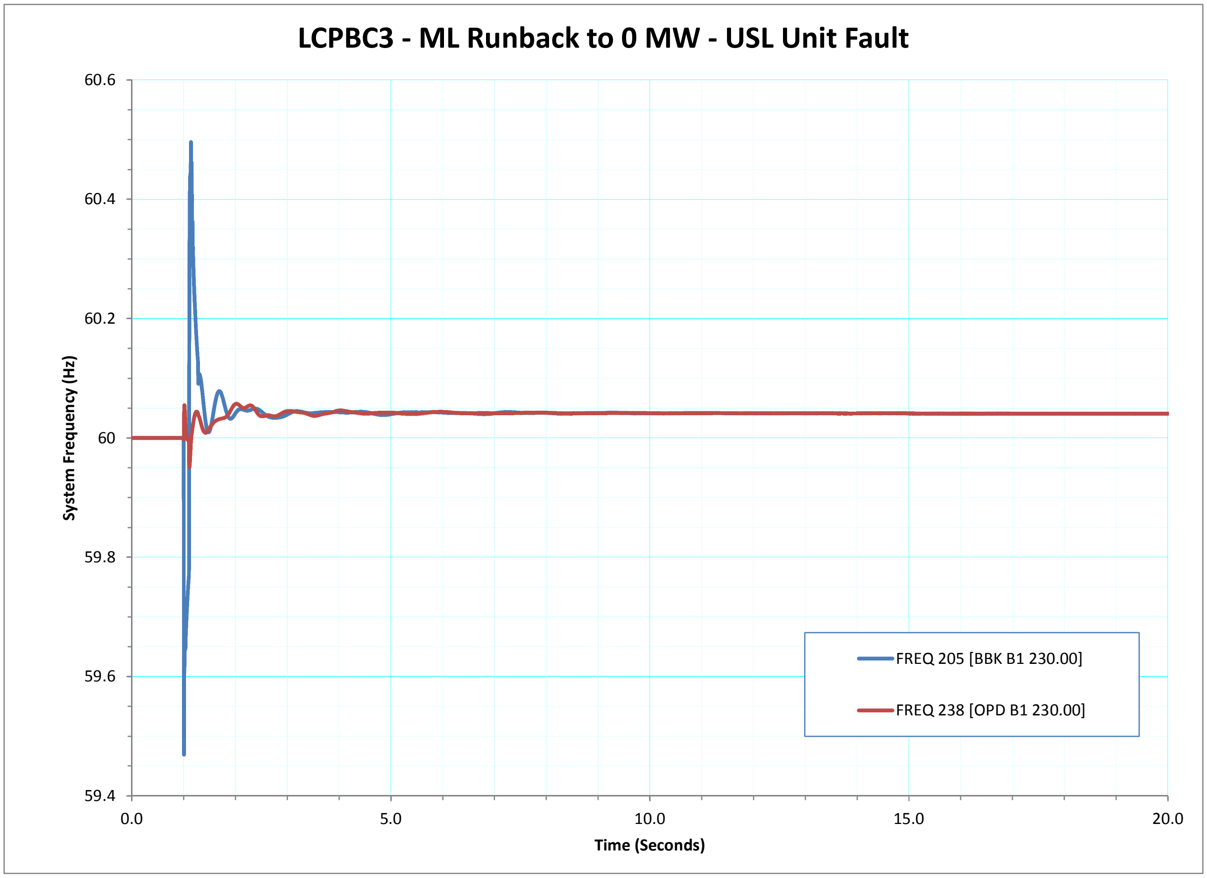


Figure 388 - LCPBC3 - ML Runback to 0 MW - USL Unit Fault - System Frequency (Hz)

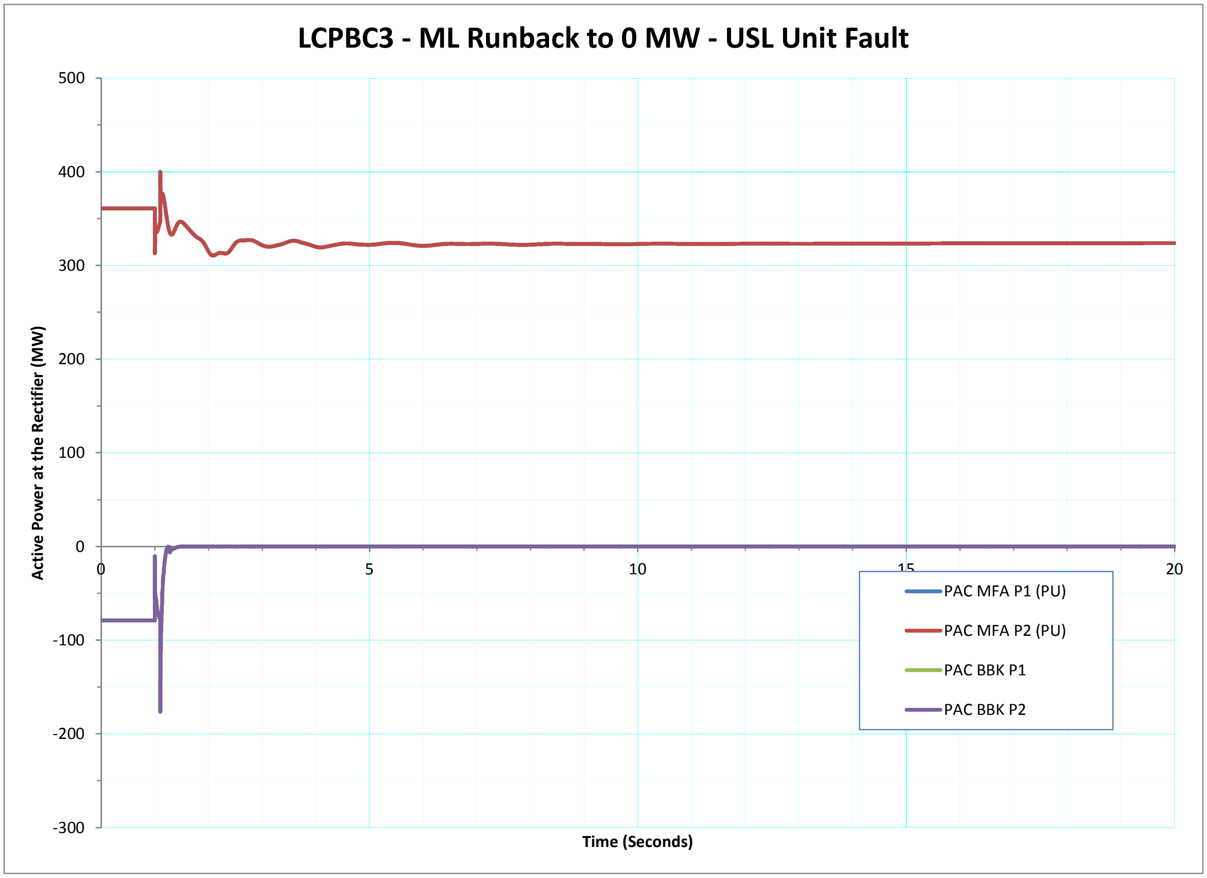


Figure 389 - LCPBC3 - ML Runback to 0 MW - USL Unit Fault - Active Power at the Rectifier (MW)

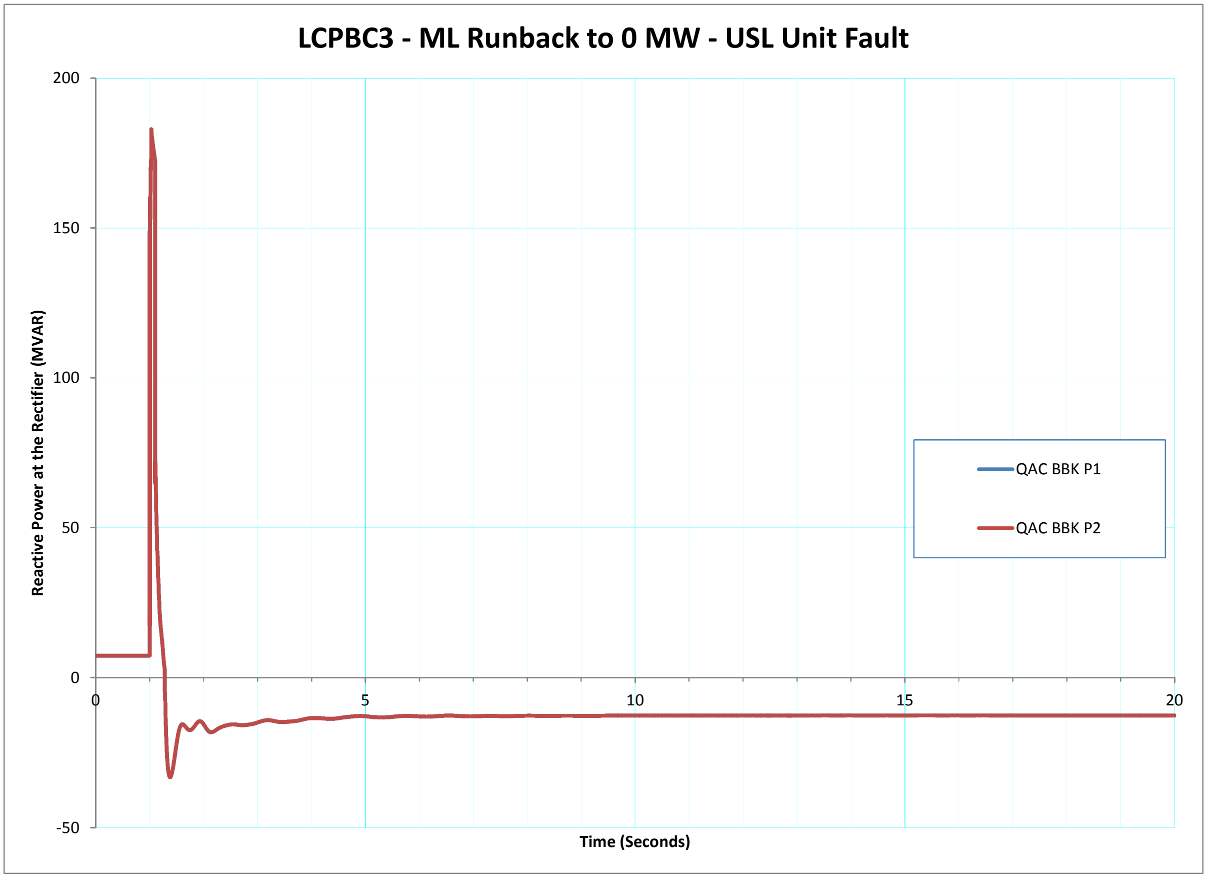


Figure 390 - LCPBC3 - ML Runback to 0 MW - USL Unit Fault - Reactive Power at the Rectifier (MVAR)

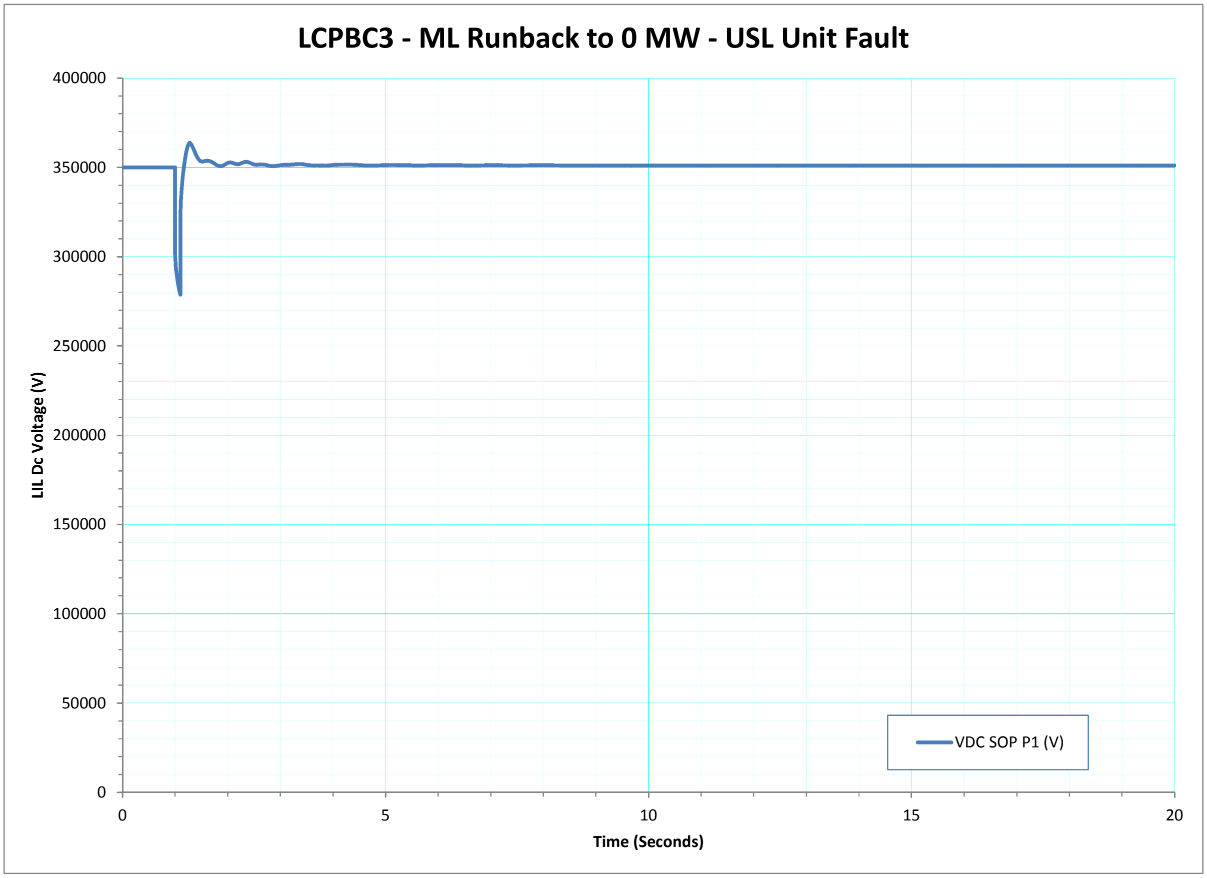


Figure 391 - LCPBC3 - ML Runback to 0 MW - USL Unit Fault - LIL Dc Voltage (V)

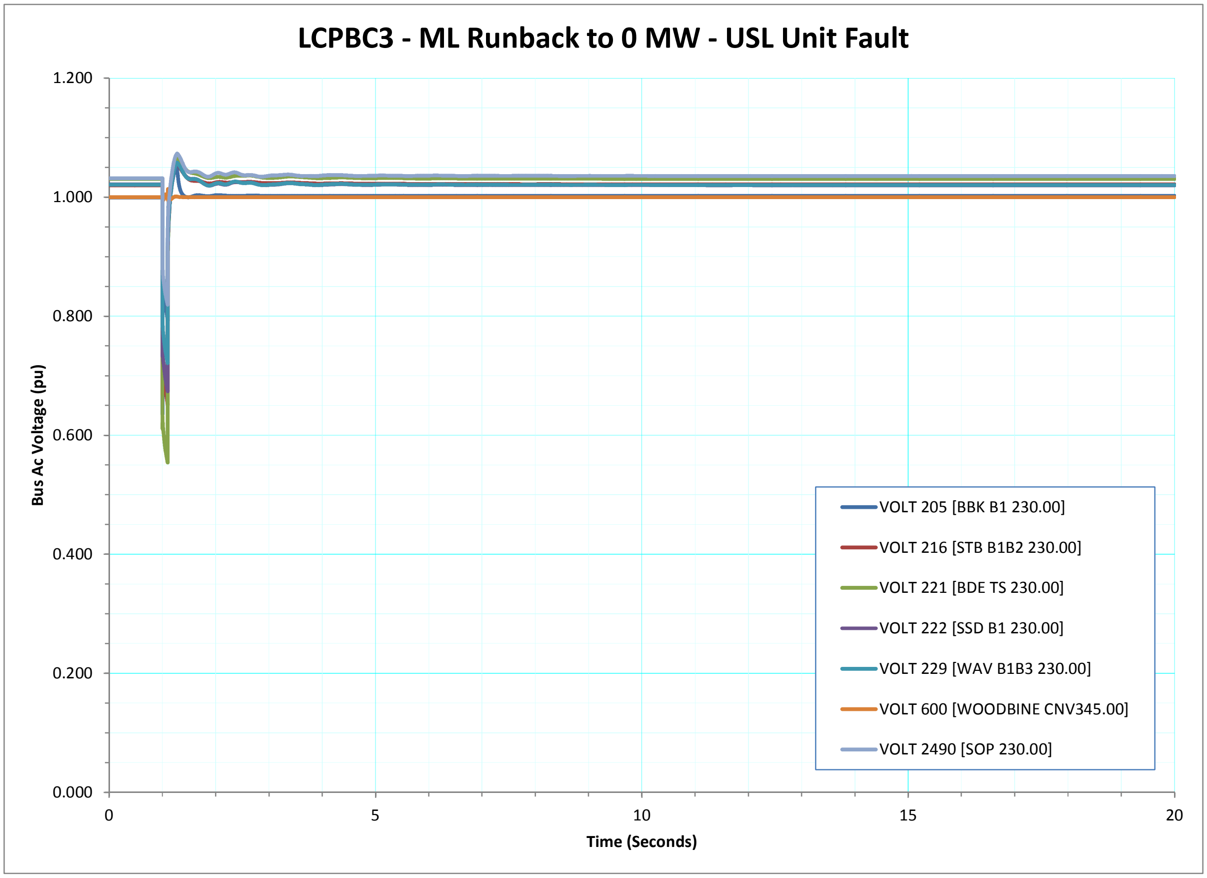


Figure 392 - LCPBC3 - ML Runback to 0 MW - USL Unit Fault - Bus Ac Voltage (pu)

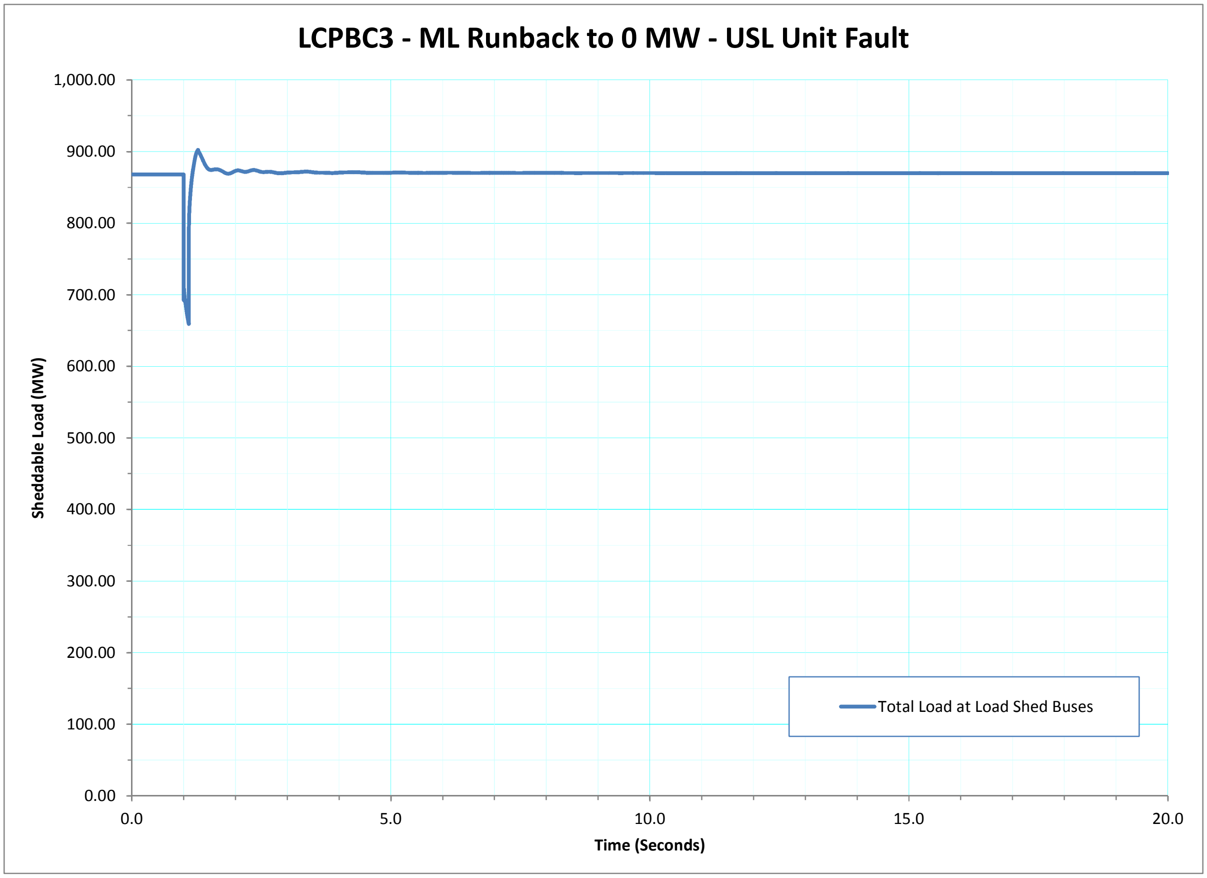


Figure 393 - LCPBC3 - ML Runback to 0 MW - USL Unit Fault - Sheddable Load (MW)

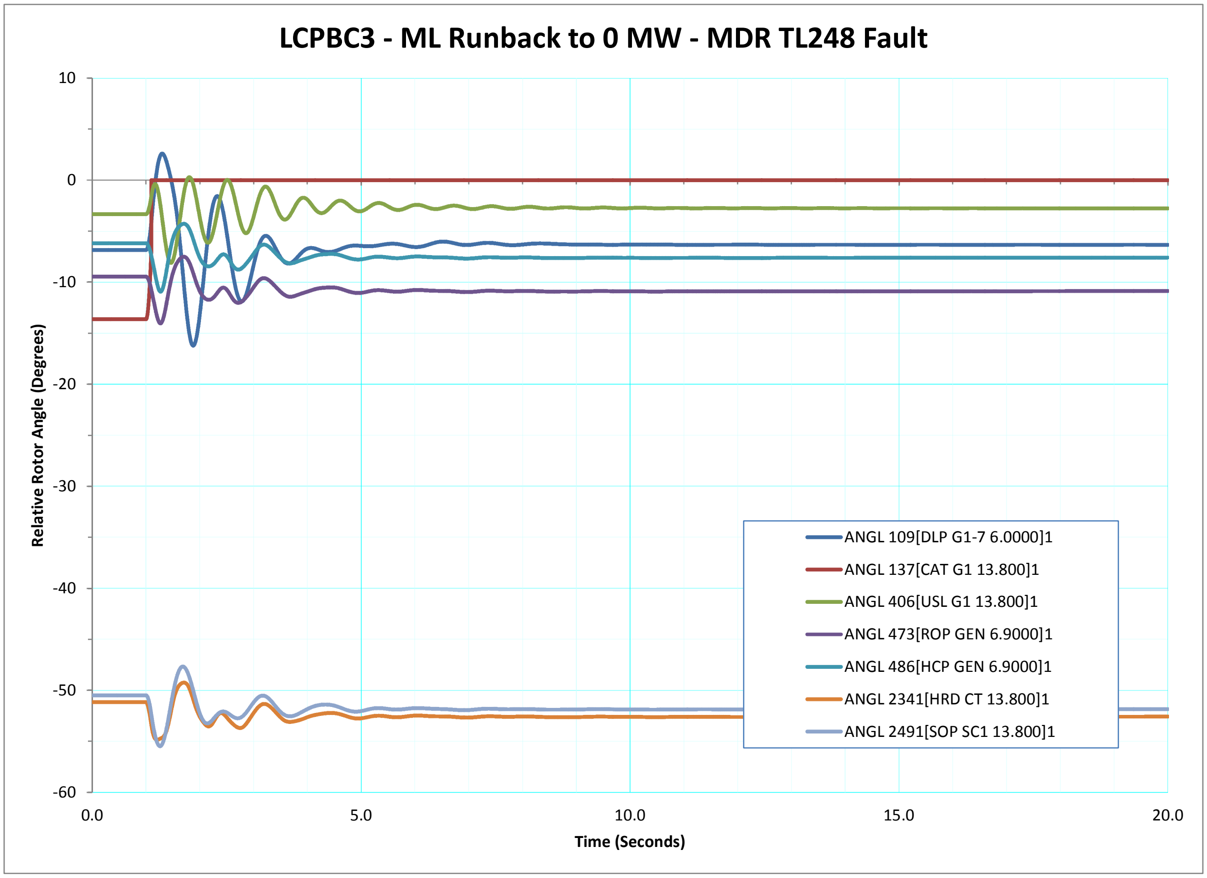


Figure 394 - LCPBC3 - ML Runback to 0 MW - MDR TL248 Fault - Relative Rotor Angle (Degrees)

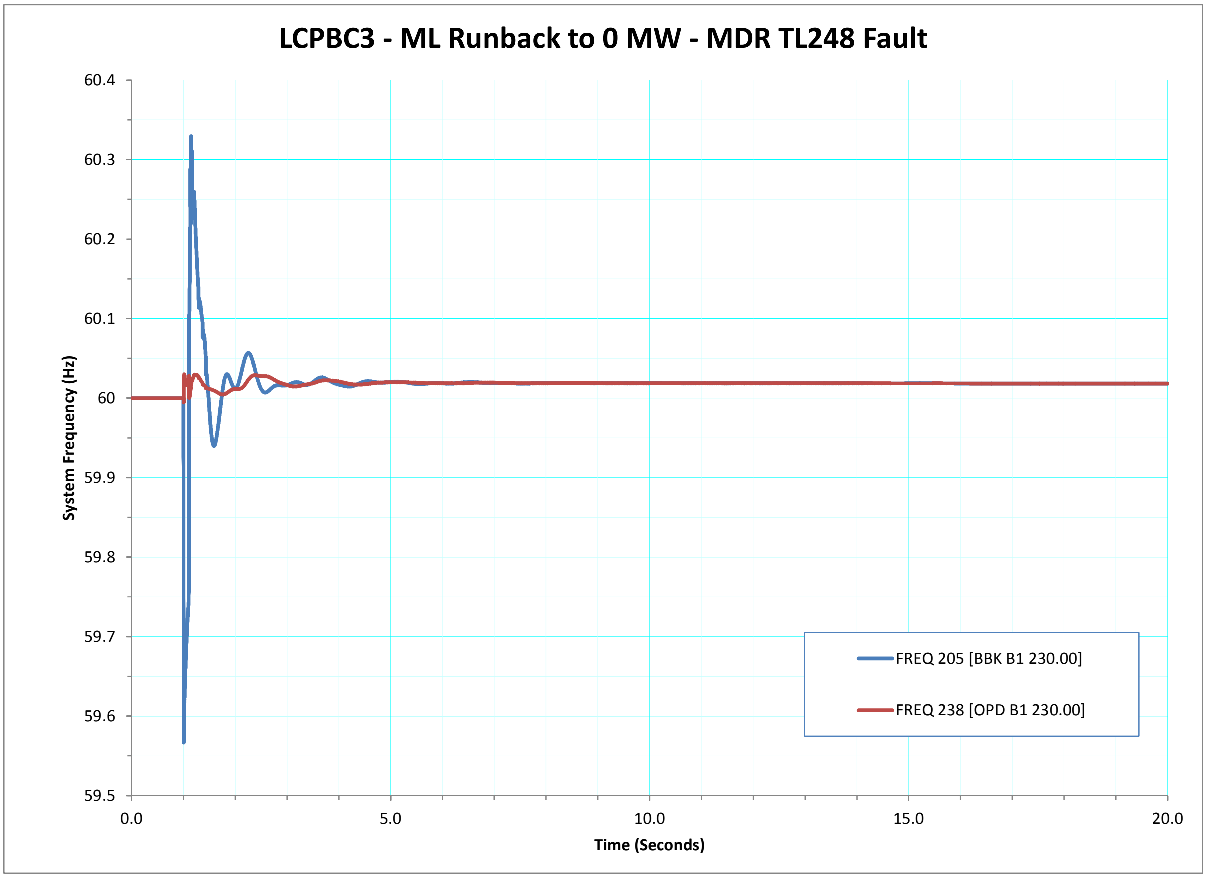


Figure 395 - LCPBC3 - ML Runback to 0 MW - MDR TL248 Fault - System Frequency (Hz)

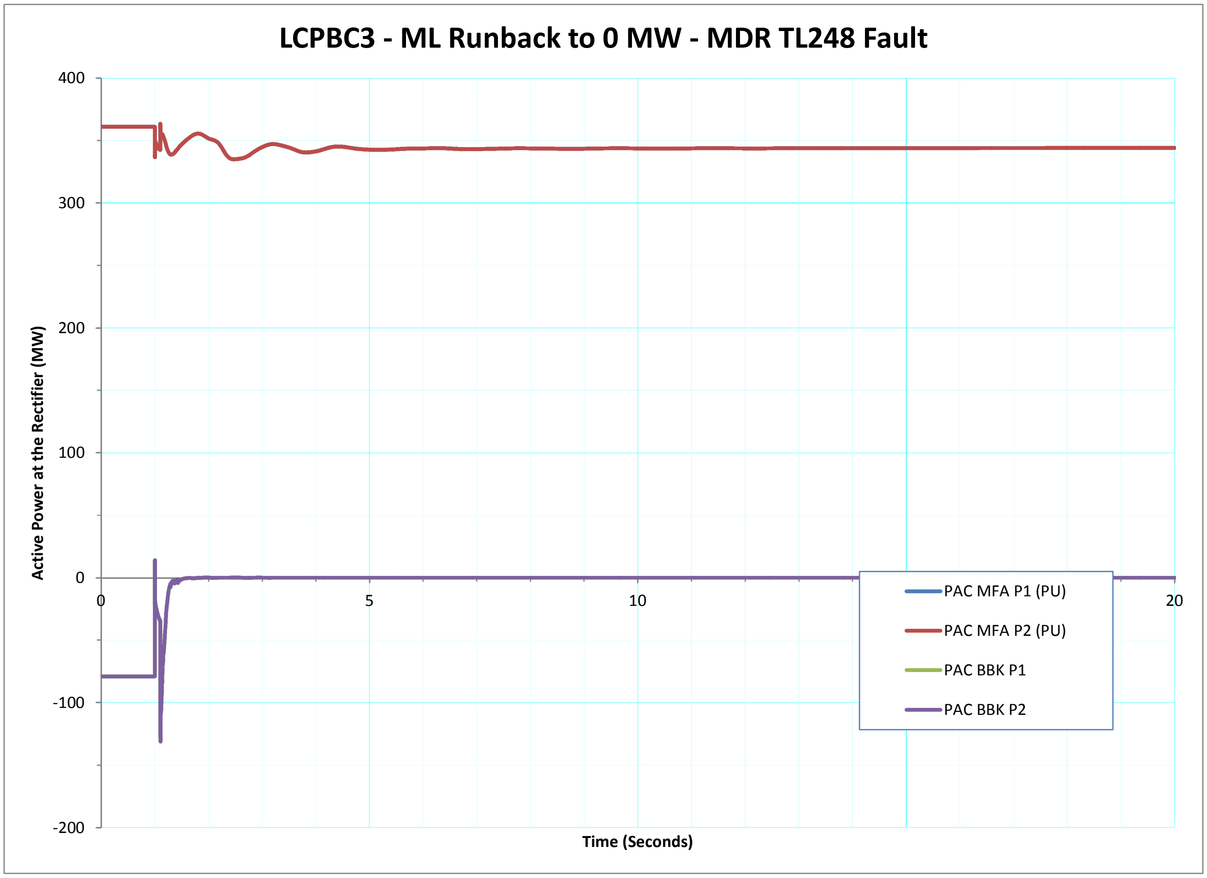


Figure 396 - LCPBC3 - ML Runback to 0 MW - MDR TL248 Fault - Active Power at the Rectifier (MW)

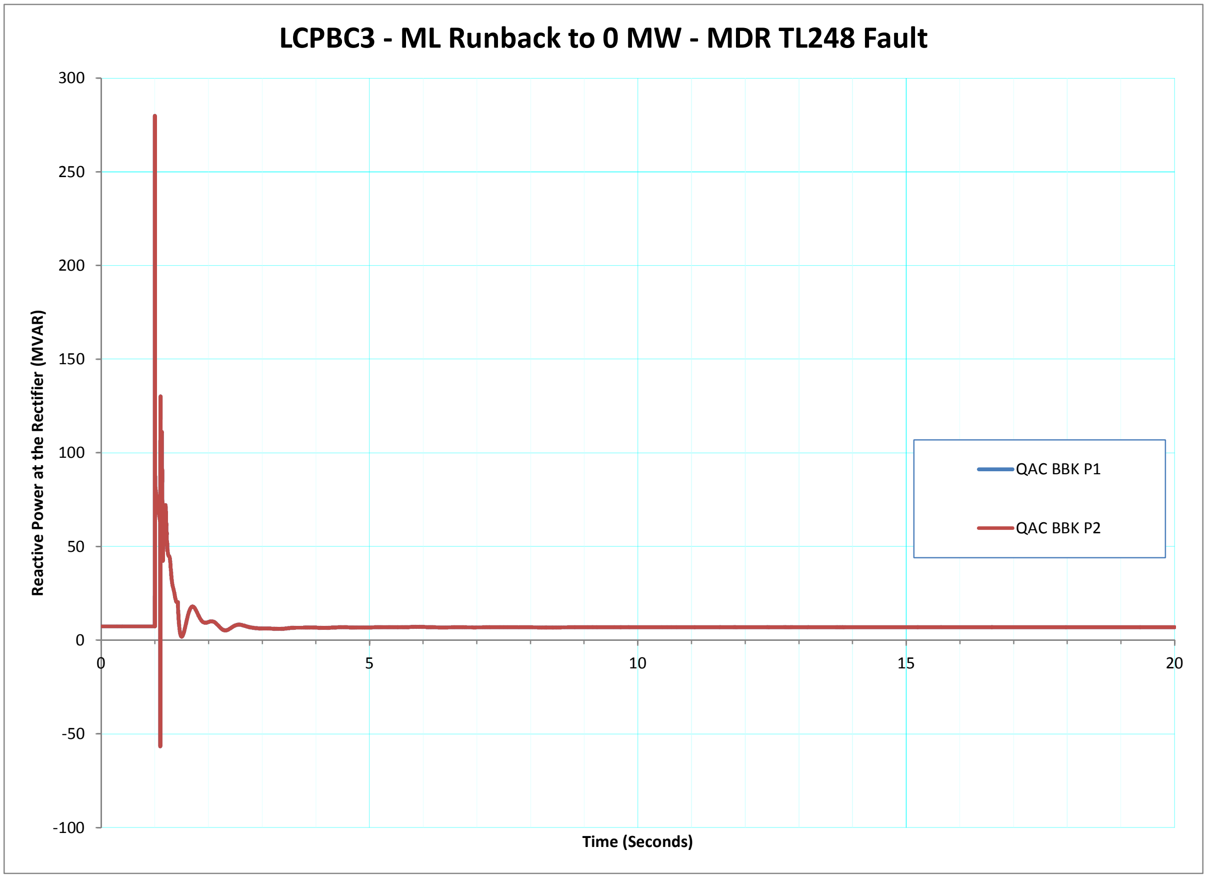


Figure 397 - LCPBC3 - ML Runback to 0 MW - MDR TL248 Fault - Reactive Power at the Rectifier (MVAR)

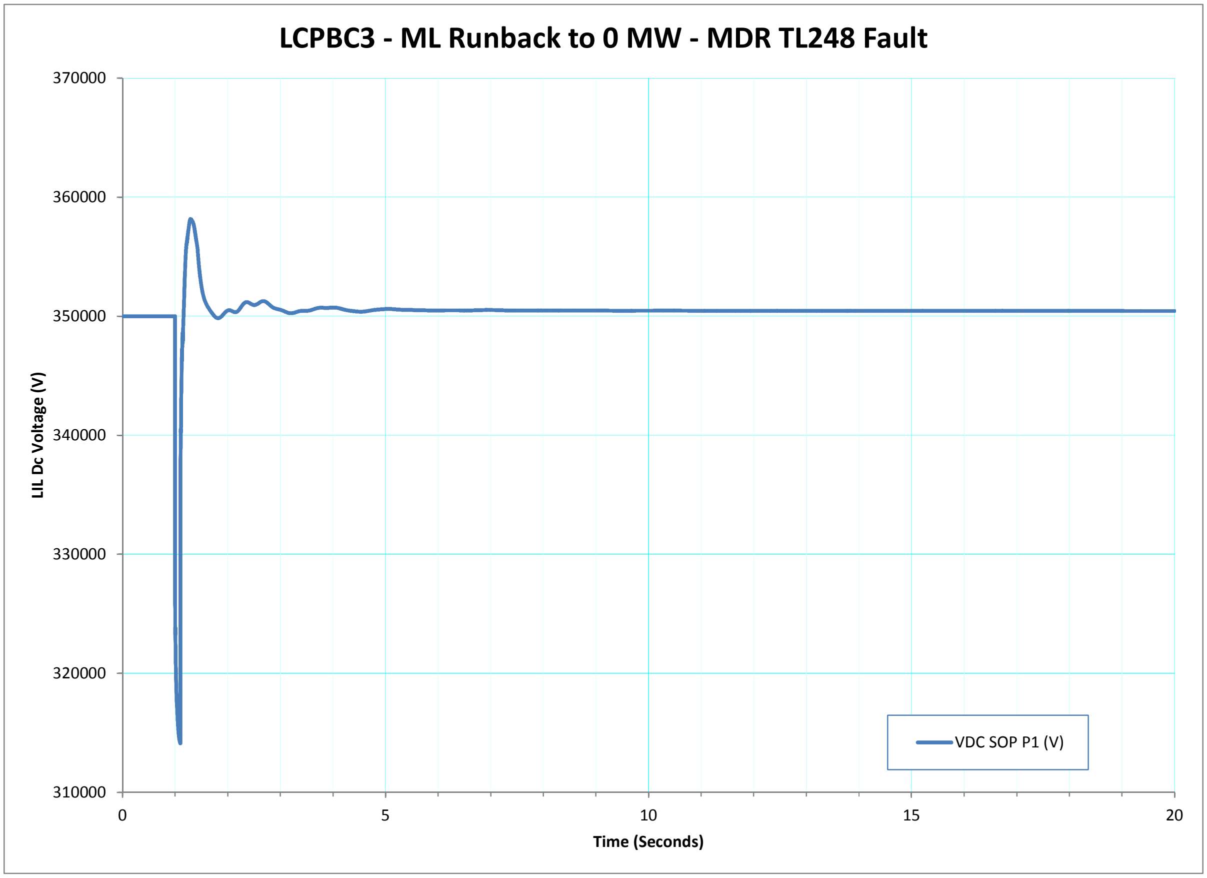


Figure 398 - LCPBC3 - ML Runback to 0 MW - MDR TL248 Fault - LIL Dc Voltage (V)

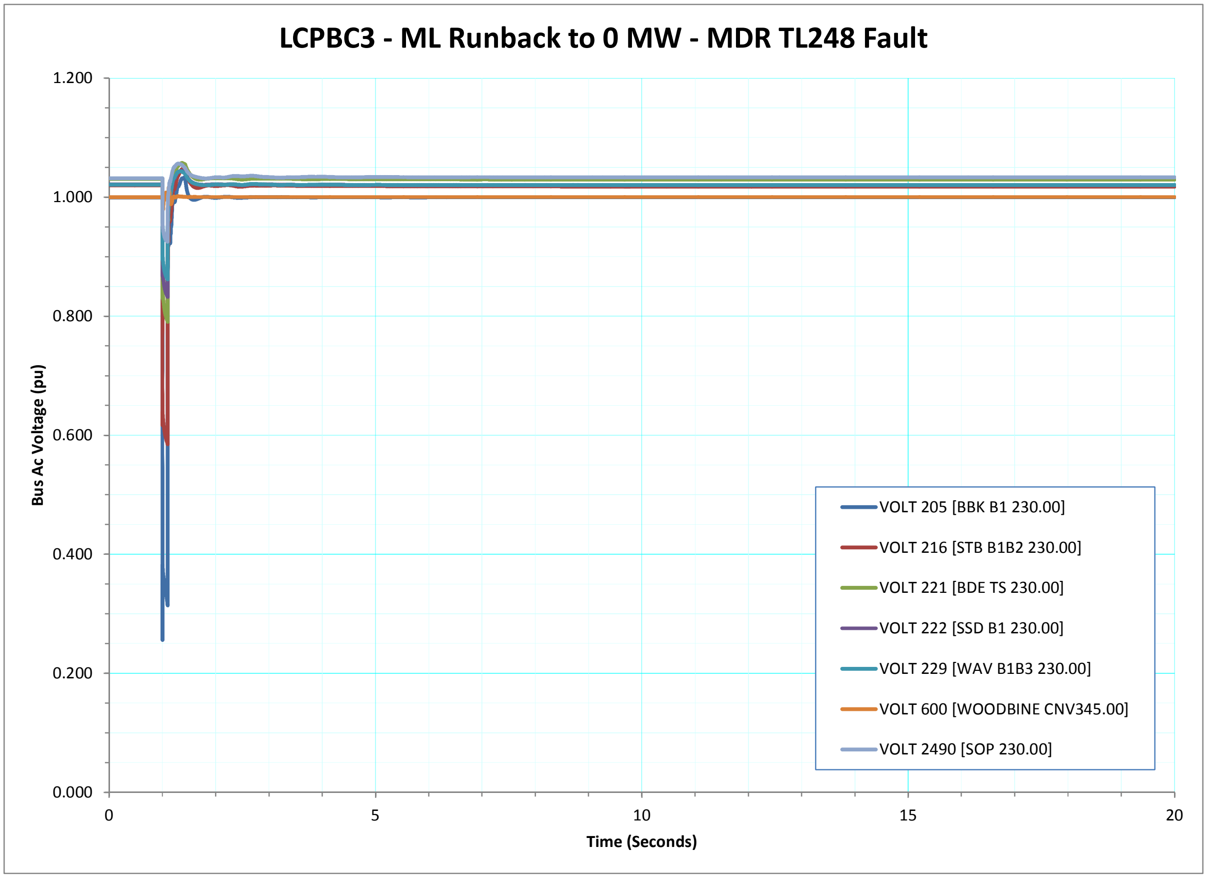


Figure 399 - LCPBC3 - ML Runback to 0 MW - MDR TL248 Fault - Bus Ac Voltage (pu)

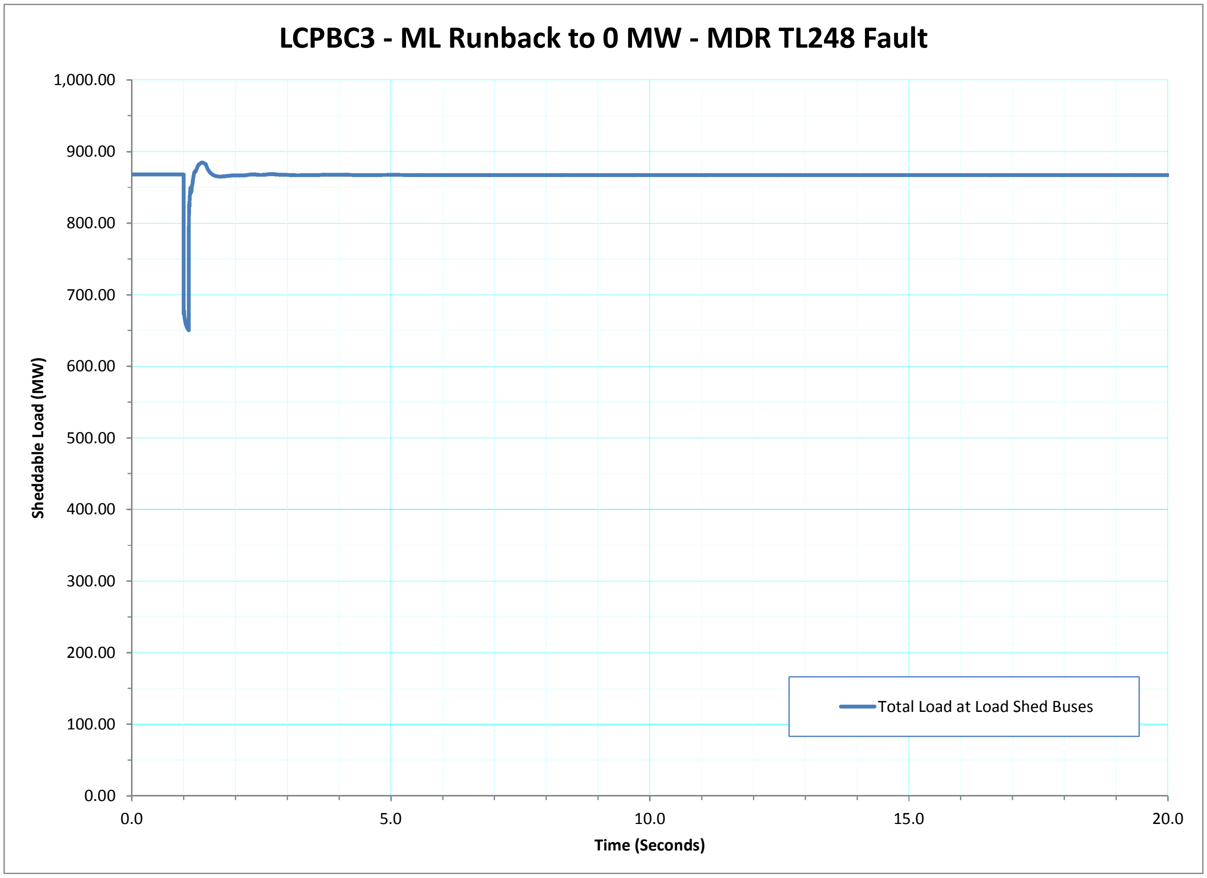


Figure 400 - LCPBC3 - ML Runback to 0 MW - MDR TL248 Fault - Sheddable Load (MW)

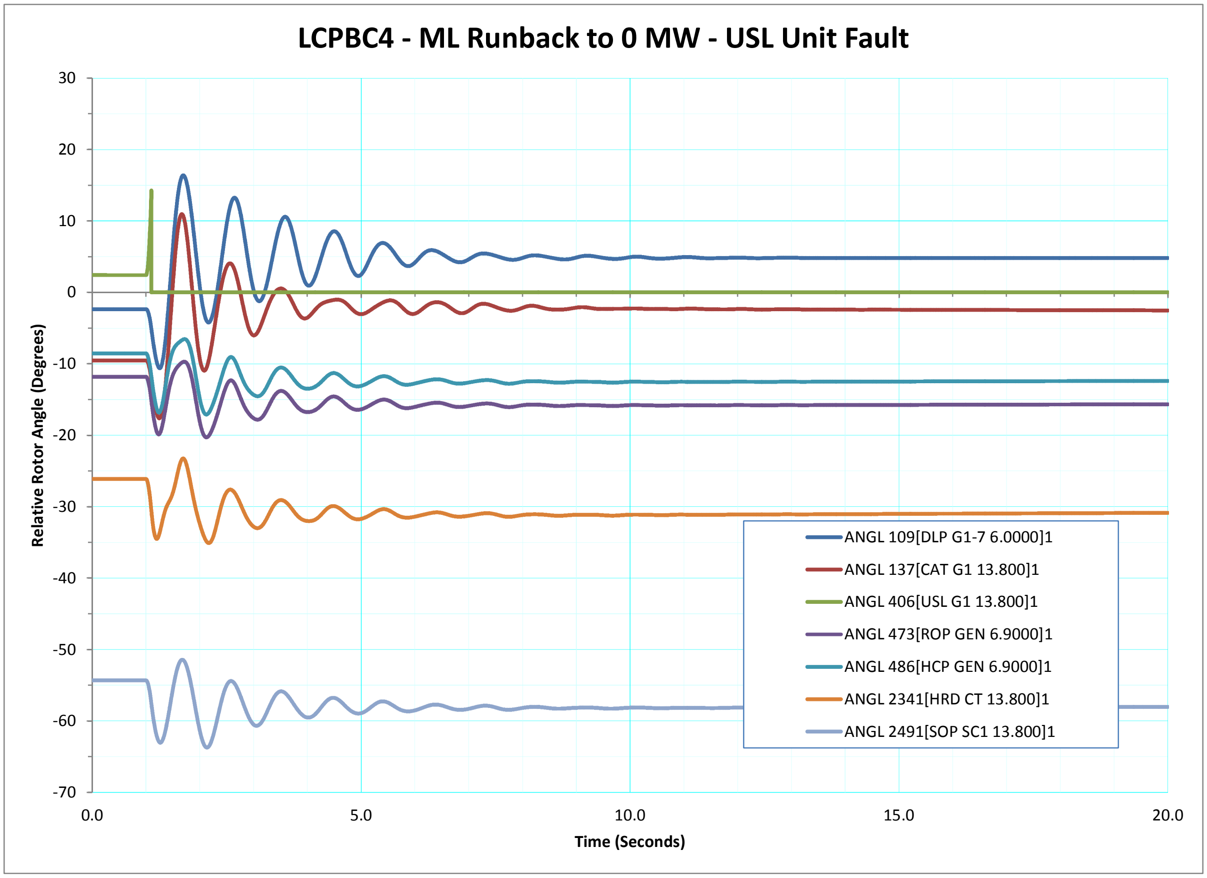


Figure 401 - LCPBC4 - ML Runback to 0 MW - USL Unit Fault - Relative Rotor Angle (Degrees)

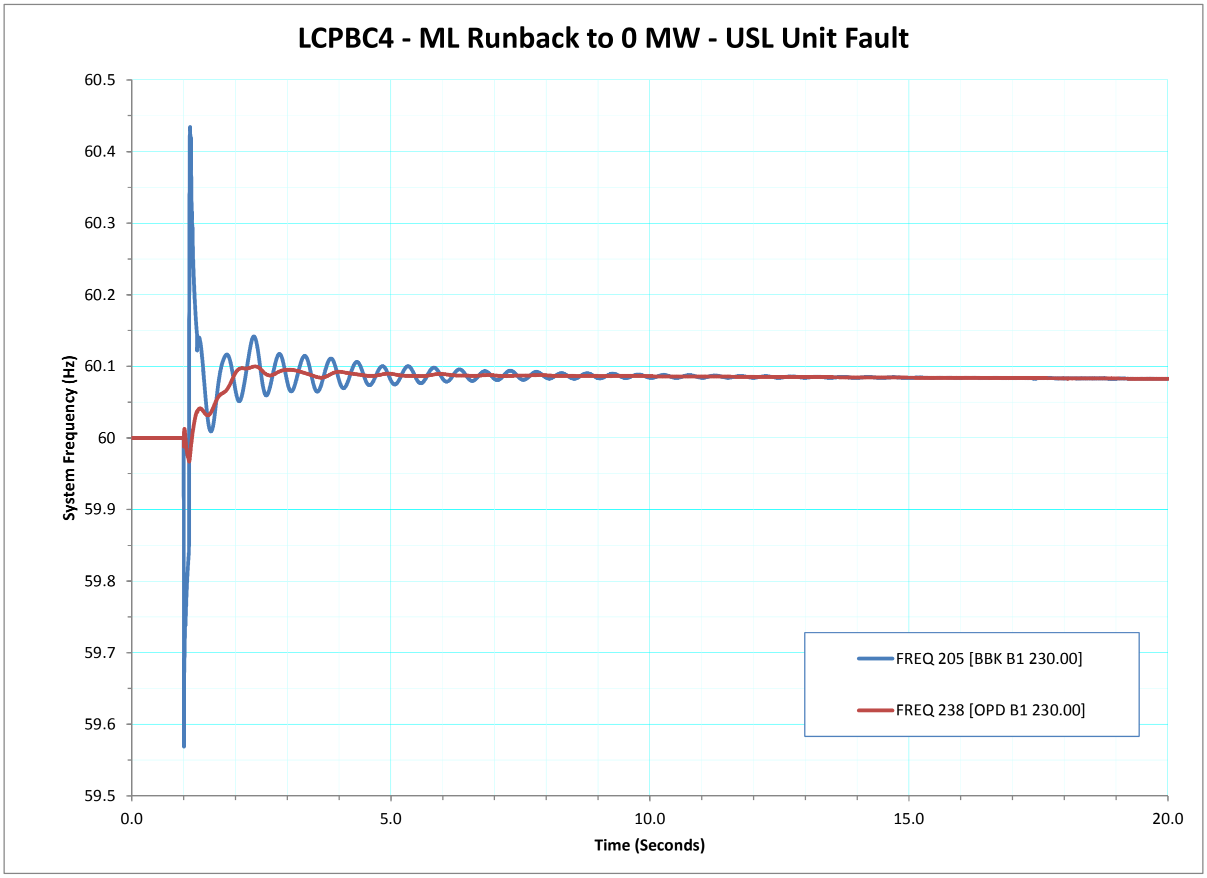


Figure 402 - LCPBC4 - ML Runback to 0 MW - USL Unit Fault - System Frequency (Hz)

