Newfoundland and Labrador Hydro
Hydro Place. 500 Columbus Drive
P.O. Box 12400. St. John's. NL
Canada A1B 4K7
t. 709.737.1400 I f. 709.737.1800
nlhydro.com

August 11, 2025

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

Attention: Jo-Anne Galarneau
Executive Director and Board Secretary

Re: *Reliability and Resource Adequacy Study Review* – Final Lower Churchill Project Operational (Stage 4F) Study

Please find enclosed Newfoundland and Labrador Hydro's Final Lower Churchill Project Operational (Stage 4F) Study, provided in accordance with the 2024 Resource Adequacy Plan Settlement Agreement.[1]

Should you have any questions, please contact the undersigned.

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

SWalsh

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

Encl.

ecc:

Board of Commissioners of Public Utilities
Jacqui H. Glynn
Ryan Oake
Board General

Island Industrial Customer Group
Paul L. Coxworthy, Stewart McKelvey
Denis J. Fleming, Cox & Palmer
Glen G. Seaborn, Poole Althouse

Labrador Interconnected Group
Senwung F. Luk, Olthuis Kleer Townshend LLP
Nicholas E. Kennedy, Olthuis Kleer Townshend LLP

Consumer Advocate
Dennis M. Browne, KC, Browne Fitzgerald Morgan & Avis
Stephen F. Fitzgerald, KC, Browne Fitzgerald Morgan & Avis
Sarah G. Fitzgerald, Browne Fitzgerald Morgan & Avis
Bernice Bailey, Browne Fitzgerald Morgan & Avis

Newfoundland Power Inc.
Dominic J. Foley
Douglas W. Wright
Regulatory Email

[1] "2025 Build Application – Bay d'Espoir Unit 8 and Avalon Combustion Turbine," Newfoundland and Labrador Hydro, March 21, 2025, sch. 2.

Final LCP Operational (Stage 4F) Study

Overview

August 11, 2025

A report to the Board of Commissioners of Public Utilities

Contents

List of Attachments

1.0 Context within the RRA Study Review

Newfoundland and Labrador Hydro ("Hydro") filed the initial "Reliability and Resource Adequacy Study" ("RRA Study") with the Board of Commissioners of Public Utilities ("Board") in November 2018 ("2018 Filing").[1] Since the 2018 Filing, throughout the continued *Reliability and Resource Adequacy Study Review* proceeding ("*RRA Study Review*"), Hydro has filed regular updates to the RRA Study, including numerous technical notes, additional studies, and third-party reports. The regulatory record for this proceeding is robust, with good reason. The provincial electrical grid is in the midst of unprecedented change—it is evolving from an isolated to an interconnected system, some of the assets the province has historically relied on most are aging and nearing retirement, there are significant new assets integrated into the electrical system and being proven reliable, and the province is facing an increase in demand driven by electrification.

Hydro's most recent study submitted to the Board on July 9, 2024, is its 2024 Resource Adequacy Plan, containing Hydro's recommended Minimum Investment Required Expansion Plan.[2] Subsequent to filing its 2024 Resource Adequacy Plan, Hydro and its experts participated in a series of technical conferences in the fall of 2024 with Board staff and intervening parties, along with their experts. These technical conferences provided an opportunity for fulsome discussion and enhanced understanding of Hydro's *RRA Study Review* and Expansion Plans. As a result of these proceedings, Hydro and the Intervenors gained consensus on a number of issues ("Settled Issues") which were enumerated in a Settlement Agreement.[3] The Settled Issues include agreement that the recommendation to build a new 150 MW unit at Bay d'Espoir (Unit 8) and a 150 MW Combustion Turbine on the Avalon Peninsula is appropriate as part of the first step in addressing the requirements for additional capacity for the Island Interconnected System, and applications for these projects should be filed for evaluation. In line with the Settled Issues, Hydro filed its 2025 Build Application for both of these assets in March 2025; the regulatory proceeding is ongoing.

---

[1] "Reliability and Resource Adequacy Study," Newfoundland and Labrador Hydro, rev. September 6, 2019 (originally filed November 16, 2018).
[2] "2024 Resource Adequacy Plan – An Update to the Reliability and Resource Adequacy Study," Newfoundland and Labrador Hydro, rev. August 26, 2024 (originally filed July 9, 2024).
[3] "2025 Build Application – Bay d'Espoir Unit 8 and Avalon Combustion Turbine," Newfoundland and Labrador Hydro, March 21, 2025 ("2025 Build Application"), sch. 2.

The *RRA Study Review* has included numerous rounds of requests for information and technical conferences, providing for ample discourse and exchange of information between Hydro, the Board, and the parties.

In the coming years and decades, beginning with the recommended assets within its Minimum Investment Required portfolio, Hydro will have to make significant investments to maintain its legislative obligation of the provision of safe, least-cost, reliable electrical service in an environmentally responsible manner to the province.[4] As such, through the *RRA Study Review*, Hydro is modelling its system expansion in consideration of various forecast scenarios and within the context of continuously evolving energy policy. The numerous studies that Hydro has completed and planned are all necessary to validate and justify the information that Hydro inputs into its models, that produce critical information on which timely, prudent decisions are to be made.

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

2.0 Background

Hydro has been working with its independent expert, TransGrid Solutions ("TransGrid"), since 2017 on a series of operational studies in support of each major phase of the asset integration process for the Lower Churchill Project ("LCP"). The objective of these studies has been to provide guidance to Hydro in ensuring the reliable operation of the Newfoundland and Labrador transmission system during each phase of the LCP integration. The primary focus of the operational studies has been to determine the Labrador-Island Link ("LIL") and Maritime Link transfer limits under various system conditions. The final operational study ("Stage 4F Study") has established system operating limits for all LCP assets subsequent to final commissioning. **The purpose of this document is to summarize the results of the Stage 4F Study, provided as Attachment 1,[5] that would be relevant to the upcoming 2026 Resource Adequacy Plan filing.**

[4] *Electrical Power Control Act*, 1994, SNL 1994, c E-5.1, s 3(b)(iii).
[5] "LCP Operational Study: Final LCP Operational Study ("Stage 4F") Report," TransGrid Solutions Inc., June 26, 2025.

The 2026 Resource Adequacy Plan filing will include an update to the firm energy analysis, which is heavily influenced by the updated LIL Bipole transfer limits developed as part of the Stage 4F Study.[6] To increase power flow to the Island over the LIL, more under-frequency load shedding ("UFLS") would be deemed acceptable following a LIL bipole trip. The increase in LIL transfer limits associated with the new proposed UFLS scheme ("Final UFLS Scheme") provides an improvement to the LIL-Maritime Link relationship and thereby will permit more energy from Labrador to be absorbed on the Island Interconnected System.

2.1 LIL-Maritime Link Relationship

The LIL and the Maritime Link are equipped to provide frequency regulation in the event of pole and bipole contingencies on either link. Consequently, flows on the LIL and the Maritime Link must be coordinated. Therefore, under normal system conditions, the amount of energy that can flow over the LIL to the Island is limited by the interdependencies with the Maritime Link. This interdependence exists because both high-voltage direct current ("HVdc") links must work together through the use of runbacks to suddenly reduce their power flows to transiently regulate system frequency in the event a contingency occurs on the other HVdc link. This LIL-Maritime Link relationship has a significant impact on the amount of power that can be absorbed on the Island (Net dc[7]), but is primarily dependent on the amount of UFLS that is available and would be triggered following a LIL bipole trip. The amount of available UFLS is directly proportional to the total Island load, as shown in Figure 1.

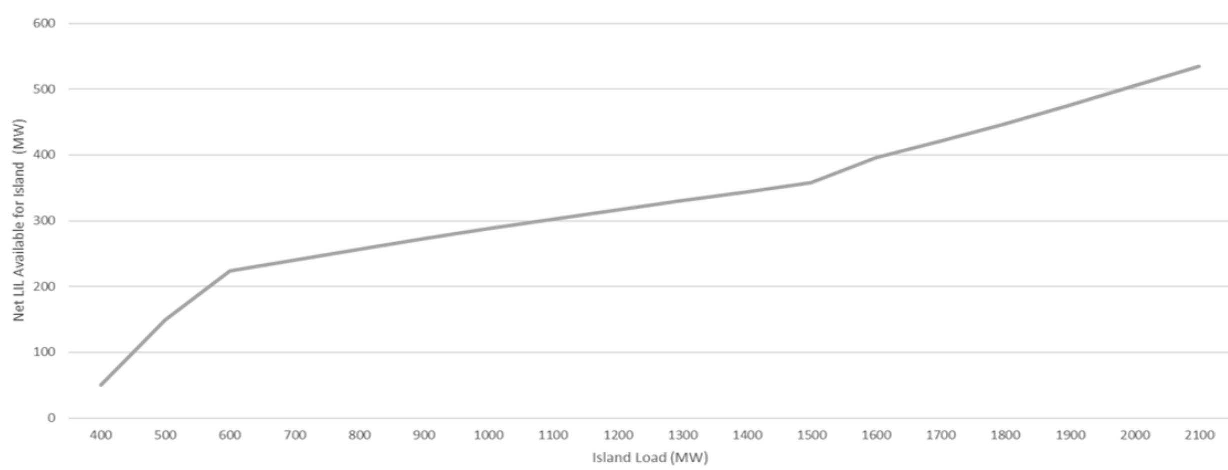


Figure 1: Illustrative Example of Current LIL-Maritime Link Relationship

[6] The updated LIL bipole transfer limits are provided in Section 4.1 of the Stage 4F Study.

[7] Direct current ("dc"). This would be the difference between Maritime Link export levels and the LIL imports at Soldiers Pond.

In the event of a LIL bipole trip and a subsequent Maritime Link runback, the Island system would experience a loss of supply at a magnitude of the Net dc. The only mechanism to transiently offset this loss of supply would be UFLS. Therefore, the higher the amount of armed UFLS, the more energy that can be sunk on the Island Interconnected System. The Stage 4F Study provides the updated LIL bipole transfer limits associated with the implementation of the Final UFLS Scheme, which in turn quantifies the improvement of the LIL–Maritime Link relationship.

2.2 UFLS Schemes

A UFLS scheme[8] is a form of system protection that involves shedding load in blocks to ensure a stable system response following a contingency event. The UFLS scheme currently in place is referred to as the "Existing UFLS Scheme." Table 1 provides a summary of the Existing and Final UFLS Schemes assuming peak demand levels of 1,800 MW and 2,000 MW,[9] respectively. The block size amounts scale proportionally to the Island Demand level.[10] Therefore, it would be expected that the total amount of UFLS for the Existing UFLS Scheme would be approximately 295 MW at an Island Demand of 900 MW.

Table 1: UFLS Schemes

	UFLS Block Size (MW)[11]	
Frequency Blocks (Hz)	**Existing UFLS Scheme**	**Final UFLS Scheme**
58.8	110	160
58.6	110	170
58.4	120	170
58.2	115	168
58.1	135	88
58.0[12]	165	-
57.7[13]	-	105
Total (Excluding Back-up Blocks)	**590**	**756**
Assumed System Peak	1,800 MW	2,000 MW
Percentage of System Peak Shed	33%	38%

[8] Hydro is responsible for UFLS design, while Newfoundland Power Inc. manages the scheme and ensures it fairly rotates amongst their customers.

[9] The Final UFLS Scheme was designed to support a peak demand of 2,000 MW. The Final UFLS Scheme can be applied above Island Demand levels of 2,000 MW, but the total UFLS amount must be limited to 756 MW. In this case, LIL transfer limits would have to be established for Island Demand beyond 2,000 MW, with total UFLS fixed at 756 MW.

[10] Hydro anticipates potential Island loads at 2,000 MW or higher by 2036 in the Reference Case load forecast.

[11] The block sizes are approximate values obtained from the Power System Simulation for Engineering (PSS/E)model.

[12] Safety Block – not intended to shed as part of the existing UFLS Scheme following a LIL bipole trip; therefore, it is not included in the total. The purpose of the back-up blocks are to protect the system in the rare event that the system does not respond as expected or if it turns into a cascading event, for example. The LIL limits determined in the Stage 4F Study were not designed to utilize the back-up block.

[13] Safety Block – not intended to shed as part of the future UFLS Scheme following a LIL bipole trip; therefore, it is not included in the total. The purpose of the back-up blocks are to protect the system in the rare event that the system does not respond as expected or if it turns into a cascading event, for example. The LIL limits determined in the Stage 4F Study were not designed to utilize the back-up block.

There is a technical limitation to the total amount of allowable UFLS on the Island Interconnected System. In the event that too much UFLS is triggered following a LIL bipole trip (and the subsequent Maritime Link runback), there would be a surplus of power on the Island Interconnected System that would result in system overfrequency. This is discussed in more detail in Sections 4.1.2 and 4.1.3 of the Stage 4F Study. The increased amount of load shedding associated with the Final UFLS Scheme permits more LIL power transfer and therefore allows more energy that can be absorbed on the Island Interconnected System.

2.3 Existing LIL Bipole Transfer Limits

The LIL bipole transfer limits currently in place are based on the Existing UFLS Scheme outlined in Table 1. Chart 1 illustrates the existing LIL bipole transfer limits for various Maritime Link export levels under normal operating conditions. There are separate plots for various Maritime Link export levels due to the LIL-Maritime Link Relationship, while the slope of each plot is directly proportional to the amount of available UFLS that could be tripped following a LIL bipole trip. The intention is that the implementation of the Final UFLS scheme will increase these transfer limits as presented in Section 3.3.

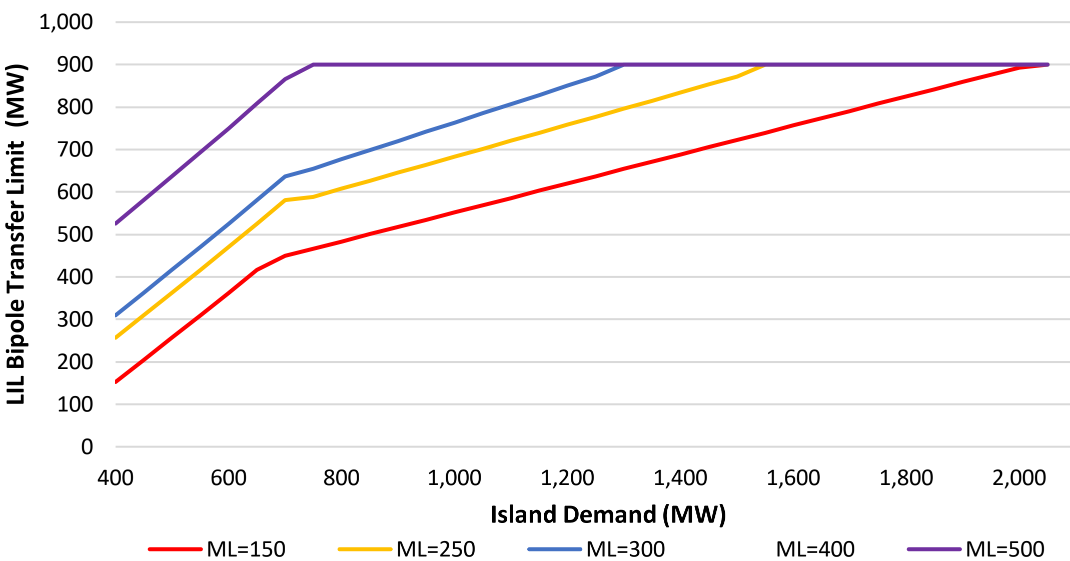


Chart 1: Existing LIL Bipole Transfer Limits (Normal Operation)[14]

[14] Measured at sending end, or Muskrat Falls.

3.0 Summary of Stage 4F Study Results Relevant to the RRA

The purpose of this overview is to provide a high-level summary of the results of the Stage 4F Study that are relevant to the ongoing *RRA Study Review,* specifically the update to the LIL bipole transfer limits with the Final UFLS Scheme applied. The updated LIL bipole transfer limits were defined to meet Hydro's Transmission Planning Criteria or avoid both an underfrequency and overfrequency event following a LIL bipole trip.

- **Underfrequency Event:** Island Interconnected System frequency must not drop below 57.8 Hz following a LIL bipole trip and must recover to avoid the risk of system instability.
- **Overfrequency Event:** Island Interconnected System frequency must not exceed 63.0 Hz following a contingency event to avoid any negative impacts to Hydro's generation assets.[15]

3.1 Underfrequency Event

The sudden loss of generation (or supply) on the Island Interconnected System will result in a decrease in system frequency that, if severe enough, could potentially lead to system instability. A LIL bipole trip would be an event that would result in a loss of supply with a Maritime Link runback, and UFLS being a means to mitigate the underfrequency.

Figure 2 shows the frequency response of the Island Interconnected System at 2,000 MW following a LIL bipole trip while operating at capacity (900 MW) during peak load conditions in which a 150 MW Maritime Link runback was activated. In this case, the system frequency drops to 57.8 Hz, triggering all UFLS blocks except the 57.7 Hz back-up block and then successfully recovers.

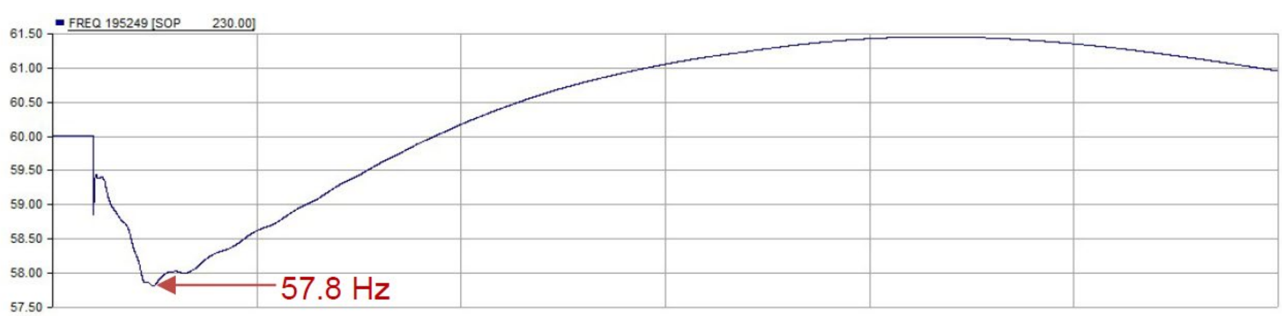


Figure 2: Underfrequency Following LIL Bipole Trip (900 MW) with a 150 MW Maritime Link Runback (Peak Load Conditions)

[15] Generating units, specifically thermal units, should not be exposed to excessive over-speeds.

3.2 Overfrequency Event

As summarized in Section 4.1.2 of the Stage 4F Study, unacceptable overfrequency events were observed on the Island Interconnected System for certain scenarios following a Maritime Link runback and UFLS after a LIL bipole trip. When the system recovers from an underfrequency event caused by a LIL bipole trip, a large overfrequency occurs because of the resulting power imbalance on the Island Interconnected System. At higher Island Interconnected System demand levels, there is inherently more load that is shed by the UFLS Scheme, which corresponds to a higher system frequency and, in some cases, will violate Hydro's Transmission Planning Criteria.

Figure 3 shows the frequency response of the Island Interconnected System following a LIL bipole trip while operating at capacity (900 MW) at an Island Demand of 2,000 MW, in which a 250 MW Maritime Link runback was activated. In this case, an overfrequency event occurs with the system increasing beyond 64 Hz, violating Hydro's Transmission Planning Criteria.

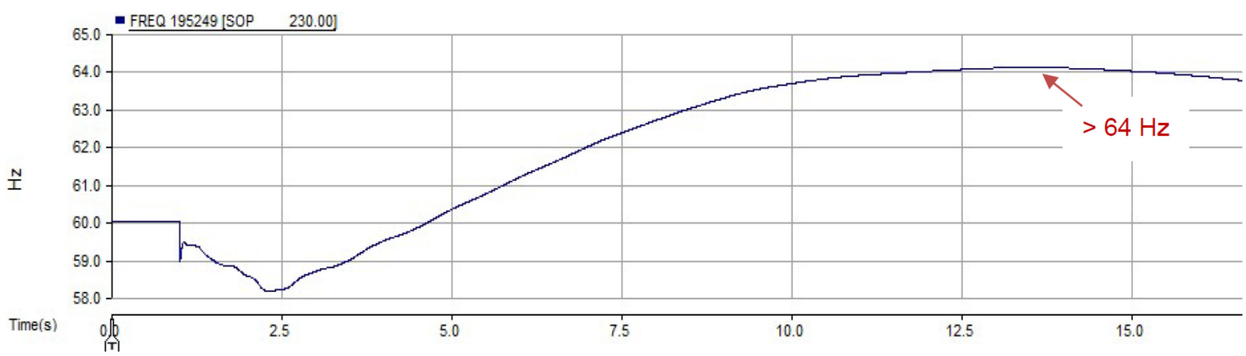


Figure 3: Underfrequency following LIL Bipole Trip (900 MW) with a 150 MW Maritime Link Runback (Future Peak Load Conditions – 2,000 MW)

3.3 Updated LIL Bipole Transfer Limits

The updated LIL bipole transfer limits under normal operating conditions are provided in Table 4-3 of the Stage 4F Study. There were nine Island Demand level simulations for Maritime Link export levels of 150 MW, 250 MW, 300 MW, 400 MW, and 500 MW, equating to the establishment of 45 scenarios or operating points. TransGrid adjusted LIL power flow and the amount of UFLS to ensure system frequency response was acceptable and remained within 57.7 Hz and 63 Hz in order to establish the optimal LIL bipole transfer limits for each operating point or scenario.

Using linear regression on all the simulated operating points, a relationship was established between LIL transfer limits and Island Demand for each Maritime Link export level and summarized in Table 2.

Charts 2 to 6 are graphs of the LIL bipole transfer limits for both the Existing and Final UFLS Schemes for various Maritime Link export levels.

As illustrated in Charts 2 to 6, the LIL Bipole Transfer limits are equal for the Existing and Final UFLS Schemes for any Island Demand levels less than approximately 700 MW. At Island Demand levels less than or equal to 700 MW, the frequency response of the Island Interconnected System is not the most limiting factor when defining LIL bipole transfer limits; the limiting factor becomes the minimum generation requirement and ensuring a balance of supply and demand on the Island Interconnected System. There must be a minimum amount of dispatched generation on the Island Interconnected System that equates to about 400 MW, which is required for reliability and to provide station service load to certain plants. In a 600 MW Island Demand scenario with 160 MW of Maritime Link exports, the minimum generation requirement of 400 MW would limit LIL delivery to Soldiers Pond to 360 MW.[16] If LIL imports are higher, there would be a surplus of supply on the Island Interconnected System.

The LIL Bipole Transfer Limits with Maritime Link exports at 150 MW are shown in Chart 2. At an Island Interconnected System load of in excess of approximately 700 MW, the final UFLS scheme allows for greater LIL imports of up to 900 MW, depending on the magnitude of the Island Interconnected System load.

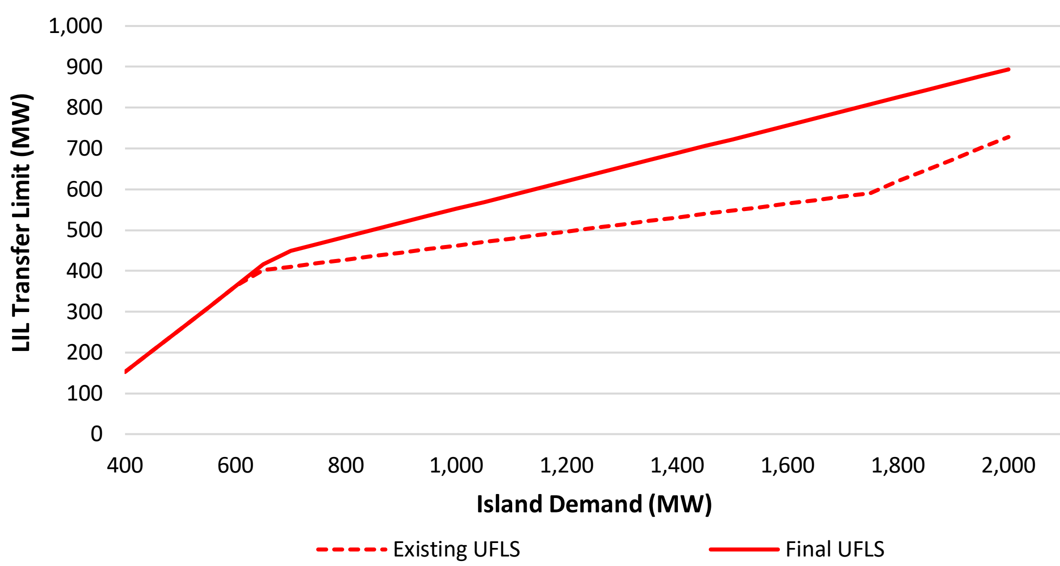


Chart 2: LIL Bipole Transfer Limits (Maritime Link=150 MW) (Normal Operation)

[16] Island Demand + Maritime Link Exports – Minimum Island Generation. 600 MW +160 MW – 400MW = 360 MW.

The LIL Bipole Transfer Limits with Maritime Link exports at 250 MW are shown in Chart 3. At an Island Interconnected System load of in excess of approximately 700 MW, the final UFLS scheme allows for greater LIL imports of up to 900 MW, depending on the magnitude of the Island Interconnected System load.

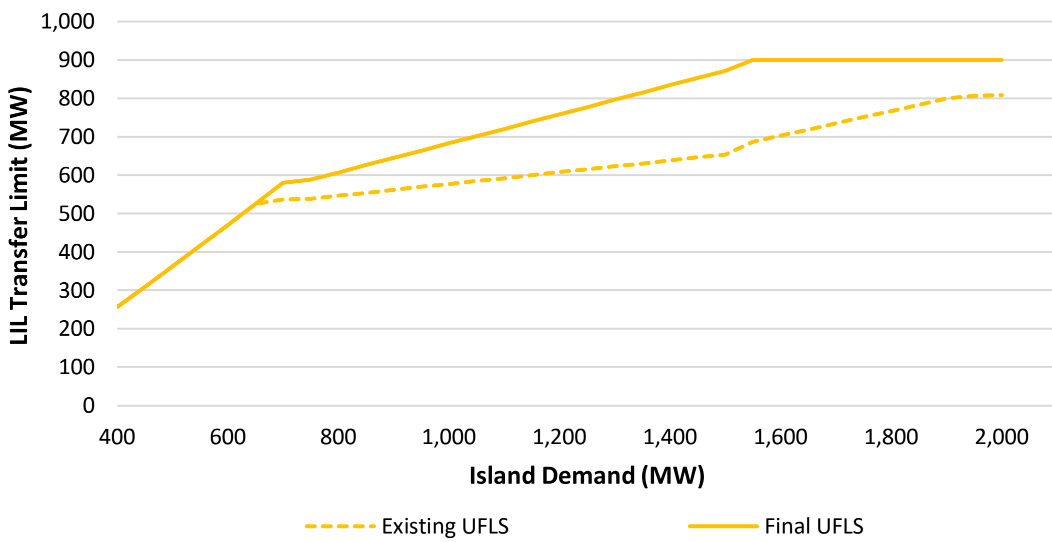


Chart 3: LIL Bipole Transfer Limits (Maritime Link=250 MW) (Normal Operation)

The LIL Bipole Transfer Limits with Maritime Link exports at 300 MW are shown in Chart 4. At an Island Interconnected System load of between approximately 700 MW and 1,900 MW, the final UFLS scheme allows for greater LIL imports of up to 900 MW, depending on the magnitude of the Island Interconnected System load.

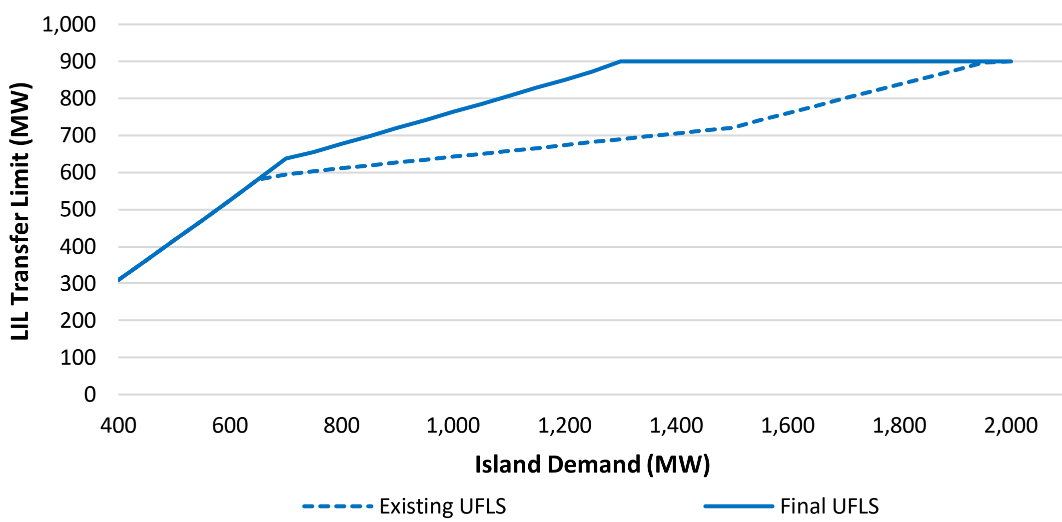


Chart 4: LIL Bipole Transfer Limits (Maritime Link =300 MW) (Normal Operation)

The LIL Bipole Transfer Limits with Maritime Link exports at 400 MW are shown in Chart 5. At an Island Interconnected System load of between approximately 700 MW and 1,600 MW, the final UFLS scheme allows for greater LIL imports of up to 900 MW, depending on the magnitude of the Island Interconnected System load.

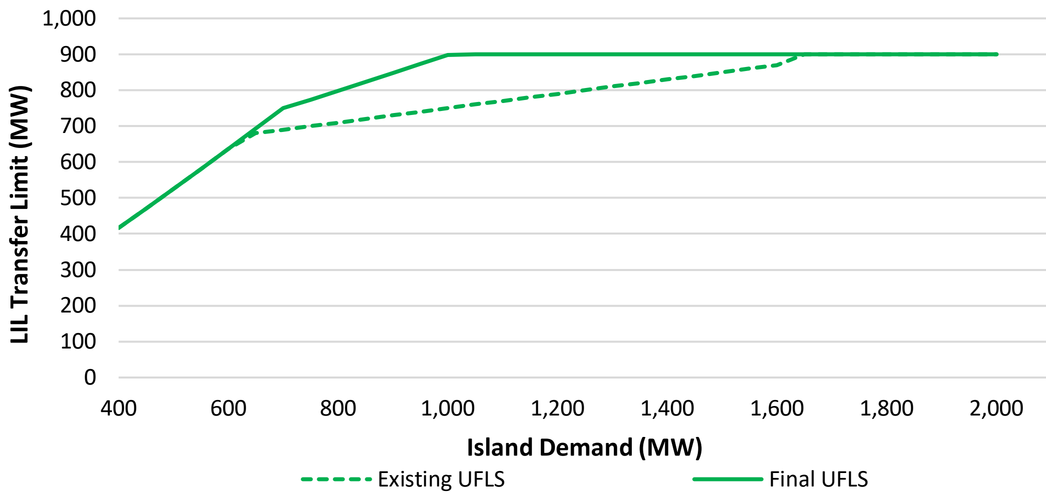


Chart 5: LIL Bipole Transfer Limits (Maritime Link=400 MW) (Normal Operation)

The LIL Bipole Transfer Limits with Maritime Link exports at 500 MW are shown in Chart 6. At an Island Interconnected System load of between approximately 700 MW and 900 MW, the final UFLS scheme allows for greater LIL imports of up to 900 MW, depending on the magnitude of the Island Interconnected System load.

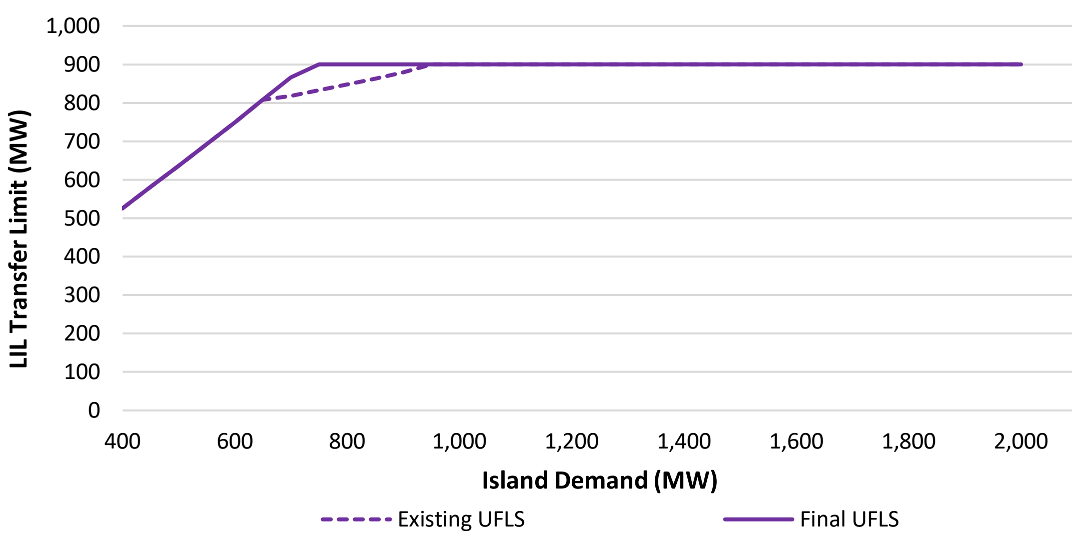


Chart 6: LIL Bipole Transfer Limits (Maritime Link=500 MW) (Normal Operation)

Table 2: LIL Bipole Transfer Limits (Final UFLS Scheme)

Island Demand (MW)	Maritime Link =150	Maritime Link =250	Maritime Link =300	Maritime Link =400	Maritime Link =500
400	153	257	310	417	526
450	204	310	363	471	581
500	257	363	417	526	637
550	310	417	471	581	693
600	363	471	526	637	750
650	417	526	581	693	808
700	449	581	637	750	866
750	466	588	655	774	900
800	483	607	677	798	900
850	501	626	698	823	900
900	518	645	720	848	900
950	535	664	742	873	900
1000	552	683	764	898	900
1050	569	702	785	900	900
1100	586	721	807	900	900
1150	603	740	829	900	900
1200	620	758	850	900	900
1250	637	777	872	900	900
1300	654	796	900	900	900
1350	671	815	900	900	900
1400	689	834	900	900	900
1450	706	853	900	900	900
1500	723	872	900	900	900
1550	740	900	900	900	900
1600	757	900	900	900	900
1650	774	900	900	900	900
1700	791	900	900	900	900
1750	808	900	900	900	900
1800	825	900	900	900	900
1850	842	900	900	900	900
1900	859	900	900	900	900
1950	877	900	900	900	900
2000	894	900	900	900	900
2050	900	900	900	900	900

3.4 Improvements to the LIL-Maritime Relationship

The LIL bipole transfer limits have increased with the Final UFLS Scheme applied as indicated in Charts 2 to 6. The increase in LIL bipole transfer limits for a given Island Demand level for each Maritime Link export level translates into more LIL energy that can be absorbed on the Island Interconnected System (or Net dc). Chart 7 illustrates the incremental increase in Net dc associated with the application of the Final UFLS Scheme compared to the Existing UFLS Scheme for various Maritime Link export levels. The LIL-Maritime Link relationship has significantly improved since LIL power transfer has less dependency on the Maritime Link export levels, meaning a higher Net dc. In a peak scenario with Island Demand approximately 1,800 MW, the incremental Net dc with the Final UFLS Scheme applied is 190 MW, which means the LIL power transfer delivered at Soldiers Pond can be 190 MW more for the same Island Demand and Maritime Link export level.

This incremental increase in Net dc using the Final UFLS Scheme will reduce the firm energy deficit analyzed in each Island Interconnected System load forecast scenario presented in the 2025 Build Application by approximately 450–500 GWh.[17] A full update to the firm energy analysis will be provided in the 2026 Resource Adequacy Plan.

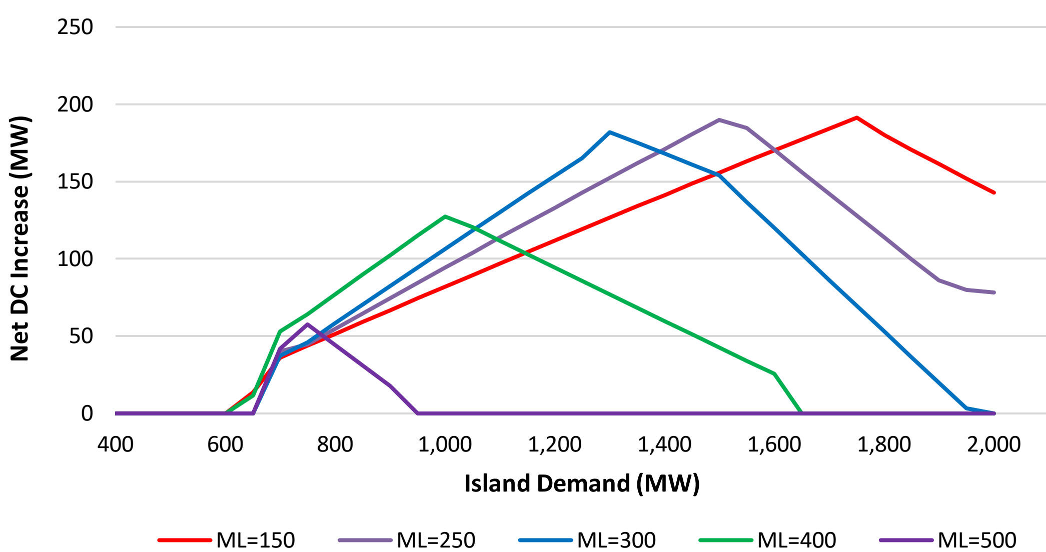


Chart 7: LIL-Maritime Link Relationship Improvement (Final UFLS Scheme – Normal Operation)

[17] "2025 Build Application – Bay d'Espoir Unit 8 and Avalon Combustion Turbine," Newfoundland and Labrador Hydro, March 21, 2025, sch. 3, sec. 4.0.

4.0 Conclusion and Next Steps

The primary objective of the TransGrid Study, as it relates to the *RRA Study Review,* is to determine the technical viability of increasing the amount of allowable UFLS with the purpose of increasing LIL bipole transfer limits to improve the LIL-Maritime Link relationship. Analysis was performed as part of the Stage 4F Study that quantified the improvement of the LIL-Maritime Link relationship. This improvement in the LIL-Maritime Link relationship will facilitate more energy that can be absorbed on the Island Interconnected System and potentially reduce or defer the requirement for future firm energy sources on the Island Interconnected System. This incremental increase in Net dc using the Final UFLS Scheme will reduce the firm energy deficit analyzed in each Island Interconnected System load forecast scenario that was presented in the 2025 Build Application by approximately 450–500 GWh.[18] This reduction results in less firm energy resources required to meet the Island Interconnected System firm energy criteria. As the least-cost resource option to meet the firm energy requirement was identified as wind, a capacity credit was assigned to this resource in the recommended Minimum Investment Required expansion plan. Therefore, the reduction of the amount of wind required will result in the reduction of the capacity contribution from wind as presented in the Minimum Investment Required expansion plan. The Final UFLS Scheme does not have any impact on the capacity projects recommended in the 2025 Build Application: Bay d'Espoir Unit 8 and the Avalon Combustion Turbine. A full update to the firm energy analysis will be provided in the 2026 Resource Adequacy Plan.

As a next step, through further power system studies, Hydro will quantify if further improvements to the LIL-Maritime Link relationship are possible with the application of a Battery Energy Storage System ("BESS") capable of providing additional frequency response following a LIL bipole trip. Any additional benefits from a BESS on the LIL-Maritime Link relationship and its effect on the firm energy analysis will be incorporated into the analysis for the 2026 Resource Adequacy Plan.

[18] *Supra*, f.n. 17.

Attachment 1

Final LCP Operational Study (Stage 4F) Report

TransGrid Solutions Inc.

LCP OPERATIONAL STUDY:

Final LCP Operational Study ("Stage 4F") Report

NEWFOUNDLAND & LABRADOR HYDRO

Attention: Matthew Carter
Report no.: R1205.01.03
Date of issue: June 26, 2025

Prepared By:
TransGrid Solutions Inc.
100-78 Innovation Dr.
Winnipeg, MB R3T 6C2
CANADA

Disclaimer

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

Revisions

Project Name:	LCP Operational Study
Document Title:	Final LCP Operational Study ("Stage 4F") Report
Document Type:	Final Report
Document No.:	R1205.01.03
Last Action Date:	June 26, 2025

Rev. No.	Status	Prepared By	Checked By	Date	Comments
00	DFC	R. Ostash	M. Carter	April 21, 2025	Draft report issued for review by Hydro
01	DFC	R. Ostash	M. Carter		Updated draft report issued for review by Hydro after addressing initial round of comments
02	DFC	R. Ostash	M. Carter		Updated draft report after additional round of comments.
03	IFA	R. Ostash	M. Carter		Updated report after additional round of comments.

Legend of Document Status:

Approved by Client	ABC
Draft for Comments	DFC
Issued for Comments	IFC
Issued for Approval	IFA

Table of Contents

Executive Summary

TransGrid Solutions has performed a series of operational studies for Newfoundland and Labrador Hydro ("Hydro") for each major phase of the asset integration process for Lower Churchill Project ("LCP"). These major assets included the Labrador Island Link ("LIL"), Maritime Link ("ML"), Soldiers Pond ("SOP") Synchronous Condensers, Muskrat Falls ("MFA") generators and the 315 kV lines between MFA and Churchill Falls ("CHF").

The objective of these studies has been to provide guidance to Hydro in ensuring the reliable operation of the Newfoundland and Labrador ("NL") transmission system during each phase of LCP commissioning. The primary focus of the operational studies has been to determine the LIL and ML transfer limits under various system conditions.

The final operational study ("The Stage 4F Study") has established system operating limits for all LCP assets assuming they have been fully commissioned. This report provides a comprehensive overview of the Stage 4F Study, which provides the following deliverables:

- Updated LIL **Bipole** Transfer Limits (with and without LIL restarts):
  - Using the existing underfrequency load shedding ("UFLS") scheme
  - Using a final modified version of the UFLS scheme for the purpose of maximizing LIL power transfer
- Updated LIL **Monopole** Transfer Limits (with and without LIL restarts)
- Updated ML **Bipole** Import/Export Transfer Limits
- Updated ML **Monopole** Import/Export Transfer Limits
- The following are other topics that were also assessed as part of the Stage 4F study that relate to the operation/integration of LCP assets:
  - Minimum Avalon Generation
  - LIL Filter Feeder Contingency Impact
  - LIL Limits with Subsea Cable Issues
  - LIL Limits with 0 or 1 SOP synchronous condensers online
  - Stability Transfer Limits (Prior Outage to TL201/TL217)
  - Update of the 315 kV Limits (with and without LIL F/C)

1. Introduction

The purpose of the Stage 4F Study is to establish system operating limits for all LCP assets assuming they have been fully commissioned. The Interconnected Island System ("IIS") and Labrador Interconnected System("LIS") are the areas of focus for this study.

The Stage 4F Study provides updated LIL and ML transfer limits for both bipole and monopole modes of operation, and addresses a list of other factors affecting LIS and IIS operation including:

- Minimum Avalon Generation
- LIL Filter Feeder Contingency Impact
- LIL Limits with Subsea Cable Issues
- LIL Limits with 0 or 1 SOP synchronous condensers
- Stability Transfer Limits (Prior Outage to TL201/TL217)
- Update of the 315 kV Limits (with and without LIL F/C)

1.1 Interconnected Island System

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

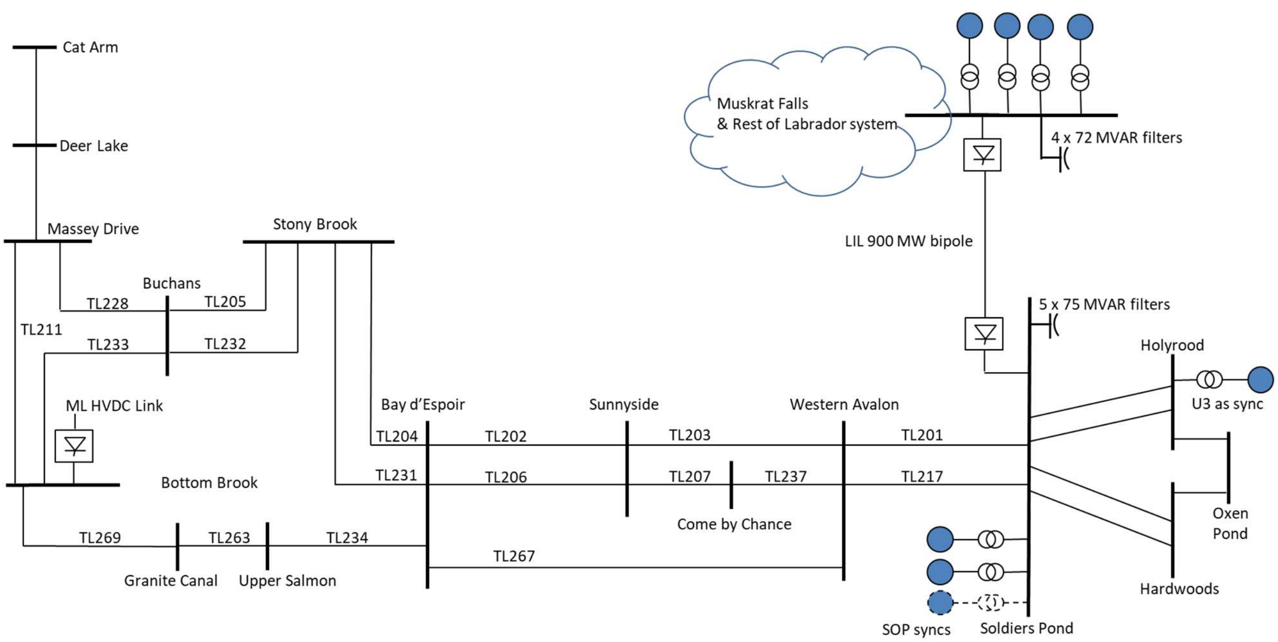


Figure 1-1. IIS - 230 kV Transmission System

1.2 Labrador Interconnected System

The LIS between Muskrat Falls and Churchill Falls is shown in Figure 1-2.

Analysis involving the 315 kV lines between MFA and CHF is addressed in this study (Section 7.6).

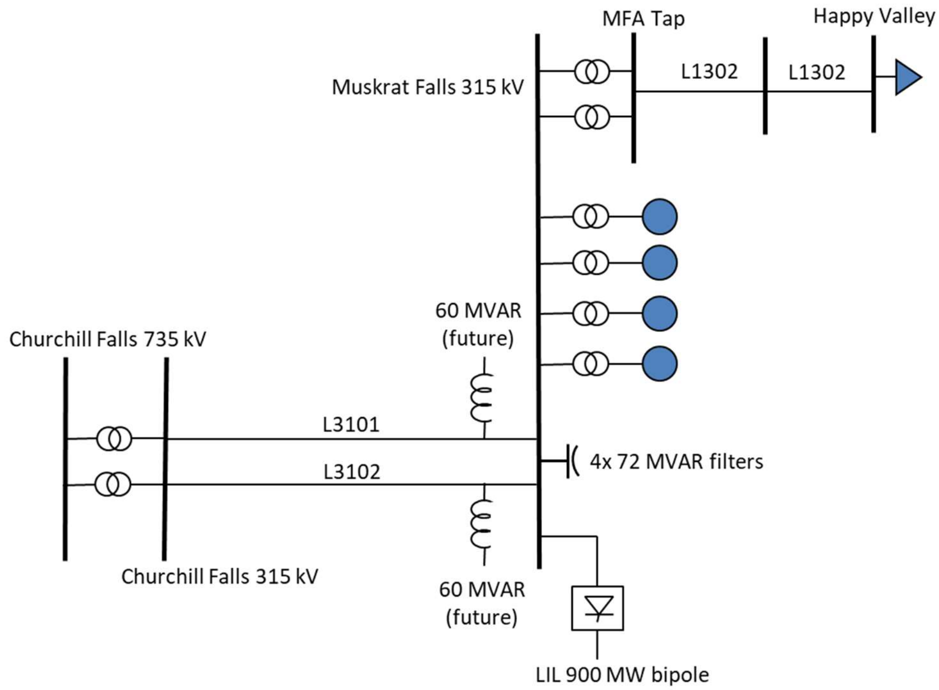


Figure 1-2. LIS between Happy Valley and Churchill Falls

2. Summary of Previous Studies

Operational studies related to the addition of the MFA generating units, the ML, the LIL and the SOP synchronous condensers to the IIS started in 2017 and have been underway since that time, leading up to this Stage 4F study. The main purpose of the operational studies has been to determine LIL transfer limits and ML import/export limits throughout the various stages of LCP asset commissioning. Previous reports determined these limits for:

- Initial scenario with only the ML in-service
- SOP synchronous condensers coming into service
- Phased approach for the LIL coming into service, first as a monopole at 225 MW maximum transfer, then as a bipole at reduced transfer and finally as a bipole at full power with full functionality (2 pu overload, frequency support); assuming Hydro's original UFLS scheme.

Addition of the LIL bipole to the IIS also required a re-design of the UFLS scheme that is currently in place to ensure the IIS can maintain stability and meet dynamic performance criteria under a LIL bipole trip. Coordination of the ML and LIL was also required, e.g. running back of ML exports following a LIL bipole trips.

Operational limits were defined for various operating conditions such as:

- 0, 1, 2 and 3 SOP SCs being on-line
- LIL operating as monopole
- ML operating as monopole
- LIL frequency support active / not active
- ML frequency support active / not active
- ML runbacks active / not active

Operation of the IIS under a LIL bipole outage has also been studied and is still under study, in which case the 230 kV transmission corridor between BDE and SOP becomes of utmost importance to transferring power from generation in the west of the IIS to the main load center on the Avalon Peninsula.

Finally, operational studies on the Labrador side were conducted to identify impacts on LIL limits[1] and transfer limits between CHF and MFA under various operating conditions including:

- 2, 3 or 4 MFA generating units on-line
- Prior outage of a 315 kV line between MFA and CHF
- Isolated operation of the LIL with vary number of MFA generating units online

[1] With and without the future 315 kV line reactors in-service.

3. Study Assumptions, Criteria and Cases

3.1 Study Assumptions

The following are the high-level assumptions made for this study:

- Thermal generation from Holyrood ("HRD") units (1,2,3) is decommissioned. HRD unit 3 is operating as a synchronous condenser.
- Bay d'Espoir ("BDE") unit 8 is in-service. When not required for MW, it is set to synchronous condenser mode.
- Two Soldiers Pond synchronous condensers are in-service.
- LIL frequency controller is in-service with control (PFC) set in SOP (with exception to Section 6.6.1).
- LIL 2 pu 10-minute overload is available.
- ML can operate between 320 MW import and 500 MW export, if not limited by operational restrictions.
- As long as import capacity is available, the ML frequency controller may be activated to provide up to 150 MW of frequency support if a LIL pole or the bipole is lost or for other underfrequency events on the IIS[2]. It is assumed that if a ML runback has taken place in response to loss of the LIL bipole or pole, that further action by the ML frequency controller will not occur in this situation.
- Under normal operation the ML frequency controller shall be active when ML flow is between -170MW (import) to 150 MW (export). Runbacks shall be enabled whenever the ML is exporting greater than 150 MW.
- The new 3x50 MW HRD CTs are assumed available but are only dispatched when required to serve IIS demand, ML export and / or for minimum Avalon generation requirements as discussed in this report.
- Happy Valley-Goose Bay ("HVY") load was assumed to range from 15 MW to 80 MW in the analysis involving the MFA-CHF 315 kV transfer limits in Labrador.
- Normal LIL filter switching schedule was assumed.
- Minimum on-Island Generation dispatched is assumed to be 400 MW.

3.2 Study Criteria

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

- Steady state voltage : 0.95 pu – 1.05 pu during n-0 conditions

[2] Unless an ML runback just occurred, at which time the ML frequency controller is automatically disabled.

- Steady state voltage : 0.90 pu – 1.1 pu during n-1 conditions
- Post fault recovery voltages on the ac system shall be as follows:
    - Transient undervoltages following fault clearing should not drop below 70%
    - The duration of the voltage below 80% following fault clearing should not exceed 20 cycles
- IIS frequency must stay within 59 Hz to 63 Hz following a single contingency event to avoid UFLS and overfrequencies that could have an adverse impact on generation assets.
- LIS Frequency must stay within 58 Hz to 63 Hz following a single contingency event to avoid tripping MFA units on under/over frequency, respectively. The tripping of the MFA units would likely have a cascading effect and trip the LIL bipole.
- For a permanent loss of the ML bipole, underfrequency load shedding shall be permitted, but controlled, and the system frequency shall not drop below 58 Hz.
- For a permanent loss of the LIL bipole, underfrequency load shedding is permitted, but controlled. In the final modified design of the UFLS scheme (to be implemented in the future), the system frequency is allowed to shed the final block (58.1 Hz) of load shed, as long as the system recovers in a stable manner[3]. The final UFLS is designed with a back-up block of load shed at 57.7 Hz which is never intended to shed.

3.3 PSSE Base Cases

The PSSE base cases used in this study represent the year 2033-34.

Table 3-1 lists the initial set base cases provided by Hydro. Base Cases reflect long term (ten year) load forecast conditions in accordance with Hydro's annual assessment process. For the purposes of operational analysis, additional cases were developed with various IIS demand levels ranging from extreme light to peak, with varying LIL transfer levels and ML transfer levels. Generation dispatches were adjusted to reflect worst-case conditions in terms of transmission line power flows, reactive support, and total system inertia.

Table 3-1. Initial set of 2033-34 base cases

Load Condition	Island Demand (MW)	On-Island Generation (MW)	LIL Power Transfer (at MFA) (MW)	ML Power Transfer (at BBK) (MW)
Peak	2017	1579	739	250
Light	812	682	400	500
Extreme Light	447	406	305	250

[3] The study found that in all cases where the system recovered in a stable manner, the system frequency was back up to 59.5 Hz after a maximum of 35 seconds.
[4] Island Demand includes load and losses. Variations in Island Demand for the same loading condition are attributed to incremental losses associated with variations in dispatch.

4. LIL Limits

4.1 LIL Bipole Limits

Loss of the LIL bipole is the contingency that defines the requirements of the UFLS scheme for the IIS. The UFLS scheme ensures that the system frequency remains stable following the loss of the LIL bipole.

4.1.1 Interim UFLS Scheme

During the preliminary Stage 4 operational studies, an "Interim" UFLS scheme was designed by modifying the previously existing UFLS scheme under the base assumption that the ML was exporting 158 MW, with the aim of being able to transfer rated power of 900 MW on the LIL over peak[5]. This reflects the worst-case shortfall for Island system where imports are maximized, and exports are limited to firm commitment values ("Emera Block"). During other ML transfer levels between 320 MW import and 500 MW export with varying IIS demand levels, LIL transfer limits were determined with the modified Interim ULFS scheme in place.

This Interim UFLS scheme is currently in operation at the time of this report, and it includes a total of 755 MW (blocks from 58.8 Hz to 58.0 Hz) based on the 2023-34 peak demand of around 1800 MW. Hydro has been setting the LIL transfer limits such that all blocks would shed with the exception of the 58 Hz block, which would be a total load shed of approximately 590 MW during peak conditions (1800 MW).

The Interim UFLS scheme is summarized in Table 4-1.

Table 4-1. Interim UFLS scheme

Frequency Block (Hz)		UFLS (MW)*
Main UFLS	58.8	110
	58.6	110
	58.4	120
	58.2	115
	58.1	135
	58.0	165
TOTAL		***755***[6]
**Assumes peak load of 1800 MW*		

[5] These preliminary studies were based on the present day 2023-24 base cases at the time where peak demand was around 1825 MW.
[6] This includes the NLH feeders, but not NLH industrial customers with motors set to trip on underfrequency.