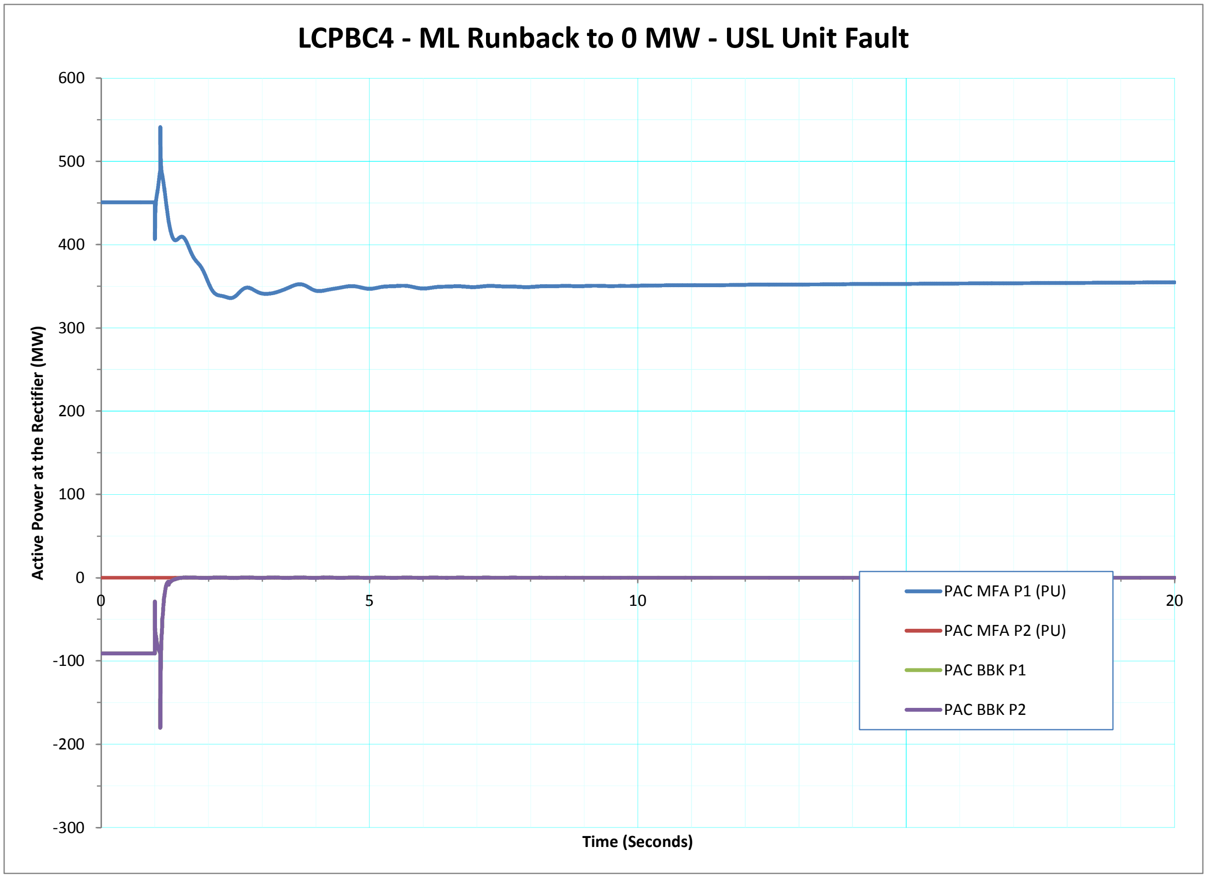


Figure 403 - LCPBC4 - ML Runback to 0 MW - USL Unit Fault - Active Power at the Rectifier (MW)

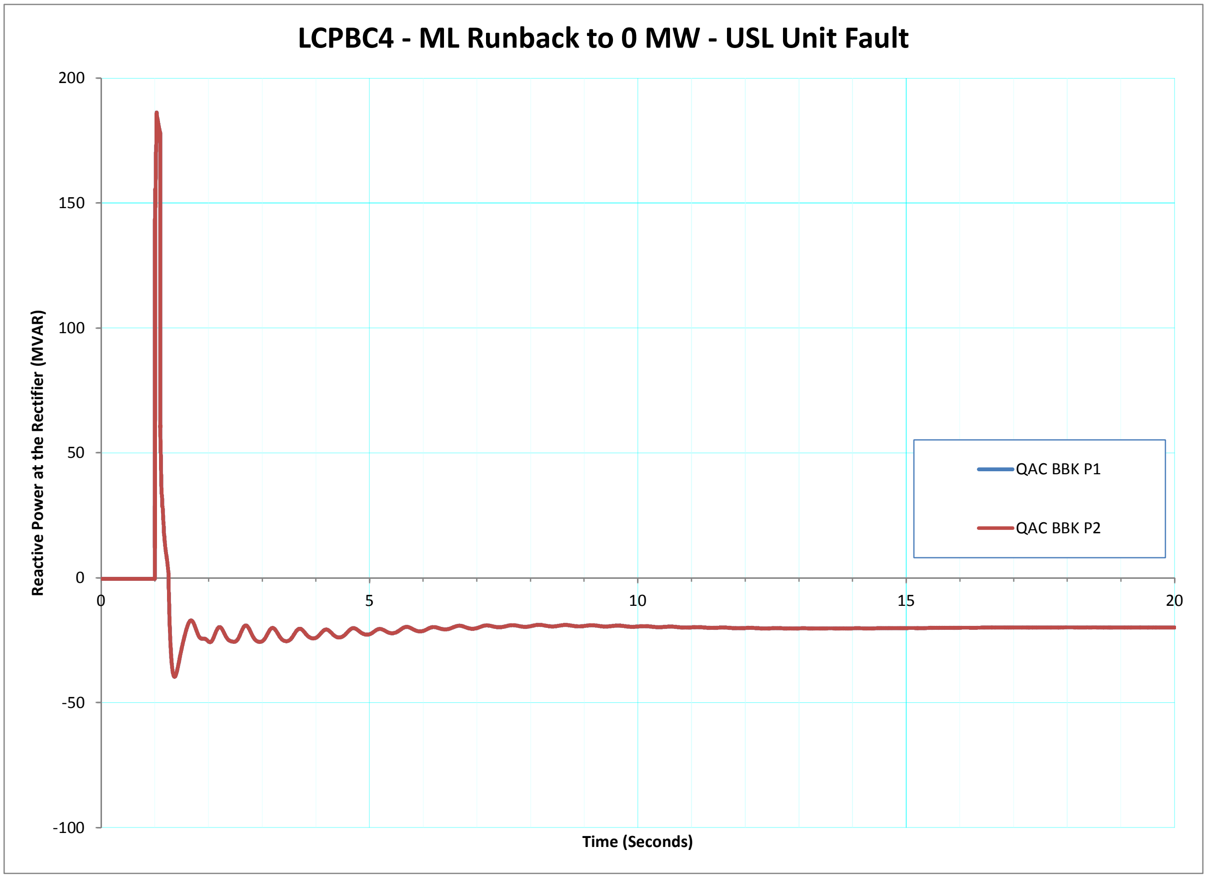


Figure 404 - LCPBC4 - ML Runback to 0 MW - USL Unit Fault - Reactive Power at the Rectifier (MVAR)

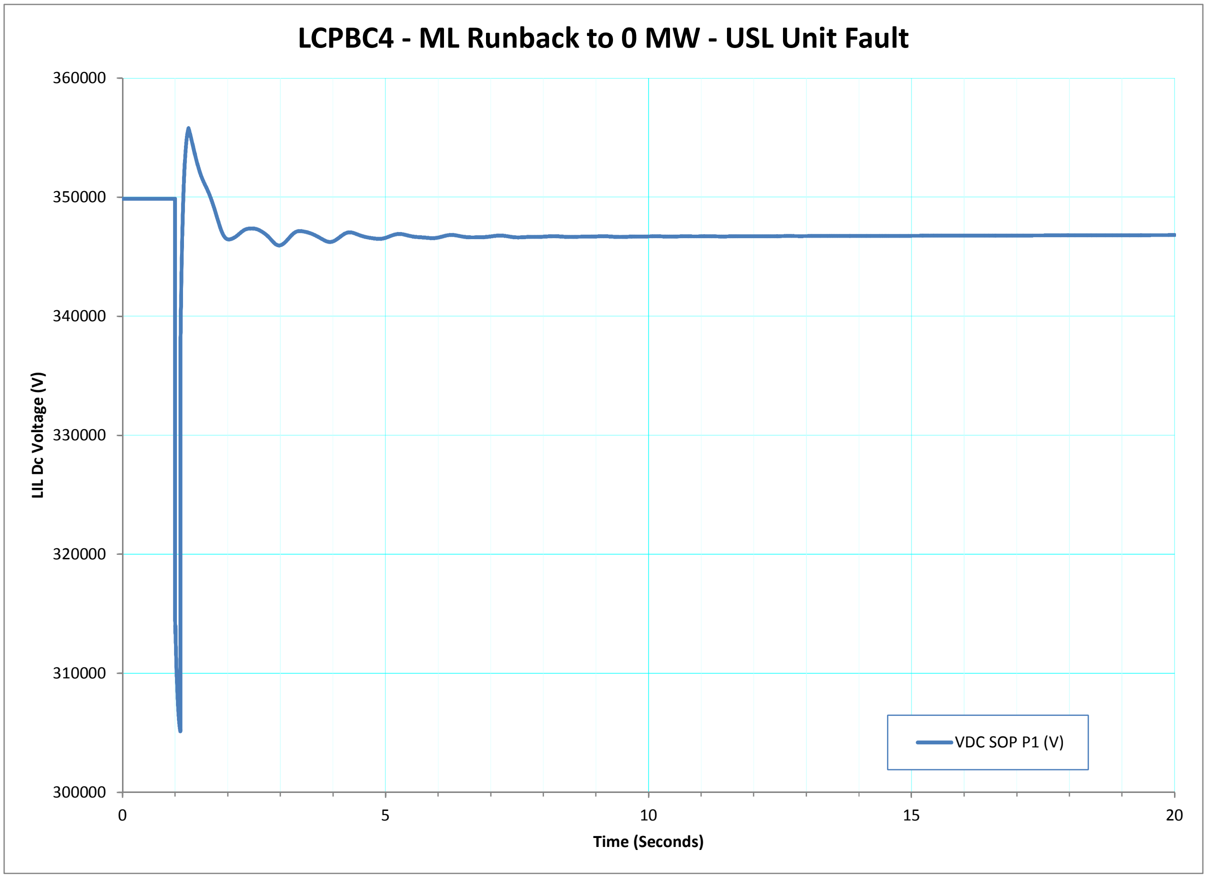


Figure 405 - LCPBC4 - ML Runback to 0 MW - USL Unit Fault - LIL Dc Voltage (V)

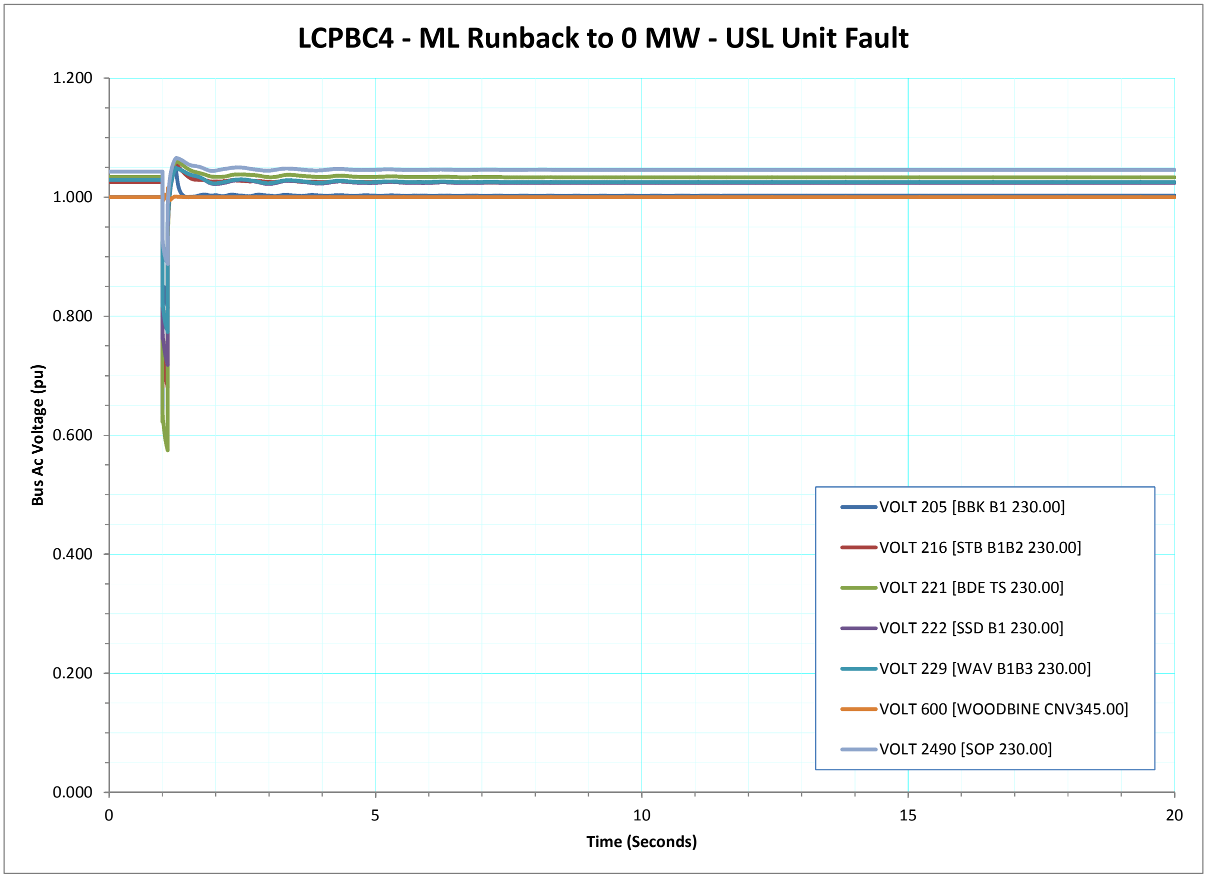


Figure 406 - LCPBC4 - ML Runback to 0 MW - USL Unit Fault - Bus Ac Voltage (pu)

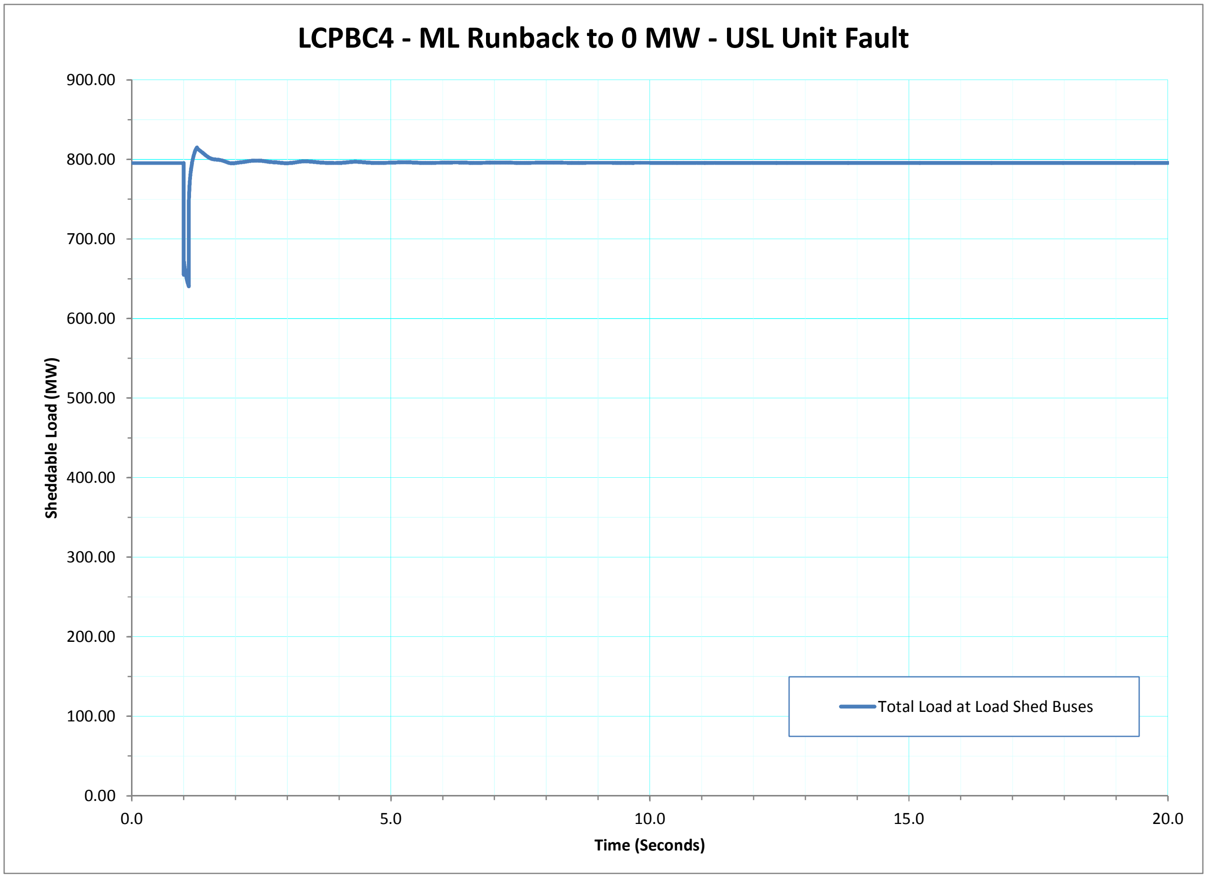


Figure 407 - LCPBC4 - ML Runback to 0 MW - USL Unit Fault - Sheddable Load (MW)

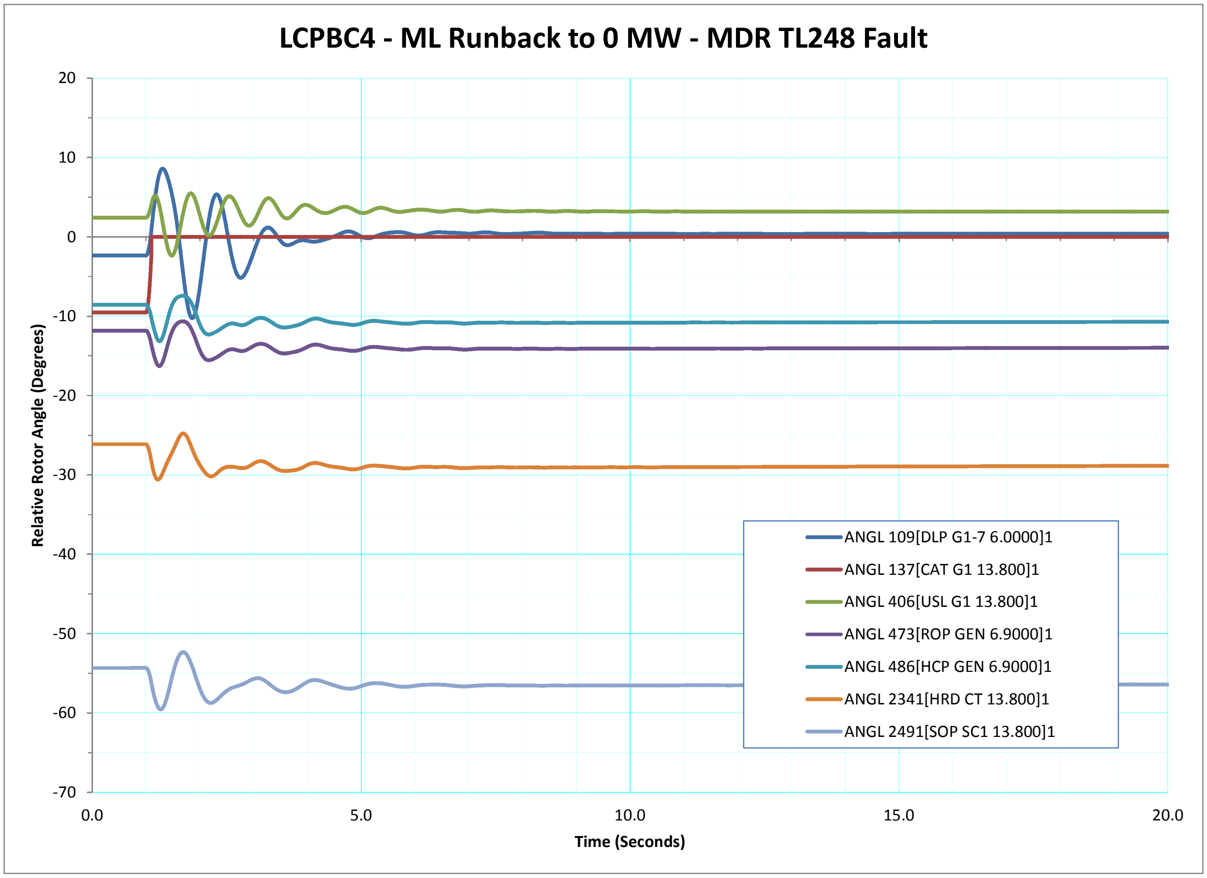


Figure 408 - LCPBC4 - ML Runback to 0 MW - MDR TL248 Fault - Relative Rotor Angle (Degrees)

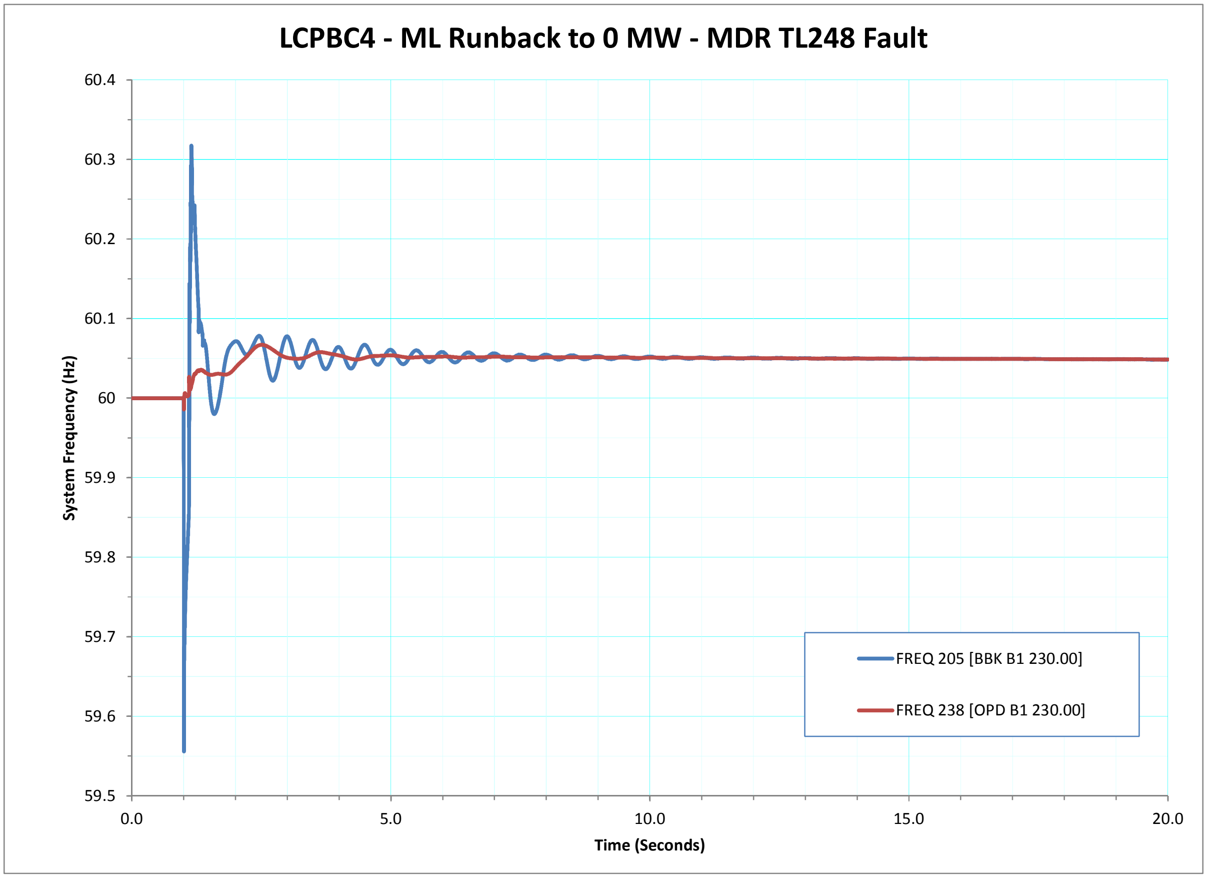


Figure 409 - LCPBC4 - ML Runback to 0 MW - MDR TL248 Fault - System Frequency (Hz)

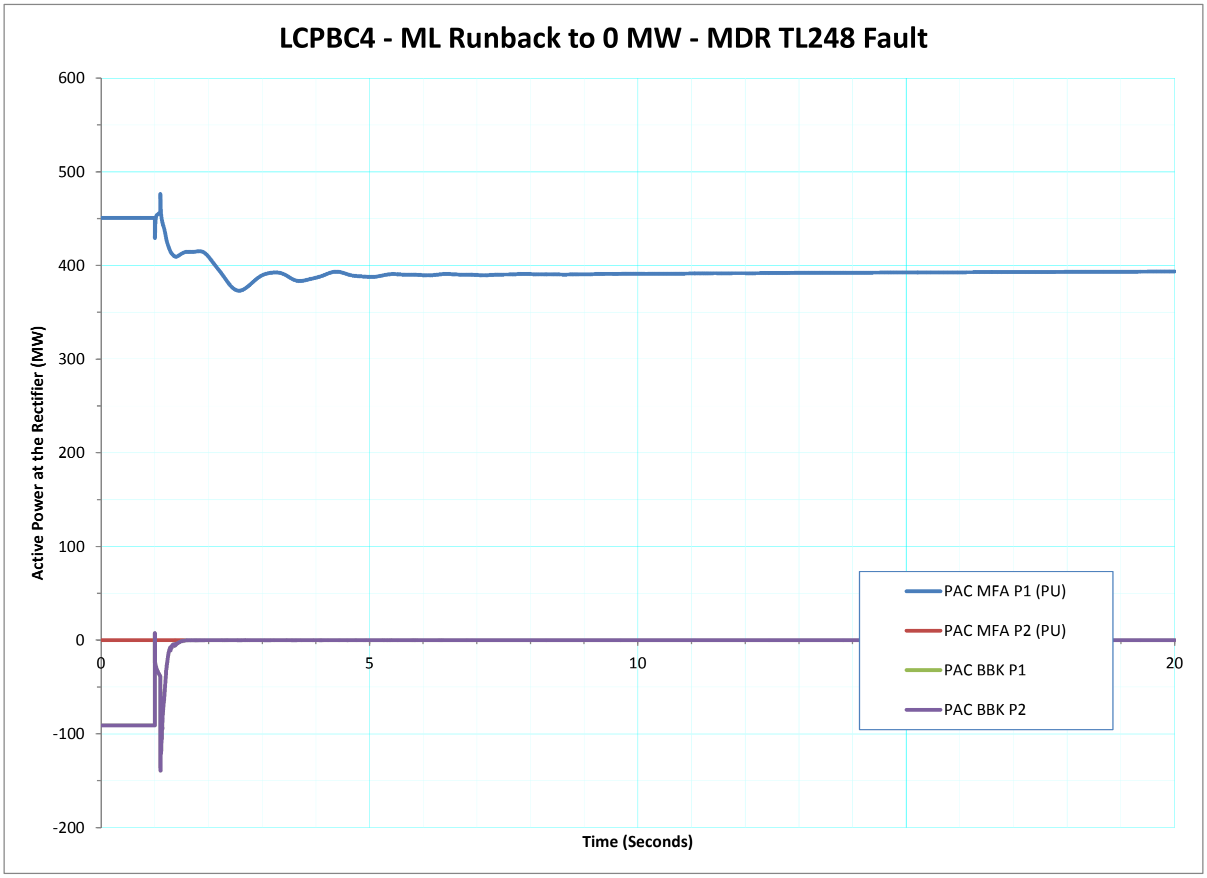


Figure 410 - LCPBC4 - ML Runback to 0 MW - MDR TL248 Fault - Active Power at the Rectifier (MW)

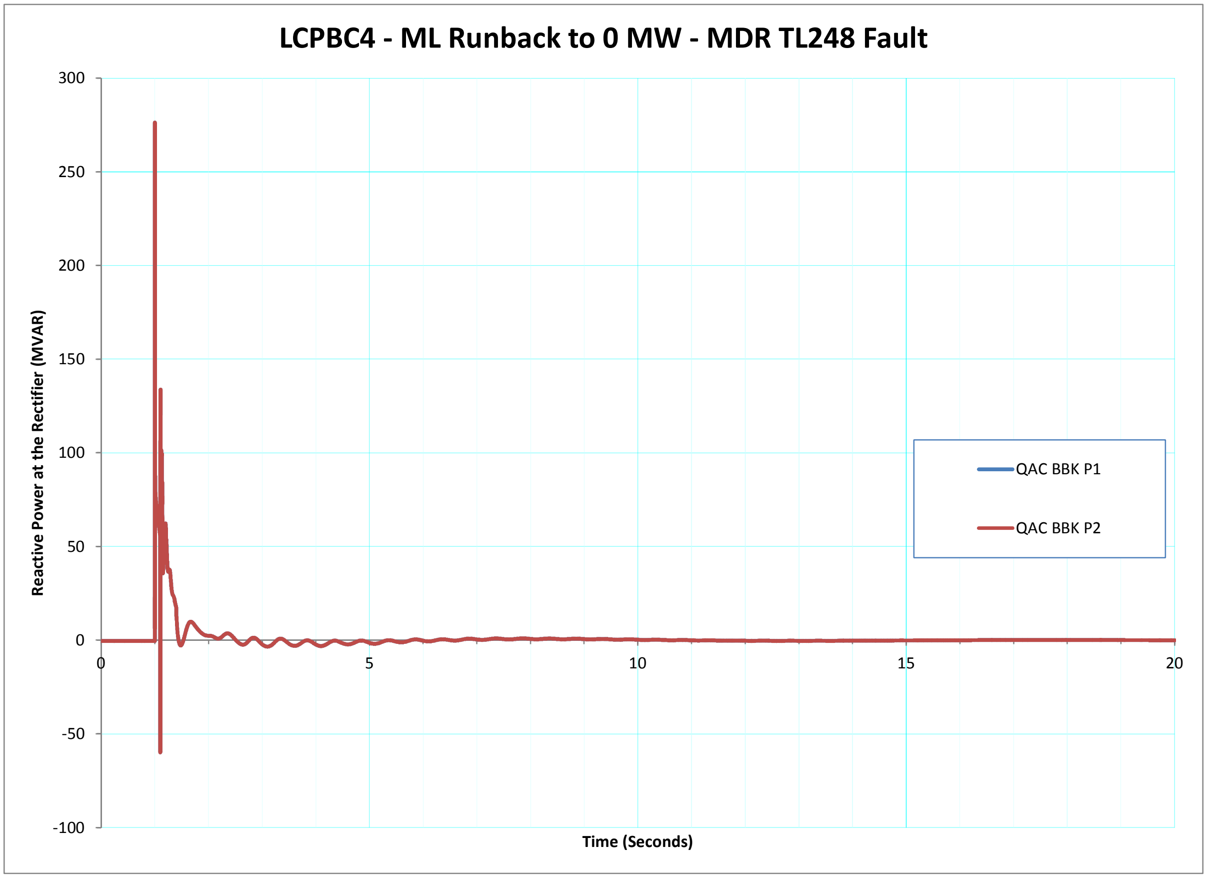


Figure 411 - LCPBC4 - ML Runback to 0 MW - MDR TL248 Fault - Reactive Power at the Rectifier (MVAR)

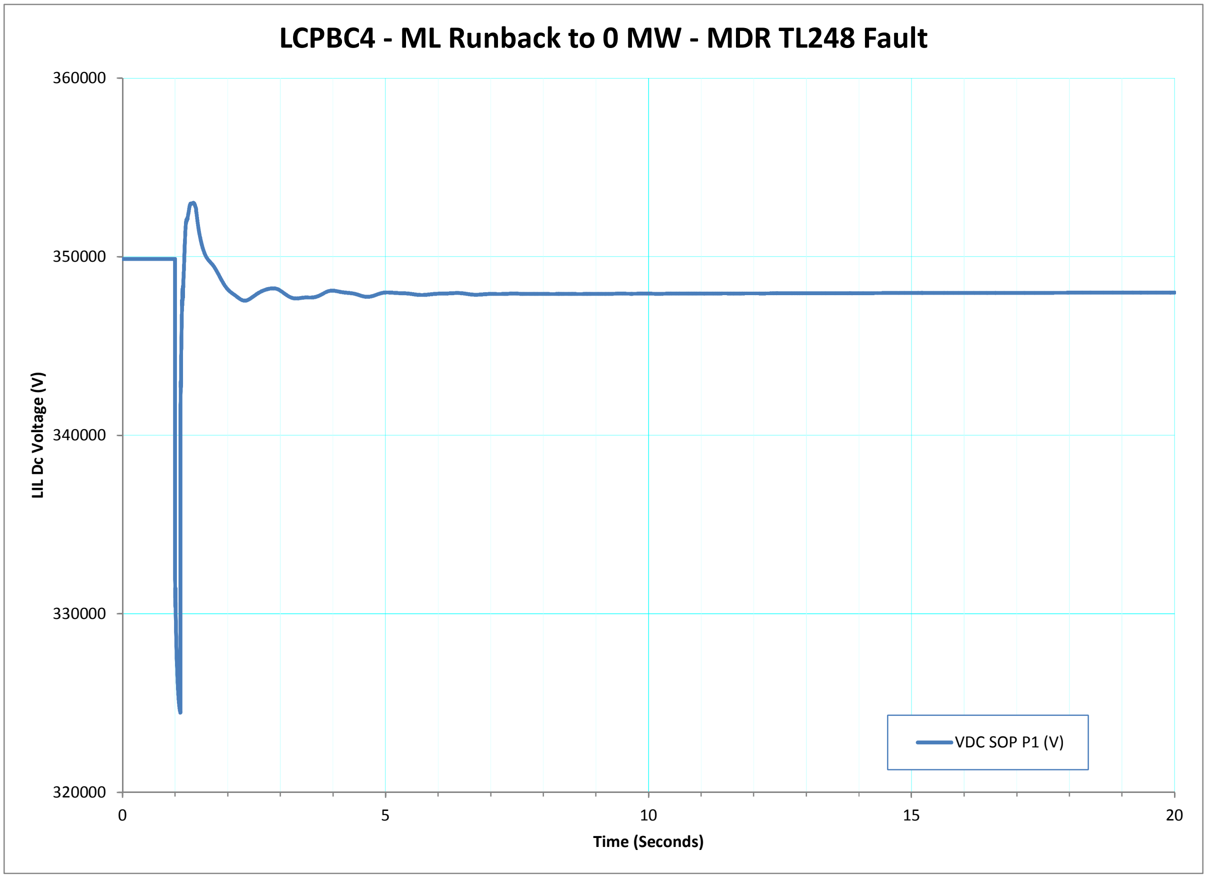


Figure 412 - LCPBC4 - ML Runback to 0 MW - MDR TL248 Fault - LIL Dc Voltage (V)

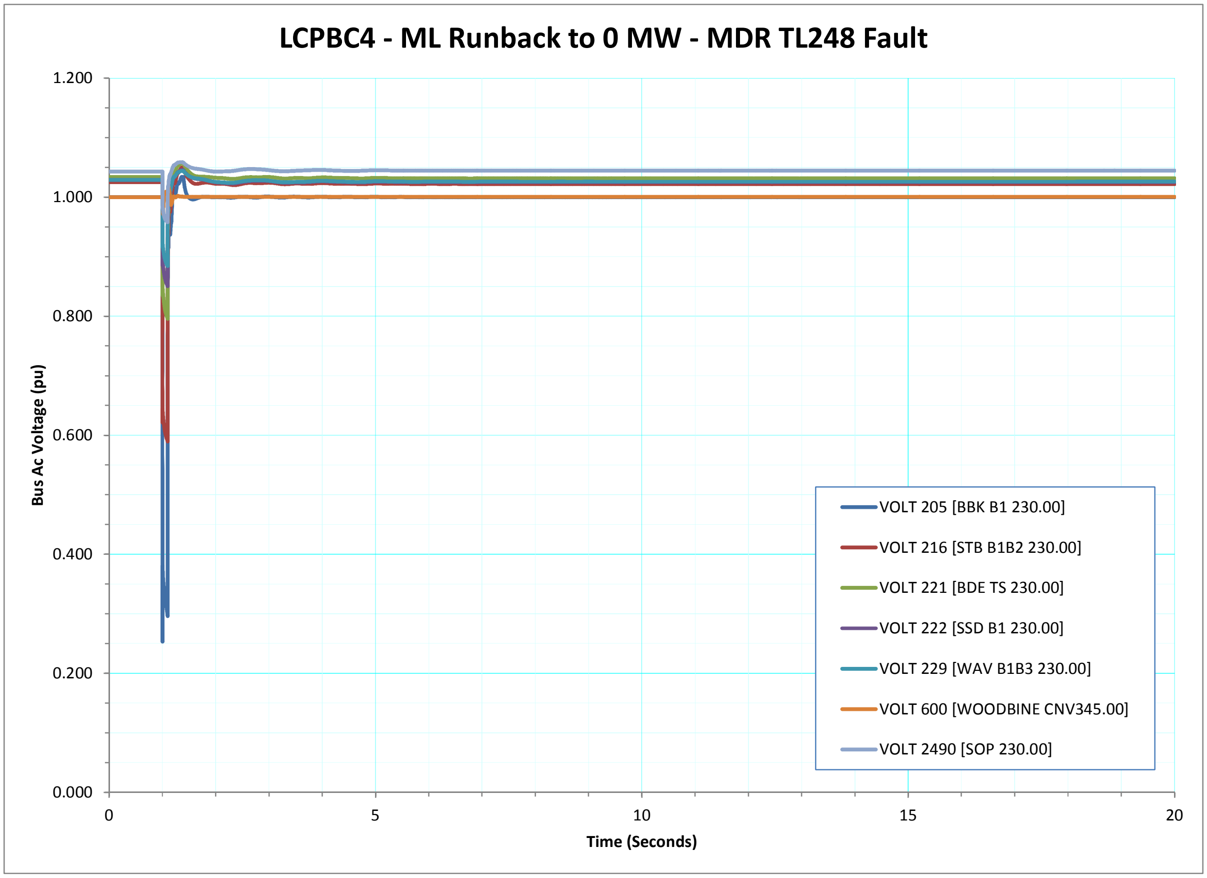


Figure 413 - LCPBC4 - ML Runback to 0 MW - MDR TL248 Fault - Bus Ac Voltage (pu)

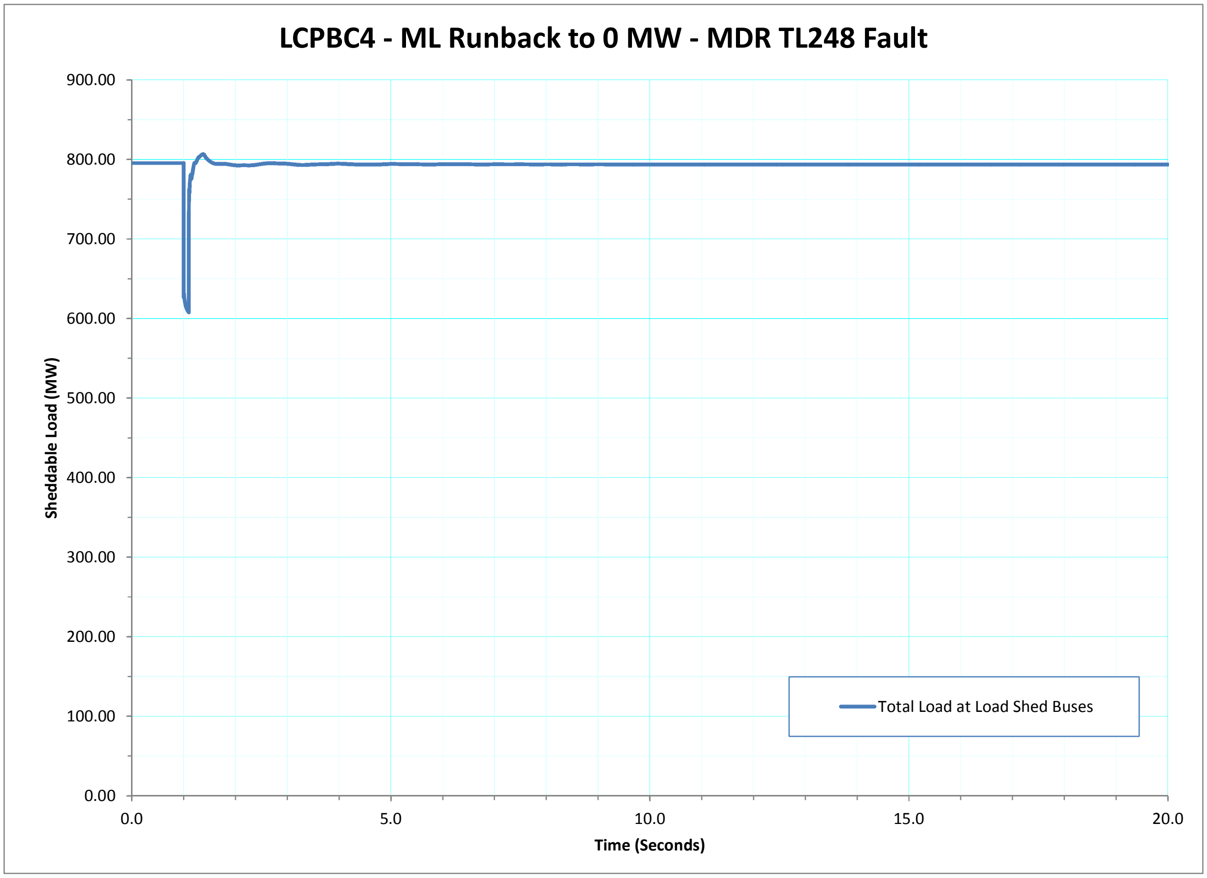


Figure 414 - LCPBC4 - ML Runback to 0 MW - MDR TL248 Fault - Sheddable Load (MW)

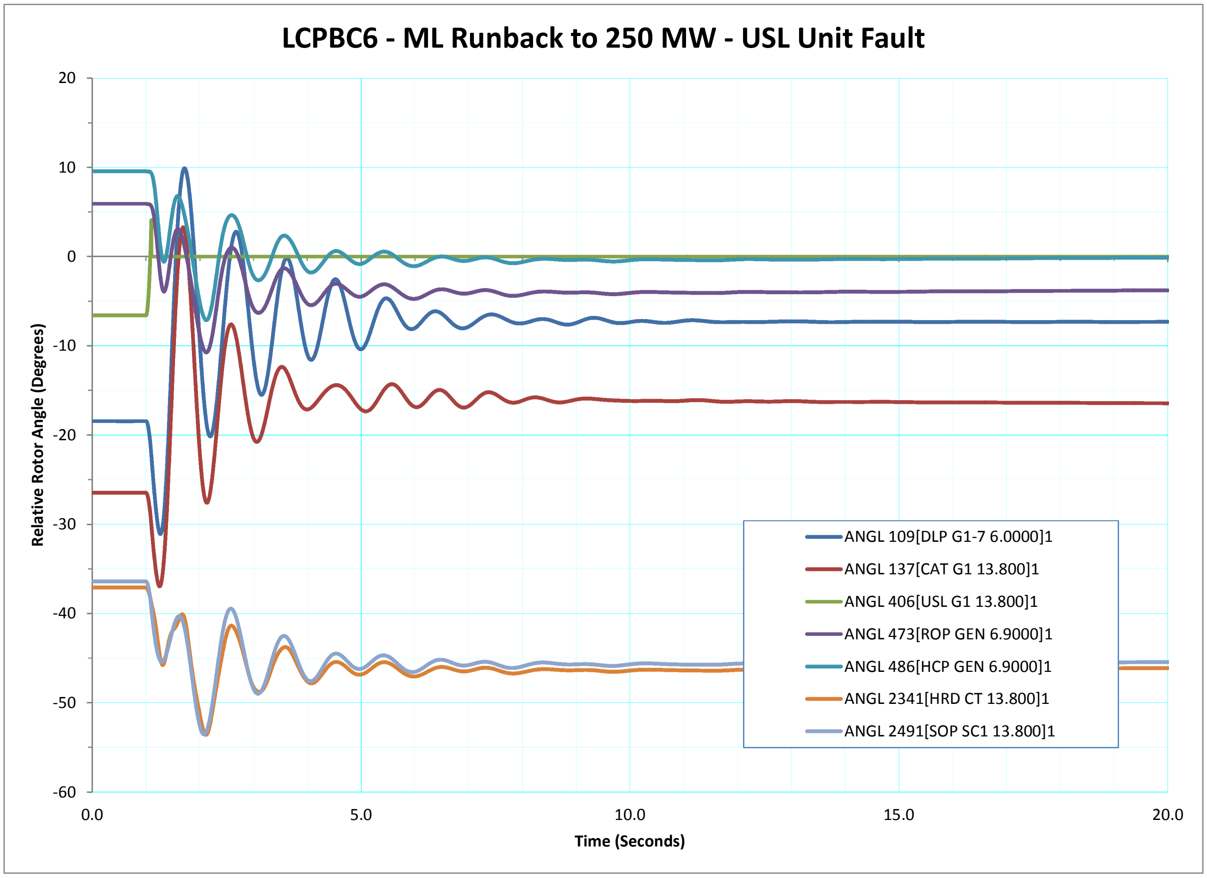


Figure 415 - LCPBC6 - ML Runback to 250 MW - USL Unit Fault - Relative Rotor Angle (Degrees)

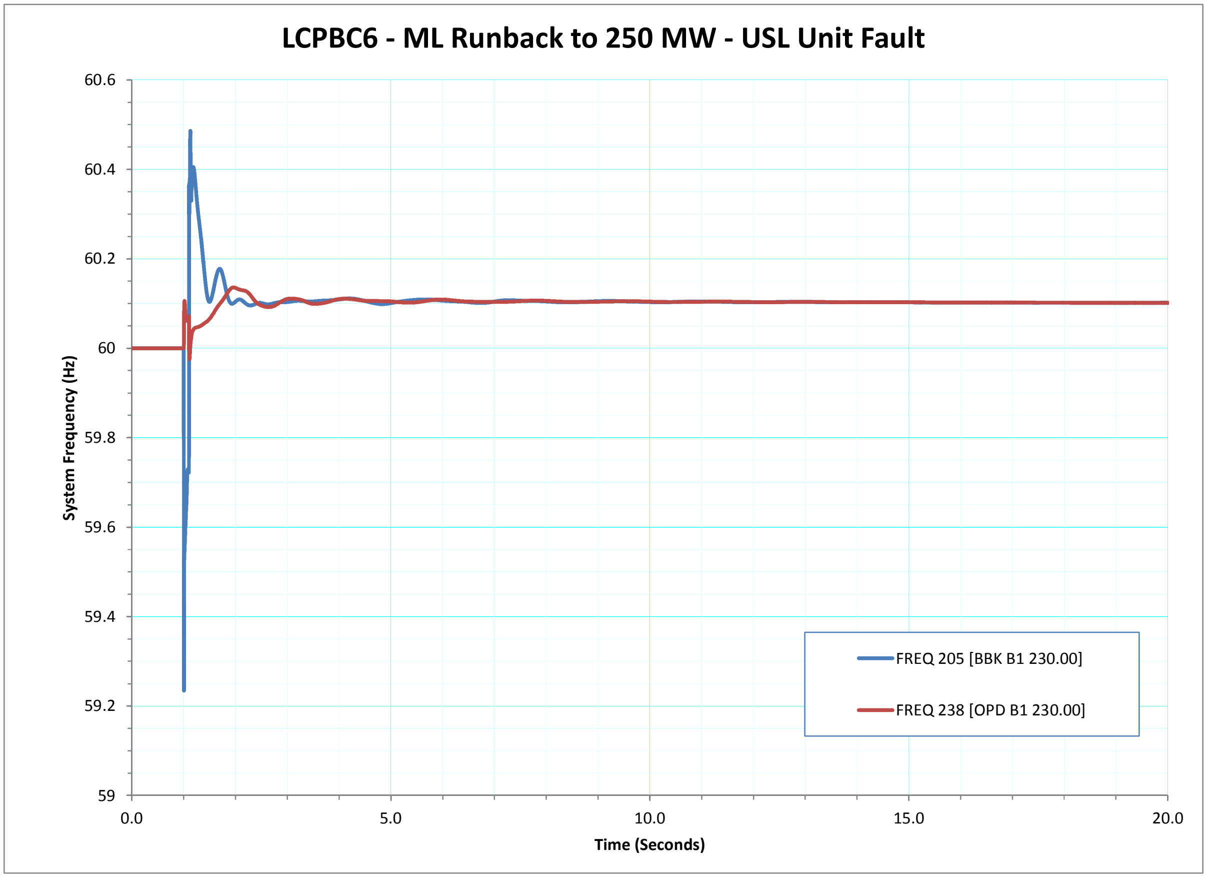


Figure 416 - LCPBC6 - ML Runback to 250 MW - USL Unit Fault - System Frequency (Hz)

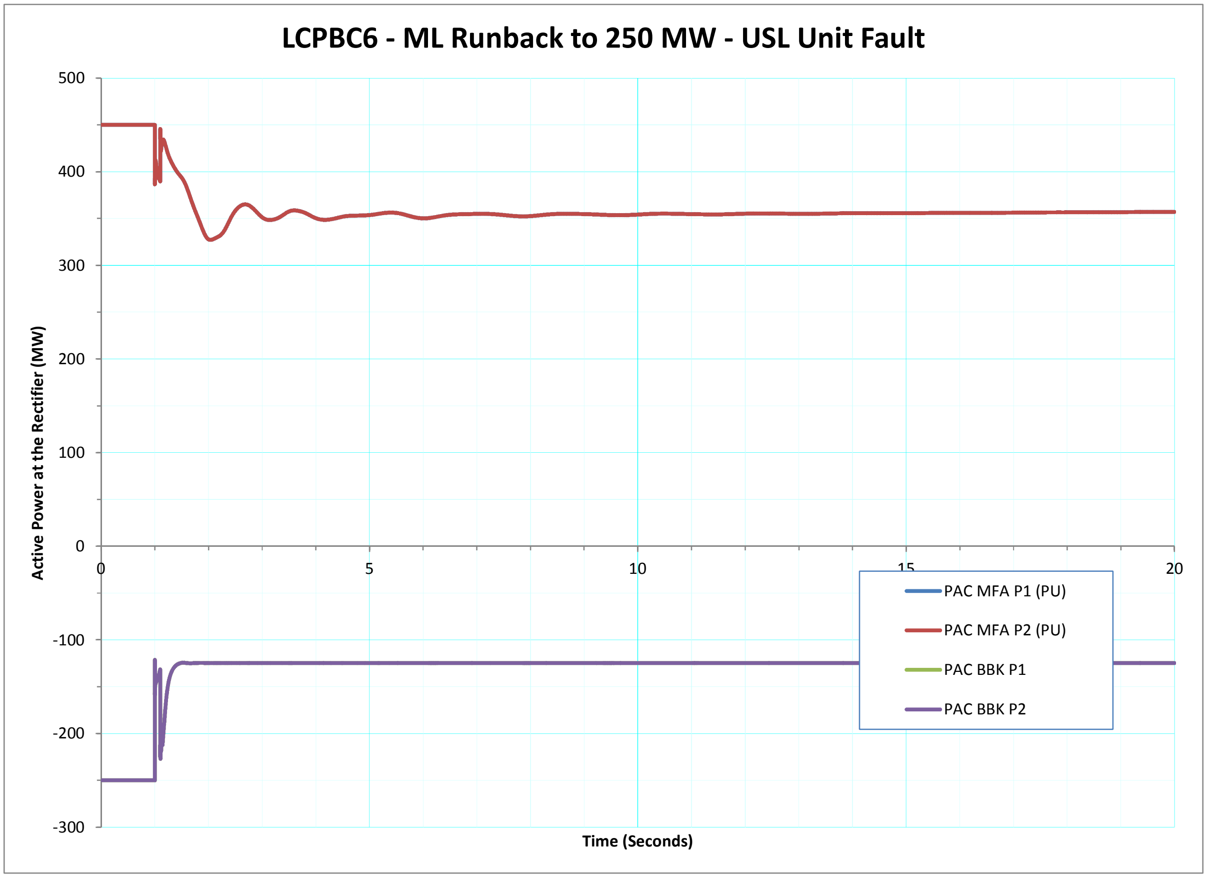


Figure 417 - LCPBC6 - ML Runback to 250 MW - USL Unit Fault - Active Power at the Rectifier (MW)

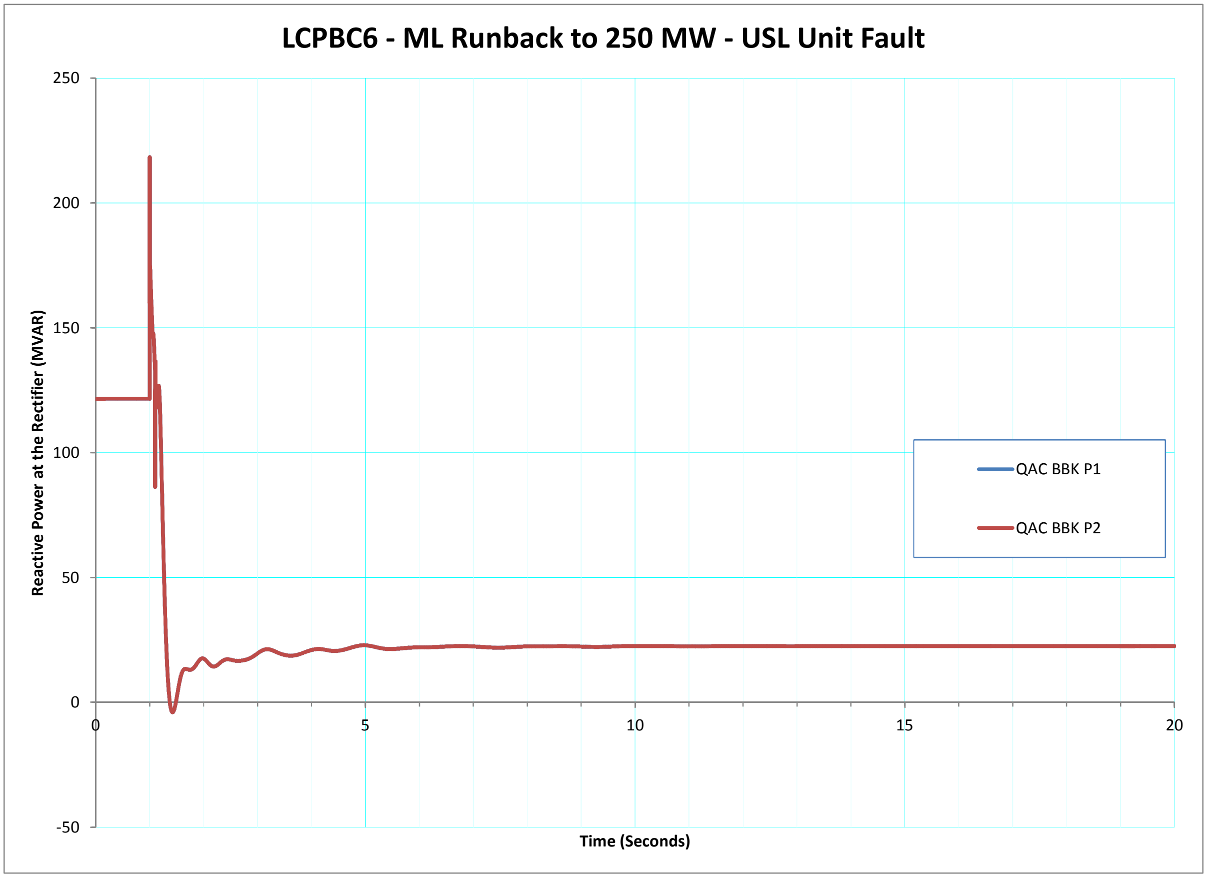


Figure 418 - LCPBC6 - ML Runback to 250 MW - USL Unit Fault - Reactive Power at the Rectifier (MVAR)

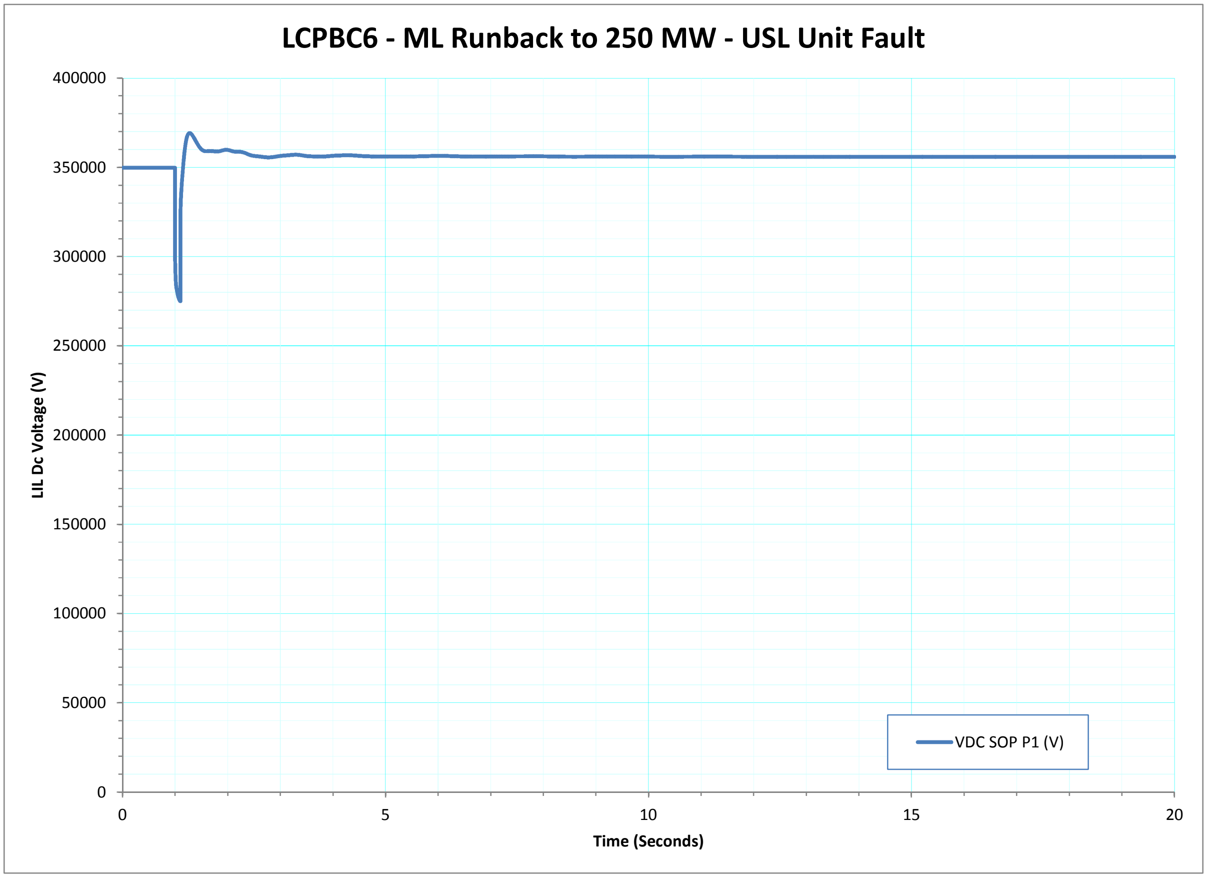


Figure 419 - LCPBC6 - ML Runback to 250 MW - USL Unit Fault - LIL Dc Voltage (V)

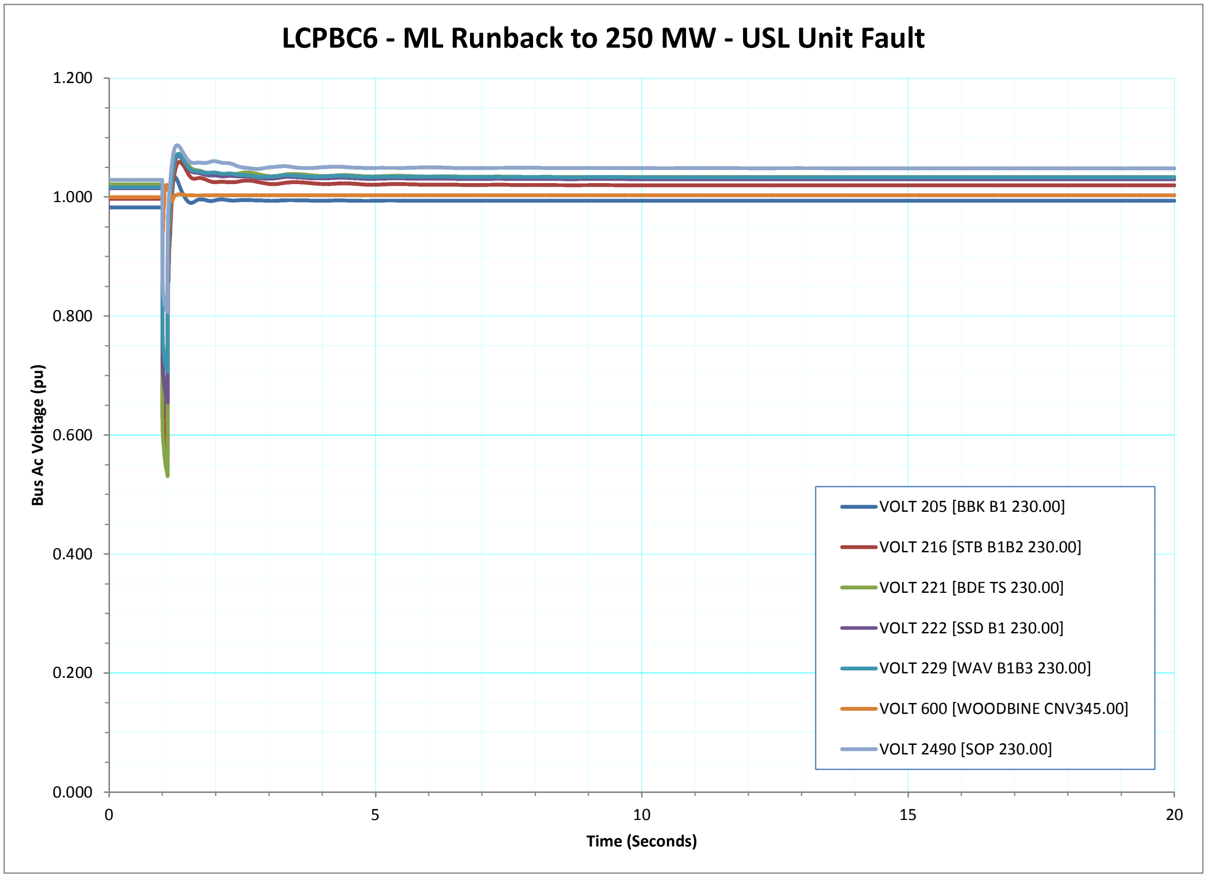


Figure 420 - LCPBC6 - ML Runback to 250 MW - USL Unit Fault - Bus Ac Voltage (pu)

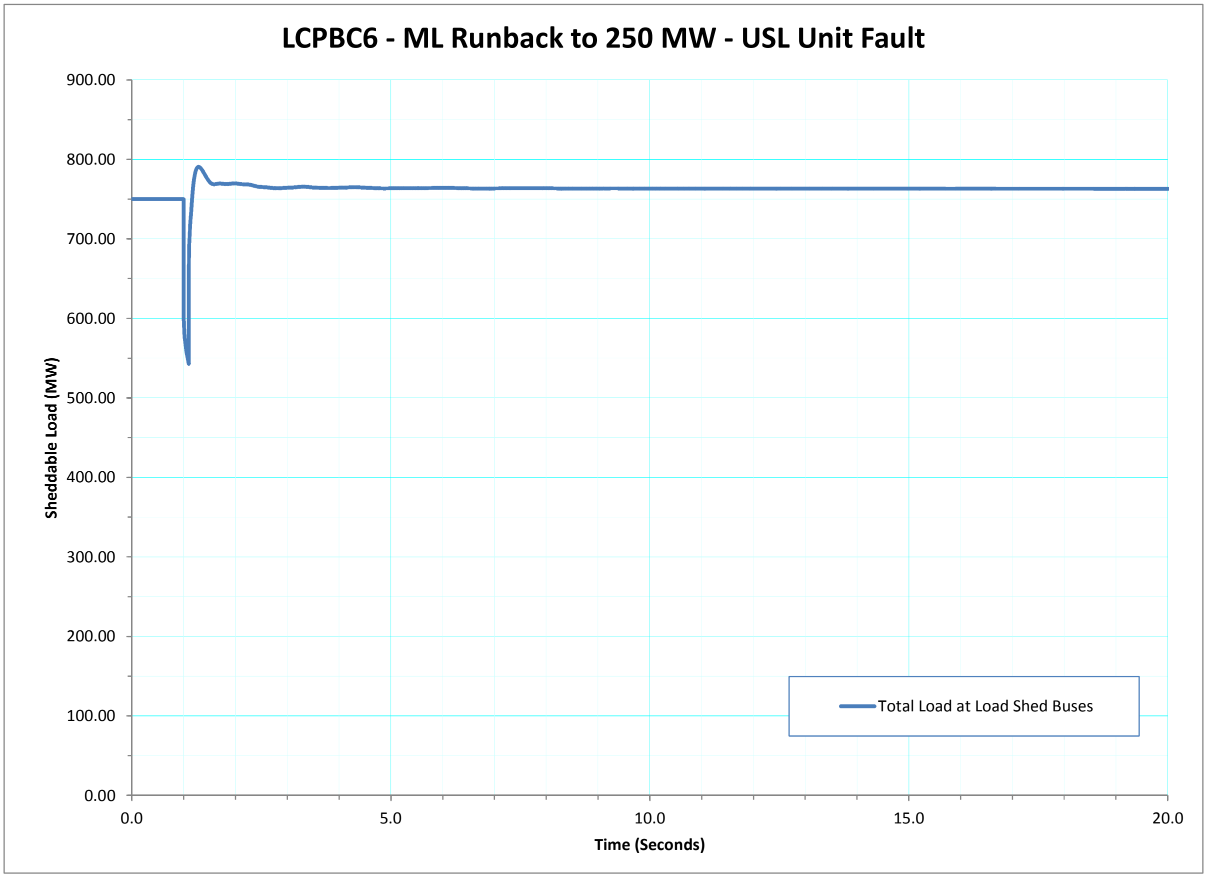


Figure 421 - LCPBC6 - ML Runback to 250 MW - USL Unit Fault - Sheddable Load (MW)

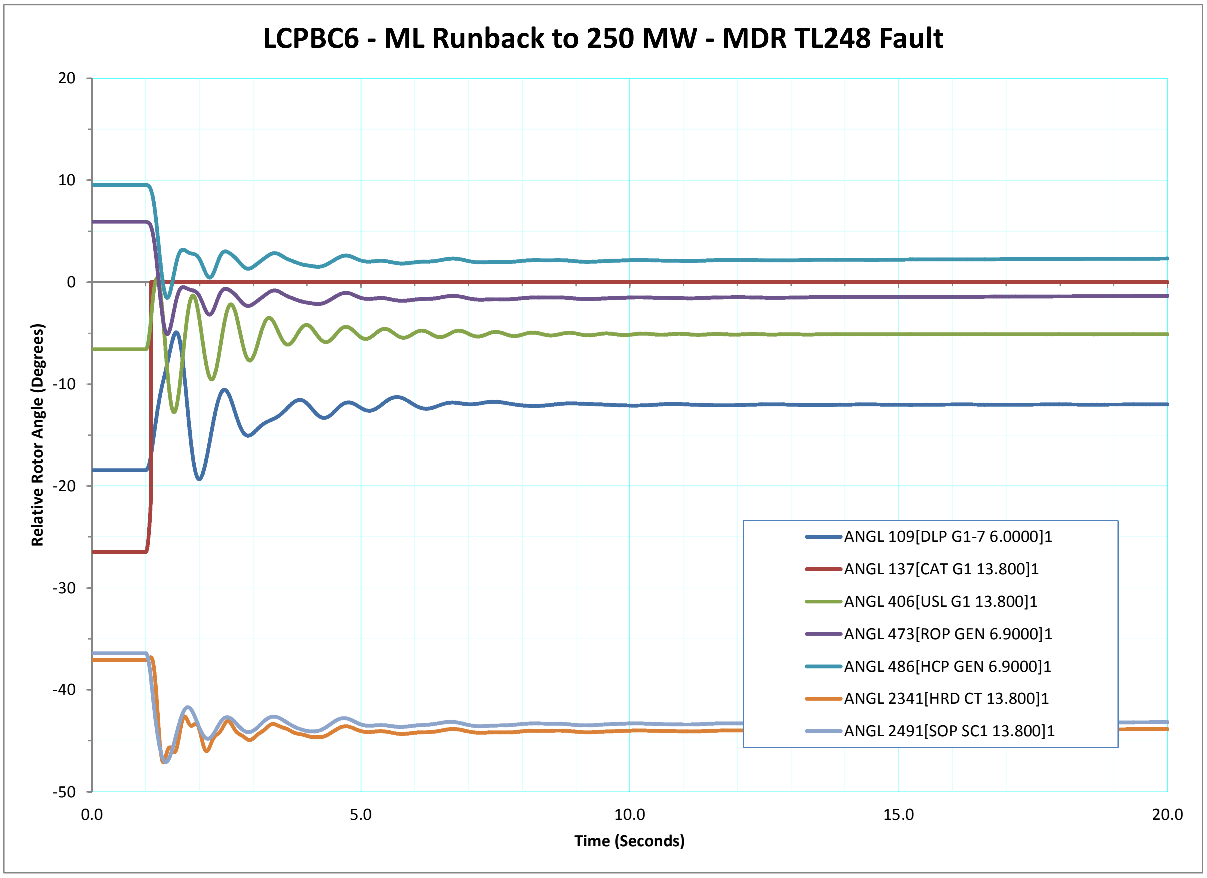


Figure 422 - LCPBC6 - ML Runback to 250 MW - MDR TL248 Fault - Relative Rotor Angle (Degrees)

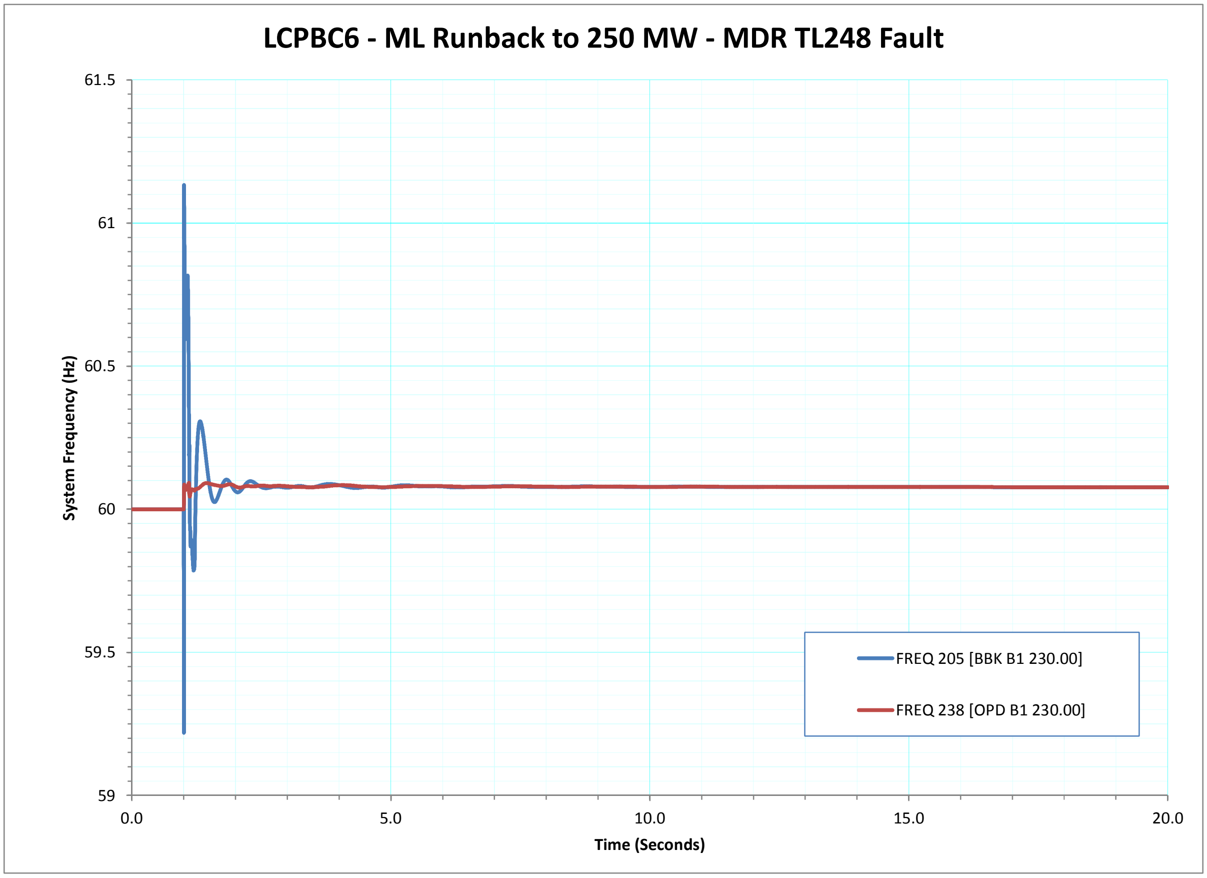


Figure 423 - LCPBC6 - ML Runback to 250 MW - MDR TL248 Fault - System Frequency (Hz)

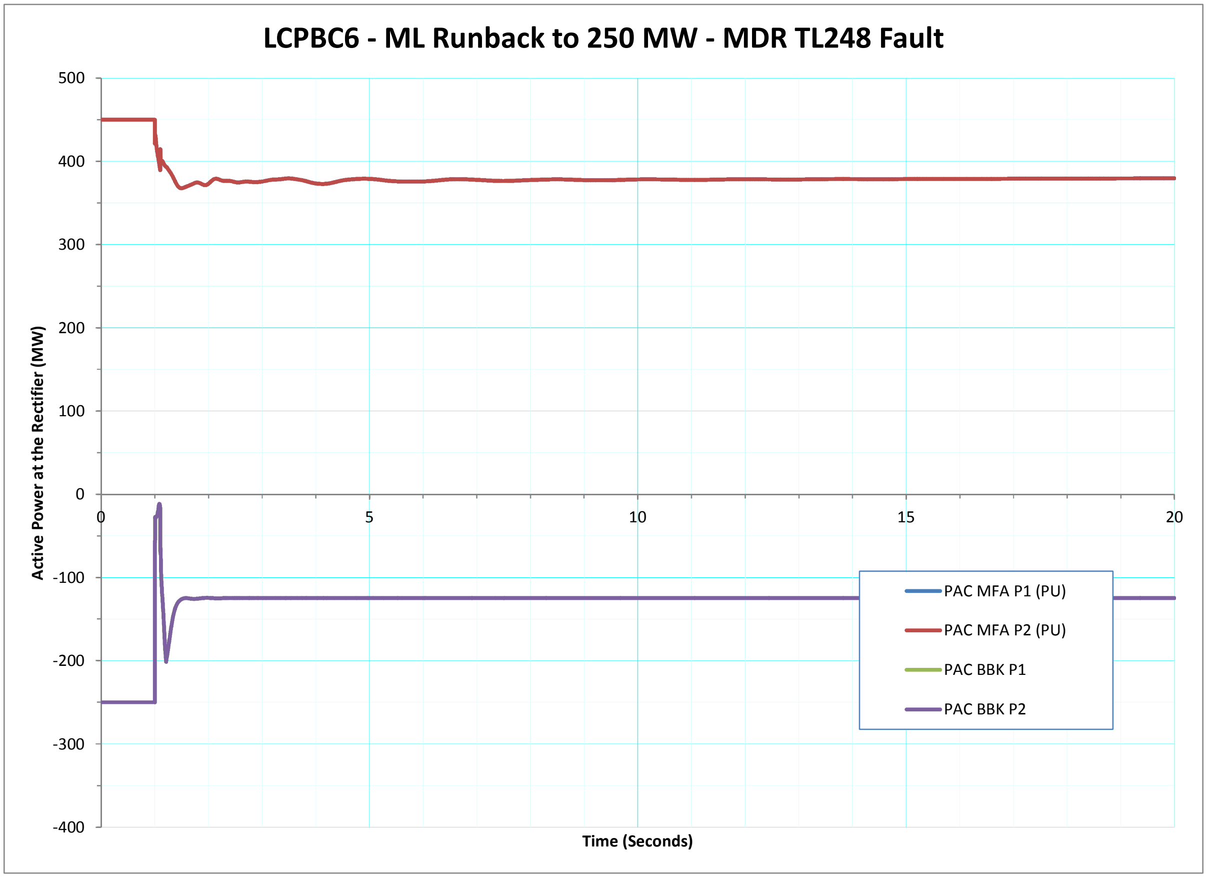


Figure 424 - LCPBC6 - ML Runback to 250 MW - MDR TL248 Fault - Active Power at the Rectifier (MW)

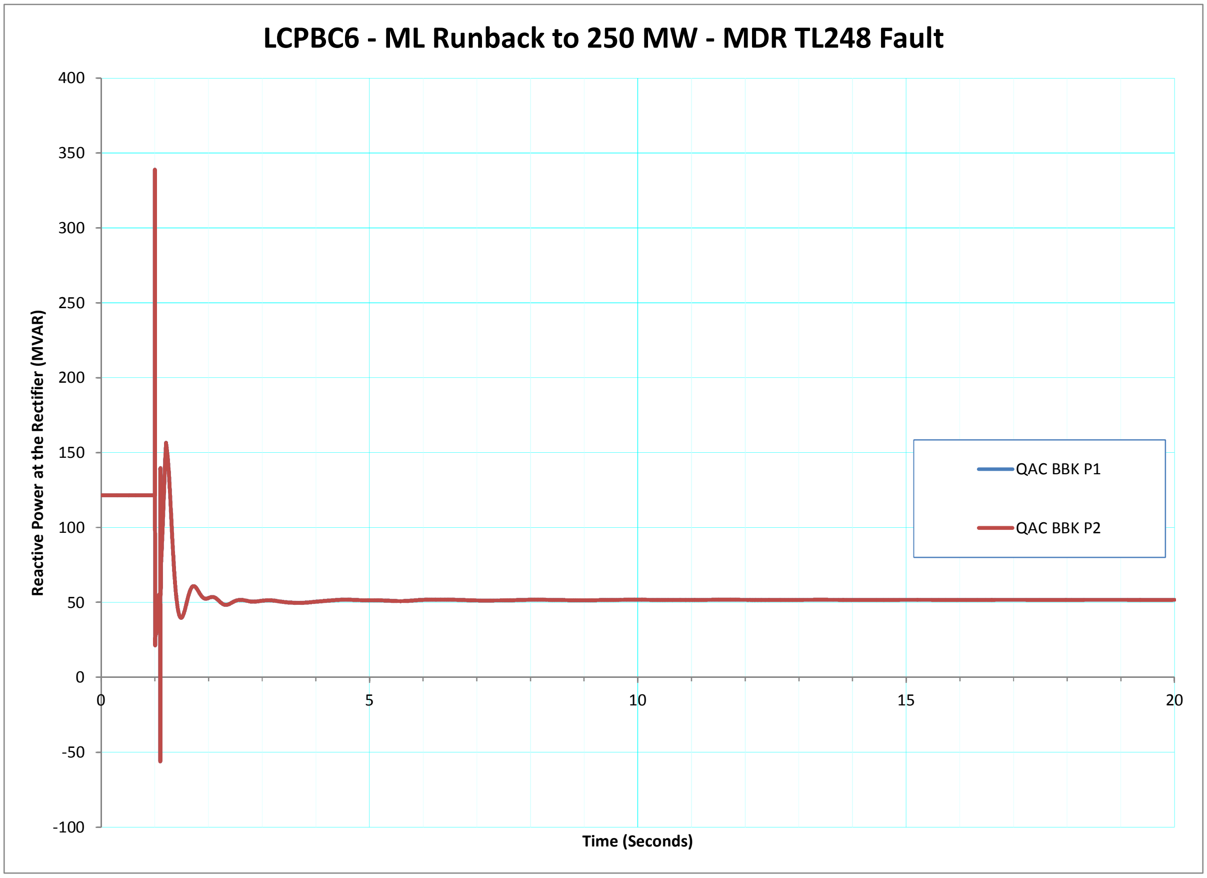


Figure 425 - LCPBC6 - ML Runback to 250 MW - MDR TL248 Fault - Reactive Power at the Rectifier (MVAR)

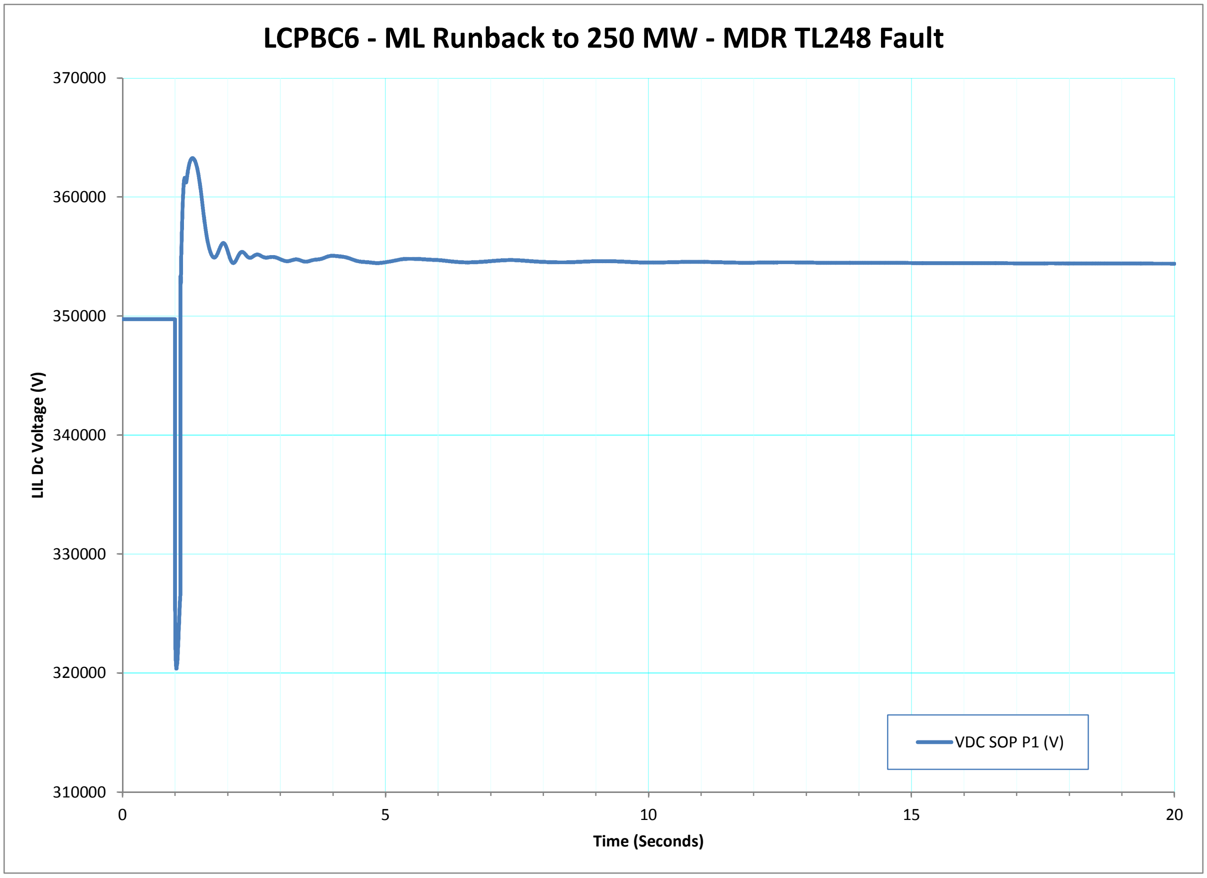


Figure 426 - LCPBC6 - ML Runback to 250 MW - MDR TL248 Fault - LIL Dc Voltage (V)

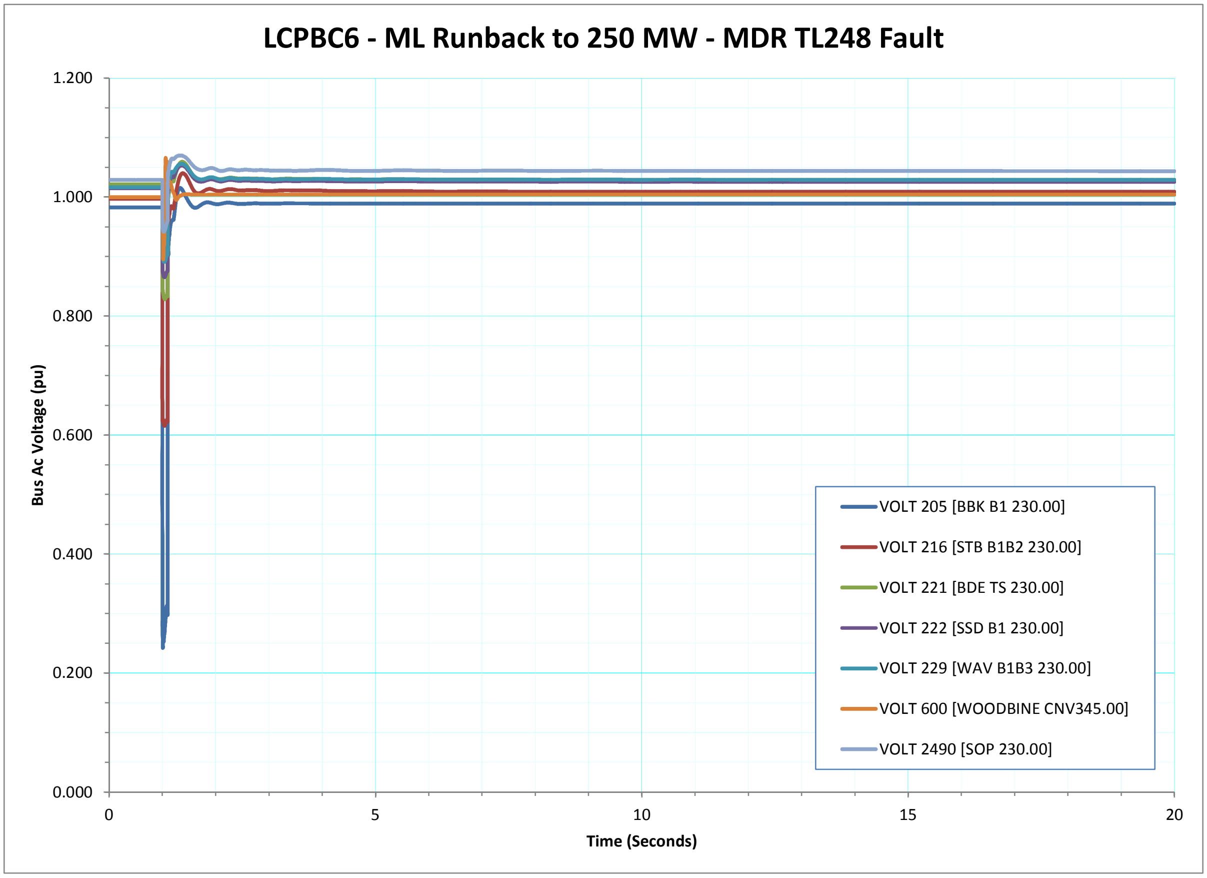


Figure 427 - LCPBC6 - ML Runback to 250 MW - MDR TL248 Fault - Bus Ac Voltage (pu)

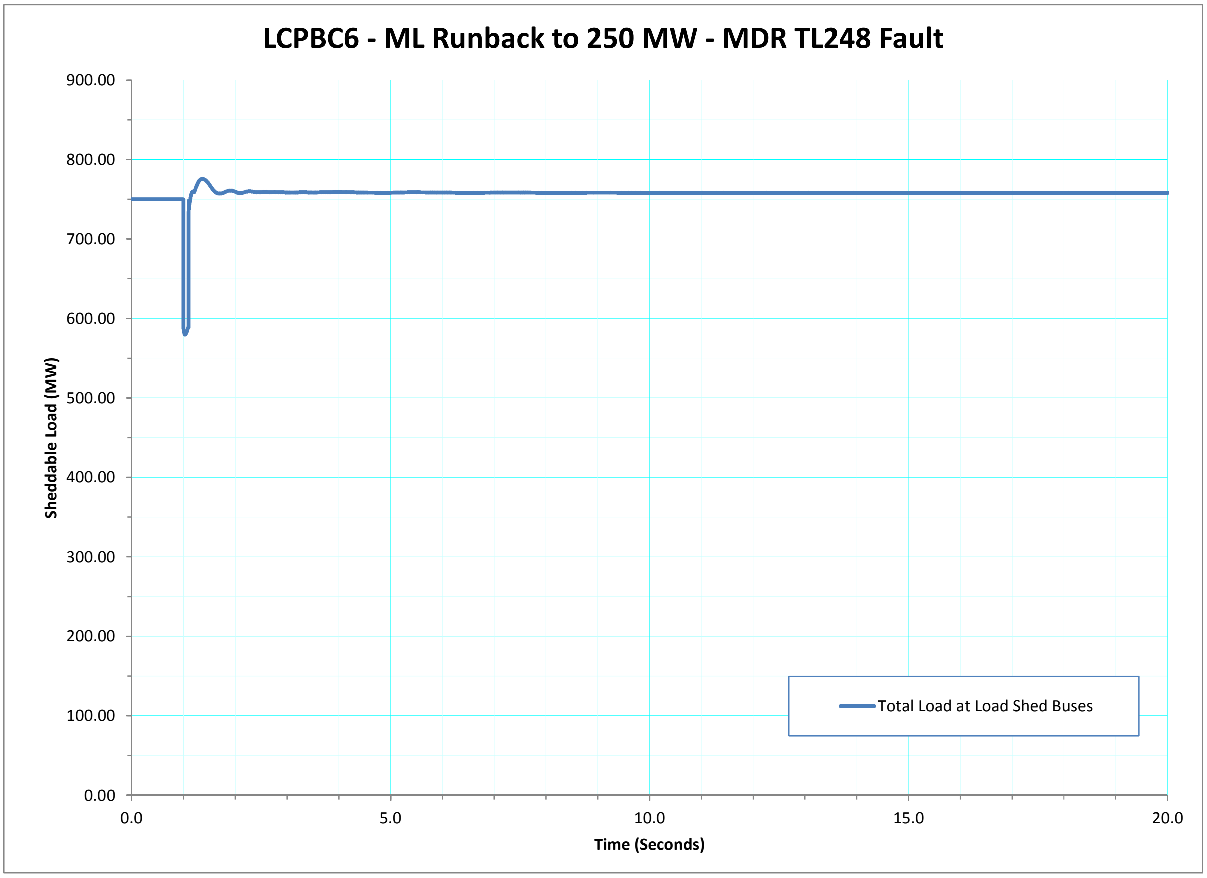


Figure 428 - LCPBC6 - ML Runback to 250 MW - MDR TL248 Fault - Sheddable Load (MW)

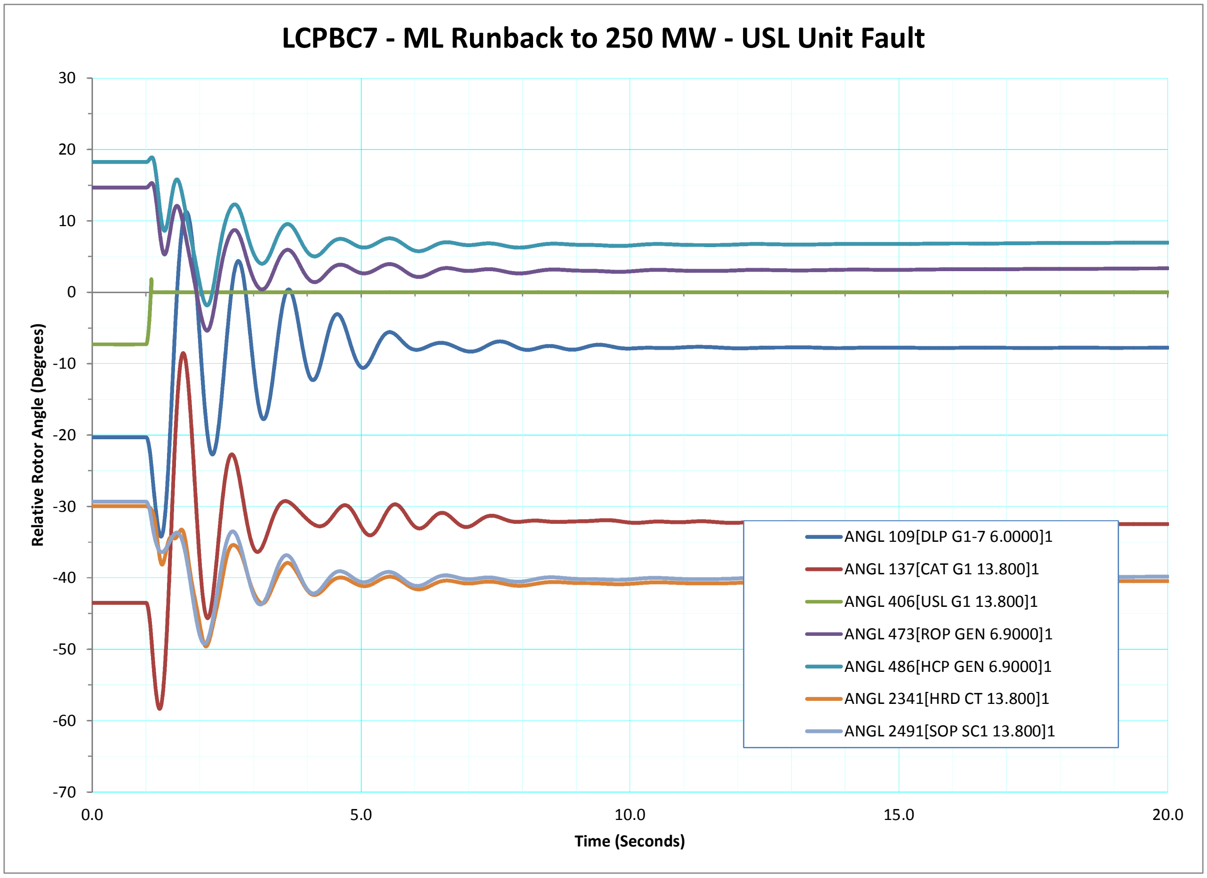


Figure 429 - LCPBC7 - ML Runback to 250 MW - USL Unit Fault - Relative Rotor Angle (Degrees)

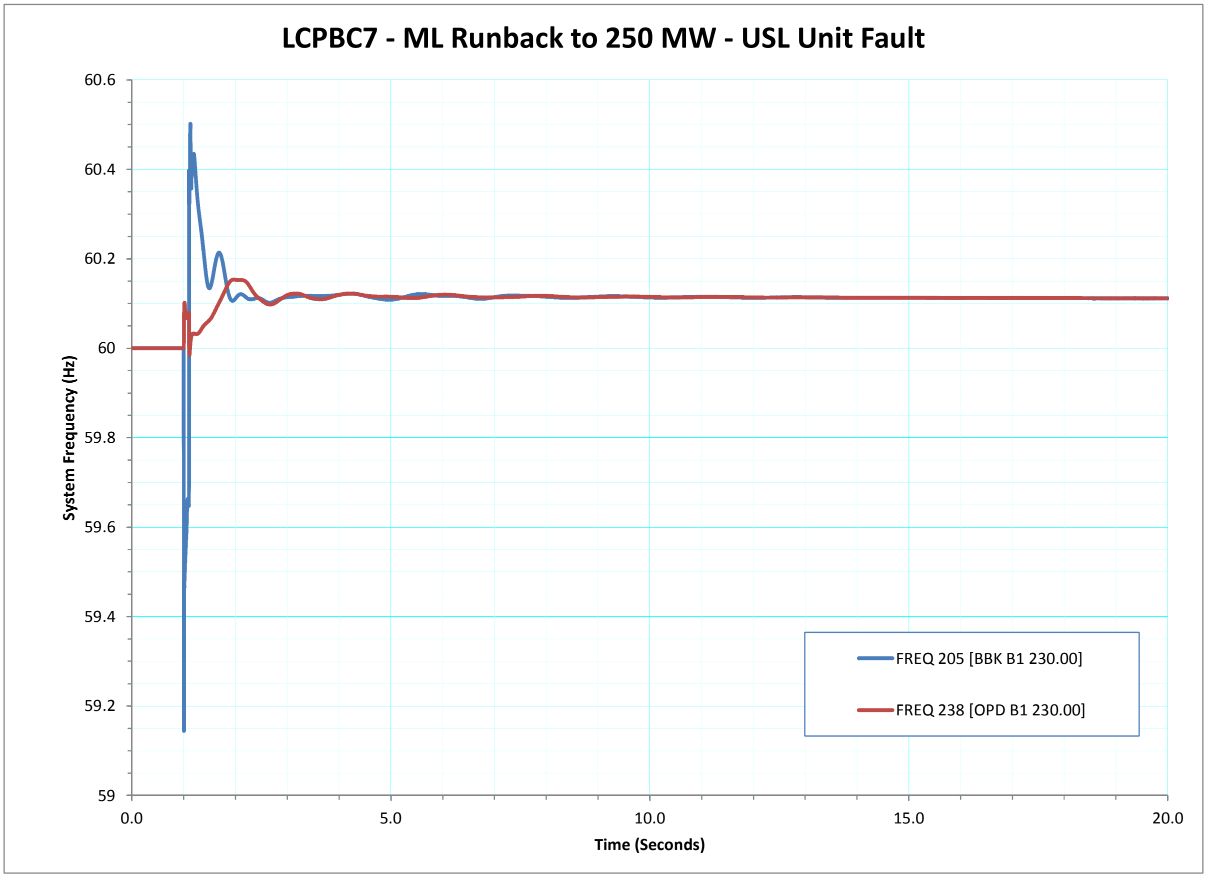


Figure 430 - LCPBC7 - ML Runback to 250 MW - USL Unit Fault - System Frequency (Hz)

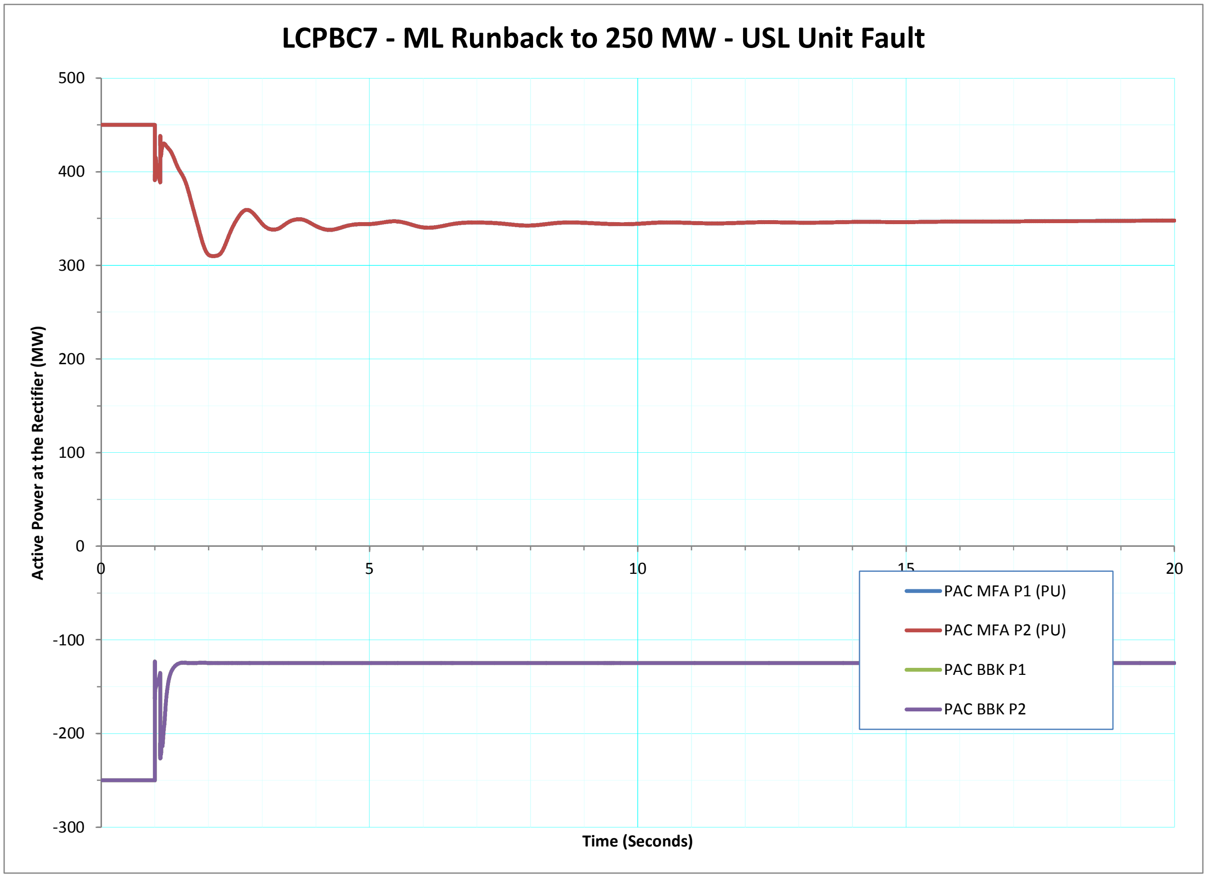


Figure 431 - LCPBC7 - ML Runback to 250 MW - USL Unit Fault - Active Power at the Rectifier (MW)

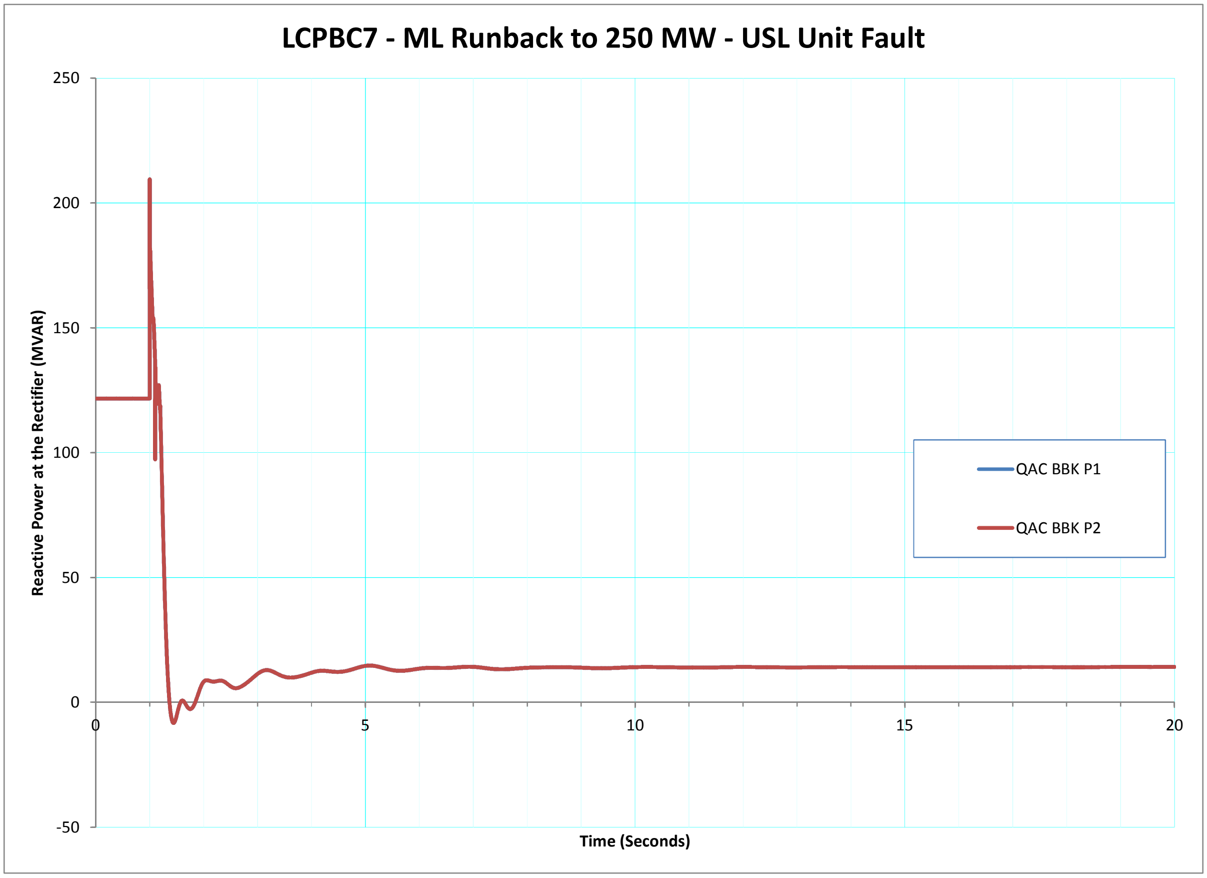


Figure 432 - LCPBC7 - ML Runback to 250 MW - USL Unit Fault - Reactive Power at the Rectifier (MVAR)

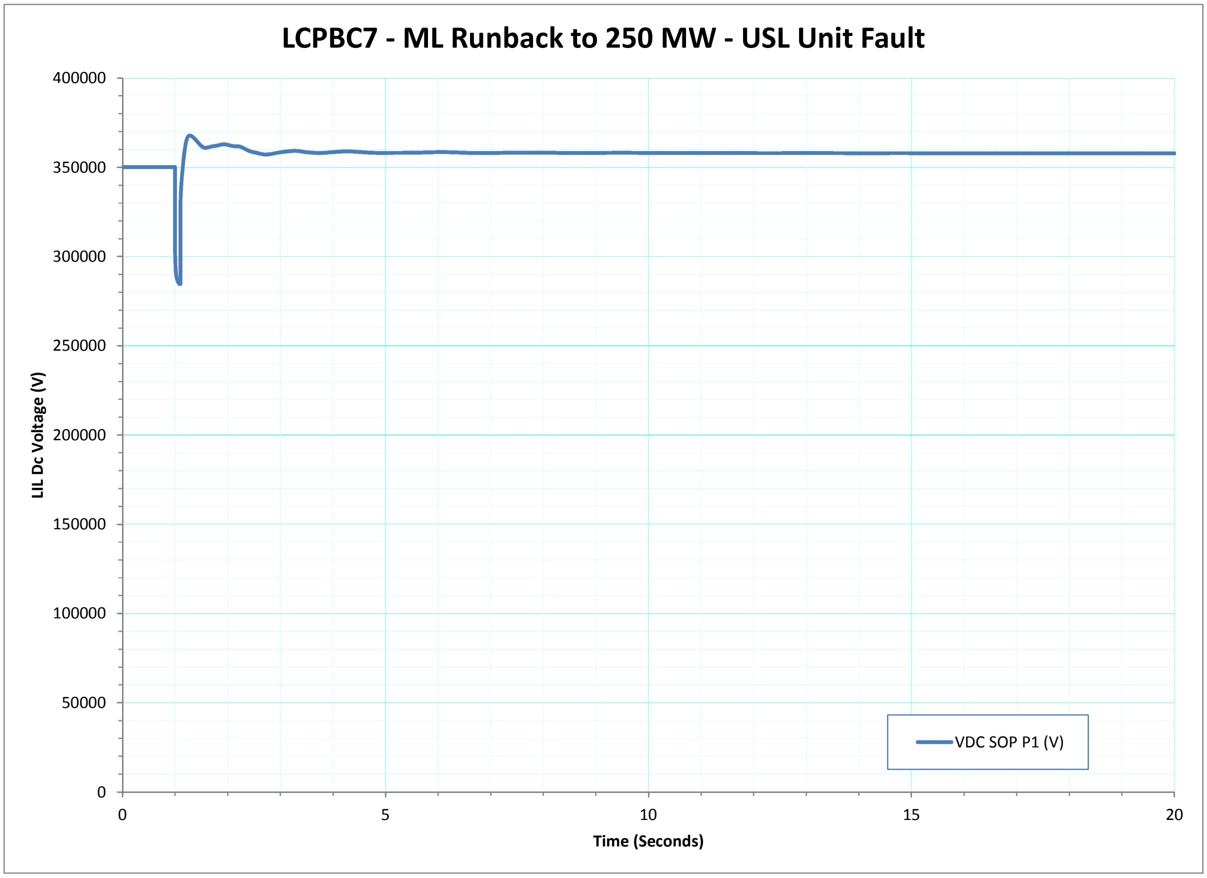


Figure 433 - LCPBC7 - ML Runback to 250 MW - USL Unit Fault - LIL Dc Voltage (V)