At the time of the earlier Stage 4 operational studies, an original “Final” UFLS scheme was also designed, which included approximately 840 MW of UFLS (based on the 2023-24 peak demand of approximately 1800 MW). The idea was to allow higher LIL transfer by shedding more load if the LIL bipole tripped. However, this UFLS was designed under the assumption that the ML frequency controller, although not able to provide additional underfrequency support after running back to 0 MW, could still support the IIS frequency by providing overfrequency support if needed after the system recovered from the LIL bipole trip and UFLS. It was since determined that the ML frequency controller is entirely disabled[7] after an ML runback, therefore, the ML frequency controller is unable to support any overfrequency that may occur as the system recovers. In the Stage 4F studies, it was determined that overfrequency can be a limiting issue, and a re-design (reduction) of the “Final” UFLS was required. The Stage 4F “Final” UFLS scheme and overfrequency issue are further discussed and demonstrated in Section 3.1.2 (Figure 4-1).

[7] At the request of Nova Scotia Power.

4.1.2 Final UFLS Scheme

The Stage 4F study is based on the set of 2033-34 PSSE base cases, in which the peak demand is approximately 2000 MW. Initially, when starting the Stage 4F study, the Interim UFLS scheme was first tested to simulate loss of the LIL bipole using these base cases. Significant overfrequencies were observed on the IIS for some scenarios involving an ML runback after the LIL bipole tripped. This is because at a higher peak demand levels (2000 MW vs. 1800 MW) the same UFLS scheme will shed more total load. The 2033-34 peak case sheds a total of approximately 840 MW when applying the Interim UFLS scheme compared to 750 MW in the 2023-24 peak case. This is further explained as follows:

Overfrequency Issue

When the LIL bipole trips, there is an approximate delay of 250 ms from the time that the LIL bipole trips to the runback of ML export. During this delay, frequency is dropping. Subsequent to the 250ms delay, the ML runs back exports to 0 MW, which is an automated process following a LIL bipole trip. In some scenarios, depending on the amount of load that is shed plus the amount of power that is runback on the ML, more load/exports are removed than was lost from the LIL infeed. Therefore, when the system recovers from the underfrequency, a large overfrequency occurs because of the resulting power imbalance on the IIS. Since the ML frequency controller becomes inactive following an ML runback, it is not available to support the IIS to reduce this overfrequency. The overfrequency issue was more severe for the Stage 4F study compared to the other preliminary Stage 4 studies because of the higher peak demand in the 2033-34 cases. As higher IIS demand grows there is inherently more load that is shed by the UFLS scheme, and the more load that is shed, the higher the overfrequency. This resulted in violations of Transmission Planning criteria (i.e. frequency > 63 Hz).

An example of such overfrequency is shown in Figure 4-1.

This example is a 2033-34 peak case (~2000 MW demand) with ML exporting 250 MW and LIL transferring 900 MW (at MFA). When the LIL bipole trips, the frequency dips to 58.15 Hz resulting in a total of 839 MW of UFLS, along with the ML runback of 250 MW, adding up to a total of 1089 MW of effective load removed from the system. Since the LIL was operating at 900 MW, 832 MW (after LIL losses) of infeed is lost to the IIS, the system ends up in a state with approximately 250 MW of excess generation, resulting in a frequency greater than 64 Hz.

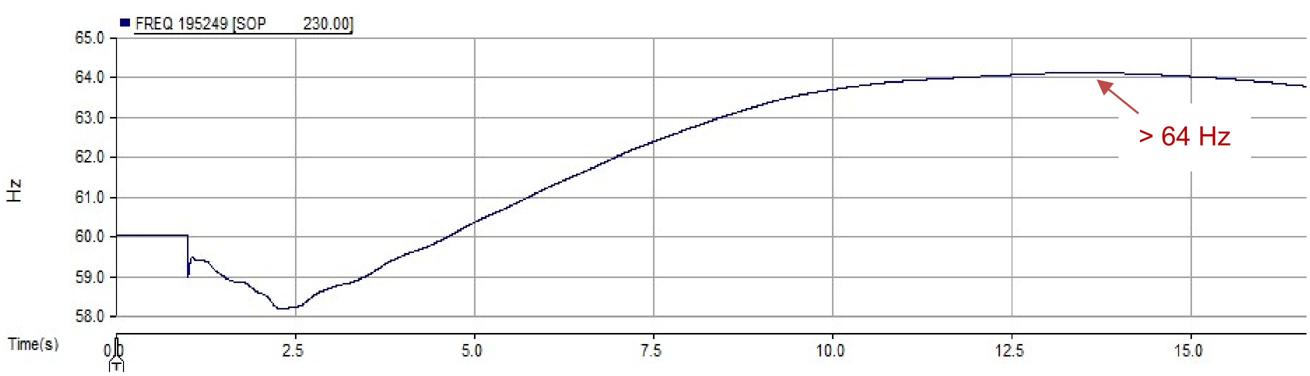


Figure 4-1. Example: Overfrequency > 64 Hz after IIS recovers from LIL bipole trip

Design of Final UFLS Scheme

To eliminate overfrequency violations under high demand scenarios, the total amount of load included in the Final UFLS scheme was reduced from the original Final UFLS scheme first introduced in the Stage 4E Study. In addition to reducing the total amount of UFLS, it was found beneficial to keep more of the load shed at higher frequency blocks, as the frequency drop can be halted slightly faster, which results in slightly less frequency dip overall. The reduction in UFLS scheme was accomplished by removing all blocks of load shed from the 58 Hz block, and some blocks from the 58.1 Hz block. Additionally, a new design concept was introduced to add a back-up block of load shed by shifting approximately 100 MW of the load block that belonged to the 58 Hz block in the Interim scheme and setting it to trip at 57.7 Hz in the Final UFLS scheme. The purpose of the back-up block is to protect the system in the rare event that the system does not respond as expected or if it turns into a cascading event, for example. The LIL limits determined in this study were not designed to utilize the back-up block.

The total load shed in the Final UFLS (based on the 2033-34 peak case) is approximately 750 MW (set to trip between 58.8 Hz and 58.1 Hz). The Final UFLS also has a back-up block of approximately 100 MW set to trip at 57.7 Hz. A minimum of 750 MW of UFLS is the amount required to allow the LIL to operate at 900 MW over 2033-34 peak (2000 MW) with ML exporting 150 MW, while leaving a 0.1 Hz margin to the 57.7 Hz back-up UFLS block.

Please note that it is recommended that UFLS blocks be re-adjusted as load grows to ensure that the blocks sizes remain the same (i.e. do not increase as peak demand grows beyond 2033-34) since the LIL limits are based on this amount of loadshed. If the blocks are not adjusted as load grows, the amount of UFLS will inherently grow and this has the potential to create additional overfrequency issues, that are discussed in upcoming Section 4.1.3.1 (page 12). **It is recommended that Hydro and NF Power should monitor these blocks and review on an annual basis.**

The Final UFLS scheme is summarized in Table 4-2 with the detailed scheme provided in Appendix 1.

Table 4-2. Final UFLS scheme

Frequency Block (Hz)		UFLS (MW)*
Main UFLS	58.8	160
	58.6	170
	58.4	170
	58.2	168
	58.1	88
	TOTAL	***756***
Back-up UFLS	57.7	105
*Assumes peak load of 2,000 MW		

4.1.3 Final LIL Limits

4.1.3.1 Loss of the LIL Bipole

LIL transfer limits were determined by simulating loss of the LIL bipole using the Final UFLS scheme and allowing the worst-case frequency dip to reach 57.8 Hz (leaving a 0.1 Hz margin to the 57.7 Hz back-up block), while ensuring a good recovery or "bounce back" of the frequency after UFLS and ML runback (if applicable). Overfrequency after the system recovered must also not be greater than 63 Hz.

Loss of the LIL bipole was tested for IIS system conditions ranging from extreme light to peak demand for the following scenarios:

a) **ML runbacks active**[8] – ML exporting between 150 MW[9] and 500 MW

b) **ML runbacks not active**[10] - ML operating at 0 MW

   a. With ML frequency controller active[11]

   b. Without ML frequency controller active

Note: each scenario was assessed with and without LIL restarts enabled

The following observations were made from the analysis:

1. **Loss of the LIL bipole** results in the following impacts to the IIS:

   a) **Underfrequency following a LIL bipole trip and subsequent UFLS**. LIL limits were set such that frequency did not dip lower than 57.8 Hz in a worst-case scenario, and such that the frequency recovered in a reasonable timeframe. The 900 MW LIL over peak scenario with ML exporting 150 MW is shown in Figure 4-2 as an example where the frequency dips to 57.8 Hz and then recovers.

---

[8] ML exports levels that result in ML runback to 0 MW following a LIL bipole trip range from 150 MW to 500 MW. ML frequency controller status has no impact on LIL limits when ML is exporting at these levels because an ML runback automatically disables ML frequency controller action.
[9] Hydro's SCADA system is setup to enable ML runbacks at 145 MW. There difference of 5 MW has no material impact on the analysis.
[10] ML runbacks are not active when ML is importing or when ML is exporting less than 150 MW. The LIL limits when ML runbacks are not active were calculated using ML=0 MW as a base assumption but these limits are also applicable to scenarios when ML is importing.
[11] If ML imports are greater than 170 MW, the full 150 MW capacity of the ML frequency controller is not available due to the maximum 320 MW import limit.

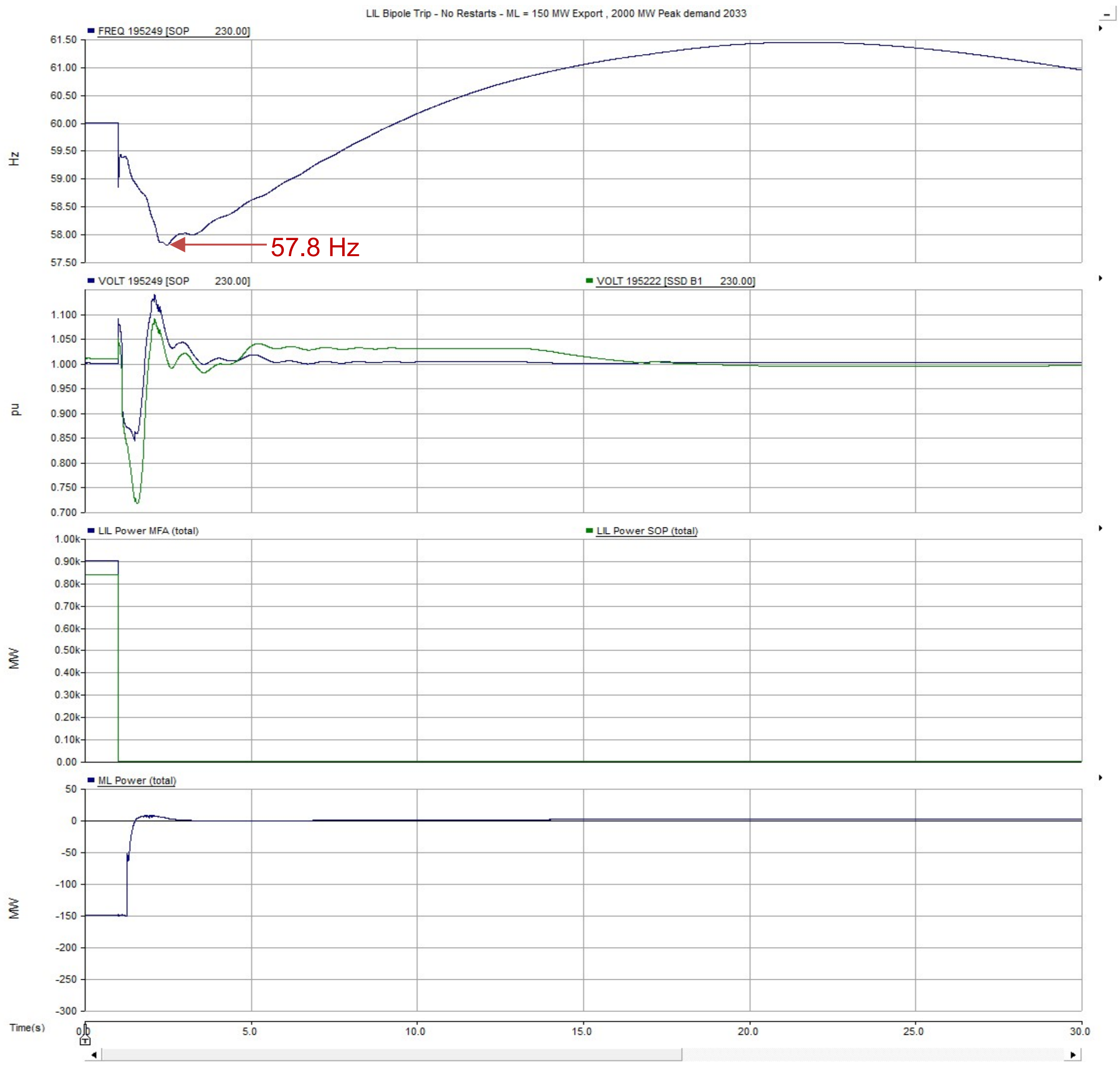


Figure 4-2. Example[12] – Worst underfrequency after Loss of LIL Bipole - 2000 MW demand, LIL 900 MW, ML 150 MW

b) **Overfrequency** occurs after UFLS and the ML runback when the system is recovering. The severity of the overfrequency depends on island demand and ML transfer levels at the time of the LIL bipole trip. The overfrequency was not a concern for scenarios that do not involve ML runbacks. With the Final UFLS scheme applied, only one scenario was observed to have frequency slightly greater than 63 Hz. The worst case overfrequency of 63.2 Hz was observed in the 1750 MW demand scenario, with LIL at 900 MW and ML exporting 400 MW, as shown in Figure 4-3. Since the overfrequency violation (>63 Hz) only occurs at a specific demand and ML export scenario and is only slightly above 63 Hz, it was deemed acceptable.

[12] A slight violation of transient undervoltage occurs. Voltage should not dip below 0.7 pu and should not dip below 0.8 pu for more than 20 cycles. In this simulation, voltage at SSD was below 0.8pu for approximately 22-23 cycles.

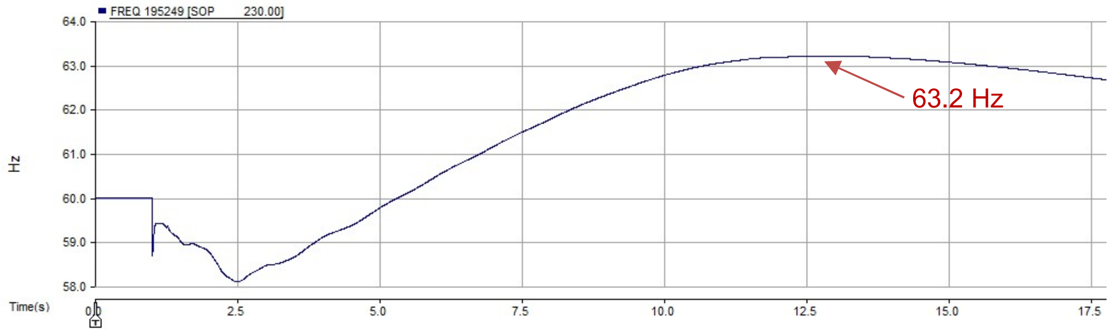


Figure 4-3. Example – Worst overfrequency after recovering from loss of LIL bipole

c) **Voltage collapse near the mid-point of the BDE-SOP 230 kV corridor** (around Sunnyside (SSD)) during high IIS demand conditions. When the LIL infeed on the Avalon is lost, a large amount of power suddenly flows from the western part of the IIS over the 230 kV BDE-SOP corridor towards the Avalon load causing a transient voltage drop along this corridor. The voltage issues were also observed in the preliminary Stage 4 studies where it was mitigated by ensuring a minimum amount of Avalon thermal generation is in-service under specified high levels of IIS demand, which is the same approach taken in the Stage 4F study. The issue is discussed further in Section 7.1 of this report. Alternative mitigation options, such as the addition of reactive power support near SSD and a Remedial Action Scheme (RAS) are being investigated in future studies. The issue is demonstrated in Figure 4-4 by plotting the 230 kV voltage at SSD (following a LIL bipole trip) for varying levels of pre-contingency Avalon thermal generation.

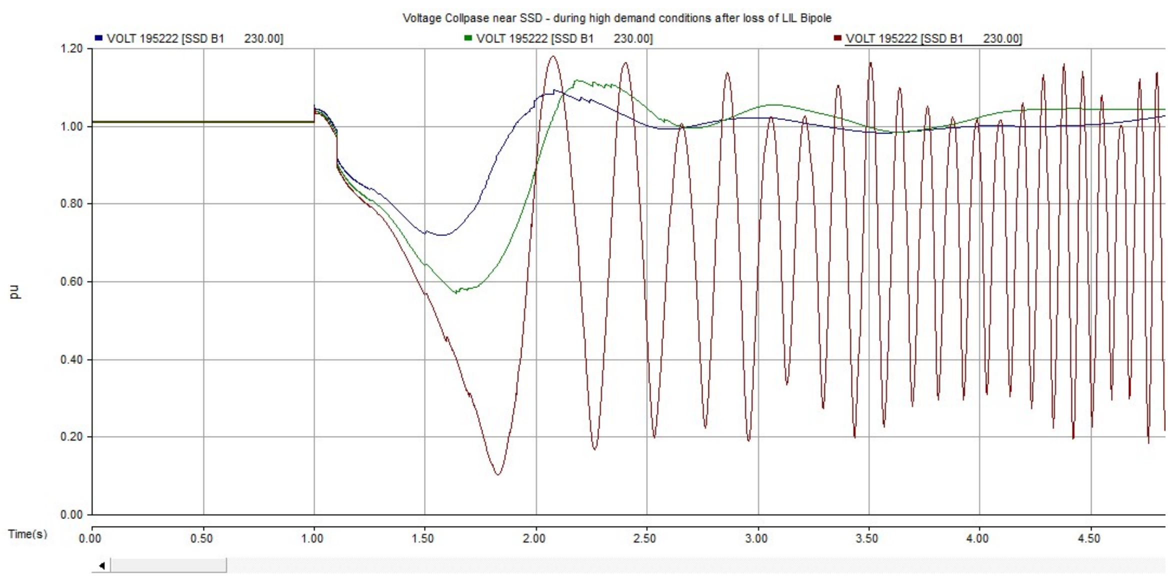


Figure 4-4. Voltage response at SSD after LIL bipole trip – as Avalon generation is reduced
Blue: Pre-contingency Avalon generation 3x47.2 MW **-** meets transient voltage criteria
Green: Pre-contingency Avalon generation 2x47.2 MW – violates transient voltage criteria
Red: Pre-contingency Avalon generation 2x30 MW – unstable

2. **Impact of LIL Restarts**: Enabling one restart on the LIL did not de-rate the LIL transfer limits. The main impact of enabling one restart is the additional delay time between the LIL bipole going to 0 MW from the

DC faults and the ML running back all exports. This scenario is simulating a very low probability event of having two DC pole faults at the same time and then neither pole is successful at reclosing and both poles trip. The timing for this event simulates a 560ms delay from LIL pole faults to ML runback, explained as follows:

The sequence for one restart attempt is demonstrated in Figure 4-5 by adding up the DC line fault detection time plus A and E.

Fault detection time of approximately 60 ms + 150 ms (force retard 1 "A") + 100 ms (deblock attempt "E") = 310 ms.

With one restart enabled, the pole(s) would then trip if the reclose attempt was not successful, and the additional delay of 250 ms to ML runback would occur. Therefore, the entire time delay from LIL bipole going to 0 MW (i.e. simultaneous DC fault on both poles) to ML runback is:

310 ms + 250 ms = ***560 ms***

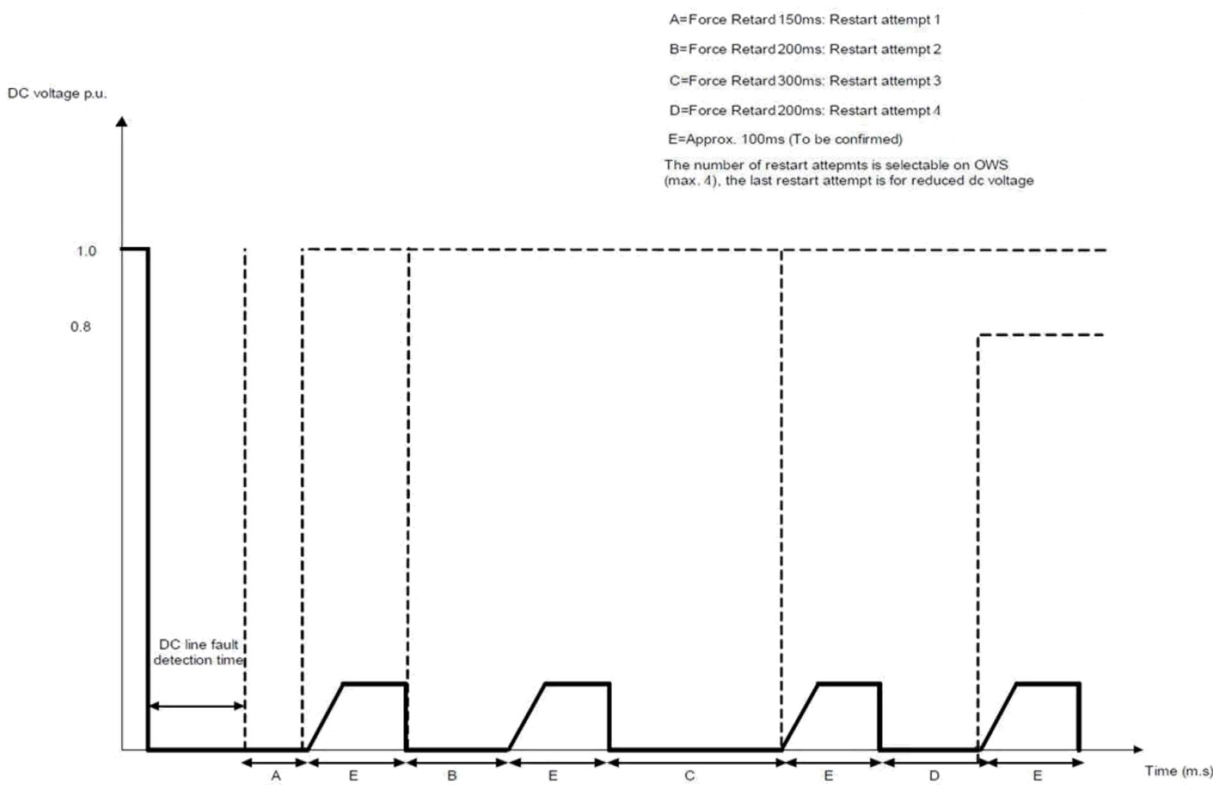


Figure 4-5. Timing of LIL restart attempts

The impacts of enabling one restart on the LIL are as follows:

a) **When LIL not operating at a transfer limit:** The impact of enabling one restart was observed in the frequency response in scenarios where the LIL is not operating at a limit (e.g. where it can transfer 900 MW without resulting in all blocks of UFLS being shed in the “no restart” scenario). In these scenarios, additional UFLS occurs in the “one restart” scenario because of the additional delay to runback the ML exports, however, the LIL transfer limits were not impacted since both frequency responses for “no restart” and “one restart attempt” were acceptable. An example is shown in Figure 4-6 where the green plots represent the “no restart” scenario and the blue plots represent the “one restart attempt” scenario.

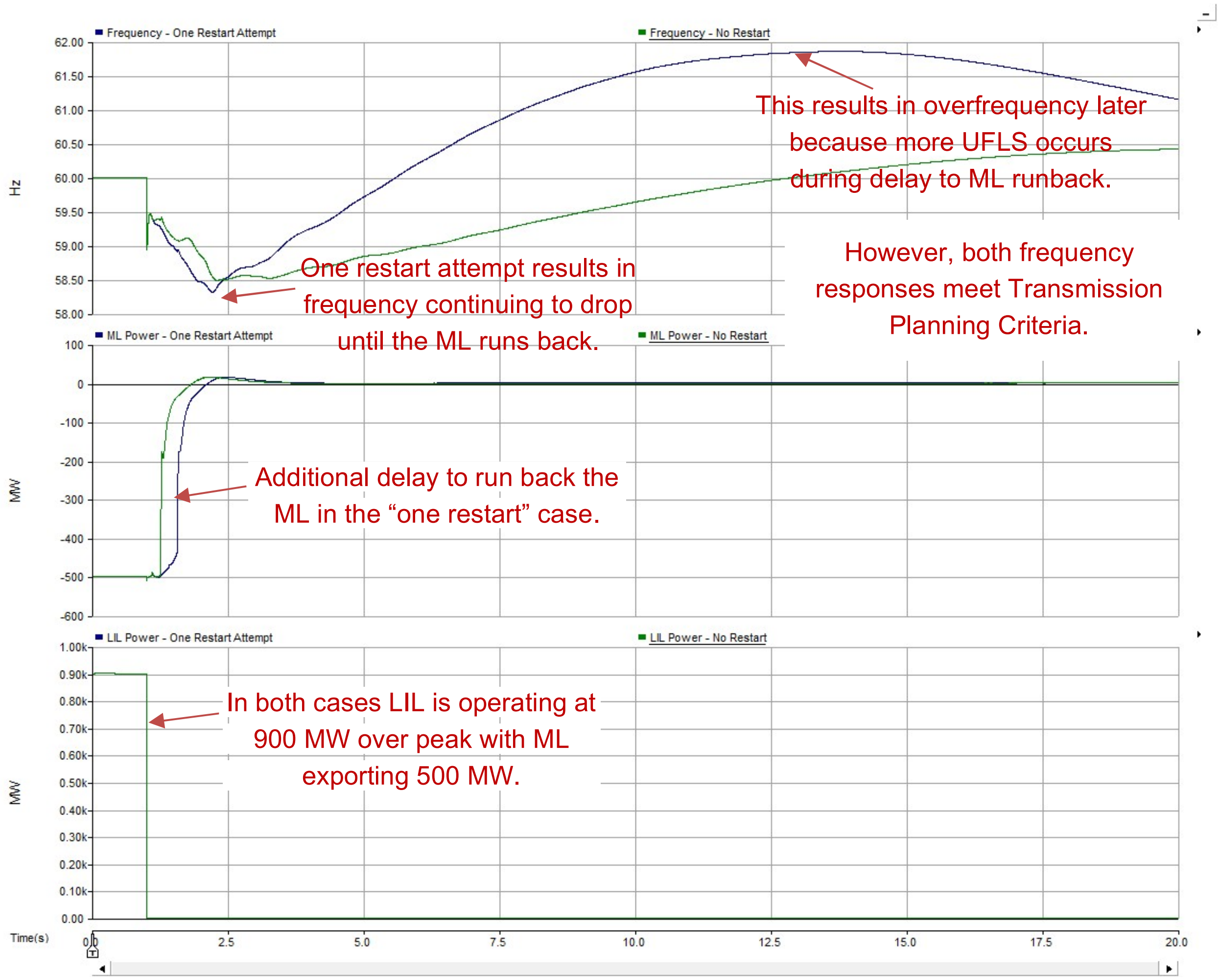


Figure 4-6. Impact of Enabling One Restart Attempt – in scenarios where LIL can operate at 900 MW without shedding all blocks of UFLS in the “no restart” scenario

b) **When LIL operating at a transfer limit:** In cases where all UFLS blocks are shed in the “no restart” scenario, i.e. when LIL is operating at a transfer limit, there was minimal impact observed on the frequency response by adding the additional delay to runback the ML for the “one restart attempt” scenario. A typical example is demonstrated in Figure 4-7, where it is observed that the frequency response is nearly identical between the “one restart” (blue curve) and the “no restart” (green curve) scenarios. Therefore, there was no impact to LIL transfer limits.

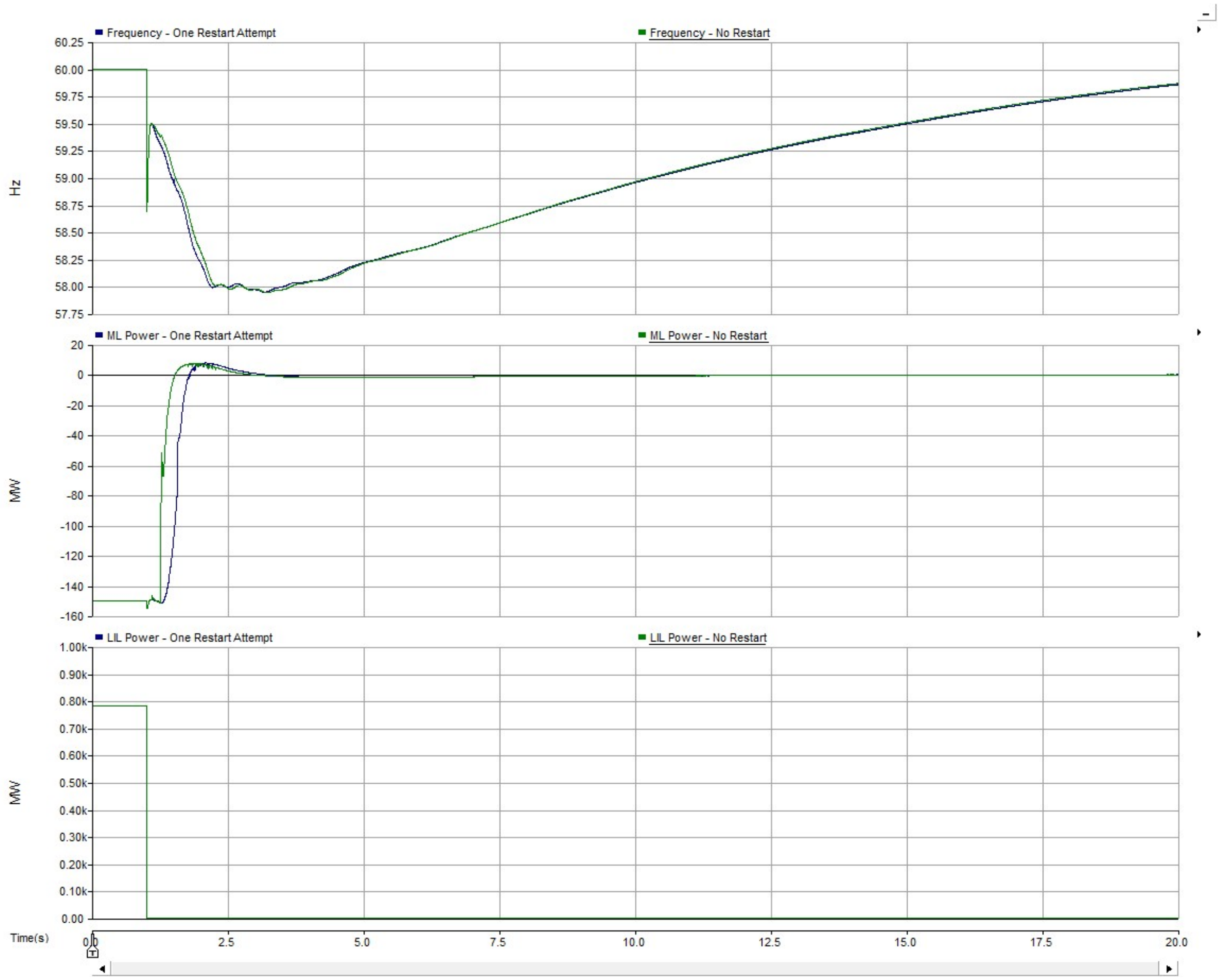


Figure 4-7. Minimal Impact of One LIL restart – 1500 MW IIS demand, ML = 150 MW, LIL at limit of 780 MW

c) **When ML runbacks are not active:** In cases where ML runbacks are not active, there is no impact from enabling one restart attempt because there are no ML runbacks, therefore, the increased time delay to runback the ML is not applicable.

Although the analysis has shown no impact of restarts on LIL transfer limits, for extra pre-caution it is desirable to avoid additional delay between ML runbacks and loss of the LIL bipole when possible. Therefore, it could be recommended that, when LIL restarts are enabled, operating the LIL to its limit should be avoided, if possible, unless adverse weather conditions (wind/lightning) advise otherwise.

3. <u>**Loss of LIL bipole – slower system response during low demand scenarios:**</u>

   a) **Slower Recovery of Frequency**. It was observed in low demand cases that because there are fewer generators on-line, the frequency recovers much slower than higher demand cases and the system takes longer to get back to 60 Hz, sometimes up to 30 or 40 seconds[13],

[13] All frequency responses recovered to 59.5 Hz within 35 seconds. Time for frequency to recover after loss of the LIL bipole for each LIL transfer limit / demand scenario is provided in Table 4-3.

whereas the high demand cases can recover as quickly as 5 seconds. A typical example of slower frequency recovery for a 750 MW demand scenario is plotted in Figure 4-8. However, despite the slower frequency recovery, the system does recover.

If the 57.7 Hz back-up block were to be hit under this scenario, the frequency would recover quicker, however, more customer load would be shed. The LIL limits were not designed to use this block of UFLS.

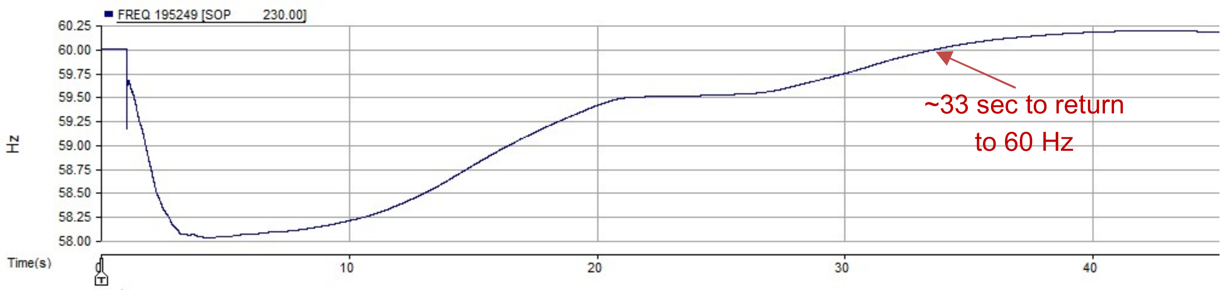


Figure 4-8. Example of slower frequency recovery in low demand scenarios.

b) **Minimum Island Generation[14] becomes more restrictive than stability.** For scenarios where IIS demand is below 700 MW, the minimum island generation becomes more restrictive than maintaining system stability following the loss of the LIL bipole. For example, at IIS demand of around 400 MW and ML exporting 150 MW, the maximum that the LIL can transfer is 240 MW, as this results in the extreme minimum allowable IIS generation of around 315 MW. Loss of the LIL bipole under this particular scenario results in a frequency dip to 58.6 Hz, which is not at a stability / UFLS limit.

In these low demand cases (<700 MW), the maximum LIL transfer due to minimum IIS generation can be calculated as:

LIL(@SOP) = (Island Load + ML Exports) - Min Island Generation

4.1.3.2 Loss of a LIL Pole (when operating as a Bipole)

The Transmission Planning Criteria for loss of a LIL pole are specified such that this event should not result in UFLS, therefore, it should not cause the IIS frequency to drop below 59.1 Hz (leaving some margin to the 58.8 Hz UFLS block).

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

[14] Minimum Island Generation is defined in Section 2.1. At lower demand scenarios, the IIS can only accept a certain amount of LIL infeed, otherwise the IIS generation must be dispatch below the Minimum Island Generation.

When the LIL is operating in 2.0 pu overload, however, losses on the LIL are higher, therefore, the infeed at SOP becomes less than it was prior to the loss of the pole. To account for this and keep frequency above 59.1 Hz:

- In scenarios where ML runbacks are active, a small pre-calculated ML runback takes place to cover the loss of infeed at SOP in scenarios where ML runbacks are active.
- In scenarios where ML runbacks are not active, the small ML runback mentioned above cannot be used to cover the loss of infeed due to increased losses. In this case, the ML frequency controller will cover the loss of infeed. However, **if the ML frequency controller is also not active**, the study determined that at high demand loss of a LIL pole is more limiting than loss of the LIL bipole, and requires a small reduction in LIL transfer limit at or near peak demand if the ML frequency controller is not active in order to ensure the IIS frequency does not dip below 59.1 Hz. This is noted in upcoming Table 4-4.

4.1.3.3 Final LIL Transfer Limits

Final LIL transfer limits with the re-designed Final UFLS scheme are provided in the following tables. Plots for simulations of loss of LIL bipole at these transfer limits are provided in Appendix 2.

- Table 4-3 – ML runbacks active – with and without one LIL restart enabled
- Table 4-4 – ML runbacks not active[15] – with and without ML Frequency Controller active
- Table 4-5 – Minimum IIS demand required for LIL to operate at 900 MW

[15] When ML runbacks are not active, there is no impact from enabling LIL restart attempts because there are no ML runbacks, therefore, the increased time delay to runback the ML is not applicable and therefore LIL limits are not impacted.

Table 4-3. LIL Limits – ML Runbacks Active – No restarts & One restart scenarios

LIL Limits - Final Stage 4F Study					FINAL UFLS - 750 MW + 100 MW back-up (No Restarts Enabled)				Time to recover (sec)		FINAL UFLS - 750 MW + 100 MW back-up (One Restart Enabled)				Time to recover (sec)	
IIS Demand (MW)	IIS Generation (MW)	Avalon generation	Gross Avalon load (MW)	ML (MW)	LIL Transfer Limit (MW)	Min Frequency (Hz)	Max Frequency (Hz)	Load Shed (MW)	to 59.5 Hz (sec)	to 60 Hz (sec)	LIL Transfer Limit (MW)	Min Frequency (Hz)	Max Frequency (Hz)	Load shed (MW)	to 59.5 Hz (sec)	to 60 Hz (sec)
2056	1729	3 x 47.2 MW* + 170 MW**	1090	500	900	58.49	60.43	333	8.9	12.9	900	58.32	61.85	457	4.6	5.5
2034	1607	3 x 47.2 MW* + 100 MW**	1088	400	900	58.29	61.33	496	6.6	8.4	900	58.22	61.18	496	6.6	8.4
2020	1493	3 x 47.2 MW*	1086	300	900	58.10	62.20	663	5.6	6.6	900	58.07	63.02	738	4.5	5.2
2016	1439	3 x 47.2 MW*	1086	250	900	58.00	62.70	751	5.1	5.9	900	57.98	62.48	737	5.1	5.9
2012	1334	3 x 47.2 MW*	1086	150	900	57.80	61.50	752	7.7	9.4	900	57.83	61.35	752	7.7	9.4
1938	1611	3 x 47.2 MW* + 70 MW**	1025	500	900	58.44	60.29	326	10.5	15.1	900	58.29	62.40	459	4.6	5.6
1919	1492	3 x 47.2 MW**	1023	400	900	58.16	62.40	564	5.4	6.3	900	58.14	62.37	564	5	6
1907	1380	2 x 47.2 MW*	1022	300	900	58.03	62.84	702	5	5.8	900	58.01	62.63	690	5	5.8
1904	1413	2 x 47.2 MW*	1022	250	900	57.92	62.36	702	5.7	6.7	900	57.92	62.30	702	5.6	6.7
1901	1223	2 x 30 MW*	1022	150	875	57.75	60.94	702	8.3	10.4	875	57.82	60.92	702	8.3	10.4
1785	1428	2 x 47.2 MW**	940	500	900	58.31	61.80	422	5.8	7.1	900	58.24	61.76	422	5.6	6.8
1768	1341	1 x 47.2 MW*	938	400	900	58.09	63.19	627	4.6	5.3	900	58.10	62.91	599	4.6	5.4
1761	1234	1 x 30 MW*	938	300	900	57.96	62.21	639	5.8	6.9	900	57.99	62.14	639	5.5	6.7
1759	1181	1 x 20 MW*	938	250	900	57.88	61.17	638	7.2	8.7	900	57.94	61.11	638	7	8.7
1750	1073	0	938	150	850	57.79	60.34	638	10.9	15	850	57.84	60.30	722	10.9	15
1535	1207	0	801	500	900	58.36	60.95	356	7.4	9.5	900	58.22	60.96	364	7	9.1
1524	1096	0	801	400	900	58.16	61.08	464	7.5	9.4	900	58.07	62.28	464	5.1	6.2
1513	985	0	801	300	900	57.99	60.57	538	9.5	13.2	900	57.97	60.50	538	9.2	12.3
1511	934	0	801	250	875	58.00	60.20	538	10.8	15.6	875	57.98	60.14	538	11.2	16.6
1502	825	0	801	150	780	57.94	-	538	13.5	20	780	57.95	-	538	13.5	20
1296	969	0	659	500	900	58.34	60.12	287	11.1	16.7	900	58.15	60.94	350	6.3	8.2
1280	853	0	659	400	900	58.16	-	385	13.4	20.3	900	58.05	60.62	428	7.9	10.7
1261	734	0	659	300	870	58.00	-	435	17	27	870	57.98	-	435	17	21
1253	744	0	657	250	800	57.99	-	435	17.5	28	800	57.98	-	435	17.5	28
1248	613	0	658	150	680	57.96	-	435	17.7	30	680	57.98	-	435	17.7	30
1067	740	0	526	500	900	58.29	-	220	21.5	37	900	58.14	-	267	11.2	18.1
1046	619	0	526	400	900	58.05	-	333	20	24.6	900	58.00	-	333	21.6	37.5
1023	609	0	521	300	785	57.97	-	332	26.9	37	785	57.95	-	333	20.9	>40
1015	598	0	520	250	720	57.99	-	332	23.9	29.1	720	57.98	-	332	28.3	>40
1003	598	0	518	150	590	57.97	-	332	19.1	23.9	590	57.98	-	332	22.1	>40
811	483	0	383	500	900	58.06	-	223	18	32	900	57.88	-	223	18	23
781	476	0	377	400	800	57.99	-	222	17.7	20.9	800	57.93	-	223	21.8	27.4
760	461	0	373	300	660	57.99	-	223	27.3	>40	660	57.96	-	223	27.3	36.3
752	457	0	371	250	600	58.02	-	222	20	28.3	600	57.99	-	222	28.2	>40
741	447	0	369	150	480	58.02	-	222	19.2	22.7	480	58.01	-	222	28.2	>40
742	415	0	329	500	900	58.05	-	183	31.9	>40	900	58.00	-	183	24.1	30
714	417	0	322	400	750	58.05	-	183	21.5	30.3	750	58.03	-	192	27.9	34.4
712	417	0	336	300	635	58.01	-	196	33.4	>40	635	57.97	-	201	24.1	33
713	418	0	331	250	570	58.02	-	193	29.9	34.4	570	57.99	-	202	31.2	37.1
704	418	0	329	150	460	57.98	-	194	34.4	>40	460	57.94	-	206	34.4	>40
468	324	0	182	500	690	58.59	-	34	28.2	>40	690	58.35	-	51	20	40
435	317	0	175	400	550	58.59	-	34	29.9	>40	550	58.55	-	34	26.4	28.4
412	323	0	170	300	410	58.60	-	34	24.4	>40	410	58.60	-	34	24.4	>40
404	321	0	169	250	350	58.59	-	34	25	>40	350	58.59	-	34	21.8	26.7
394	315	0	167	150	240	58.60	-	34	25.8	30	240	58.60	-	34	24.5	33.1

LIL limit at 415 MW min generation
330 MW extreme min gen - max LIL (not at a transfer limit)
*to meet transient UV criteria at SSD
**to meet ML export

Table 4-4. LIL Limits – ML Runbacks Not Active

LIL Bipole Limits (ML Runbacks Not Active) - ML F/C Active (150 MW)							
Demand (MW)	LIL (MW) @ MFA	LIL (MW) @ SOP	Net DC (MW)	Min Frequency (Hz)	Max Freq (Hz)	Load Shed (MW)	Loss of Pole - Min Frequency (Hz)
2012	900	834	834	57.85	-	757	59.02*
1889	875	813	813	57.83	-	702	59.11
1738	850	791	791	57.85	-	637	59.21
1492	780	730	730	57.93	-	541	59.36
1235	680	642	642	57.97	-	435	59.42
995	580	552	552	57.98	-	332	59.48
741	470	452	452	58.05	-	222	59.58
594	410	396	396	58.05	-	159	59.62
463	350	340	340	58.05	-	96	59.67
400	320	311	311	58.02	-	76	59.67

* A slight reduction in LIL transfer limit would be needed to keep frequency ≥ 59.1 Hz, however 59.02 Hz is still above the 58.8 Hz UFLS block

LIL Bipole Limits (ML Runbacks Not Active) - ML F/C Not Active								
Demand (MW)	LIL (MW) @ MFA	LIL (MW) @ SOP	Net DC (MW)	Min Frequency (Hz)	Max Freq (Hz)	Load Shed (MW)	Loss of Pole - Min Frequency (Hz)	Reduced LIL Transfer for Loss of LIL Pole (MW) (59.1 Hz)
2018	780	730	730	57.80	60.75	757	58.77	720
1898	715	673	673	57.80	60.82	702	58.95	705
1747	690	644	644	57.80	-	637	59.23	-
1497	620	588	588	57.90	-	541	59.38	-
1238	520	498	498	57.94	-	435	59.51	-
996	420	398	398	57.97	-	332	59.61	-
735	310	302	302	58.04	-	222	59.69	-
586	245	240	240	58.02	-	159	59.78	-
438	180	177	177	58.05	-	96	59.92	-
390	160	150	150	57.97	-	76	59.94	-

Table 4-5. Minimum IIS Demand to Operate LIL at 900 MW

Minimum Island Demand for LIL 900 MW					
Demand (MW)	IIS Generation (MW)	LIL Transfer Limit (MW)	ML (MW)	Min Frequency (Hz)	Load Shed (MW)
742	415	900	500	58.05	183
1005	577	900	400	57.99	314
1308	781	900	300	57.93	454
1551	974	900	250	57.97	557
2012	1334	900	150	57.8	752

* at min gen

4.1.4 UFLS: 57.7 Hz Back-up Block

The final UFLS scheme was designed with a 57.7 Hz back-up block of approximately 100 MW over peak. The final LIL transfer limits provided in Section 4.1.3 provide at least 0.1 Hz margin to the 57.7 Hz back-up block of UFLS.

The purpose of the back-up block is to provide an additional layer of protection to maintain IIS stability above and beyond the LIL transfer limits. Therefore, the following are recommendations for further protection to minimize the risk of instability after a LIL bipole trip:

- Hydro should set all under-frequency protection for their generation assets as low as possible, preferably less than 57.5 Hz, to ensure no additional loss of supply.
- Hydro should further investigate if setting the ML under-frequency protection to 57.7 Hz as a back-up is a feasible option in the event a ML runback is not triggered.

To test the back-up block's ability to maintain stability and to see how far the system can be pushed beyond the LIL transfer limit (i.e. to see how much additional power can be lost while maintaining system stability), additional simulations were performed as follows:

- Trip a generator along with the LIL bipole (LIL operating at its transfer limit) to see how much additional power can be lost.
- Trip the LIL bipole when it is operating beyond the transfer limit to see how much additional power can be lost.

The amount of power being supplied by the generator that was tripped or the amount of power on the LIL above the transfer limit was recorded when it caused the 57.7 Hz back-up block to trip. In all cases, system stability was maintained at these higher power loss scenarios when the 57.7 Hz back-up block tripped.

Table 4-6 summarizes the additional loss of power (beyond the LIL transfer limit) that the system can withstand while maintaining system stability if the 57.7 Hz back-up block is in place and avoiding overfrequency during system recovery.

Table 4-6. Approximate additional MW loss the system can handle with the 57.7 Hz UFLS block

IIS Demand (MW)	Additional MW beyond LIL Limit*	Amount of load shed by 57.7 Hz back-up block (MW)
2000	100	98
1900	100	92
1750	100	79-84
1500	75-100	71
1250	75-100	57-58

1000	40-75	44-45
800	20-40	29-30
700	<35	23-26

*exact amounts depend on ML exports, please refer to Table 4-7

Full results for the testing of the back-up UFLS are provided in Table 4-7. The table is explained as follows:

- The blue shaded portion represents the normal LIL limits (from Section 4.1.3) that do not invoke the 57.7 Hz back up UFLS block.
- The orange shaded portion represents the tripping of a generator along with the LIL bipole operating at the LIL transfer limit.
- The yellow shaded portion represents the tripping of the LIL bipole when operating the LIL beyond the LIL transfer limit.
- Purple shaded cells show scenarios when the 57.7 Hz back-up block operated and how much additional load was shed by the back-up block.

Table 4-7. Testing the UFLS Back-up Block

Limit Limits FINAL UFLS 750 MW + 100 MW back-up (No Restarts Enabled)									Testing 57.7 Hz Back-up Block: Operating beyond LIL Transfer Limits											
									Tripping Additional Generator							Additional MW on the LIL beyond limit				
Demand (MW)	Generation (MW)	ML (MW)	LIL Transfer Limit (MW)	LIL Infeed at SOP (MW)	Min Frequency (Hz)	Max Frequency (Hz)	Max Frequency (Hz)	Load Shed (MW)	+ Gen trip (in addition to LIL bipole) (MW)	+ Gen trip Min freq (Hz)	+ Gen trip Max freq (Hz)	Total Load shed (MW)	Backup UFLS (MW)	Total Loss of Supply (LIL infeed @ SOP + gen trip) (MW)	Total UFLS + ML runback (MW)	+ additional LIL MW beyond limit to just hit back-up UFLS (MW)	Total Loss of Supply (LIL infeed @SOP) (MW)	Min freq (Hz)	Backup UFLS (MW)	+ additional LIL MW beyond limit to just maintain stability*
2056	1729	500	900	832	58.49	60.43	60.43	333	100	58.30	61.19	497		932	997					
2034	1607	400	900	832	58.29	60.64	61.33	496	100	58.12	62.31	643		932	1043					
2020	1493	300	900	832	58.10	60.81	62.20	663	100	57.95	62.27	751		932	1051					
2016	1439	250	900	832	58.00	60.94	62.70	751	100	57.85	61.47	751		932	1001					
2012	1334	150	900	832	57.80	60.64	61.50	752	100	57.67	61.73	850	98	932	1000					
1938	1611	500	900	832	58.44	60.54	60.29	326	100	58.26	61.07	464		932	964					
1919	1492	400	900	832	58.16	60.83	62.40	564	100	58.06	62.94	690		932	1090					
1907	1380	300	900	832	58.03	60.91	62.84	702	100	57.89	61.64	702		932	1002					
1904	1413	250	900	832	57.92	60.81	62.36	702	100	57.79	60.79	702		932	952					
1901	1223	150	875	813	57.75	60.58	60.94	702	100	57.64	61.07	794	92	913	944					
1785	1428	500	900	832	58.31	60.62	61.80	422	100	58.20	61.82	506		932	1006					
1768	1341	400	900	832	58.09	60.74	63.19	627	100	58.05	62.37	638		932	1038					
1761	1234	300	900	832	57.96	60.79	62.21	639	100	57.82	60.63	639		932	939	These cases were only tested as loss of LIL bipole at transfer limit + loss of additional generator				
1759	1181	250	900	832	57.88	60.64	61.17	638	100	57.69	61.13	717	79	932	967					
1750	1073	150	850	791	57.79	60.34	60.34	638	100	57.62	60.25	722	84	891	872					
1535	1207	500	900	832	58.36	60.59	60.95	356	100	58.16	60.94	440		932	940					
1524	1096	400	900	832	58.16	60.64	61.08	464	100	57.98	60.86	540		932	940					
1513	985	300	900	832	57.99	60.53	60.57	538	100	57.65	60.00	609	71	932	909					
1511	934	250	875	813	58.00	60.20	60.20	538	75	57.68	60.35	609	71	888	859					
1502	825	150	780	730	57.94	-	-	538	75	57.66	-	609	71	805	759					
1296	969	500	900	832	58.34	60.12	60.12	287	100	58.11	60.18	385		932	885					
1280	853	400	900	832	58.16	-	-	385	75	57.99	-	435		907	835					
1261	734	300	870	809	58.00	-	-	435	75	57.55	-	493	58	884	793					
1253	744	250	800	748	57.99	-	-	435	75	57.64	-	493	58	823	743					
1248	613	150	680	642	57.96	-	-	435	75	57.63	-	492	57	717	642					
1067	740	500	900	832	58.29	-	-	220	75	58.11	-	294		907	794					
1046	619	400	900	832	58.05	-	-	333	60	57.67	-	377	44	892	777					
1023	609	300	785	735	57.97	-	-	332	50	57.69	-	377	45	785	677	50	785	57.69	45	75 MW - 57.64 Hz, stable but slow recovery
1015	598	250	720	678	57.99	-	-	332	50	57.68	-	377	45	728	627	40	718	57.7	45	65 MW - 57.65 HZ, stable but slow recovery
1003	598	150	590	561	57.97	-	-	332	50	57.69	-	376	44	611	526	40	601	57.69	45	70 MW - 57.65 Hz, stable but slow recovery
811	483	500	900	832	58.06	-	-	223	50	57.66	-	252	29	882	752					
781	476	400	800	748	57.99	-	-	222	50	57.69	-	252	30	798	652	35	783	57.69	30	40 MW - 57.65 Hz, stable but slow recovery
760	461	300	660	624	57.99	-	-	223	35	57.69	-	252	29	659	552	20	644	57.69	30	40 MW - 57.67 Hz, stable but slow recovery
752	457	250	600	570	58.02	-	-	222	35	57.69	-	251	29	605	501	20	590	57.69	30	30 MW - 57.69 Hz
741	447	150	480	461	58.02	-	-	222	35	57.69	-	251	29	496	401	20	481	57.7	30	30 MW - 57.69 Hz
742	415	500	900	832	58.05	-	-	183	35	57.66	-	207	24	867	707					
714	417	400	750	704	58.05	-	-	183	35	57.69	-	206	23	739	606					
712	417	300	635	602	58.01	-	-	196	30	57.52	-	222	26	632	522	These cases are already at minimum generation so cannot increase LIL further.				
713	418	250	570	543	58.02	-	-	193	30	57.67	-	219	26	573	469					
704	418	150	460	442	57.98	-	-	194	30	57.68	-	220	26	472	370					
468	324	500	690	651	58.59	-	-	34												
435	317	400	550	525	58.59	-	-	34												
412	323	300	410	396	58.60	-	-	34	These cases are already at minimum generation so cannot increase LIL further.											
404	321	250	350	340	58.59	-	-	34												
394	315	150	240	235	58.60	-	-	34												

LIL limit at 415 MW min generation
330 MW extreme min gen - max LIL (not at a transfer limit)
Back-up UFLS has occurred
*how much further can the LIL be pushed past the limit while just maintaining system stability

4.2 LIL Monopole Limits

If the LIL is operating as a monopole and it trips, UFLS should not occur and, therefore, IIS frequency should not dip below 58.8 Hz[16]. LIL monopole limits were set to keep the IIS frequency at 59.1 Hz, to provide a 0.3 Hz margin to 58.8 Hz. These LIL monopole limits are summarized in the following tables:

- Table 4-8 – ML runbacks active – with and without one LIL restart enabled
- Table 4-9 – ML runbacks not active – with and without ML Frequency Controller active

Please note the following:

- Unlike in bipole mode, restarts do have a marginal impact on transfer limits as per Table 4-8.
- There are some scenarios listed in Table 4-8 where the allowable LIL transfer (measured at SOP) is less than ML exports (i.e. when ML is exporting in the range of 400 MW to 500 MW). Enabling LIL restarts in these scenarios should be avoided.
- In Table 4-9, when ML runbacks are not active and the ML frequency controller is not available, the LIL monopole was set to operate at its minimum of 45 MW. Although the 58.8 Hz UFLS is not reached when the monopole trips, the goal of maintaining some margin and ensuring frequency does not dip below 59.1 Hz is not achievable.
- There is an interesting trend to note in the LIL MP limits; starting at peak demand the LIL MP limits initially decrease as demand decreases, however, once IIS demand reaches around 1500 MW, the LIL MP limits begin to increase as demand decreases. An example of this trend is shown in Figure 4-9. It is theorized that the lower demand cases have more inertia in-service if normalized against the demand, and this ratio of inertia to demand starts increasing around the 1250 MW demand cases and continues increasing as demand decreases, thereby allowing the LIL MP limits to increase while still maintaining frequency above 59 Hz.