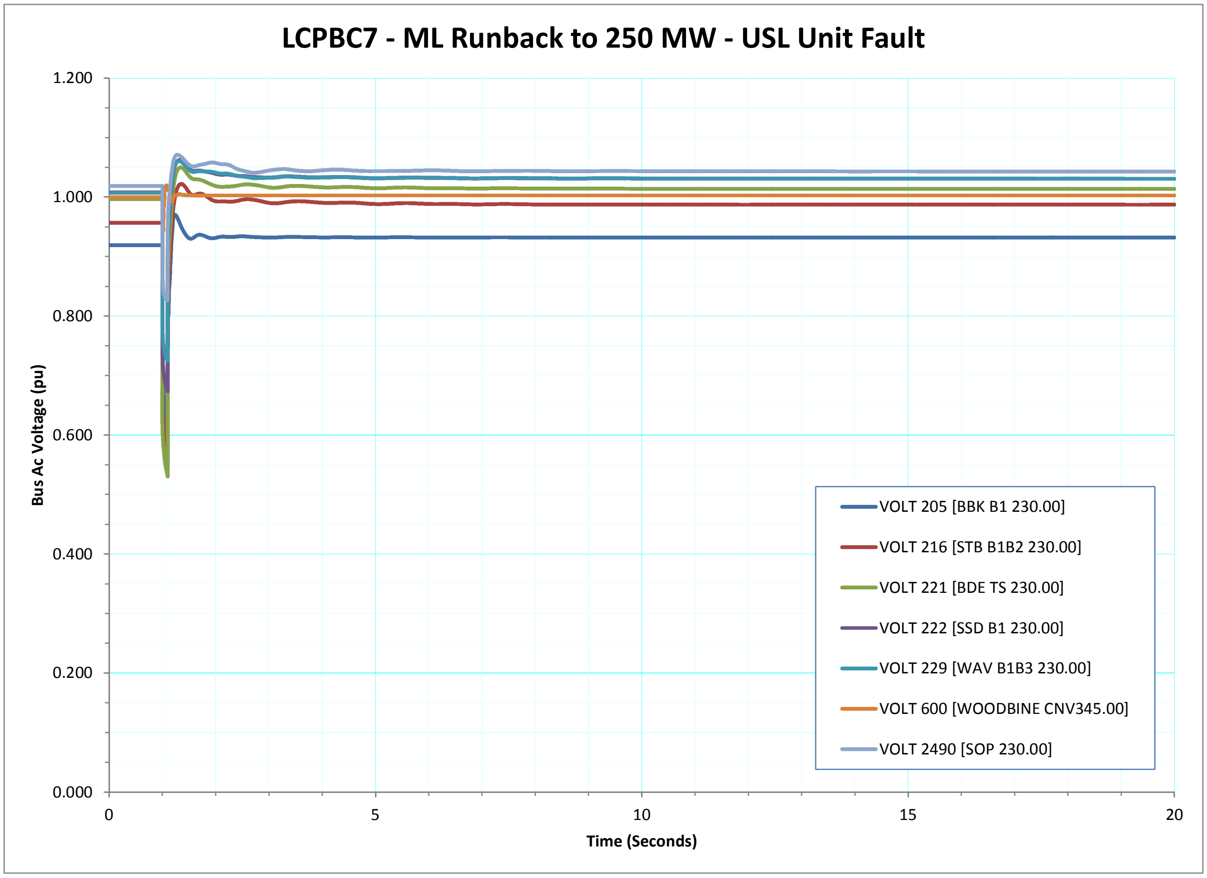


Figure 434 - LCPBC7 - ML Runback to 250 MW - USL Unit Fault - Bus Ac Voltage (pu)

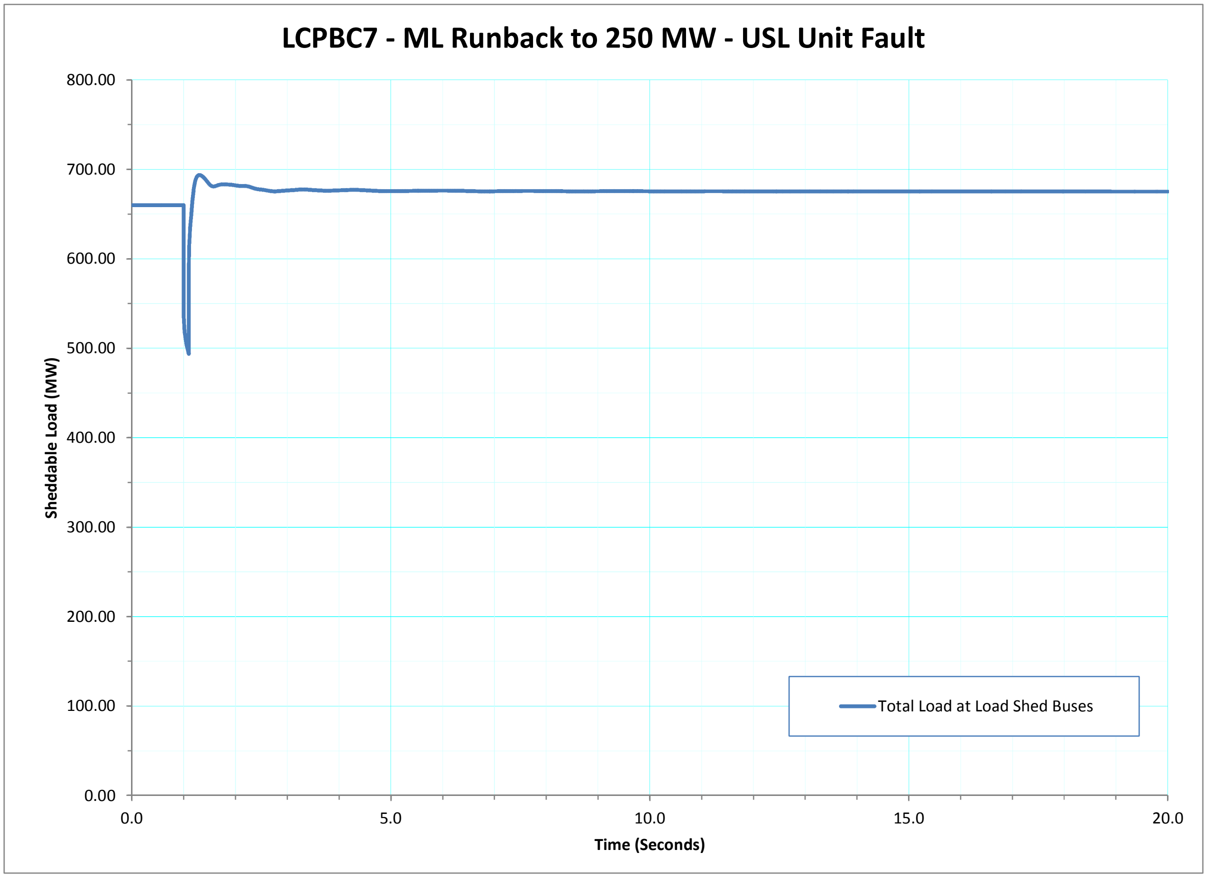


Figure 435 - LCPBC7 - ML Runback to 250 MW - USL Unit Fault - Sheddable Load (MW)

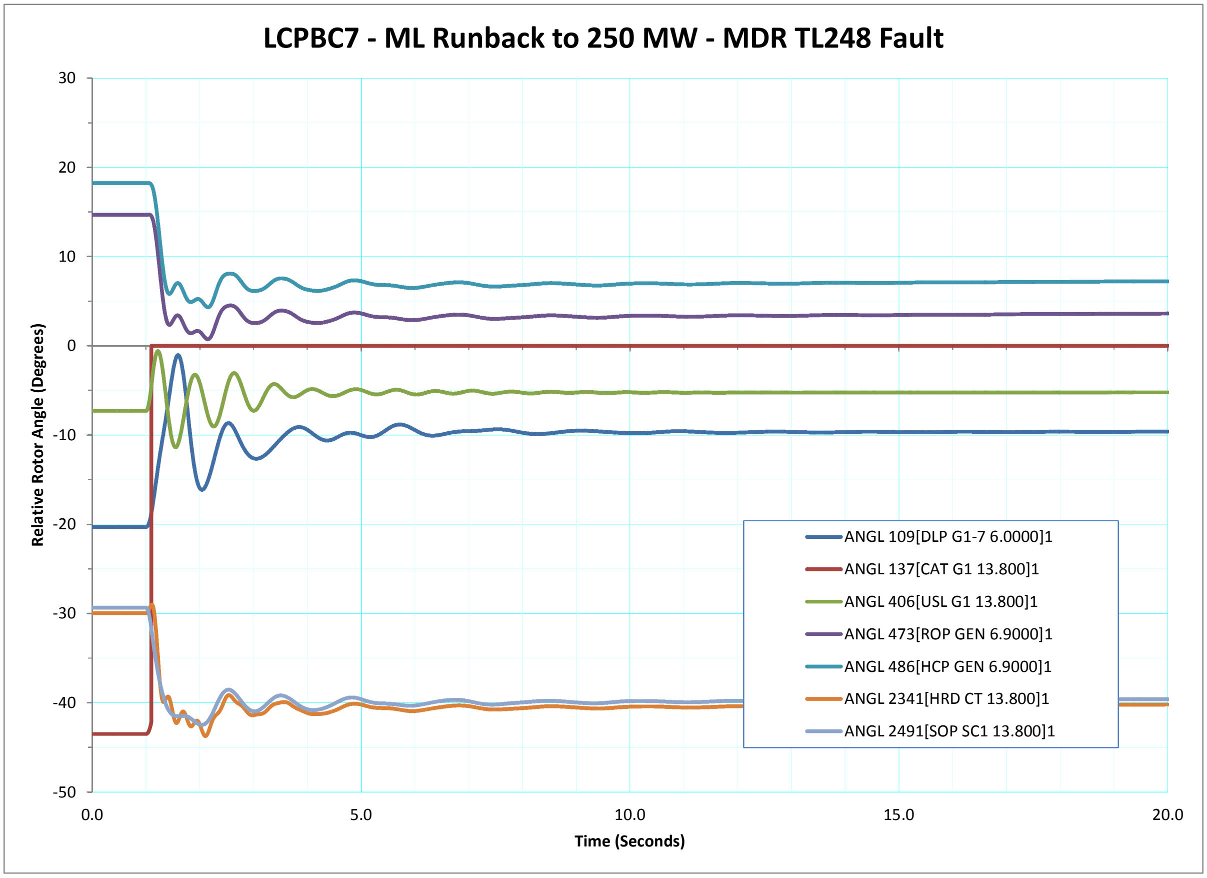


Figure 436 - LCPBC7 - ML Runback to 250 MW - MDR TL248 Fault - Relative Rotor Angle (Degrees)

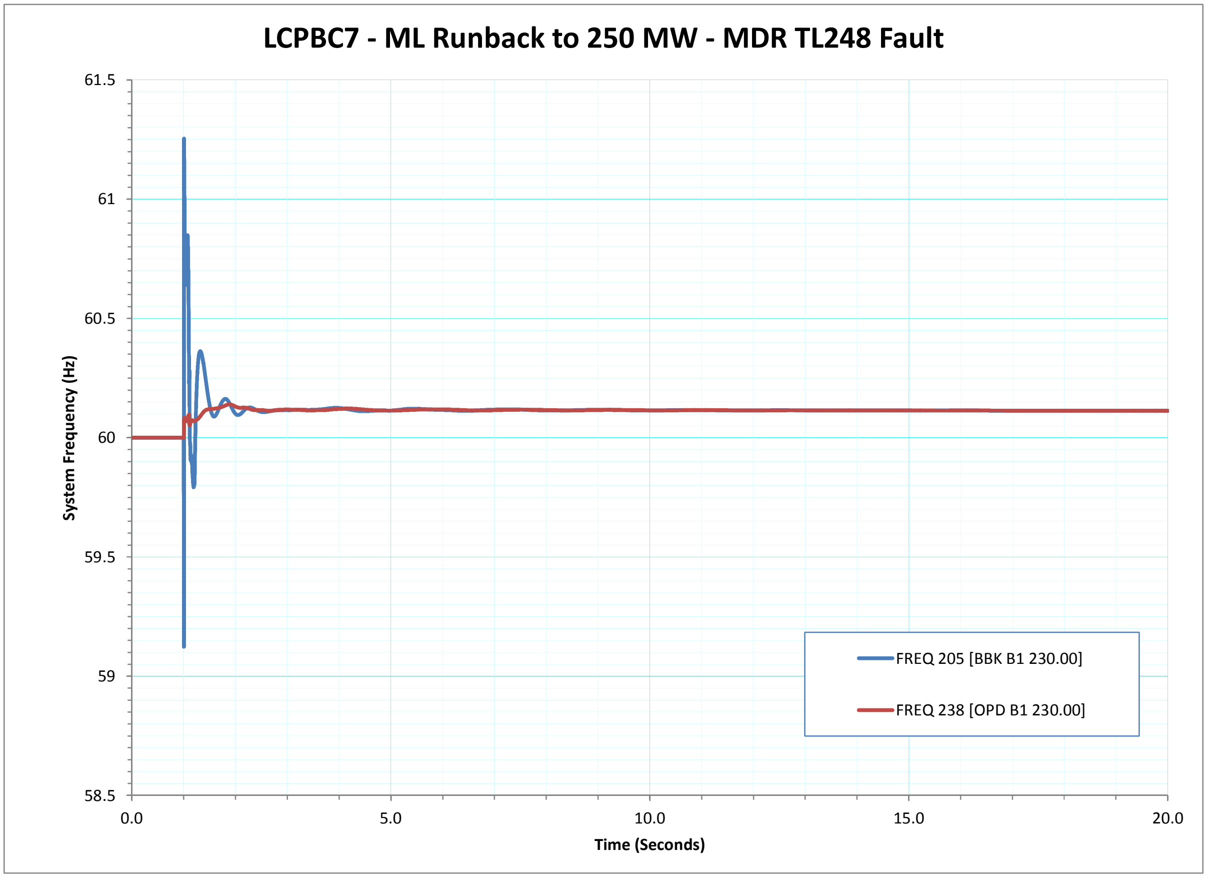


Figure 437 - LCPBC7 - ML Runback to 250 MW - MDR TL248 Fault - System Frequency (Hz)

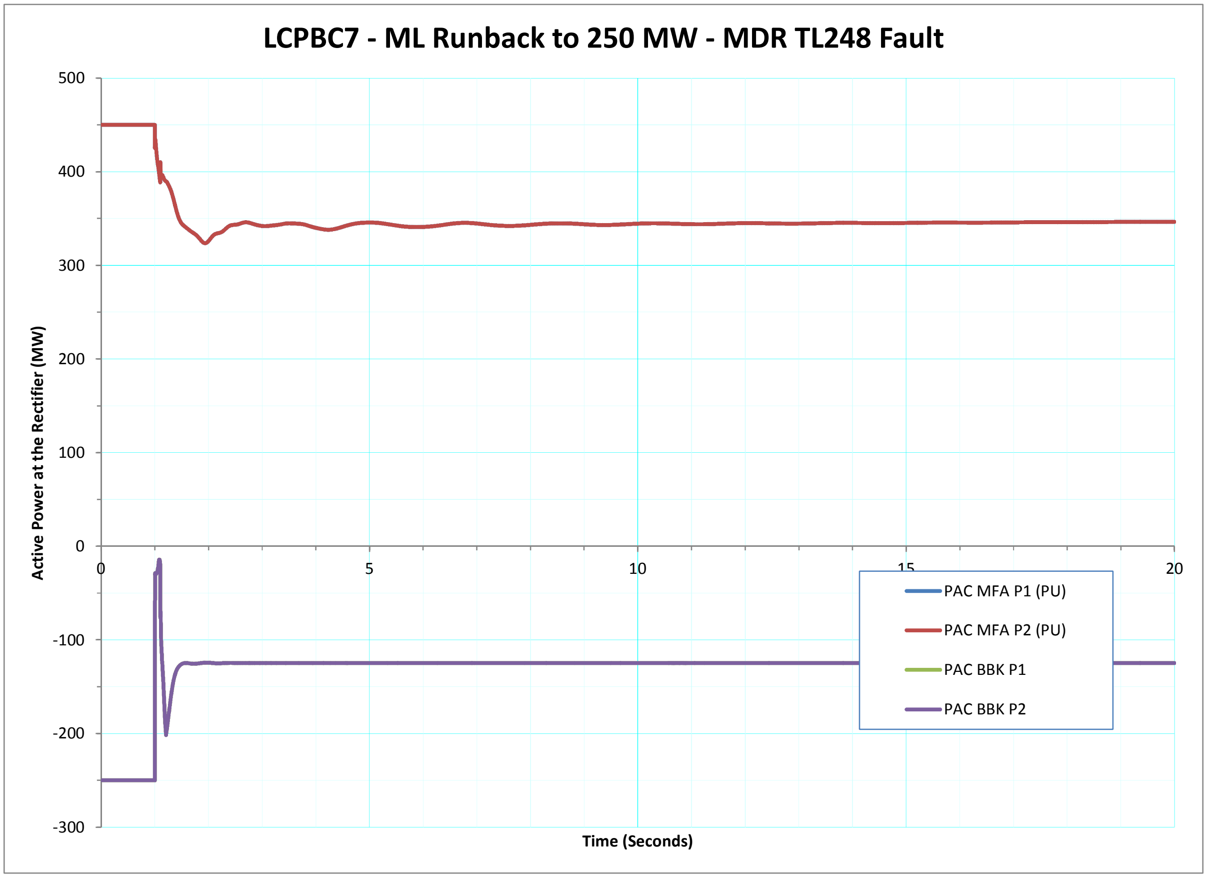


Figure 438 - LCPBC7 - ML Runback to 250 MW - MDR TL248 Fault - Active Power at the Rectifier (MW)

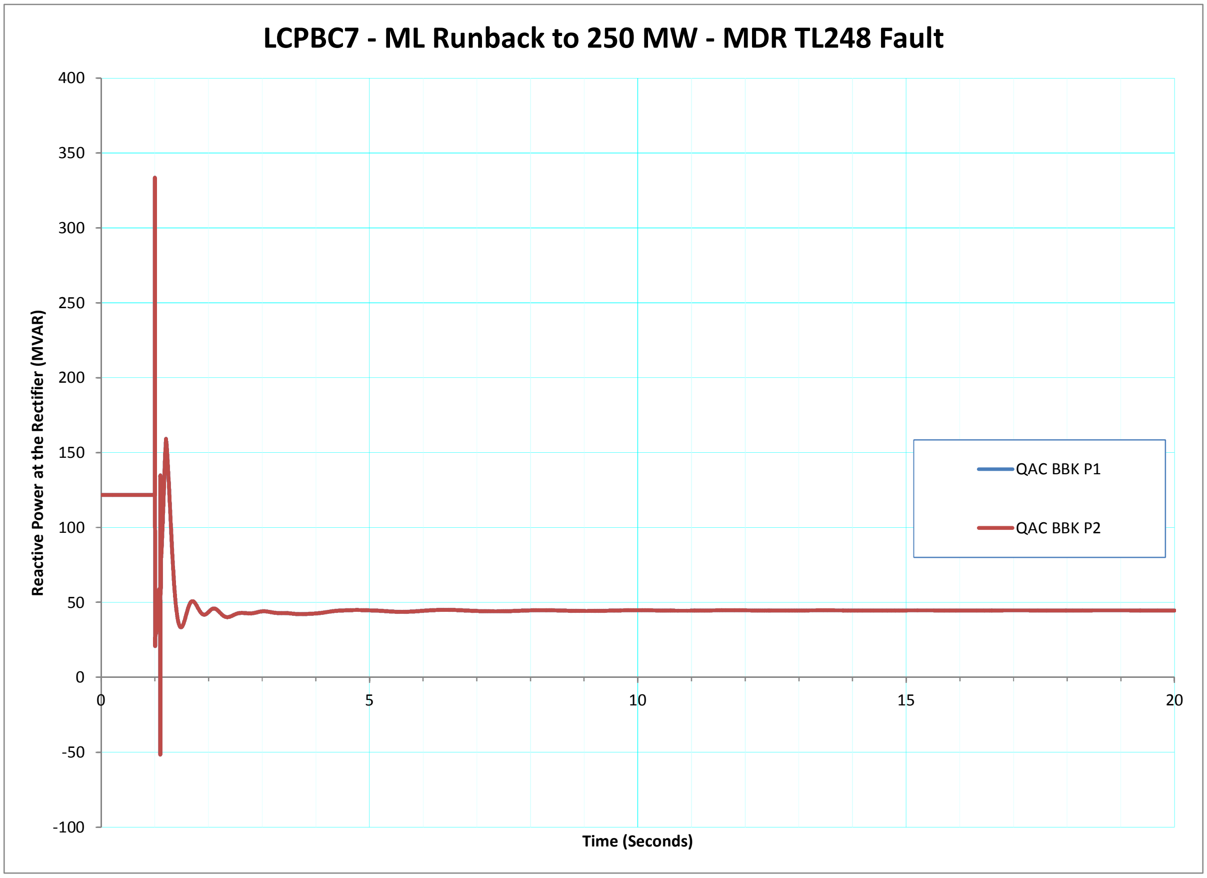


Figure 439 - LCPBC7 - ML Runback to 250 MW - MDR TL248 Fault - Reactive Power at the Rectifier (MVAR)

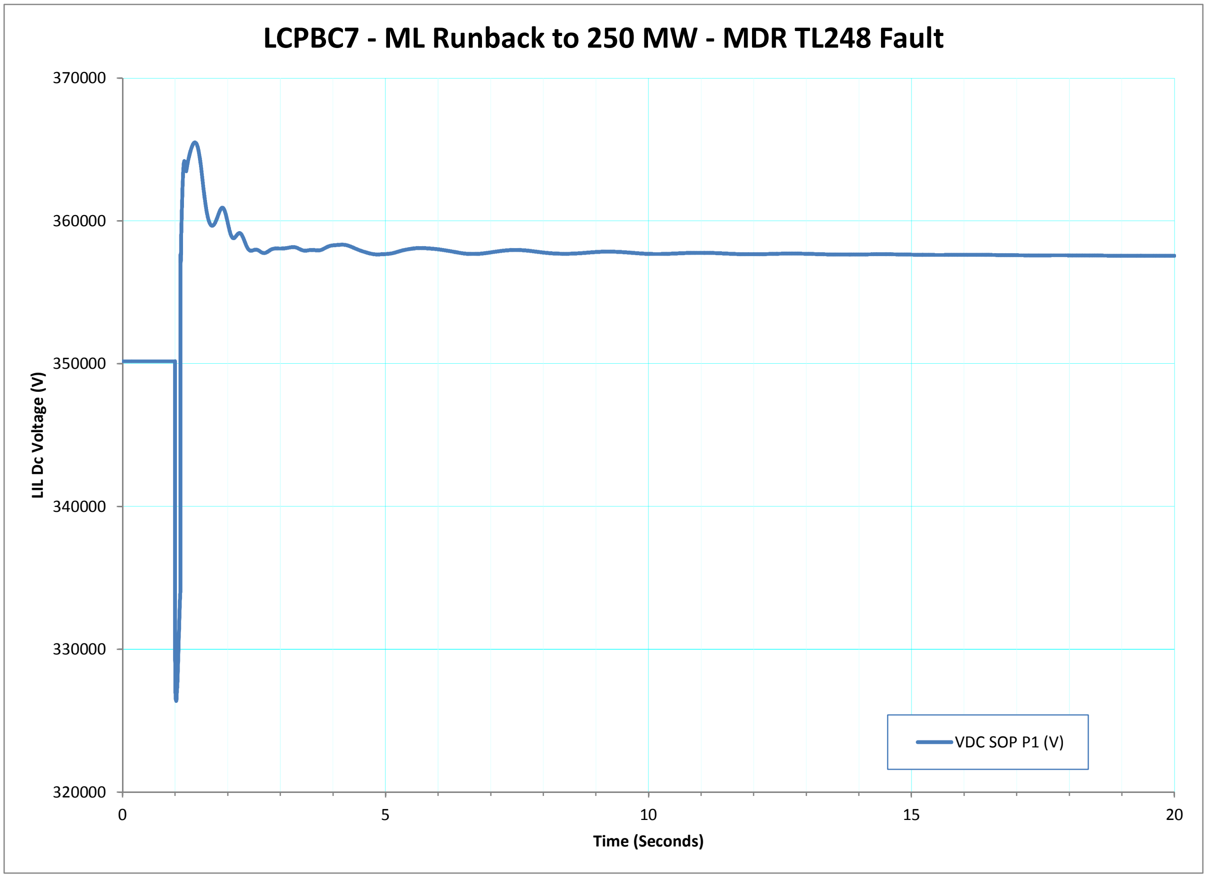


Figure 440 - LCPBC7 - ML Runback to 250 MW - MDR TL248 Fault - LIL Dc Voltage (V)

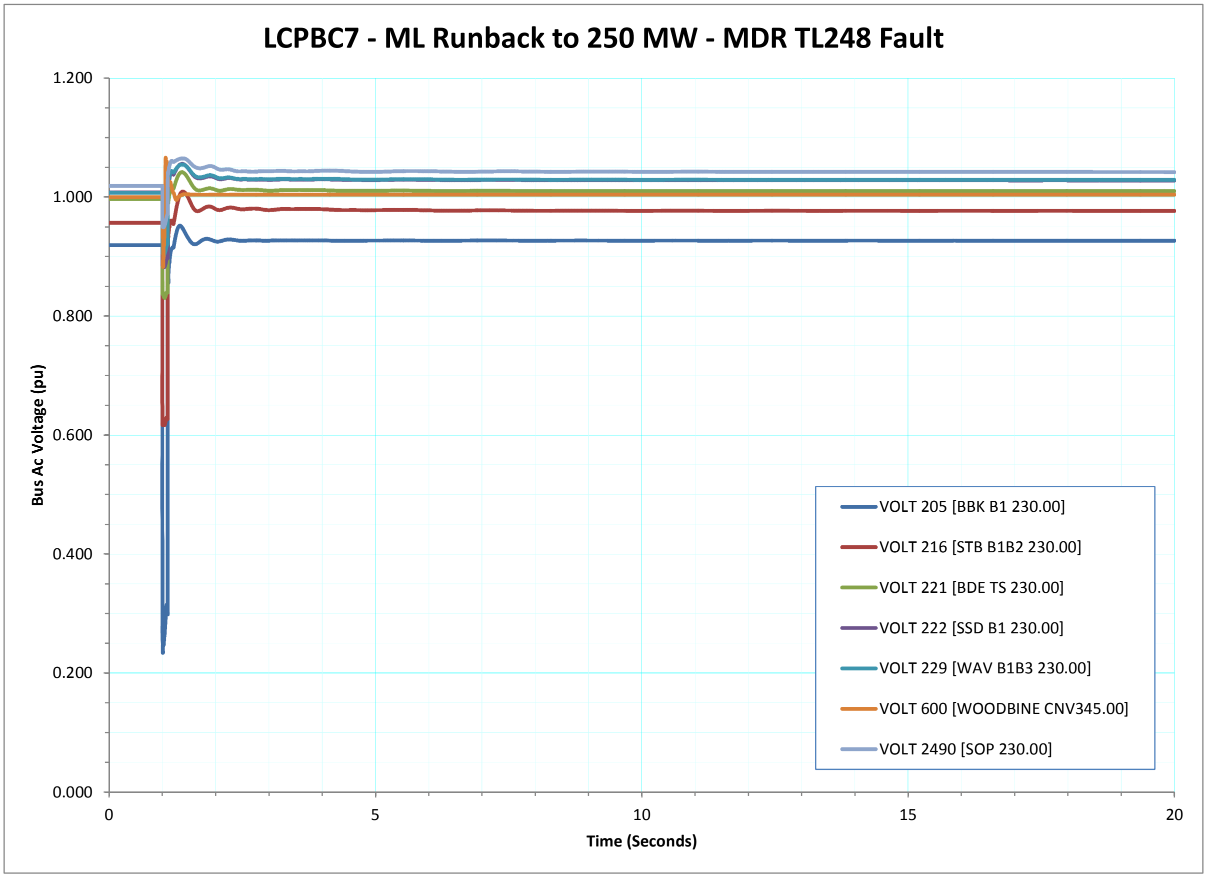


Figure 441 - LCPBC7 - ML Runback to 250 MW - MDR TL248 Fault - Bus Ac Voltage (pu)

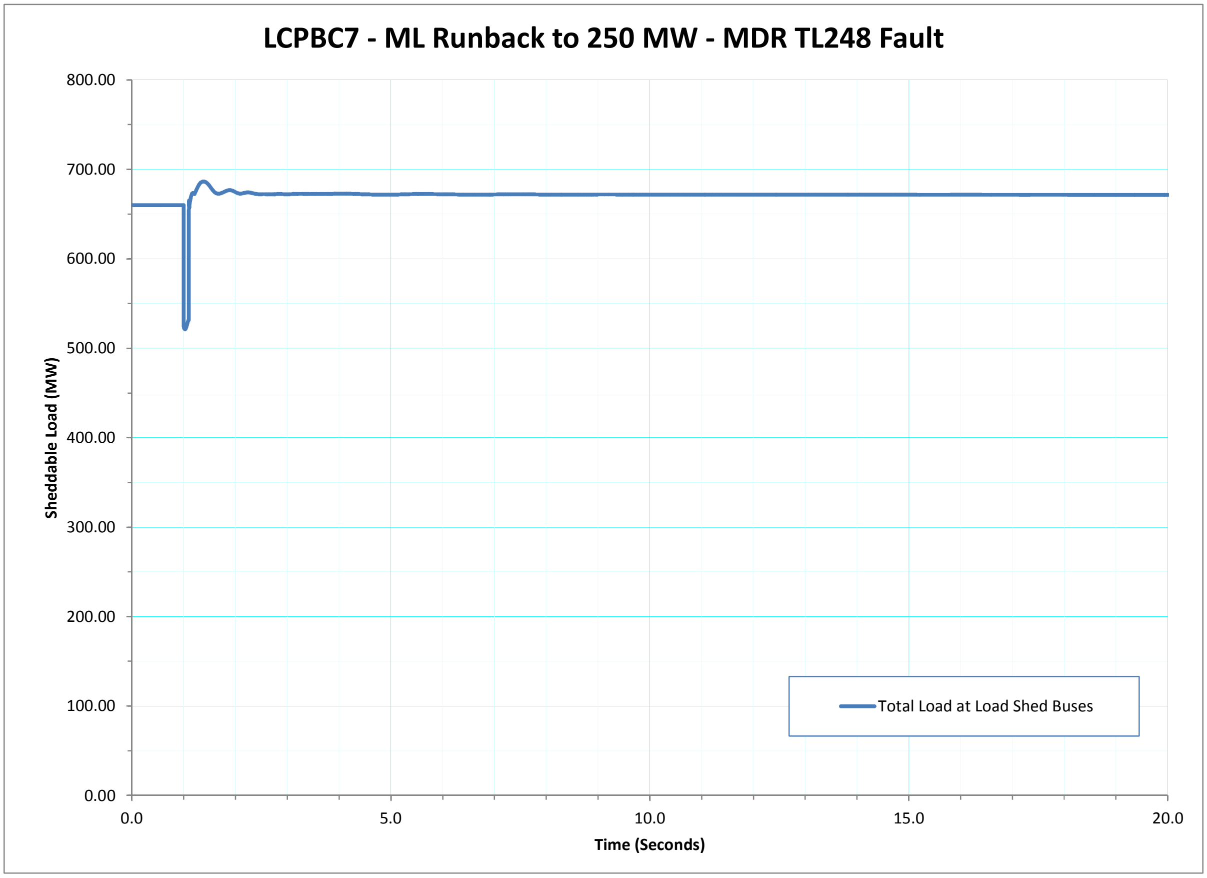


Figure 442 - LCPBC7 - ML Runback to 250 MW - MDR TL248 Fault - Sheddable Load (MW)

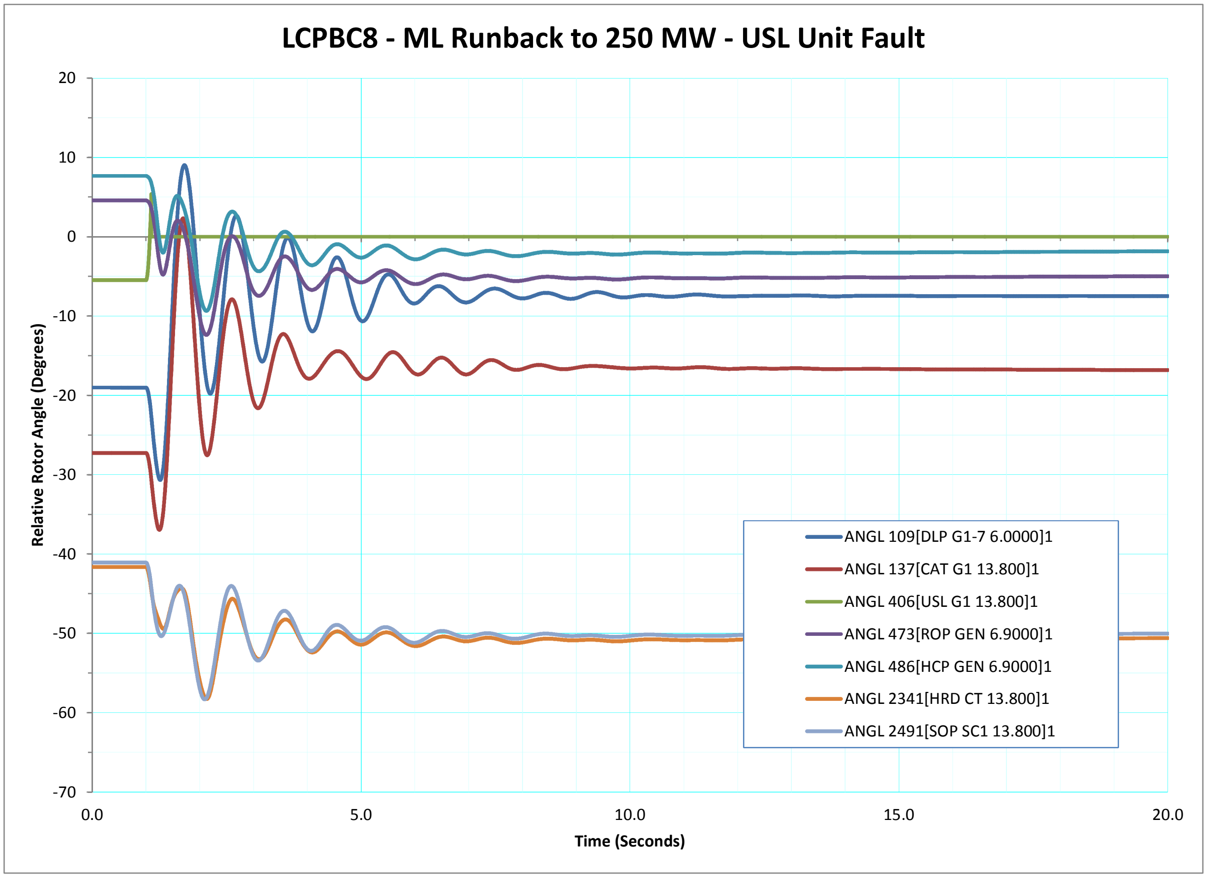


Figure 443 - LCPBC8 - ML Runback to 250 MW - USL Unit Fault - Relative Rotor Angle (Degrees)

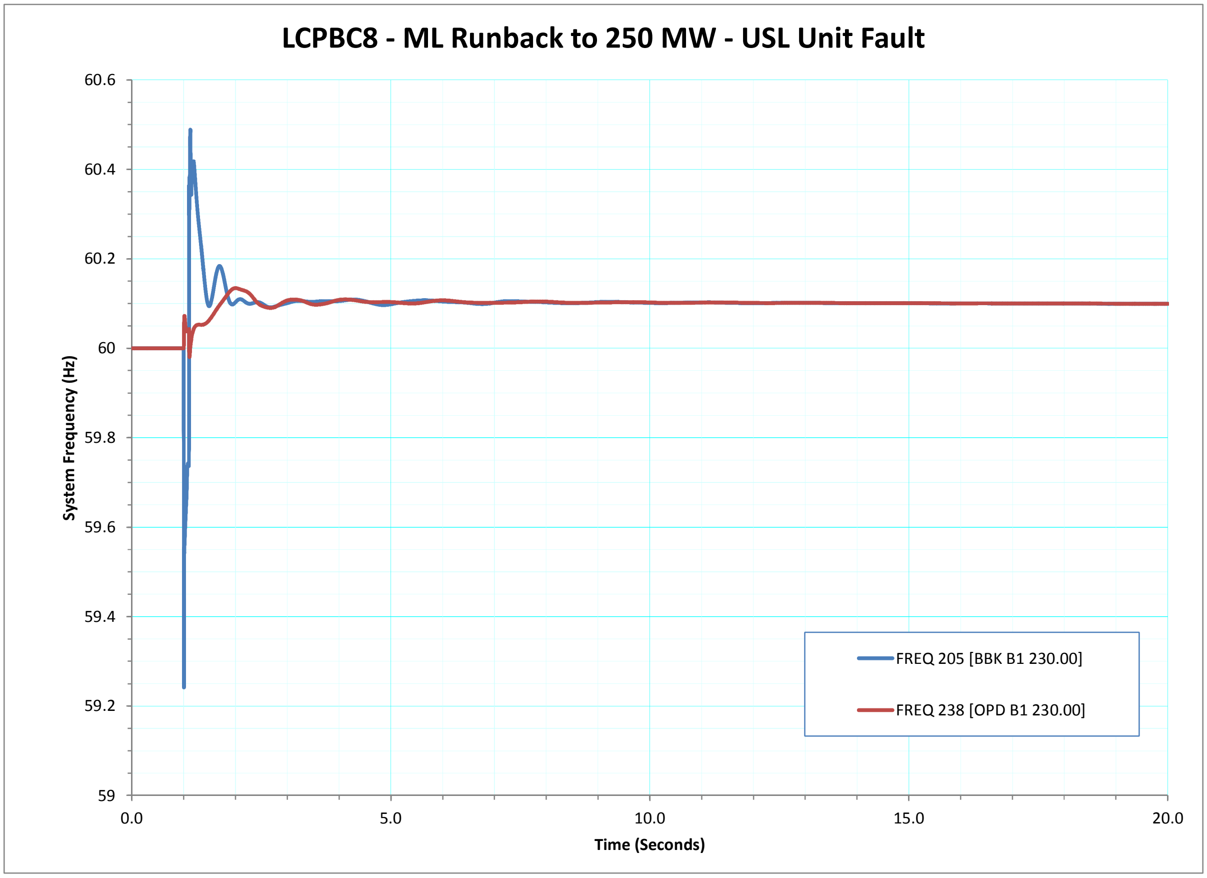


Figure 444 - LCPBC8 - ML Runback to 250 MW - USL Unit Fault - System Frequency (Hz)

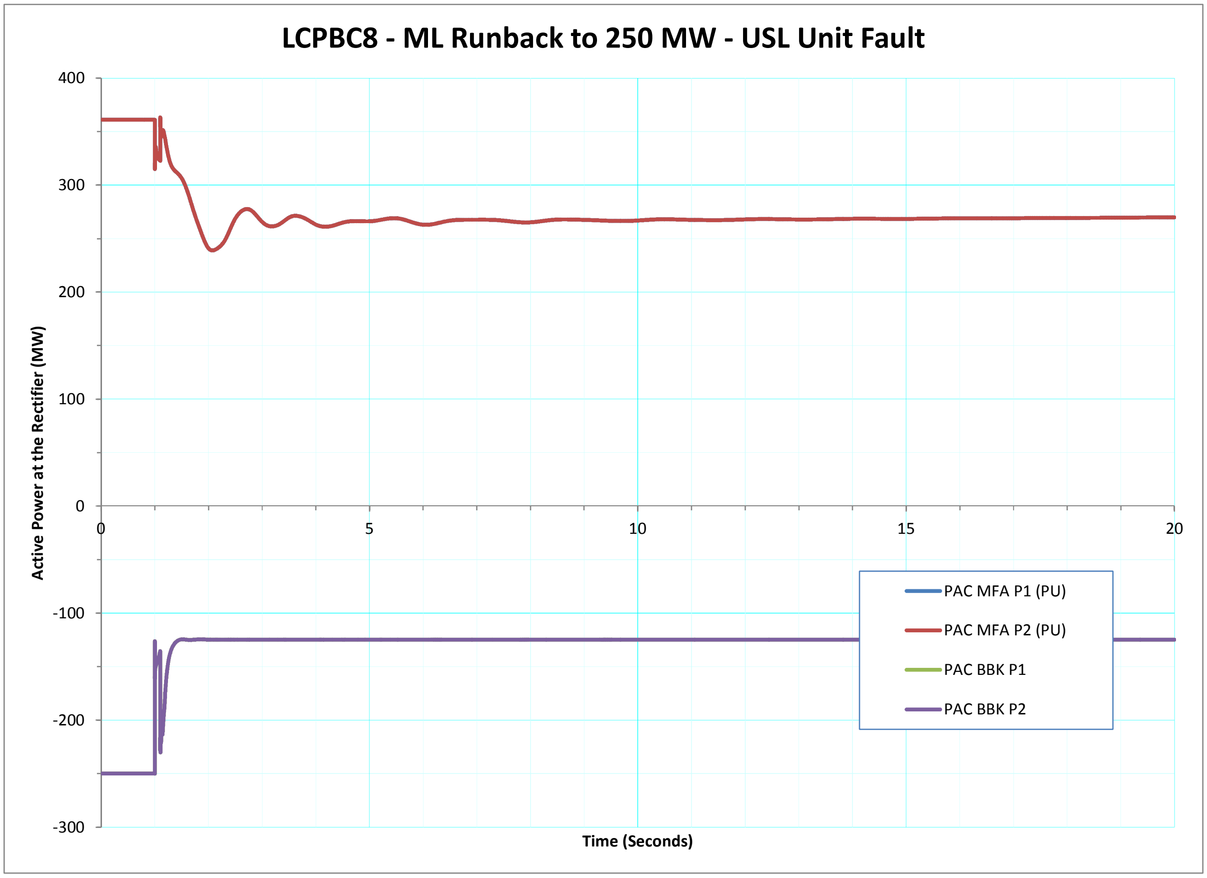


Figure 445 - LCPBC8 - ML Runback to 250 MW - USL Unit Fault - Active Power at the Rectifier (MW)

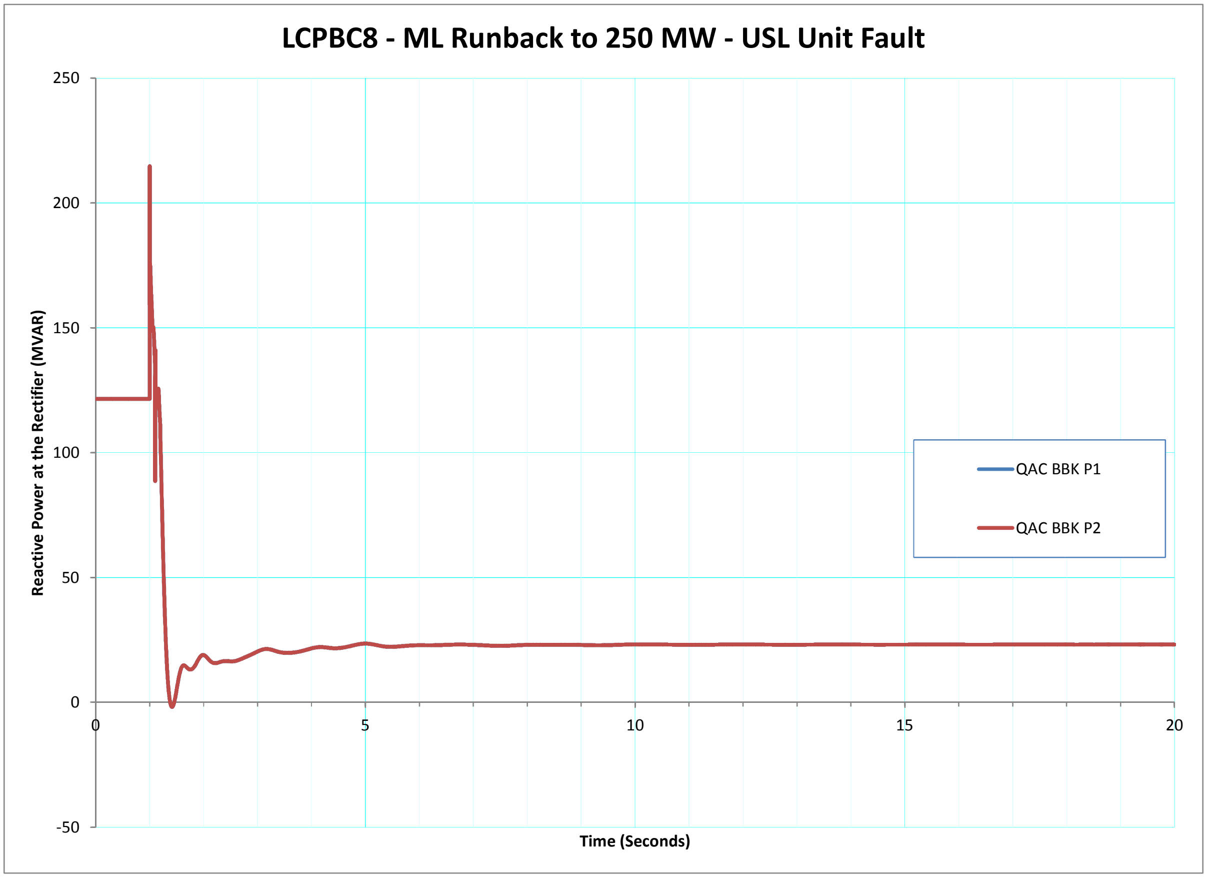


Figure 446 - LCPBC8 - ML Runback to 250 MW - USL Unit Fault - Reactive Power at the Rectifier (MVAR)

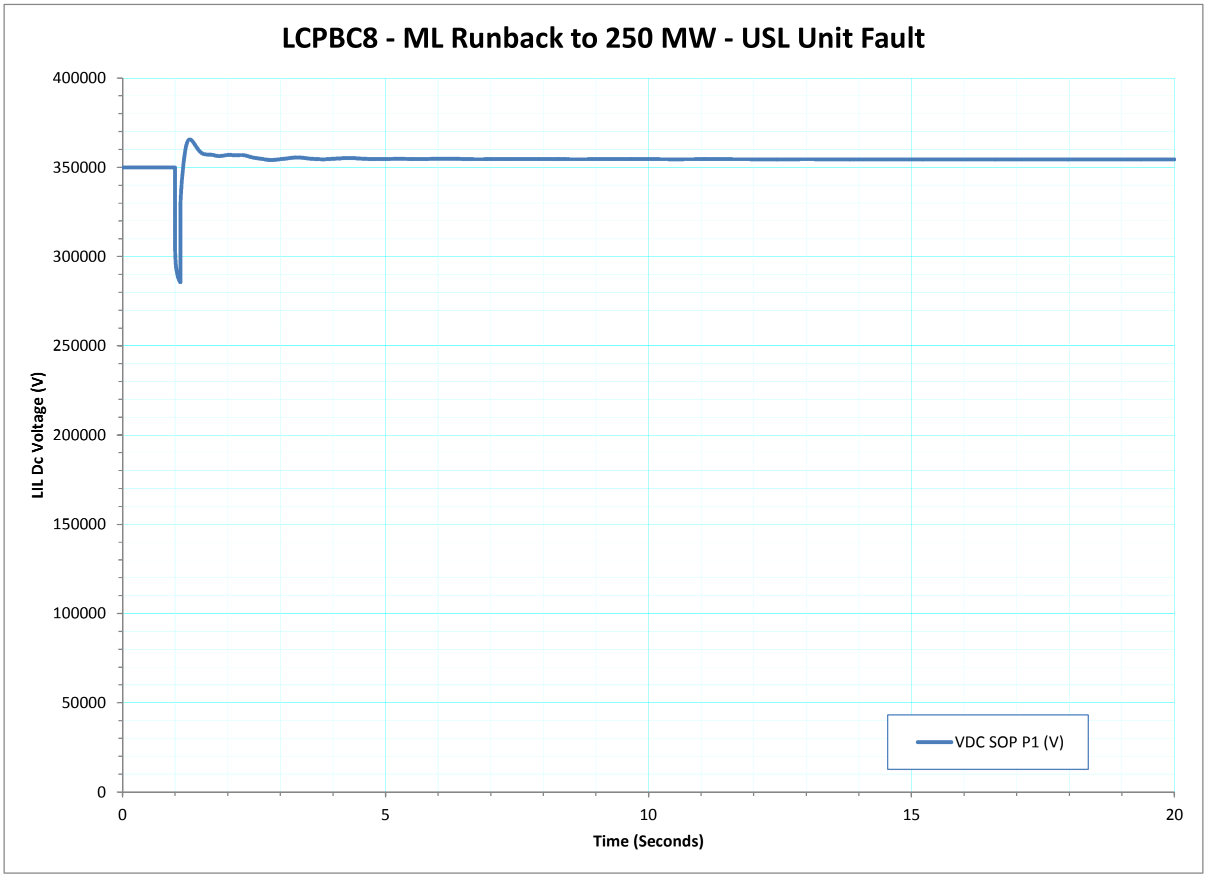


Figure 447 - LCPBC8 - ML Runback to 250 MW - USL Unit Fault - LIL Dc Voltage (V)

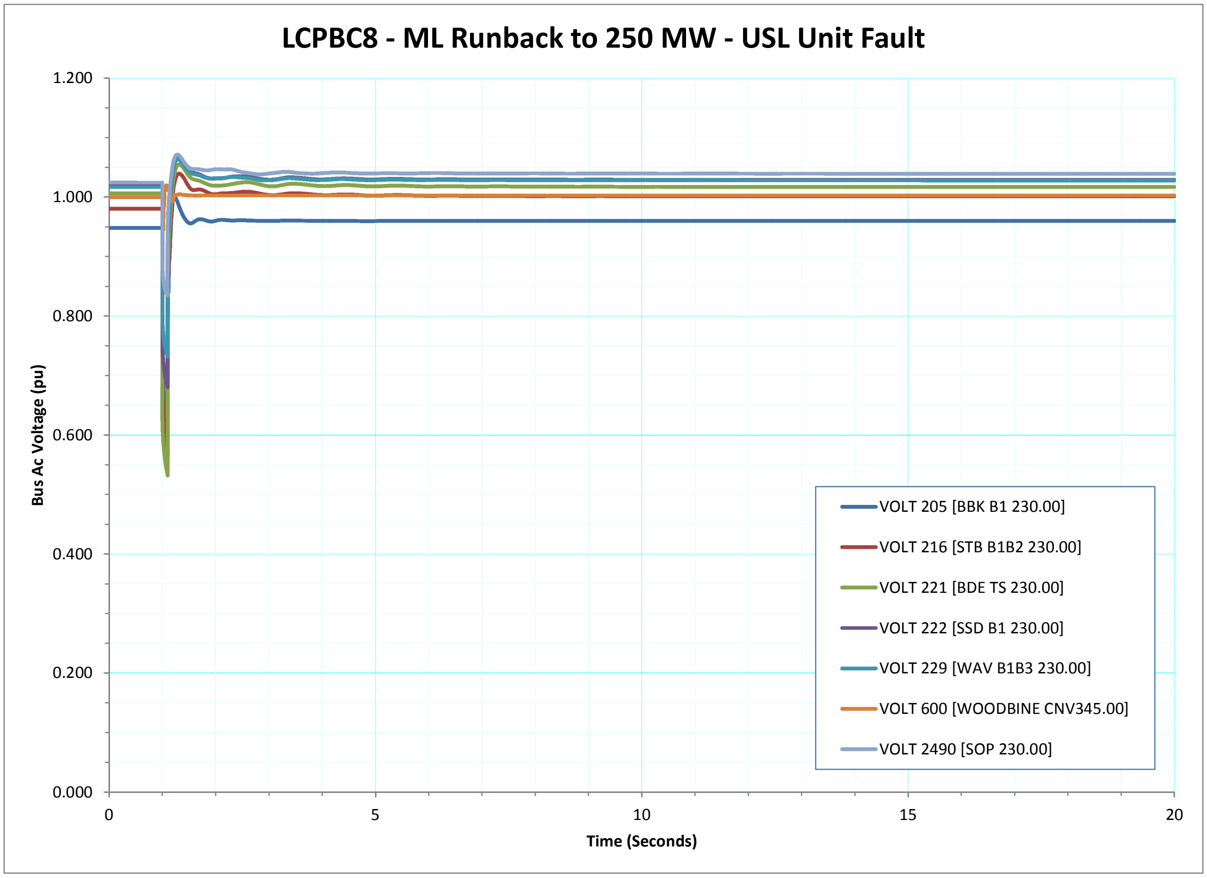


Figure 448 - LCPBC8 - ML Runback to 250 MW - USL Unit Fault - Bus Ac Voltage (pu)

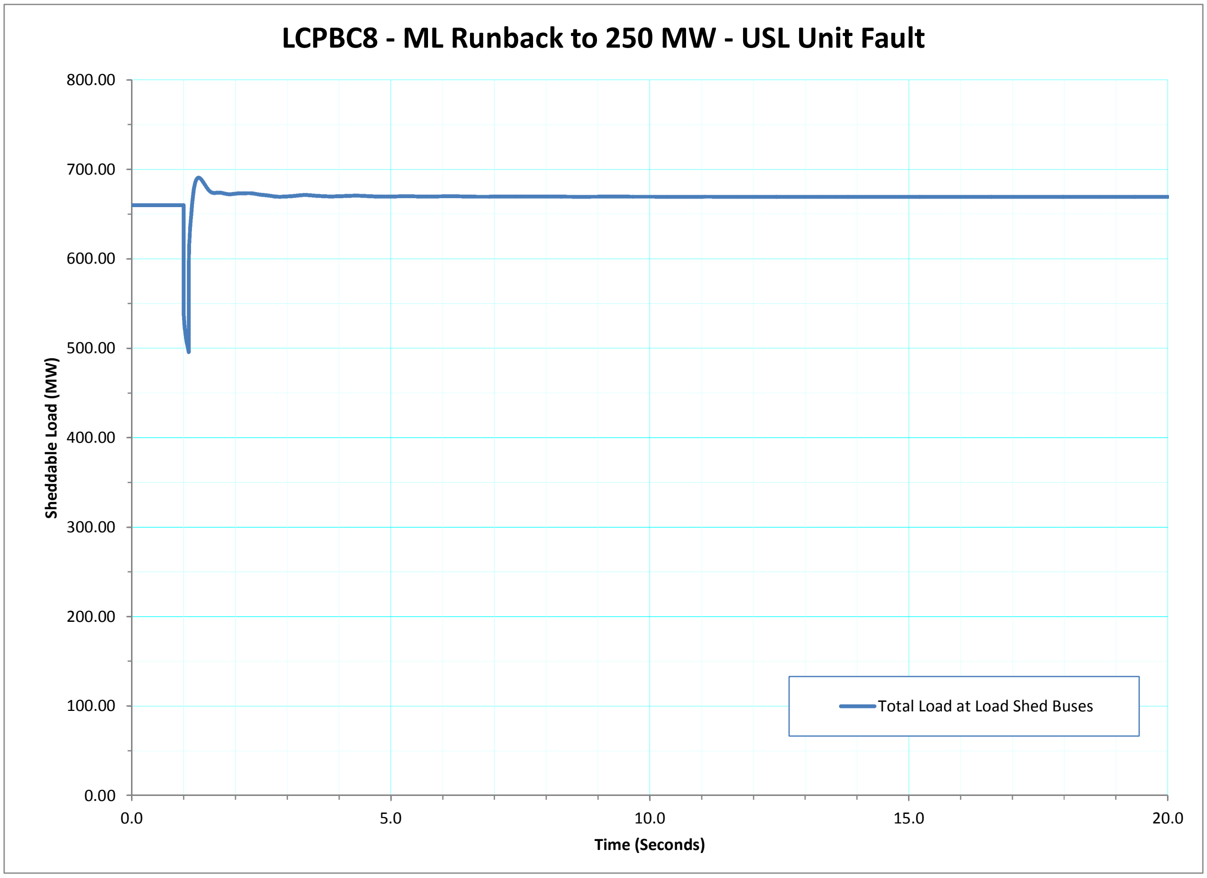


Figure 449 - LCPBC8 - ML Runback to 250 MW - USL Unit Fault - Sheddable Load (MW)

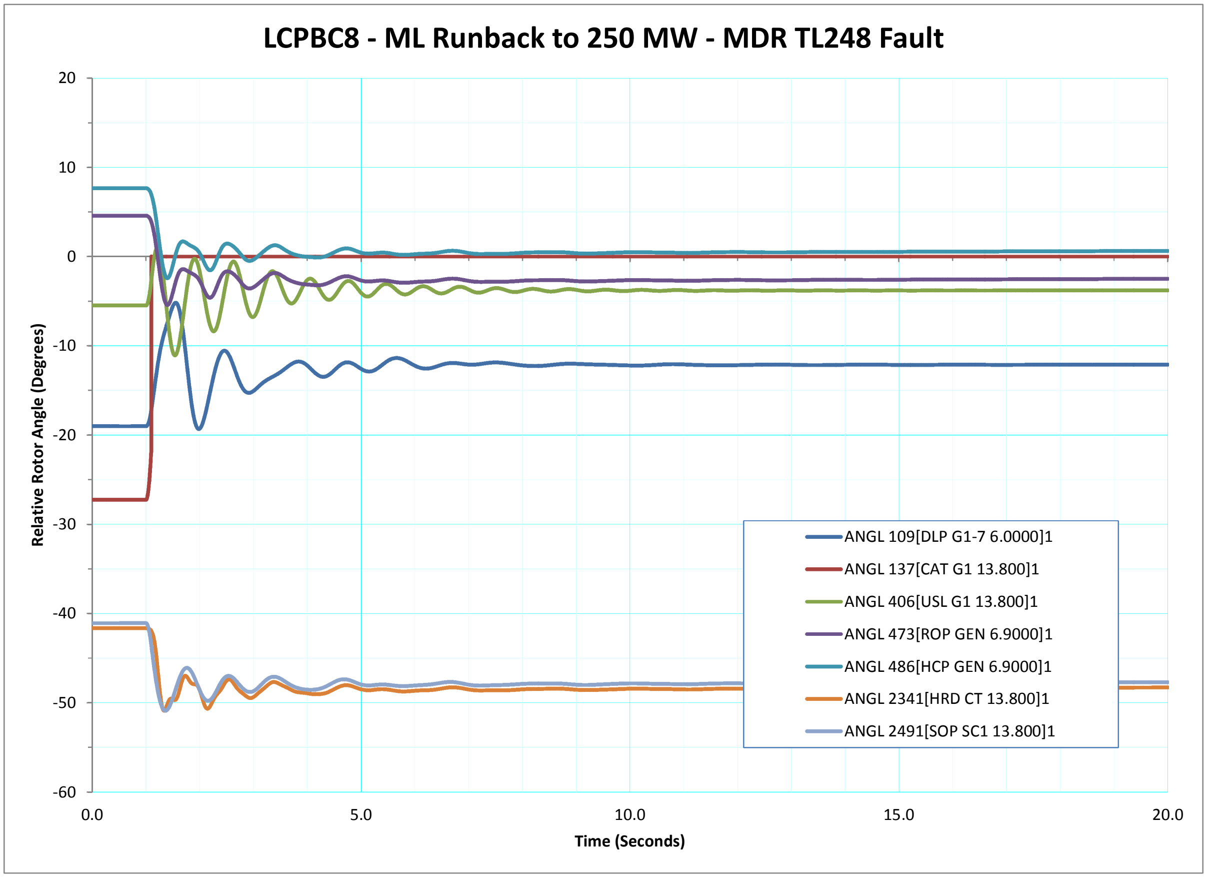


Figure 450 - LCPBC8 - ML Runback to 250 MW - MDR TL248 Fault - Relative Rotor Angle (Degrees)

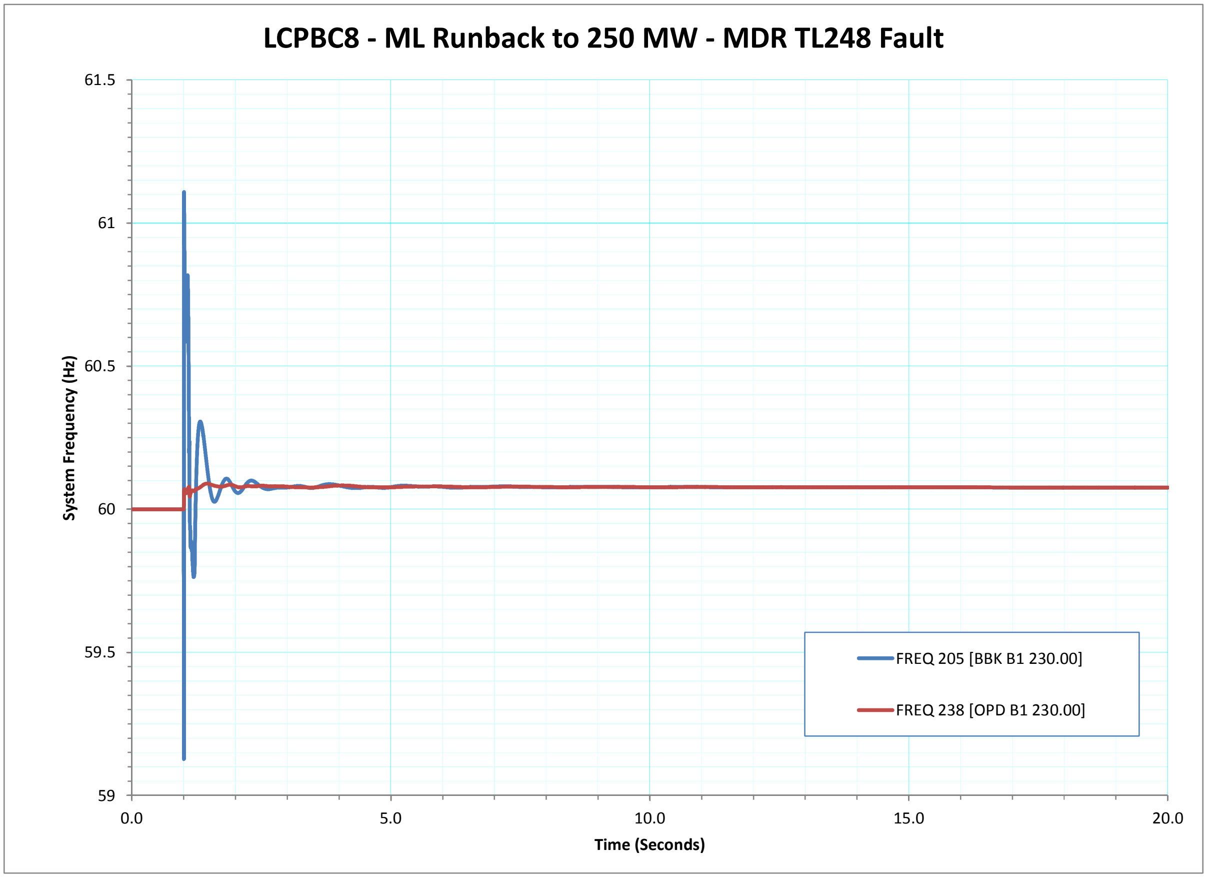


Figure 451 - LCPBC8 - ML Runback to 250 MW - MDR TL248 Fault - System Frequency (Hz)

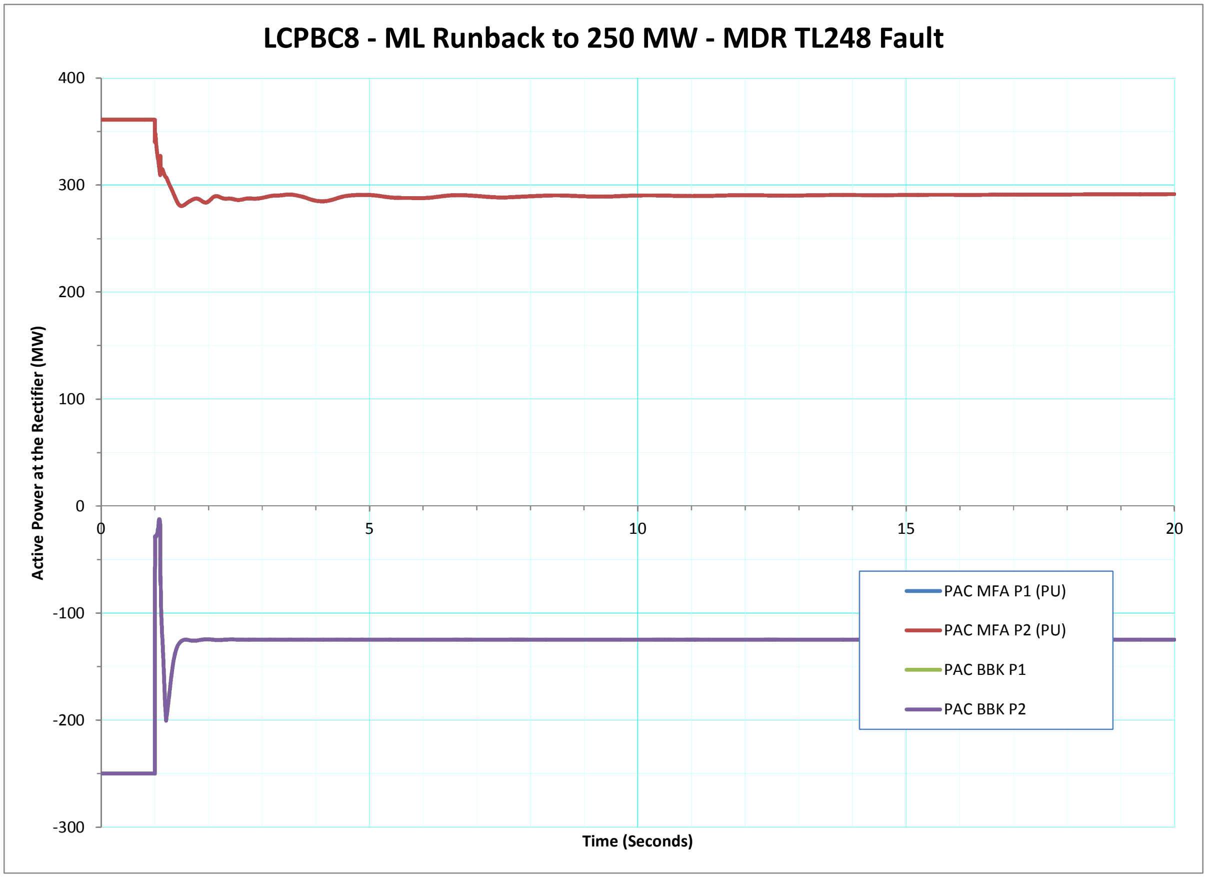


Figure 452 - LCPBC8 - ML Runback to 250 MW - MDR TL248 Fault - Active Power at the Rectifier (MW)

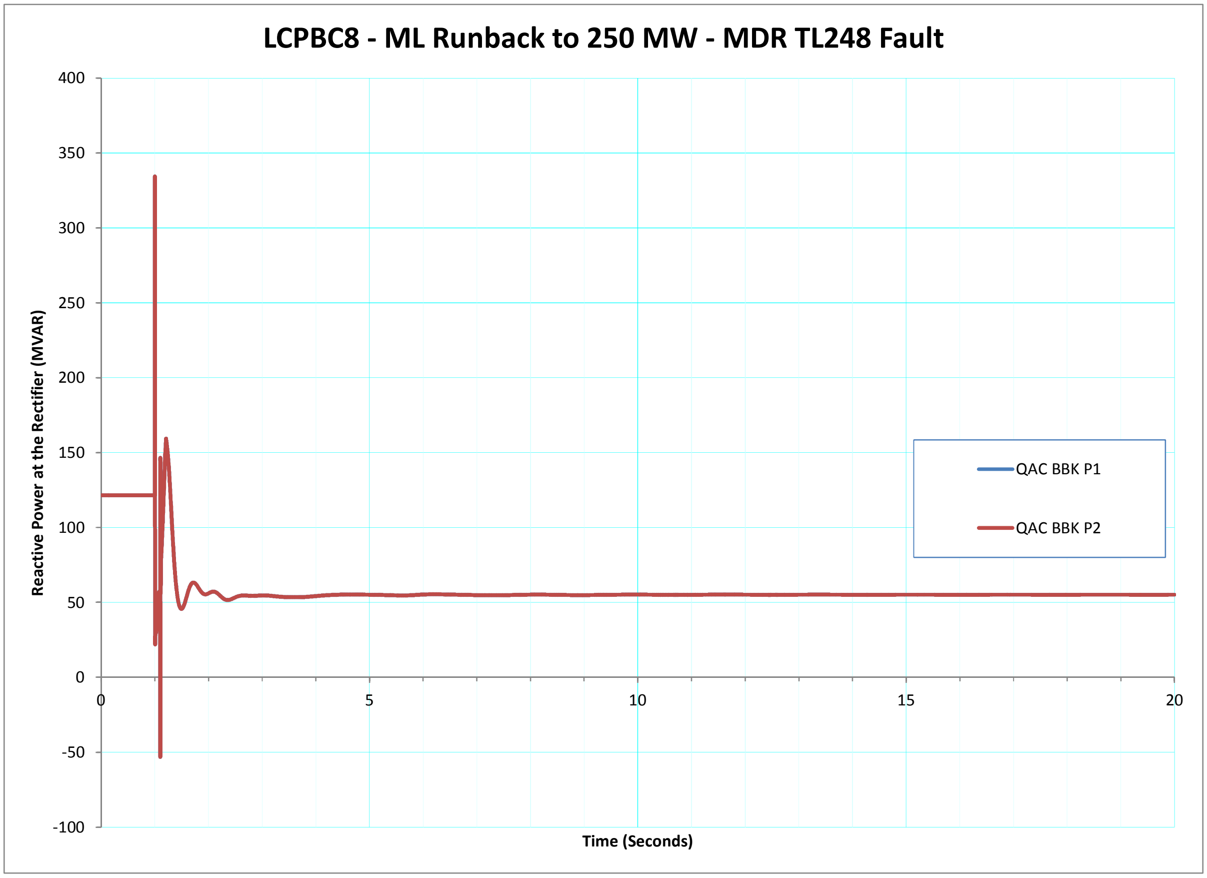


Figure 453 - LCPBC8 - ML Runback to 250 MW - MDR TL248 Fault - Reactive Power at the Rectifier (MVAR)

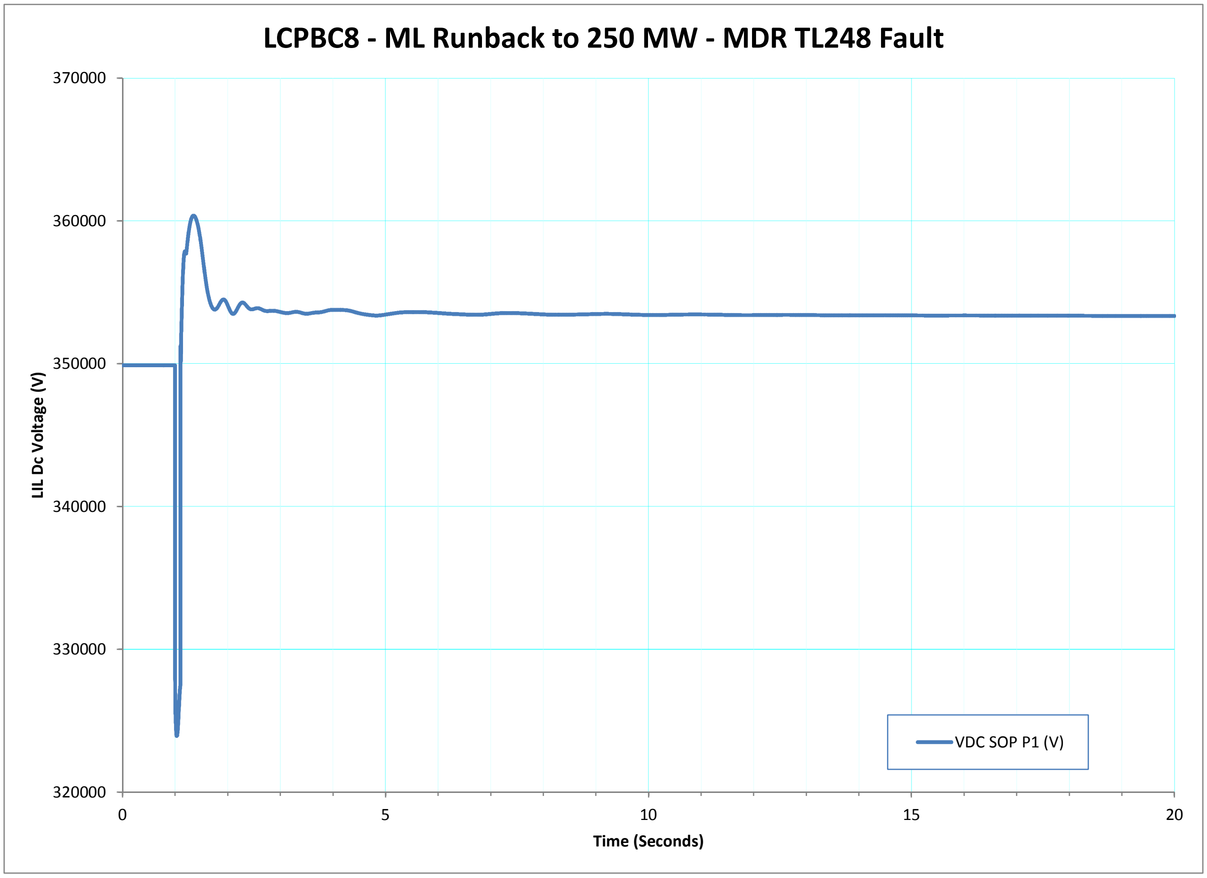


Figure 454 - LCPBC8 - ML Runback to 250 MW - MDR TL248 Fault - LIL Dc Voltage (V)

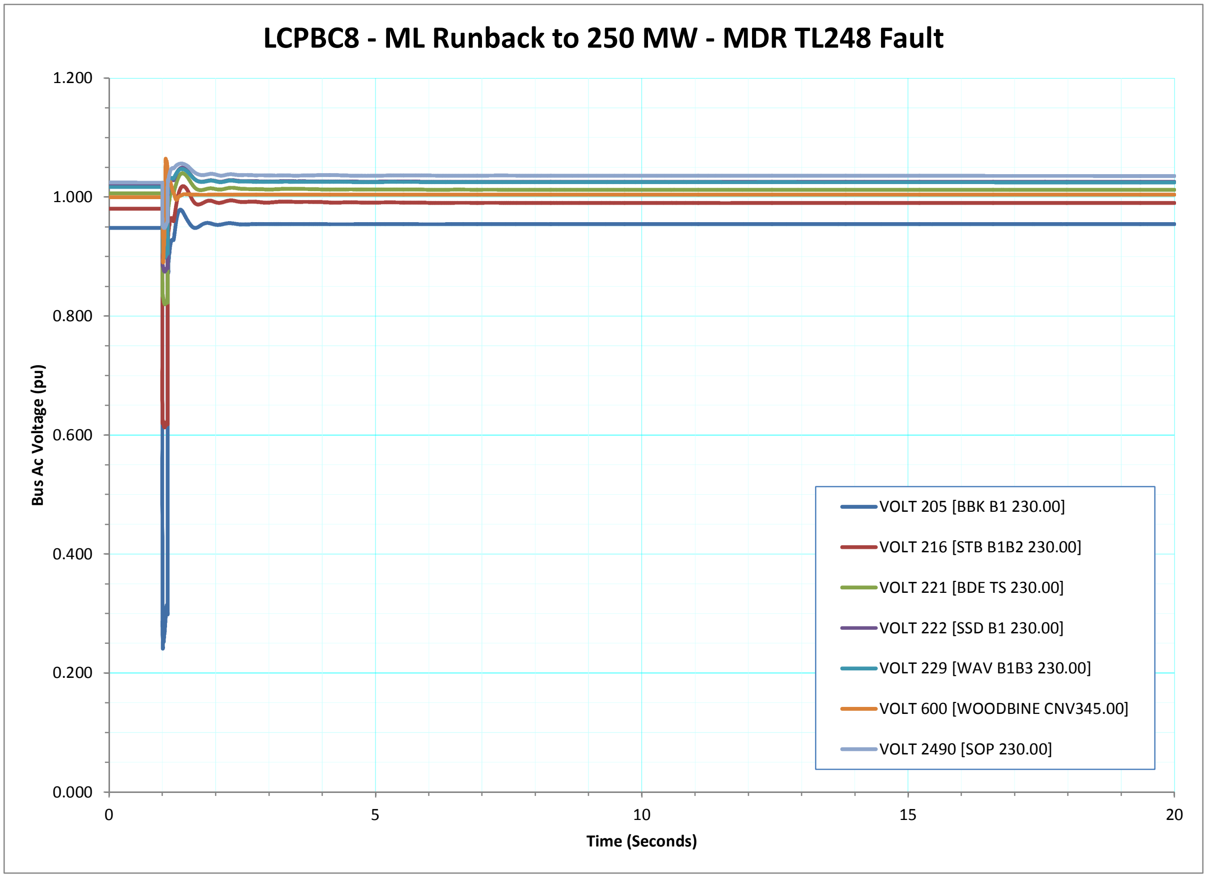


Figure 455 - LCPBC8 - ML Runback to 250 MW - MDR TL248 Fault - Bus Ac Voltage (pu)

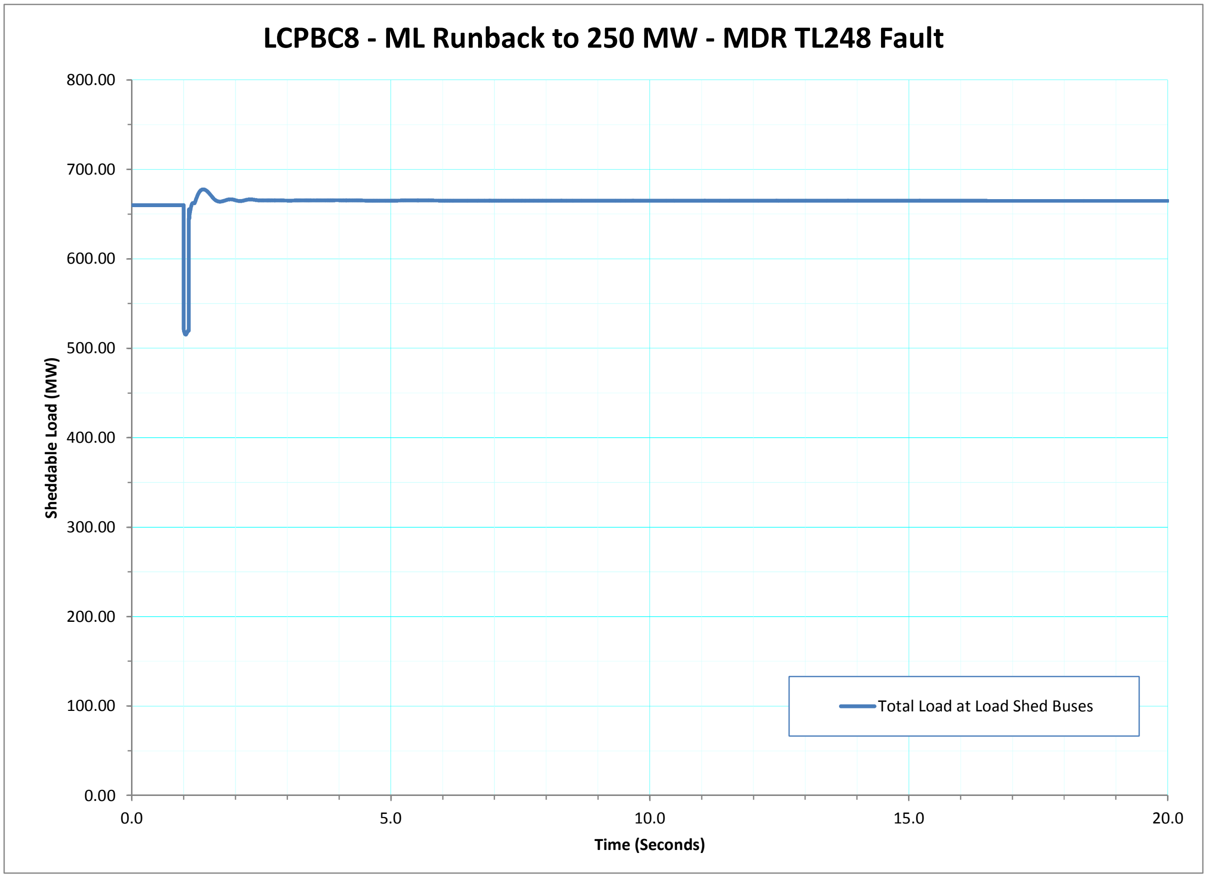


Figure 456 - LCPBC8 - ML Runback to 250 MW - MDR TL248 Fault - Sheddable Load (MW)

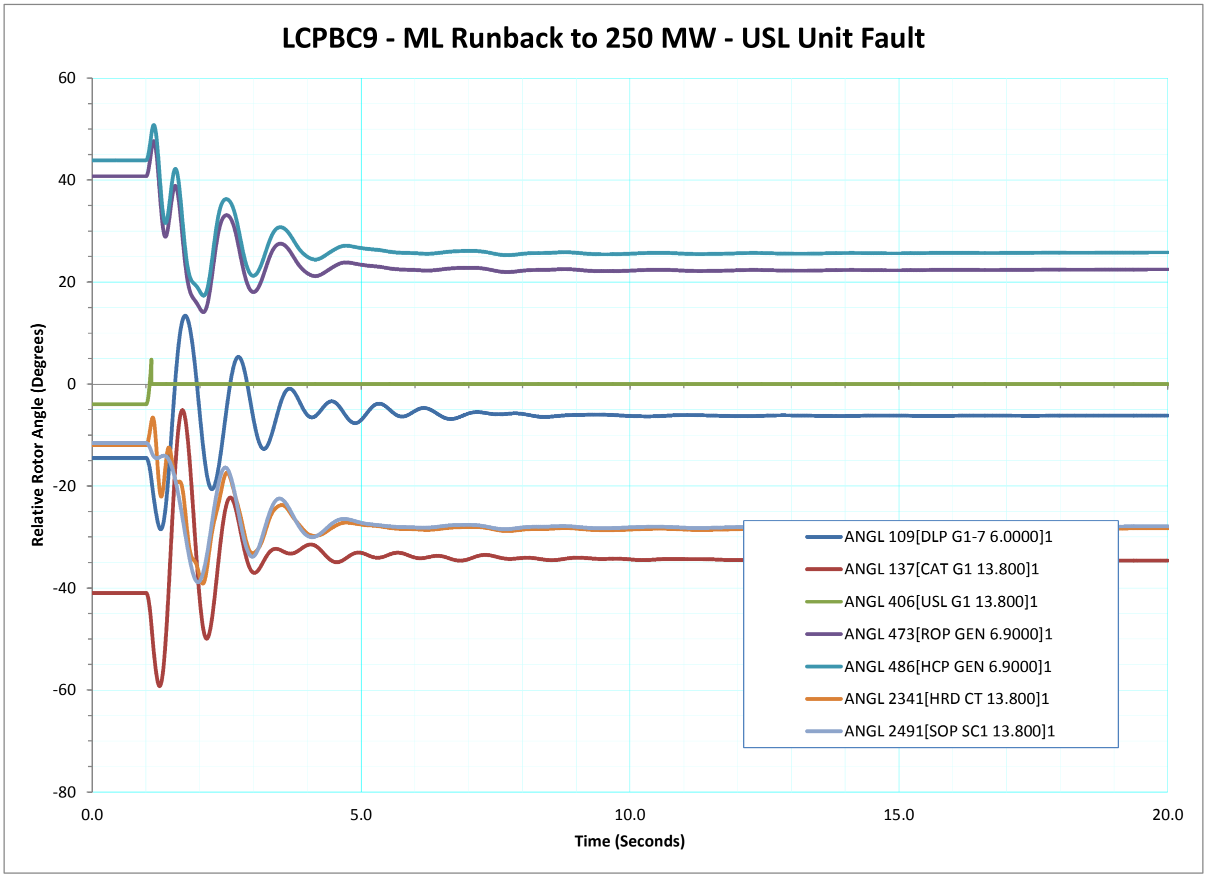


Figure 457 - LCPBC9 - ML Runback to 250 MW - USL Unit Fault - Relative Rotor Angle (Degrees)

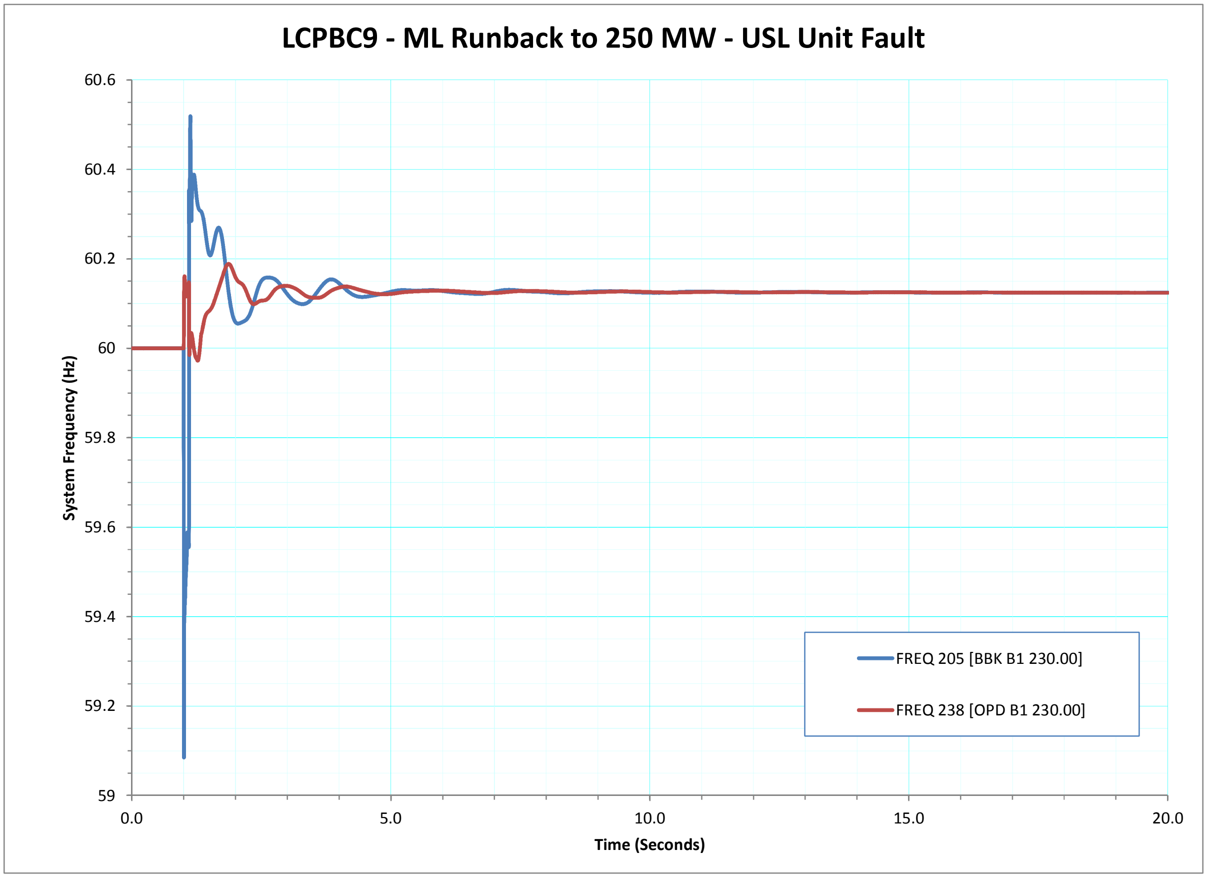


Figure 458 - LCPBC9 - ML Runback to 250 MW - USL Unit Fault - System Frequency (Hz)

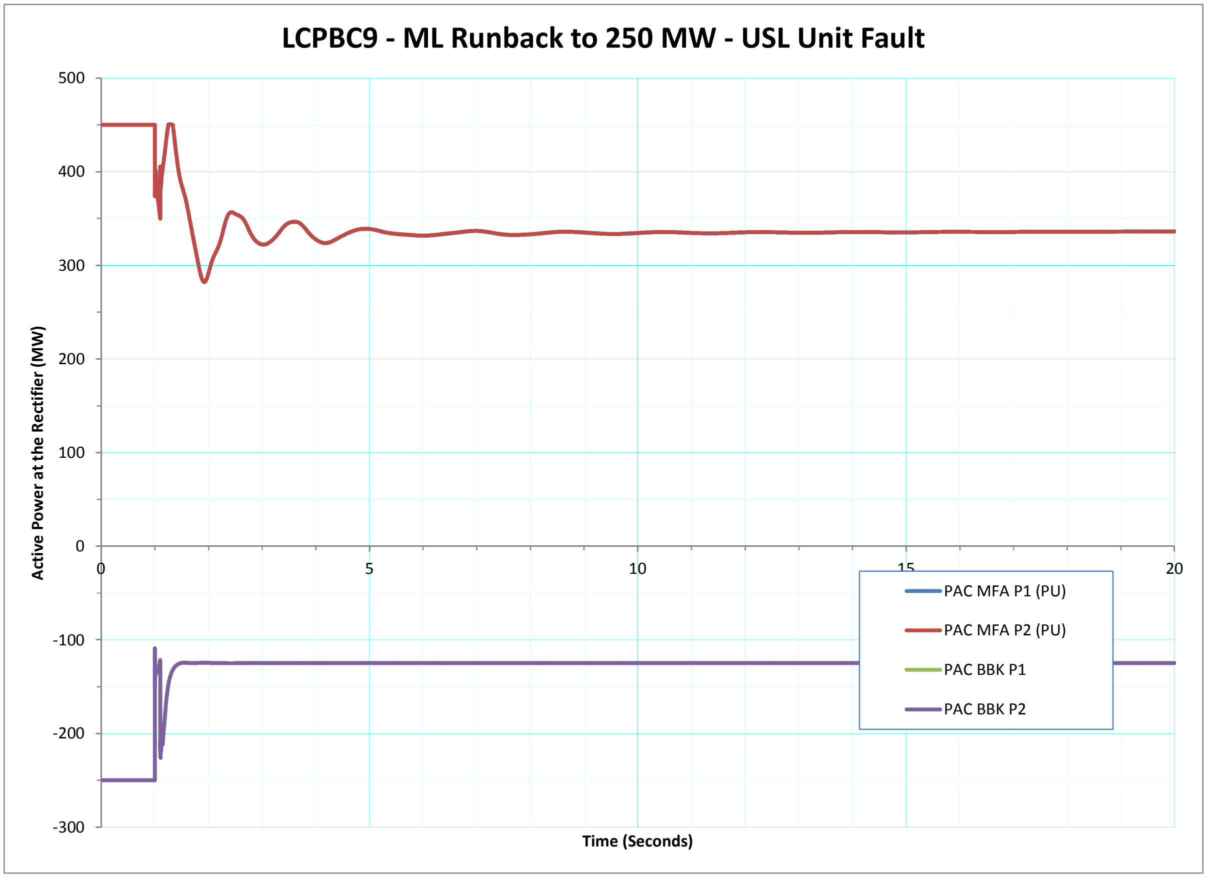


Figure 459 - LCPBC9 - ML Runback to 250 MW - USL Unit Fault - Active Power at the Rectifier (MW)

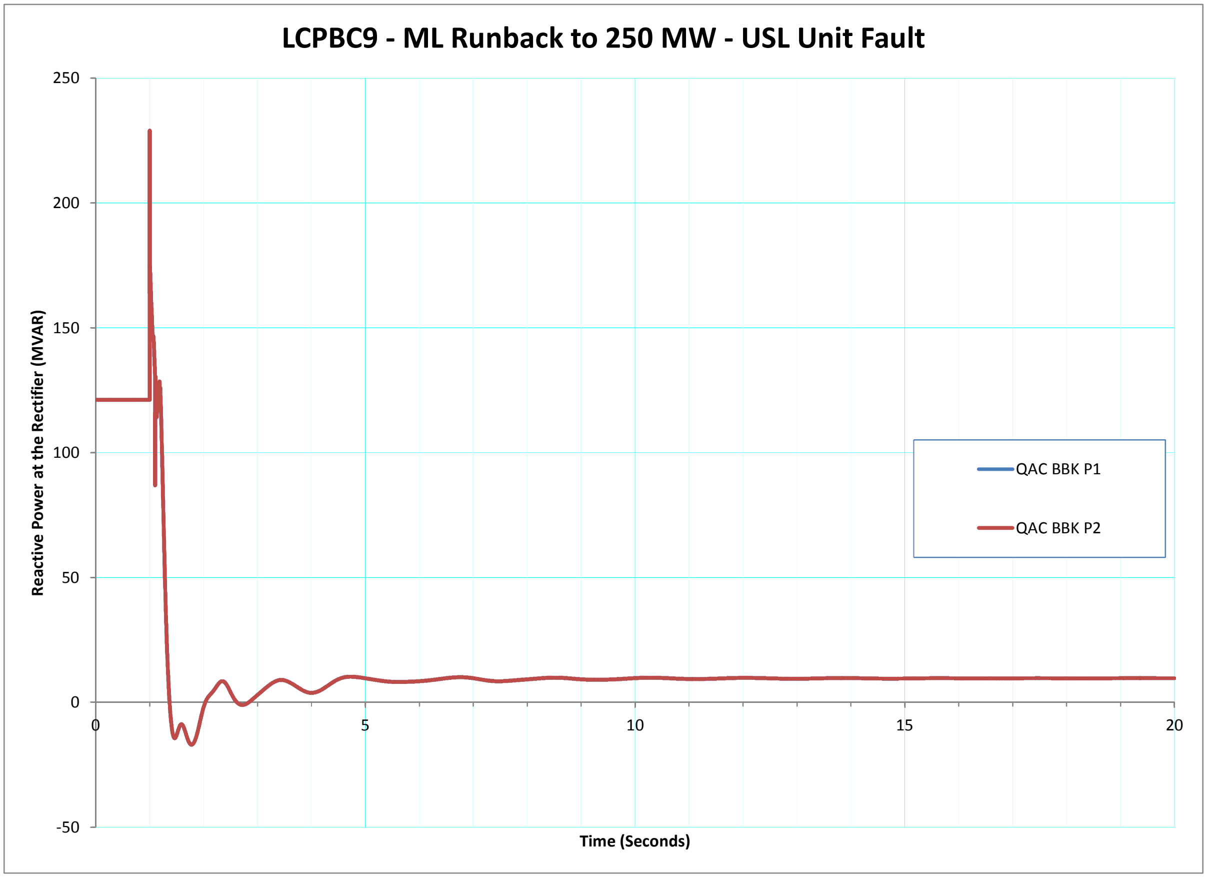


Figure 460 - LCPBC9 - ML Runback to 250 MW - USL Unit Fault - Reactive Power at the Rectifier (MVAR)

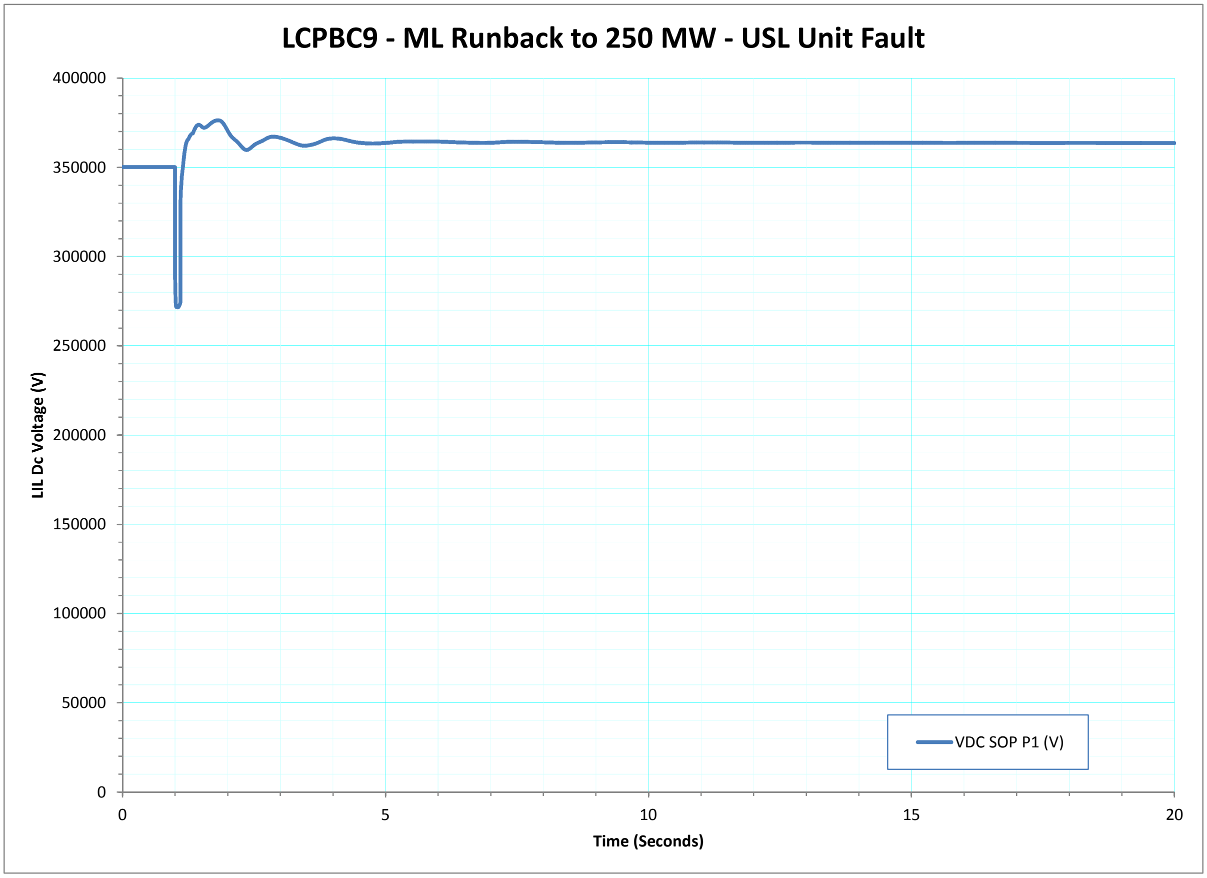


Figure 461 - LCPBC9 - ML Runback to 250 MW - USL Unit Fault - LIL Dc Voltage (V)

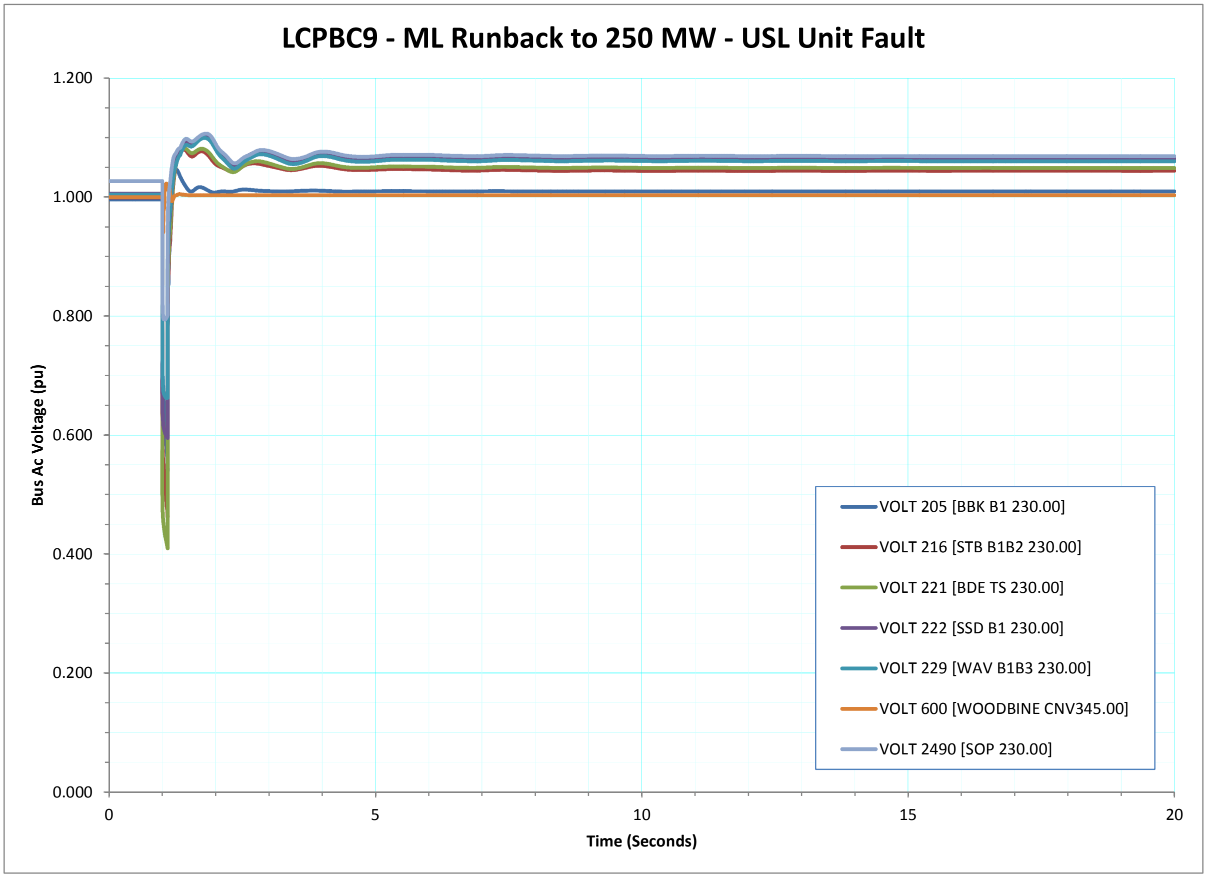


Figure 462 - LCPBC9 - ML Runback to 250 MW - USL Unit Fault - Bus Ac Voltage (pu)

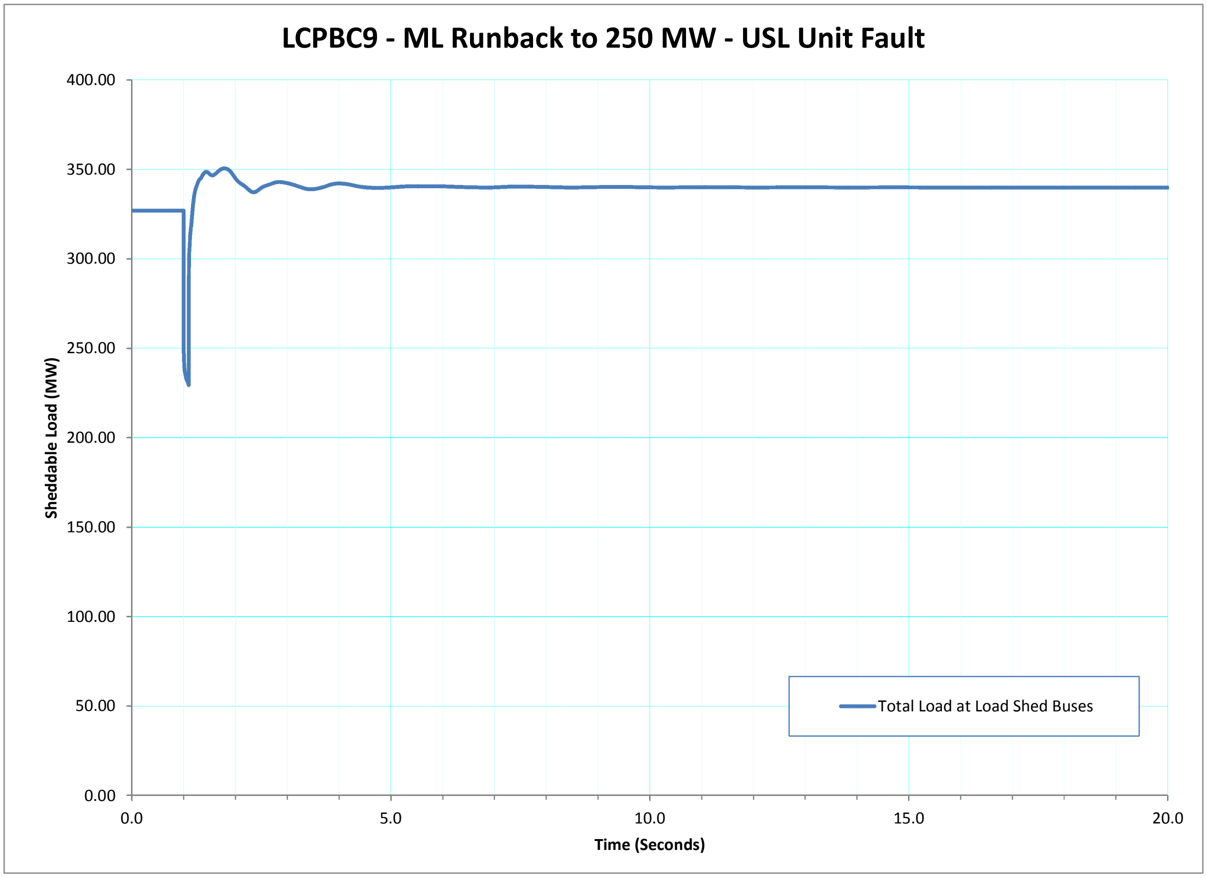


Figure 463 - LCPBC9 - ML Runback to 250 MW - USL Unit Fault - Sheddable Load (MW)

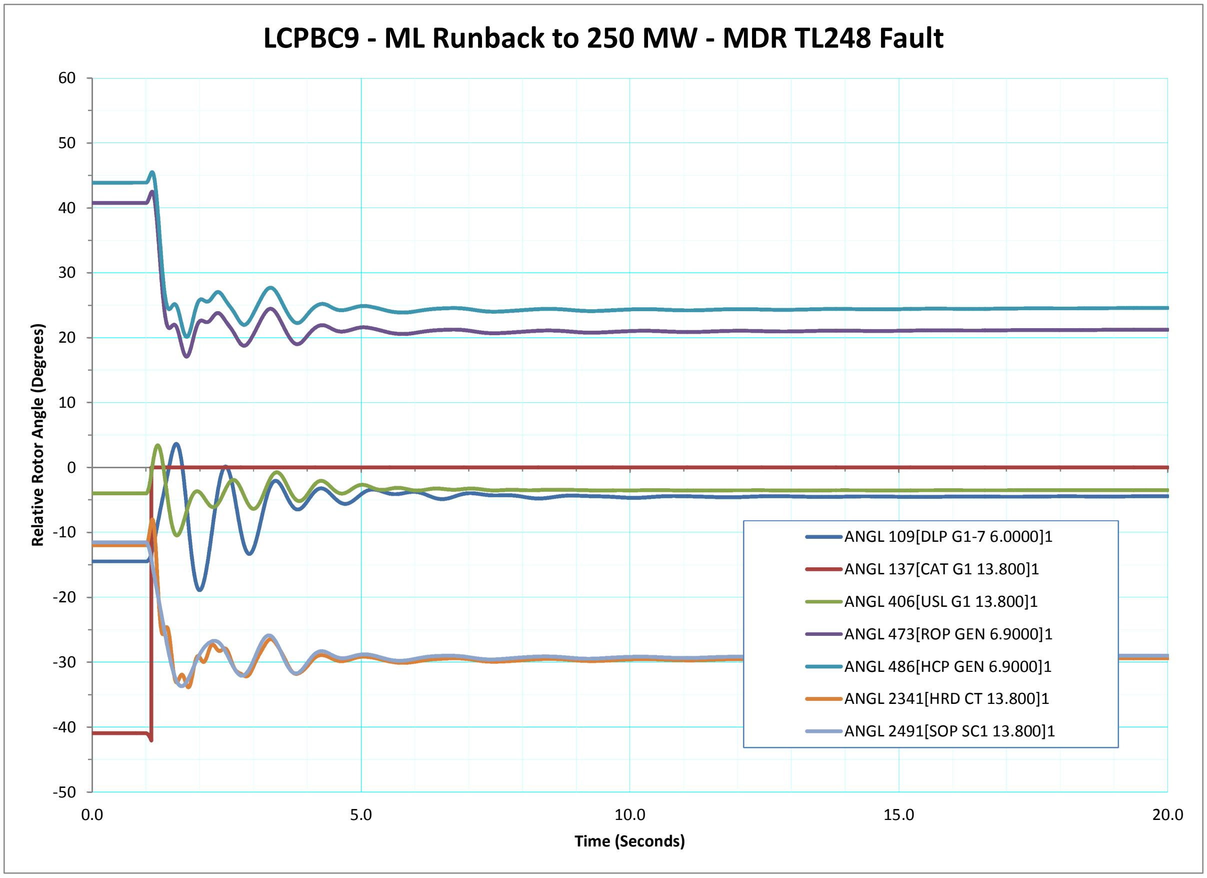


Figure 464 - LCPBC9 - ML Runback to 250 MW - MDR TL248 Fault - Relative Rotor Angle (Degrees)