[16] Hydro does have “LIL Monopole Protocols” in which LIL monopole transfers can be increased for economic or low Island supply scenarios at the expense of risking UFLS for loss of LIL monopole.

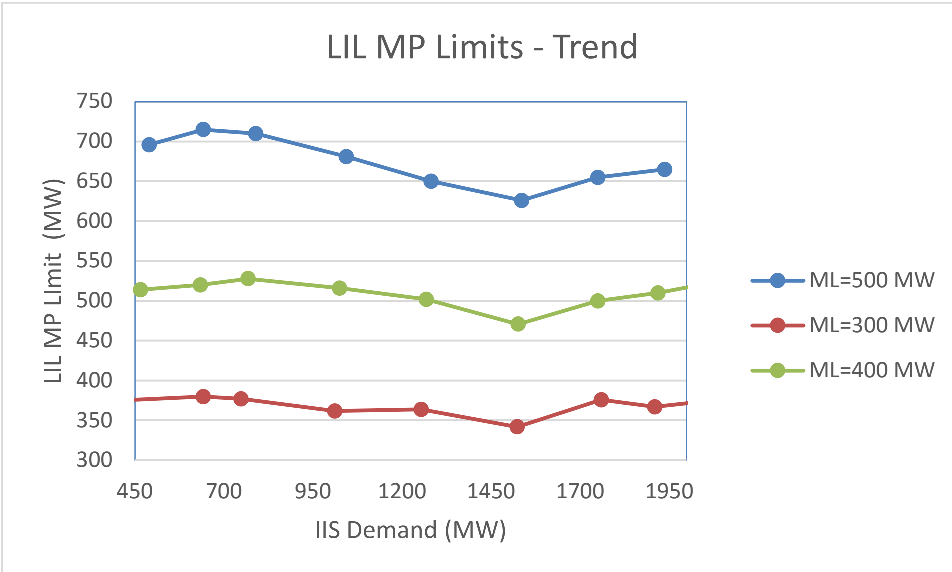


Figure 4-9. LIL MP Limit – trend over IIS demand range.

If it is deemed acceptable to allow UFLS to occur if the LIL monopole were to trip, then the same LIL bipole limits provided in Table 4-3 can be used, as long as it results in the same LIL power **at SOP**, i.e. that the LIL limits at MFA take into account the additional losses on the LIL when operating in monopole mode compare to bipole mode.

Table 4-8. LIL Monopole Limits – No UFLS – ML runbacks active

LIL MP Limits - No UFLS			No Restarts Enabled (250 ms delay ML runback)			1 Restart Enabled (560 ms delay ML runback)		
IIS Demand (MW)	IIS Generation (MW)	ML (MW)	LIL Transfer Limit (MW) @ MFA (GR)	LIL Transfer Limit (MW) @ SOP	Min Frequency (Hz)	LIL Transfer Limit (MW) @ MFA (GR)	LIL Transfer Limit (MW) @ SOP	Min Frequency (Hz)
1939	1898	500	665	548	59.1	615	513	59.1
1751	1714	500	655	543	59.11	595	501	59.1
1537	1523	500	626	521	59.1	565	480	59.1
1283	1250	500	650	540	59.1	560	476	59.1
1044	993	500	681	558	59.1	540	462	59.1
790	720	500	710	578	59.1	534	459	59.1
642	571	500	715	581	59.1	519	448	59.1
490	429	500	696	569	59.11	489	425	59.1
2130	2082	400	528	455	59.1	514	444	59.1
1920	1886	400	510	441	59.1	500	434	59.11
1751	1757	400	500	434	59.1	488	425	59.1
1527	1523	400	471	412	59.1	486	423	59.1
1269	1241	400	502	435	59.1	484	422	59.1
1025	986	400	516	446	59.11	484	422	59.1
768	720	400	528	455	59.11	454	399	59.1
634	592	400	520	449	59.1	444	391	59.1
466	424	400	514	444	59.1	429	380	59.1
2115	2082	300	377	339	59.1	373	336	59.11
1911	1887	300	367	331	59.1	363	328	59.11
1761	1729	300	376	339	59.1	372	336	59.1
1525	1522	300	342	310	59.1	337	306	59.11
1255	1233	300	364	329	59.1	356	323	59.11
1012	992	300	362	328	59.1	354	321	59.1
748	715	300	377	340	59.1	370	334	59.1
642	606	300	380	343	59.1	374	337	59.1
448	416	300	376	339	59.1	362	328	59.1
2110	2083	225	280	259	59.1	278	257	59.1
1906	1876	225	282	261	59.1	278	258	59.11
1761	1743	225	269	250	59.1	267	248	59.1
1511	1473	225	292	270	59.1	288	266	59.11
1259	1244	225	266	247	59.1	263	244	59.1
1012	988	225	276	256	59.11	273	254	59.11
744	714	225	283	262	59.1	279	259	59.1
439	415	225	277	256	59.11	275	255	59.1
2016	1990	150	193	183	59.1	192	182	59.11
1910	1886	150	190	181	59.1	190	191	50.09
1763	1744	150	185	176	59.11	184	175	59.11
1517	1492	150	192	182	59.1	191	181	59.1
1259	1246	150	178	170	59.11	177	169	59.11
1005	976	150	196	186	59.1	195	185	59.1
744	721	150	189	179	59.11	188	178	59.11
434	413	150	187	178	59.1	185	176	59.12

Table 4-9. LIL Monopole Limits – No UFLS – ML runbacks not active

LIL MP Limits (no UFLS, ML Runbacks Not Active) - ML Active F/C (150 MW)					
IIS Demand (MW)	IIS Generation (MW)	ML (MW)	LIL Transfer Limit (MW) @ MFA (GR)	LIL Transfer Limit (MW) @ SOP	Min Frequency (Hz)
2130	1977	0	167	160	59.1
1914	1762	0	166	159	59.1
1769	1614	0	169	162	59.1
1532	1386	0	159	152	59.1
1275	1139	0	149	143	59.1
1013	877	0	149	143	59.11
742	672	0	155	149	59.11
598	603	0	169	162	59.1
461	543	0	172	164	59.1

LIL MP Limits (no UFLS, ML Runbacks Not Active) - ML Not Active F/C (0 MW)					
IIS Demand (MW)	IIS Generation (MW)	ML (MW)	LIL Transfer Limit (MW) @ MFA (GR)	LIL Transfer Limit (MW) @ SOP	Min Frequency (Hz)
2124	2086	0	45	44	58.94
1922	1884	0	45	44	58.96
1772	1734	0	45	44	59.08
1557	1520	0	45	44	58.83
1275	1238	0	45	44	59.02
1029	991	0	45	44	58.86
750	785	0	45	44	58.89
603	725	0	45	44	59
462	665	0	45	44	58.95

5. ML Export Limits

Loss of the ML bipole while exporting is the contingency that defines the ML export limits. If the ML bipole (or monopole) is lost while exporting, the Island frequency will increase. Transmission Planning Criteria state that this overfrequency should not go above 63 Hz.

ML Export limits can be defined in terms of Island Generation rather than Island Demand, since they are more of a function of inertia and not UFLS.

5.1 LIL Frequency Support Available

The LIL is equipped with runback/runup functionality[17] and frequency controller functionality to regulate IIS frequency if the ML bipole or pole trips. This study determined that if LIL frequency support is available (in the form of the frequency controller or runbacks), there are no restrictions on ML exports if the ML bipole trips. Analysis confirmed that the frequency response when relying on the LIL frequency controller versus LIL runbacks is the same. Please note that this is assuming the LIL is dispatched in such a way that the required frequency support can be provided. For example; if LIL is at 90 MW, there will not be any frequency support available.

ML export of 500 MW was simulated with the LIL frequency support in-service (in the form of the frequency controller or runbacks). The resulting maximum IIS frequency excursion following loss of the ML bipole is around 61.1 Hz as summarized in Table 5-1.

It is concluded that if the LIL bipole is in-service and can provide its full range of frequency support, the ML can export its full rating of 500 MW without violating Transmission Planning Criteria at any Island Generation level.

Table 5-1. Frequency Excursions due to loss of ML bipole (LIL frequency support available)

LIL (MW)	Demand (MW)	Generation (MW)	Loss of ML Bipole	
			ML Export (MW)	Max Frequency (Hz)
900	2057	1730	500	61.1
900	1939	1611		61.1
900	1785	1457		61.1
900	1542	1214		61.1
900	1291	963		61.1
900	1067	739		61.1
900	811	483		61.13
875	724	418		61.13
690	468	324		61.15

[17] PDO_X Active --> PFC at SOP Disabled --> Bipole Power Regulating Active --> Bipole Power Regulating Not Active --> PDO_X Not Active --> PFC at SOP Enable

5.2 LIL Frequency Support Unavailable

ML export must be limited to meet Transmission Planning Criteria if frequency support from the LIL is unavailable (frequency controller or runbacks). ML export limits were determined for two frequency criteria scenarios:

1. Ensuring system frequency does not exceed 62.5 Hz (HRD Unit Online)[18]
2. Ensuring system frequency does not exceed 63 Hz (HRD Unit Offline)

One option to increase ML export limits is to cross-trip Cat Arm generation to help reduce the frequency and keep it within criteria. ML export limits were determined for the following scenarios without frequency support from the LIL:

- No cross-tripping of Cat Arm generation
- Cross-tripping of varying amounts of Cat Arm generation to aid in reducing overfrequency if frequency exceeds:
  - 61 Hz
  - 61.5 Hz
  - 62 Hz[19]

The ML export limits without frequency support from the LIL are provided in:

- Table 5-2 - to keep IIS frequency below 62.5 Hz
- Table 5-3 - to keep IIS frequency below 63 Hz

Table 5-2. ML Export Limit – IIS Frequency Criteria 62.5 Hz (HRD Online)

Demand (MW)	Generation (MW)	ML Export Limits (MW) - No LIL F/C - IIS Frequency Criteria 62.5 Hz												
		No CAT ARM X-trip	Trip CAT ARM on Overfrequency of 61, 61.5, 62 Hz											
			35 MW			67 MW			90 MW			134 MW		
			61 Hz	61.5 Hz	62 Hz	61 Hz	61.5 Hz	62 Hz	61 Hz	61.5 Hz	62 Hz	61 Hz	61.5 Hz	62 Hz
1900	1355	136	165	163	160	195	190	185	216	211	205	245	240	230
1750	1265	132	153	151	148	182	176	170	213	209	203	232	228	218
1500	1034	124	144	142	138	173	170	164	202	198	192	226	221	212
1250	832	110	138	136	132	170	166	160	199	196	191	222	218	210
1000	551	106	128	126	123	160	158	154	185	183	180	212	208	204
750	400	76	108	107	105	138	136	132	170	168	165	190	187	183
450	415	90	111	110	109	142	140	138	182	180	177	205	204	201

[18] It is preferred that the HRD Thermal Units not experience frequency greater than 62.5 Hz as per direction from the asset owner. This criterion only applies in the interim and these limits will not be applicable once HRD is relegated to a backup role only (or decommissioned)
[19] Hydro currently applies these limits.

Table 5-3. ML Export Limits – IIS Frequency Criteria 63 Hz (HRD Offline)

Demand (MW)	Generation (MW)	ML Export Limits (MW) - No LIL F/C - IIS Frequency Criteria 63 Hz												
		No CAT ARM X-trip	Trip CAT ARM on Overfrequency of 61, 61.5, 62 Hz											
			35 MW			67 MW			90 MW			134 MW		
			61 Hz	61.5 Hz	62 Hz	61 Hz	61.5 Hz	62 Hz	61 Hz	61.5 Hz	62 Hz	61 Hz	61.5 Hz	62 Hz
1900	1372	178	198	196	194	230	226	222	240	237	232	280	276	270
1750	1310	176	196	194	192	228	225	220	238	236	230	279	275	268
1500	1074	162	182	180	178	214	211	206	230	227	222	266	262	255
1250	882	158	178	176	174	210	207	202	222	218	215	262	258	252
1000	577	131	158	157	155	190	188	185	204	202	200	244	242	238
750	440	115	133	132	131	164	163	161	188	186	184	228	227	224
450	453	127	148	147	146	178	177	175	200	198	197	241	239	236

6. ML Import Limits

Loss of the ML bipole is the contingency that defines the ML import limits. If the ML bipole is lost while importing, the Island frequency will decrease. Transmission Planning Criteria state that for loss of the bipole UFLS is acceptable, as long as the system recovers. Similar to how the LIL bipole limits are determined, the frequency should stay above 57.8 Hz to give some margin to the 57.7 Hz UFLS back-up block.

For loss of a pole, the frequency should remain above 59.1 Hz. Following an ML pole trip (while the ML is operating as a bipole), it is assumed that the healthy ML pole will pick up the transfer that was lost on the other ML pole, up to its rating of 250 MW at the rectifier end.

6.1 LIL Frequency Support Available

The LIL is equipped with runback/runup functionality and frequency controller functionality to assist IIS frequency if the ML bipole or pole trips. This study determined that if the LIL is in-service and can provide its full range of frequency support, there are no restrictions on ML imports if the ML bipole trips.

Maximum ML import of 320 MW was simulated with LIL frequency support available and the Final UFLS in-service. The resulting worst-case IIS frequency excursions are summarized in Table 6-1 for loss of the ML bipole.

It is concluded that, if LIL frequency support is available, the ML can import the full 320 MW transfer limit without violating the underfrequency criteria the ML bipole trips.

Table 6-1. Frequency Excursions due to loss of ML bipole (LIL frequency support available)

LIL (MW)	Demand (MW)	Generation (MW)	Loss of ML Bipole		
			ML Transfer (MW)	Min Frequency (Hz)	UFLS (MW)
780	1998	954	-320	58.59	316
690	1743	779		58.77	136
620	1495	594		58.75	116
500	1240	448		59.16	-
170	1001	430		59.23	-

6.2 LIL Frequency Support Unavailable

6.2.1 ML operating as bipole

A maximum ML import level of 320 MW was tested without LIL frequency support and with the Final UFLS scheme in place. The results are summarized in Table 6-2, with conclusions summarized below:

- For loss of the ML bipole, the ML can transfer the full 320 MW over all IIS demand scenarios, except for the 723 MW demand case at minimum IIS generation, which has an ML import limit of 300 MW. UFLS occurs as summarized in the table.

- Loss of an ML pole is more limiting than loss of the ML bipole when LIL frequency support is not available. When operating a 320 MW import, each pole is at 160 MW. If a pole is lost, the healthy pole will increase to 250 MW, resulting in a loss of approximately 70 MW to the IIS, which is too high to maintain the 59.1 Hz criteria when the LIL frequency support is not available. The ML import limits are therefore defined by loss of a pole and range from 280 MW to 287 MW import as listed in Table 6-2. Since the limits do not vary widely, it is recommended to use an ML bipole import limit of 280 MW under all IIS conditions when LIL frequency support is not available.

Table 6-2. ML Bipole – Import Limits – No LIL frequency support available

Loss of ML Bipole (Import) - No LIL frequency support							
LIL (MW)	Demand (MW)	Generation (MW)	ML limit – Loss of bipole (MW)	Frequency (Hz)	UFLS (MW)	ML limit – Loss of Pole (MW)	Frequency (Hz)
780	1998	954	-320	58.51	333	-284	59.1
690	1743	779	-320	58.44	283	-287	59.1
620	1495	594	-320	58.38	358	-285	59.1
500	1240	448	-320	58.33	287	-280	59.1
170	1001	430	-320	58.19	294	-287	59.1
45*	723	385	-300	58.01	210	-286	59.12

*to meet minimum IIS generation

6.2.2 ML operating as monopole

If the ML is operating as a monopole when it trips, UFLS should not occur, and IIS frequency should not drop below 58.8 Hz. ML import limits were set to keep the IIS frequency above 59.1 Hz, to provide a 0.3 Hz margin to 58.8 Hz.

The ML monopole import limits range from 24 MW to 33 MW when LIL frequency support is not available in the form of the frequency controller or LIL runbacks and are summarized in Table 6-3. Since the limits do not vary widely, it is recommended to use an ML monopole import limit of 24 MW under all IIS conditions when LIL frequency support is not available.

Table 6-3. ML Monopole – Import Limits – LIL frequency support available

Loss of ML Monopole (Import) - No LIL Frequency Support				
LIL (MW)	Demand (MW)	Generation (MW)	ML limit (MW)	Frequency (Hz)
900	2004	1144	-30	59.11
850	1738	920	-33	59.12
780	1491	734	-33	59.1
680	1234	570	-29	59.12
580	995	425	-24	59.1
300	735	420	-28	59.11

7. Other Considerations

7.1 Minimum Avalon Generation

As discussed in Section 4.1.3, voltage collapse can occur near the mid-point of the BDE-SOP 230 kV corridor (around SSD) during high IIS demand conditions when the LIL bipole trips. When the LIL infeed on the Avalon is lost, a large amount of power suddenly flows from the western part of the IIS over the 230 kV BDE-SOP corridor towards the Avalon load causing a transient voltage drop along this corridor. The voltage issues were also observed in the preliminary Stage 4 studies where it was mitigated by ensuring a minimum amount of Avalon generation is in-service under specified high levels of IIS demand to offload BDE-SOP flow, which is the same approach taken in the Stage 4F study. A previous study[20] assessing the 230 kV transmission corridor between BDE and SOP also identified the possibility of shedding more load on the Avalon following a LIL bipole trip to reduce or eliminate the need for a minimum amount Avalon generation to be in-service.

The voltage collapse issue was demonstrated in Section 4.1.3 and shown again here in Figure 7-1 by plotting the 230 kV voltage at SSD (following a LIL bipole trip) for varying levels of pre-contingency Avalon generation. Please note that HRD3 was assumed to be in-service as a synchronous condenser for this analysis.

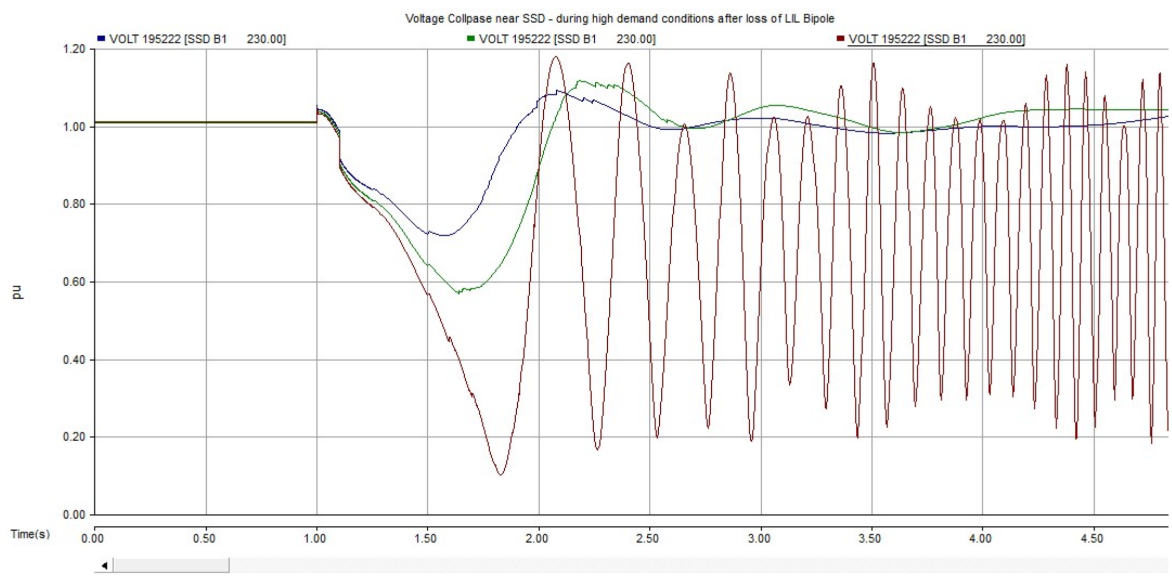


Figure 7-1. Voltage response at SSD after LIL bipole trip – as Avalon generation is reduced
Blue: Pre-contingency Avalon generation 3x47.2 MW **-** meets transient voltage criteria
Green: Pre-contingency Avalon generation 2x47.2 MW – violates transient voltage criteria
Red: Pre-contingency Avalon generation 2x30 MW – unstable

[20] Section 2.3.2 of TGS report TN1817.01.05 "Assessment of the BDE/SOP Transmission Constraints ", dated October 25, 2023.

The minimum Avalon generation requirements were calculated for the set of 2023-24[21] cases and the 2033-34 cases for varying LIL and ML transfer levels with two SOP synchronous condensers in-service[22], as summarized in Table 7-1. The following observations are made:

- The need for a minimum amount of Avalon generation to be in-service to prevent voltage collapse following the loss of the LIL bipole starts at an IIS demand of approximately 1650 MW.
- At higher levels of ML export and IIS demand, Avalon generation amounts in grey-shaded cells marked with ** indicate that the Avalon generation required to be in-service to serve demand/ML exports is higher than the Avalon generation required to prevent the voltage collapse issue, therefore voltage collapse is inherently not the limiting factor in these scenarios.
- The minimum Avalon generation requirements vary based on LIL and ML transfer levels. Yellow-shaded cells indicate the Avalon generation requirement for a particular demand level that would cover all LIL / ML transfer level scenarios. Using this single yellow-shaded number would avoid a large look-up table, however, it means that more Avalon generation may be on-line than needed in some scenarios.

Alternative mitigation options, such as the addition of reactive power support near SSD, are being investigated in future studies. A previous study[16] also evaluated various transmission upgrades to the 230 kV BDE-SOP corridor, including the possibility of adding a 3rd 230 kV line between WAV and SOP.

---

[21] 2023-24 cases differ from the 2033-34 cases in that BDE unit 8 and the three new 50 MW HRD CTs are not in-service.
[22] HRD3 was assumed to be online as a synchronous condenser.

Table 7-1. Minimum Avalon Generation required to prevent voltage collapse after LIL bipole trip

Avalon Generation Requirements (MW)				2 SOP SCs		
				2033-34 Cases		
Demand (MW)	**Generation (MW)**	**Gross Avalon load (MW)**	**ML (MW)**	**LIL = 900 MW**	**LIL = 700 MW**	**LIL = 600 MW**
2056	1729	1090	500	310 **	**	**
2034	1607	1088	400	240**	**	**
2020	1493	1086	300	180	**	**
2016	1439	1086	250	145	**	**
2012	1334	1086	150	140	180	**
			0	120	140	160
1938	1611	1025	500	210**	**	**
1919	1492	1023	400	140**	**	**
1907	1380	1022	300	95	**	**
1904	1413	1022	250	80	115	**
1901	1223	1022	150	60	95	115
			0	30	60	80
1785	1428	940	500	95**	**	**
1768	1341	938	400	30	**	**
1761	1234	938	300	0	40	**
1759	1181	938	250	0	20	**
1750	1073	938	150	0	10	30
			0	0	0	0
1535	1207	801	500	0		**
1524	1096	801	400	0		0
1513	985	801	300	0		0
1511	934	801	250	0		0
1502	825	801	150	0		0
				2023-24 Cases		
Demand (MW)	**Generation (MW)**	**Gross Avalon load (MW)**	**ML (MW)**	**LIL = 900 MW**	**LIL = 700 MW**	**LIL = 600 MW**
1923	1587	1019	500	443 **	**	**
1895	1459	1014	400	310 **	**	**
1877	1342	1010	300	180 **	**	**
1872	1286	1009	250	140	233 **	**
1865	1189	1009	150	115	140	**
1864	1528	987	500	363.5**	**	**
1839	1404	983	400	250**	**	**
1824	1288	981	300	150**	**	**
1816	1206	980	250	100	**	**
1812	1127	979	150	60	**	**
1808	972	979	0	40	100	**
1804	1468	954	500	330 **	**	**
1779	1344	950	400	190 **	**	**
1765	1229	948	300	90 **	**	**
1760	1174	947	250	70	**	**
1755	1069	947	150	40	60 (LIL=800)	**
1693	1357	893	500	223 **	**	**
1671	1236	890	400	100 **	**	**
1659	1123	888	300	0 (on verge)	**	**
1655	1069	888	250	0 (on verge)	20 (LIL=800)	**
1649	963	888	150	0 MW	0 (LIL=800)	20 (LIL=700)

** Needed for MW

7.1.1 Impact of Synchronous Condensers

Please note that the status of the SOP SCs and the HRD3 SC will impact the minimum Avalon generation requirements. Fewer SCs in-service will require more Avalon generation to be in-service, and additional SCs in-service will require less Avalon generation to be in-service. Table 7-2 provides an example of the impact of adding the 3rd SOP SC to the minimum Avalon generation requirements for the 2023-24 cases.

Table 7-2. Minimum Avalon Generation Requirements with 2 and 3 SOP SCs in-service

2023-24	Min Avalon Gen (MW)	
IIS demand	2 SOP SCs	3 SOP SCs
1870	140	60
1815	100	50
1760	70	0
1650	20	0

A previous study[23] performed a more thorough evaluation of the impact of HRD3 and SOP SCs on the need for Avalon generation at high demand. Conclusions from that study were as follows:

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

Additional future analysis will identify the updated full set of Avalon generation requirements for all combinations of SCs in/out-of-service, as well as the alternative solutions to reduce or eliminate these requirements, such as the addition of dynamic reactive power support near SSD.

[23] TGS report TN1817.01.05, “Assessment of the BDE/SOP Transmission Constraints”, dated October 25, 2023.

7.2 LIL Filter Feeder Impact

There is an additional contingency that requires evaluation to determine the impact to the LIL transfer limits. The contingency involves the loss of a LIL filter feeder, in which up to three filters can trip at once, resulting in a fast reduction in LIL power transfer. In contrast to a LIL trip, this contingency is not setup to trigger a runback of ML exports. Therefore, the expectation is that under certain scenarios, LIL transfer limits could be further restricted when considering this specific contingency and the inability to perform an ML runback.

A previous study[24] assessed the impact of this contingency on LIL transfer limits. This study evaluated loss of LIL filter feeder B311 at Muskrat Falls ("MFA"). In a worst-case scenario, loss of this filter feeder will cause the LIL to quickly reduce power transfer to 271 MW[25].

The Stage 4F study repeated the analysis of the LIL filter feeder contingency using the Final UFLS scheme and the 2033-34 set of PSSE base cases with the LIL operating at the Final LIL transfer limit. The results are summarized in the following tables:

- Table 7-3– LIL limits with ML runbacks active – with and without ML Frequency Controller active
- Table 7-4 – LIL limits with ML runbacks not active – with and without ML Frequency Controller active

Red text in Table 7-3 indicates scenarios where loss of the filter feeder requires a reduction in the LIL transfer limit. The majority of these scenarios are at lower IIS demand levels with higher ML exports, and mostly when the ML frequency controller is not in-service. These scenarios would be unlikely operating states.

When ML runbacks are not active (Table 7-4) no reduction in LIL transfer limits is needed due to the filter feeder contingency.

[24] TGS report TN1205.87.07, "Revised LIL Transfer Limits – Consideration for Loss of a LIL Filter Feeder", dated January 10, 2022.
[25] The contingency was modeled by reducing LIL power to 271 MW and setting MFA filters to 2x72 MVAR. The filters at SOP were left as is, leaving the LIL's reactive power controller to adjust SOP filters as required for the new LIL operating point.

Table 7-3. LIL limits for loss of filter feeder – ML runbacks active

LIL Limits				FILTER FEEDER (ML F/C in)					FILTER FEEDER (ML F/C out)				
IIS Demand (MW)	IIS Generation (MW)	ML (MW)	LIL Transfer Limit (MW)	LIL Transfer Limit (MW)	Min Frequency (Hz)	Load shed (MW)	LIL Limit using Back-up block (MW)	Min Frequency (Hz)	LIL Transfer Limit (MW)	Min Frequency (Hz)	Load shed (MW)	LIL Limit using Back-up block (MW)	Min Frequency (Hz)
2056	1729	500	900	900	58.39	482			900	58.22	666		
2034	1607	400	900	900	58.38	490			900	58.19	652		
2020	1493	300	900	900	58.35	496			900	58.18	664		
2016	1439	250	900	900	58.35	495			900	58.18	663		
2012	1334	150	900	900	58.33	496			900	58.16	665		
1938	1611	500	900	900	58.38	458			900	58.18	622		
1919	1492	400	900	900	58.34	464			900	58.17	621		
1907	1380	300	900	900	58.31	464			900	58.15	621		
1904	1413	250	900	900	58.29	463			900	58.14	620		
1901	1223	150	875	875	58.37	463			875	58.16	620		
1785	1428	500	900	900	58.37	422			900	58.15	565		
1768	1341	400	900	900	58.31	421			900	58.08	638		
1761	1234	300	900	900	58.29	422			900	58.09	627		
1759	1181	250	900	900	58.31	421			900	58.09	638		
1750	1073	150	850	850	58.37	421			850	58.17	564		
1535	1207	500	900	900	58.19	437			900	58.01	539		
1524	1096	400	900	900	58.17	477			900	57.94	540		
1513	985	300	900	900	58.18	476			900	57.94	538		
1511	934	250	875	875	58.26	356			875	58.07	538		
1502	825	150	780	780	58.37				780	58.15			
1296	969	500	900	900	58.11	385			830	57.92	434	900	57.68
1280	853	400	900	900	58.15	385			820	57.92	434	880	57.67
1261	734	300	870	870	58.17	385			810	57.97	434	870	57.69
1253	744	250	800	800	58.3	287			800	57.98	435		
1248	613	150	680	680	58.49	193			680	58.15	381		
1067	740	500	900	900	58.03	333			740	57.85	332	790	57.67
1046	619	400	900	900	58.02	333			725	57.89	332	775	57.67
1023	609	300	785	785	58.21	263			720	57.95	332	760	57.69
1015	598	250	720	720	58.38	220			720	57.95	332		
1003	598	150	590	590	58.61	147			590	58.22	219		
811	483	500	900	820	57.94	222	850	57.69	620	58.00	222	675	57.68
781	476	400	800	800	57.9	223			610	57.98	222	650	57.67
760	461	300	660	660	58.39	147			610	57.97	222	640	57.67
752	457	250	600	600	58.58	98			600	57.99	222		
741	447	150	480	480	58.85	0			480	58.38	147		
742	415	500	900	750	57.98	189	780	57.70	580	57.98	189	610	57.69
714	417	400	750	750	57.99	192			580	57.95	189	610	57.68
712	417	300	635	635	58.39	133			580	57.97	201	600	57.69
713	418	250	570	570	58.58	89			570	58.01	202		
704	418	150	460	460	59.07	0			460	58.39	137		
468	324	500	690	655	57.94	96	675	57.70	470	57.99	96	480	57.68
435	317	400	550	550	58.54	34			470	57.96	96	480	57.73
412	323	300	410	410	59.18	0			410	58.17	68		
404	321	250	350	350	59.33	0			350	58.60	34		
394	315	150	240	240	n/a	n/a			240	n/a	n/a		

LIL limit at 415 MW min generation
330 MW extreme min gen - max LIL (not at a transfer limit)

Table 7-4. LIL limits for loss of filter feeder – ML runbacks not active

Loss of Filter Feeder						
Demand	ML F/C Active (150 MW)			ML F/C Not Active		
	LIL	Freq Hz	UFLS	LIL	Freq Hz	UFLS
2012	900	58.30	499	900	58.15	669
1892	900	58.26	464	900	58.13	626
1739	900	58.26	421	900	58.07	627
1492	900	58.19	479	900	58.03	541
1242	900	58.15	385	800	58.00	434
1021	880	58.01	333	700	58.00	332
782	770	58.04	223	580	58.06	222
640	710	58.07	160	520	58.05	159
504	640	58.07	96	450	58.07	96

7.3 LIL Limits with Cable Issues

In a scenario where a LIL cable fails to switch 5 minutes after a pole trip, the LIL power order will suddenly drop to 450 MW on the healthy pole. The system should not experience UFLS when the LIL drops its transfer down to 450 MW.

These LIL limits are provided in Table 7-5 for scenarios with the ML frequency controller active and not active to ensure the frequency stays above 59.1 Hz to provide a 0.3 Hz margin to the 58.8 Hz block of UFLS. Hydro's operators have only 5 minutes to re-enable the ML frequency controller after a ML runback, and therefore Hydro should take caution when operating to the limits in Table 6-5 assuming the ML frequency controller can be reactivated.

Given the relatively small range (~10-20 MW) of LIL limits over the large range of IIS demand and ML transfer, it is recommended for simplicity to use a fixed LIL limit for the cable failure scenario as follows:

- ML Frequency controller in-service: 667 MW LIL limit
- ML Frequency control out-of-service: 486 MW LIL limit

Table 7-5. LIL Limits for the Cable Switching Failure Contingency

Cable Switching Failure								
Demand (MW)	Generation (MW)	ML before runback	LIL BP Transfer before pole trip	Infeed @ SOP before (MW)	LIL losses in MP (GR)	ML runback due to pole trip	ML after initial Runback	Min Freq after LIL -> 450 MW
ML F/C Active (150 MW)								
1904	1570	300	670	629.5	114.4	73.9	226.1	59.10
1758	1438	300	670	629.5	114.4	73.9	226.1	59.10
1509	1191	300	670	629.5	114.4	73.9	226.1	59.10
1247	926	300	675	633.9	115.9	74.9	225.1	59.10
1008	680	300	685	642.8	119.1	76.8	223.2	59.10
753	424	300	685	642.8	119.1	76.8	223.2	59.10
1899	1432	150	667	626.8	113.5	73.3	76.7	59.10
1752	1285	150	667	626.8	113.5	73.3	76.7	59.10
1502	1032	150	670	629.5	114.4	73.9	76.1	59.10
1240	764	150	680	638.4	117.5	75.8	74.2	59.10
998	522	150	680	638.4	117.5	75.8	74.2	59.10
739	418	150	500	476.7	67.8	44.5	105.5	59.43
ML F/C not Active (0 MW)								
1907	1742	300	491	468.5	65.7	43.2	256.8	59.10
1760	1595	300	491	468.5	65.7	43.2	256.8	59.10
1522	1355	300	493	470.3	66.1	43.5	256.5	59.10
1258	1091	300	494	471.2	66.4	43.6	256.4	59.10
1011	842	300	497	474.0	67.1	44.1	255.9	59.10
750	583	300	493	470.3	66.1	43.5	256.5	59.10
1909	1594	150	491	468.5	65.7	43.2	106.8	59.10
1754	1449	150	491	468.5	65.7	43.2	106.8	59.10
1514	1199	150	491	468.5	65.7	43.2	106.8	59.10
1245	926	150	497	474.0	67.1	44.1	105.9	59.10
999	683	150	493	470.3	66.1	43.5	106.5	59.10
739	427	150	486	463.9	64.5	42.4	107.6	59.10

Min gen, not at a LIL limit

7.4 LIL Limits with 0 / 1 SOP SC

Previous Stage 4 operational studies have been performed to identify LIL operating restrictions when there is only one (1) or no (0) SOP synchronous condensers in-service.

Please refer to the previous study report for details – "Updated LIL Restrictions with 0 and 1 SOP Synchronous Condensers", TN1205.97.03, dated June 2, 2023.

7.5 Stability Transfer Limits (Prior Outage TL201/TL217)

Previous Stage 4 operational studies found that there is a stability limit on the TL201/TL217 corridor between WAV and SOP if there is a prior outage of either TL201 or TL217. During this prior outage, if the other line trips, the power flow is forced to flow via the underlying 138 kV transmission, which results in both thermal and stability limitations. The stability limit is a transient voltage violation, as shown in Figure 7-2.

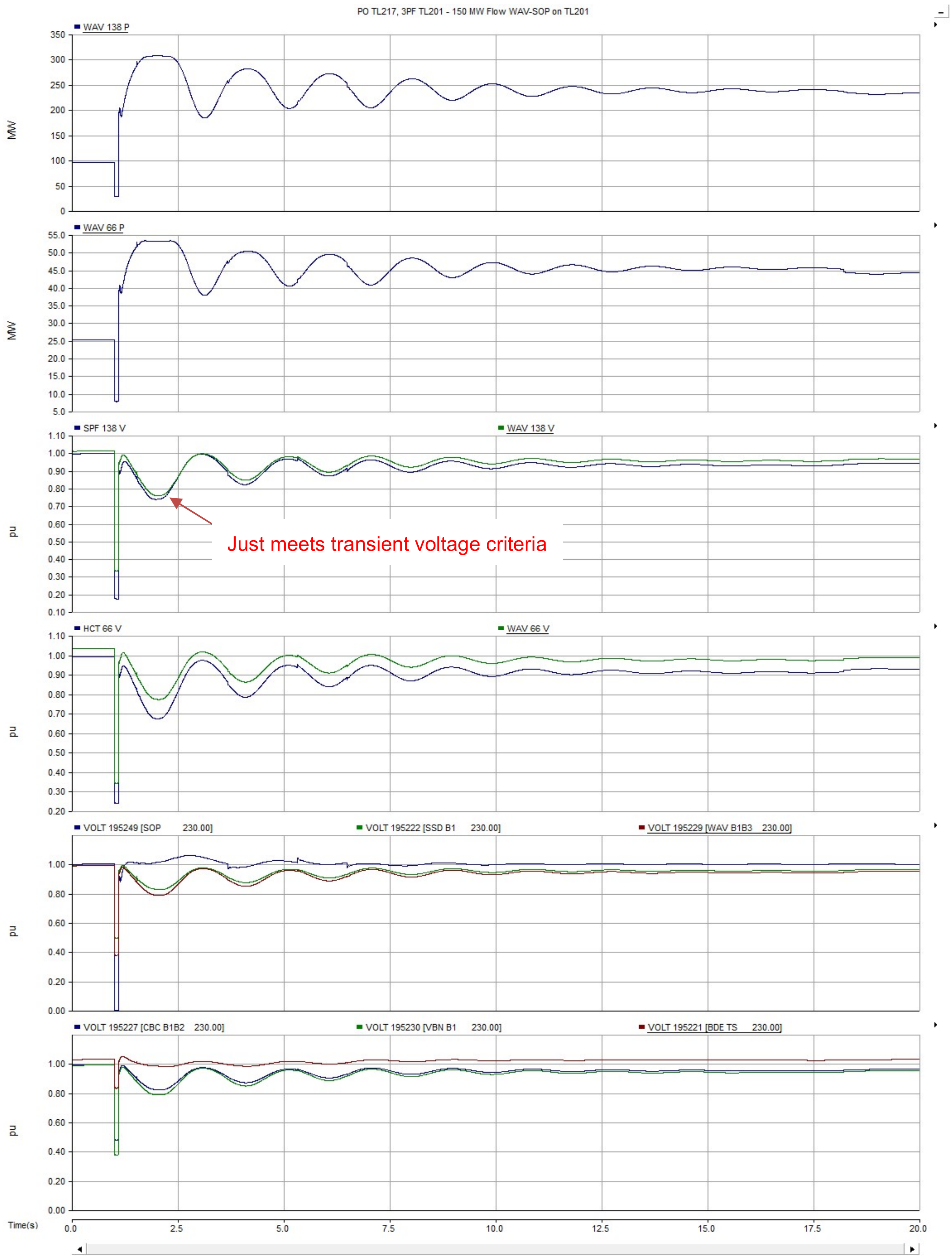


Figure 7-2. Transient Voltage Criteria defines the stability limit – prior outage TL217, loss of TL201

The stability limits were revisited in the Stage 4F and were found to remain unchanged as listed in Table 7-6.

Table 7-6. Prior outage Stability Transfer Limits on TL201/TL217

Demand (MW)	Stability / Transient voltage limit
	TL201/TL217 Flow (MW)
1900**	150
1750***	150
1500	155
1250	160
1000	165
750	133

*not a stability limit (LIL at min)

**HRD CT in-service @ 70 MW for minimum Avalon generation

***HRD CT in- service @ 40 MW for minimum Avalon generation

7.6 315 kV Prior Outage Limits

Previous Stage 4 operational studies[26] determined LIL operating restrictions based on the Labrador end of the link. The 315 kV prior outage limits were revisited in the Stage 4F studies in order to test the frequency response at MFA and on the IIS to confirm the deadband settings for the LIL frequency controller for PFC and FLC modes of operation.

There are two parallel 315 kV lines connecting MFA to CHF. A prior outage of one of these 315 kV lines requires transfer limits on the remaining in-service 315 kV line in case it trips. These transfer limits depend on whether the LIL frequency controller is in-service or not, and which direction the power on the 315 kV line is flowing; MFA to CHF, or CHF to MFA. If the LIL frequency controller is in-service when there is a 315 kV prior outage, it is operating in “PFC” mode at MFA and the SOP end is operating in “FLC” mode.

If the remaining 315 kV line trips, the LIL becomes isolated with the MFA generators and the Happy Valley load area, and the following issues arise:

- Overfrequency if the 315 kV power transfer was in the direction from MFA to CHF
- Underfrequency if the 315 kV power transfer was in the direction from CHF to MFA
- The frequency at which the systems settle is not necessarily 60 Hz (observable in the upcoming Figures 7-3 through 7-6). This is because the LIL frequency controller at the MFA end (PFC) and at the SOP end (FLC) are giving opposing inputs which are summed and passed to the LIL frequency controller to add to the LIL power order. If for example, there is an underfrequency at MFA and the MFA units are already operating at maximum power output, the PFC (at MFA) will

[26] TGS report TN1205.79.02, “Stage 4C: Updates for Labrador Transfer Analysis”, dated October 1, 2020.
TGS report TN1205.66.09, “Stage 4C: Labrador Transfer Analysis”, dated November 6, 2020.

ask the LIL to reduce transfer, however, reduced transfer will cause an underfrequency at SOP, which will cause the FLC (at SOP) to ask the LIL to increase transfer. Hence, with nothing set to control the frequency to 60 Hz, the system can settle out at off-nominal frequency. Hydro is currently investigating options to resolve this steady state frequency issue that may require further studies.

The 315 kV transfer limits are needed to ensure the frequency response at MFA is stable and remains between 57.5 Hz and 62.5 Hz[27] when LIL becomes isolated with HVY load to prevent MFA units from tripping on frequency protection. Additionally, when the LIL frequency controller at MFA (PFC mode) responds to changes in frequency at MFA, this will also affect the LIL power infeed at SOP, which then affect the IIS frequency, which can in turn causes the LIL frequency controller at SOP (FLC mode) to respond and oppose the modulation to the power order being requested by the MFA end. Therefore, the 315 kV transfer limits are also needed to ensure that the IIS frequency remains within the Transmission Planning criteria and that no UFLS occurs (i.e. frequency remains above 59.1 Hz).

7.6.1 LIL Frequency Controller in-service

When the LIL frequency controller is in-service and the LIL becomes isolated at the MFA end, the LIL frequency controller at MFA (PFC mode) will respond to the frequency changes at MFA, which modifies the LIL infeed at SOP and affects the IIS frequency, which in turn can result in the operation of the LIL frequency controller at SOP (FLC mode) as well. Therefore, the analysis for determining the 315 kV prior outage transfer limits involves ensuring that no UFLS occurs on the IIS, and therefore, the limits are also dependent on whether the ML frequency controller is in-service or not and IIS demand levels.

The 315 kV prior outage limits with the LIL frequency controller in-service are summarized in the following tables. Limits are provided for scenarios with 2, 3 and 4 MFA generators in-service:

- Table 7-7 – LIL frequency controller in-service, 315 kV MFA-CHF direction
- Table 7-8– LIL frequency controller in-service, 315 kV CHF-MFA direction

Each table provides the following:

- 315 kV prior outage transfer limit for the given scenario
- LIL bipole steady state operating point (MW)
- LIL bipole maximum transient real power (MW) (includes impact of power order modulation from the frequency controller)
- LIL bipole steady state post-contingency real power (MW) (includes impact of power order modulation from the frequency controller)
- the limiting factor that determined the 315 kV transfer limit.

This information will help define the necessary LIL frequency controller settings.

[27] MFA generating unit protection is set to 57 Hz ad 63 Hz (with a delay). This study used criteria of maintaining isolated system frequency between 57.5 Hz and 62.5 Hz to ensure some margin to the protection settings.

7.6.1.1 315 kV MFA -> CHF Direction

When the power direction is from MFA to CHF, MFA experiences an overfrequency if the remaining 315 kV line trips, which results in the LIL frequency controller increasing the LIL power order in an attempt to reduce the overfrequency, which also causes an overfrequency on the IIS.

With the ML frequency controller in-service, the limiting factor that determined the 315 kV limits in the MFA to CHF direction is keeping the MFA frequency below 62.5 Hz. An example is shown in Figure 7-3, where there are 3 MFA units on-line @ 206 MW each, IIS demand is 1900 MW and the remaining 315 kV line is transferring 305 MW from MFA to CHF when it trips. Note that the 315 kV limits are marginally dependent on IIS demand when the ML frequency controller is in-service due to frequency impacts on the IIS. A similar trend in 315 kV limits vs IIS demand was observed as was discussed in Section 3.2 Figure 4-9.

With the ML frequency controller out-of-service, some of the scenarios were limited due to frequency decreasing below 59.1 Hz on the IIS. The same example used in Figure 7-3 is shown again in Figure 7-4, this time with the ML frequency controller out-of-service. Initially MFA experiences an overfrequency, which causes the LIL frequency controller to increase LIL transfer, which then results in an overfrequency on the IIS. The overfrequency on the IIS causes the LIL frequency controller at SOP to reduce the LIL transfer, which then results in an underfrequency as the frequency swings up/down as the system settles over time. Without the ML frequency controller active, the frequency swings on the IIS are larger and take longer to settle.

Table 7-7. 315 kV prior outage limits MFA->CHF – LIL Frequency controller in-service

315 kV Prior Outage - Transfer Limits (MFA -> CHF) - LIL F/C with PFC@MFA														
Number of MFA units on-line	MFA Loading (MW)	IIS Demand (MW)	IIS Generation (MW)	ML F/C in-service					IIS Generation (MW)	ML F/C out-of-service				
				315 kV limit (MW)	LIL Bipole (MW) steady state pre-contingency	LIL Bipole (MW)* maximum transient	LIL Bipole (MW)* Steady state post-contingency	Limiting factor		315 kV limit (MW)	LIL Bipole (MW) steady state pre-contingency	LIL Bipole (MW)* maximum transient	LIL Bipole (MW)* Steady state post-contingency	Limiting factor
4	206	1900	1461	273	465	821	699	62.5 Hz MFA	1254	61	677	843	677	59.0 Hz SOP
	150		1823	415	100	638	378	62.5 Hz MFA	1685	289	225	603	371	62.5 Hz MFA
	103		1834	386	90	602	374	62.5 Hz MFA	1834	262	90	444	244	62.5 Hz MFA, 62.2 Hz SOP
	206	1000	524	240	498	806	698	62.5 Hz MFA	566	39	700	748	718	59.46 Hz SOP
	150		827	322	192	610	382	62.5 Hz MFA	686	186	328	576	408	62.5 Hz MFA
	103		940	290	90	474	286	62.5 Hz MFA	861	166	161	387	249	62.5 Hz MFA
	206	500	464	258	480	810	698	62.5 Hz MFA	420	34	704	758	714	59.3 Hz SOP
	150		704	324	190	608	382	62.5 Hz MFA	518	123	391	557	443	59.08 Hz SOP
	103		802	294	90	478	290	62.5 Hz MFA	713	144	183	389	281	62.5 Hz MFA, 59.05 Hz SOP
3	206	1900	1700	305	220	666	504	62.5 Hz MFA, 62.1 Hz SOP	1516	112	420	580	526	62.1 Hz MFA, 59 Hz SOP
	150		1836	383	90	636	370	62.5 Hz MFA, 62.1 Hz SOP	1824	265	100	460	256	62.5 Hz MFA, 62.3 Hz SOP, 59.5 Hz SOP
	103		1836	361	90	614	376	62.5 Hz MFA, 62.1 Hz SOP	1836	240	90	434	248	62.5 Hz MFA, 62.2 Hz SOP
	206	1000	720	238	294	632	504	62.5 Hz MFA, 62.2 Hz SOP	559	72	460	564	518	62.2 Hz MFA, SOP / 59.2 Hz SOP
	150		937	291	90	504	280	62.5 Hz MFA, 62.1 Hz SOP	828	175	190	440	276	62.5 Hz MFA, 62.4 Hz SOP / 59.2 Hz SOP
	103		937	272	90	486	288	62.5 Hz MFA, 62.1 Hz SOP	937	158	90	314	178	62.5 Hz MFA, 62.3 Hz SOP
	206	500	427	242	290	630	502	62.5 Hz MFA	431	38	492	592	514	59.0 Hz SOP
	150		426	279	90	486	264	62.5 Hz MFA, 62.1 Hz SOP	435	140	226	426	356	62.5 Hz MFA, SOP / 58.9 Hz SOP
	103		426	258	90	464	268	62.5 Hz MFA, 62.2 Hz SOP	426	134	90	290	170	62.55 Hz MFA/ 59.5 Hz SOP
2	206	1900	1836	334	90	628	406	62.5 Hz MFA, 62.1 Hz SOP	1813	217	110	474	306	62.5 Hz MFA, 62.2 Hz SOP
	150		1836	361	90	680	384	62.5 Hz MFA, 62.1 Hz SOP	1836	240	90	470	258	62.5 Hz MFA, 62.3 Hz SOP
	103		1836	348	90	682	386	62.5 Hz MFA, 62.1 Hz SOP	1836	225	90	452	260	62.5 Hz MFA, 62.2 Hz SOP
	206	1000	937	247	90	488	316	62.5 Hz MFA, 62.1 Hz SOP	817	126	200	400	320	62.5 Hz MFA, SOP/ 59.1 Hz SOP
	150		937	264	90	514	286	62.5 Hz MFA, 62.0 Hz SOP	937	156	90	338	184	62.5 Hz MFA, 62.3 Hz SOP
	103		937	253	90	502	290	62.5 Hz MFA, 62.0 Hz SOP	937	143	90	324	184	62.5 Hz MFA, 62.3 Hz SOP
	206	500	418	229	98	468	306	62.5 Hz MFA	434	66	260	392	310	59.0 Hz SOP
	150		426	258	90	504	276	62.5 Hz MFA, 62.1 Hz SOP	426	128	90	294	234	62.5 Hz MFA, 62.4 Hz SOP
	103		426	244	90	488	278	62.5 Hz MFA, 62.1 Hz SOP	426	114	90	278	210	62.5 Hz MFA, 62.4 Hz SOP

* Includes impact of power order modulation by the LIL frequency controller

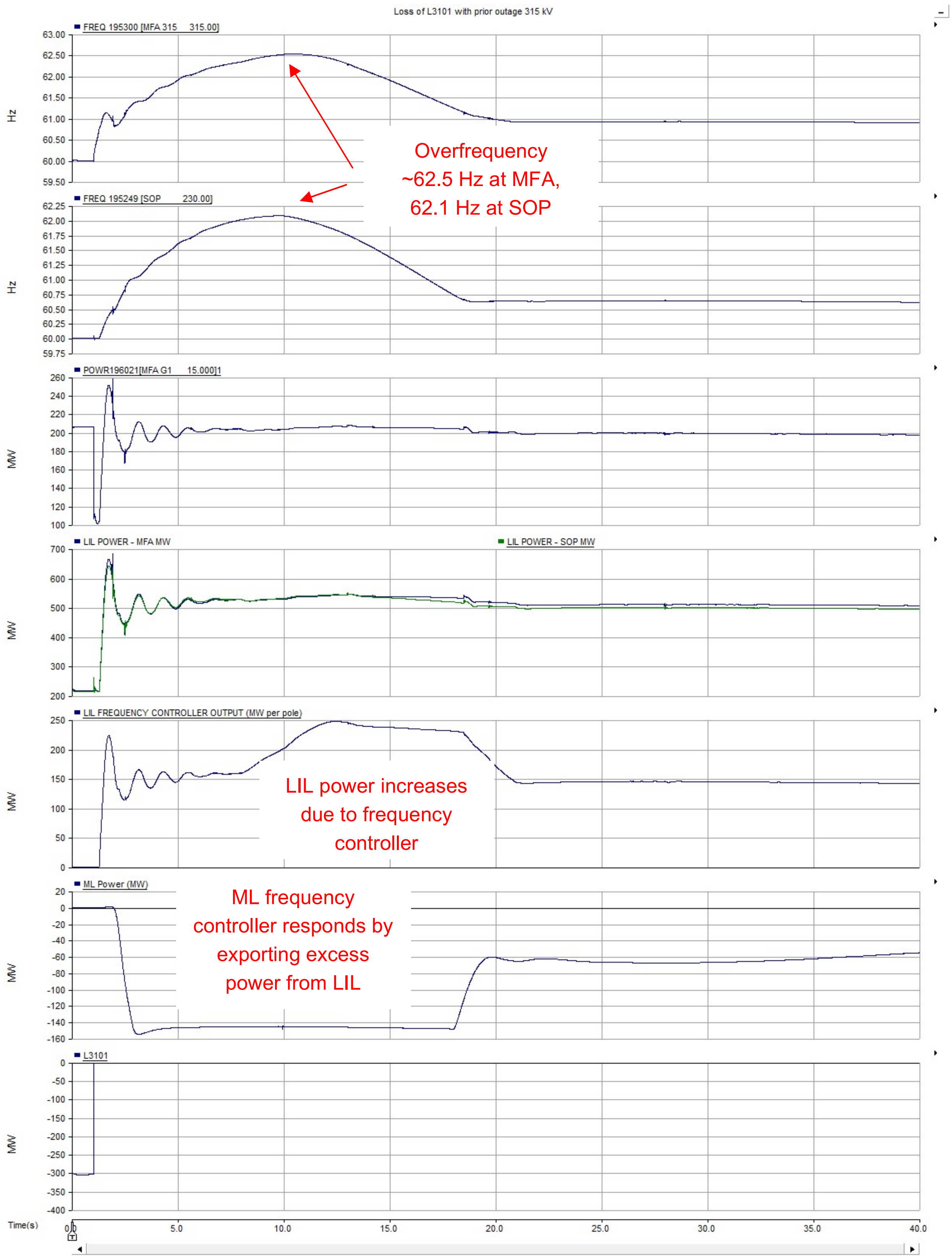


Figure 7-3. 3 MF units (206 MW), IIS demand 1900 MW, ML F/C in, Loss of L3101 @ 305 MW

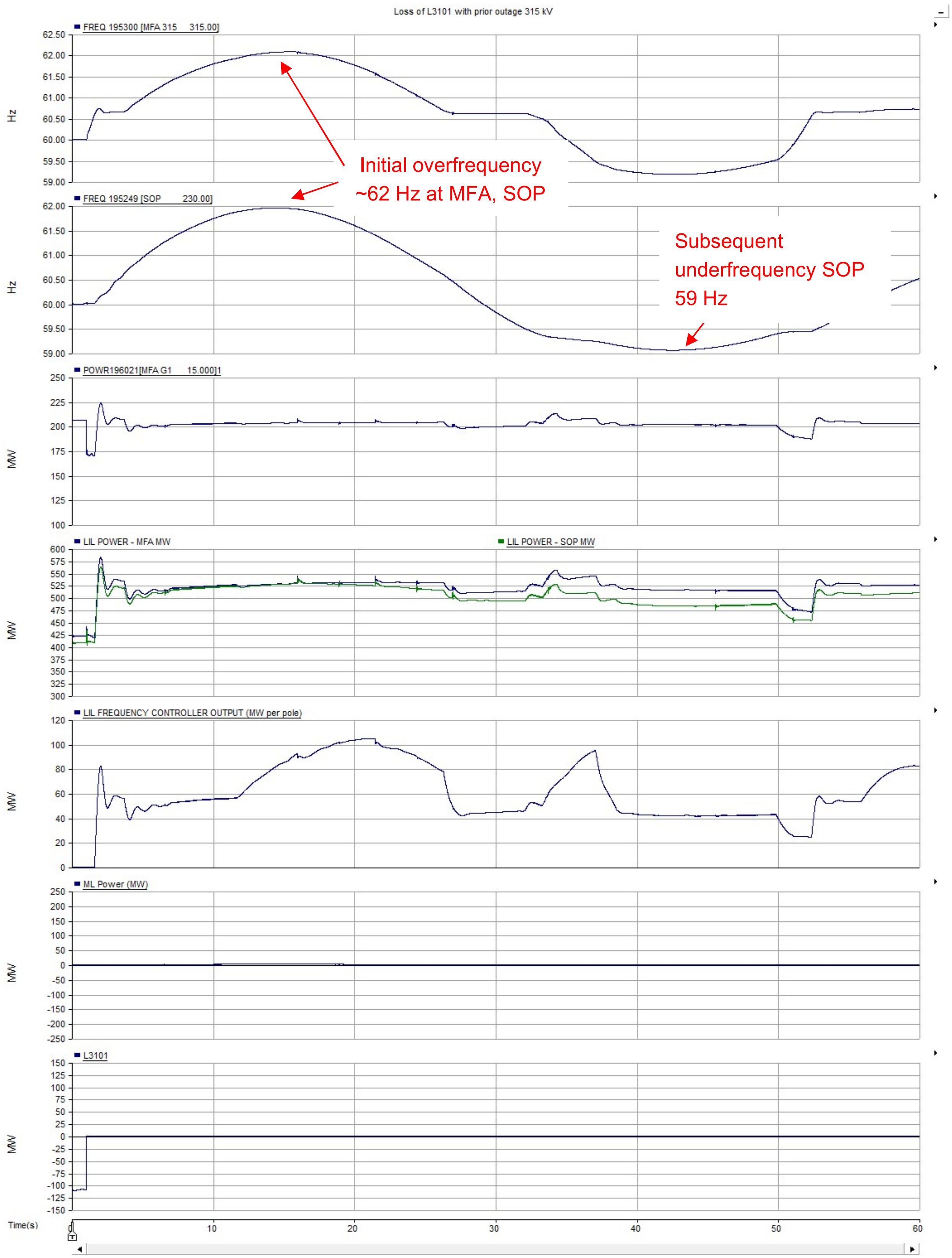


Figure 7-4. 3 MF units (206 MW), IIS demand 1900 MW, ML F/C out, Loss of L3101 @ 112 MW

7.6.1.2 315 kV CHF -> MFA Direction

When the power direction is from CHF to MFA, MFA experiences an underfrequency if the remaining 315 kV line trips, which results in the LIL frequency controller decreasing the LIL power order in an attempt to mitigate the underfrequency, which also causes an underfrequency on the IIS.

Whether the ML frequency controller is in-service or out-of-service, the limiting factor that determined the 315 kV limits in the CHF to MFA direction is keeping the SOP frequency above 59 Hz to avoid UFLS. However, **the 315 kV transfer limits are significantly less if the ML frequency controller is not in-service.** An example is shown in Figure 7-5[28], in which 2 MFA units are in-service at 206 MW each, IIS demand is 1000 MW, ML frequency controller is in-service, and the remaining 315 kV line is transferring 190 MW before it trips. The same scenario with the ML frequency controller out-of-service is shown in Figure 7-6, in which case the remaining 315 kV line was only transferring 45 MW before it trips.

Please also note that when the ML frequency controller is in-service, the 315 kV limits are marginally dependent on IIS demand due to frequency impacts in the IIS. A similar trend in 315 kV limits vs IIS demand was observed as was discussed in Section 3.2 Figure 4-9.

[28] As noted in Section 7.6, the frequency at which the systems settle in Figure 7-5 is necessarily 60 Hz. This is because the LIL frequency controller at the MFA end (PFC) and at the SOP end (FLC) are giving opposing inputs which are summed and passed to the LIL frequency controller to add to the LIL power order. If for example, there is an underfrequency at MFA and the MFA units are already operating at maximum power output, the PFC (at MFA) will ask the LIL to reduce transfer, however, reduced transfer will cause an underfrequency at SOP, which will cause the FLC (at SOP) to ask the LIL to increase transfer. Hence, with nothing set to control the frequency to 60 Hz, the system can settle out at off-nominal frequency. Hydro is currently investigating options to resolve this steady state frequency issue that may require further studies.

Table 7-8. 315 kV prior outage limits CHF->MFA – LIL Frequency controller in-service

315 kV Prior Outage - Transfer Limits (CHF -> MFA) - LIL F/C with PFC@MFA														
Number of MFA units on-line	MFA Loading (MW)	IIS Demand (MW)	IIS Generation (MW)	ML F/C in-service					IIS Generation (MW)	ML F/C out-of-service				
				315 kV limit (MW)	LIL Bipole (MW) steady state pre-contingency	LIL Bipole (MW)* maximum transient	LIL Bipole (MW)* Steady state post-contingency	Limiting factor		315 kV limit (MW)	LIL Bipole (MW) steady state pre-contingency	LIL Bipole (MW)* maximum transient	LIL Bipole (MW)* Steady state post-contingency	Limiting factor
4	206	1900	1055	183	902	708	728	58.7 Hz MFA, 59.0 Hz SOP	1172	35	773	729	749	59.0 Hz SOP
	150		1205	221	736	482	626	59.0 Hz SOP	1350	73	587	523	587	59.0 Hz SOP
	103		1388	211	538	280	410	59.0 Hz SOP	1527	73	400	332	400	59.0 Hz SOP
	206	1500	914	199	902	686	710	58.7 Hz MFA, 59.0 Hz SOP	1022	40	778	728	748	59.0 Hz SOP
	150		955	218	733	489	627	59.0 Hz SOP	1184	82	596	540	596	59.0 Hz SOP
	103		1134	208	535	317	413	59.0 Hz SOP	1368	78	405	333	403	59.0 Hz SOP
	206	1000	437	204	902	682	706	58.7 Hz MFA, 59.0 Hz SOP	540	35	773	729	749	59.0 Hz SOP
	150		454	232	747	479	631	59.0 Hz SOP	686	84	598	542	598	59.0 Hz SOP
	103		625	220	547	279	413	59.0 Hz SOP	864	78	405	343	401	59.0 Hz SOP
	206	500		LIL at max, powerflow still MFA > CHF										
	150		309	251	766	468	628	58.75 Hz MFA, 59.03 Hz SOP	451	60	575	517	575	59.0 Hz SOP
	103		429	226	553	277	413	59.0 Hz SOP	603	66	393	345	393	59.0 Hz SOP
3	206	1900	1249	149	681	503	535	59.0 Hz SOP	1355	38	570	522	536	59.0 Hz SOP
	150		551	218	583	323	451	59.0 Hz SOP	1496	65	430	366	430	59.0 Hz SOP
	103		690	207	431	195	291	59.0 Hz SOP	1654	59	283	225	281	59.0 Hz SOP
	206	1500	926	185	718	502	542	59.0 Hz SOP	1071	33	565	525	539	59.0 Hz SOP
	150		1065	205	570	302	450	59.0 Hz SOP	1198	62	427	369	427	59.0 Hz SOP
	103		1223	191	415	197	287	59.0 Hz SOP	1349	57	281	225	277	59.0 Hz SOP
	206	1000	428	193	724	474	530	59.0 Hz SOP	461	35	566	520	536	59.0 Hz SOP
	150		449	216	580	288	450	59.0 Hz SOP	585	68	432	366	432	59.0 Hz SOP
	103		587	207	430	170	290	59.0 Hz SOP	725	66	290	240	290	59.0 Hz SOP
	206	500	319	219	752	468	534	59.7 Hz MFA, 59.0 Hz SOP	440	26	558	522	536	59.0 Hz SOP
	150		430	236	600	292	452	59.0 Hz SOP	443	55	420	368	420	59.0 Hz SOP
	103		437	216	440	156	290	59.0 Hz SOP	443	50	274	242	274	59.0 Hz SOP
2	206	1900	1424	173	500	256	330	59.0 Hz SOP	1556	46	372	318	330	59.0 Hz SOP
	150		1517	194	409	159	275	59.0 Hz SOP	1624	58	273	217	269	59.0 Hz SOP
	103		1632	181	302	86	166	59.0 Hz SOP	1641	53	174	122	160	59.0 Hz SOP
	206	1500	1041	165	492	264	324	59.0 Hz SOP	1162	37	363	319	327	59.0 Hz SOP
	150		1131	189	404	164	272	59.0 Hz SOP	1258	58	273	219	265	59.0 Hz SOP
	103		1221	185	306	86	162	59.0 Hz SOP	1365	57	178	122	160	59.0 Hz SOP
	206	1000	507	190	516	278	328	59.0 Hz SOP	645	45	370	320	330	59.0 Hz SOP
	150		600	202	416	148	276	59.0 Hz SOP	735	65	280	218	280	59.0 Hz SOP
	103		697	196	317	99	167	59.0 Hz SOP	839	59	180	124	180	59.0 Hz SOP
	206	500	452	195	520	220	320	59.0 Hz SOP	437	27	352	324	332	59.0 Hz SOP
	150		441	215	430	128	280	59.0 Hz SOP	432	47	262	222	262	59.0 Hz SOP
	103		431	200	320	50	168	59.0 Hz SOP	420	43	164	124	164	59.0 Hz SOP

* Includes impact of power order modulation by the LIL frequency controller

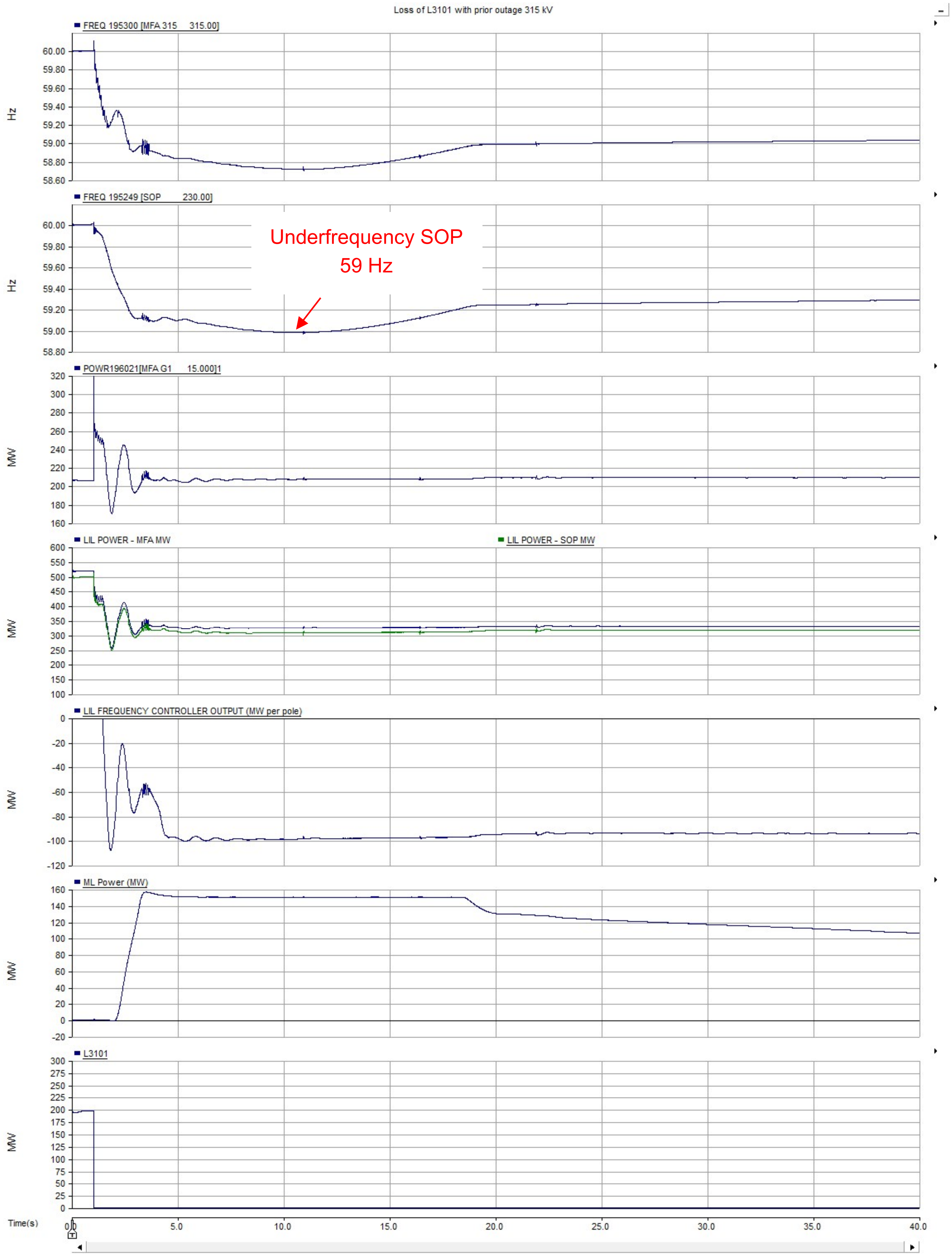


Figure 7-5. 2 MFA units (206 MW), IIS demand 1000 MW, ML F/C in, Loss of L3101 @ 190 MW

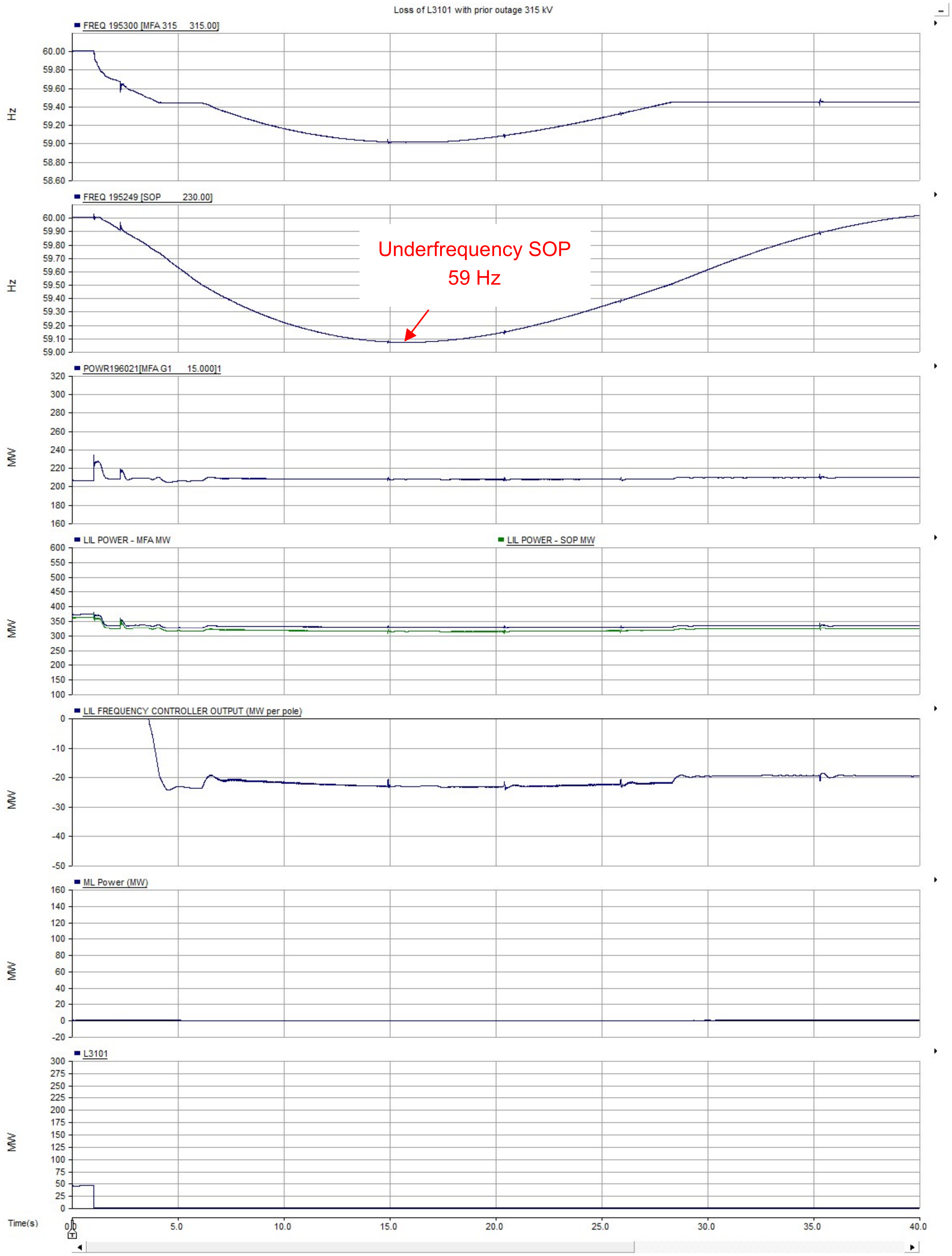


Figure 7-6. 2 MFA units (206 MW), IIS demand 1000 MW, ML F/C out, Loss of L3101 @ 45 MW

7.6.2 LIL Frequency Controller out-of-service

When the LIL frequency controller is not in-service and the LIL becomes isolated at MFA, the IIS system no longer impacts the 315 kV limits, and the MFA generators are the only factor affecting the frequency response at MFA. The limiting factors are overfrequency at MFA if prior outage 315 kV power flow direction is from MFA to CHF, and underfrequency at MFA if prior outage 315 kV power flow direction is from CHF to MFA. The MFA unit frequency protection defines the allowable frequency levels, since tripping all MFA units will have a negative impact on both the Island and Labrador systems; given the LIL would also trip.

The 315 kV prior outage limits without the LIL frequency controller are summarized in the following tables. Limits are provided for scenarios with 2, 3 and 4 MFA generators in-service, at low and high HVY load scenarios and with the power system stabilizers (PSSes) on the MF units in and out-of-service:

- Table 7-9 – LIL frequency controller out-of-service, 315 kV MFA-CHF direction
- Table 7-10 – LIL frequency controller out-of-service, 315 kV CHF-MFA direction

The following observations were made:

- When operating in isolated mode, the PSSes on the MF units made the response of the MFA generators significantly less stable compared to the cases with the PSSes out-of-service. Examples are shown in Figure 7-7 (MFA->CHF) and Figure 7-8 (CHF->MFA) to overlay the responses with the PSS in (blue plots) and PSS out (green plots). Based on these results **it is recommended to disable the PSSes if the LIL and MFA units are isolated together when the LIL frequency controller is not in-service. Alternatively, the PSSes should be better tuned for this isolated mode of operation. It is therefore recommended to perform a PSS tuning study.**
- The 315 kV transfer limit is 0 MW (or very small in some cases) if the MFA units are operated at full power rating of 206 MW. Therefore, **some amount of room is needed on the MFA units to be able to respond to frequency changes at MFA if the remaining 315 kV line trips**. This study tested MF units loaded at 103 MW (minimum generation), 150 MW and 206 MW (maximum generation).
- The 315 kV transfer limits are slightly lower with lower HVY load (e.g. 15 MW vs 80 MW load).

Table 7-9. 315 kV prior outage limits MFA->CHF – LIL Frequency controller out-of-service

315 kV Prior Outage - Transfer Limits (MFA -> CHF) - LIL F/C out-of-service						
Number of MFA units on-line	MFA Loading (MW)	HVY Load (MW)	PSS in		PSS out	
			315 kV limit (MW)	Limiting factor	315 kV limit (MW)	Limiting factor
4	206	80	~6	62.5 Hz MFA	~6	62.5 Hz MFA
	150		50	57.5 Hz MFA	60	62.5 Hz MFA
	103		40	62.5 Hz MFA	51	62.5 Hz MFA
	206	15	~0	instability	~0	instability
	150		41	57.5 Hz MFA	58	62.5 Hz MFA
	103		36	62.5 Hz MFA	49	62.5 Hz MFA
3	206	80	~2	62.5 Hz MFA	~2	62.5 Hz MFA
	150		24	57.5 Hz MFA	47	62.5 Hz MFA
	76.5		51	62.5 Hz MFA	55	62.5 Hz MFA
	103		31	62.5 Hz MFA	35	62.5 Hz MFA
	206	15	~4	62.5 Hz MFA	~4	62.5 Hz MFA
	150		27	57.5 Hz MFA	46	62.5 Hz MFA
	103		25	57.5 Hz MFA	37	62.5 Hz MFA
2	206	80	~4	62.5 Hz MFA	~4	62.5 Hz MFA
	150		22	57.5 Hz MFA	31	62.5 Hz MFA
	103		23	62.5 Hz MFA	25	62.5 Hz MFA
	206	15	~3	57.5 Hz MFA	~3	62.5 Hz MFA
	150		20	57.5 Hz MFA	30	62.5 Hz MFA
	103		19	62.5 Hz MFA	24	62.5 Hz MFA

Table 7-10. 315 kV prior outage limits CHF->MFA – LIL Frequency controller out-of-service

315 kV Prior Outage - Transfer Limits (CHF -> MFA) - LIL F/C out-of-service						
Number of MFA units on-line	MFA Loading (MW)	HVY Load (MW)	PSS in		PSS out	
			315 kV limit (MW)	Limiting factor	315 kV limit (MW)	Limiting factor
4	206	80	0	instability	0	instability
	150		65	57.5 Hz MFA	57	57.5 Hz MFA
	103		73	57.5 Hz MFA	54	57.5 Hz MFA
	206	15	0	instability	0	instability
	150		55	57.5 Hz MFA	51	57.5 Hz MFA
	103		66	57.5 Hz MFA	53	57.5 Hz MFA
3	206	80	~0	instability	0	instability
	150		57	57.5 Hz MFA	45	57.5 Hz MFA
	103		53	57.5 Hz MFA	41	57.5 Hz MFA
	206	15	0	instability	0	instability
	150		56	57.5 Hz MFA	43	57.5 Hz MFA
	103		54	57.5 Hz MFA	39	57.5 Hz MFA
2	206	80	0	instability	0	instability
	150		46	57.5 Hz MFA	31	57.5 Hz MFA
	103		37	57.5 Hz MFA	29	57.5 Hz MFA
	206	15	0	instability	0	instability
	150		43	62.5 Hz MFA	30	57.5 Hz MFA
	103		36	57.5 Hz MFA	29	57.5 Hz MFA

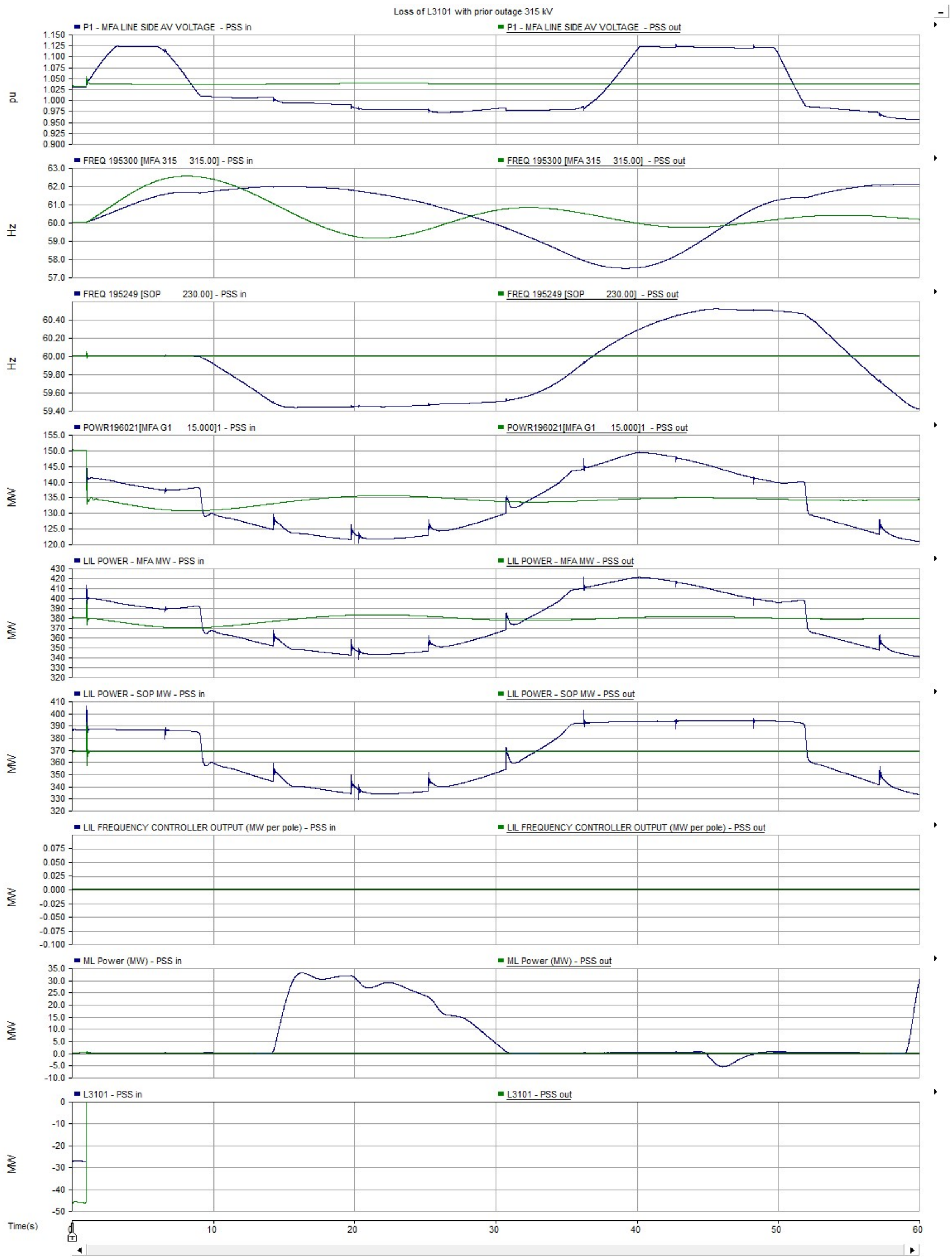


Figure 7-7. MFA->CHF, LIL F/C out, 3 MFA units (150 MW):
PSS in: Blue, PSS out: Green

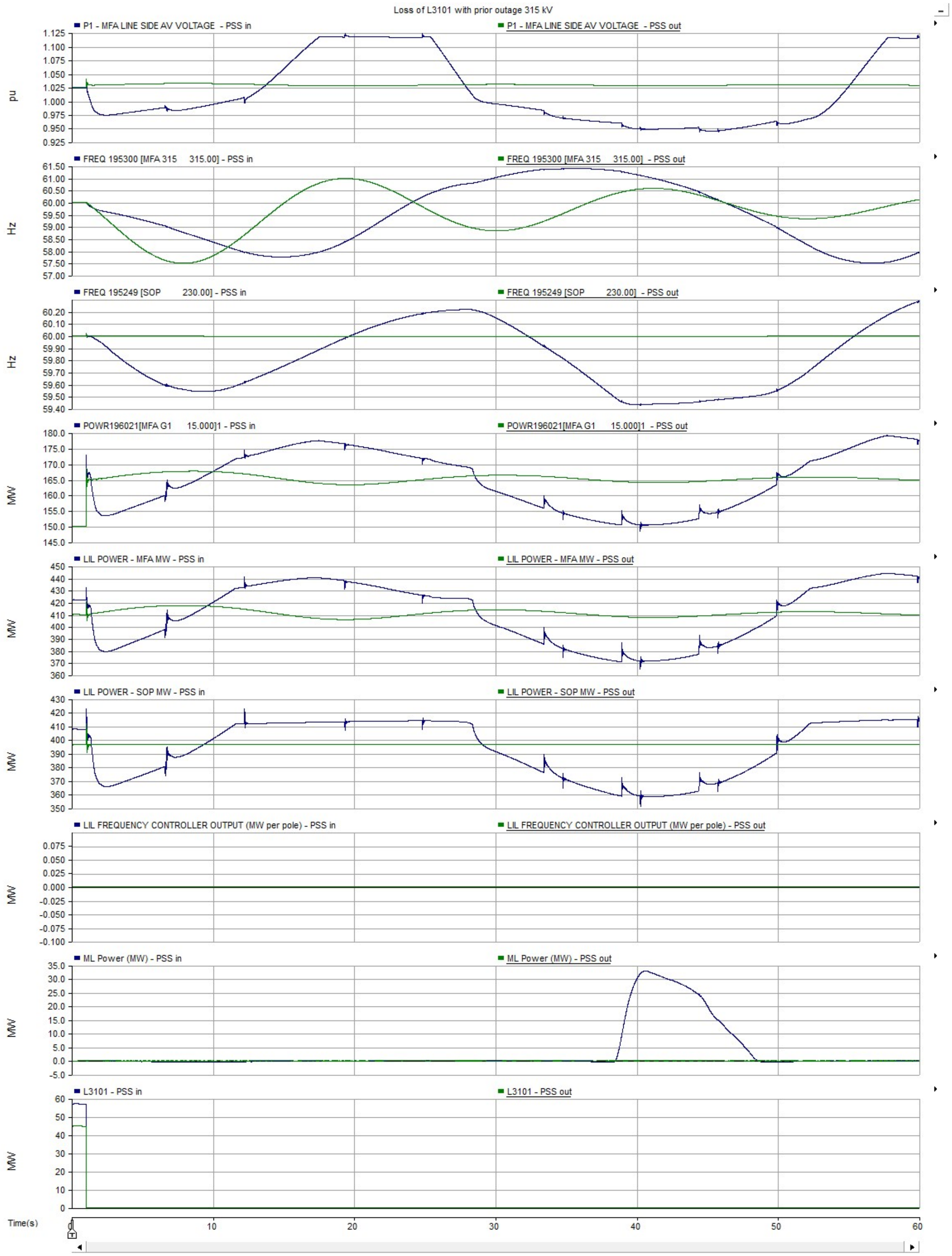


Figure 7-8. MFA->CHF, LIL F/C out, 3 MFA units (150 MW):
PSS in: Blue, PSS out: Green

7.7 Maximum Generator Unit Loading

Loss of a generator should not result in UFLS, therefore, the maximum generator unit loading was determined such that the IIS frequency does not drop below 59.1 Hz, leaving a 0.3 Hz margin to UFLS (58.8 Hz).

Maximum generator unit loading was determined for the following scenarios, with IIS demand ranging from peak to extreme light conditions:

- LIL frequency controller out-of-service
  - ML frequency controller in-service
  - ML frequency control out-of-service
- LIL frequency controller in- service
  - ML frequency controller in-service
  - ML frequency control out-of-service

7.7.1 LIL Frequency controller out-of-service

With the LIL frequency controller out-of-service, the maximum generator unit loading is determined mainly by the status of the ML frequency controller. The IIS demand level has a much smaller impact.

- **With the ML frequency controller in-service**, the maximum generator unit loading ranges from 157 MW to 165 MW.
- **With the ML frequency controller out-of-service,** the maximum generator unit loading ranges from 25 to 36 MW.

The maximum generator unit loading with the LIL frequency controller is out-of-service is summarized in Table 7-11. These tables should be used to define the limitations around the amount of frequency response that can be provided to Nova Scotia by the ML frequency controller.

Table 7-11. Maximum generator unit loading – LIL F/C out of service

LIL F/C Out-of-Service			
Maximum Generator Unit Loading			
Demand (MW)	Generation (MW)	Max Gen loading (MW)	Min frequency (Hz)
ML F/C Active (150 MW)			
2014	1336	165	59.1
1900	1244	165	59.1
1749	1115	165	59.1
1502	929	165	59.1
1243	758	165	59.1
1002	597	159	59.1
740	586	158	59.1
435	548	157	59.1
ML F/C inactive (0 MW)			
2014	1336	28	59.1
1900	1244	30	59.1
1749	1115	29	59.1
1502	929	36	59.1
1243	758	30	59.1
1002	597	25	59.1
742	438	28	59.1
423	434	31	59.1

7.7.2 LIL Frequency controller in-service

With the LIL frequency controller in-service, the maximum generator unit loading is determined mainly by:

- the status of the ML frequency controller
- LIL reserve[29]

The IIS demand level has a small impact, with the maximum generator unit loading being slightly less at lower demand than higher demand.

The maximum generator unit loading with the LIL frequency controller is in-service is summarized in Table 7-12 for LIL reserve starting from 100 MW up to 350 MW (450 MW for lighter demand cases) in steps of 50 MW.

[29] The amount the LIL can increase up to its capacity (or limit) when providing frequency support.

Table 7-12. Maximum generator unit loading – LIL F/C in service

LIL Reserve (MW)	LIL F/C In-Service					
	ML F/C Inactive			ML F/C Active		
	Max Gen loading (MW)	Min frequency (Hz)	Additional MW Beyond LIL reserve (MW)	Max Gen loading (MW)	Min frequency (Hz)	Additional MW Beyond LIL reserve (MW)
	2000 MW Demand			2000 MW Demand		
100	122	59.1	22	255	59.1	155
150	170	59.1	20	296	59.1	146
200	215	59.1	15	331	59.1	131
250	250	59.1	0	371	59.1	121
300	280	59.1	-20	411	59.1	111
350	319	59.1	-31	434	59.1	84
	1750 MW Demand			1750 MW Demand		
100	120	59.1	20	250	59.1	150
150	166	59.1	16	290	59.1	140
200	210	59.1	10	333	59.1	133
250	240	59.1	-10	374	59.1	124
300	277	59.1	-23	414	59.1	114
350	323	59.1	-27	436	59.1	86
	1500 MW Demand			1500 MW Demand		
100	113	59.1	13	245	59.1	145
120	136	59.1	16	260	59.1	140
150	158	59.1	8	285	59.1	135
200	201	59.1	1	320	59.1	120
250	235	59.1	-15	365	59.1	115
300	277	59.1	-23	404	59.1	104
350	315	59.1	-35	430	59.1	80
	1250 MW Demand			1250 MW Demand		
100	103	59.1	3	225	59.1	125
150	145	59.1	-5	263	59.1	113
200	189	59.1	-11	310	59.1	110
250	222	59.1	-28	345	59.1	95
300	266	59.1	-34	385	59.1	85
350	310	59.1	-40	415	59.1	65
	1000 MW Demand			1000 MW Demand		
100	102	59.1	2	210	59.1	110
150	142	59.1	-8	244	59.1	94
200	166	59.1	-34	280	59.1	80
250	220	59.1	-30	330	59.1	80
300	248	59.1	-52	363	59.1	63
350	287	59.1	-63	385	59.1	35
400	311	59.1	-89	400	59.1	0
450	348	59.1	-102	440	59.1	-10
	750 MW Demand			750 MW Demand		
100	97	59.1	-3	205	59.1	105
150	132	59.1	-18	230	59.13	80
200	166	59.1	-34	260	59.1	60
250	210	59.1	-40	310	59.1	60
300	232	59.1	-68	338	59.1	38
350	272	59.1	-78	358	59.1	8
400	295	59.1	-105	383	59.1	-17
450	325	59.1	-125	410	59.1	-40
	450 MW Demand			450 MW Demand		
200	85	59.5	-115	85	59.5	-115
300	120	59.43	-180	120	59.46	-180
500	230	59.34	-270	230	59.26	-270
660	310	59.14	-350	310	59.26	-350

Min gen is limiting - not at max generator unit loading

APPENDIX 1

FINAL UFLS SCHEME

/***
/ NLH Underfrequency Load Shedding
/***

PSSE Bus #	Frequency (Hz)	UFLS (MW)
195432,'L	58.6	6.6
195404,'L	58.4	4.8
195407,'L	58.2	5
195435,'L	58.1	2.6
195436,'L	58.1	3
195437,'L	58.1	7.7
		29.7 MW

/***
/ NP Underfrequency Load Shedding
/***

/ 58.8 Hz block

PSSE Bus #	Frequency (Hz)	Total MW	% for UFLS	UFLS (MW)	
196574,	58.8	46.3	0.21	9.723	
196574,	58.8	46.3	0.16	7.408	
196572,	58.8	47.2	0.1	4.72	
196572,	58.8	47.2	0.08	3.776	
196572,	58.8	47.2	0.08	3.776	
196571,	58.8	27.1	0.21	5.691	
196571,	58.8	27.1	0.19	5.149	
196567,	58.8	54.5	0.12	6.54	
196563,	58.8	64.3	0.13	8.359	
196563,	58.8	64.3	0.05	3.215	
196561,	58.8	62.8	0.21	13.188	
196560,	58.8	26.4	0.29	7.656	
196556,	58.8	59.7	0.08	4.776	
196540,	58.8	12.6	0.19	2.394	
196517,	58.8	7.1	0.27	1.917	
196500,	58.8	24.4	0.33	8.052	
196221,	58.8	16.4	0.39	6.396	
195655,	58.8	95.3	0.11	10.483	
195635,	58.8	59.6	0.12	7.152	
195169,	58.8	13.5	0.43	5.805	
195167,	58.8	24.5	0.25	6.125	
195167,	58.8	24.5	0.15	3.675	
195144,	58.8	67.2	0.08	5.376	
195144,	58.8	67.2	0.03	2.016	
195127,	58.8	24	0.15	3.6	
195127,	58.8	24	0.16	3.84	
195126,	58.8	45.5	0.19	8.645	
195120,	58.8	10.3	0.19	1.957	
				159.453	MW @58.8 Hz

/ 58.6 Hz block

PSSE Bus #	Frequency (Hz)	Total MW	% for UFLS	UFLS (MW)	
196576,	58.6	15.2	0.26	3.952	
196572,	58.6	47.2	0.09	4.248	
196572,	58.6	47.2	0.1	4.72	
196572,	58.6	47.2	0.21	9.912	
196570,	58.6	45.8	0.15	6.87	
196570,	58.6	45.8	0.16	7.328	
196570,	58.6	45.8	0.13	5.954	
196568,	58.6	51.9	0.1	5.19	
196568,	58.6	51.9	0.08	4.152	
196566,	58.6	27.7	0.14	3.878	
196565,	58.6	61	0.21	12.81	
196565,	58.6	61	0.23	14.03	
196565,	58.6	61	0.17	10.37	
196564,	58.6	28.5	0.39	11.115	
196562,	58.6	30.7	0.23	7.061	
196556,	58.6	59.7	0.06	3.582	
196556,	58.6	59.7	0.11	6.567	
196556,	58.6	59.7	0.03	1.791	
196556,	58.6	59.7	0.08	4.776	
196546,	58.6	38.5	0.02	0.77	
196207,	58.6	3.5	0.85	2.975	
195173,	58.6	15.5	0.26	4.03	
195169,	58.6	13.5	0.46	6.21	
195167,	58.6	24.5	0.11	2.695	
195157,	58.6	20.3	0.27	5.481	
195157,	58.6	20.3	0.11	2.233	
195155,	58.6	6.2	0.51	3.162	
195144,	58.6	67.2	0.05	3.36	
195134,	58.6	21.2	0.31	6.572	
				165.794	MW @58.6 Hz

/ 58.4 Hz block

PSSE Bus #	Frequency (Hz)	Total MW	% for UFLS	UFLS (MW)	
196573,	58.4	67.3	0.14	9.422	
196570,	58.4	45.8	0.22	10.076	
196570,	58.4	45.8	0.14	6.412	
196568,	58.4	51.9	0.06	3.114	
196568,	58.4	51.9	0.07	3.633	
196567,	58.4	54.5	0.05	2.725	
196567,	58.4	54.5	0.19	10.355	
196566,	58.4	27.7	0.01	0.277	
196564,	58.4	28.5	0.36	10.26	
196564,	58.4	28.5	0.25	7.125	
196562,	58.4	30.7	0.15	4.605	
196561,	58.4	62.8	0.22	13.816	
196556,	58.4	59.7	0.07	4.179	
196556,	58.4	59.7	0.08	4.776	
196546,	58.4	38.5	0.05	1.925	
196520,	58.4	3	0.86	2.58	
196500,	58.4	24.4	0.34	8.296	
196500,	58.4	24.4	0.33	8.052	
195655,	58.4	95.3	0.05	4.765	
195655,	58.4	95.3	0.1	9.53	
195624,	58.4	102.4	0.06	6.144	
195624,	58.4	102.4	0.08	8.192	
195624,	58.4	102.4	0.05	5.12	
195157,	58.4	20.3	0.31	6.293	
195127,	58.4	24	0.18	4.32	
195126,	58.4	45.5	0.19	8.645	
195120,	58.4	10.3	0.05	0.515	
				165.152	MW @58.4 Hz

/ 58.2 Hz block

PSSE Bus #	Frequency (Hz)	Total MW	% for UFLS	UFLS (MW)	
196574,	58.2	46.3	0.25	11.575	
196574,	58.2	46.3	0.15	6.945	
196567,	58.2	54.5	0.05	2.725	
196567,	58.2	54.5	0.11	5.995	
196567,	58.2	54.5	0.12	6.54	
196566,	58.2	27.7	0.14	3.878	
196566,	58.2	27.7	0.16	4.432	
196563,	58.2	64.3	0.07	4.501	
196563,	58.2	64.3	0.09	5.787	
196562,	58.2	30.7	0.34	10.438	
196546,	58.2	38.5	0.15	5.775	
196546,	58.2	38.5	0.05	1.925	
196546,	58.2	38.5	0.12	4.62	
196517,	58.2	7.1	0.11	0.781	
196517,	58.2	7.1	0.36	2.556	
195655,	58.2	95.3	0.16	15.248	
195655,	58.2	95.3	0.17	16.201	
195624,	58.2	102.4	0.05	5.12	
195169,	58.2	13.6	0.11	1.496	
195134,	58.2	21.2	0.3	6.36	
195134,	58.2	21.2	0.23	4.876	
195132,	58.2	19.3	0.14	2.702	
195132,	58.2	19.3	0.12	2.316	
195130,	58.2	31.7	0.14	4.438	
195130,	58.2	31.7	0.25	7.925	
195126,	58.2	45.5	0.21	9.555	
195126,	58.2	45.5	0.19	8.645	
				163.355	MW @58.2 Hz

/ 58.1 Hz block

PSSE Bus #	Frequency (Hz)	Total MW	% for UFLS	UFLS (MW)	
196574,	58.1	46.3	0.19	8.797	
196573,	58.1	67.3	0.12	8.076	
196573,	58.1	67.3	0.11	7.403	
196573,	58.1	67.3	0.13	8.749	
196573,	58.1	67.3	0.12	8.076	
196571,	58.1	27.1	0.31	8.401	
196571,	58.1	27.1	0.18	4.878	
196571,	58.1	27.1	0.11	2.981	
196570,	58.1	45.8	0.2	9.16	
196568,	58.1	51.9	0.11	5.709	
196567,	58.1	54.5	0.04	2.18	
				74.41	MW @58.1 Hz

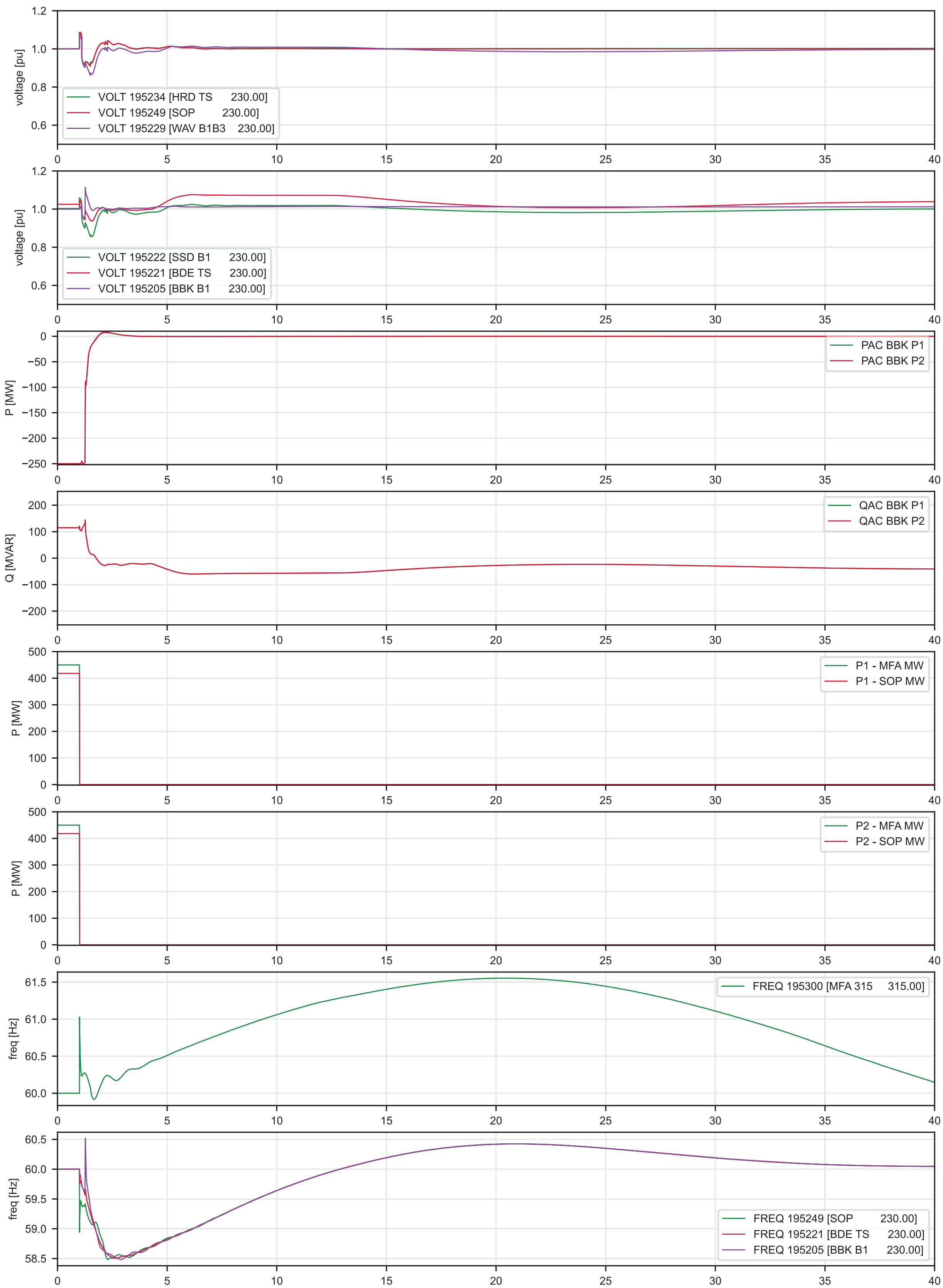
/ Back-up 57.7 Hz block

PSSE Bus #	Frequency (Hz)	Total MW	% for UFLS	UFLS (MW)	
196576,	57.7	15.2	0.67	10.184	
196573,	57.7	67.3	0.15	10.095	
196573,	57.7	67.3	0.1	6.73	
196572,	57.7	47.2	0.23	10.856	
196568,	57.7	51.9	0.08	4.152	
196568,	57.7	51.9	0.13	6.747	
196568,	57.7	51.9	0.15	7.785	
196568,	57.7	51.9	0.08	4.152	
196566,	57.7	27.7	0.2	5.54	
196566,	57.7	27.7	0.17	4.709	
196563,	57.7	64.3	0.09	5.787	
196563,	57.7	64.3	0.16	10.288	
196561,	57.7	62.8	0.21	13.188	
196556,	57.7	59.7	0.09	5.373	
				105.586	MW @57.7 Hz

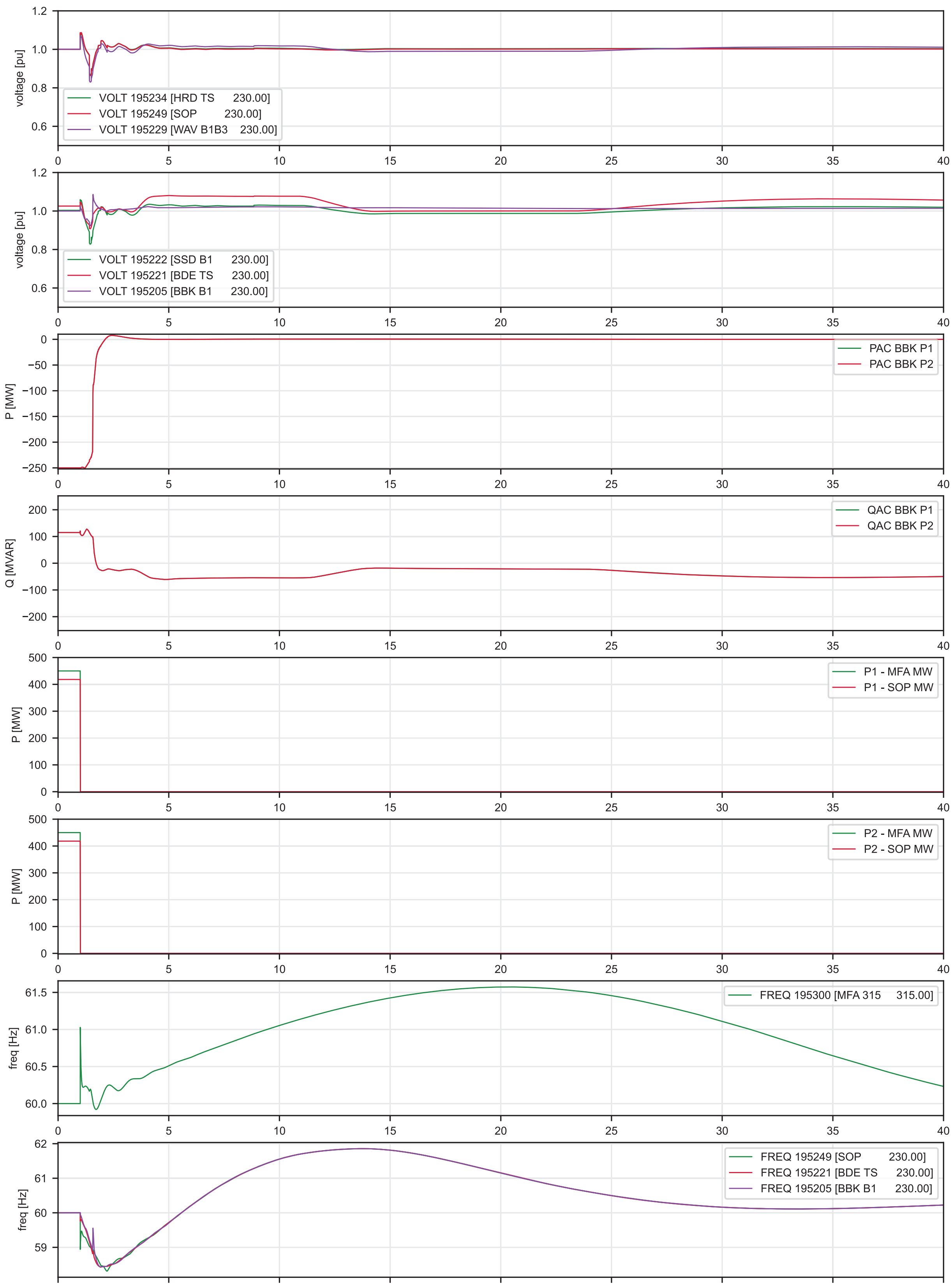
APPENDIX 2

PLOTS – LIL BIPOLE TRIP AT LIL TRANSFER LIMITS

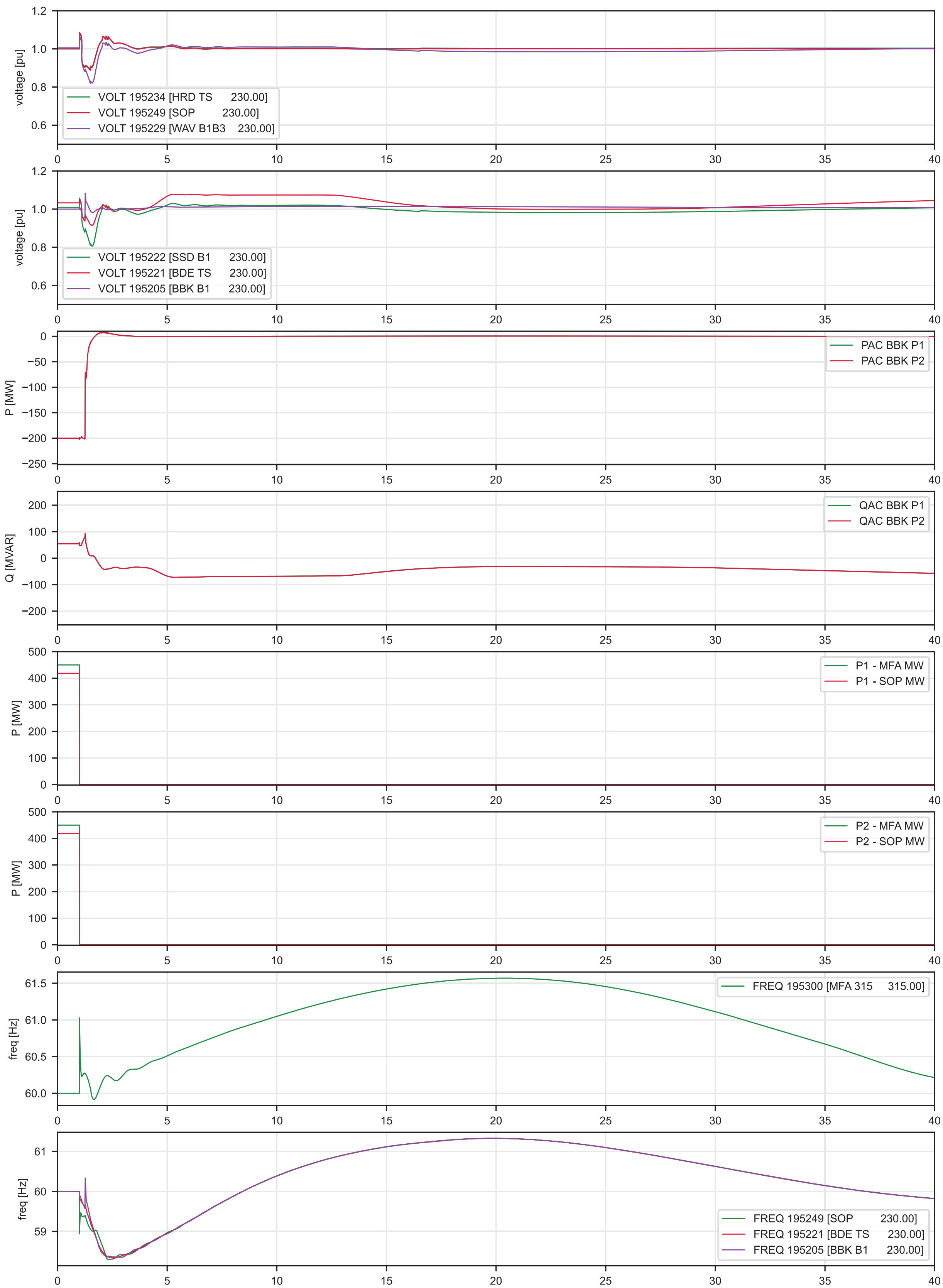
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 2000 MW - ML 500 MW - No LIL restarts enabled