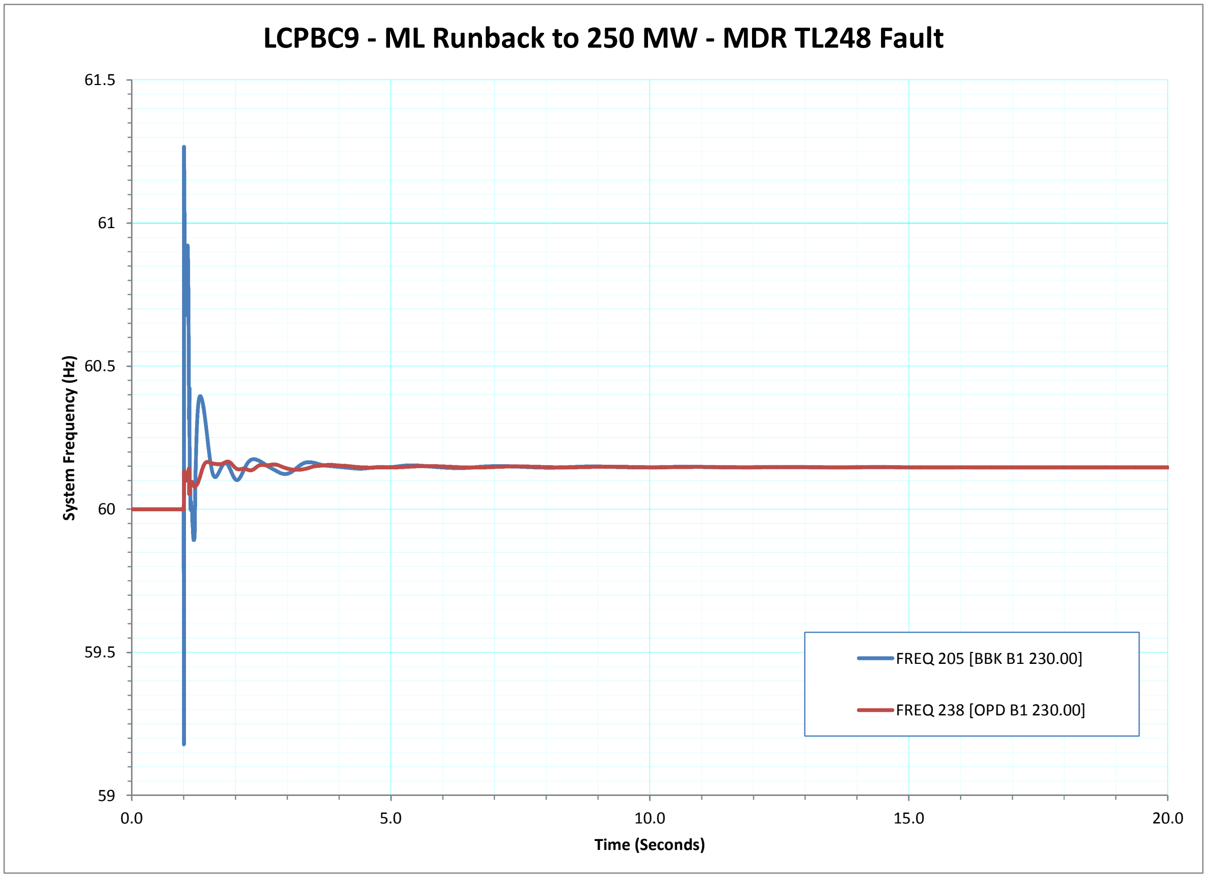


Figure 465 - LCPBC9 - ML Runback to 250 MW - MDR TL248 Fault - System Frequency (Hz)

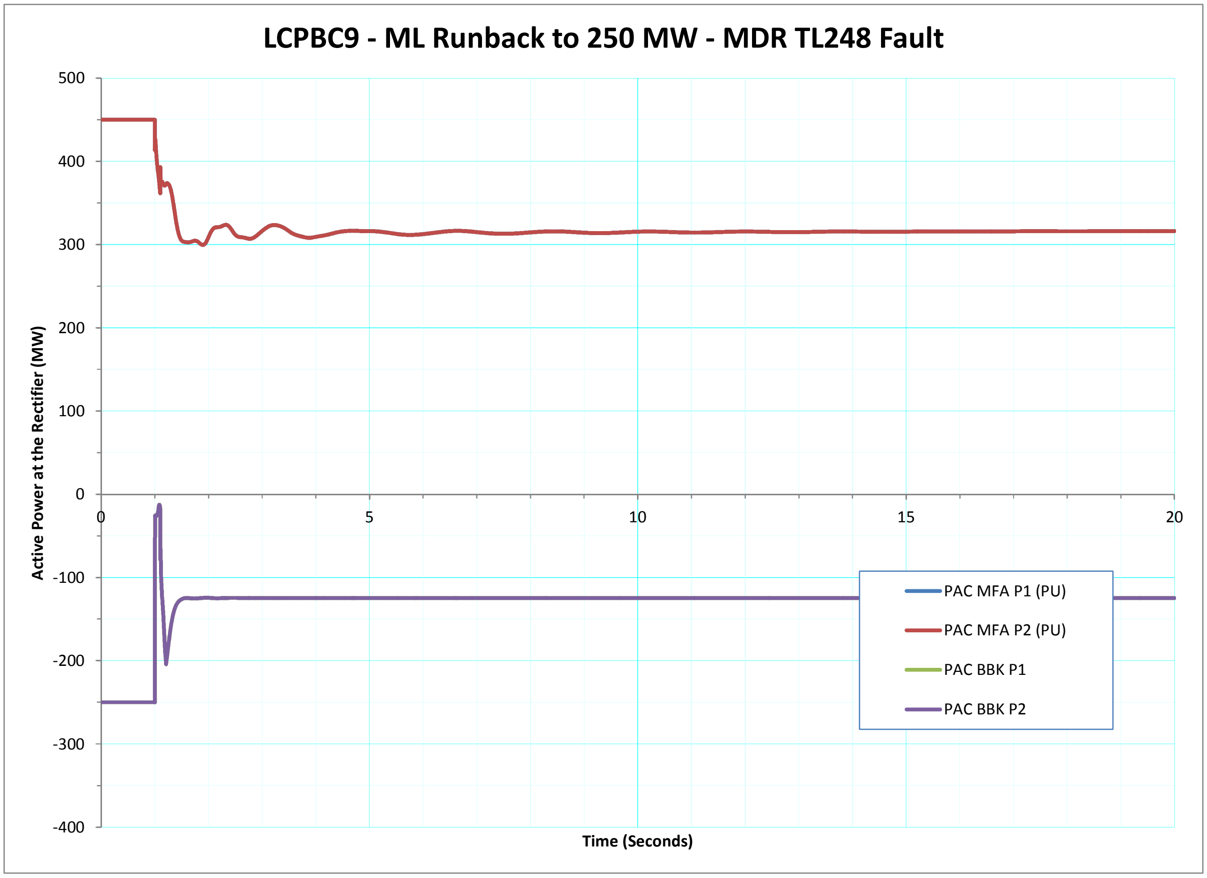


Figure 466 - LCPBC9 - ML Runback to 250 MW - MDR TL248 Fault - Active Power at the Rectifier (MW)

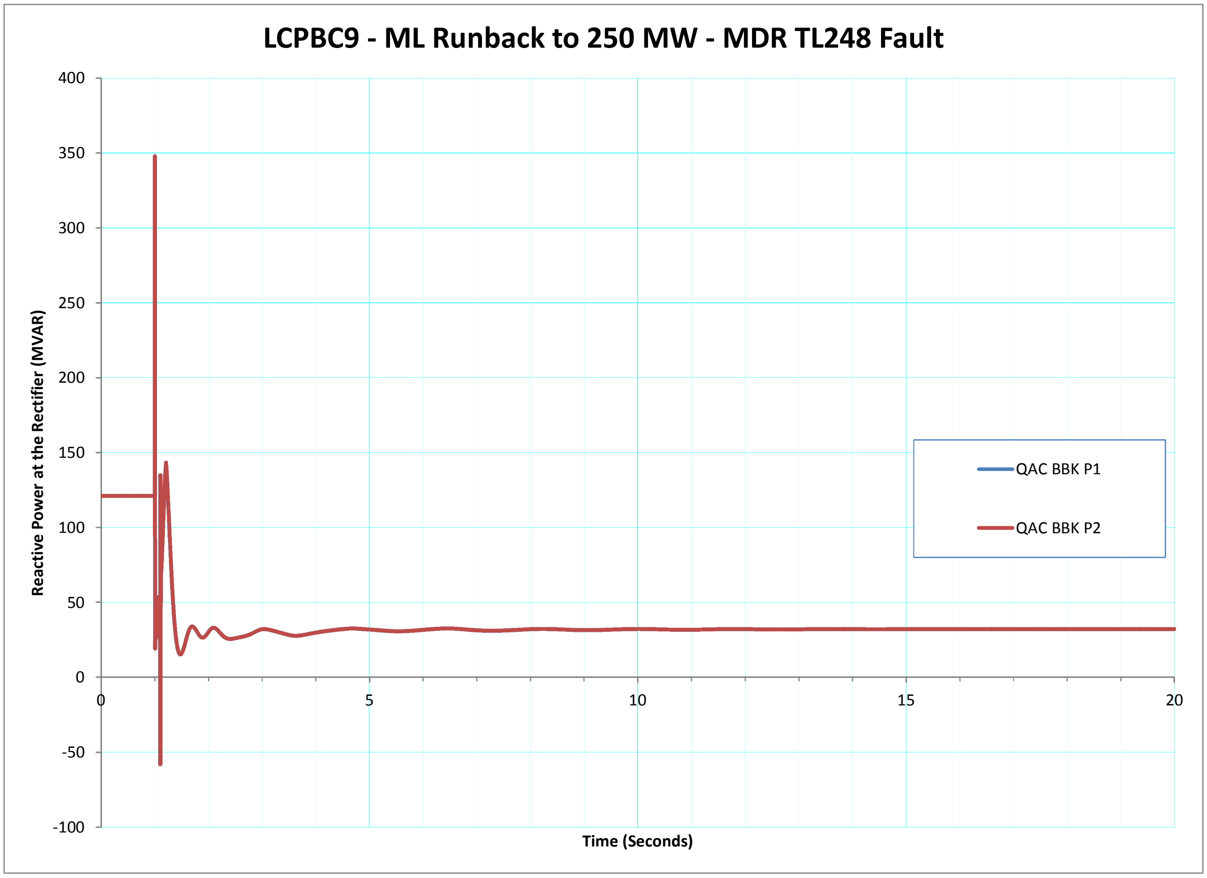


Figure 467 - LCPBC9 - ML Runback to 250 MW - MDR TL248 Fault - Reactive Power at the Rectifier (MVAR)

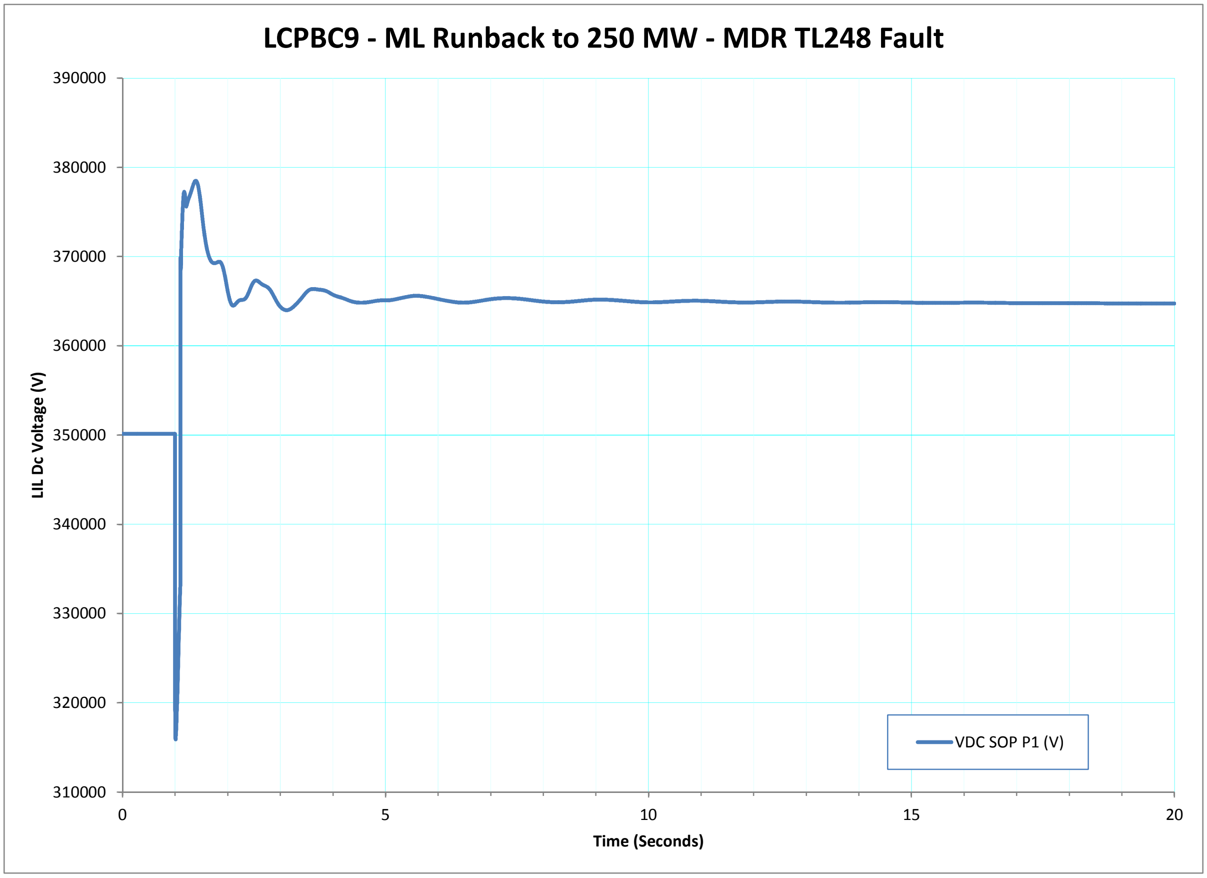


Figure 468 - LCPBC9 - ML Runback to 250 MW - MDR TL248 Fault - LIL Dc Voltage (V)

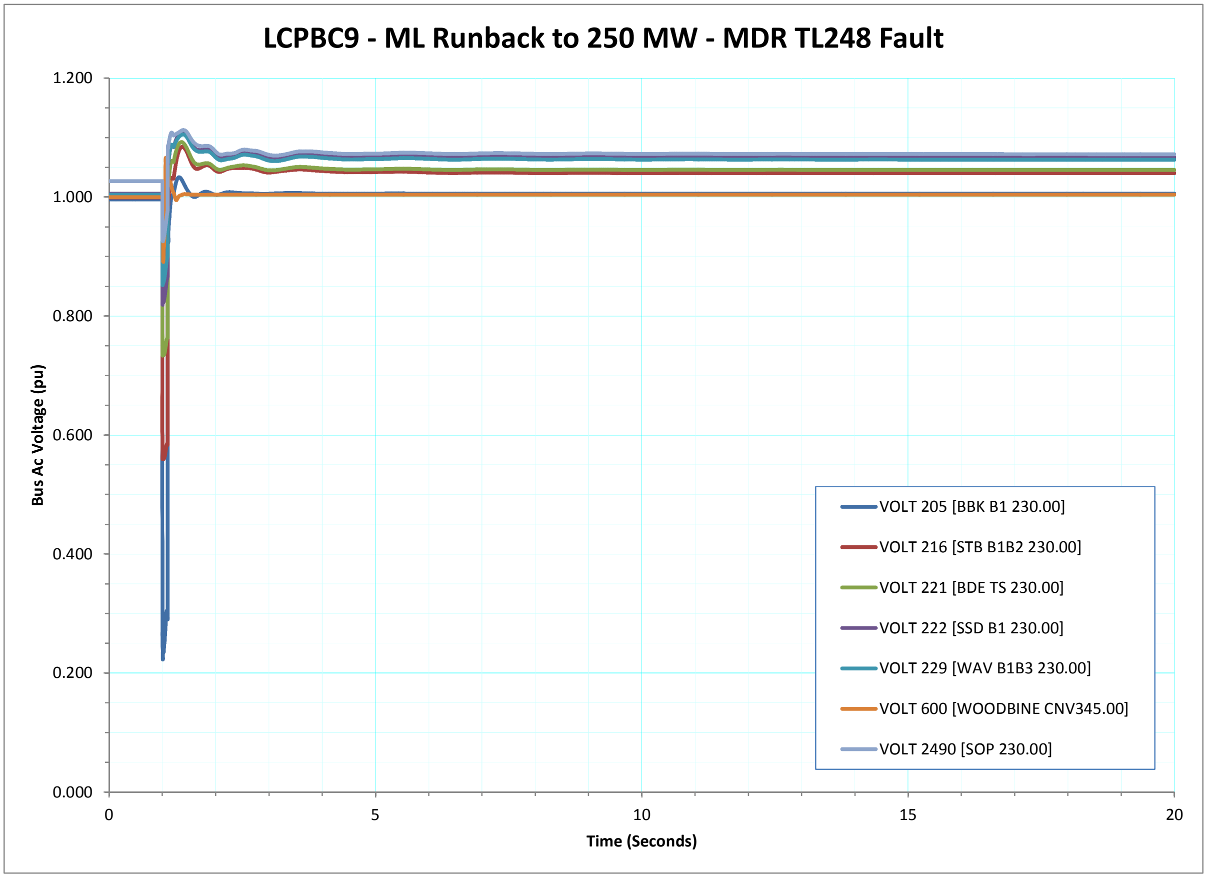


Figure 469 - LCPBC9 - ML Runback to 250 MW - MDR TL248 Fault - Bus Ac Voltage (pu)

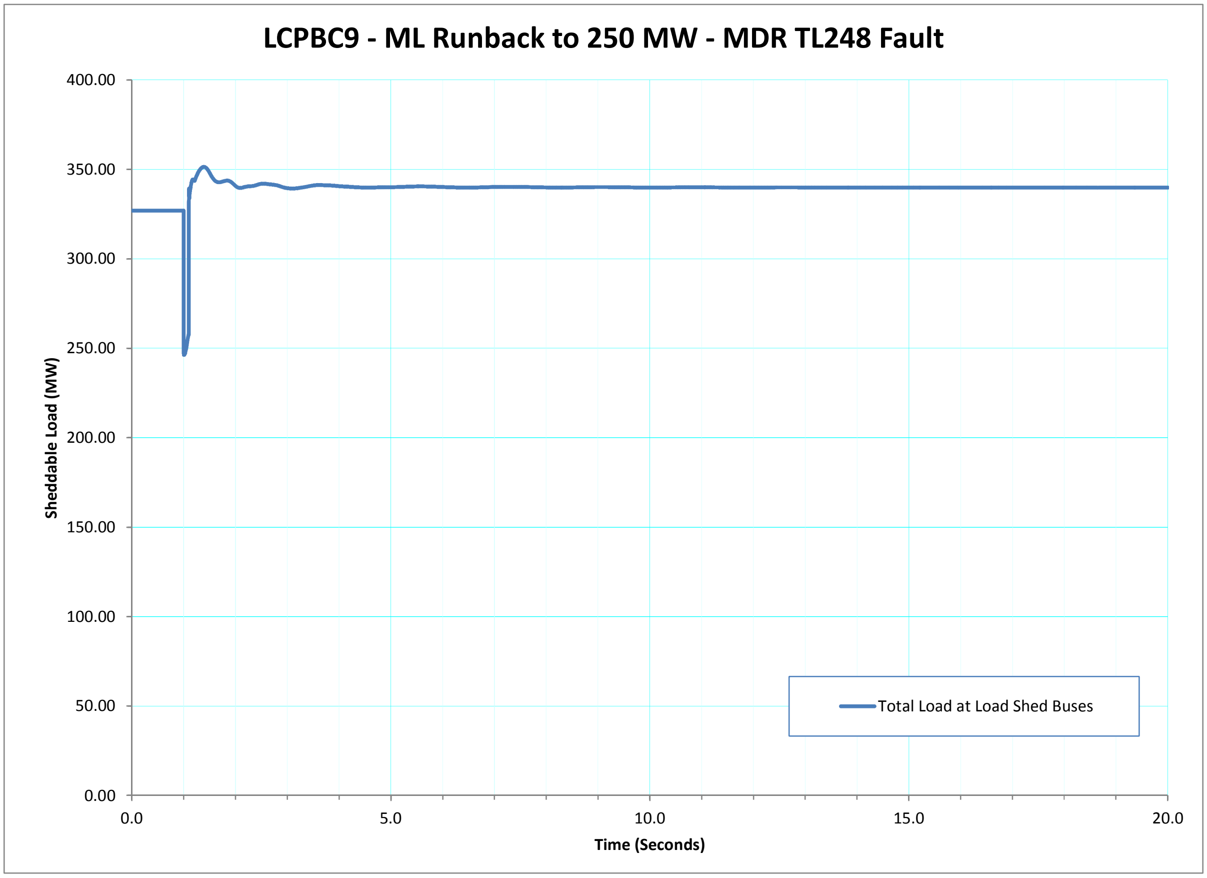


Figure 470 - LCPBC9 - ML Runback to 250 MW - MDR TL248 Fault - Sheddable Load (MW)

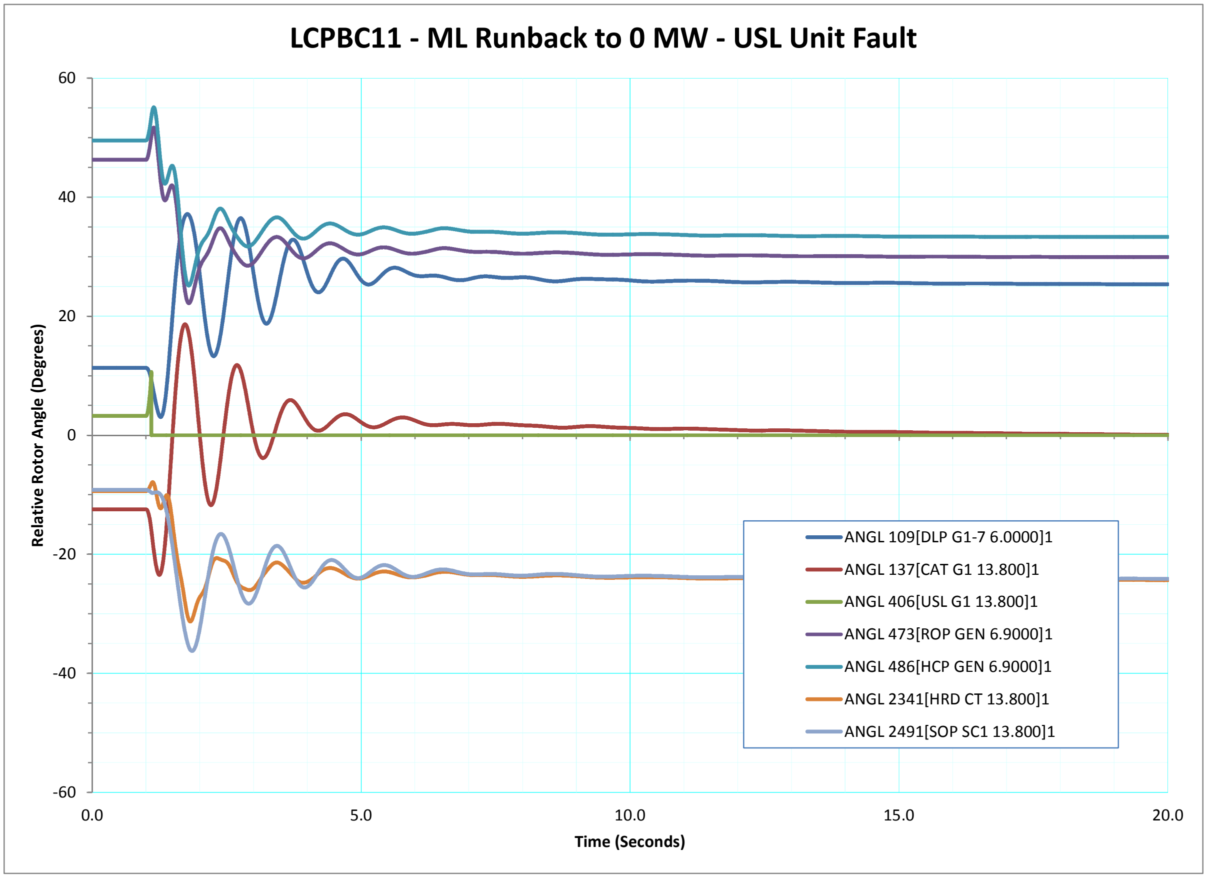


Figure 471 - LCPBC11 - ML Runback to 0 MW - USL Unit Fault - Relative Rotor Angle (Degrees)

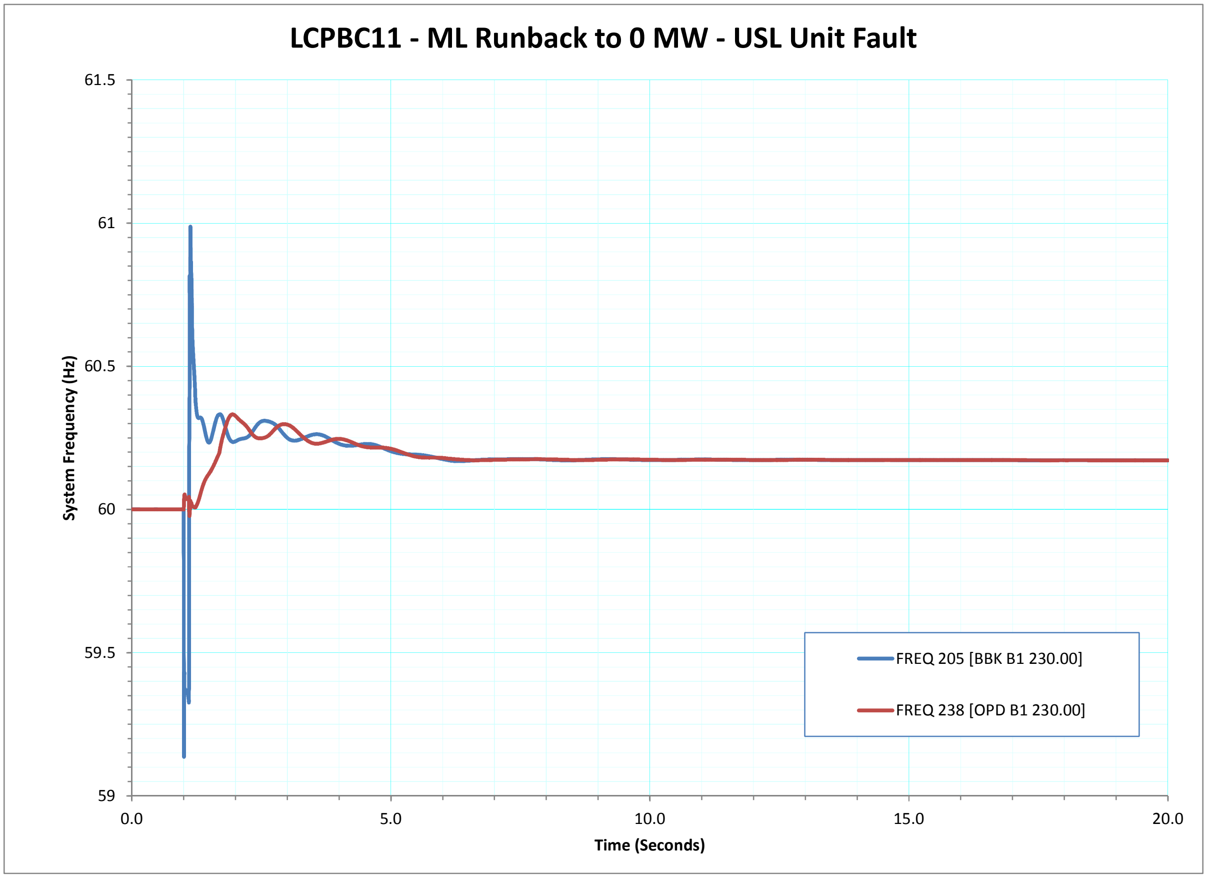


Figure 472 - LCPBC11 - ML Runback to 0 MW - USL Unit Fault - System Frequency (Hz)

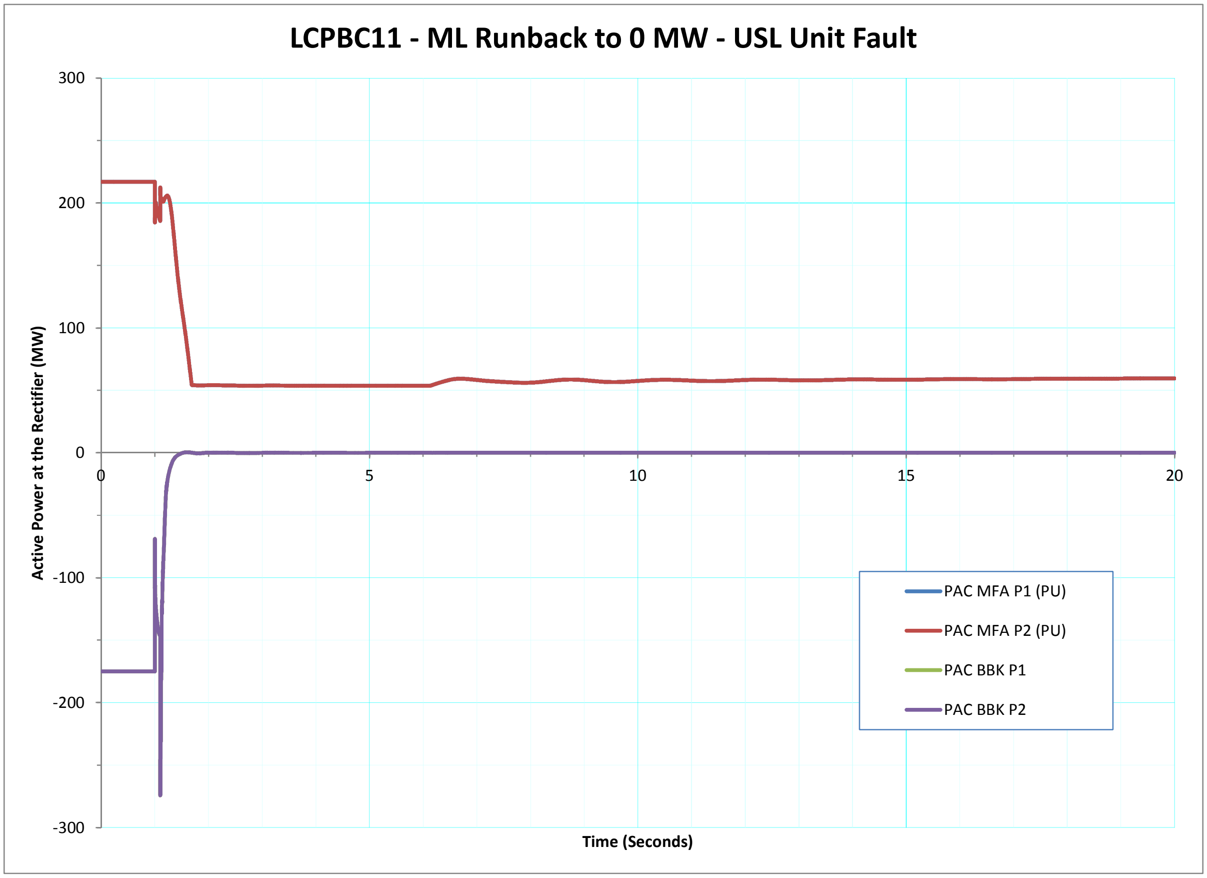


Figure 473 - LCPBC11 - ML Runback to 0 MW - USL Unit Fault - Active Power at the Rectifier (MW)

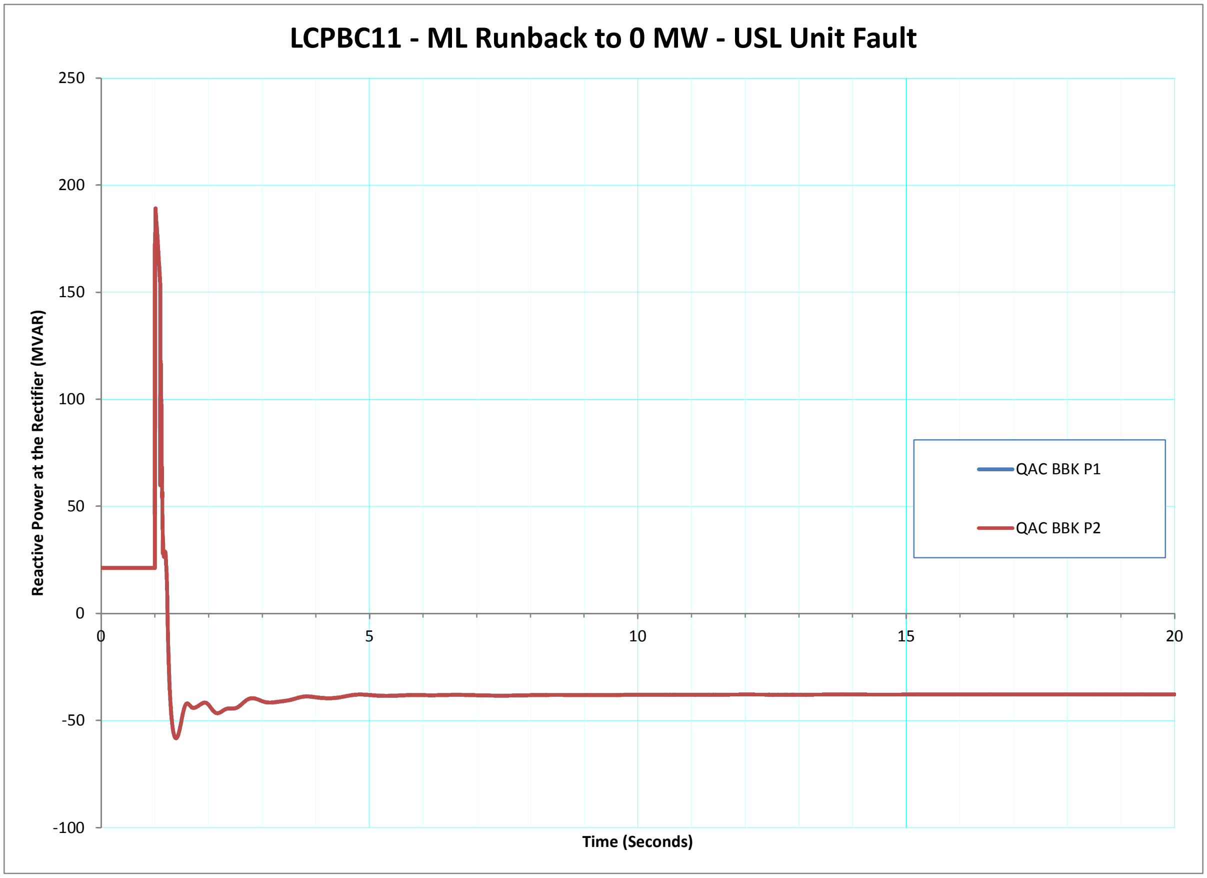


Figure 474 - LCPBC11 - ML Runback to 0 MW - USL Unit Fault - Reactive Power at the Rectifier (MVAR)

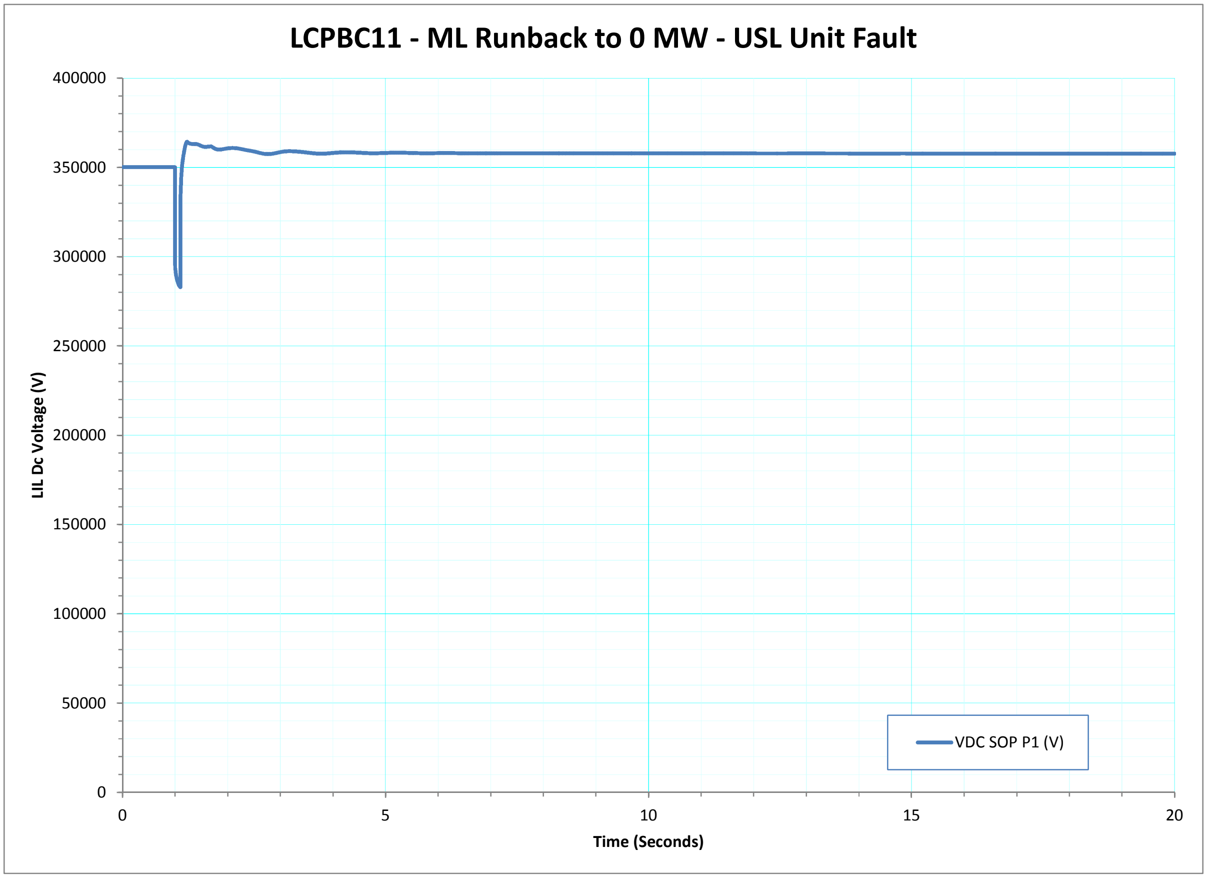


Figure 475 - LCPBC11 - ML Runback to 0 MW - USL Unit Fault - LIL Dc Voltage (V)

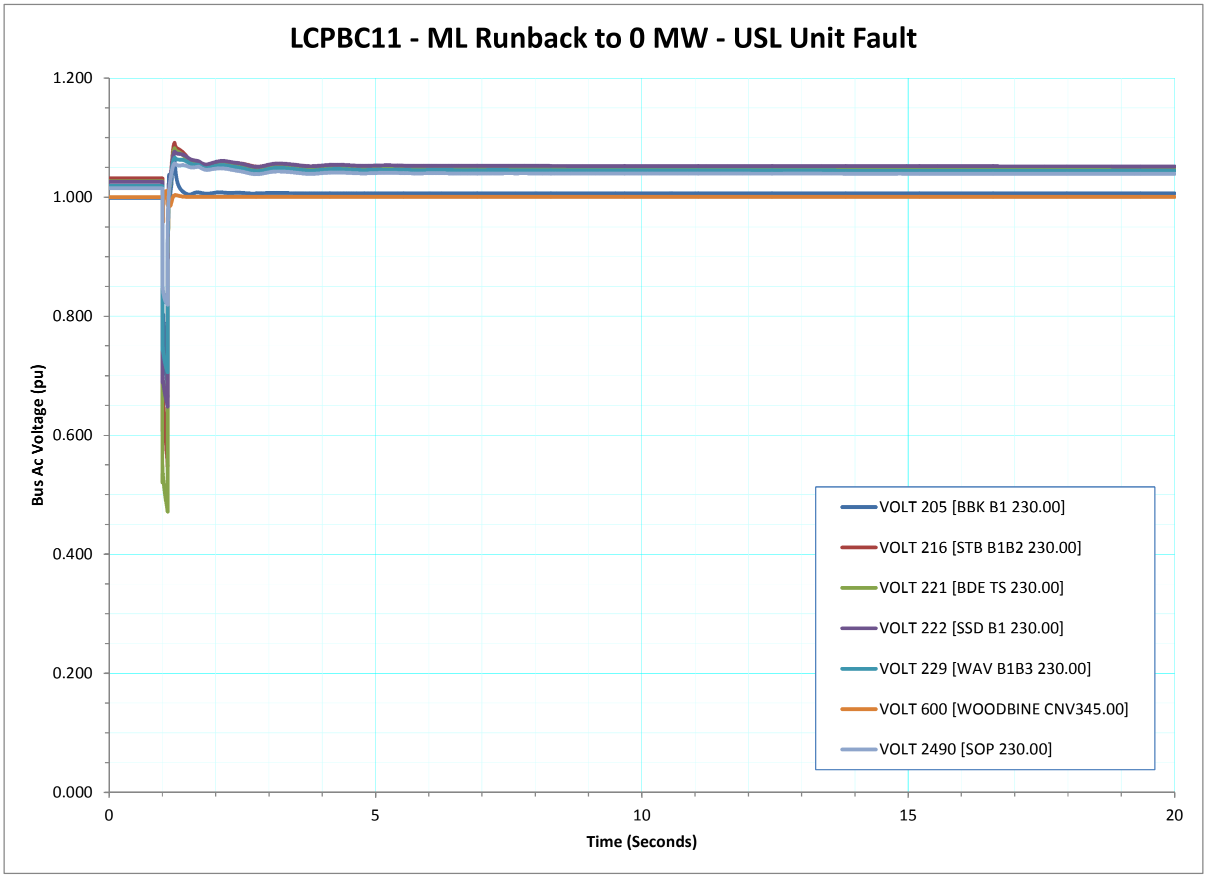


Figure 476 - LCPBC11 - ML Runback to 0 MW - USL Unit Fault - Bus Ac Voltage (pu)

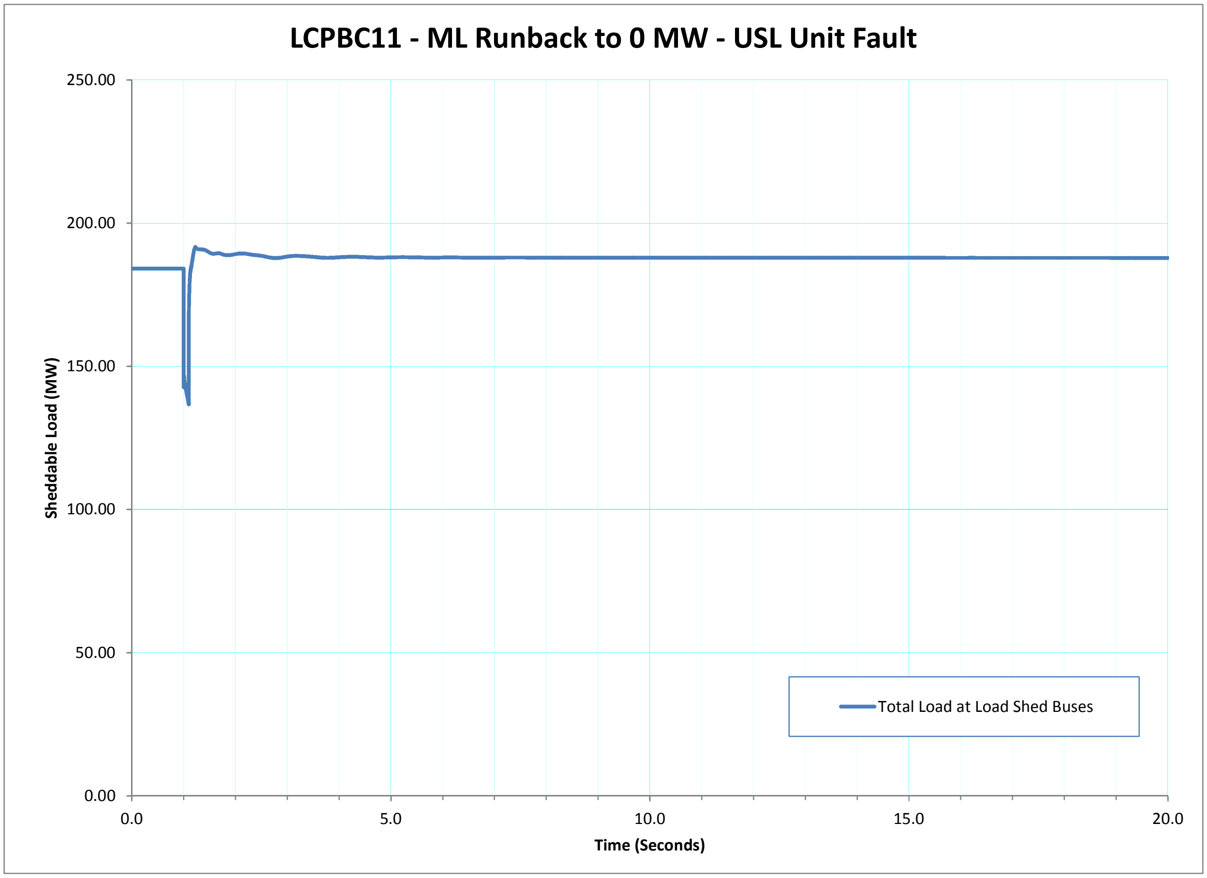


Figure 477 - LCPBC11 - ML Runback to 0 MW - USL Unit Fault - Sheddable Load (MW)

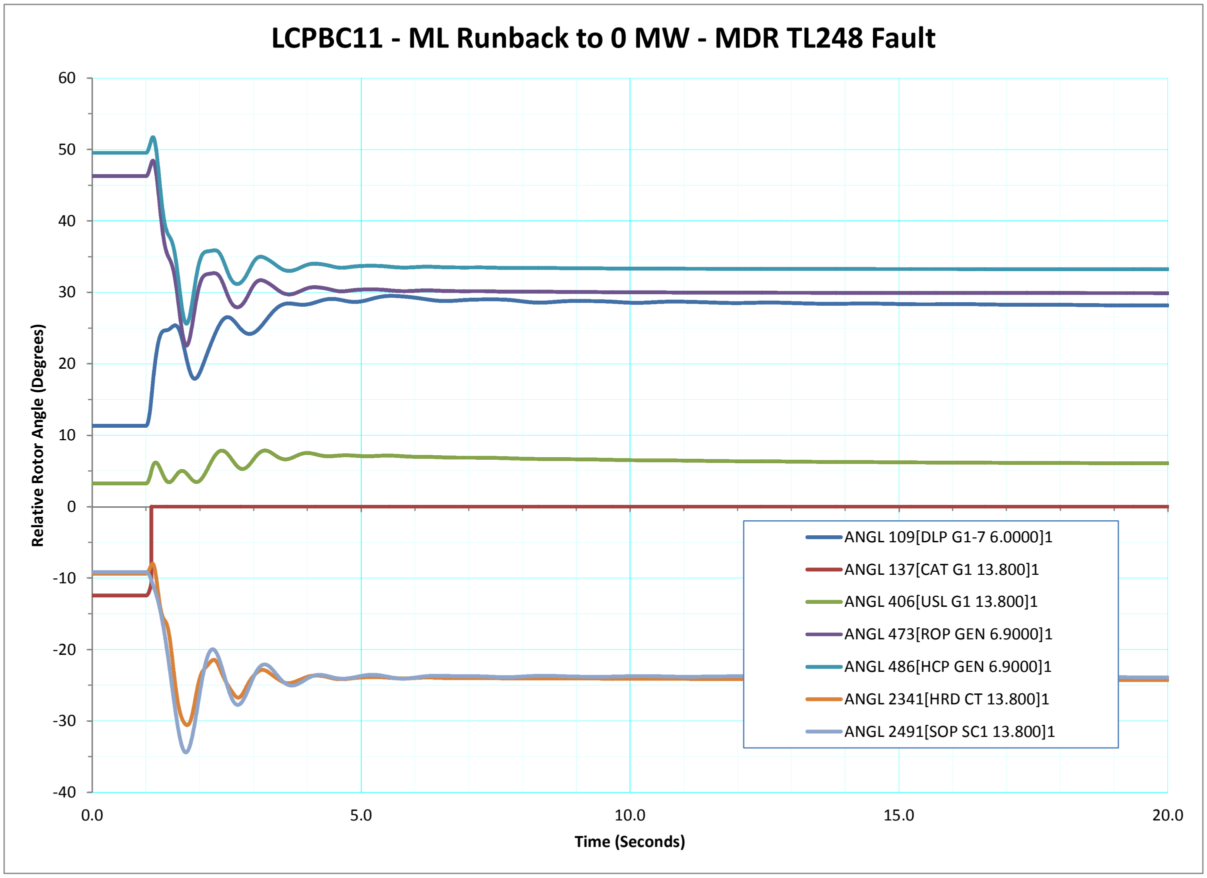


Figure 478 - LCPBC11 - ML Runback to 0 MW - MDR TL248 Fault - Relative Rotor Angle (Degrees)

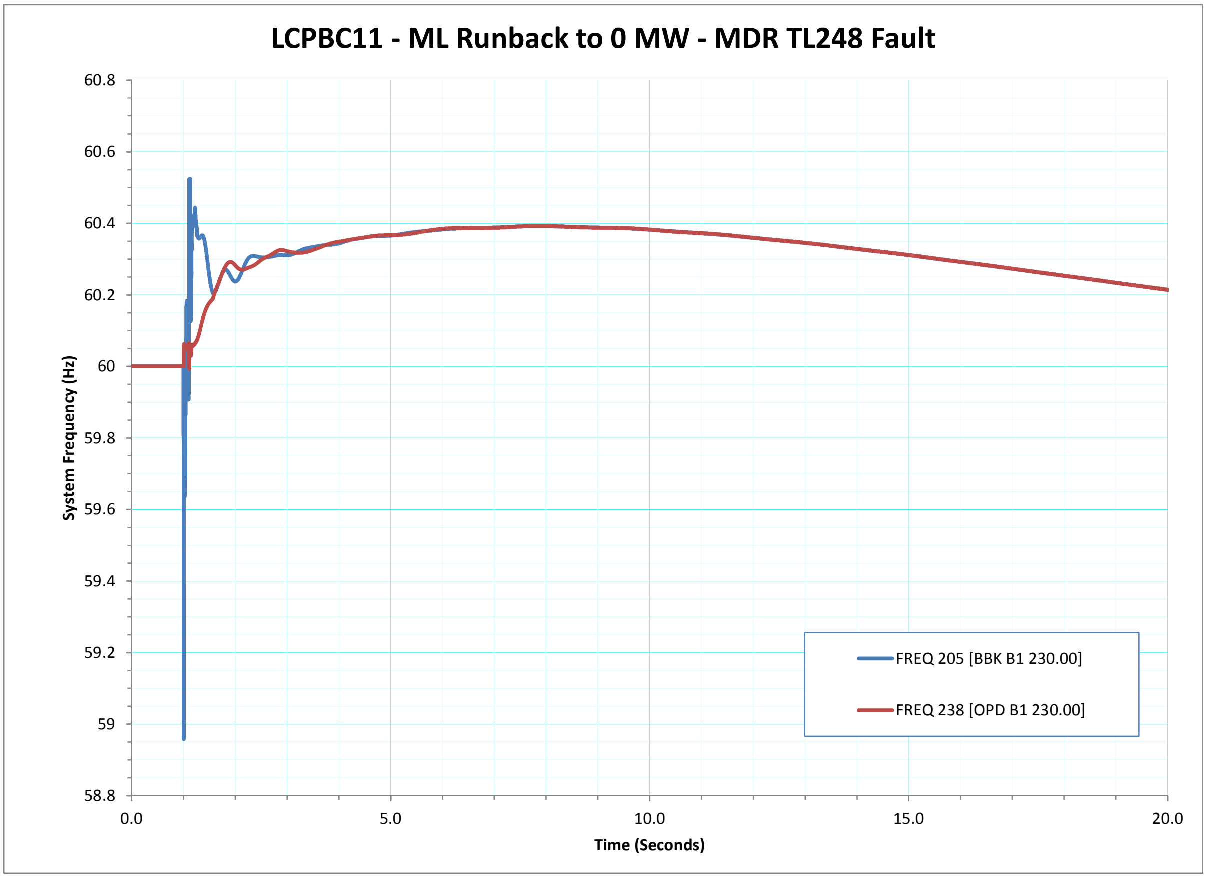


Figure 479 - LCPBC11 - ML Runback to 0 MW - MDR TL248 Fault - System Frequency (Hz)