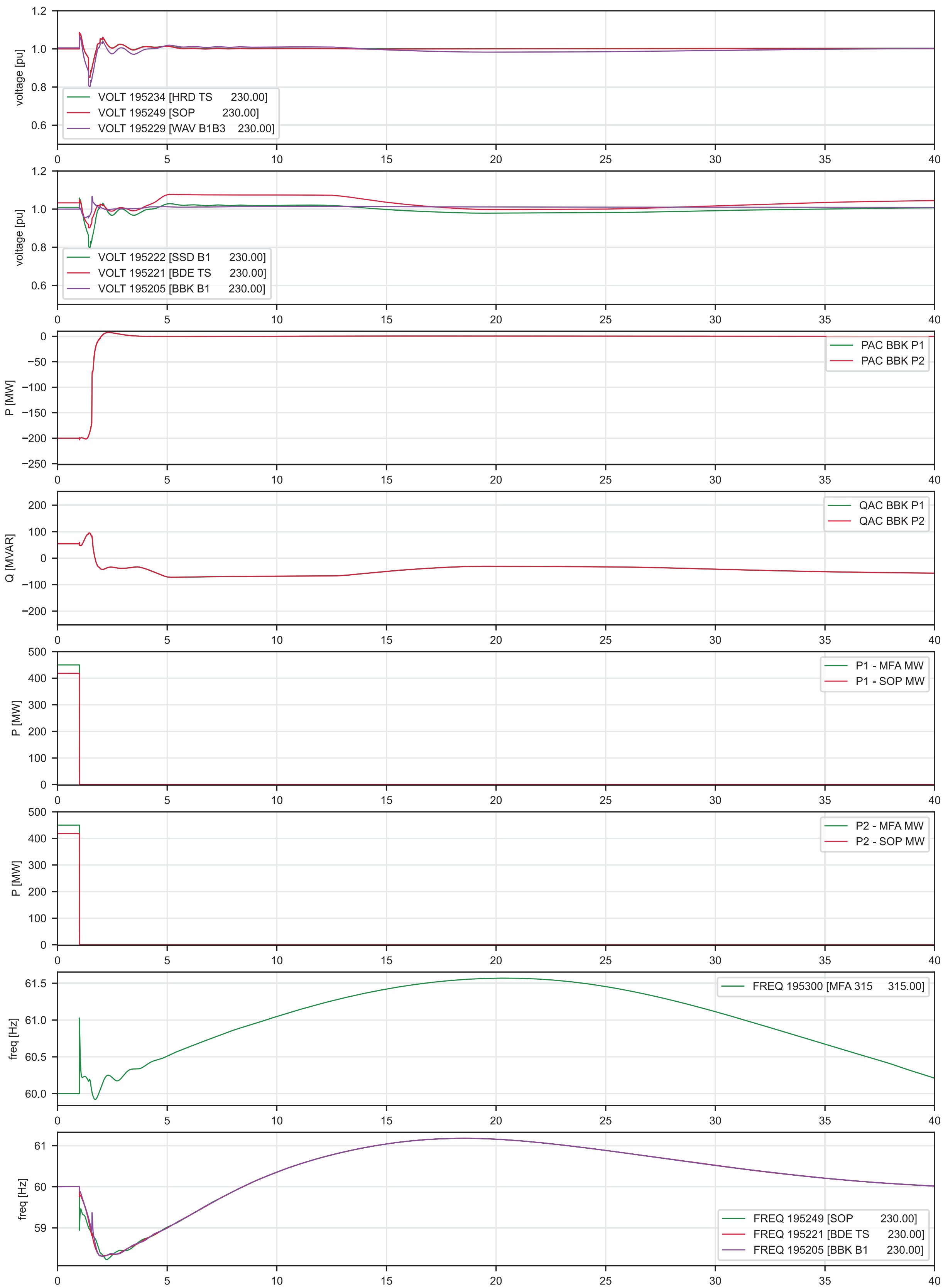
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 2000 MW - ML 500 MW - One LIL restart enabled



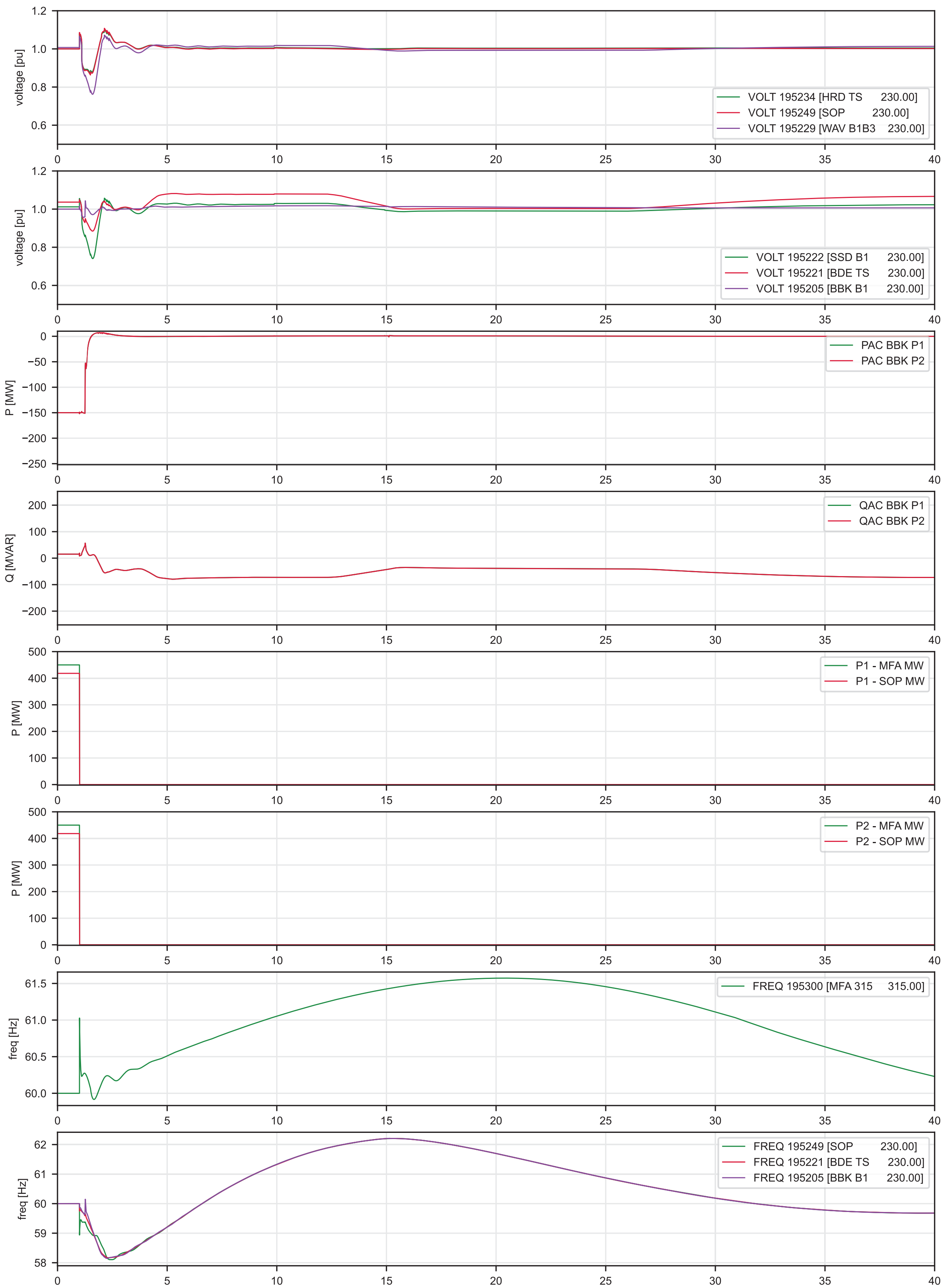
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 2000 MW - ML 400 MW - No LIL restarts enabled



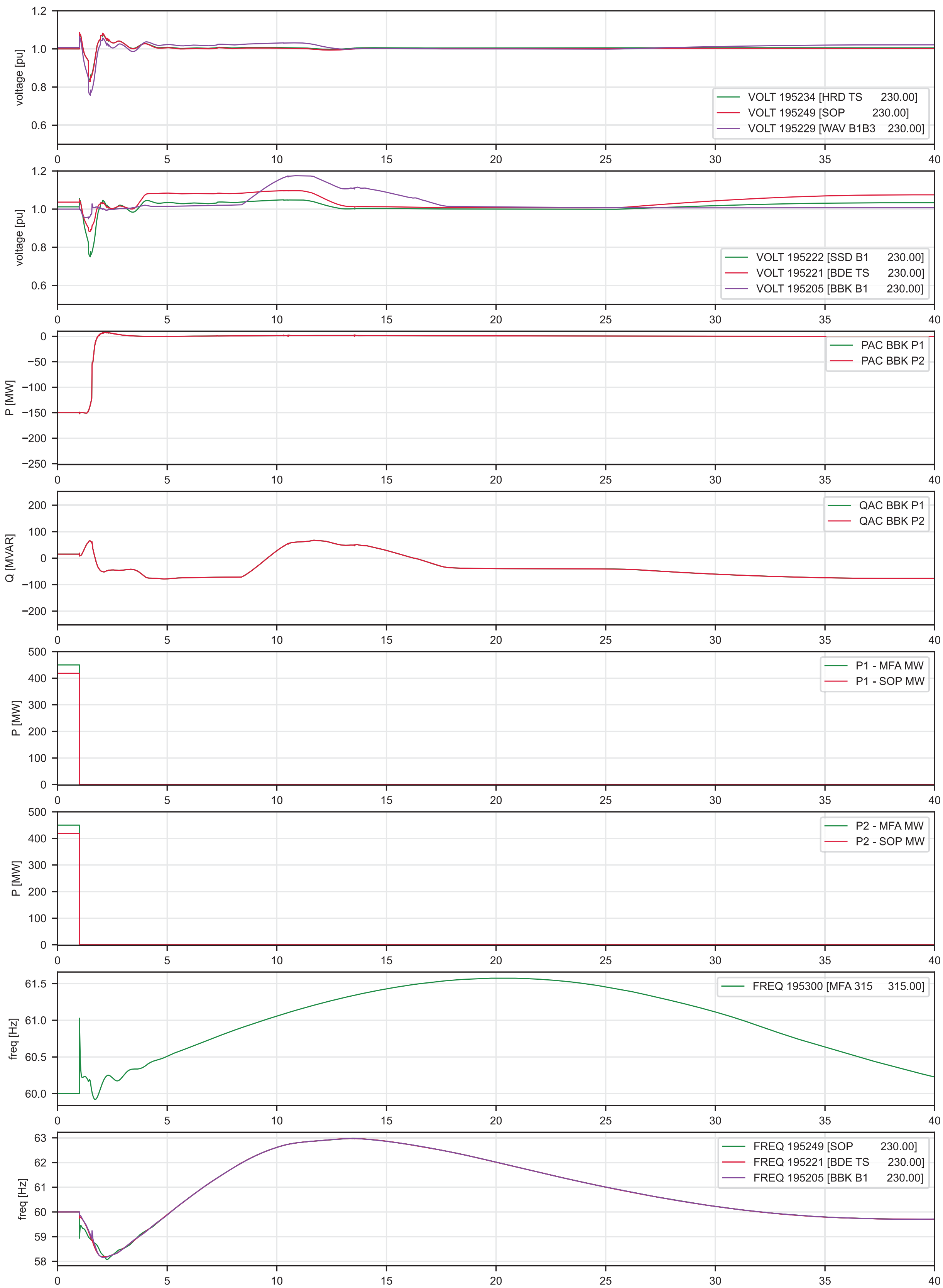
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 2000 MW - ML 400 MW - One LIL restart enabled



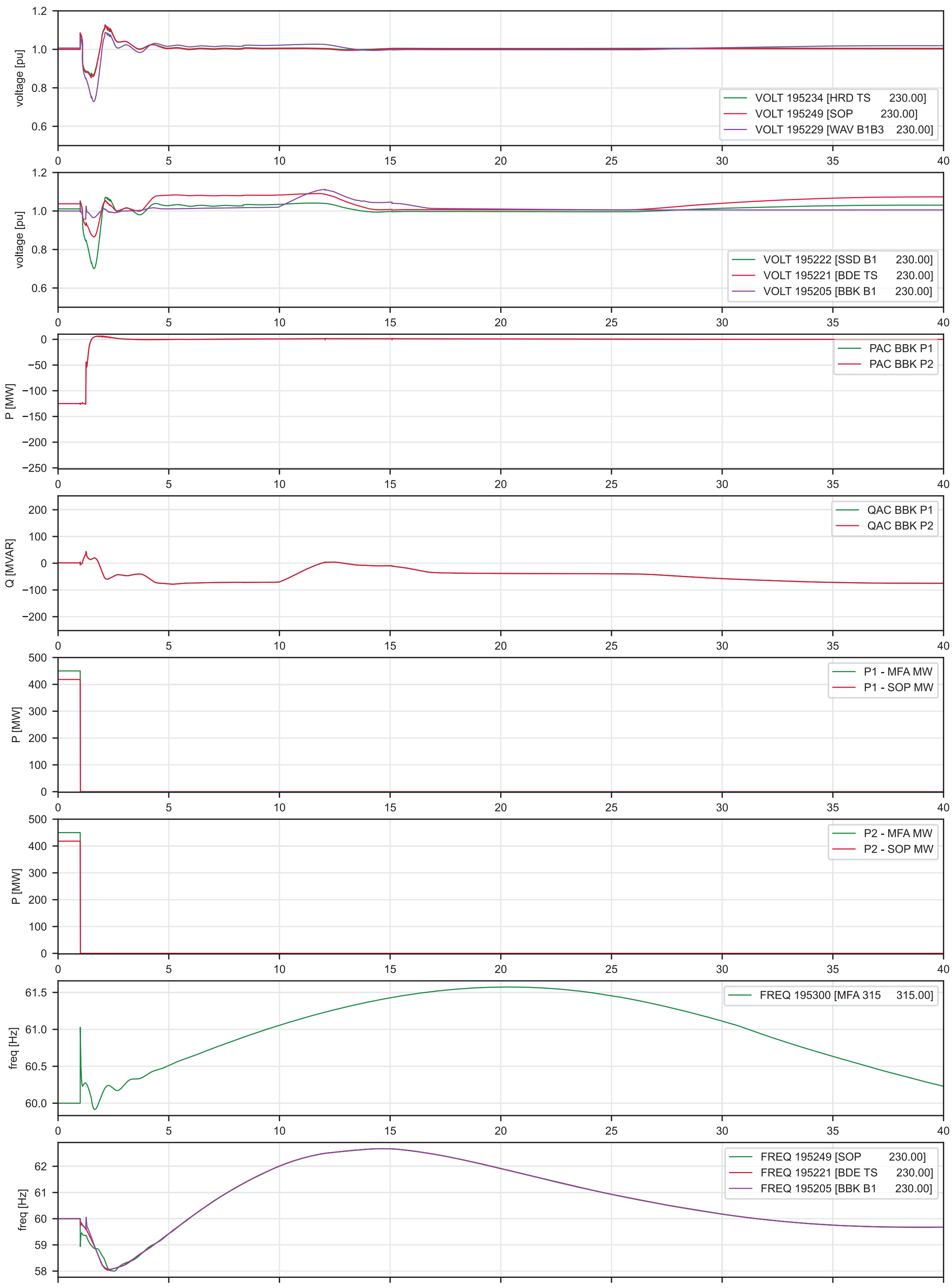
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 2000 MW - ML 300 MW - No LIL restarts enabled



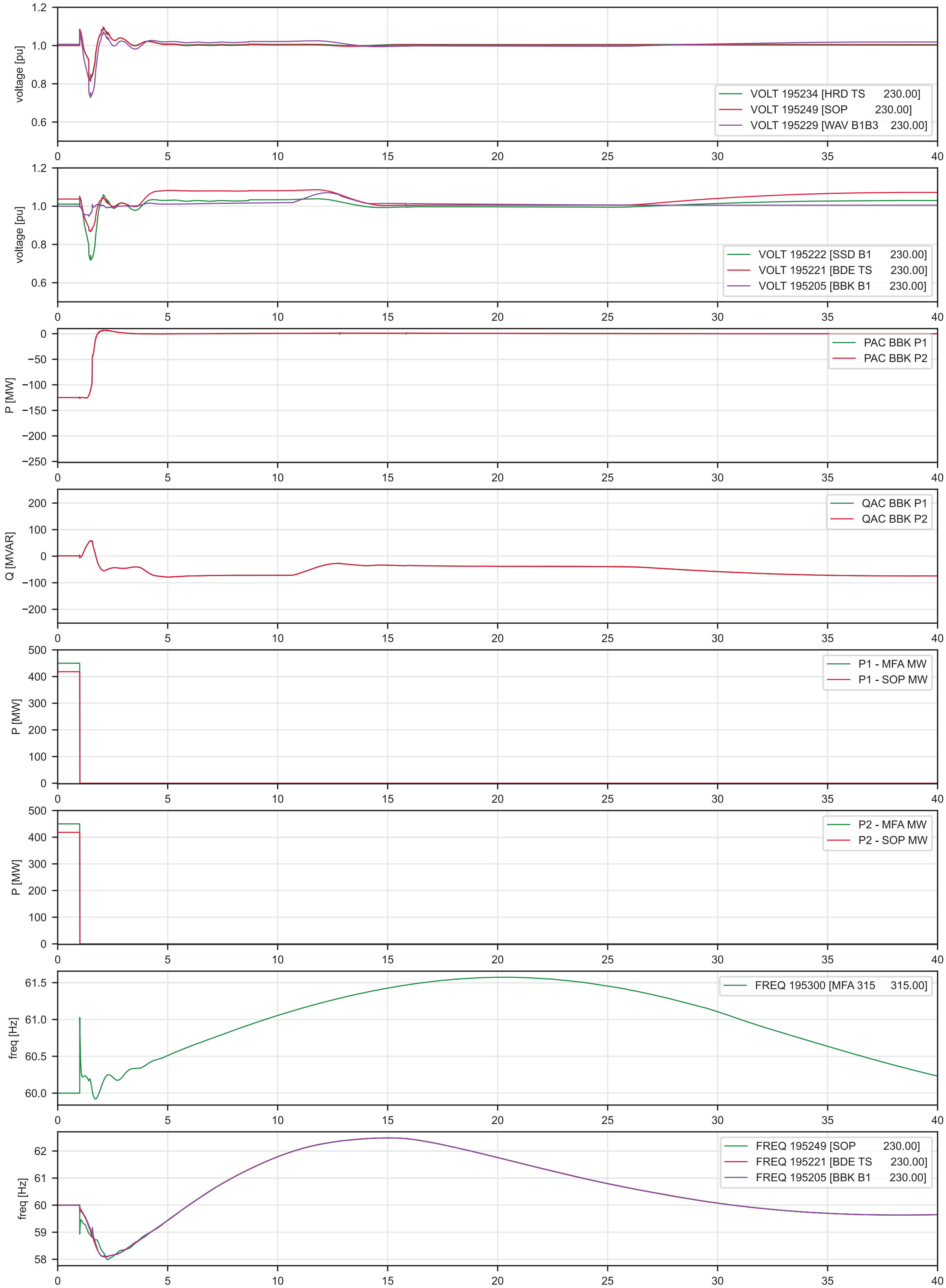
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 2000 MW - ML 300 MW - One LIL restart enabled



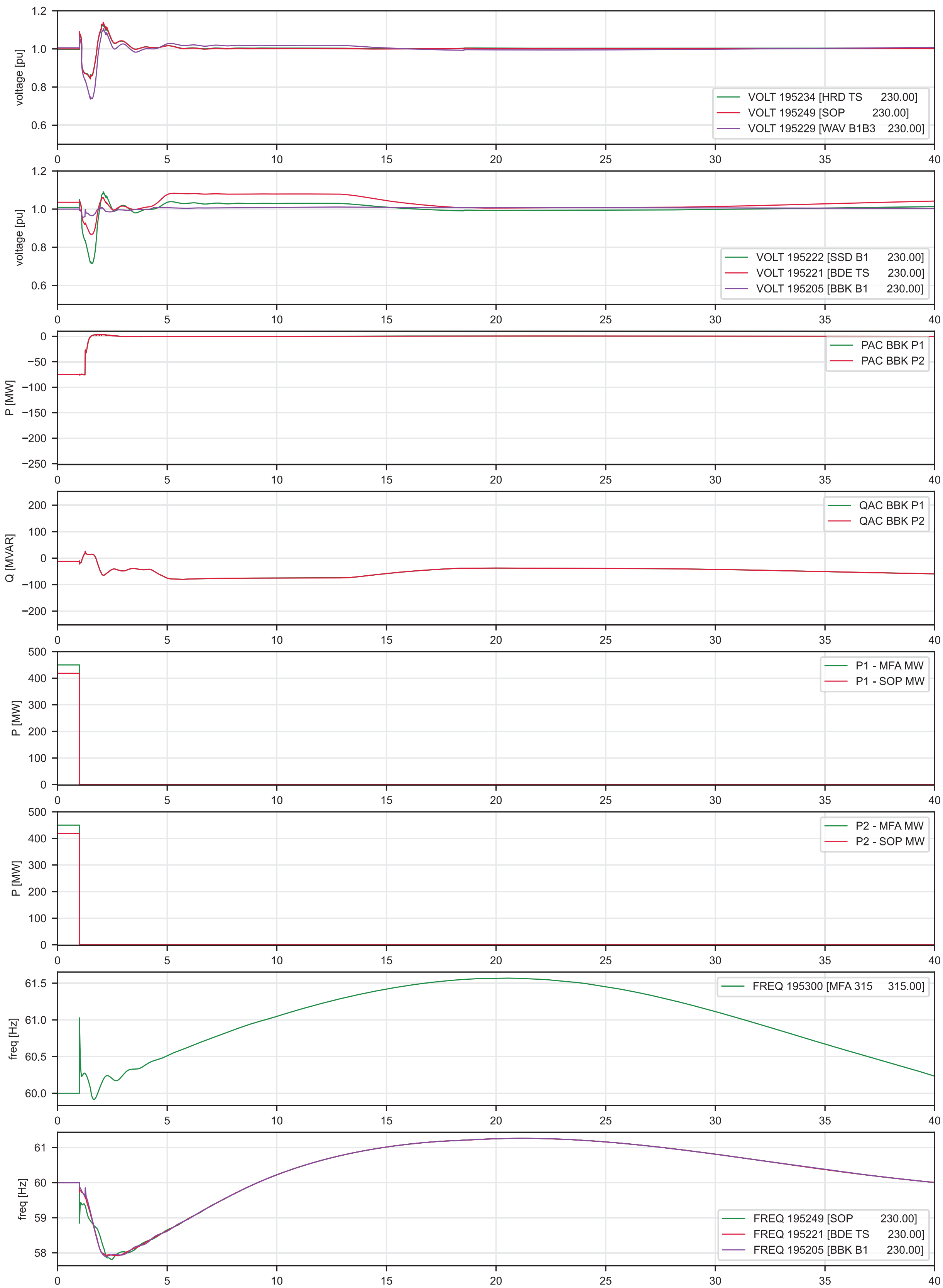
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 2000 MW - ML 250 MW - No LIL restarts enabled



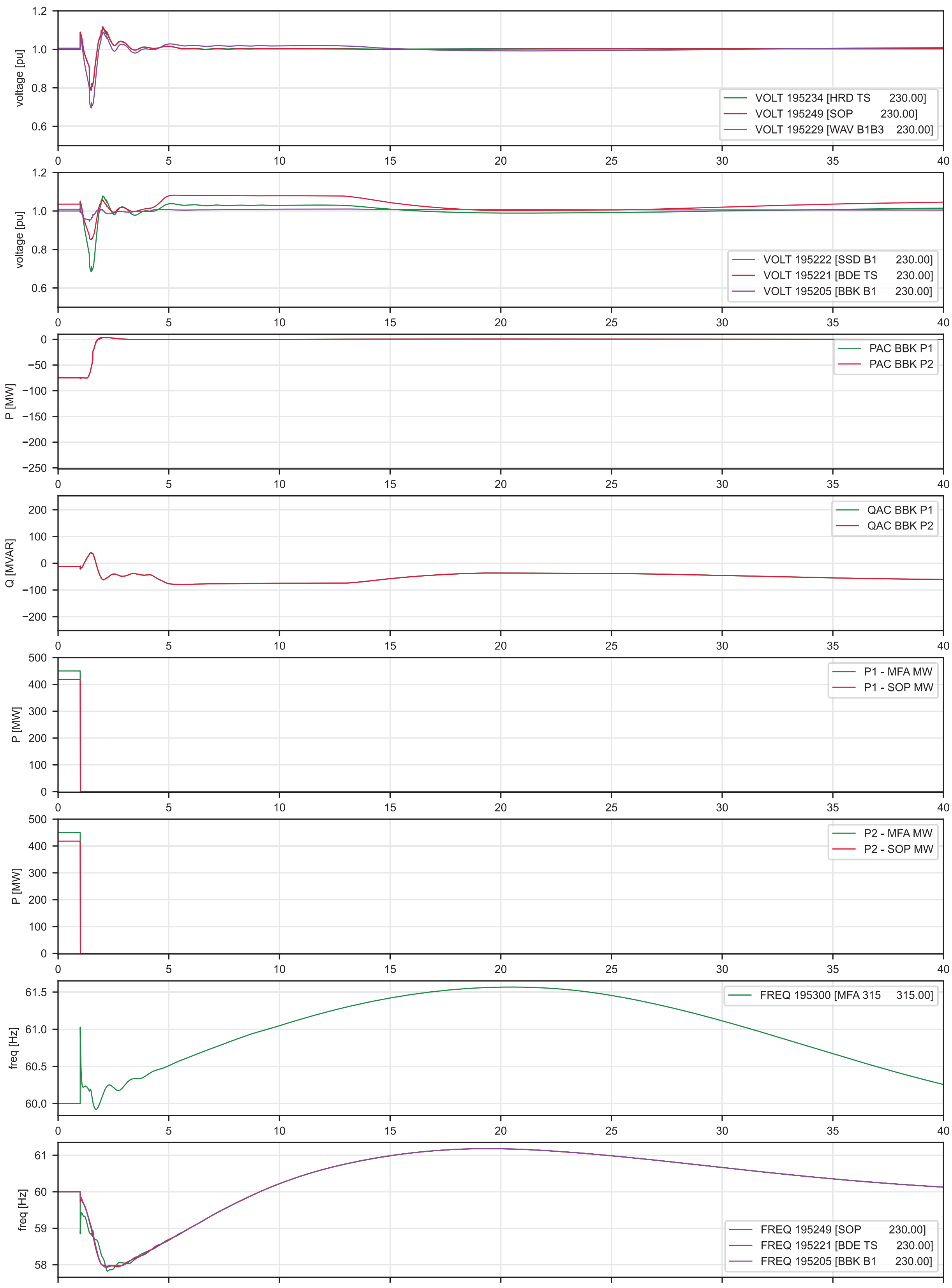
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 2000 MW - ML 250 MW - One LIL restart enabled



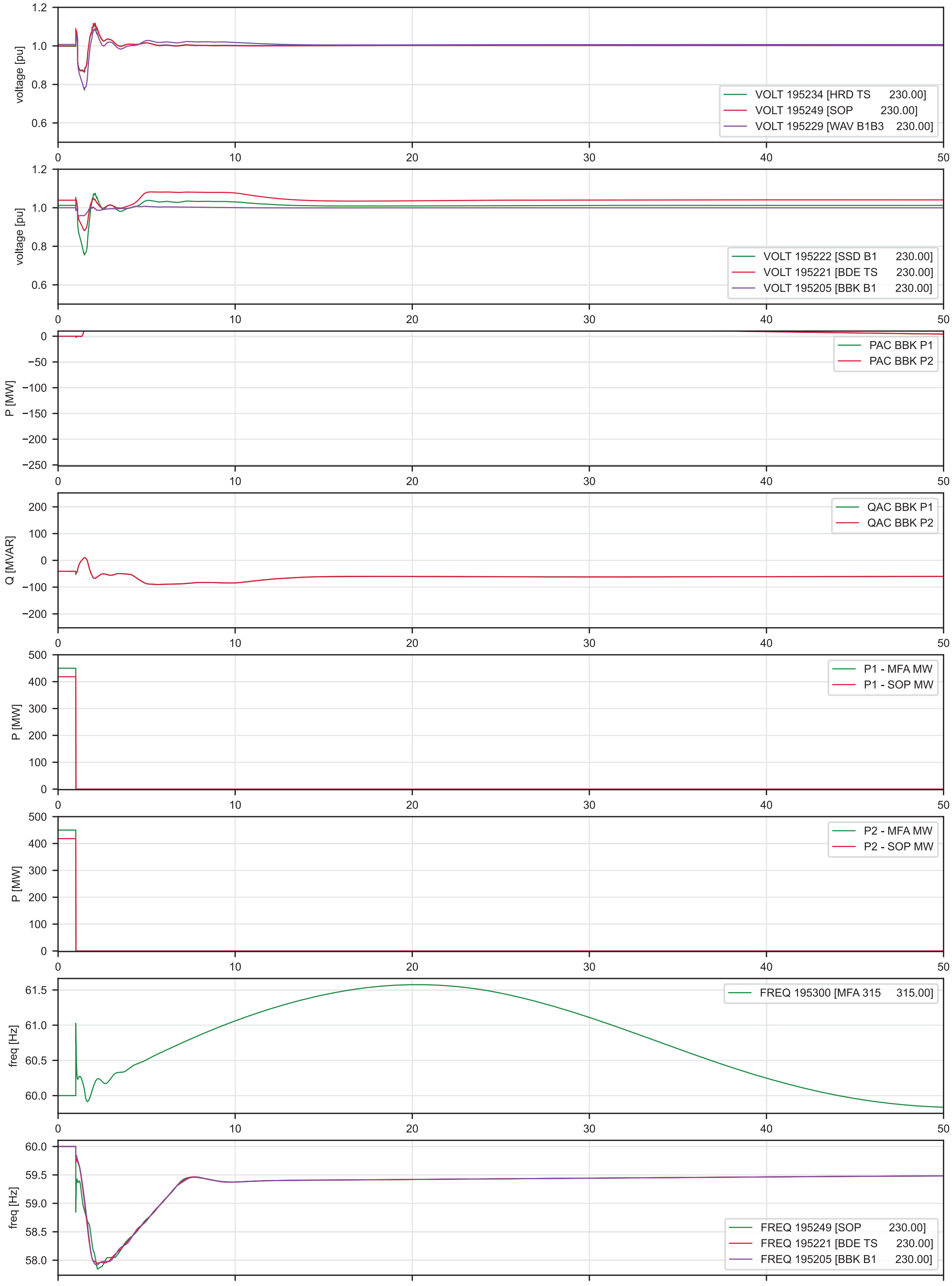
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 2000 MW - ML 150 MW - No LIL restarts enabled



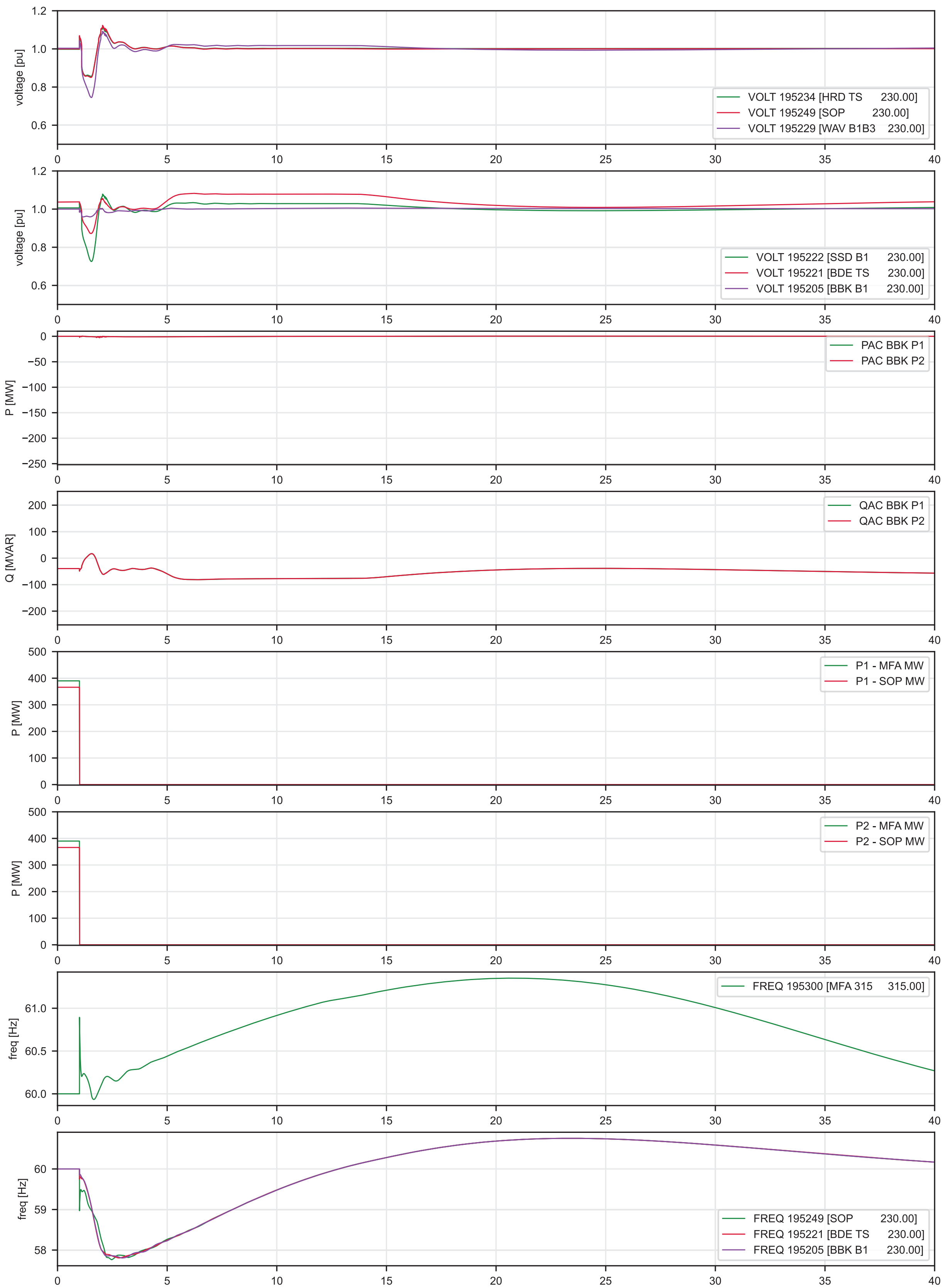
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 2000 MW - ML 150 MW - One LIL restart enabled



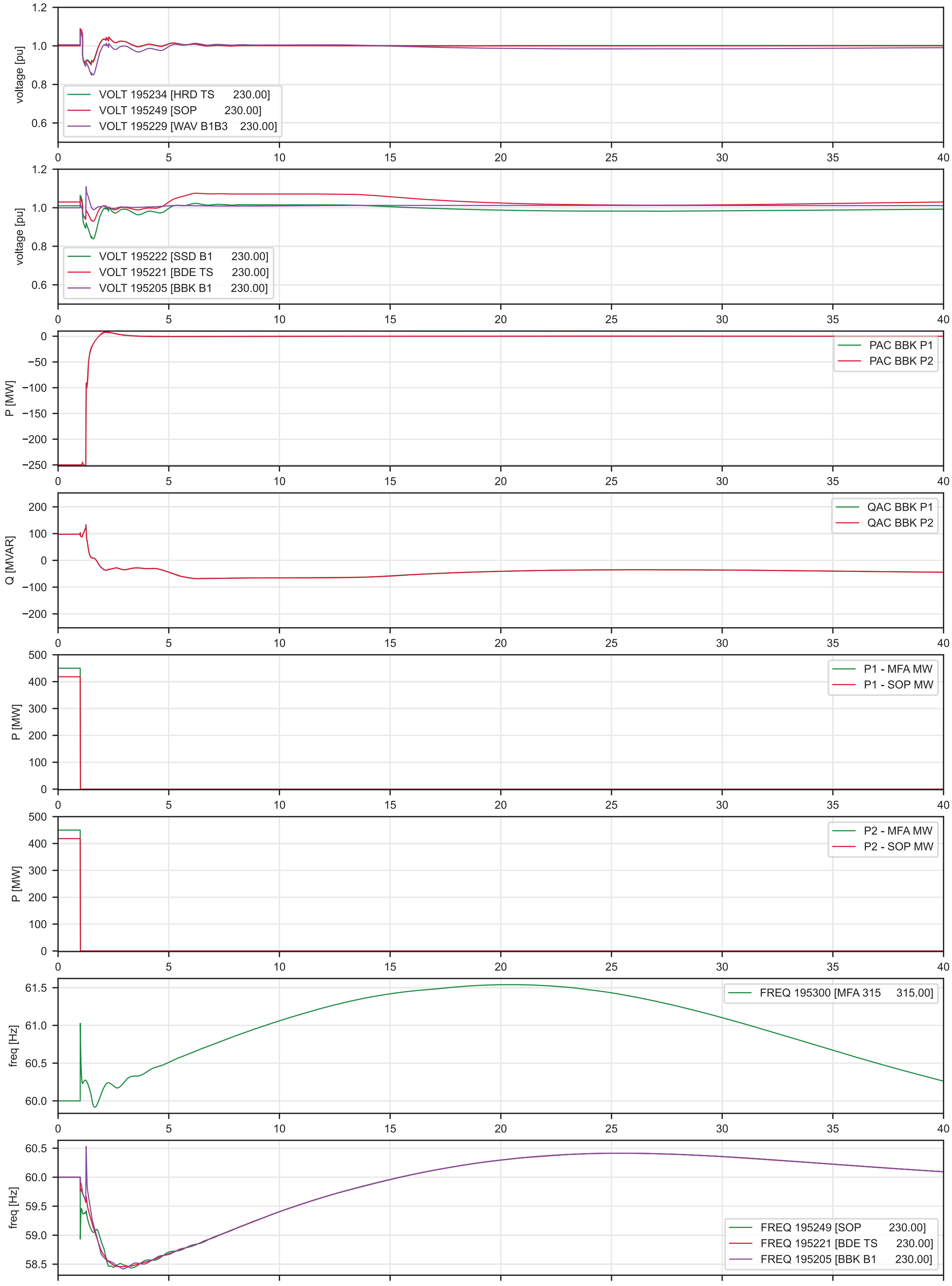
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 2000 MW - ML 0 MW / ML Runbacks Inactive / ML F/C Active - No LIL restarts enabled



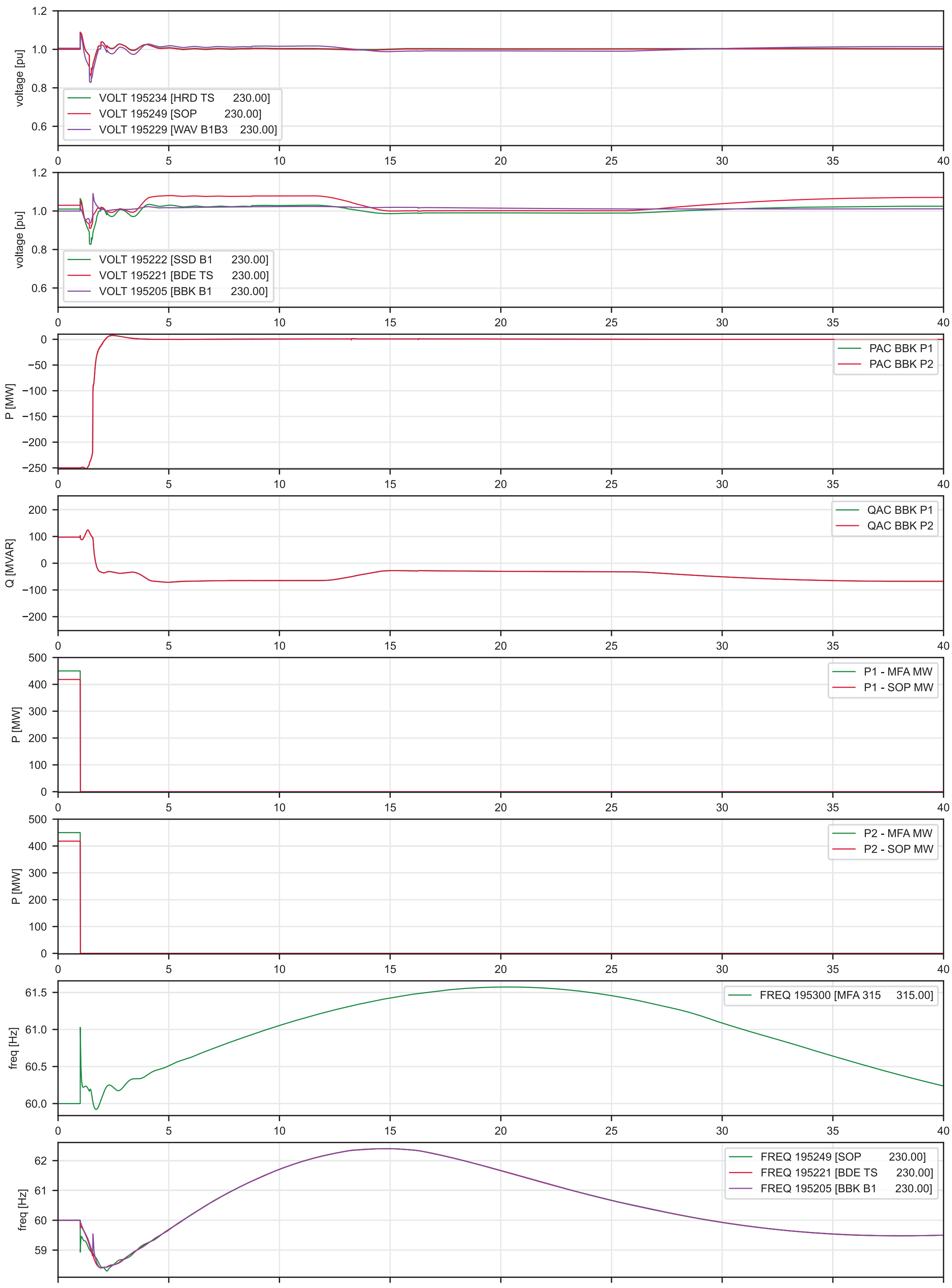
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 2000 MW - ML 0 MW / ML Runbacks Inactive / ML F/C Inactive - No LIL restarts enabled



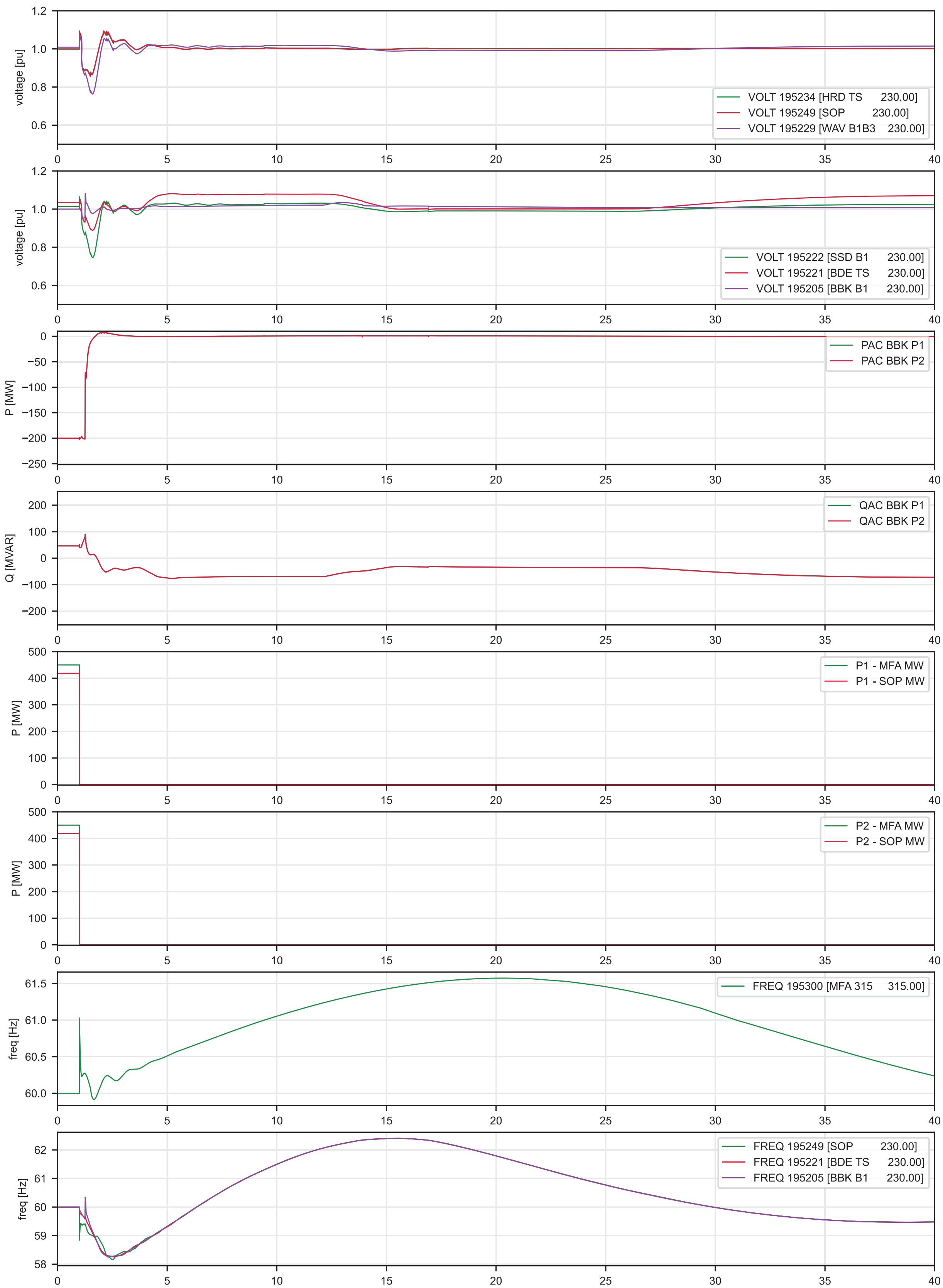
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1900 MW - ML 500 MW - No LIL restarts enabled



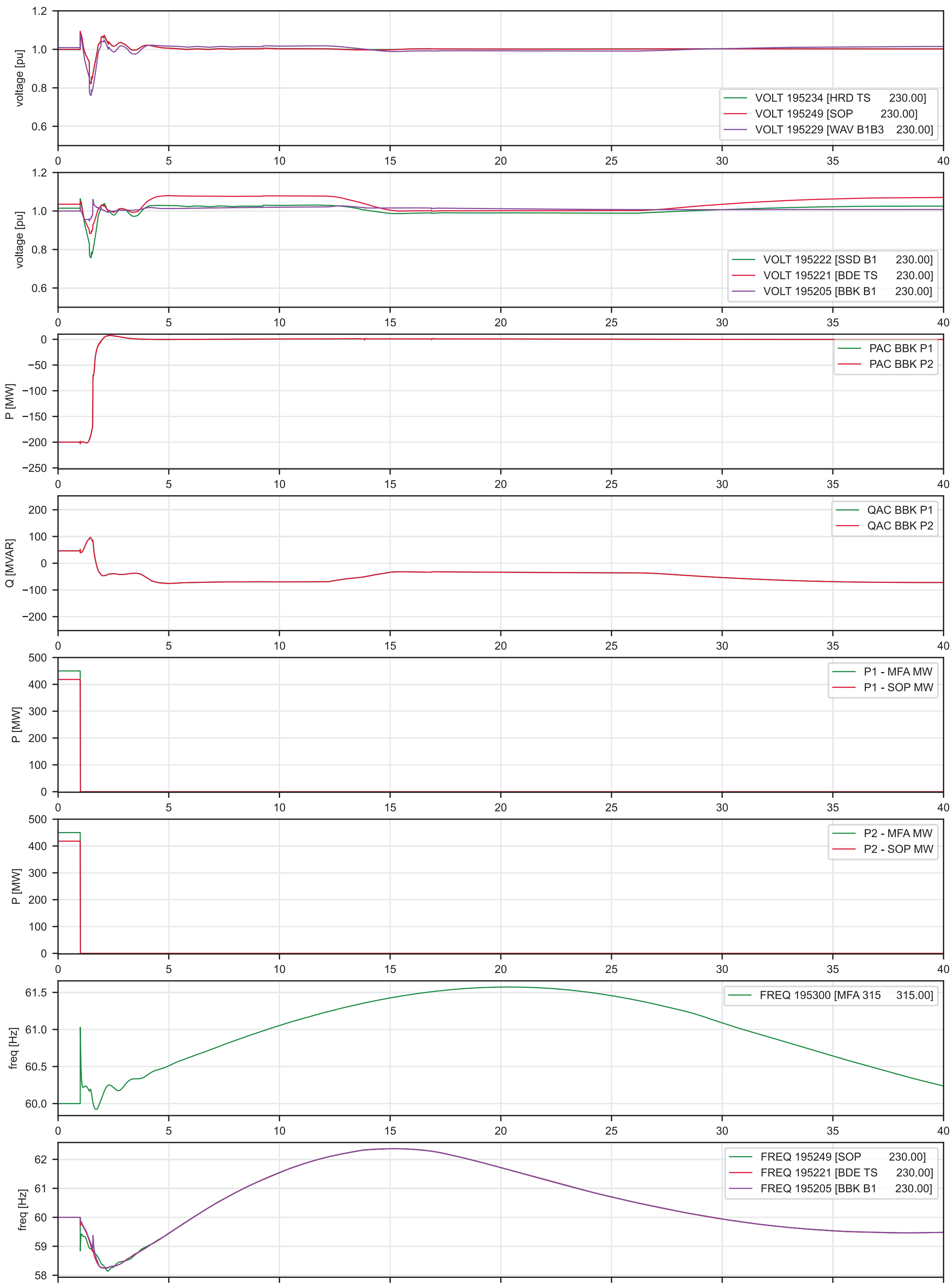
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1900 MW - ML 500 MW - One LIL restart enabled



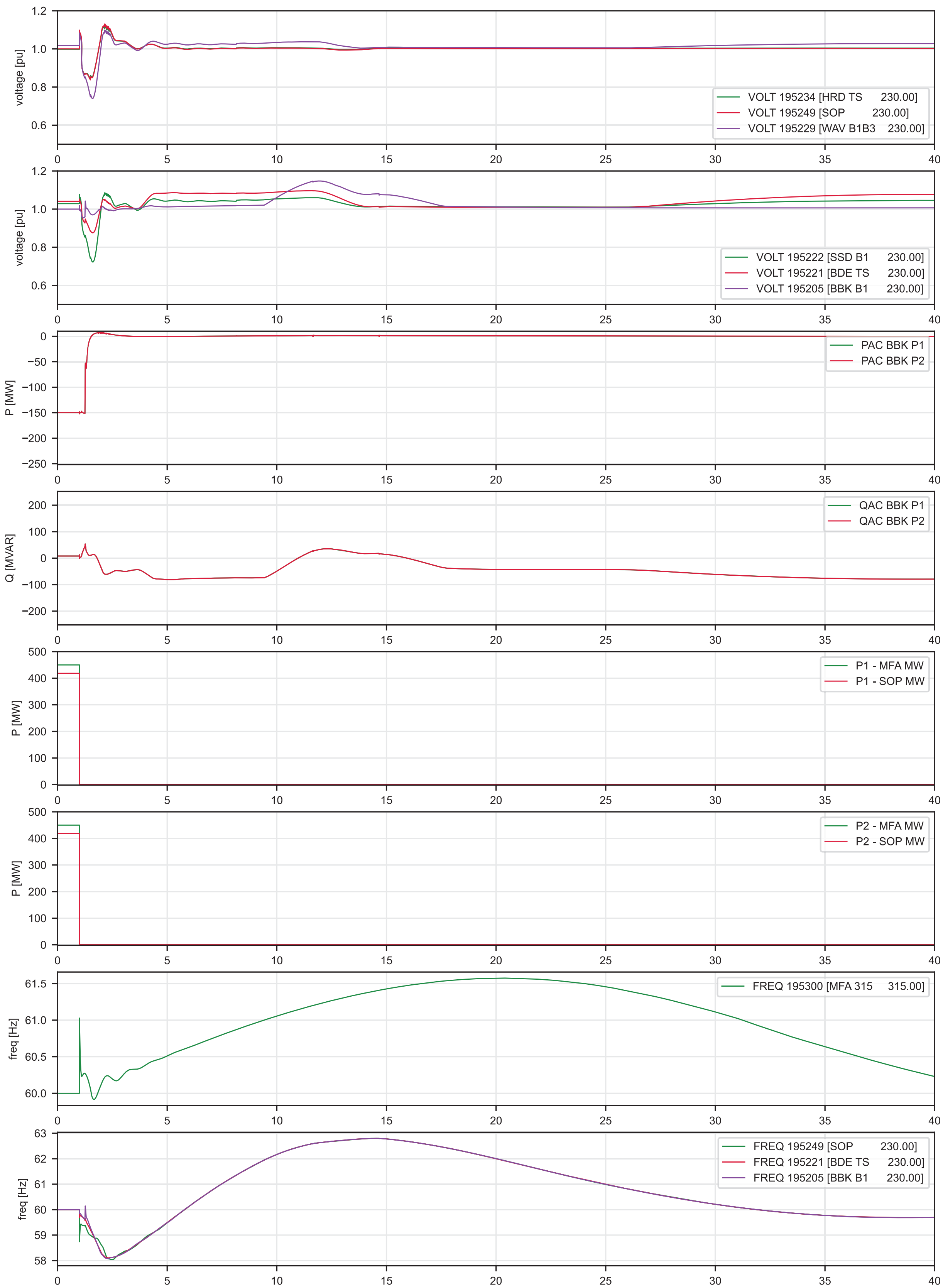
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1900 MW - ML 400 MW - No LIL restarts enabled



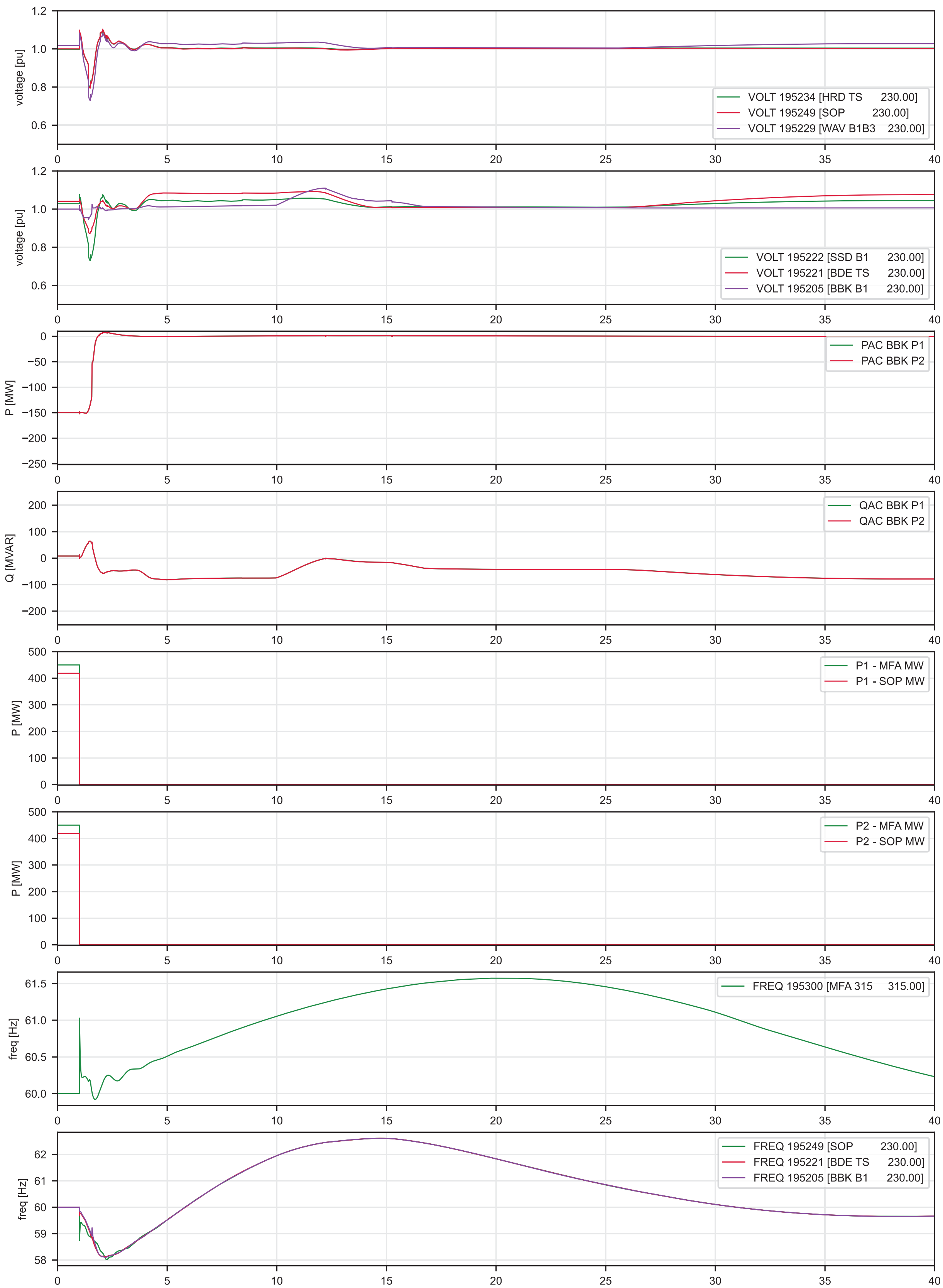
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1900 MW - ML 400 MW - One LIL restart enabled



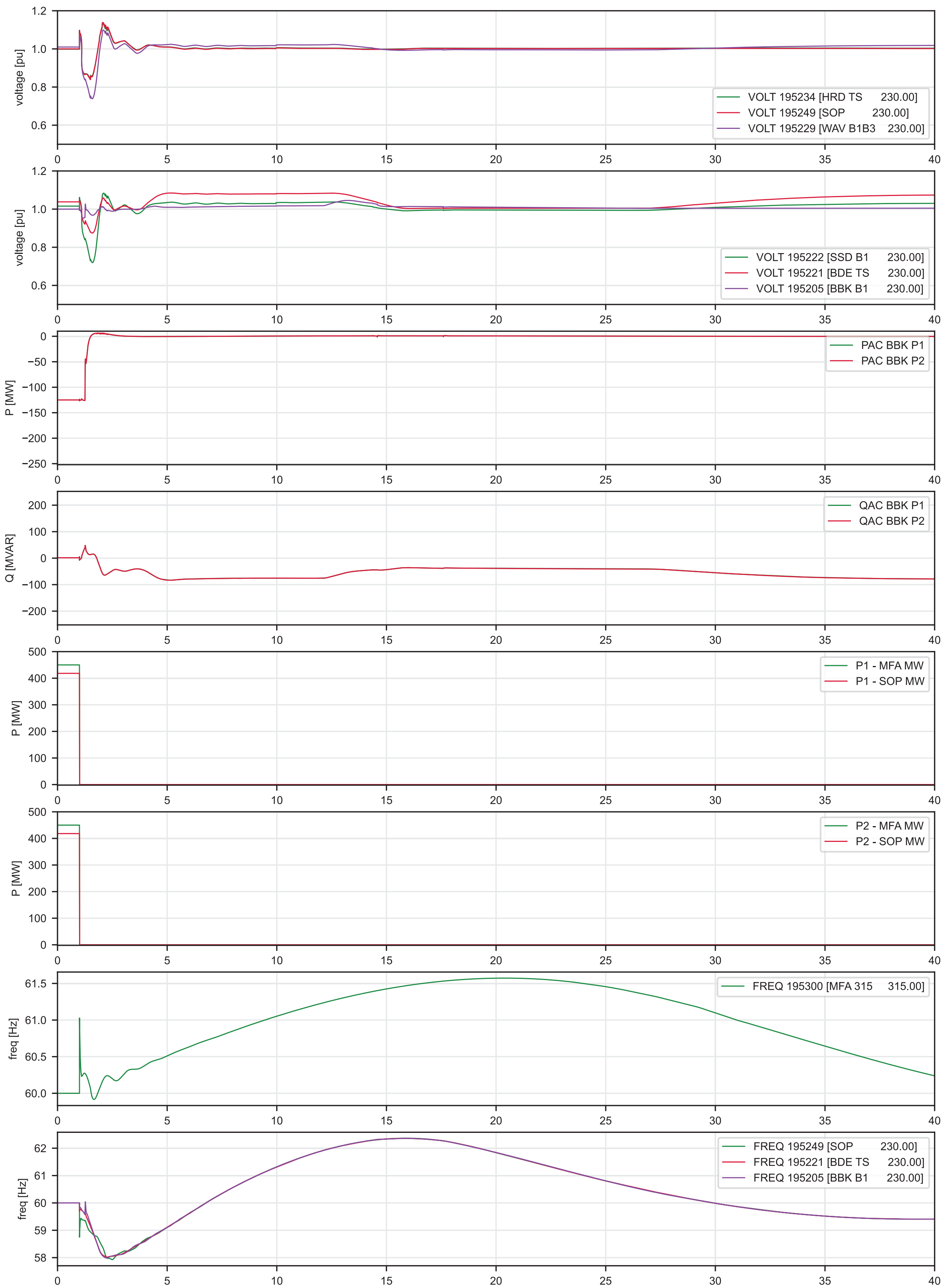
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1900 MW - ML 300 MW - No LIL restarts enabled



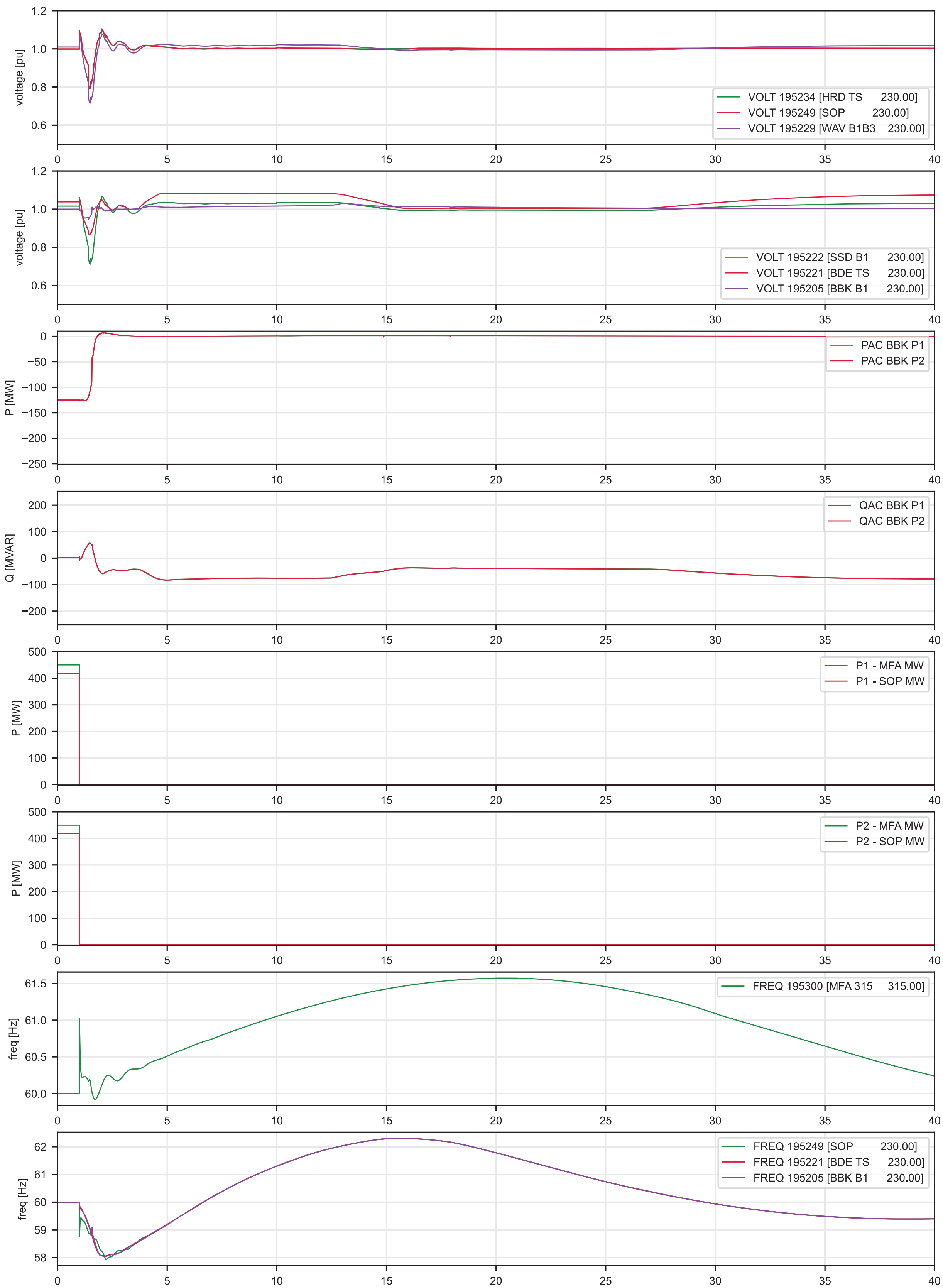
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1900 MW - ML 300 MW - One LIL restart enabled



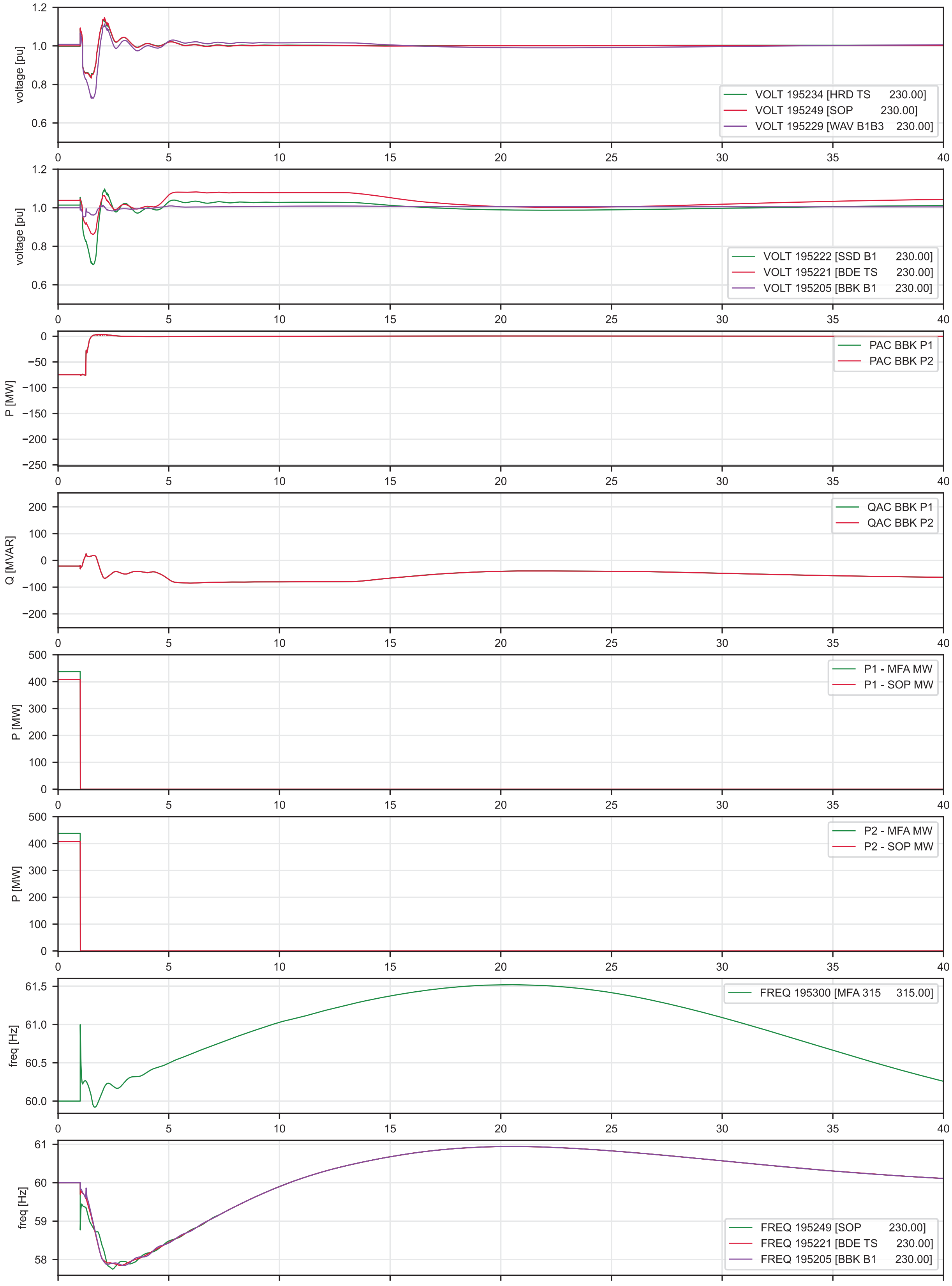
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1900 MW - ML 250 MW - No LIL restarts enabled

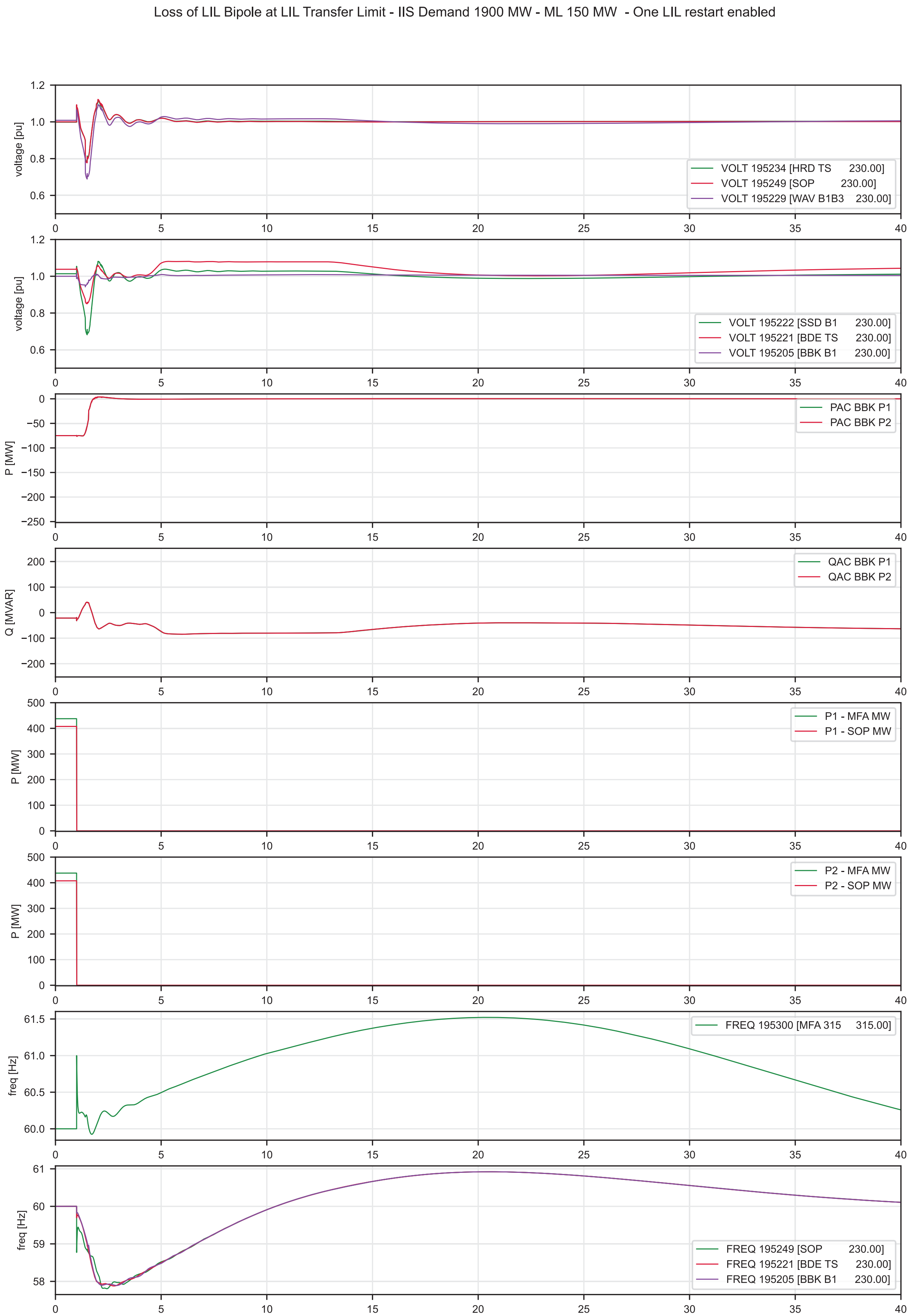


Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1900 MW - ML 250 MW - One LIL restart enabled

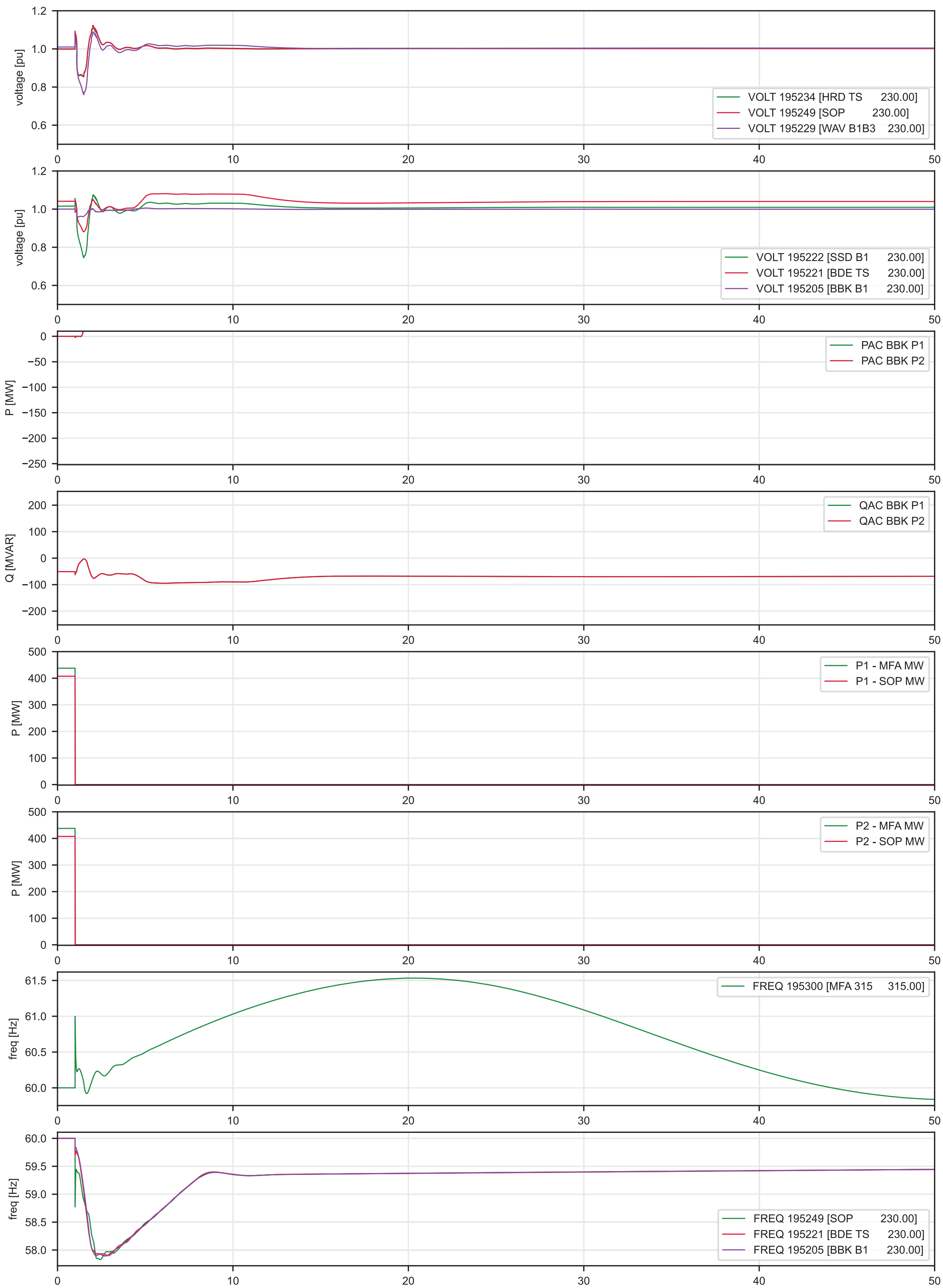


Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1900 MW - ML 150 MW - No LIL restarts enabled

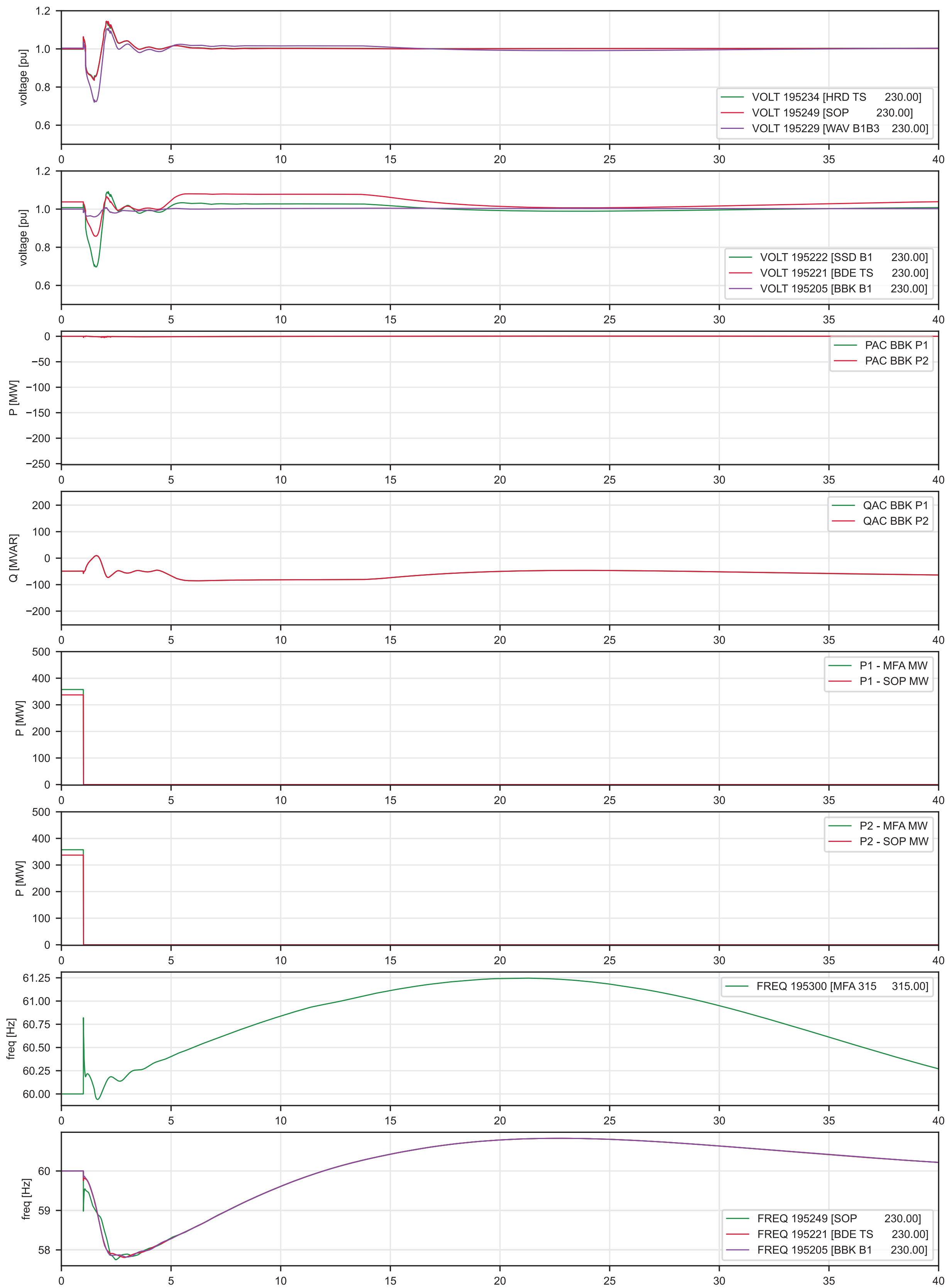


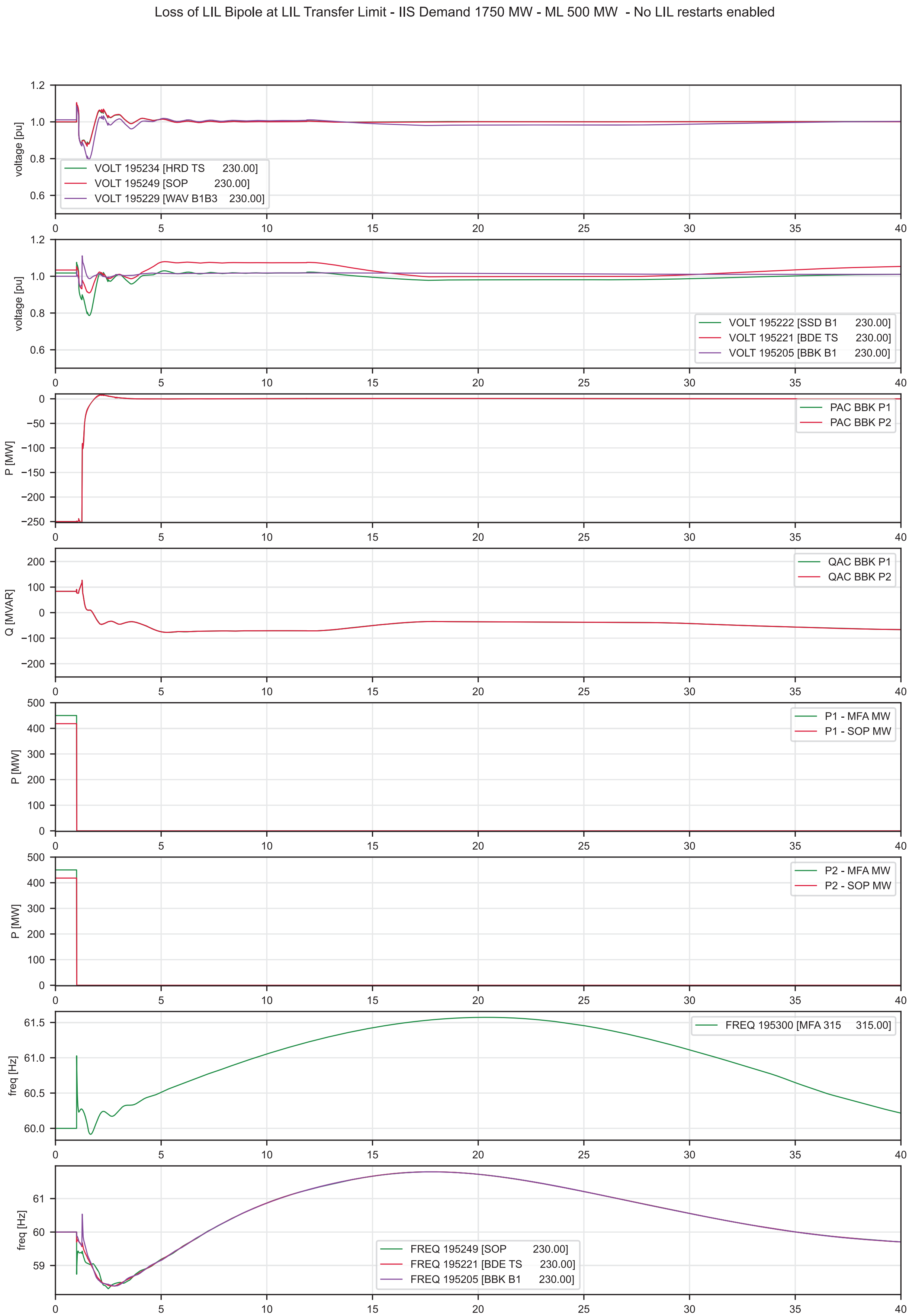

Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1900 MW - ML 150 MW - One LIL restart enabled
voltage [pu]
VOLT 195234 [HRD TS 230.00]
VOLT 195249 [SOP 230.00]
VOLT 195229 [WAV B1B3 230.00]
voltage [pu]
VOLT 195222 [SSD B1 230.00]
VOLT 195221 [BDE TS 230.00]
VOLT 195205 [BBK B1 230.00]
P [MW]
PAC BBK P1
PAC BBK P2
Q [MVAR]
QAC BBK P1
QAC BBK P2
P [MW]
P1 - MFA MW
P1 - SOP MW
P [MW]
P2 - MFA MW
P2 - SOP MW
freq [Hz]
FREQ 195300 [MFA 315 315.00]
freq [Hz]
FREQ 195249 [SOP 230.00]
FREQ 195221 [BDE TS 230.00]
FREQ 195205 [BBK B1 230.00]

Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1900 MW - ML 0 MW / ML Runbacks Inactive / ML F/C Active - No LIL restarts enabled

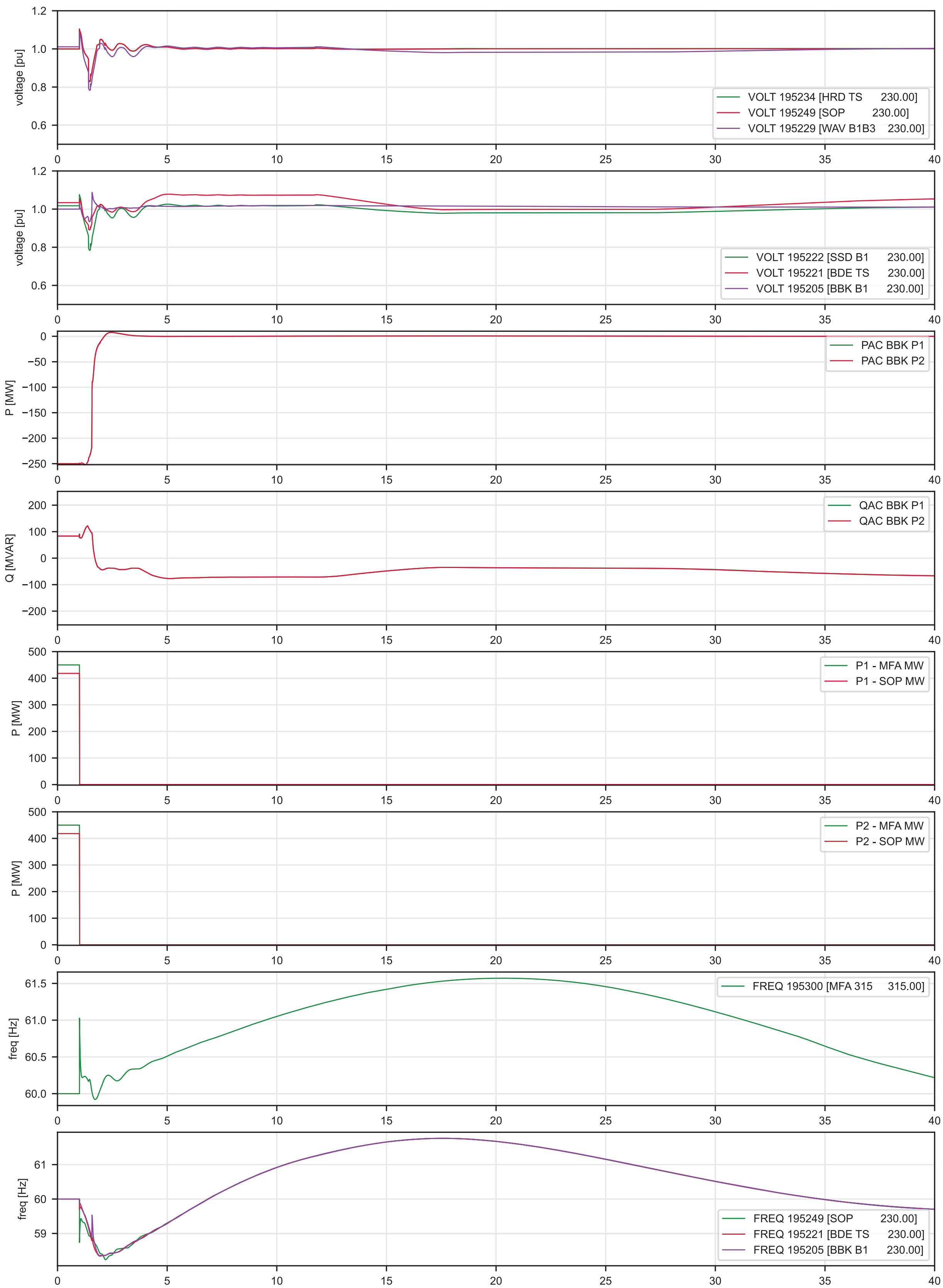


Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1900 MW - ML 0 MW / ML Runbacks Inactive / ML F/C Inactive - No LIL restarts enabled

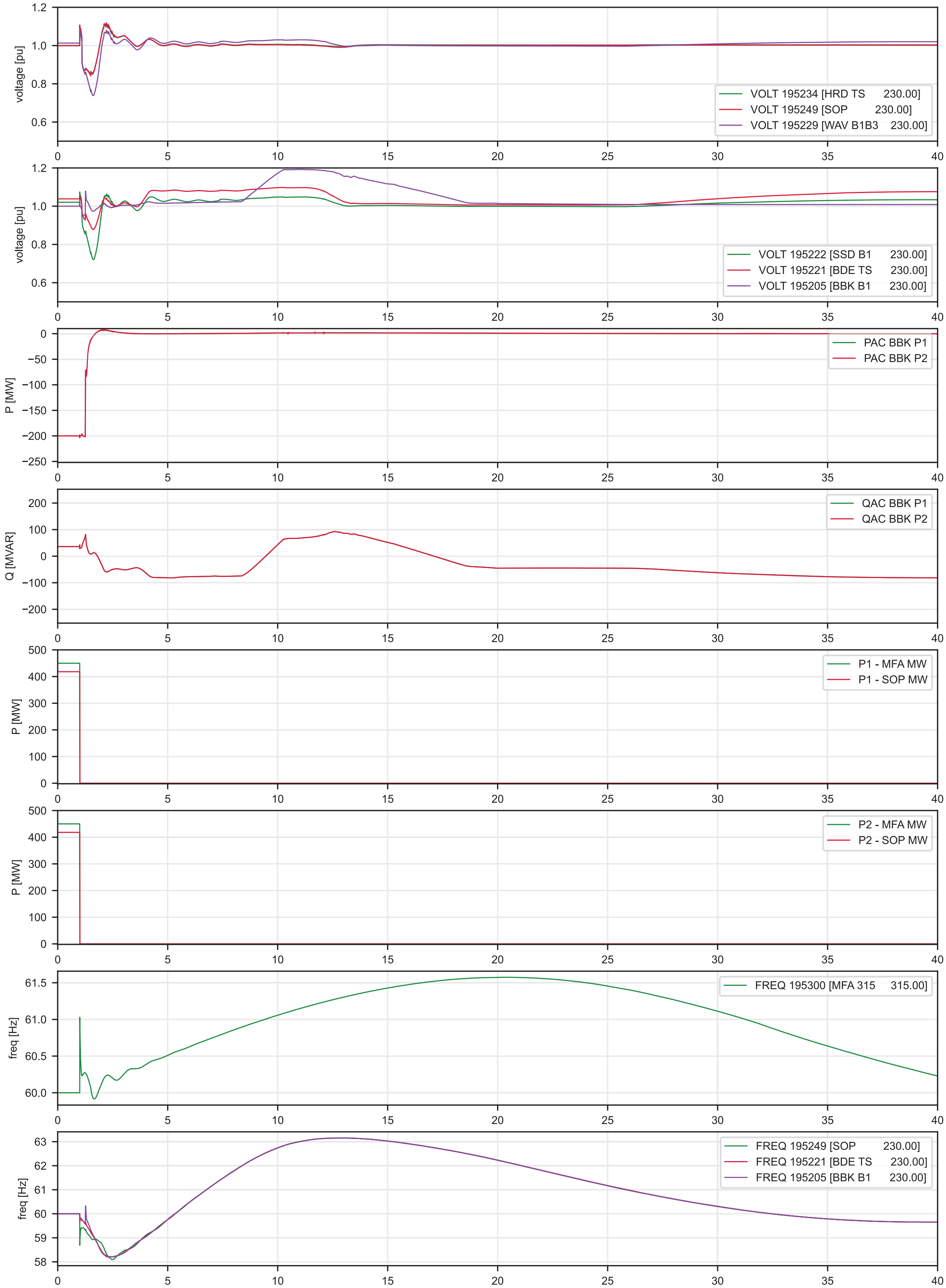



Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1750 MW - ML 500 MW - No LIL restarts enabled
voltage [pu]
VOLT 195234 [HRD TS 230.00]
VOLT 195249 [SOP 230.00]
VOLT 195229 [WAV B1B3 230.00]
VOLT 195222 [SSD B1 230.00]
VOLT 195221 [BDE TS 230.00]
VOLT 195205 [BBK B1 230.00]
P [MW]
PAC BBK P1
PAC BBK P2
Q [MVAR]
QAC BBK P1
QAC BBK P2
P1 - MFA MW
P1 - SOP MW
P2 - MFA MW
P2 - SOP MW
freq [Hz]
FREQ 195300 [MFA 315 315.00]
FREQ 195249 [SOP 230.00]
FREQ 195221 [BDE TS 230.00]
FREQ 195205 [BBK B1 230.00]

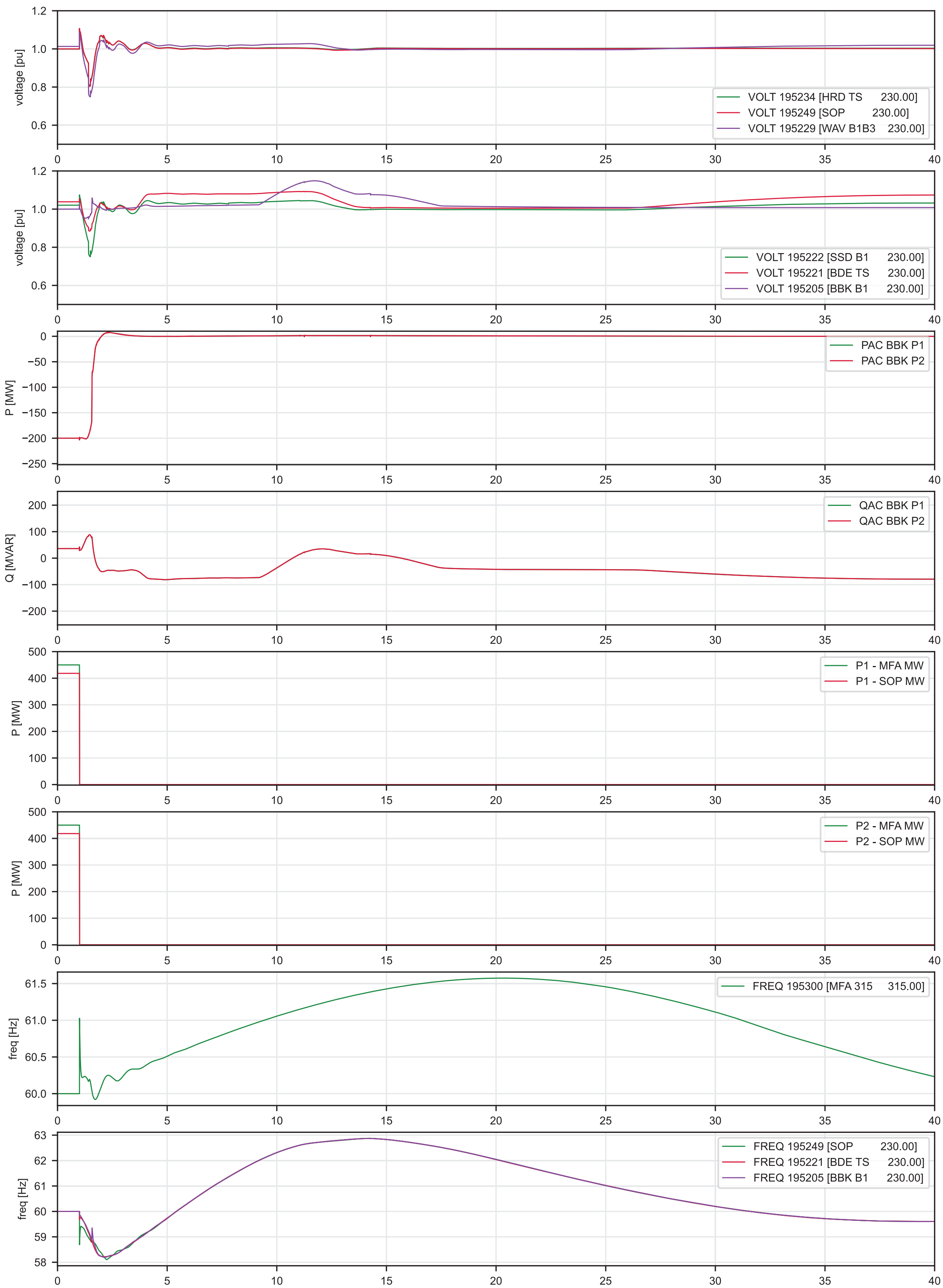
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1750 MW - ML 500 MW - One LIL restart enabled



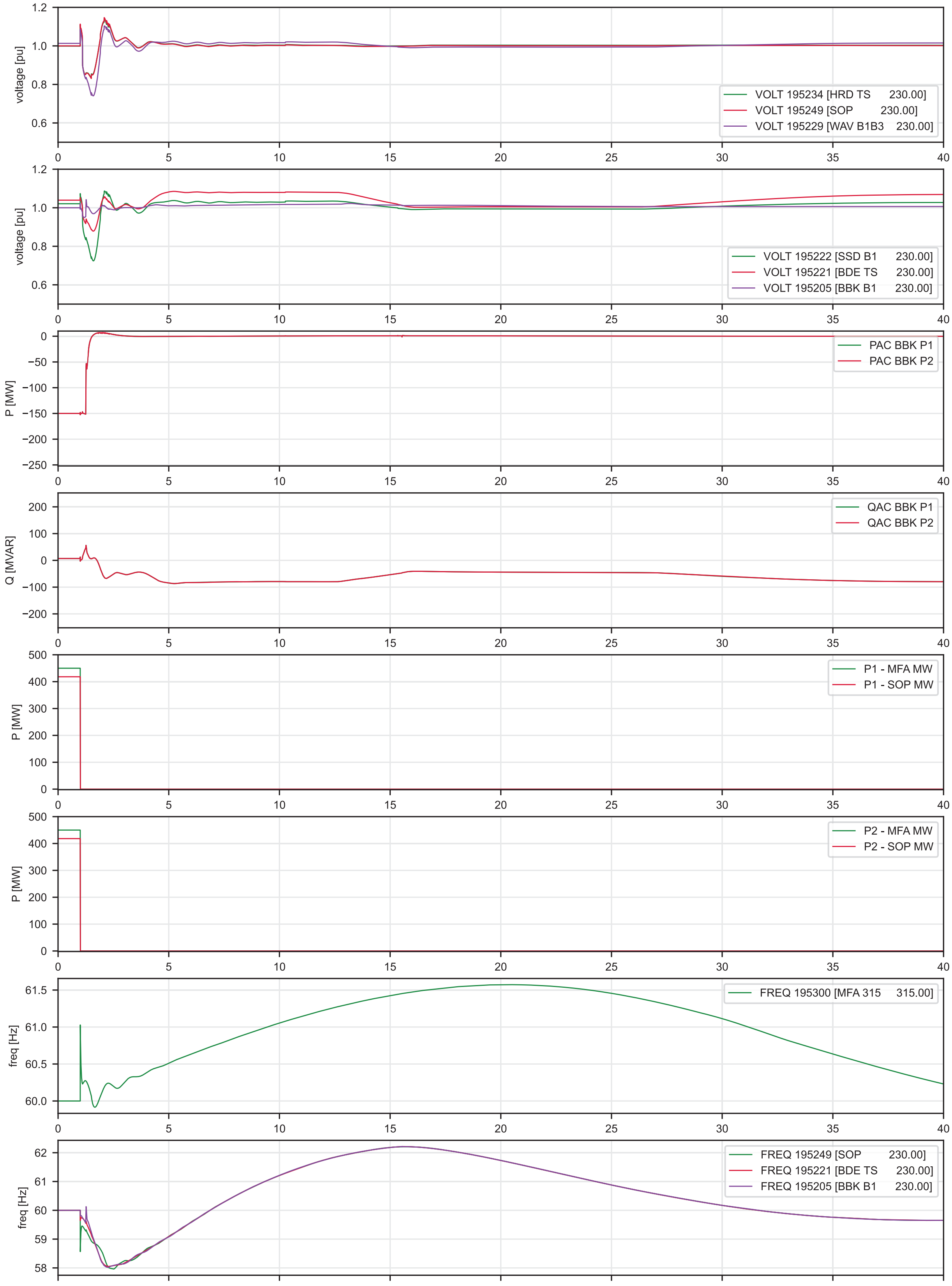
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1750 MW - ML 400 MW - No LIL restarts enabled



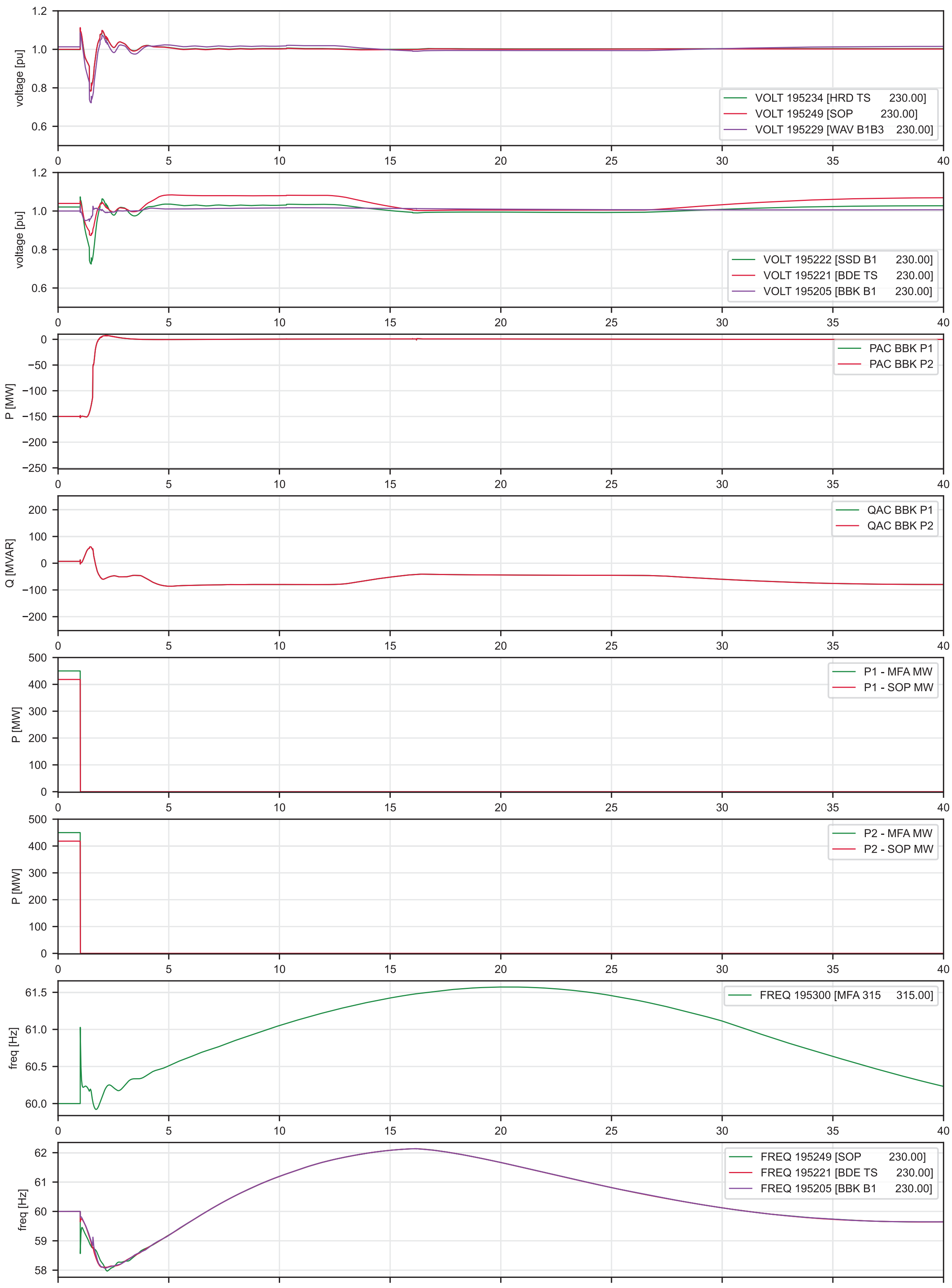
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1750 MW - ML 400 MW - One LIL restart enabled



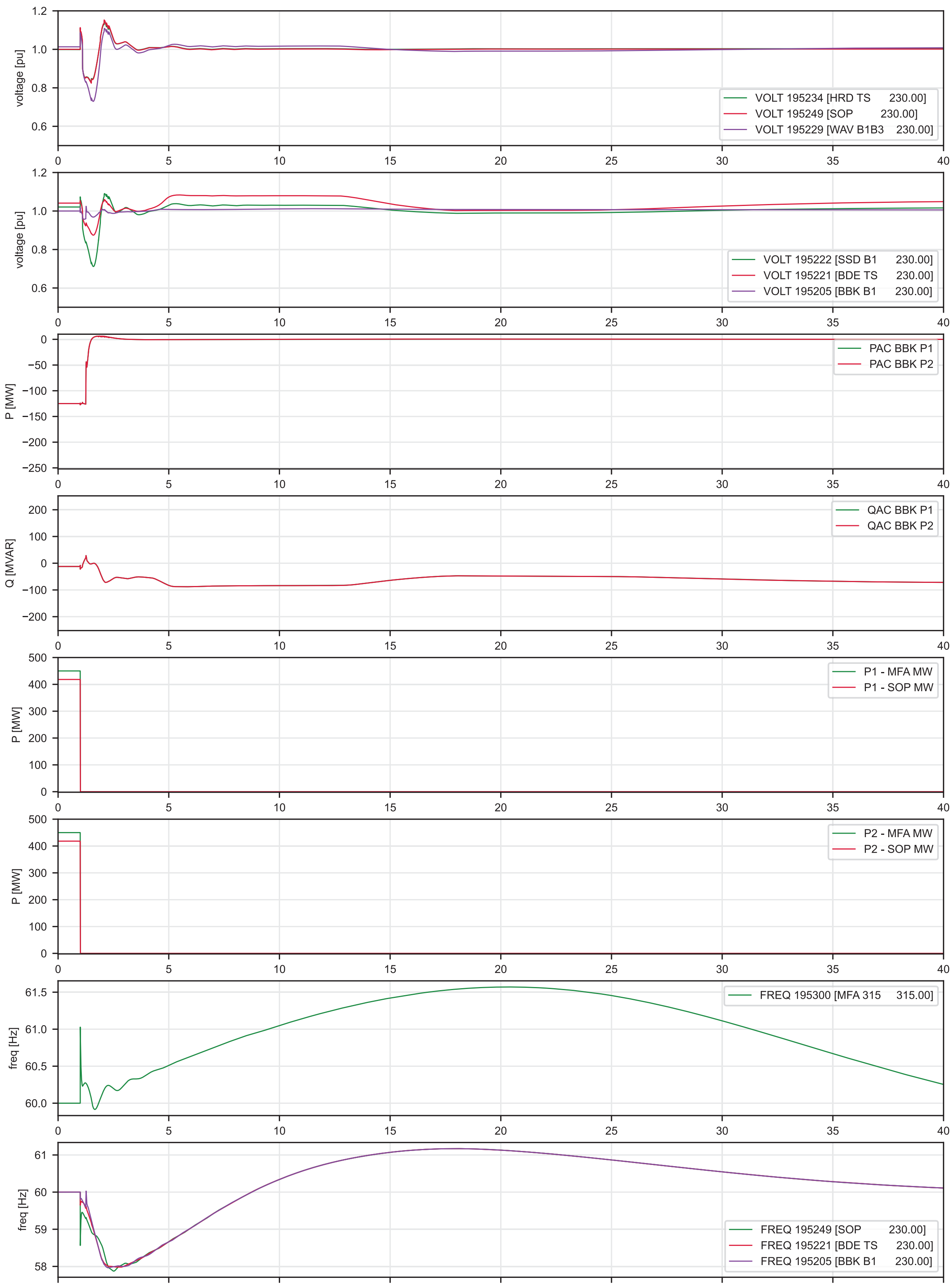
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1750 MW - ML 300 MW - No LIL restarts enabled



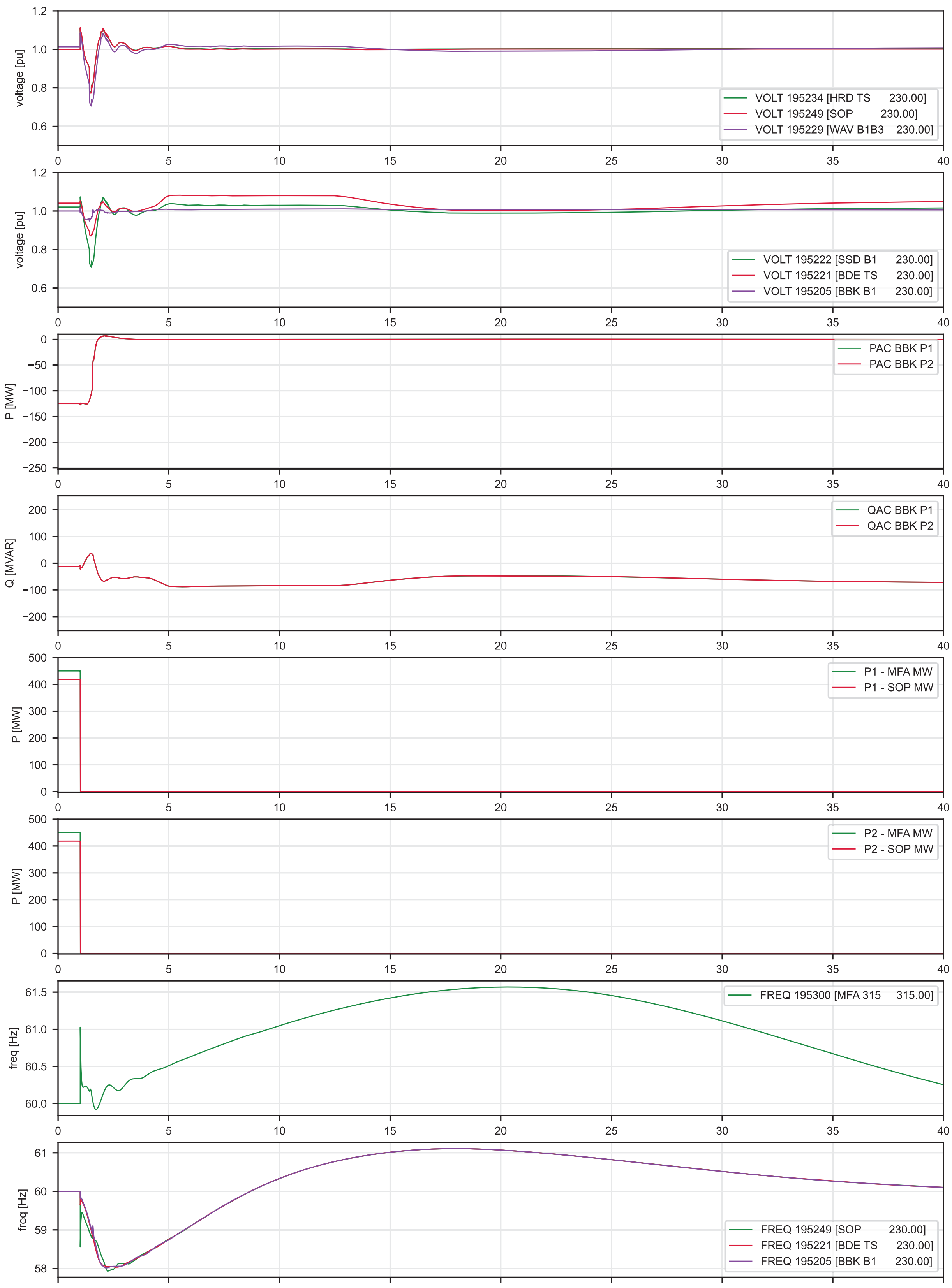
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1750 MW - ML 300 MW - One LIL restart enabled