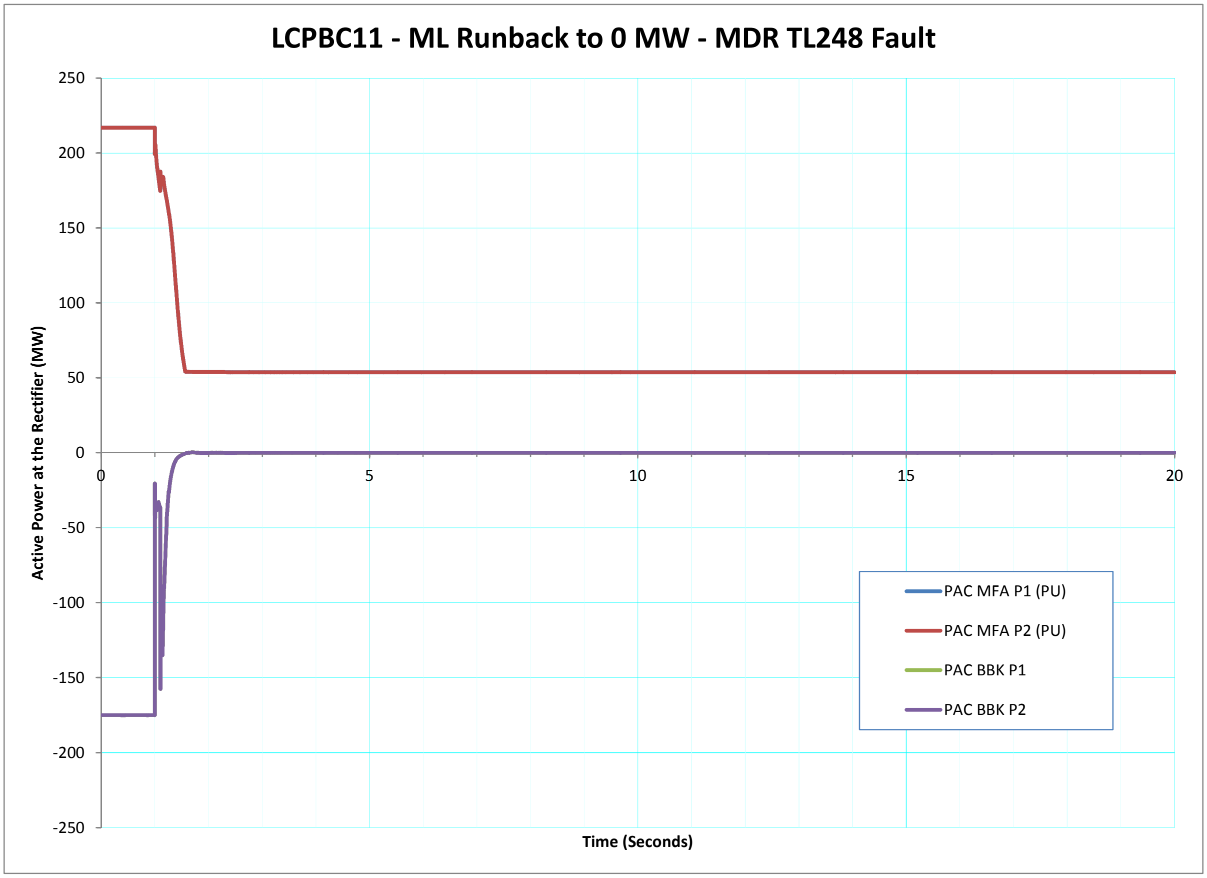


Figure 480 - LCPBC11 - ML Runback to 0 MW - MDR TL248 Fault - Active Power at the Rectifier (MW)

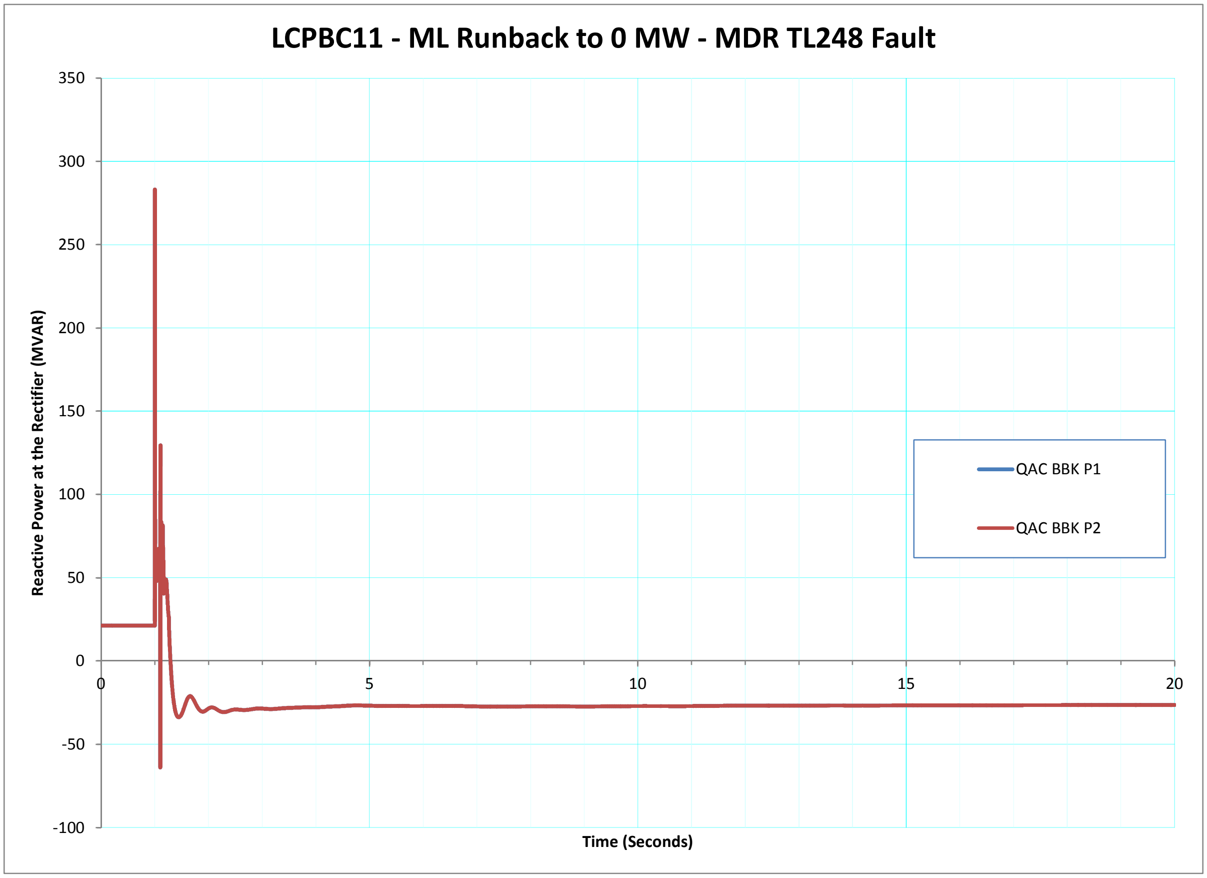


Figure 481 - LCPBC11 - ML Runback to 0 MW - MDR TL248 Fault - Reactive Power at the Rectifier (MVAR)

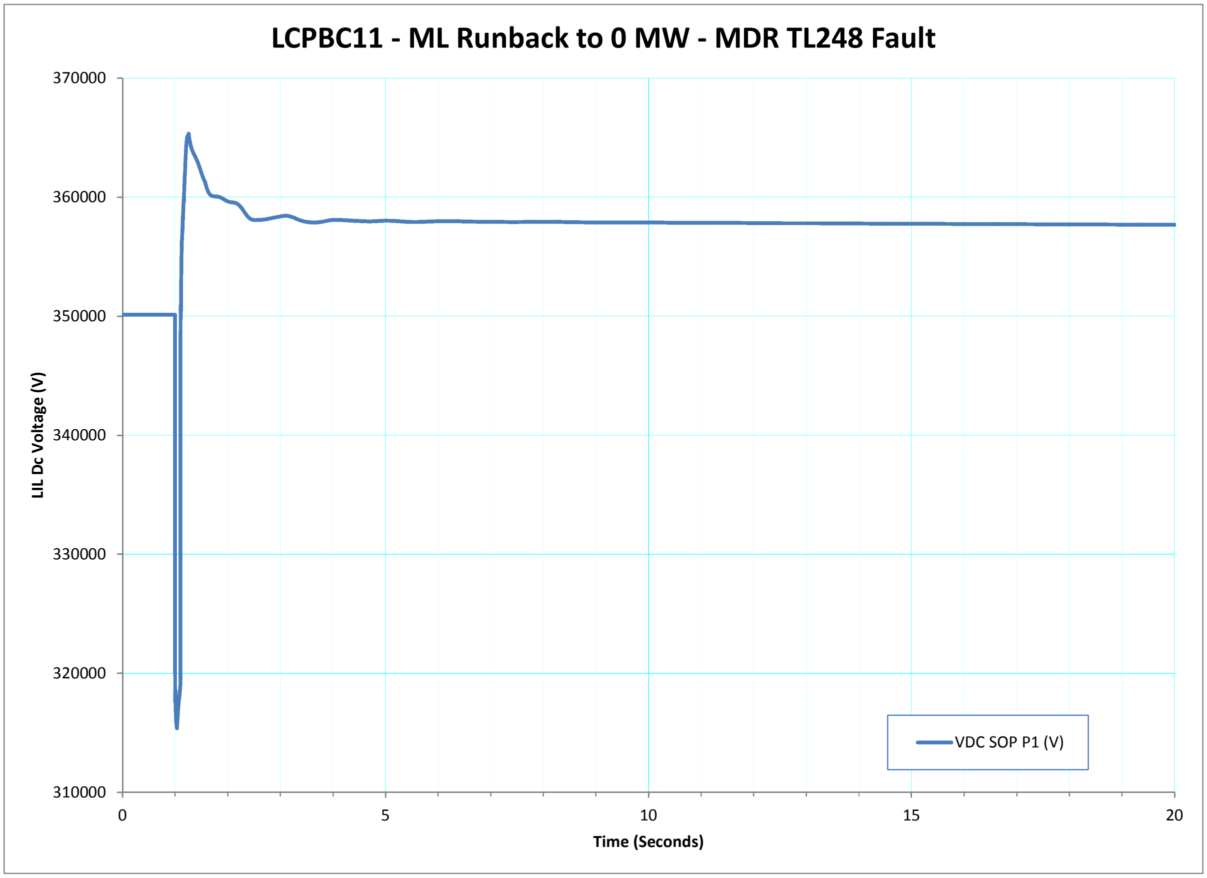


Figure 482 - LCPBC11 - ML Runback to 0 MW - MDR TL248 Fault - LIL Dc Voltage (V)

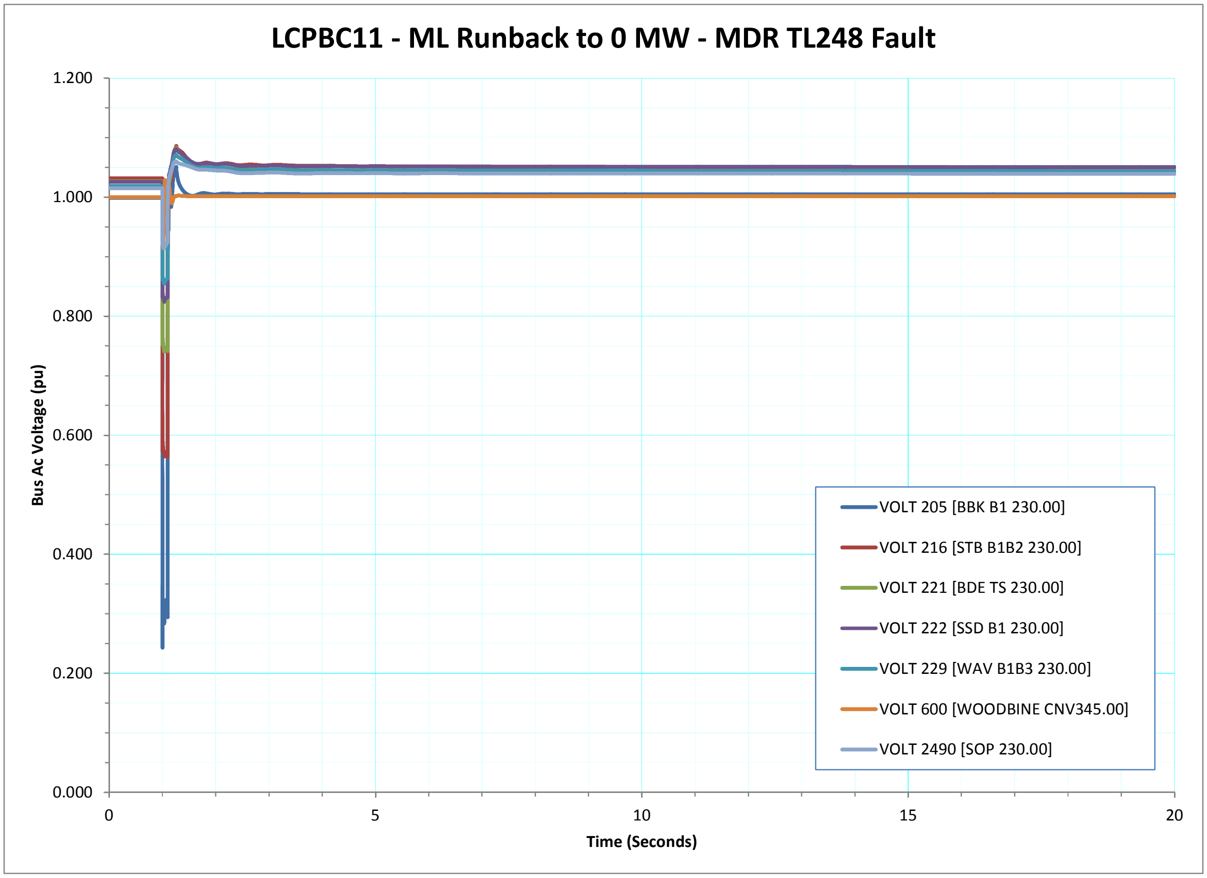


Figure 483 - LCPBC11 - ML Runback to 0 MW - MDR TL248 Fault - Bus Ac Voltage (pu)

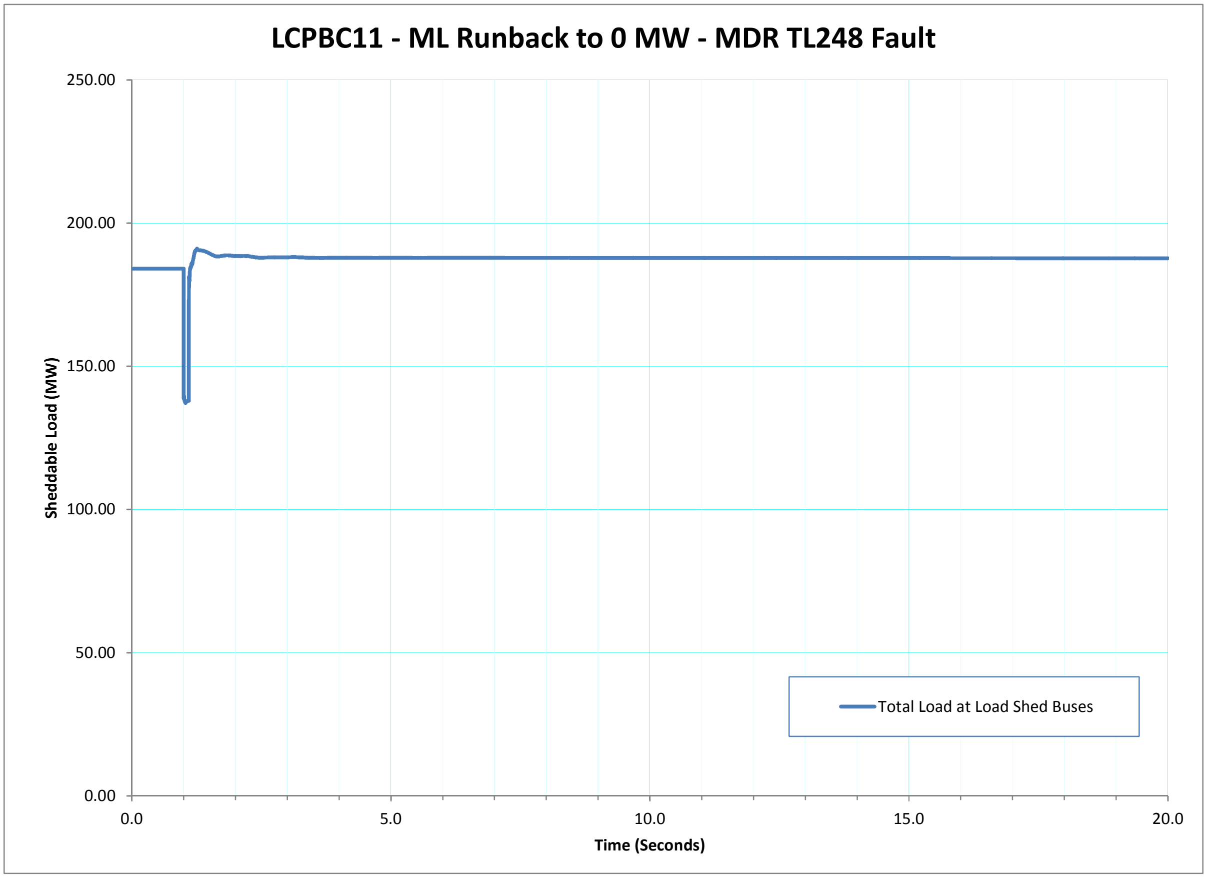
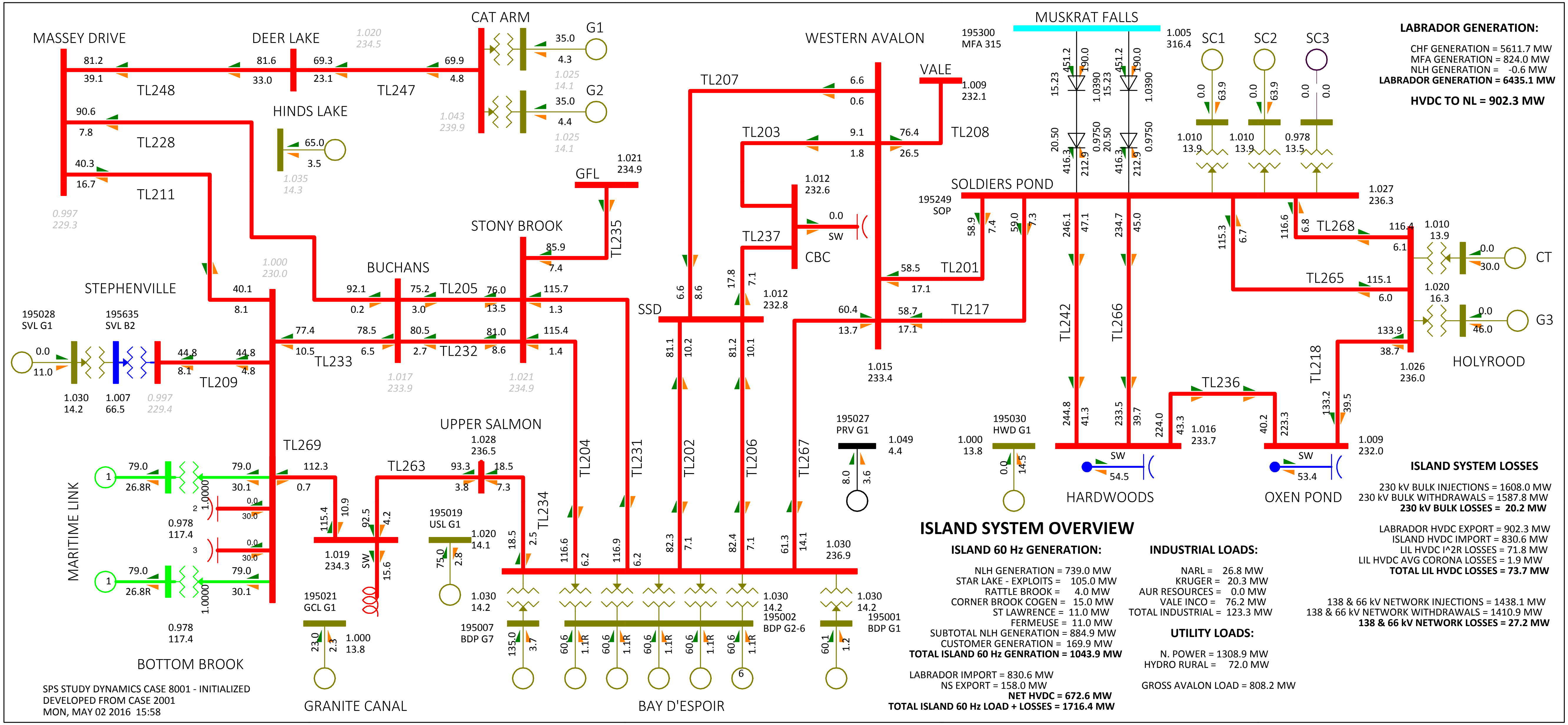
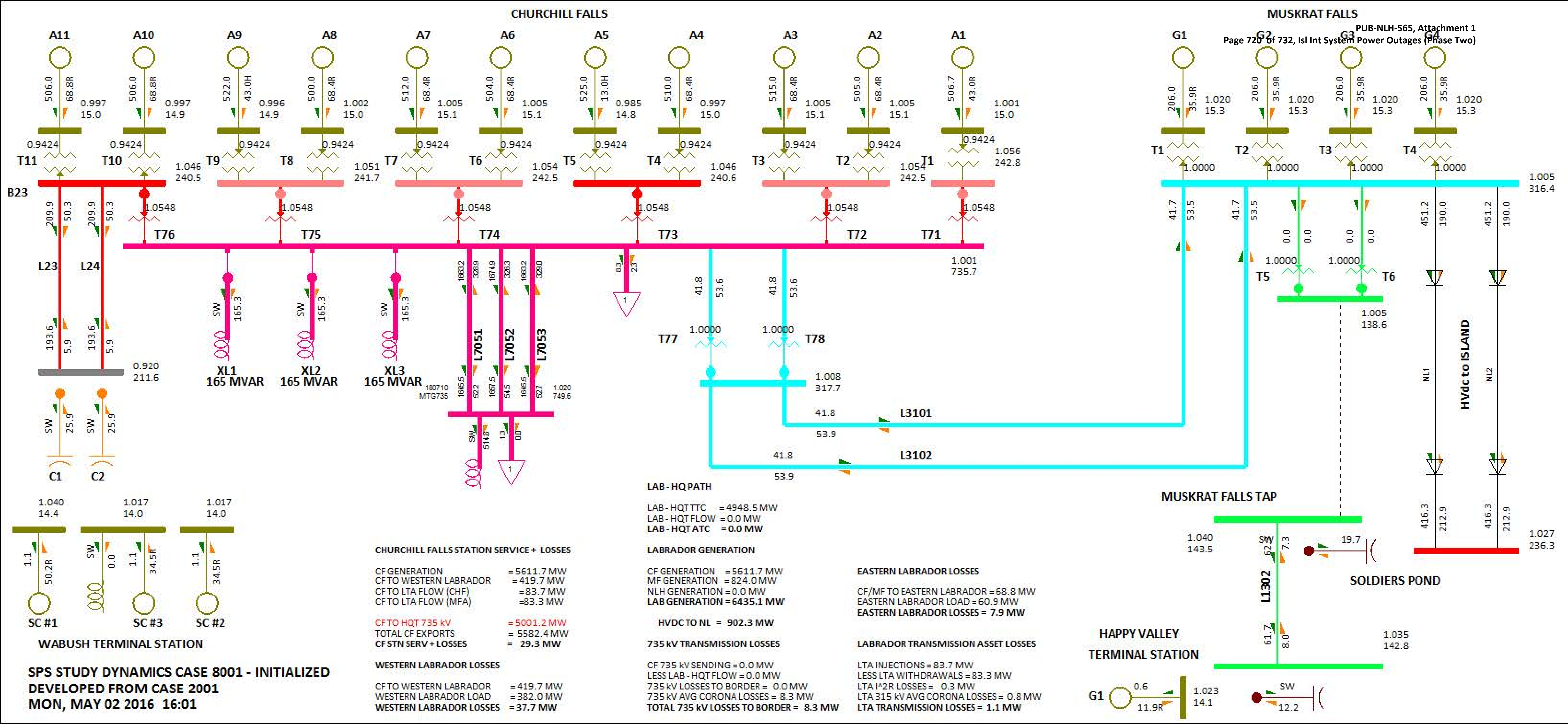


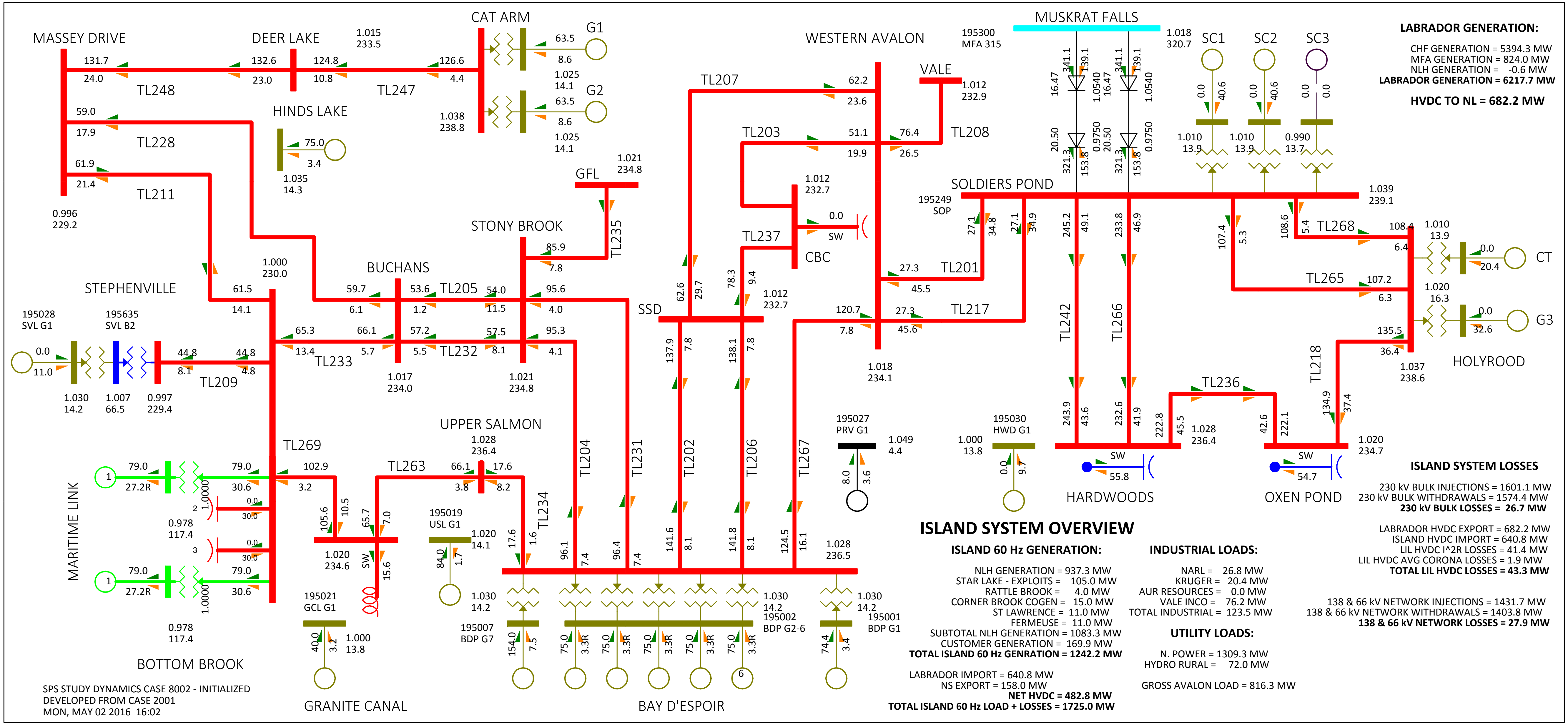
Figure 484 - LCPBC11 - ML Runback to 0 MW - MDR TL248 Fault - Sheddable Load (MW)

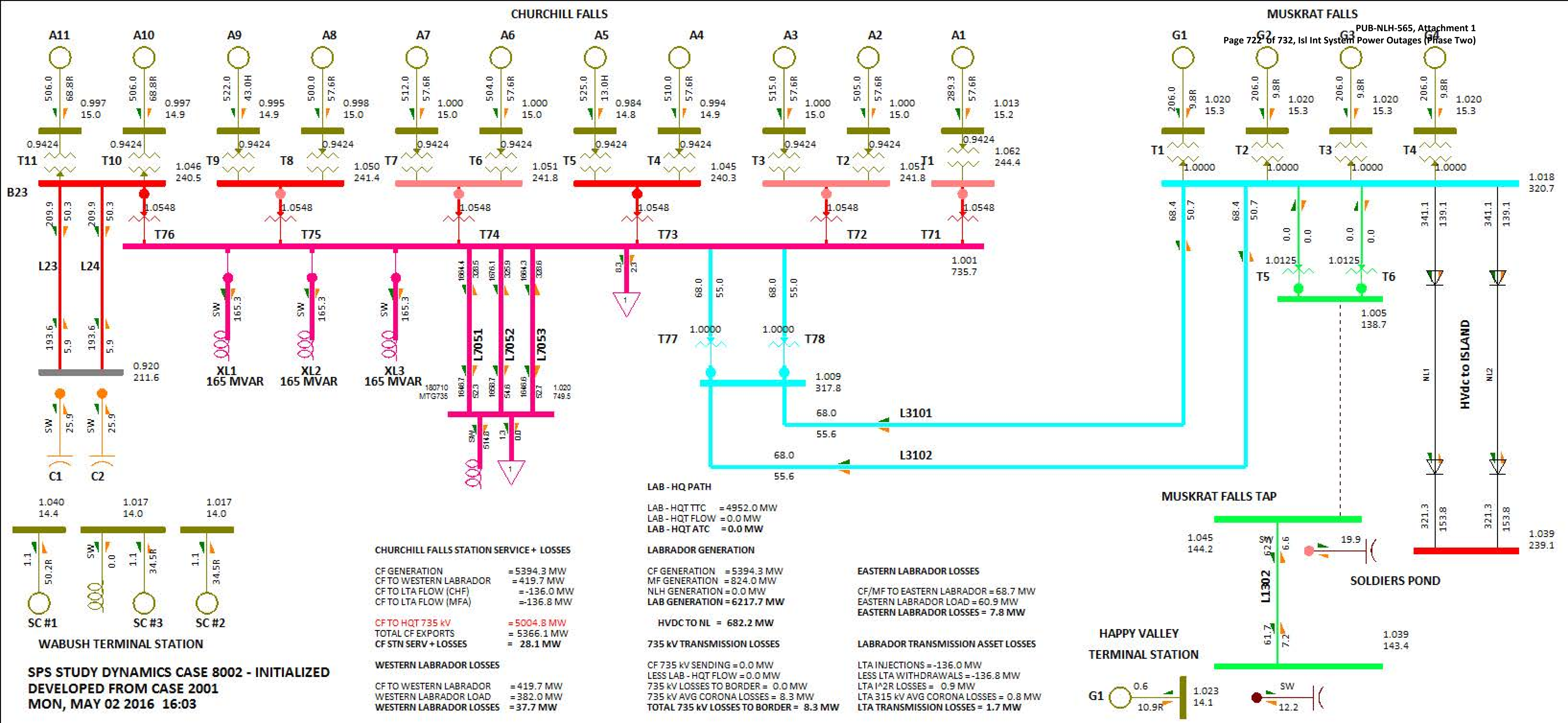
APPENDIX C

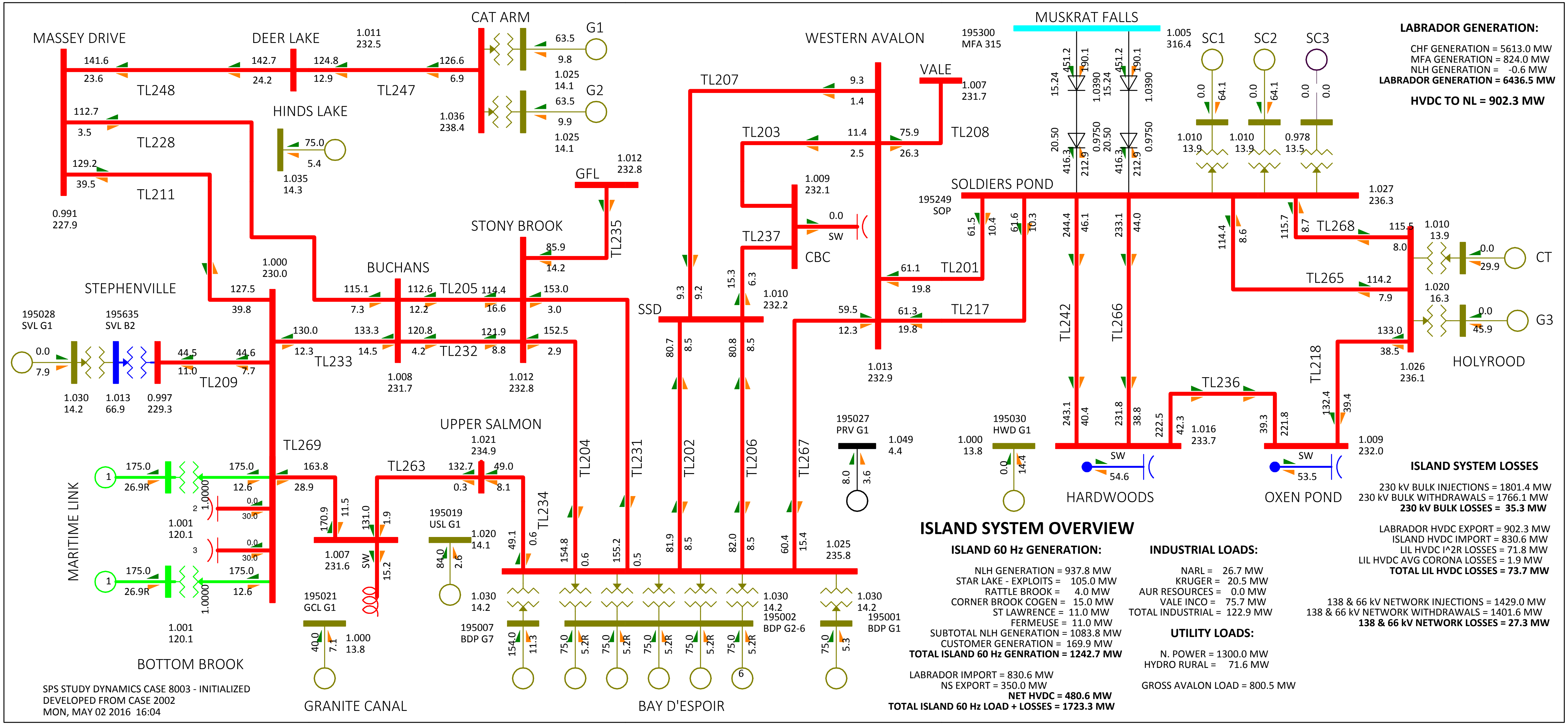
POWER SYSTEM STUDY BASE CASE LOAD FLOW DIAGRAMS

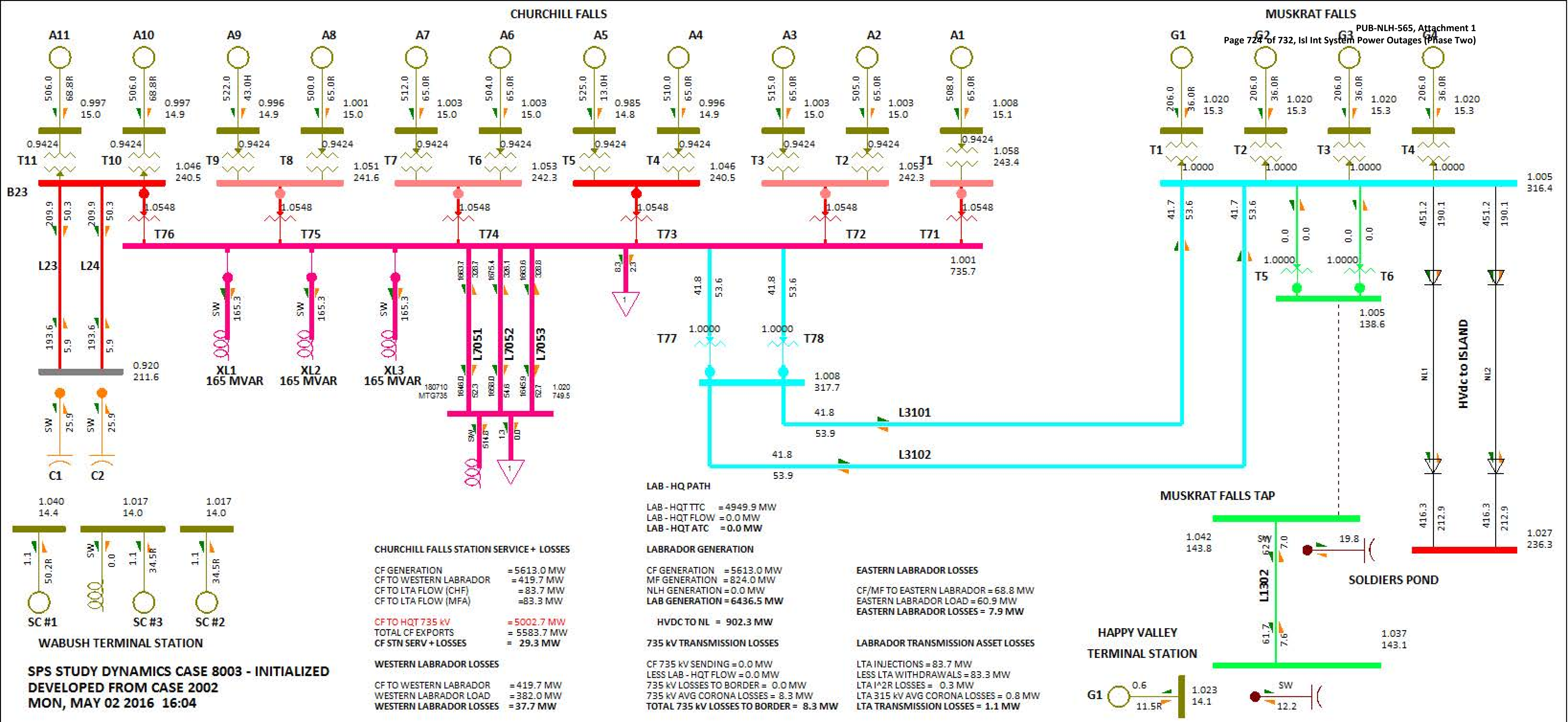

LABRADOR GENERATION:
CHF GENERATION = 5611.7 MW
MFA GENERATION = 824.0 MW
NLH GENERATION = -0.6 MW
LABRADOR GENERATION = 6435.1 MW
HVDC TO NL = 902.3 MW
ISLAND SYSTEM OVERVIEW
ISLAND 60 Hz GENERATION:
NLH GENERATION = 739.0 MW
STAR LAKE - EXPLOITS = 105.0 MW
RATTLE BROOK = 4.0 MW
CORNER BROOK COGEN = 15.0 MW
ST LAWRENCE = 11.0 MW
FERMEUSE = 11.0 MW
SUBTOTAL NLH GENERATION = 884.9 MW
CUSTOMER GENERATION = 169.9 MW
TOTAL ISLAND 60 Hz GENERATION = 1043.9 MW
LABRADOR IMPORT = 830.6 MW
NS EXPORT = 158.0 MW
NET HVDC = 672.6 MW
TOTAL ISLAND 60 Hz LOAD + LOSSES = 1716.4 MW
INDUSTRIAL LOADS:
NARL = 26.8 MW
KRUGER = 20.3 MW
AUR RESOURCES = 0.0 MW
VALE INCO = 76.2 MW
TOTAL INDUSTRIAL = 123.3 MW
UTILITY LOADS:
N. POWER = 1308.9 MW
HYDRO RURAL = 72.0 MW
GROSS AVALON LOAD = 808.2 MW
ISLAND SYSTEM LOSSES
230 kV BULK INJECTIONS = 1608.0 MW
230 kV BULK WITHDRAWALS = 1587.8 MW
230 kV BULK LOSSES = 20.2 MW
LABRADOR HVDC EXPORT = 902.3 MW
ISLAND HVDC IMPORT = 830.6 MW
LIL HVDC I^2R LOSSES = 71.8 MW
LIL HVDC AVG CORONA LOSSES = 1.9 MW
TOTAL LIL HVDC LOSSES = 73.7 MW
138 & 66 kV NETWORK INJECTIONS = 1438.1 MW
138 & 66 kV NETWORK WITHDRAWALS = 1410.9 MW
138 & 66 kV NETWORK LOSSES = 27.2 MW
MASSEY DRIVE
DEER LAKE
CAT ARM
HINDS LAKE
STEPHENVILLE
BUCHANS
STONY BROOK
GFL
WESTERN AVALON
VALE
CBC
SSD
MUSKRAT FALLS
SOLDIERS POND
HOLYROOD
UPPER SALMON
HARDWOODS
OXEN POND
MARITIME LINK
BOTTOM BROOK
GRANITE CANAL
BAY D'ESPOIR
SPS STUDY DYNAMICS CASE 8001 - INITIALIZED
DEVELOPED FROM CASE 2001
MON, MAY 02 2016 15:58

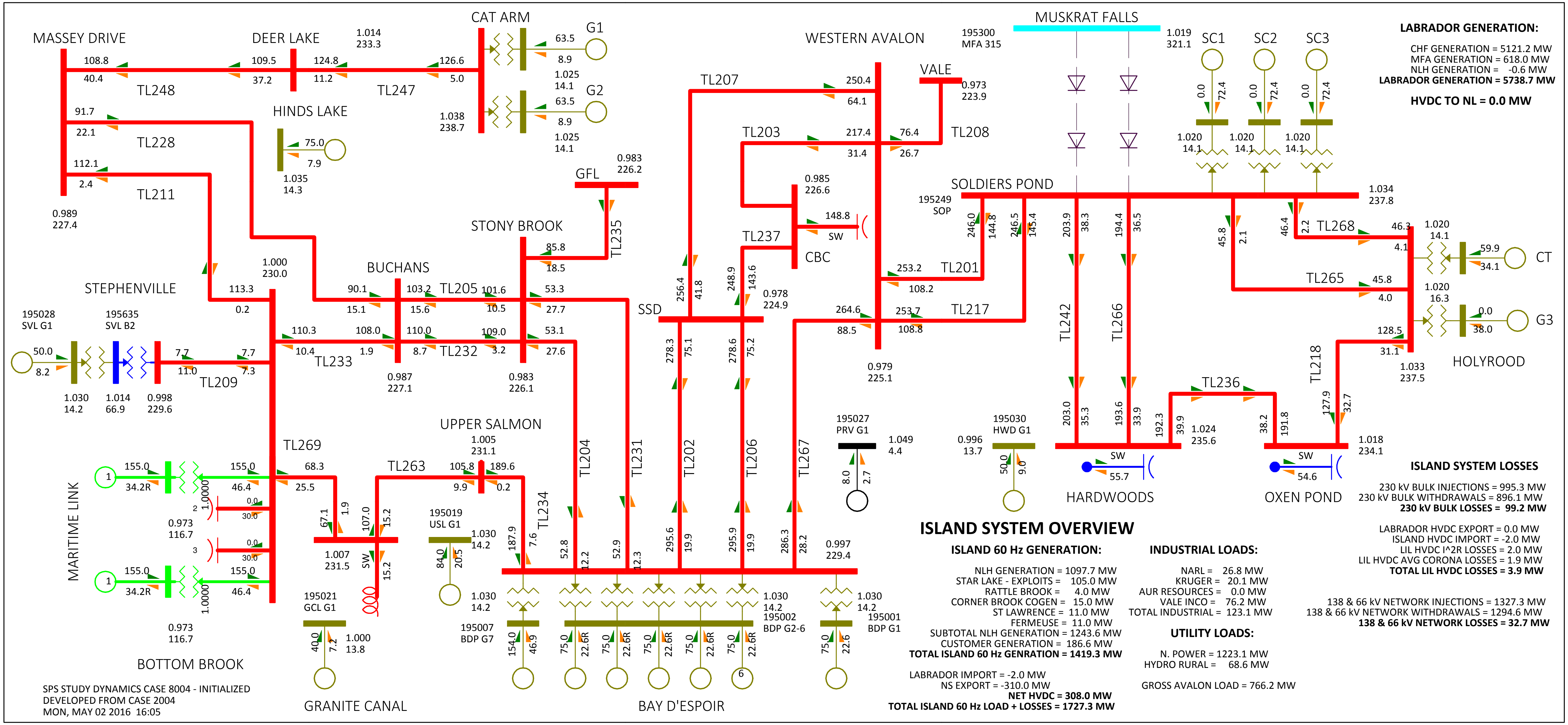

CHURCHILL FALLS
MUSKRAT FALLS
A11
A10
A9
A8
A7
A6
A5
A4
A3
A2
A1
G1
G2
G3
G4
T11
T10
T9
T8
T7
T6
T5
T4
T3
T2
T1
B23
T76
T75
T74
T73
T72
T71
L23
L24
XL1
165 MVAR
XL2
165 MVAR
XL3
165 MVAR
L7051
L7052
L7053
T77
T78
L3101
L3102
HVdc to ISLAND
C1
C2
SC #1
SC #3
SC #2
WABUSH TERMINAL STATION
MUSKRAT FALLS TAP
SOLDIERS POND
L1302
HAPPY VALLEY
TERMINAL STATION
LAB - HQ PATH
LAB - HQT TTC = 4948.5 MW
LAB - HQT FLOW = 0.0 MW
LAB - HQT ATC = 0.0 MW
LABRADOR GENERATION
CF GENERATION = 5611.7 MW
MF GENERATION = 824.0 MW
NLH GENERATION = 0.0 MW
LAB GENERATION = 6435.1 MW
HVDC TO NL = 902.3 MW
735 kV TRANSMISSION LOSSES
CF 735 kV SENDING = 0.0 MW
LESS LAB - HQT FLOW = 0.0 MW
735 kV LOSSES TO BORDER = 0.0 MW
735 kV AVG CORONA LOSSES = 8.3 MW
TOTAL 735 kV LOSSES TO BORDER = 8.3 MW
CHURCHILL FALLS STATION SERVICE + LOSSES
CF GENERATION = 5611.7 MW
CF TO WESTERN LABRADOR = 419.7 MW
CF TO LTA FLOW (CHF) = 83.7 MW
CF TO LTA FLOW (MFA) = 83.3 MW
CF TO HQT 735 kV = 5001.2 MW
TOTAL CF EXPORTS = 5582.4 MW
CF STN SERV + LOSSES = 29.3 MW
WESTERN LABRADOR LOSSES
CF TO WESTERN LABRADOR = 419.7 MW
WESTERN LABRADOR LOAD = 382.0 MW
WESTERN LABRADOR LOSSES = 37.7 MW
EASTERN LABRADOR LOSSES
CF/MF TO EASTERN LABRADOR = 68.8 MW
EASTERN LABRADOR LOAD = 60.9 MW
EASTERN LABRADOR LOSSES = 7.9 MW
LABRADOR TRANSMISSION ASSET LOSSES
LTA INJECTIONS = 83.7 MW
LESS LTA WITHDRAWALS = 83.3 MW
LTA I^2R LOSSES = 0.3 MW
LTA 315 kV AVG CORONA LOSSES = 0.8 MW
LTA TRANSMISSION LOSSES = 1.1 MW
SPS STUDY DYNAMICS CASE 8001 - INITIALIZED
DEVELOPED FROM CASE 2001
MON, MAY 02 2016 16:01

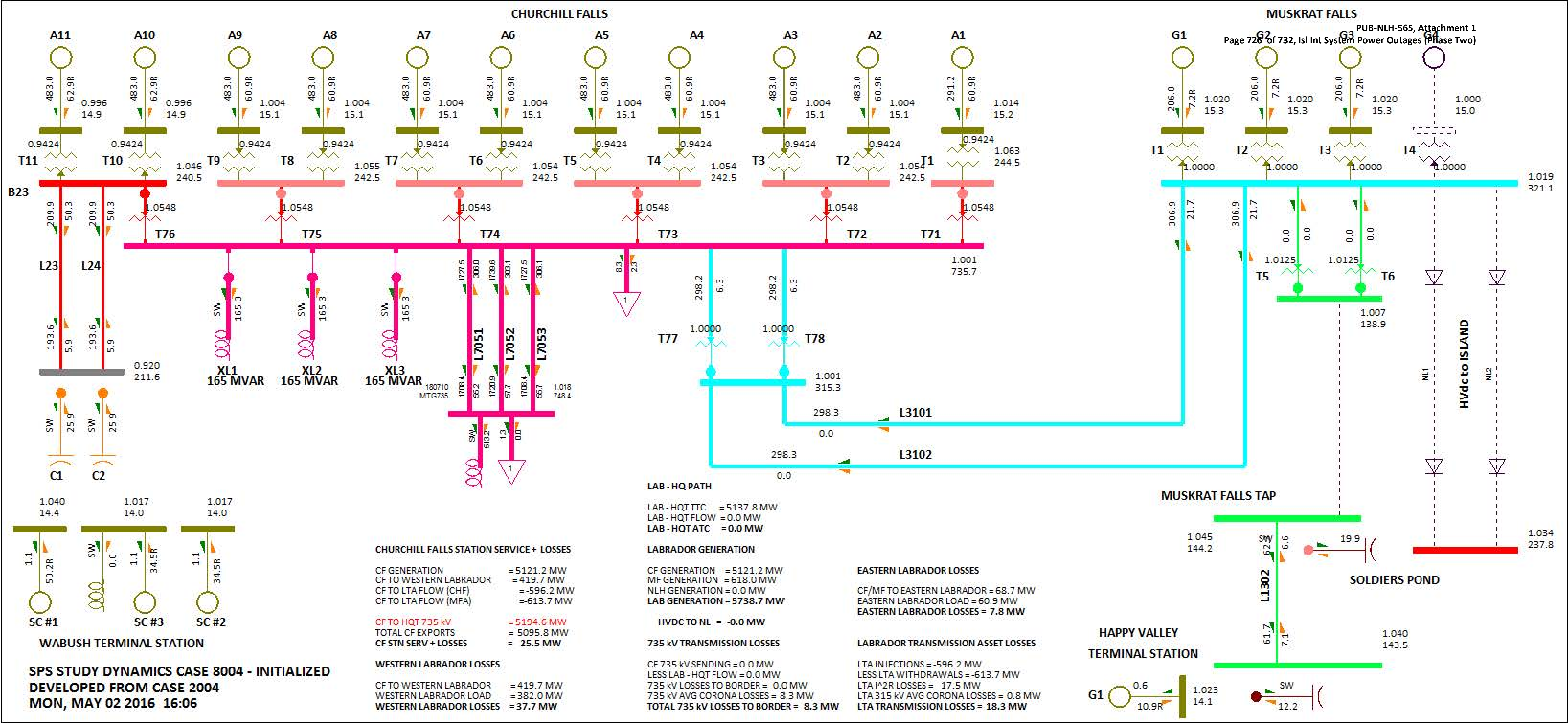

MASSEY DRIVE
DEER LAKE
CAT ARM
HINDS LAKE
WESTERN AVALON
VALE
MUSKRAT FALLS
SC1
SC2
SC3
SOLDIERS POND
GFL
STONY BROOK
BUCHANS
STEPHENVILLE
SSD
CBC
UPPER SALMON
HARDWOODS
OXEN POND
HOLYROOD
CT
G1
G2
G3
MARITIME LINK
BOTTOM BROOK
GRANITE CANAL
BAY D'ESPOIR
TL248
TL247
TL228
TL211
TL207
TL203
TL208
TL237
TL235
TL205
TL232
TL233
TL209
TL201
TL217
TL268
TL265
TL242
TL266
TL236
TL218
TL269
TL263
TL234
TL204
TL231
TL202
TL206
TL267
LABRADOR GENERATION:
CHF GENERATION = 5394.3 MW
MFA GENERATION = 824.0 MW
NLH GENERATION = -0.6 MW
LABRADOR GENERATION = 6217.7 MW
HVDC TO NL = 682.2 MW
ISLAND SYSTEM LOSSES
230 kV BULK INJECTIONS = 1601.1 MW
230 kV BULK WITHDRAWALS = 1574.4 MW
230 kV BULK LOSSES = 26.7 MW
LABRADOR HVDC EXPORT = 682.2 MW
ISLAND HVDC IMPORT = 640.8 MW
LIL HVDC I^2R LOSSES = 41.4 MW
LIL HVDC AVG CORONA LOSSES = 1.9 MW
TOTAL LIL HVDC LOSSES = 43.3 MW
138 & 66 kV NETWORK INJECTIONS = 1431.7 MW
138 & 66 kV NETWORK WITHDRAWALS = 1403.8 MW
138 & 66 kV NETWORK LOSSES = 27.9 MW
ISLAND SYSTEM OVERVIEW
ISLAND 60 Hz GENERATION:
NLH GENERATION = 937.3 MW
STAR LAKE - EXPLOITS = 105.0 MW
RATTLE BROOK = 4.0 MW
CORNER BROOK COGEN = 15.0 MW
ST LAWRENCE = 11.0 MW
FERMEUSE = 11.0 MW
SUBTOTAL NLH GENERATION = 1083.3 MW
CUSTOMER GENERATION = 169.9 MW
TOTAL ISLAND 60 Hz GENERATION = 1242.2 MW
LABRADOR IMPORT = 640.8 MW
NS EXPORT = 158.0 MW
NET HVDC = 482.8 MW
TOTAL ISLAND 60 Hz LOAD + LOSSES = 1725.0 MW
INDUSTRIAL LOADS:
NARL = 26.8 MW
KRUGER = 20.4 MW
AUR RESOURCES = 0.0 MW
VALE INCO = 76.2 MW
TOTAL INDUSTRIAL = 123.5 MW
UTILITY LOADS:
N. POWER = 1309.3 MW
HYDRO RURAL = 72.0 MW
GROSS AVALON LOAD = 816.3 MW
SPS STUDY DYNAMICS CASE 8002 - INITIALIZED
DEVELOPED FROM CASE 2001
MON, MAY 02 2016 16:02