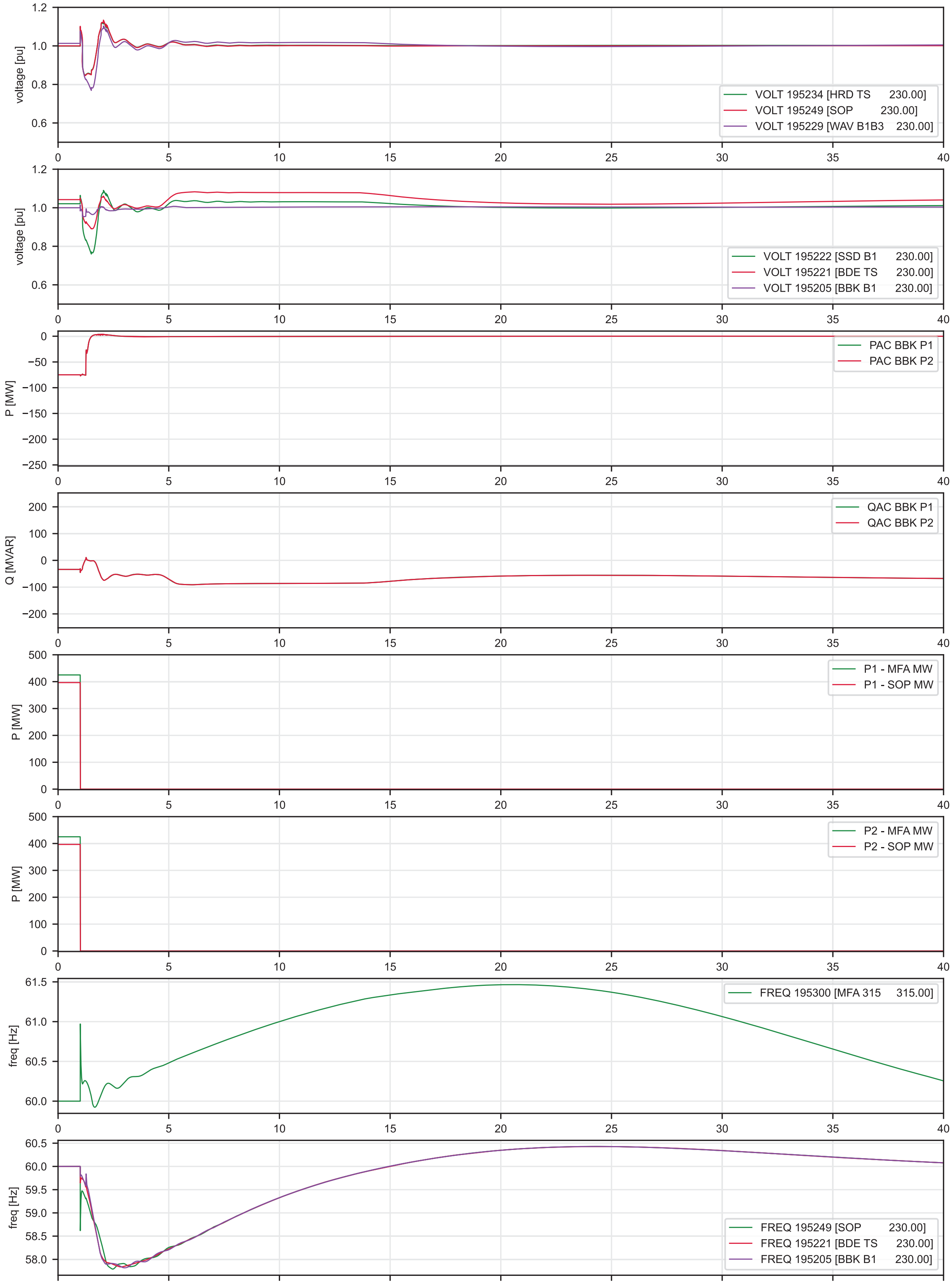
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1750 MW - ML 250 MW - No LIL restarts enabled



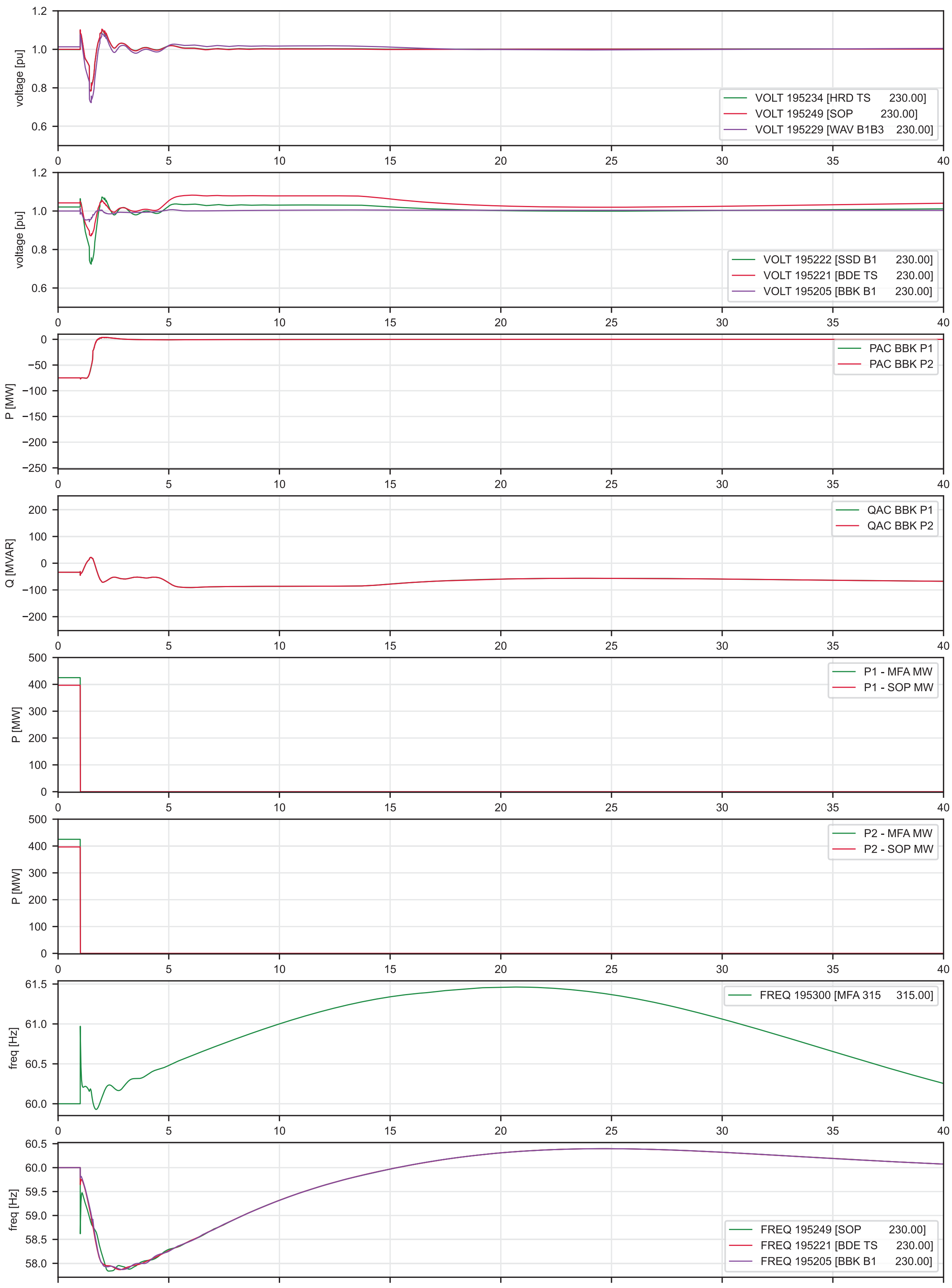
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1750 MW - ML 250 MW - One LIL restart enabled



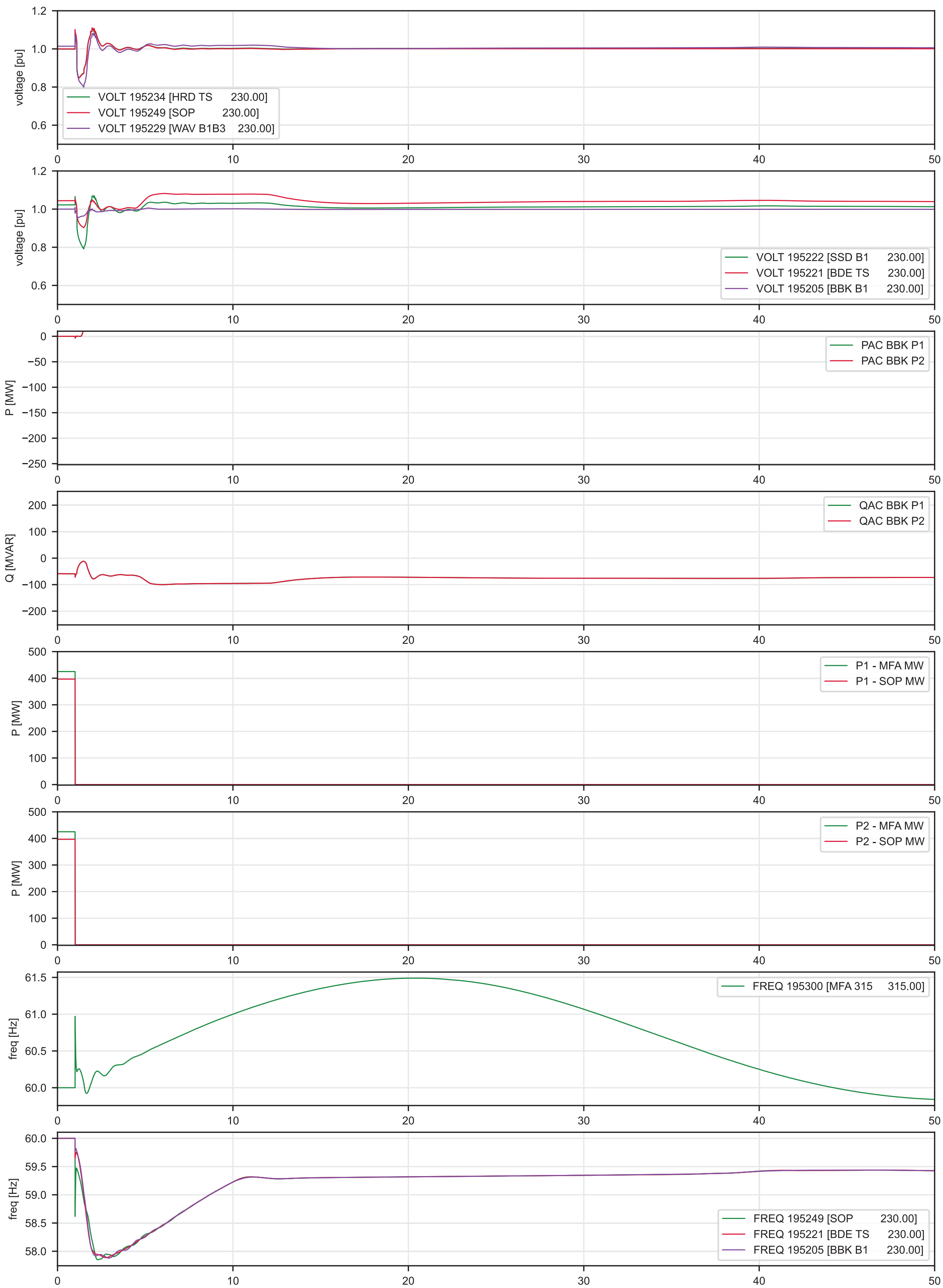
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1750 MW - ML 150 MW - No LIL restarts enabled



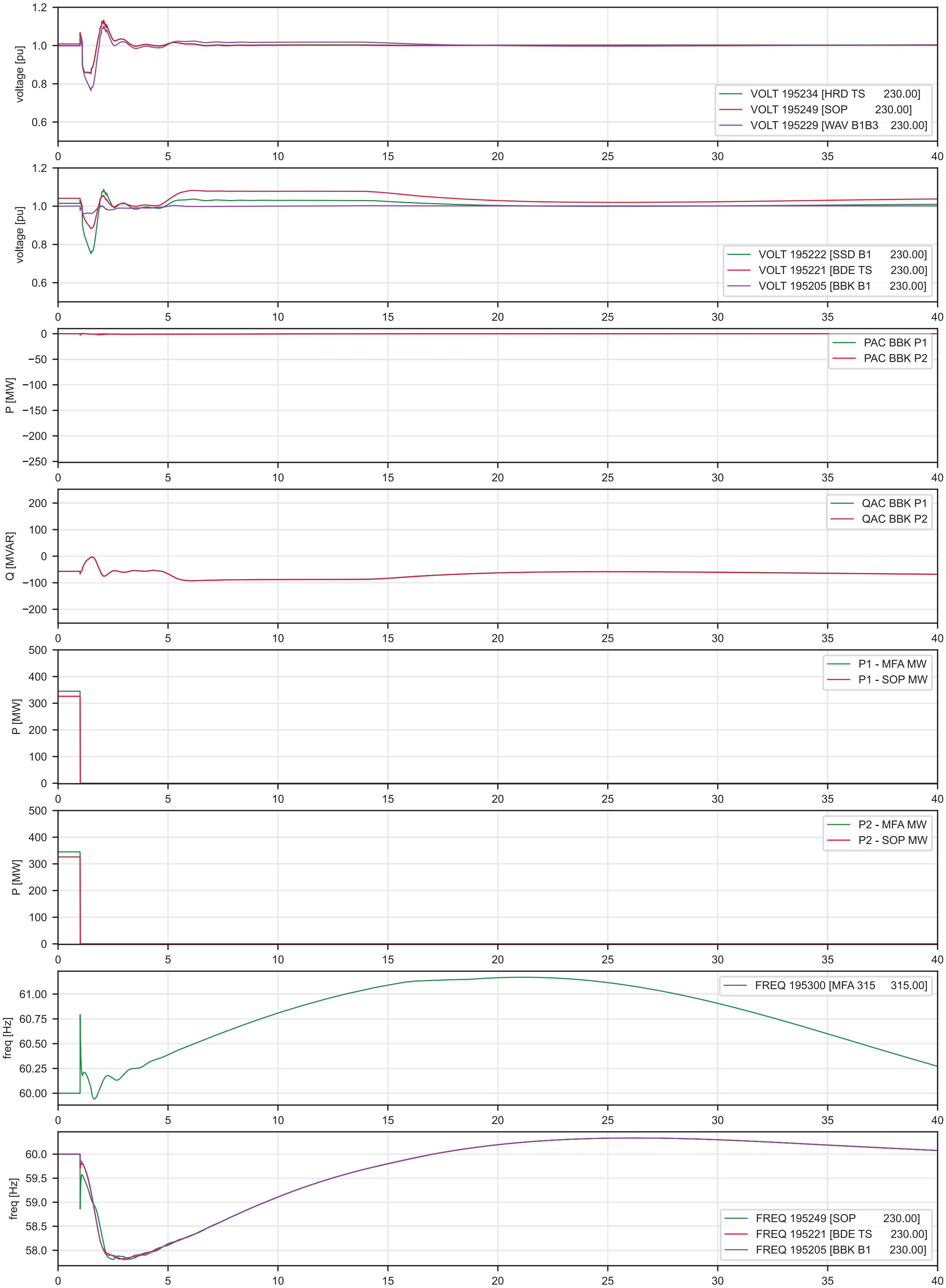
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1750 MW - ML 150 MW - One LIL restart enabled



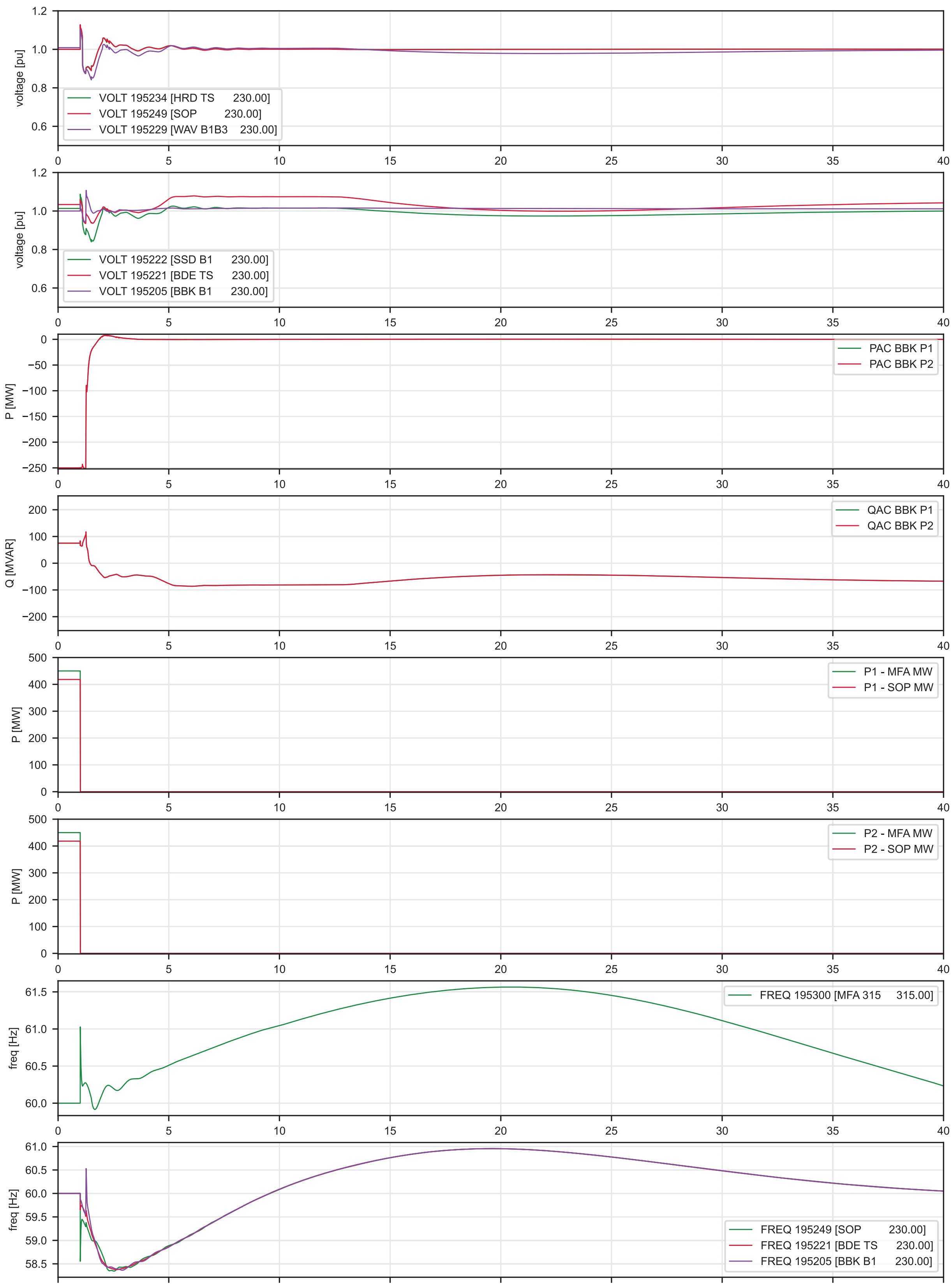
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1750 MW - ML 0 MW / ML Runbacks Inactive / ML F/C Active - No LIL restarts enabled



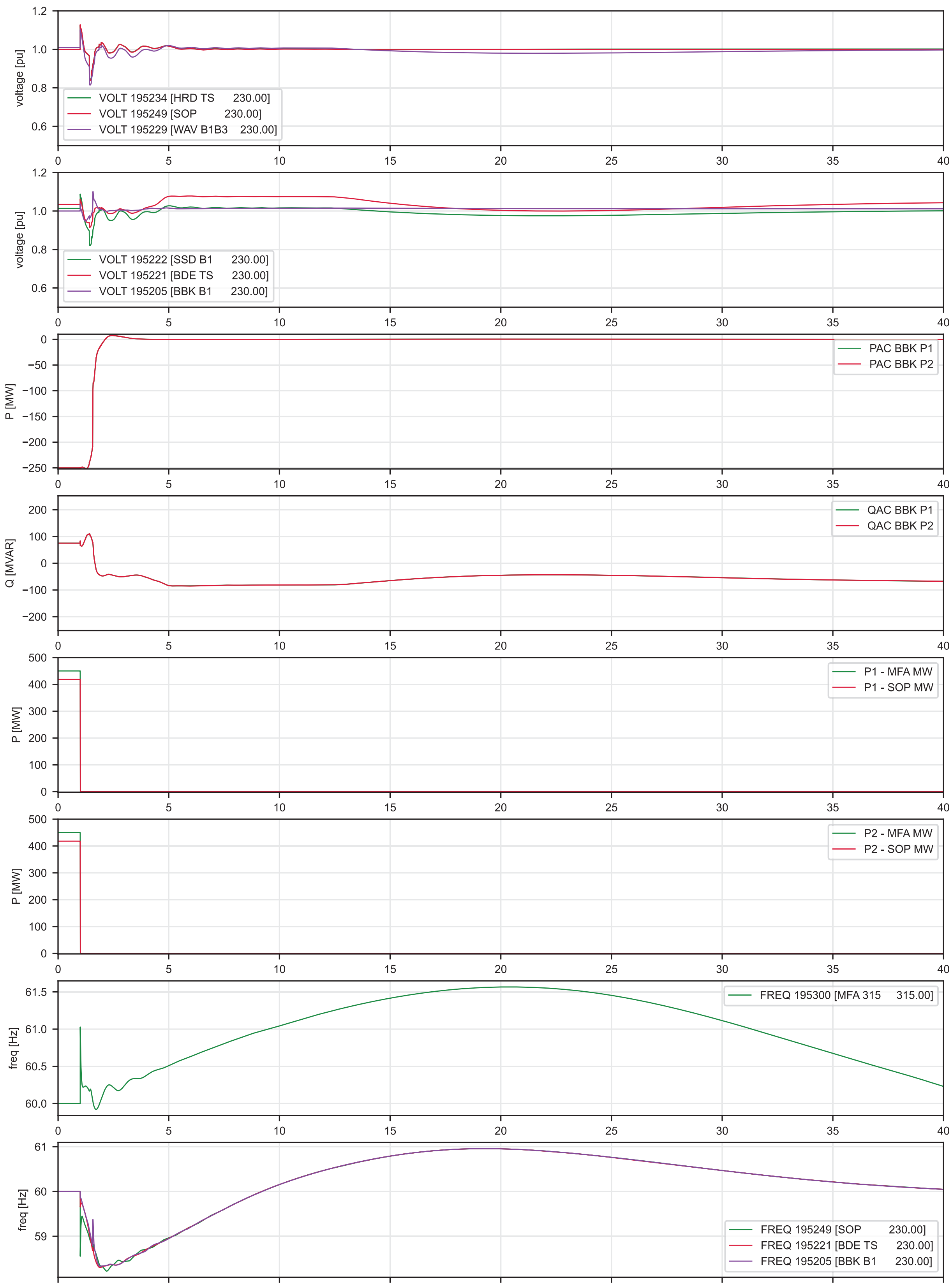
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1750 MW - ML 0 MW / ML Runbacks Inactive / ML F/C Inactive - No LIL restarts enabled



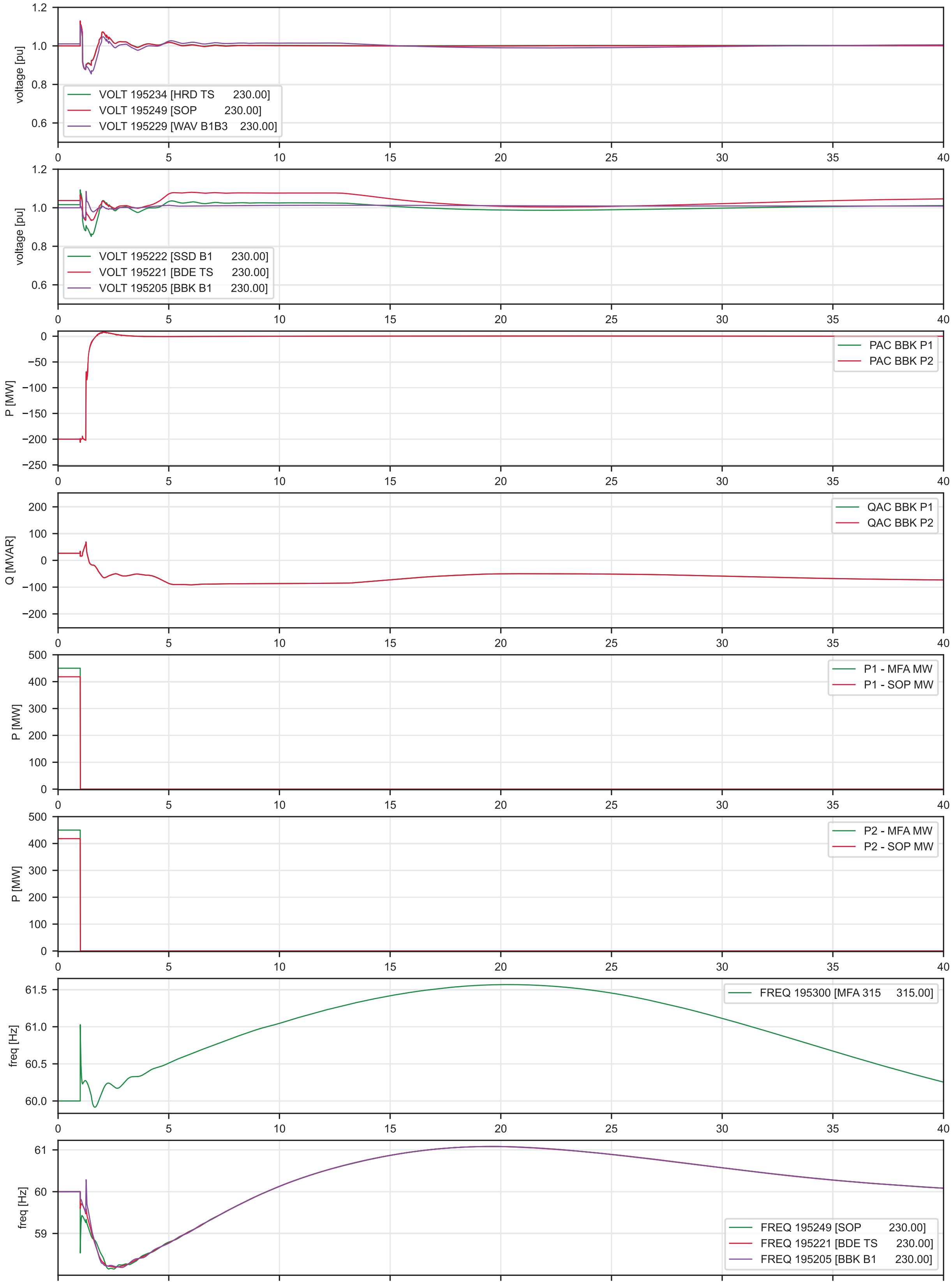
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1500 MW - ML 500 MW - No LIL restarts enabled



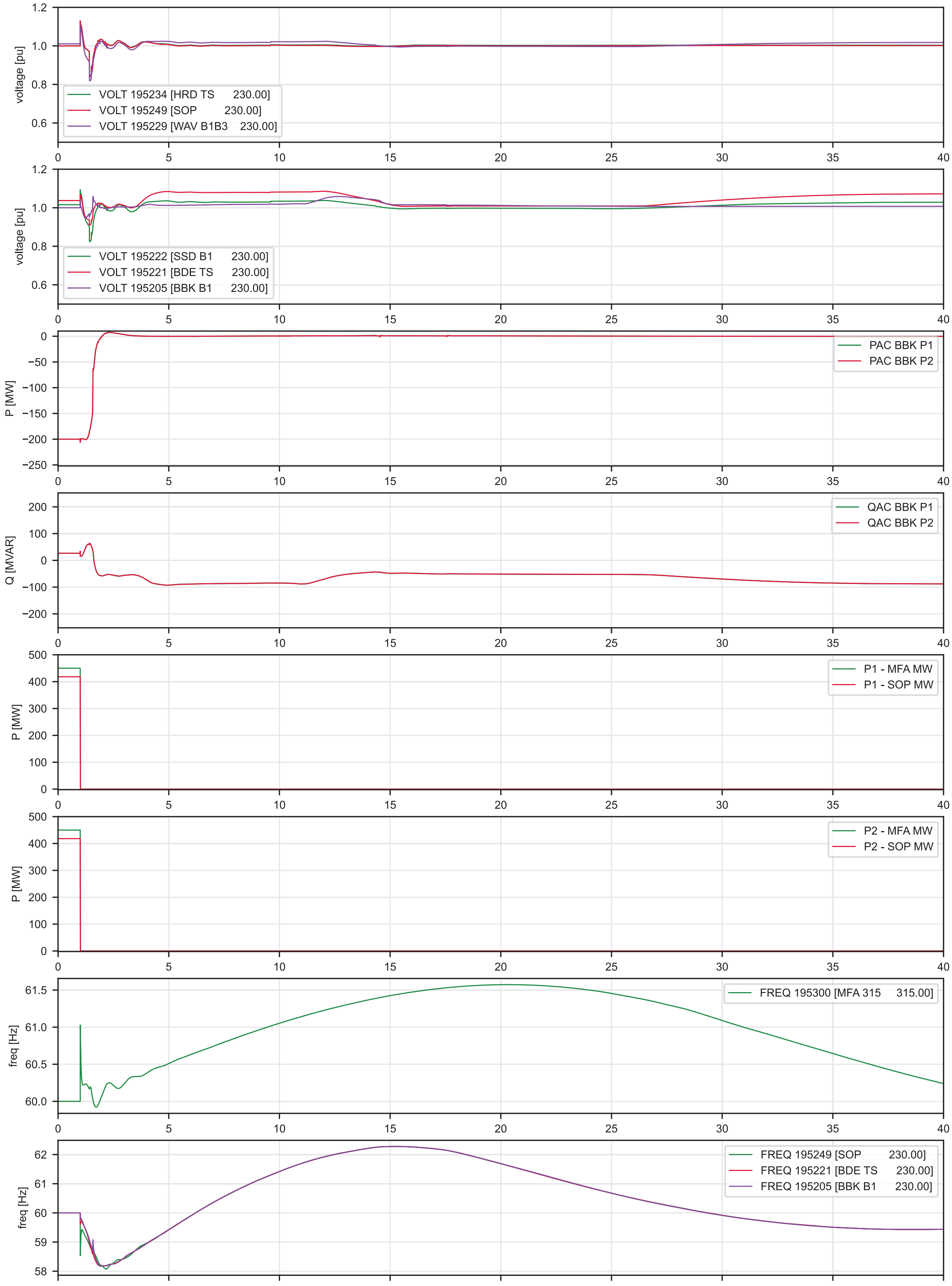
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1500 MW - ML 500 MW - One LIL restart enabled

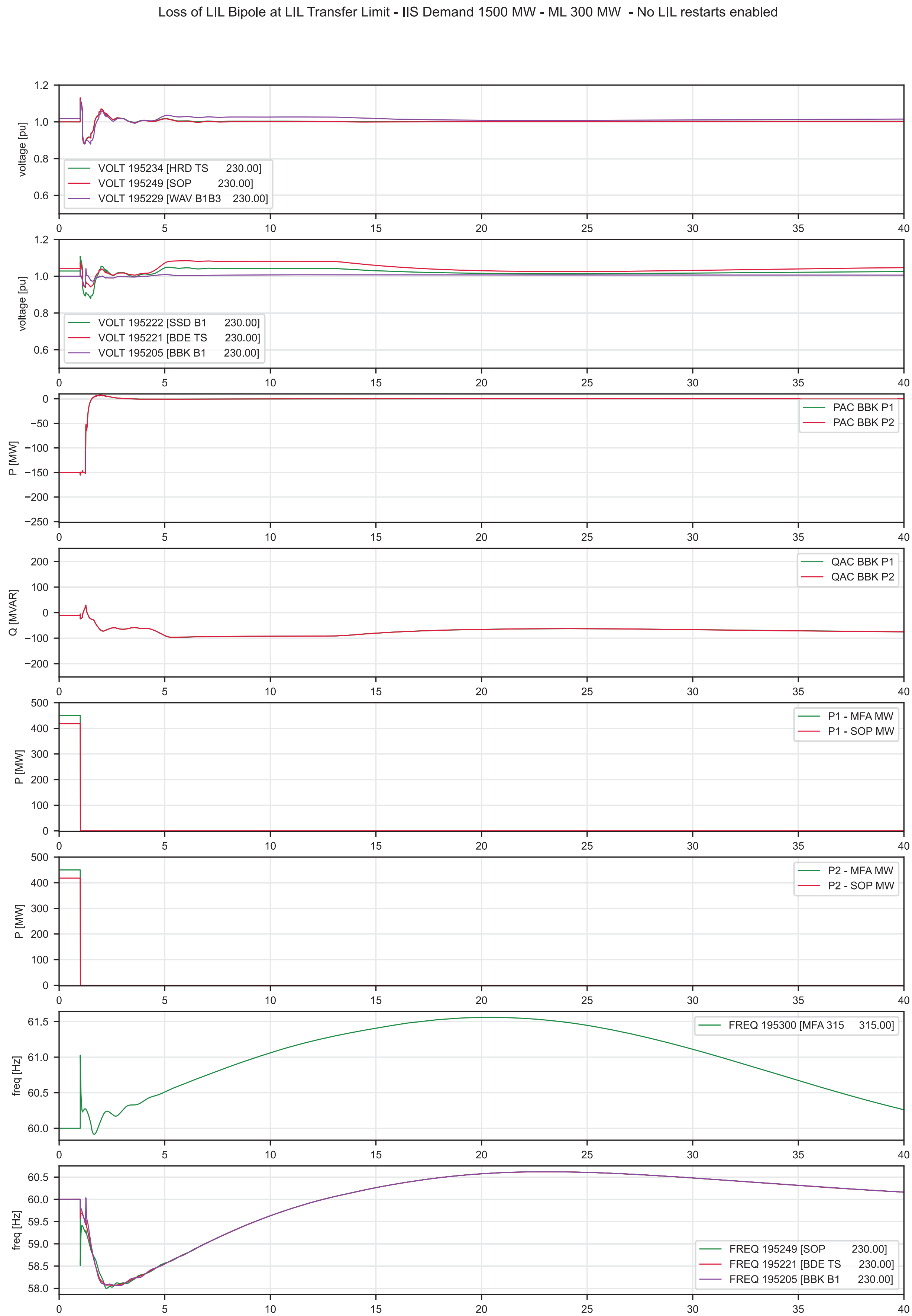


Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1500 MW - ML 400 MW - No LIL restarts enabled

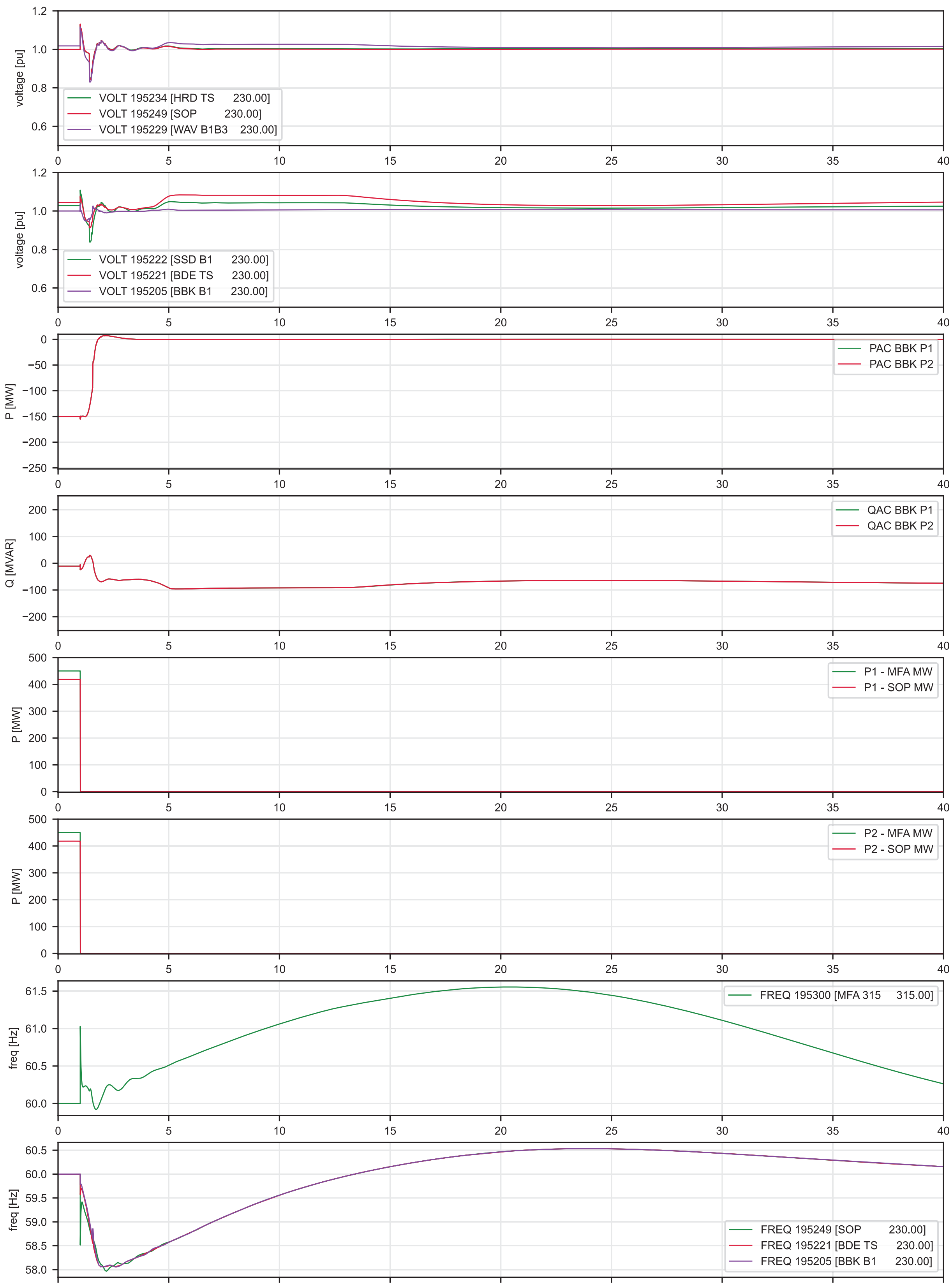


Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1500 MW - ML 400 MW - One LIL restart enabled

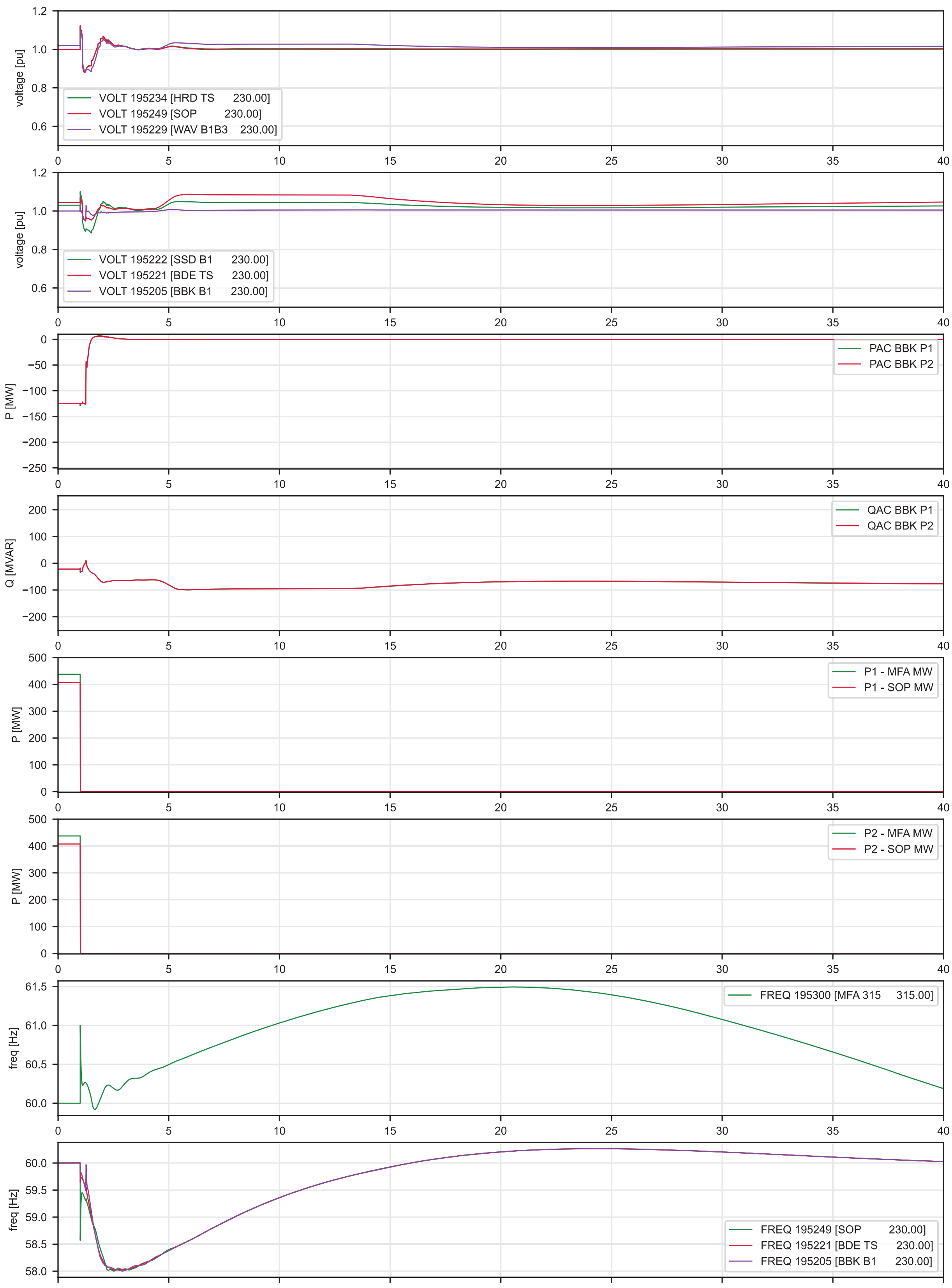



Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1500 MW - ML 300 MW - No LIL restarts enabled
voltage [pu]
VOLT 195234 [HRD TS 230.00]
VOLT 195249 [SOP 230.00]
VOLT 195229 [WAV B1B3 230.00]
VOLT 195222 [SSD B1 230.00]
VOLT 195221 [BDE TS 230.00]
VOLT 195205 [BBK B1 230.00]
P [MW]
PAC BBK P1
PAC BBK P2
Q [MVAR]
QAC BBK P1
QAC BBK P2
P1 - MFA MW
P1 - SOP MW
P2 - MFA MW
P2 - SOP MW
freq [Hz]
FREQ 195300 [MFA 315 315.00]
FREQ 195249 [SOP 230.00]
FREQ 195221 [BDE TS 230.00]
FREQ 195205 [BBK B1 230.00]

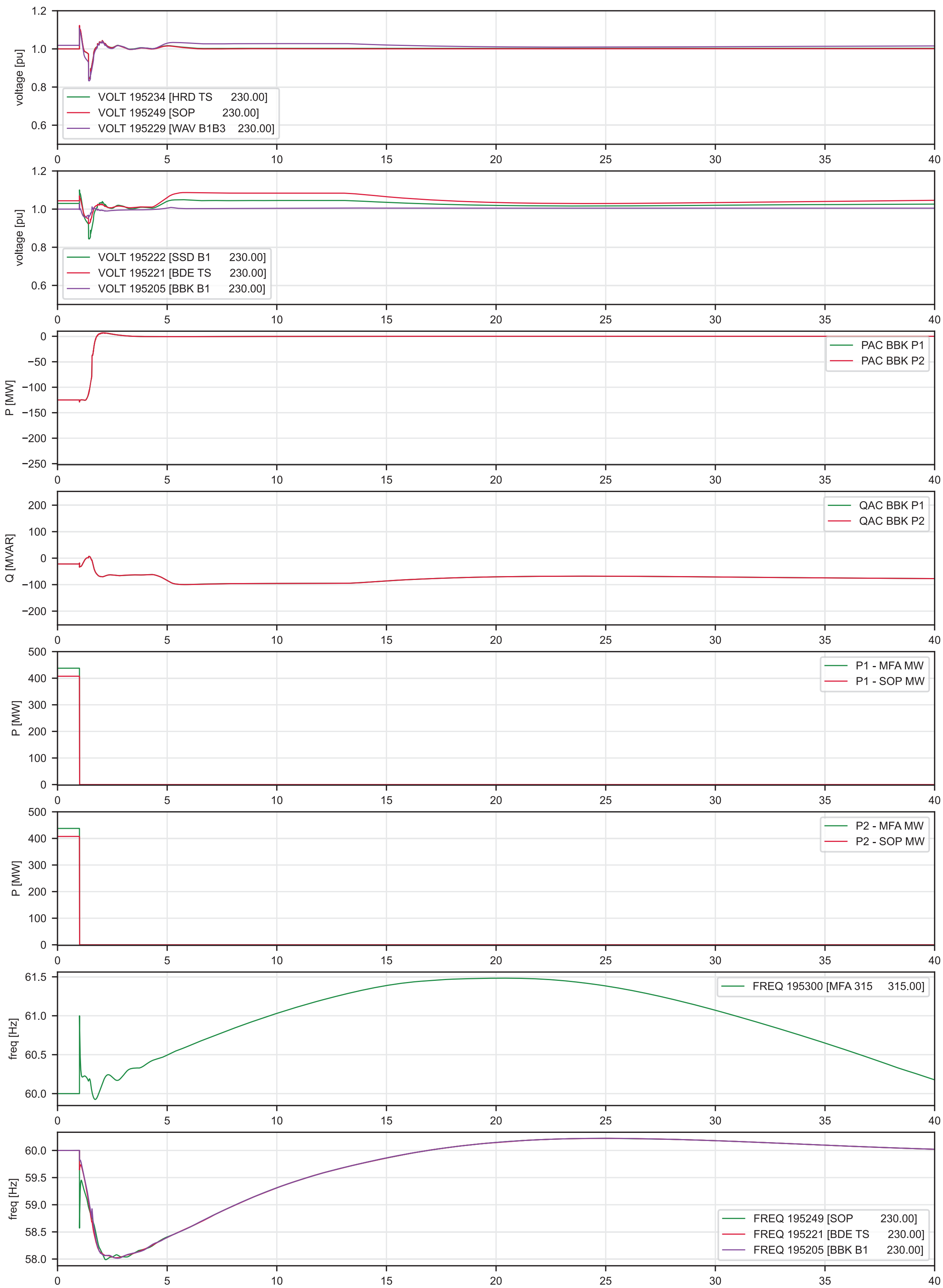
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1500 MW - ML 300 MW - One LIL restart enabled



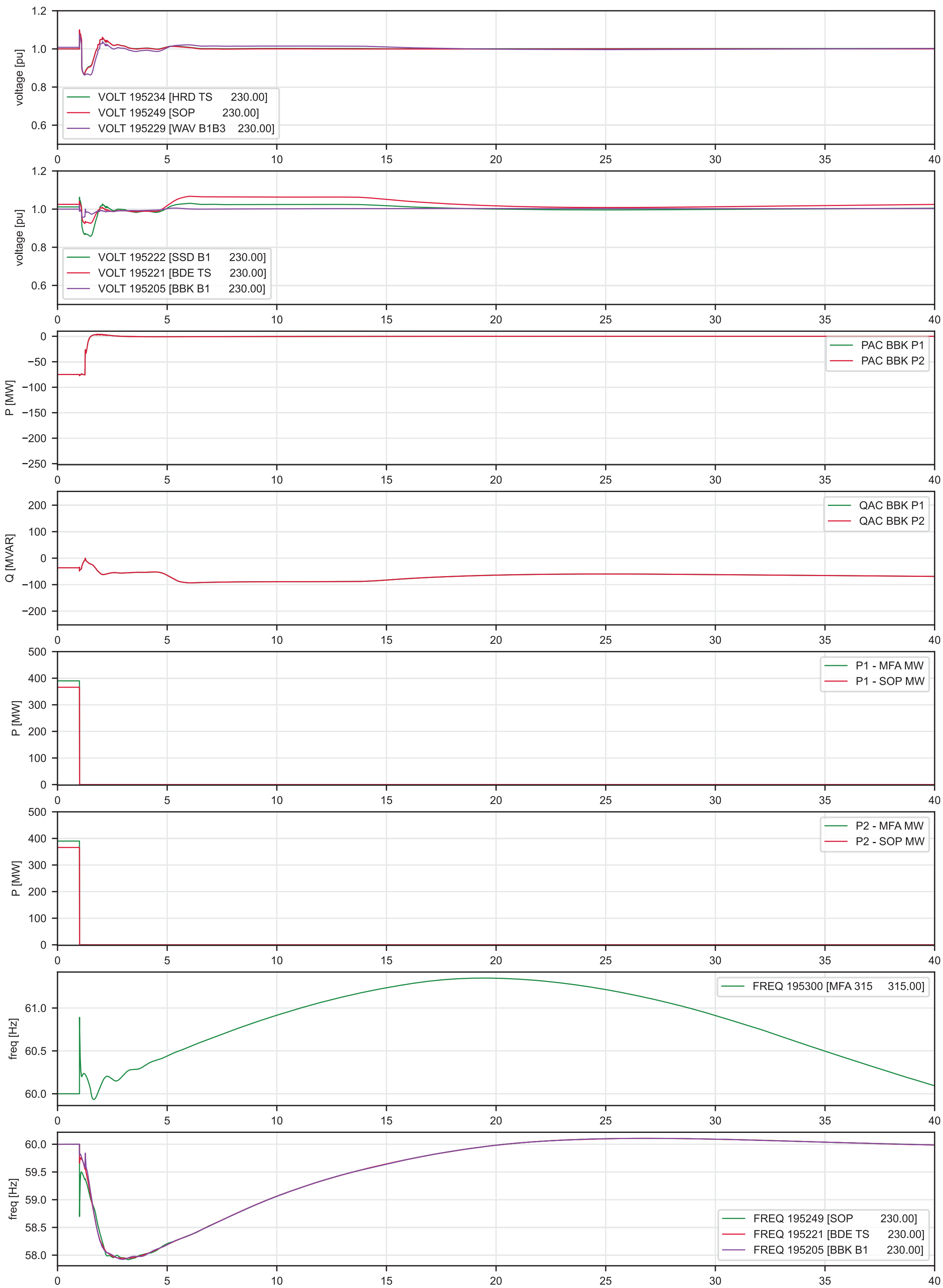
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1500 MW - ML 250 MW - No LIL restarts enabled



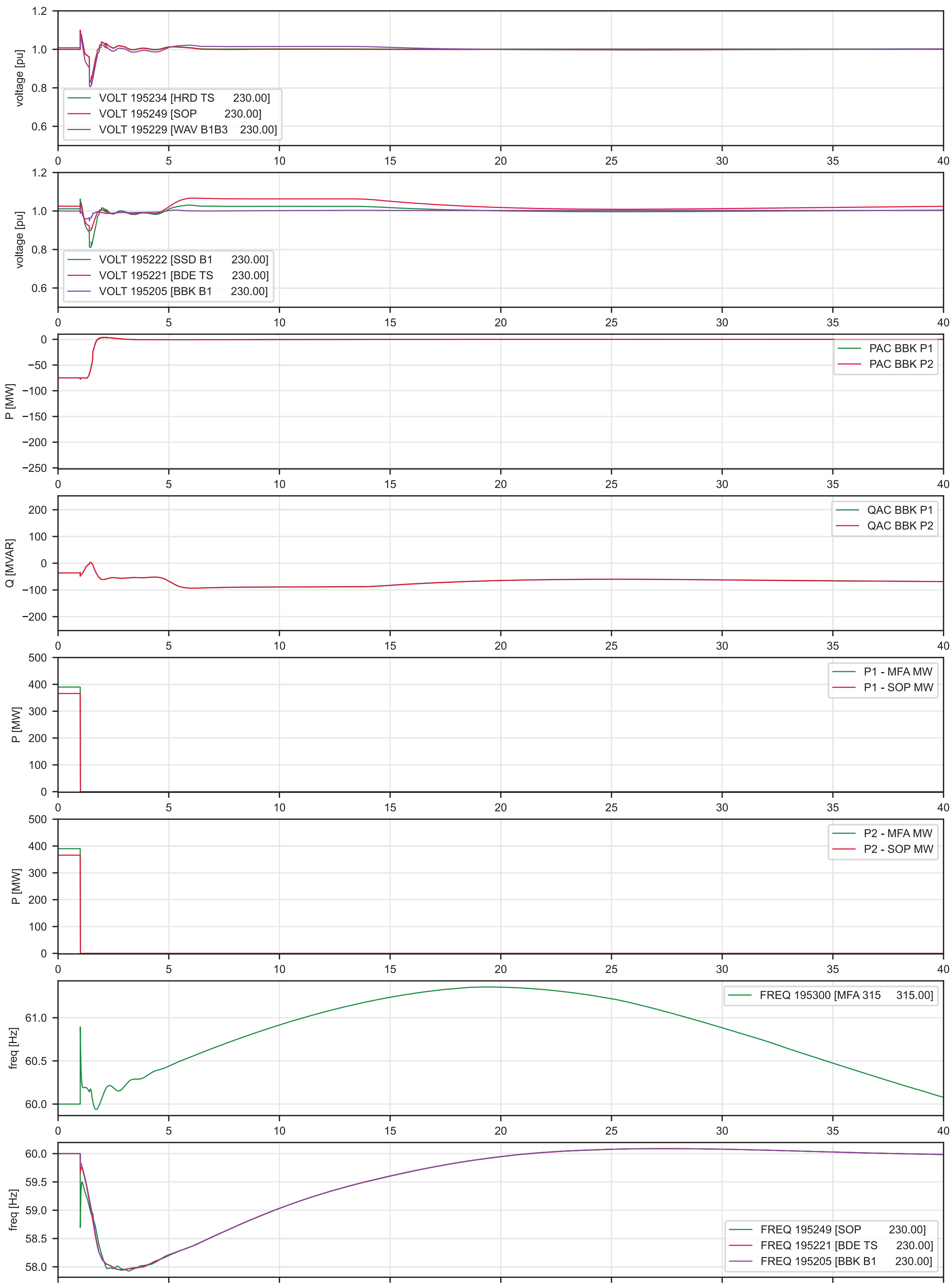
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1500 MW - ML 250 MW - One LIL restart enabled