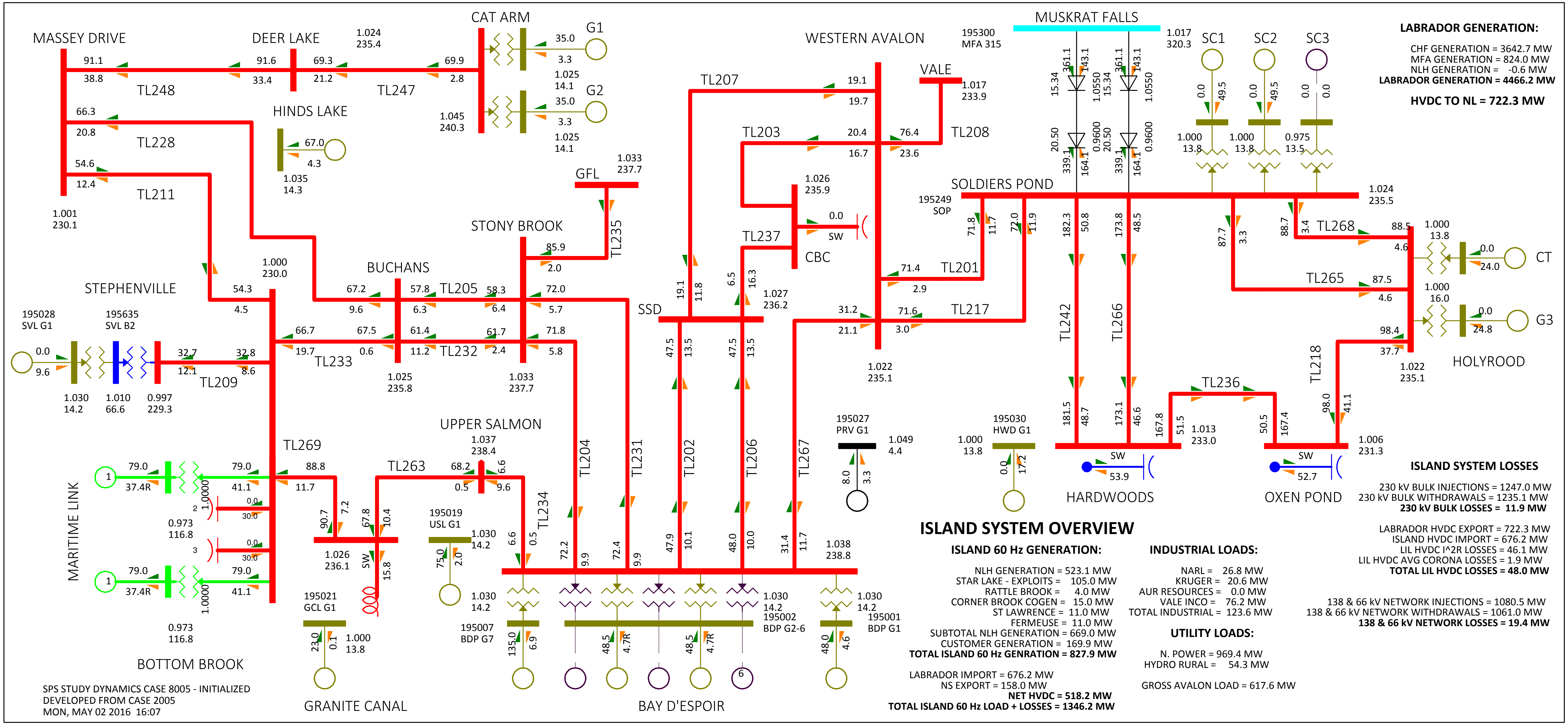

CHURCHILL FALLS
MUSKRAT FALLS
A11 A10 A9 A8 A7 A6 A5 A4 A3 A2 A1
G1 G2 G3 G4
T11 T10 T9 T8 T7 T6 T5 T4 T3 T2 T1
T1 T2 T3 T4
B23
T76 T75 T74 T73 T72 T71
L23 L24
XL1 165 MVAR
XL2 165 MVAR
XL3 165 MVAR
L7051 L7052 L7053
T77 T78
T5 T6
L3101
L3102
HVdc to ISLAND
C1 C2
MUSKRAT FALLS TAP
SOLDIERS POND
L1302
HAPPY VALLEY TERMINAL STATION
G1
SC #1 SC #3 SC #2
WABUSH TERMINAL STATION
CHURCHILL FALLS STATION SERVICE + LOSSES
CF GENERATION = 5394.3 MW
CF TO WESTERN LABRADOR = 419.7 MW
CF TO LTA FLOW (CHF) = -136.0 MW
CF TO LTA FLOW (MFA) =-136.8 MW
CF TO HQT 735 kV = 5004.8 MW
TOTAL CF EXPORTS = 5366.1 MW
CF STN SERV + LOSSES = 28.1 MW
WESTERN LABRADOR LOSSES
CF TO WESTERN LABRADOR = 419.7 MW
WESTERN LABRADOR LOAD = 382.0 MW
WESTERN LABRADOR LOSSES = 37.7 MW
LAB - HQ PATH
LAB - HQT TTC = 4952.0 MW
LAB - HQT FLOW = 0.0 MW
LAB - HQT ATC = 0.0 MW
LABRADOR GENERATION
CF GENERATION = 5394.3 MW
MF GENERATION = 824.0 MW
NLH GENERATION = 0.0 MW
LAB GENERATION = 6217.7 MW
HVDC TO NL = 682.2 MW
735 kV TRANSMISSION LOSSES
CF 735 kV SENDING = 0.0 MW
LESS LAB - HQT FLOW = 0.0 MW
735 kV LOSSES TO BORDER = 0.0 MW
735 kV AVG CORONA LOSSES = 8.3 MW
TOTAL 735 kV LOSSES TO BORDER = 8.3 MW
EASTERN LABRADOR LOSSES
CF/MF TO EASTERN LABRADOR = 68.7 MW
EASTERN LABRADOR LOAD = 60.9 MW
EASTERN LABRADOR LOSSES = 7.8 MW
LABRADOR TRANSMISSION ASSET LOSSES
LTA INJECTIONS = -136.0 MW
LESS LTA WITHDRAWALS = -136.8 MW
LTA I^2R LOSSES = 0.9 MW
LTA 315 kV AVG CORONA LOSSES = 0.8 MW
LTA TRANSMISSION LOSSES = 1.7 MW
SPS STUDY DYNAMICS CASE 8002 - INITIALIZED
DEVELOPED FROM CASE 2001
MON, MAY 02 2016 16:03

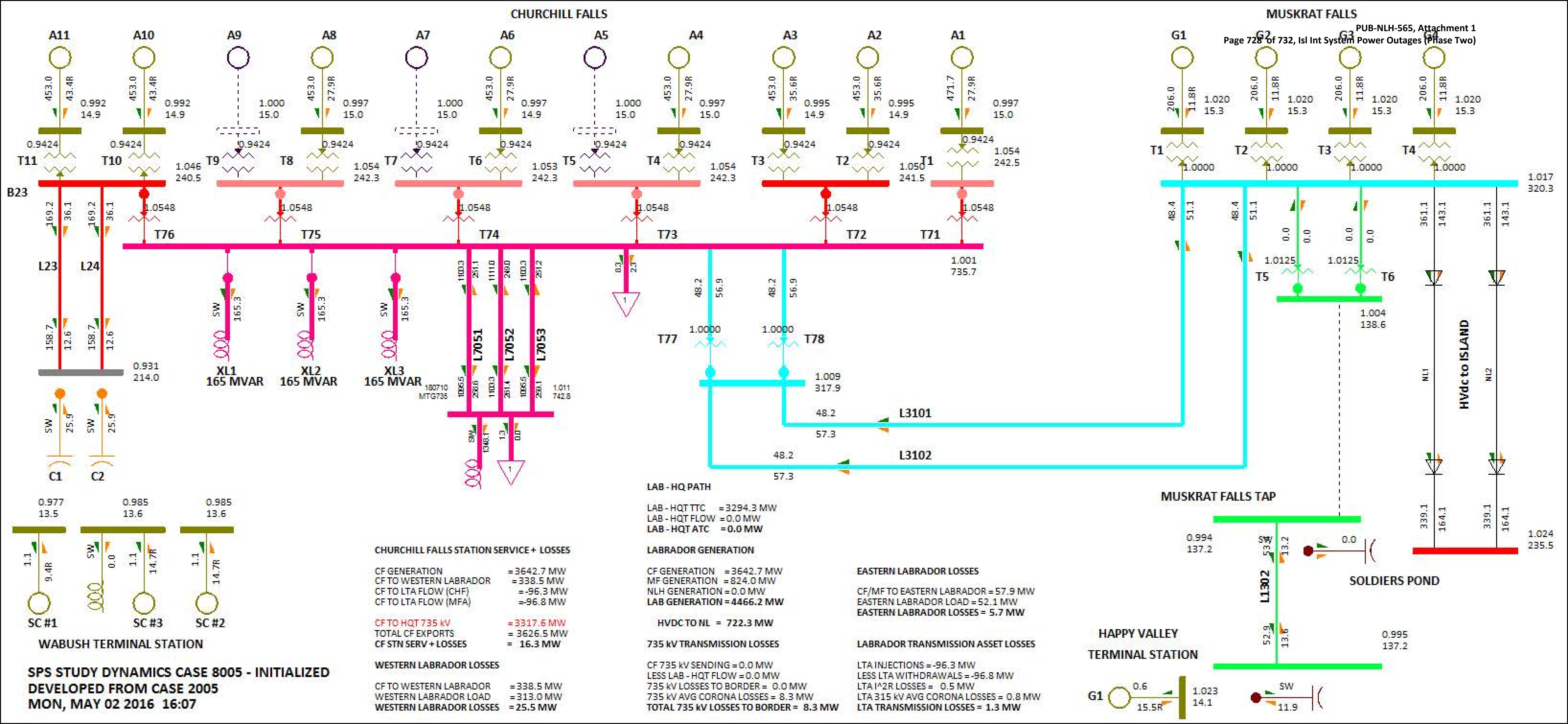

MASSEY DRIVE
DEER LAKE
CAT ARM
HINDS LAKE
WESTERN AVALON
VALE
MUSKRAT FALLS
SC1
SC2
SC3
GFL
STONY BROOK
BUCHANS
STEPHENVILLE
SSD
CBC
SOLDIERS POND
CT
G1
G2
G3
HOLYROOD
UPPER SALMON
HARDWOODS
OXEN POND
MARITIME LINK
BOTTOM BROOK
GRANITE CANAL
BAY D'ESPOIR
TL248
TL228
TL211
TL247
TL207
TL203
TL208
TL237
TL235
TL205
TL201
TL217
TL268
TL265
TL242
TL266
TL236
TL218
TL233
TL232
TL209
TL269
TL263
TL234
TL204
TL231
TL202
TL206
TL267
LABRADOR GENERATION:
CHF GENERATION = 5613.0 MW
MFA GENERATION = 824.0 MW
NLH GENERATION = -0.6 MW
LABRADOR GENERATION = 6436.5 MW
HVDC TO NL = 902.3 MW
ISLAND SYSTEM LOSSES
230 kV BULK INJECTIONS = 1801.4 MW
230 kV BULK WITHDRAWALS = 1766.1 MW
230 kV BULK LOSSES = 35.3 MW
LABRADOR HVDC EXPORT = 902.3 MW
ISLAND HVDC IMPORT = 830.6 MW
LIL HVDC I^2R LOSSES = 71.8 MW
LIL HVDC AVG CORONA LOSSES = 1.9 MW
TOTAL LIL HVDC LOSSES = 73.7 MW
138 & 66 kV NETWORK INJECTIONS = 1429.0 MW
138 & 66 kV NETWORK WITHDRAWALS = 1401.6 MW
138 & 66 kV NETWORK LOSSES = 27.3 MW
ISLAND SYSTEM OVERVIEW
ISLAND 60 Hz GENERATION:
NLH GENERATION = 937.8 MW
STAR LAKE - EXPLOITS = 105.0 MW
RATTLE BROOK = 4.0 MW
CORNER BROOK COGEN = 15.0 MW
ST LAWRENCE = 11.0 MW
FERMEUSE = 11.0 MW
SUBTOTAL NLH GENERATION = 1083.8 MW
CUSTOMER GENERATION = 169.9 MW
TOTAL ISLAND 60 Hz GENERATION = 1242.7 MW
LABRADOR IMPORT = 830.6 MW
NS EXPORT = 350.0 MW
NET HVDC = 480.6 MW
TOTAL ISLAND 60 Hz LOAD + LOSSES = 1723.3 MW
INDUSTRIAL LOADS:
NARL = 26.7 MW
KRUGER = 20.5 MW
AUR RESOURCES = 0.0 MW
VALE INCO = 75.7 MW
TOTAL INDUSTRIAL = 122.9 MW
UTILITY LOADS:
N. POWER = 1300.0 MW
HYDRO RURAL = 71.6 MW
GROSS AVALON LOAD = 800.5 MW
SPS STUDY DYNAMICS CASE 8003 - INITIALIZED
DEVELOPED FROM CASE 2002
MON, MAY 02 2016 16:04

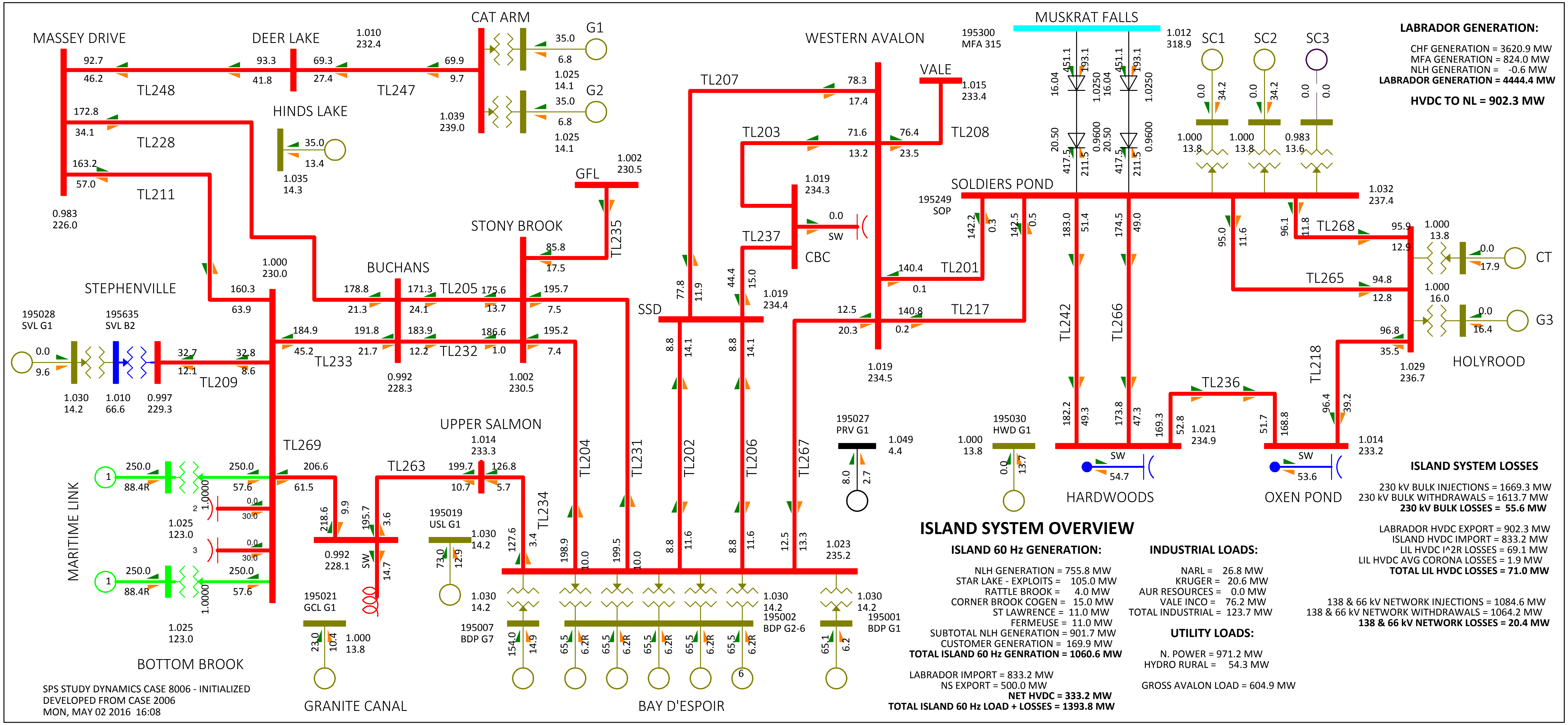

CHURCHILL FALLS
MUSKRAT FALLS
A11 A10 A9 A8 A7 A6 A5 A4 A3 A2 A1
G1 G2 G3 G4
T11 T10 T9 T8 T7 T6 T5 T4 T3 T2 T1
B23
T76 T75 T74 T73 T72 T71
L23 L24
XL1 165 MVAR
XL2 165 MVAR
XL3 165 MVAR
L7051 L7052 L7053
T77 T78
T5 T6
L3101
L3102
HVdc to ISLAND
C1 C2
SC #1 SC #3 SC #2
WABUSH TERMINAL STATION
MUSKRAT FALLS TAP
L1302
SOLDIERS POND
HAPPY VALLEY
TERMINAL STATION
G1
SPS STUDY DYNAMICS CASE 8003 - INITIALIZED
DEVELOPED FROM CASE 2002
MON, MAY 02 2016 16:04
CHURCHILL FALLS STATION SERVICE + LOSSES
CF GENERATION = 5613.0 MW
CF TO WESTERN LABRADOR = 419.7 MW
CF TO LTA FLOW (CHF) = 83.7 MW
CF TO LTA FLOW (MFA) = 83.3 MW
CF TO HQT 735 kV = 5002.7 MW
TOTAL CF EXPORTS = 5583.7 MW
CF STN SERV + LOSSES = 29.3 MW
WESTERN LABRADOR LOSSES
CF TO WESTERN LABRADOR = 419.7 MW
WESTERN LABRADOR LOAD = 382.0 MW
WESTERN LABRADOR LOSSES = 37.7 MW
LAB - HQ PATH
LAB - HQT TTC = 4949.9 MW
LAB - HQT FLOW = 0.0 MW
LAB - HQT ATC = 0.0 MW
LABRADOR GENERATION
CF GENERATION = 5613.0 MW
MF GENERATION = 824.0 MW
NLH GENERATION = 0.0 MW
LAB GENERATION = 6436.5 MW
HVDC TO NL = 902.3 MW
735 kV TRANSMISSION LOSSES
CF 735 kV SENDING = 0.0 MW
LESS LAB - HQT FLOW = 0.0 MW
735 kV LOSSES TO BORDER = 0.0 MW
735 kV AVG CORONA LOSSES = 8.3 MW
TOTAL 735 kV LOSSES TO BORDER = 8.3 MW
EASTERN LABRADOR LOSSES
CF/MF TO EASTERN LABRADOR = 68.8 MW
EASTERN LABRADOR LOAD = 60.9 MW
EASTERN LABRADOR LOSSES = 7.9 MW
LABRADOR TRANSMISSION ASSET LOSSES
LTA INJECTIONS = 83.7 MW
LESS LTA WITHDRAWALS = 83.3 MW
LTA I^2R LOSSES = 0.3 MW
LTA 315 kV AVG CORONA LOSSES = 0.8 MW
LTA TRANSMISSION LOSSES = 1.1 MW

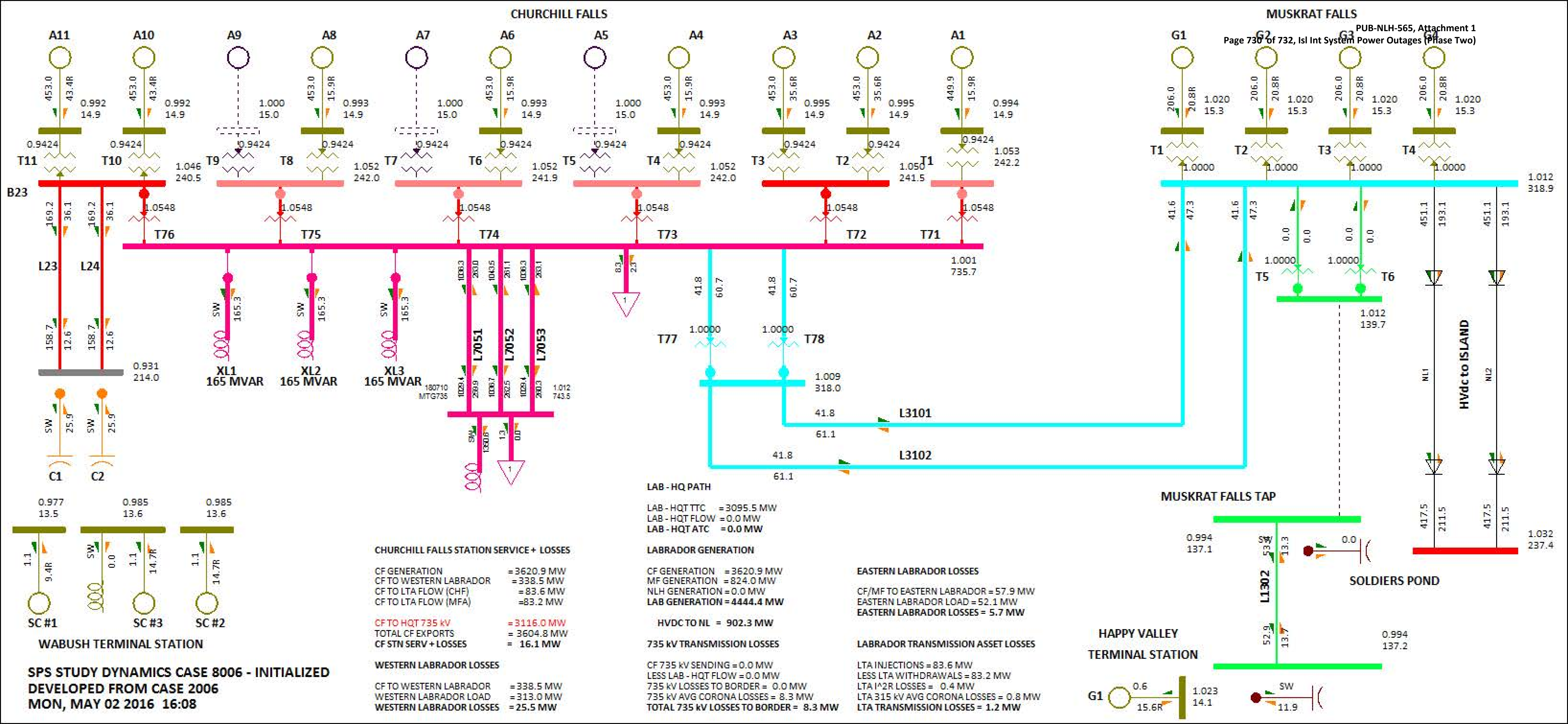

MASSEY DRIVE
DEER LAKE
CAT ARM
G1
G2
HINDS LAKE
WESTERN AVALON
VALE
MUSKRAT FALLS
195300
MFA 315
SC1
SC2
SC3
LABRADOR GENERATION:
CHF GENERATION = 5121.2 MW
MFA GENERATION = 618.0 MW
NLH GENERATION = -0.6 MW
LABRADOR GENERATION = 5738.7 MW
HVDC TO NL = 0.0 MW
TL248
TL247
TL228
TL211
TL207
TL203
TL208
GFL
TL235
STONY BROOK
SOLDIERS POND
195249
SOP
TL237
CBC
TL268
CT
BUCHANS
TL205
TL201
TL265
STEPHENVILLE
195028
SVL G1
195635
SVL B2
SSD
TL217
G3
TL233
TL232
TL209
HOLYROOD
TL242
TL266
TL218
TL236
UPPER SALMON
TL269
TL263
TL204
TL231
TL202
TL206
TL267
195027
PRV G1
195030
HWD G1
HARDWOODS
OXEN POND
SW
MARITIME LINK
TL234
195019
USL G1
195021
GCL G1
195007
BDP G7
195002
BDP G2-6
195001
BDP G1
BOTTOM BROOK
GRANITE CANAL
BAY D'ESPOIR
ISLAND SYSTEM LOSSES
230 kV BULK INJECTIONS = 995.3 MW
230 kV BULK WITHDRAWALS = 896.1 MW
230 kV BULK LOSSES = 99.2 MW
LABRADOR HVDC EXPORT = 0.0 MW
ISLAND HVDC IMPORT = -2.0 MW
LIL HVDC I^2R LOSSES = 2.0 MW
LIL HVDC AVG CORONA LOSSES = 1.9 MW
TOTAL LIL HVDC LOSSES = 3.9 MW
138 & 66 kV NETWORK INJECTIONS = 1327.3 MW
138 & 66 kV NETWORK WITHDRAWALS = 1294.6 MW
138 & 66 kV NETWORK LOSSES = 32.7 MW
ISLAND SYSTEM OVERVIEW
ISLAND 60 Hz GENERATION:
NLH GENERATION = 1097.7 MW
STAR LAKE - EXPLOITS = 105.0 MW
RATTLE BROOK = 4.0 MW
CORNER BROOK COGEN = 15.0 MW
ST LAWRENCE = 11.0 MW
FERMEUSE = 11.0 MW
SUBTOTAL NLH GENERATION = 1243.6 MW
CUSTOMER GENERATION = 186.6 MW
TOTAL ISLAND 60 Hz GENERATION = 1419.3 MW
LABRADOR IMPORT = -2.0 MW
NS EXPORT = -310.0 MW
NET HVDC = 308.0 MW
TOTAL ISLAND 60 Hz LOAD + LOSSES = 1727.3 MW
INDUSTRIAL LOADS:
NARL = 26.8 MW
KRUGER = 20.1 MW
AUR RESOURCES = 0.0 MW
VALE INCO = 76.2 MW
TOTAL INDUSTRIAL = 123.1 MW
UTILITY LOADS:
N. POWER = 1223.1 MW
HYDRO RURAL = 68.6 MW
GROSS AVALON LOAD = 766.2 MW
SPS STUDY DYNAMICS CASE 8004 - INITIALIZED
DEVELOPED FROM CASE 2004
MON, MAY 02 2016 16:05

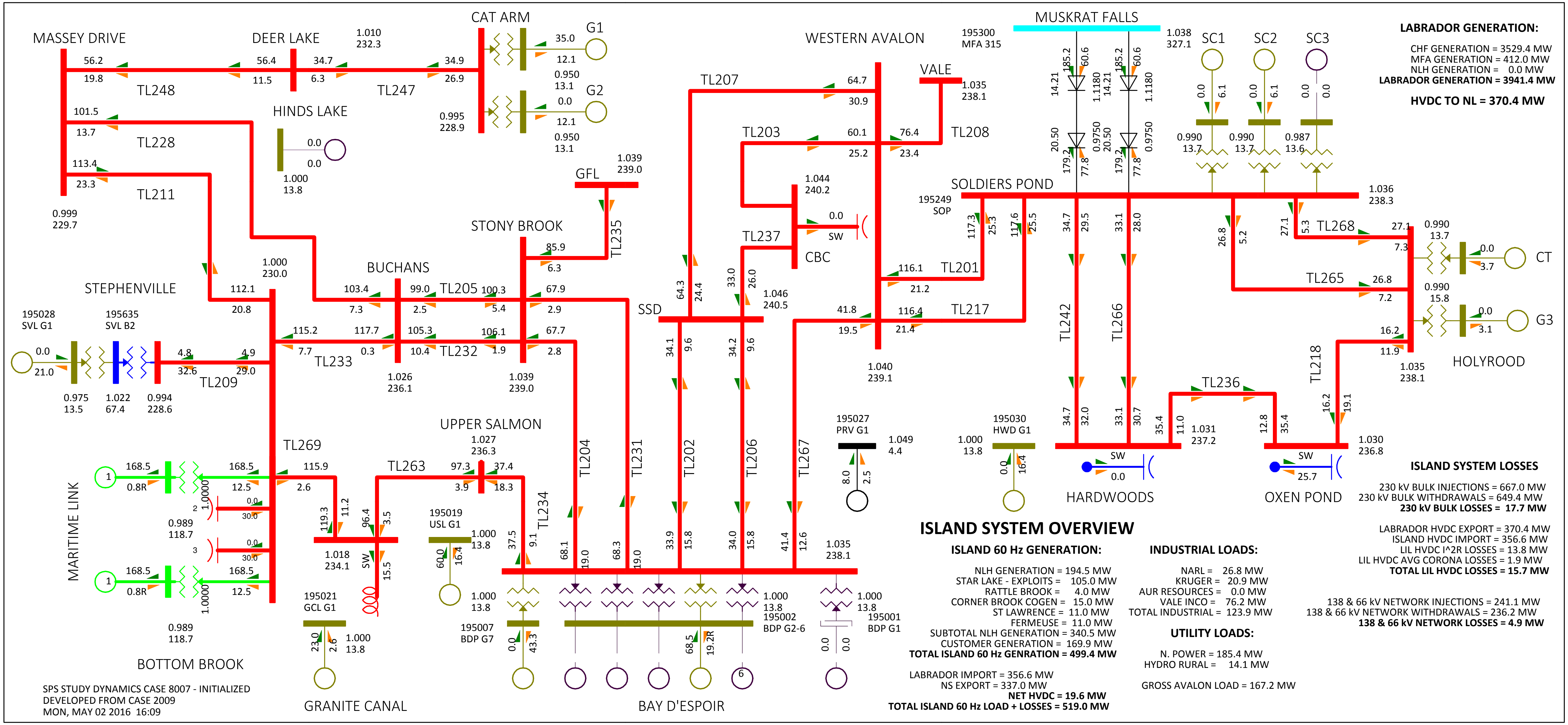

CHURCHILL FALLS
MUSKRAT FALLS
A11
A10
A9
A8
A7
A6
A5
A4
A3
A2
A1
G1
G2
G3
G4
T11
T10
T9
T8
T7
T6
T5
T4
T3
T2
T1
B23
T76
T75
T74
T73
T72
T71
L23
L24
XL1
165 MVAR
XL2
165 MVAR
XL3
165 MVAR
L7051
L7052
L7053
T77
T78
L3101
L3102
HVdc to ISLAND
C1
C2
SC #1
SC #3
SC #2
WABUSH TERMINAL STATION
MUSKRAT FALLS TAP
L1302
SOLDIERS POND
HAPPY VALLEY
TERMINAL STATION
LAB - HQ PATH
LAB - HQT TTC = 5137.8 MW
LAB - HQT FLOW = 0.0 MW
LAB - HQT ATC = 0.0 MW
CHURCHILL FALLS STATION SERVICE + LOSSES
CF GENERATION = 5121.2 MW
CF TO WESTERN LABRADOR = 419.7 MW
CF TO LTA FLOW (CHF) = -596.2 MW
CF TO LTA FLOW (MFA) =-613.7 MW
CF TO HQT 735 kV = 5194.6 MW
TOTAL CF EXPORTS = 5095.8 MW
CF STN SERV + LOSSES = 25.5 MW
WESTERN LABRADOR LOSSES
CF TO WESTERN LABRADOR = 419.7 MW
WESTERN LABRADOR LOAD = 382.0 MW
WESTERN LABRADOR LOSSES = 37.7 MW
LABRADOR GENERATION
CF GENERATION = 5121.2 MW
MF GENERATION = 618.0 MW
NLH GENERATION = 0.0 MW
LAB GENERATION = 5738.7 MW
HVDC TO NL = -0.0 MW
735 kV TRANSMISSION LOSSES
CF 735 kV SENDING = 0.0 MW
LESS LAB - HQT FLOW = 0.0 MW
735 kV LOSSES TO BORDER = 0.0 MW
735 kV AVG CORONA LOSSES = 8.3 MW
TOTAL 735 kV LOSSES TO BORDER = 8.3 MW
EASTERN LABRADOR LOSSES
CF/MF TO EASTERN LABRADOR = 68.7 MW
EASTERN LABRADOR LOAD = 60.9 MW
EASTERN LABRADOR LOSSES = 7.8 MW
LABRADOR TRANSMISSION ASSET LOSSES
LTA INJECTIONS = -596.2 MW
LESS LTA WITHDRAWALS = -613.7 MW
LTA I^2R LOSSES = 17.5 MW
LTA 315 kV AVG CORONA LOSSES = 0.8 MW
LTA TRANSMISSION LOSSES = 18.3 MW
SPS STUDY DYNAMICS CASE 8004 - INITIALIZED
DEVELOPED FROM CASE 2004
MON, MAY 02 2016 16:06


MASSEY DRIVE
DEER LAKE
CAT ARM
HINDS LAKE
WESTERN AVALON
VALE
MUSKRAT FALLS
195300
MFA 315
SC1
SC2
SC3
LABRADOR GENERATION:
CHF GENERATION = 3642.7 MW
MFA GENERATION = 824.0 MW
NLH GENERATION = -0.6 MW
LABRADOR GENERATION = 4466.2 MW
HVDC TO NL = 722.3 MW
TL248
TL247
TL228
TL211
TL207
TL203
TL208
TL235
TL237
TL201
TL217
TL205
TL232
TL233
TL209
TL242
TL266
TL268
TL265
TL236
TL218
TL269
TL263
TL234
TL204
TL231
TL202
TL206
TL267
GFL
STONY BROOK
BUCHANS
STEPHENVILLE
SOLDIERS POND
195249
SOP
CBC
SSD
CT
G1
G2
G3
HOLYROOD
195028
SVL G1
195635
SVL B2
UPPER SALMON
195027
PRV G1
195030
HWD G1
HARDWOODS
OXEN POND
MARITIME LINK
195019
USL G1
195021
GCL G1
195007
BDP G7
195002
BDP G2-6
195001
BDP G1
BOTTOM BROOK
GRANITE CANAL
BAY D'ESPOIR
ISLAND SYSTEM LOSSES
230 kV BULK INJECTIONS = 1247.0 MW
230 kV BULK WITHDRAWALS = 1235.1 MW
230 kV BULK LOSSES = 11.9 MW
LABRADOR HVDC EXPORT = 722.3 MW
ISLAND HVDC IMPORT = 676.2 MW
LIL HVDC I^2R LOSSES = 46.1 MW
LIL HVDC AVG CORONA LOSSES = 1.9 MW
TOTAL LIL HVDC LOSSES = 48.0 MW
138 & 66 kV NETWORK INJECTIONS = 1080.5 MW
138 & 66 kV NETWORK WITHDRAWALS = 1061.0 MW
138 & 66 kV NETWORK LOSSES = 19.4 MW
ISLAND SYSTEM OVERVIEW
ISLAND 60 Hz GENERATION:
NLH GENERATION = 523.1 MW
STAR LAKE - EXPLOITS = 105.0 MW
RATTLE BROOK = 4.0 MW
CORNER BROOK COGEN = 15.0 MW
ST LAWRENCE = 11.0 MW
FERMEUSE = 11.0 MW
SUBTOTAL NLH GENERATION = 669.0 MW
CUSTOMER GENERATION = 169.9 MW
TOTAL ISLAND 60 Hz GENERATION = 827.9 MW
LABRADOR IMPORT = 676.2 MW
NS EXPORT = 158.0 MW
NET HVDC = 518.2 MW
TOTAL ISLAND 60 Hz LOAD + LOSSES = 1346.2 MW
INDUSTRIAL LOADS:
NARL = 26.8 MW
KRUGER = 20.6 MW
AUR RESOURCES = 0.0 MW
VALE INCO = 76.2 MW
TOTAL INDUSTRIAL = 123.6 MW
UTILITY LOADS:
N. POWER = 969.4 MW
HYDRO RURAL = 54.3 MW
GROSS AVALON LOAD = 617.6 MW
SPS STUDY DYNAMICS CASE 8005 - INITIALIZED
DEVELOPED FROM CASE 2005
MON, MAY 02 2016 16:07


CHURCHILL FALLS
MUSKRAT FALLS
A11
A10
A9
A8
A7
A6
A5
A4
A3
A2
A1
G1
G2
G3
G4
T11
T10
T9
T8
T7
T6
T5
T4
T3
T2
T1
B23
T76
T75
T74
T73
T72
T71
L23
L24
XL1
165 MVAR
XL2
165 MVAR
XL3
165 MVAR
L7051
L7052
L7053
T77
T78
T5
T6
L3101
L3102
HVdc to ISLAND
C1
C2
SC #1
SC #3
SC #2
WABUSH TERMINAL STATION
MUSKRAT FALLS TAP
SOLDIERS POND
L1302
HAPPY VALLEY
TERMINAL STATION
SPS STUDY DYNAMICS CASE 8005 - INITIALIZED
DEVELOPED FROM CASE 2005
MON, MAY 02 2016 16:07
CHURCHILL FALLS STATION SERVICE + LOSSES
CF GENERATION =3642.7 MW
CF TO WESTERN LABRADOR =338.5 MW
CF TO LTA FLOW (CHF) =-96.3 MW
CF TO LTA FLOW (MFA) =-96.8 MW
CF TO HQT 735 kV =3317.6 MW
TOTAL CF EXPORTS = 3626.5 MW
CF STN SERV + LOSSES = 16.3 MW
WESTERN LABRADOR LOSSES
CF TO WESTERN LABRADOR =338.5 MW
WESTERN LABRADOR LOAD =313.0 MW
WESTERN LABRADOR LOSSES =25.5 MW
LAB - HQ PATH
LAB - HQT TTC =3294.3 MW
LAB - HQT FLOW =0.0 MW
LAB - HQT ATC =0.0 MW
LABRADOR GENERATION
CF GENERATION =3642.7 MW
MF GENERATION =824.0 MW
NLH GENERATION = 0.0 MW
LAB GENERATION = 4466.2 MW
HVDC TO NL = 722.3 MW
735 kV TRANSMISSION LOSSES
CF 735 kV SENDING = 0.0 MW
LESS LAB - HQT FLOW = 0.0 MW
735 kV LOSSES TO BORDER = 0.0 MW
735 kV AVG CORONA LOSSES = 8.3 MW
TOTAL 735 kV LOSSES TO BORDER = 8.3 MW
EASTERN LABRADOR LOSSES
CF/MF TO EASTERN LABRADOR = 57.9 MW
EASTERN LABRADOR LOAD = 52.1 MW
EASTERN LABRADOR LOSSES = 5.7 MW
LABRADOR TRANSMISSION ASSET LOSSES
LTA INJECTIONS = -96.3 MW
LESS LTA WITHDRAWALS = -96.8 MW
LTA I^2R LOSSES = 0.5 MW
LTA 315 kV AVG CORONA LOSSES = 0.8 MW
LTA TRANSMISSION LOSSES = 1.3 MW


MASSEY DRIVE
DEER LAKE
CAT ARM
G1
G2
HINDS LAKE
WESTERN AVALON
VALE
MUSKRAT FALLS
SC1
SC2
SC3
LABRADOR GENERATION:
CHF GENERATION = 3620.9 MW
MFA GENERATION = 824.0 MW
NLH GENERATION = -0.6 MW
LABRADOR GENERATION = 4444.4 MW
HVDC TO NL = 902.3 MW
TL248
TL247
TL228
TL211
TL207
TL203
TL208
GFL
SOLDIERS POND
195249 SOP
195300 MFA 315
STONY BROOK
TL235
TL237
CBC
SW
TL201
TL268
CT
TL265
G3
HOLYROOD
BUCHANS
TL205
SSD
TL217
STEPHENVILLE
195028 SVL G1
195635 SVL B2
TL233
TL232
TL209
TL242
TL266
TL218
TL236
UPPER SALMON
195027 PRV G1
195030 HWD G1
HARDWOODS
OXEN POND
TL269
TL263
TL204
TL231
TL202
TL206
TL267
TL234
MARITIME LINK
195019 USL G1
195021 GCL G1
195007 BDP G7
195002 BDP G2-6
195001 BDP G1
BOTTOM BROOK
GRANITE CANAL
BAY D'ESPOIR
ISLAND SYSTEM OVERVIEW
ISLAND 60 Hz GENERATION:
NLH GENERATION = 755.8 MW
STAR LAKE - EXPLOITS = 105.0 MW
RATTLE BROOK = 4.0 MW
CORNER BROOK COGEN = 15.0 MW
ST LAWRENCE = 11.0 MW
FERMEUSE = 11.0 MW
SUBTOTAL NLH GENERATION = 901.7 MW
CUSTOMER GENERATION = 169.9 MW
TOTAL ISLAND 60 Hz GENERATION = 1060.6 MW
LABRADOR IMPORT = 833.2 MW
NS EXPORT = 500.0 MW
NET HVDC = 333.2 MW
TOTAL ISLAND 60 Hz LOAD + LOSSES = 1393.8 MW
INDUSTRIAL LOADS:
NARL = 26.8 MW
KRUGER = 20.6 MW
AUR RESOURCES = 0.0 MW
VALE INCO = 76.2 MW
TOTAL INDUSTRIAL = 123.7 MW
UTILITY LOADS:
N. POWER = 971.2 MW
HYDRO RURAL = 54.3 MW
GROSS AVALON LOAD = 604.9 MW
ISLAND SYSTEM LOSSES
230 kV BULK INJECTIONS = 1669.3 MW
230 kV BULK WITHDRAWALS = 1613.7 MW
230 kV BULK LOSSES = 55.6 MW
LABRADOR HVDC EXPORT = 902.3 MW
ISLAND HVDC IMPORT = 833.2 MW
LIL HVDC I^2R LOSSES = 69.1 MW
LIL HVDC AVG CORONA LOSSES = 1.9 MW
TOTAL LIL HVDC LOSSES = 71.0 MW
138 & 66 kV NETWORK INJECTIONS = 1084.6 MW
138 & 66 kV NETWORK WITHDRAWALS = 1064.2 MW
138 & 66 kV NETWORK LOSSES = 20.4 MW
SPS STUDY DYNAMICS CASE 8006 - INITIALIZED
DEVELOPED FROM CASE 2006
MON, MAY 02 2016 16:08


CHURCHILL FALLS
MUSKRAT FALLS
A11
A10
A9
A8
A7
A6
A5
A4
A3
A2
A1
G1
G2
G3
G4
T11
T10
T9
T8
T7
T6
T5
T4
T3
T2
T1
B23
T76
T75
T74
T73
T72
T71
L23
L24
XL1
165 MVAR
XL2
165 MVAR
XL3
165 MVAR
L7051
L7052
L7053
T77
T78
L3101
L3102
T5
T6
HVdc to ISLAND
C1
C2
SC #1
SC #3
SC #2
WABUSH TERMINAL STATION
MUSKRAT FALLS TAP
L1302
SOLDIERS POND
HAPPY VALLEY
TERMINAL STATION
G1
LAB - HQ PATH
LAB - HQT TTC =3095.5 MW
LAB - HQT FLOW =0.0 MW
LAB - HQT ATC =0.0 MW
LABRADOR GENERATION
CF GENERATION =3620.9 MW
MF GENERATION =824.0 MW
NLH GENERATION = 0.0 MW
LAB GENERATION = 4444.4 MW
HVDC TO NL = 902.3 MW
735 kV TRANSMISSION LOSSES
CF 735 kV SENDING = 0.0 MW
LESS LAB - HQT FLOW = 0.0 MW
735 kV LOSSES TO BORDER = 0.0 MW
735 kV AVG CORONA LOSSES = 8.3 MW
TOTAL 735 kV LOSSES TO BORDER = 8.3 MW
CHURCHILL FALLS STATION SERVICE + LOSSES
CF GENERATION =3620.9 MW
CF TO WESTERN LABRADOR =338.5 MW
CF TO LTA FLOW (CHF) =83.6 MW
CF TO LTA FLOW (MFA) =83.2 MW
CF TO HQT 735 kV =3116.0 MW
TOTAL CF EXPORTS = 3604.8 MW
CF STN SERV + LOSSES = 16.1 MW
WESTERN LABRADOR LOSSES
CF TO WESTERN LABRADOR =338.5 MW
WESTERN LABRADOR LOAD =313.0 MW
WESTERN LABRADOR LOSSES =25.5 MW
EASTERN LABRADOR LOSSES
CF/MF TO EASTERN LABRADOR = 57.9 MW
EASTERN LABRADOR LOAD = 52.1 MW
EASTERN LABRADOR LOSSES = 5.7 MW
LABRADOR TRANSMISSION ASSET LOSSES
LTA INJECTIONS = 83.6 MW
LESS LTA WITHDRAWALS = 83.2 MW
LTA I^2R LOSSES = 0.4 MW
LTA 315 kV AVG CORONA LOSSES = 0.8 MW
LTA TRANSMISSION LOSSES = 1.2 MW
SPS STUDY DYNAMICS CASE 8006 - INITIALIZED
DEVELOPED FROM CASE 2006
MON, MAY 02 2016 16:08


MASSEY DRIVE
DEER LAKE
CAT ARM
G1
G2
HINDS LAKE
WESTERN AVALON
VALE
MUSKRAT FALLS
195300
MFA 315
SC1
SC2
SC3
LABRADOR GENERATION:
CHF GENERATION = 3529.4 MW
MFA GENERATION = 412.0 MW
NLH GENERATION = 0.0 MW
LABRADOR GENERATION = 3941.4 MW
HVDC TO NL = 370.4 MW
TL248
TL247
TL228
TL211
TL207
TL203
TL208
GFL
STONY BROOK
TL235
SOLDIERS POND
195249
SOP
TL268
CT
TL237
CBC
SW
BUCHANS
TL205
TL201
TL265
STEPHENVILLE
195028
SVL G1
195635
SVL B2
SSD
TL217
TL233
TL232
TL209
TL242
TL266
HOLYROOD
G3
TL218
TL236
UPPER SALMON
TL269
TL263
TL204
TL231
TL202
TL206
TL267
TL234
195027
PRV G1
195030
HWD G1
HARDWOODS
OXEN POND
MARITIME LINK
195019
USL G1
195021
GCL G1
195007
BDP G7
195002
BDP G2-6
195001
BDP G1
BOTTOM BROOK
GRANITE CANAL
BAY D'ESPOIR
ISLAND SYSTEM LOSSES
230 kV BULK INJECTIONS = 667.0 MW
230 kV BULK WITHDRAWALS = 649.4 MW
230 kV BULK LOSSES = 17.7 MW
LABRADOR HVDC EXPORT = 370.4 MW
ISLAND HVDC IMPORT = 356.6 MW
LIL HVDC I^2R LOSSES = 13.8 MW
LIL HVDC AVG CORONA LOSSES = 1.9 MW
TOTAL LIL HVDC LOSSES = 15.7 MW
138 & 66 kV NETWORK INJECTIONS = 241.1 MW
138 & 66 kV NETWORK WITHDRAWALS = 236.2 MW
138 & 66 kV NETWORK LOSSES = 4.9 MW
ISLAND SYSTEM OVERVIEW
ISLAND 60 Hz GENERATION:
NLH GENERATION = 194.5 MW
STAR LAKE - EXPLOITS = 105.0 MW
RATTLE BROOK = 4.0 MW
CORNER BROOK COGEN = 15.0 MW
ST LAWRENCE = 11.0 MW
FERMEUSE = 11.0 MW
SUBTOTAL NLH GENERATION = 340.5 MW
CUSTOMER GENERATION = 169.9 MW
TOTAL ISLAND 60 Hz GENERATION = 499.4 MW
LABRADOR IMPORT = 356.6 MW
NS EXPORT = 337.0 MW
NET HVDC = 19.6 MW
TOTAL ISLAND 60 Hz LOAD + LOSSES = 519.0 MW
INDUSTRIAL LOADS:
NARL = 26.8 MW
KRUGER = 20.9 MW
AUR RESOURCES = 0.0 MW
VALE INCO = 76.2 MW
TOTAL INDUSTRIAL = 123.9 MW
UTILITY LOADS:
N. POWER = 185.4 MW
HYDRO RURAL = 14.1 MW
GROSS AVALON LOAD = 167.2 MW
SPS STUDY DYNAMICS CASE 8007 - INITIALIZED
DEVELOPED FROM CASE 2009
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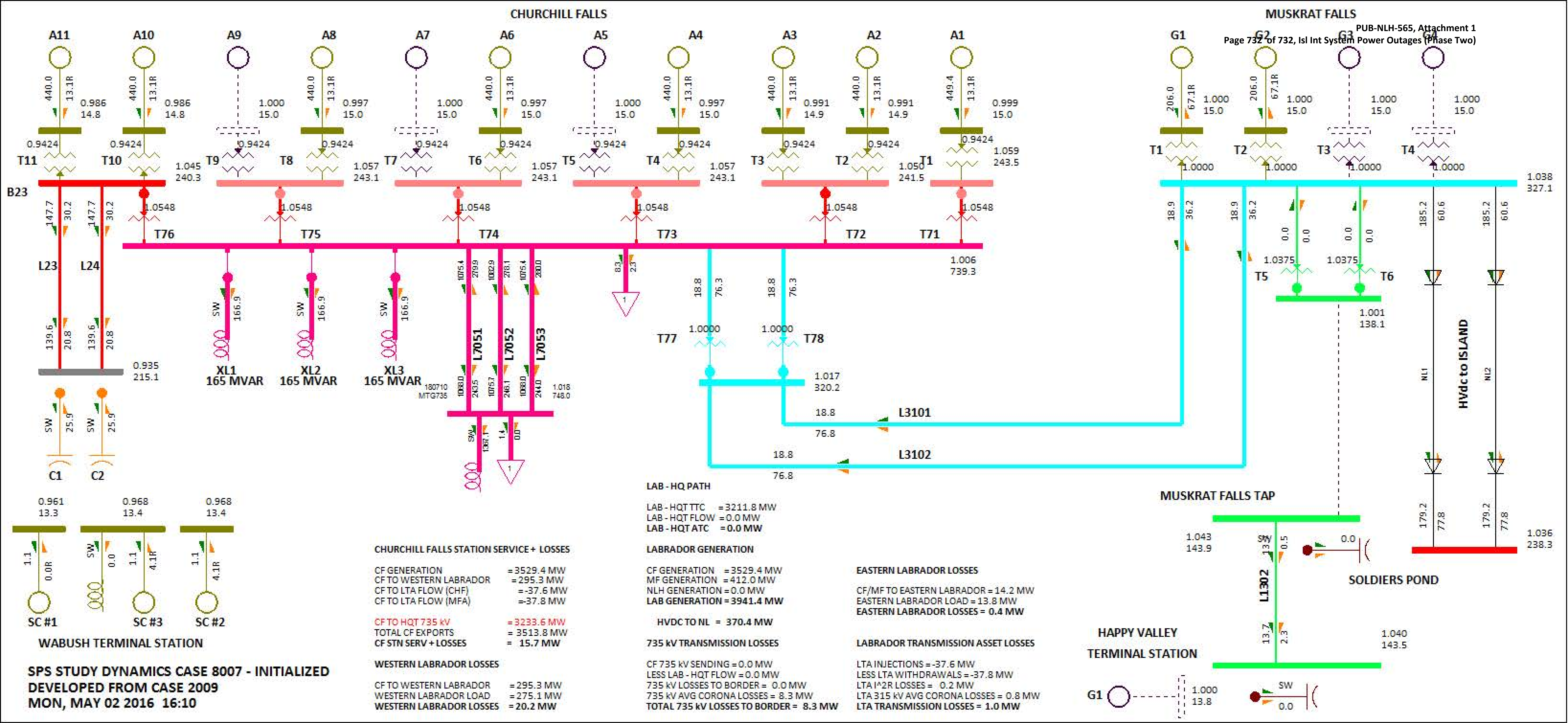
CHURCHILL FALLS
MUSKRAT FALLS
A11
A10
A9
A8
A7
A6
A5
A4
A3
A2
A1
G1
G2
G3
G4
T11
T10
T9
T8
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T5
T4
T3
T2
T1
B23
T76
T75
T74
T73
T72
T71
L23
L24
XL1
165 MVAR
XL2
165 MVAR
XL3
165 MVAR
L7051
L7052
L7053
T77
T78
L3101
L3102
C1
C2
HVdc to ISLAND
MUSKRAT FALLS TAP
SOLDIERS POND
L1302
HAPPY VALLEY
TERMINAL STATION
SC #1
SC #3
SC #2
WABUSH TERMINAL STATION
LAB - HQ PATH
LAB - HQT TTC = 3211.8 MW
LAB - HQT FLOW = 0.0 MW
LAB - HQT ATC = 0.0 MW
CHURCHILL FALLS STATION SERVICE + LOSSES
CF GENERATION = 3529.4 MW
CF TO WESTERN LABRADOR = 295.3 MW
CF TO LTA FLOW (CHF) = -37.6 MW
CF TO LTA FLOW (MFA) = -37.8 MW
CF TO HQT 735 kV = 3233.6 MW
TOTAL CF EXPORTS = 3513.8 MW
CF STN SERV + LOSSES = 15.7 MW
WESTERN LABRADOR LOSSES
CF TO WESTERN LABRADOR = 295.3 MW
WESTERN LABRADOR LOAD = 275.1 MW
WESTERN LABRADOR LOSSES = 20.2 MW
LABRADOR GENERATION
CF GENERATION = 3529.4 MW
MF GENERATION = 412.0 MW
NLH GENERATION = 0.0 MW
LAB GENERATION = 3941.4 MW
HVDC TO NL = 370.4 MW
735 kV TRANSMISSION LOSSES
CF 735 kV SENDING = 0.0 MW
LESS LAB - HQT FLOW = 0.0 MW
735 kV LOSSES TO BORDER = 0.0 MW
735 kV AVG CORONA LOSSES = 8.3 MW
TOTAL 735 kV LOSSES TO BORDER = 8.3 MW
EASTERN LABRADOR LOSSES
CF/MF TO EASTERN LABRADOR = 14.2 MW
EASTERN LABRADOR LOAD = 13.8 MW
EASTERN LABRADOR LOSSES = 0.4 MW
LABRADOR TRANSMISSION ASSET LOSSES
LTA INJECTIONS = -37.6 MW
LESS LTA WITHDRAWALS = -37.8 MW
LTA I^2R LOSSES = 0.2 MW
LTA 315 kV AVG CORONA LOSSES = 0.8 MW
LTA TRANSMISSION LOSSES = 1.0 MW
SPS STUDY DYNAMICS CASE 8007 - INITIALIZED
DEVELOPED FROM CASE 2009
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