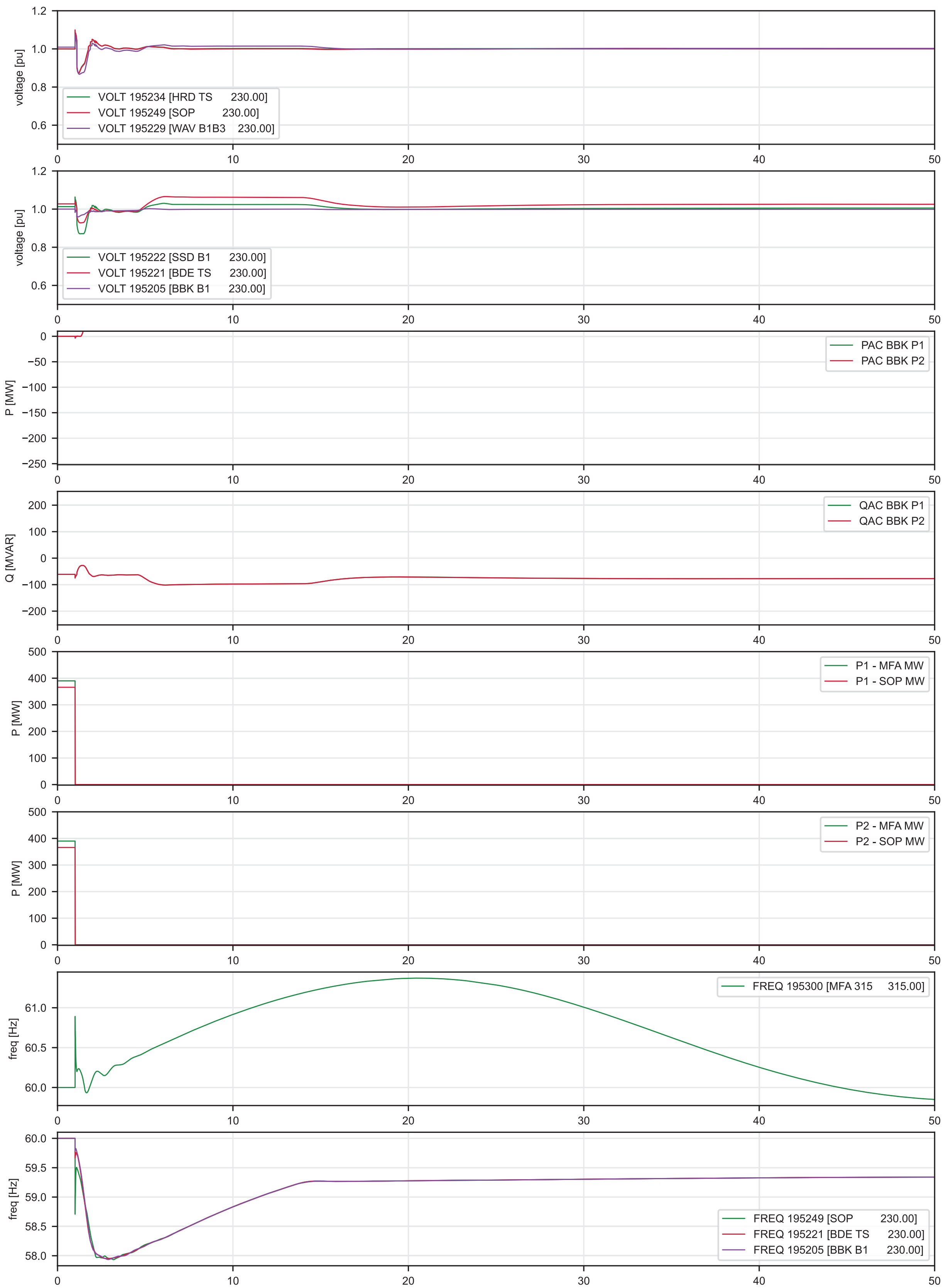
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1500 MW - ML 150 MW - No LIL restarts enabled



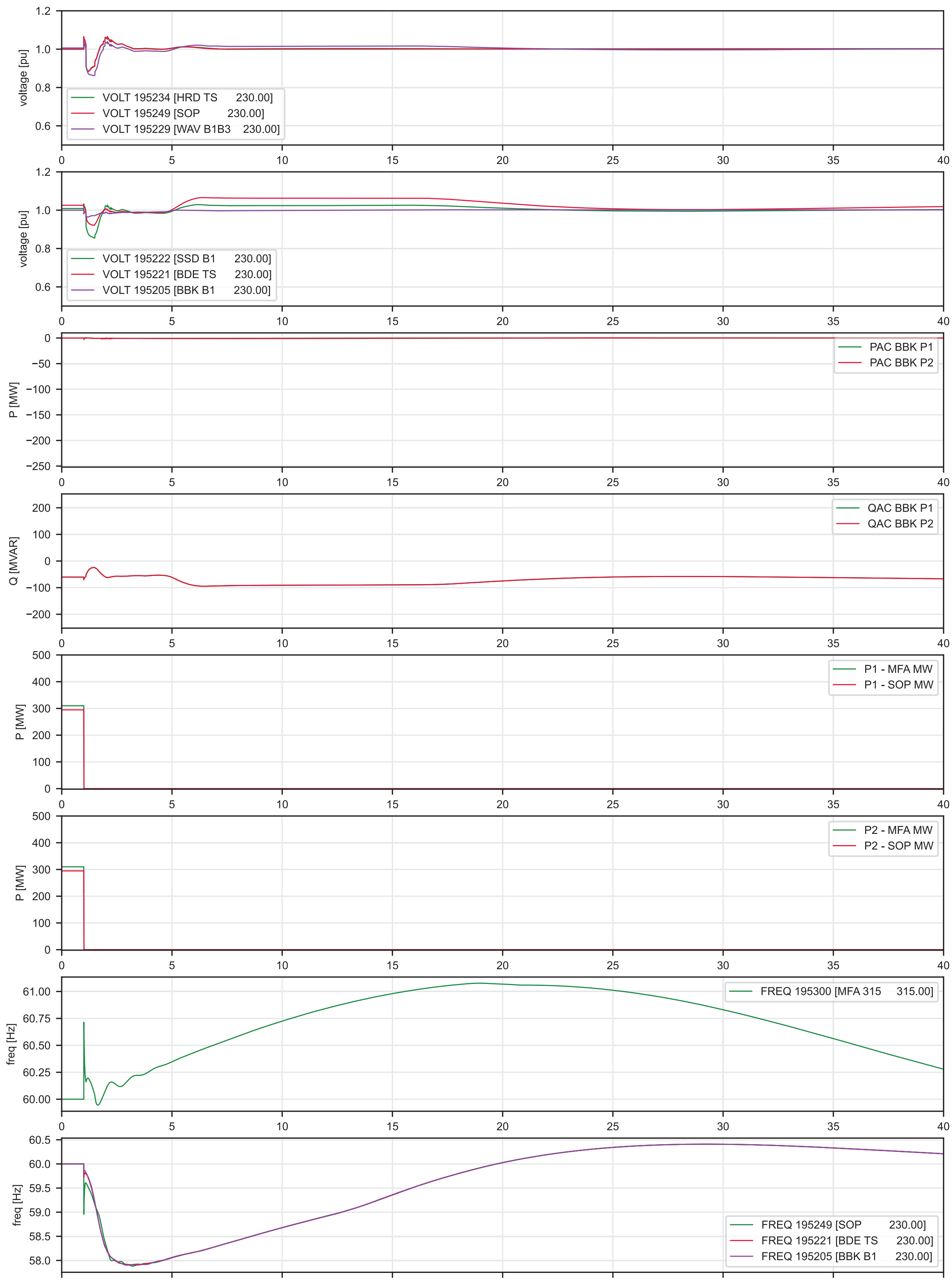
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1500 MW - ML 150 MW - One LIL restart enabled



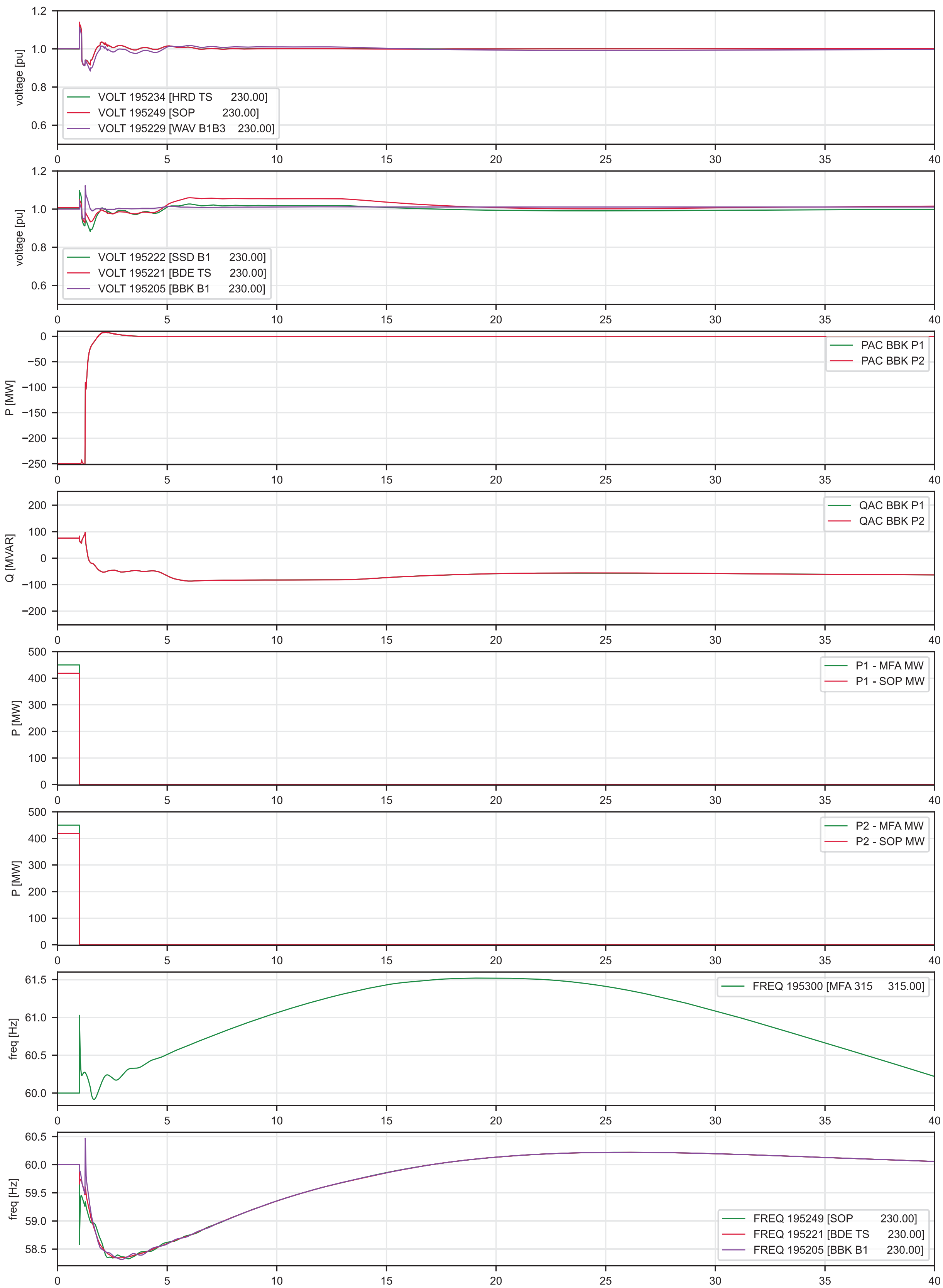
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1500 MW - ML 0 MW / ML Runbacks Inactive / ML F/C Active - No LIL restarts enabled



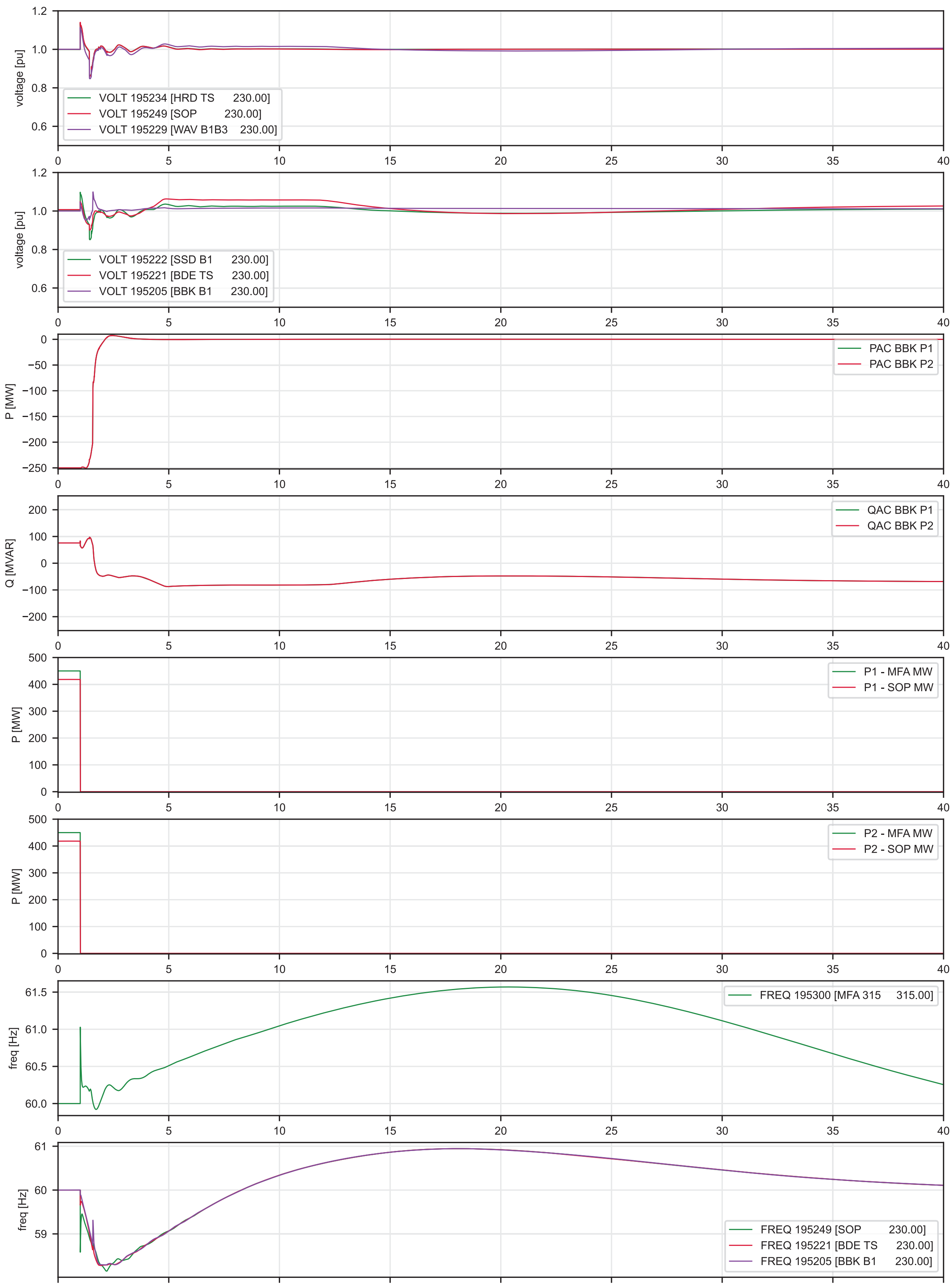
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1500 MW - ML 0 MW / ML Runbacks Inactive / ML F/C Inactive - No LIL restarts enabled



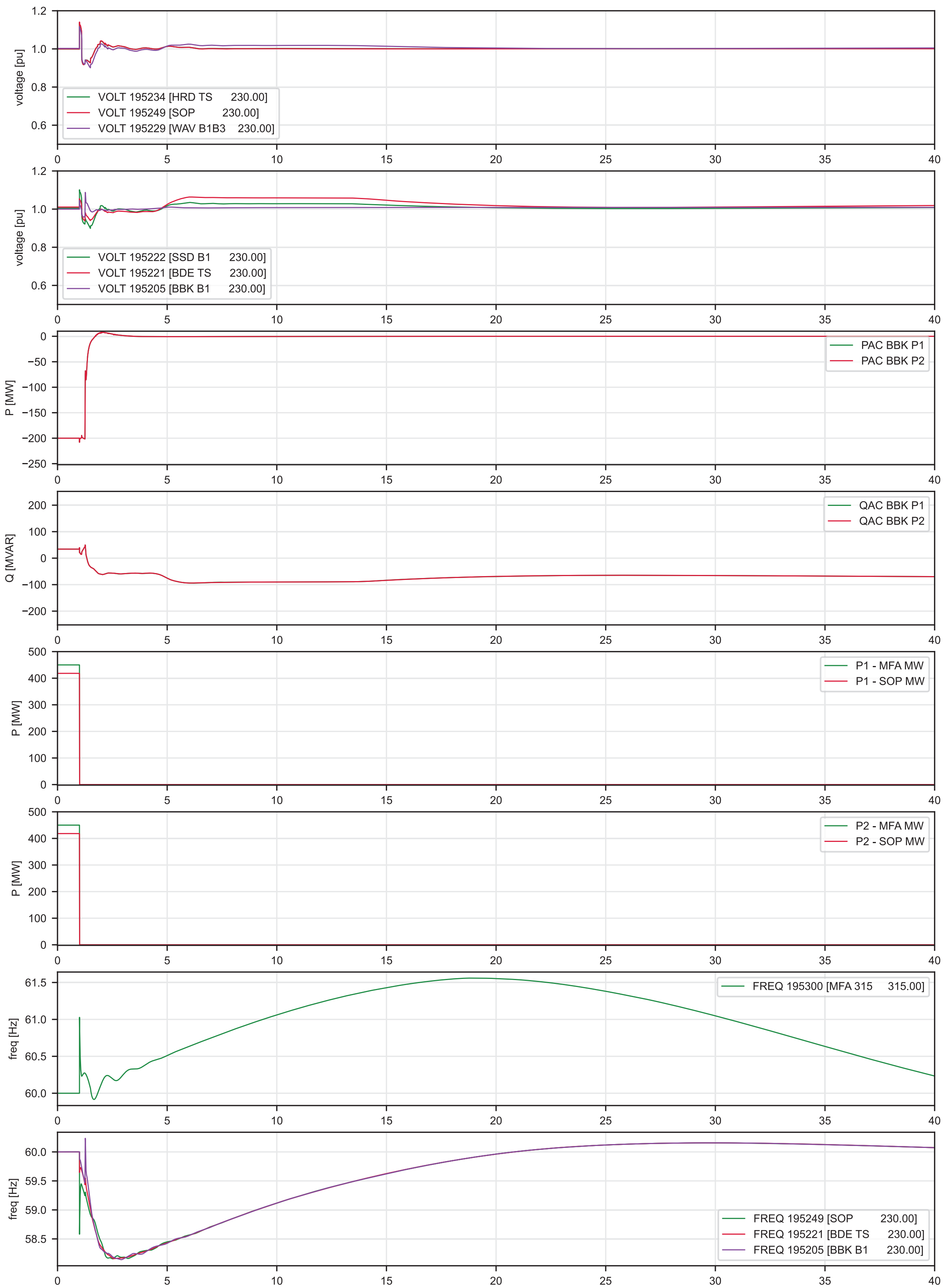
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1250 MW - ML 500 MW - No LIL restarts enabled



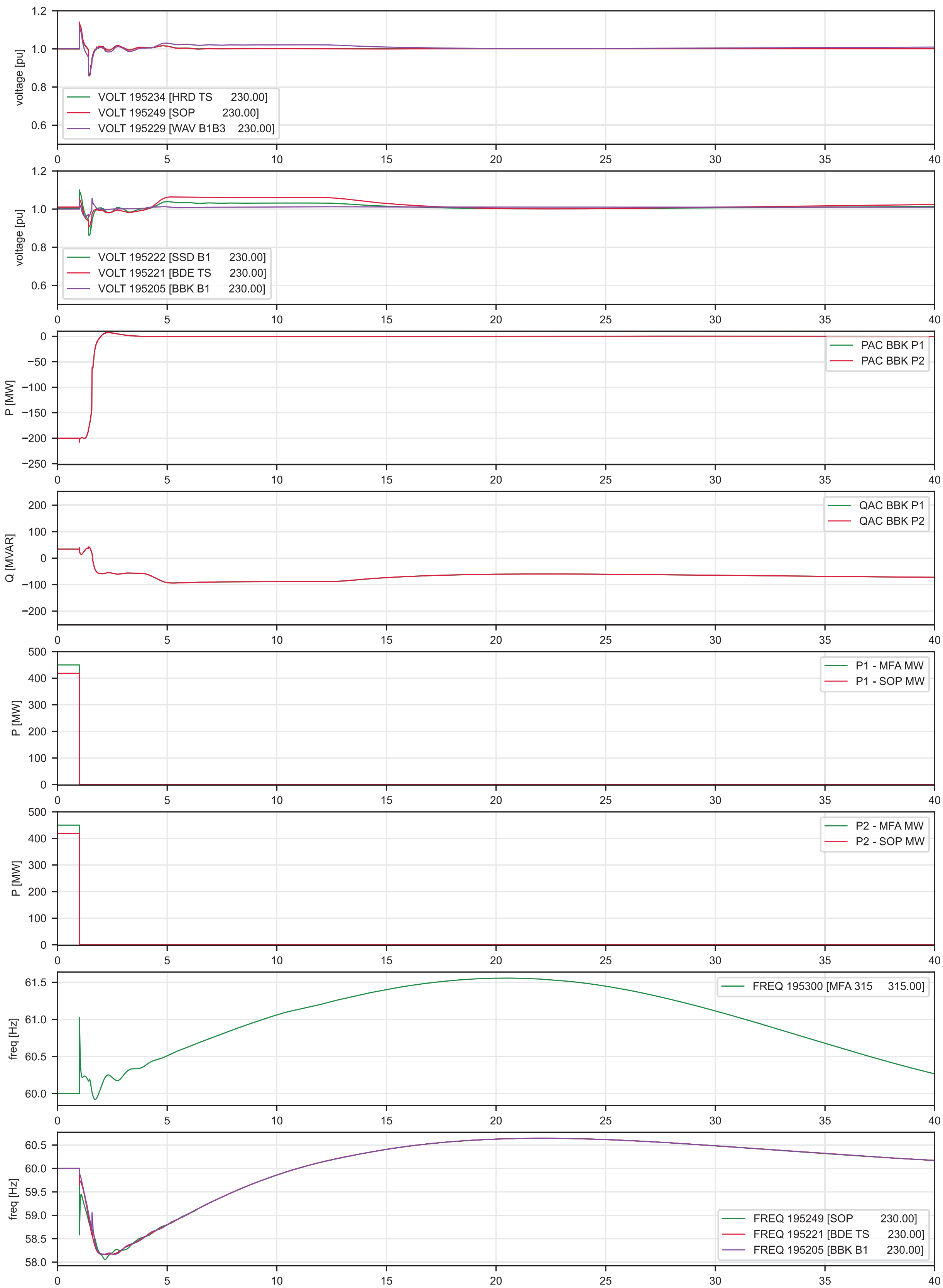
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1250 MW - ML 500 MW - One LIL restart enabled



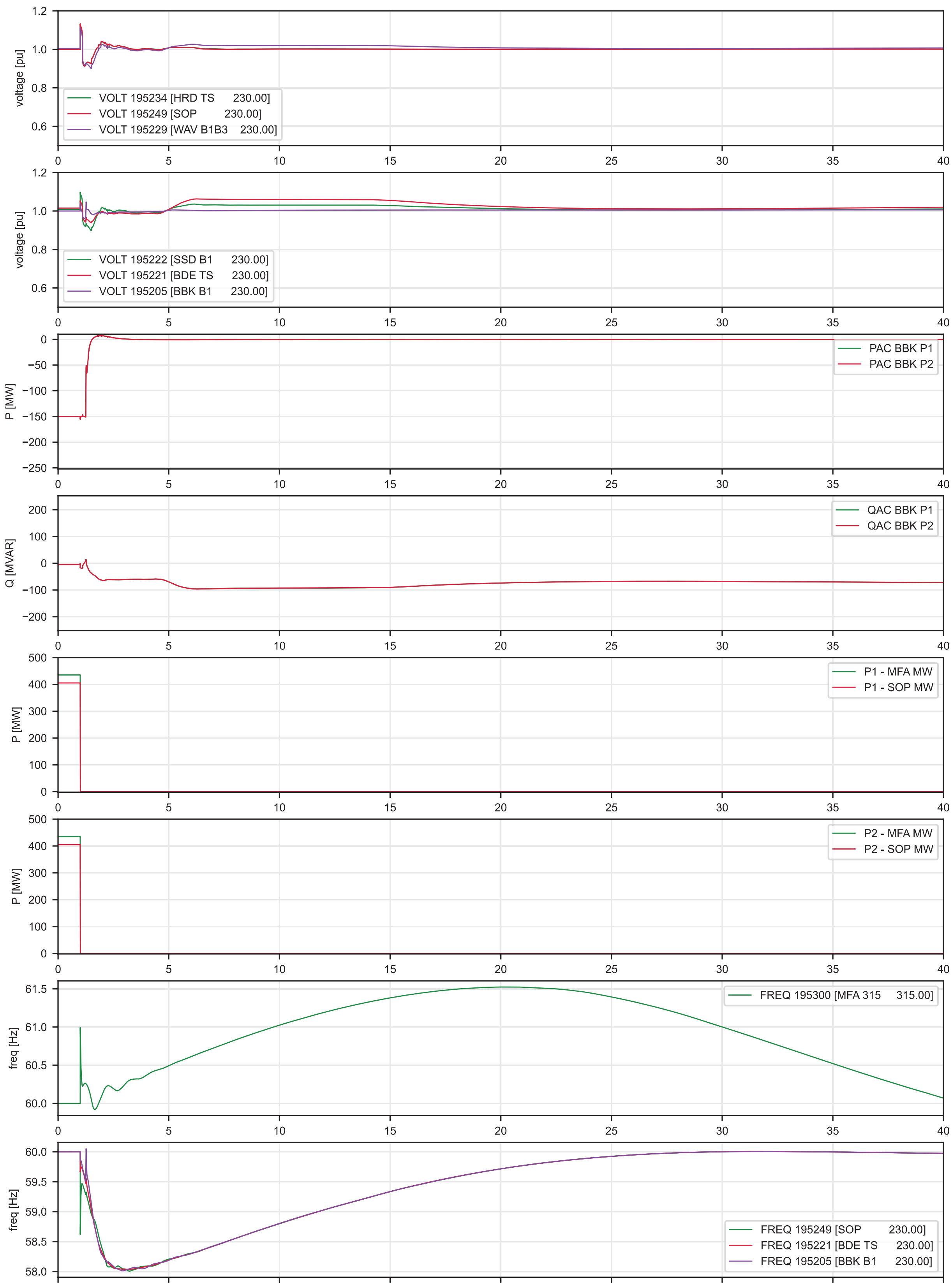
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1250 MW - ML 400 MW - No LIL restarts enabled



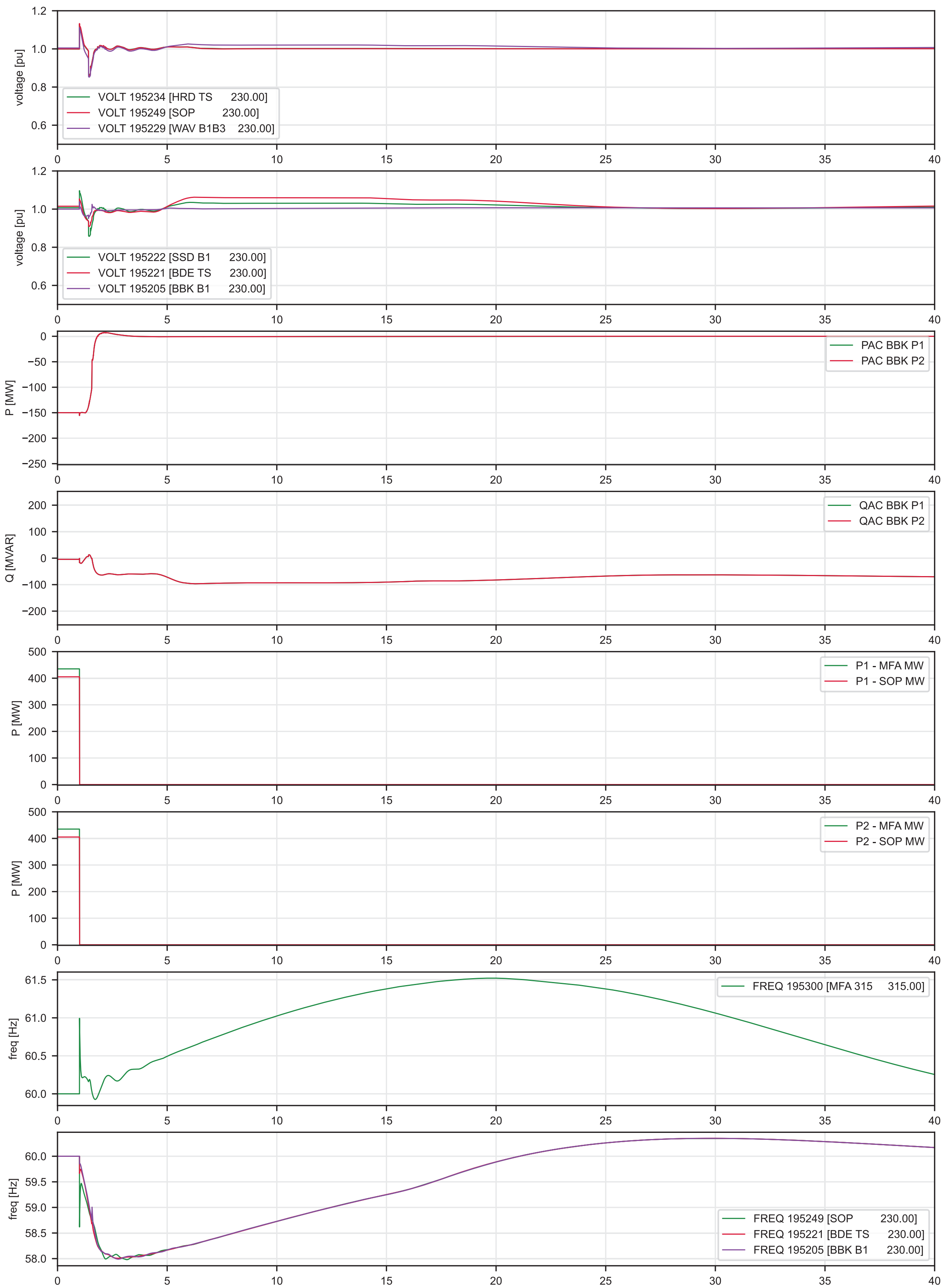
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1250 MW - ML 400 MW - One LIL restart enabled



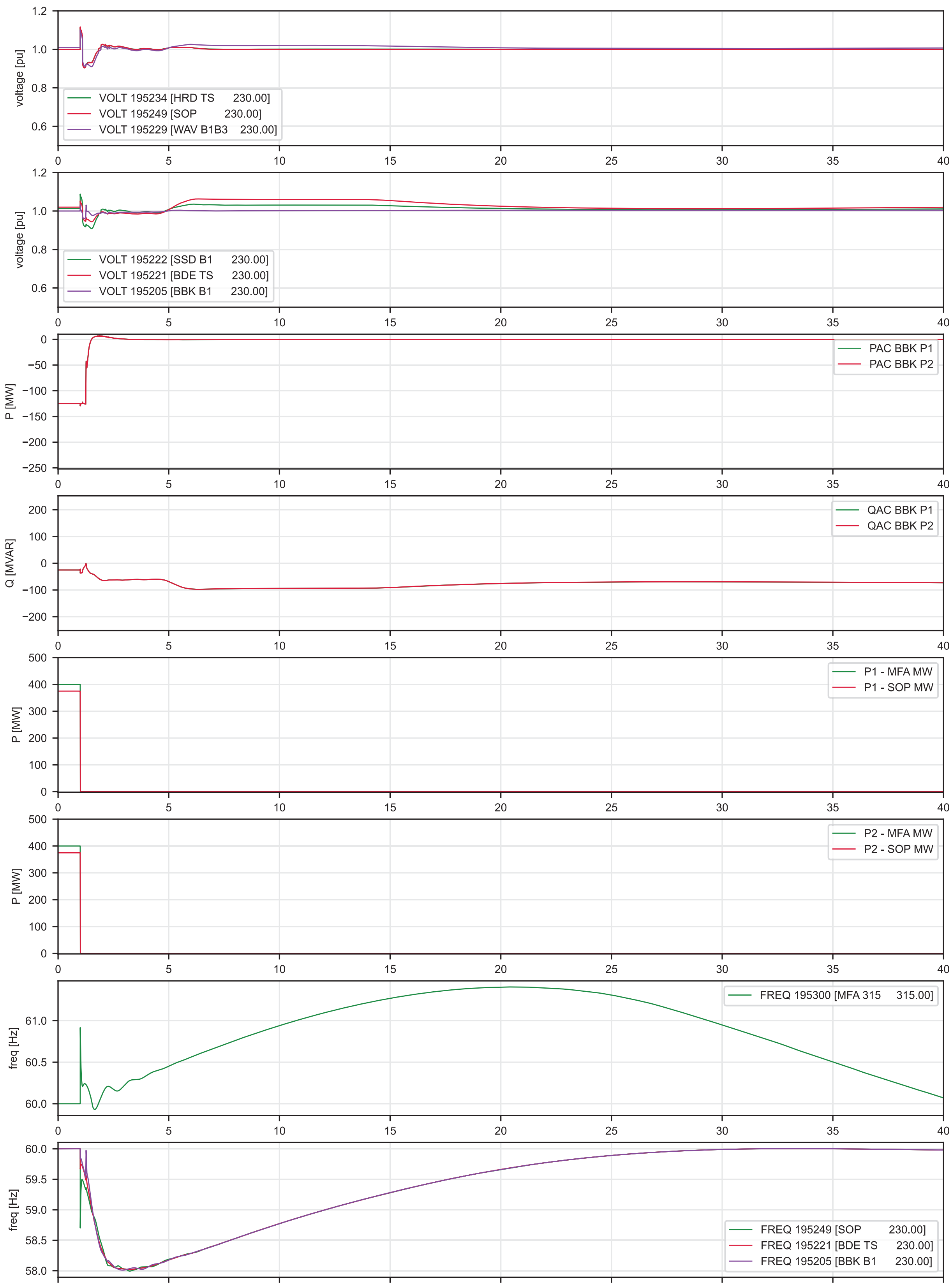
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1250 MW - ML 300 MW - No LIL restarts enabled



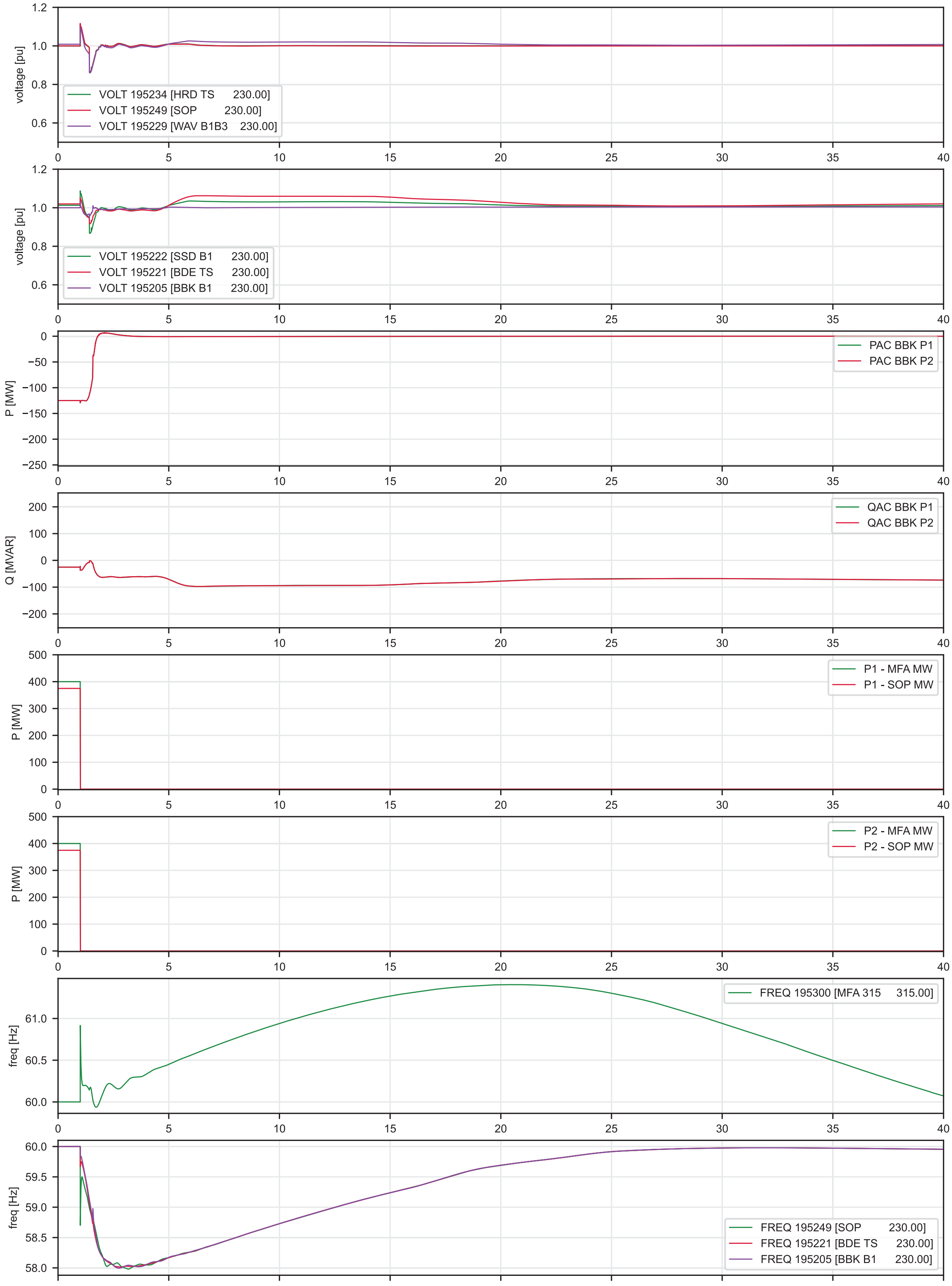
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1250 MW - ML 300 MW - One LIL restart enabled



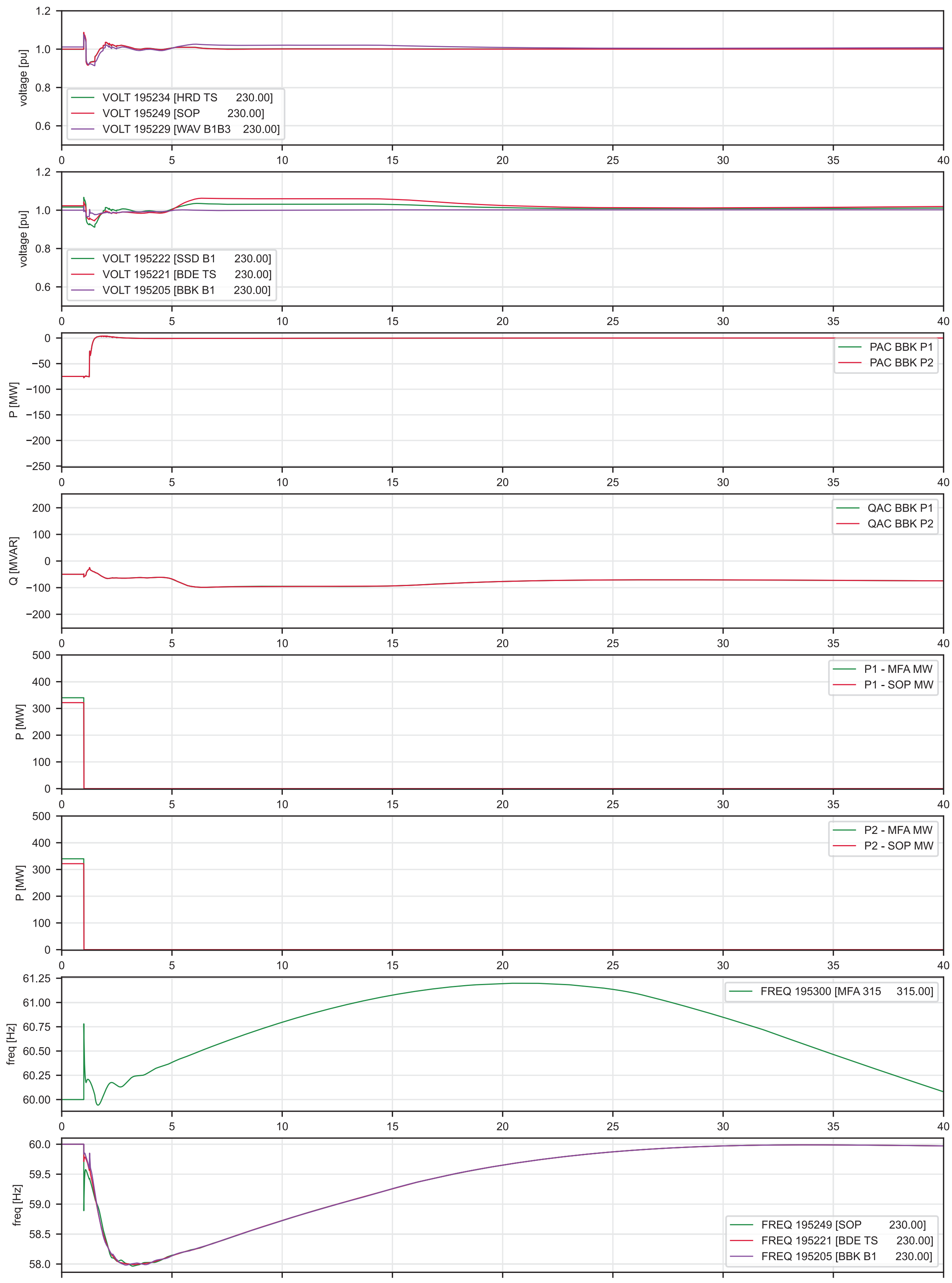
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1250 MW - ML 250 MW - No LIL restarts enabled



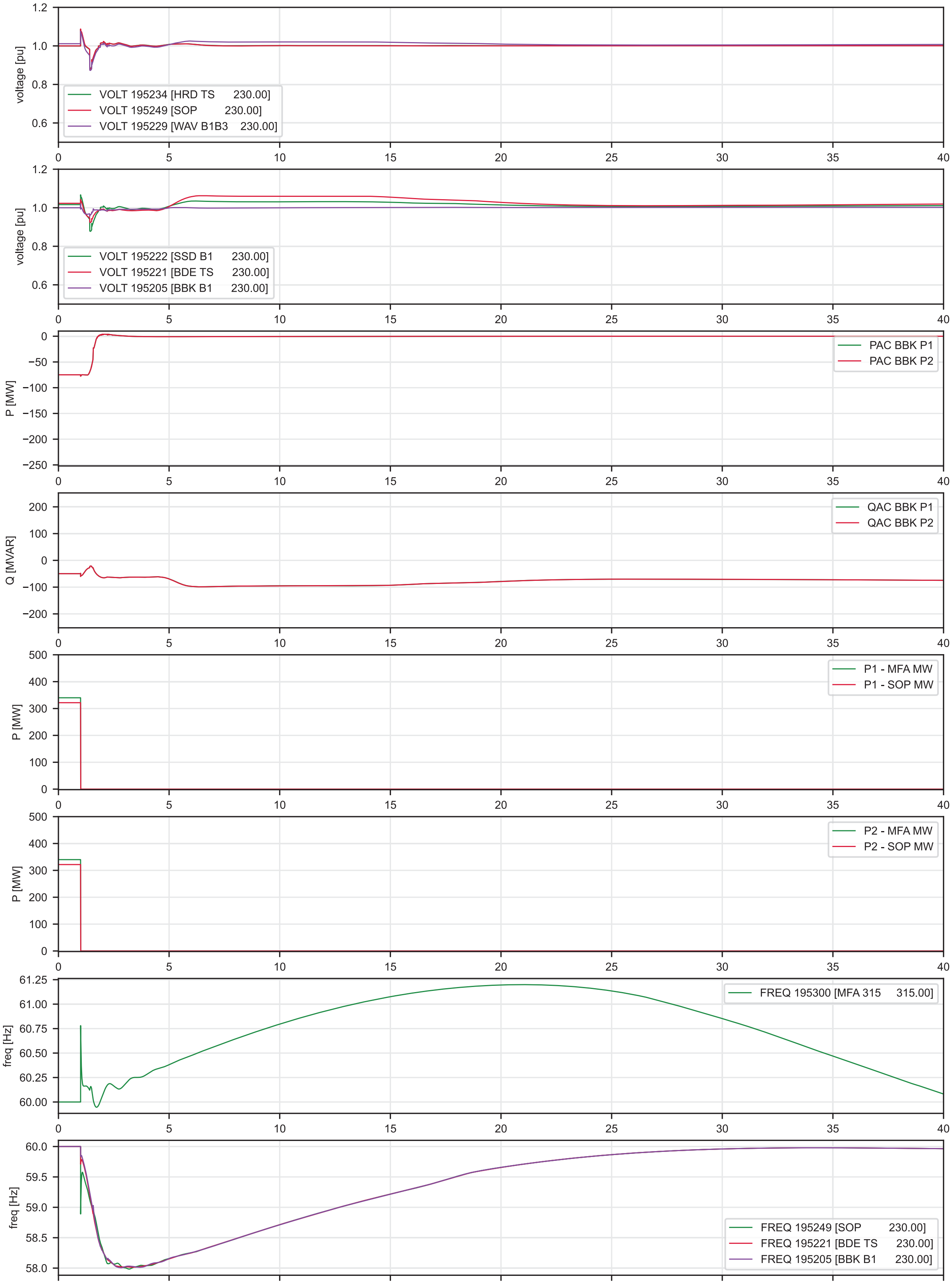
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1250 MW - ML 250 MW - One LIL restart enabled



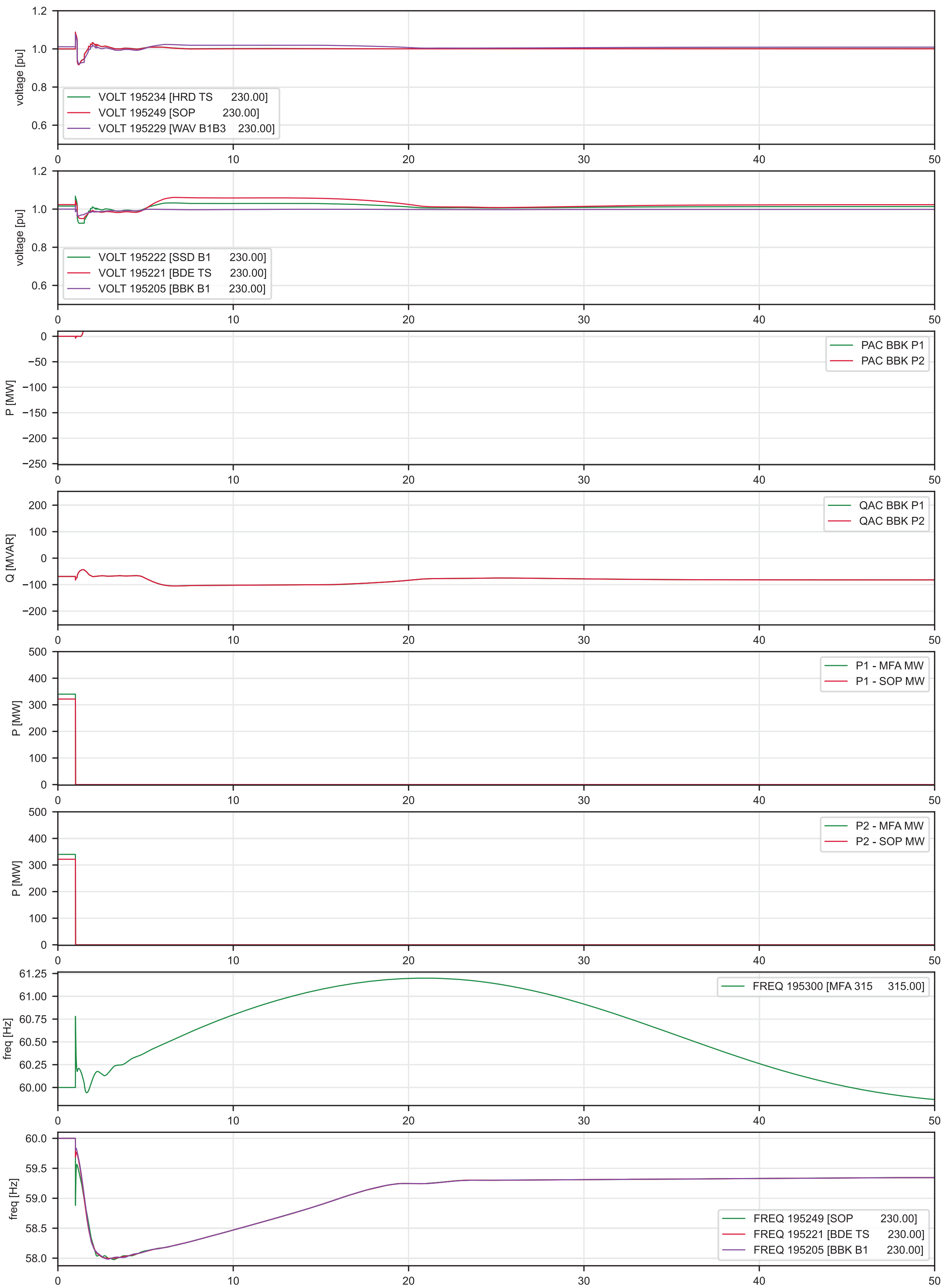
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1250 MW - ML 150 MW - No LIL restarts enabled



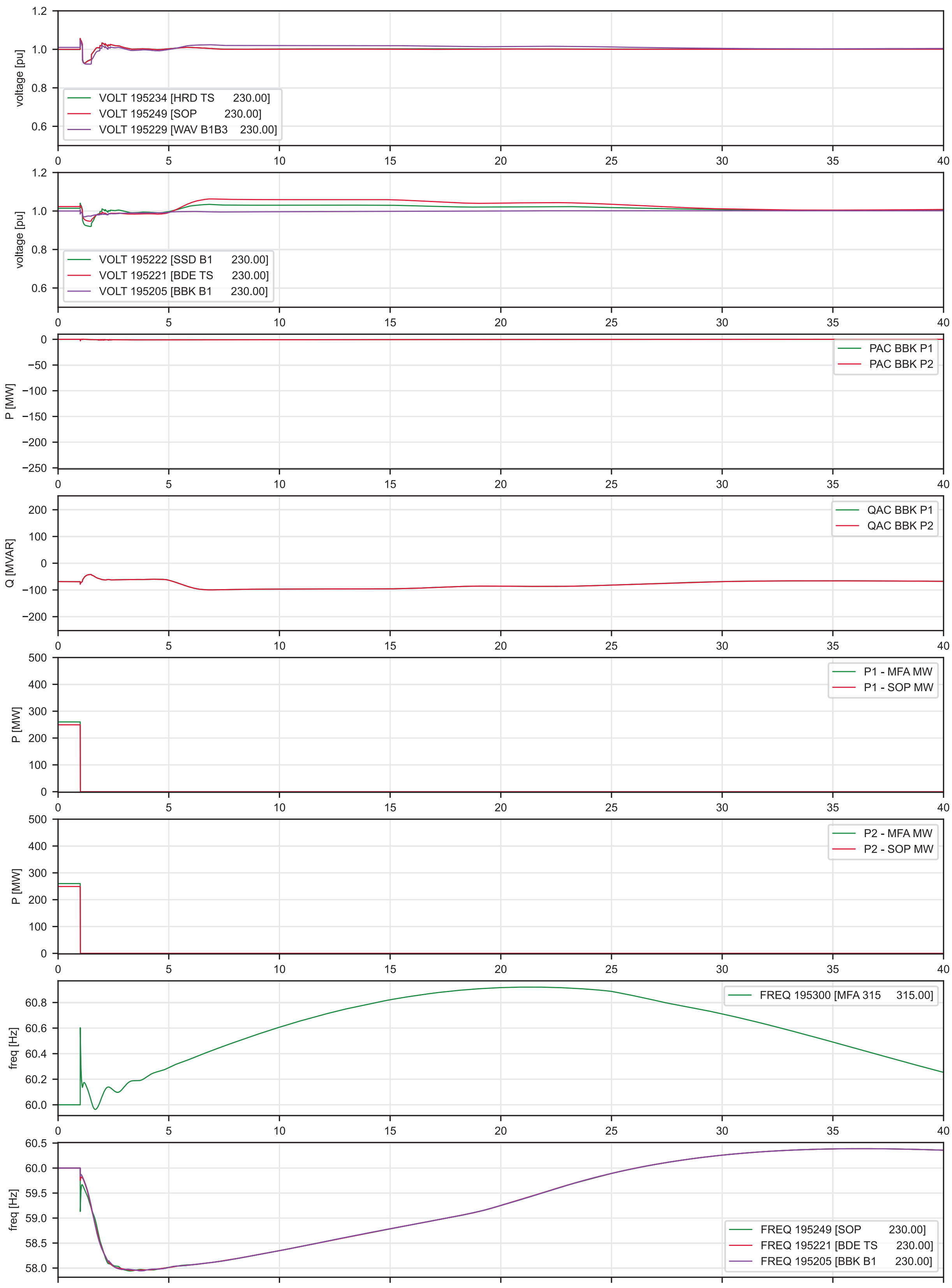
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1250 MW - ML 150 MW - One LIL restart enabled



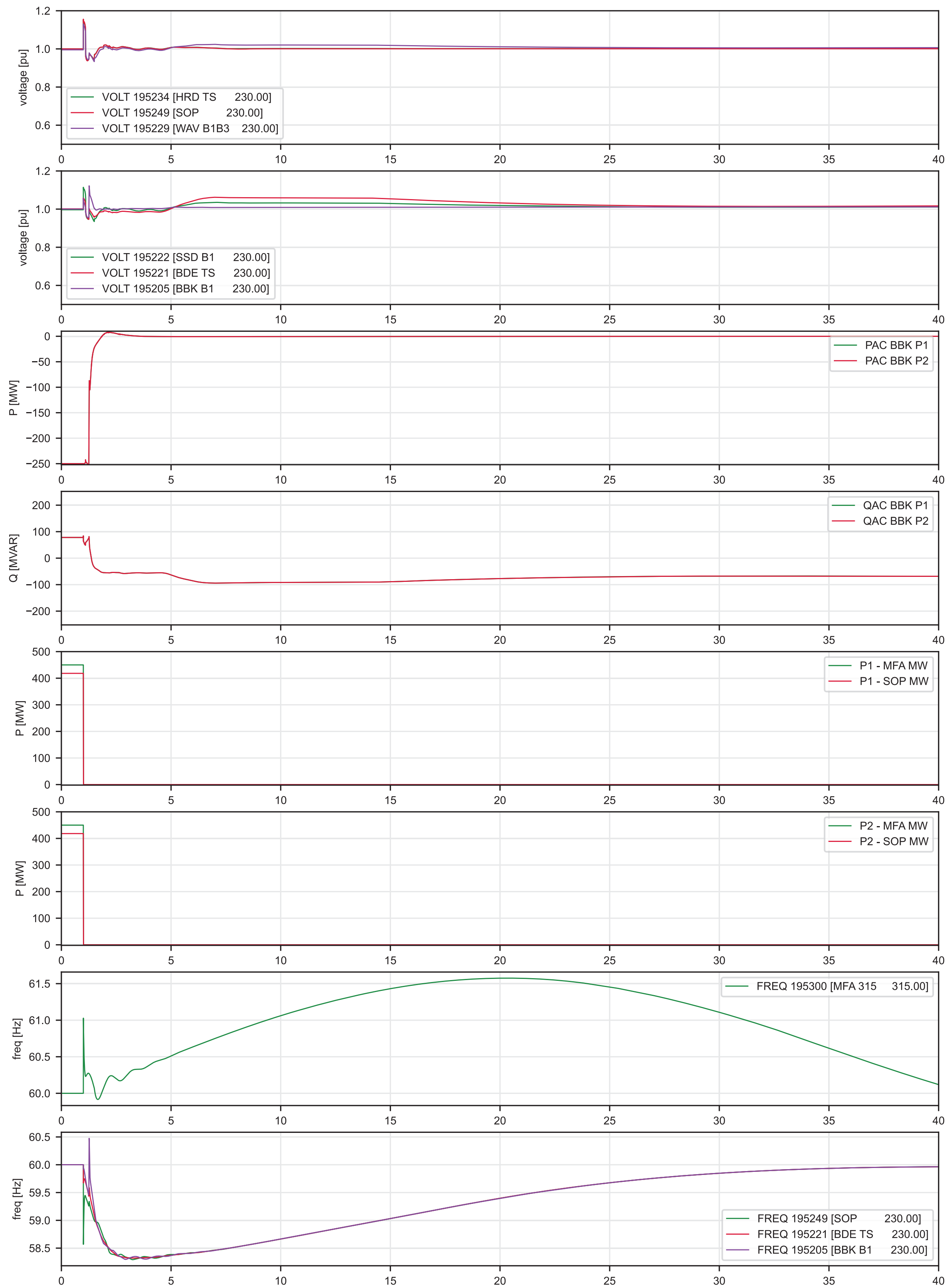
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1250 MW - ML 0 MW / ML Runbacks Inactive / ML F/C Active - No LIL restarts enabled



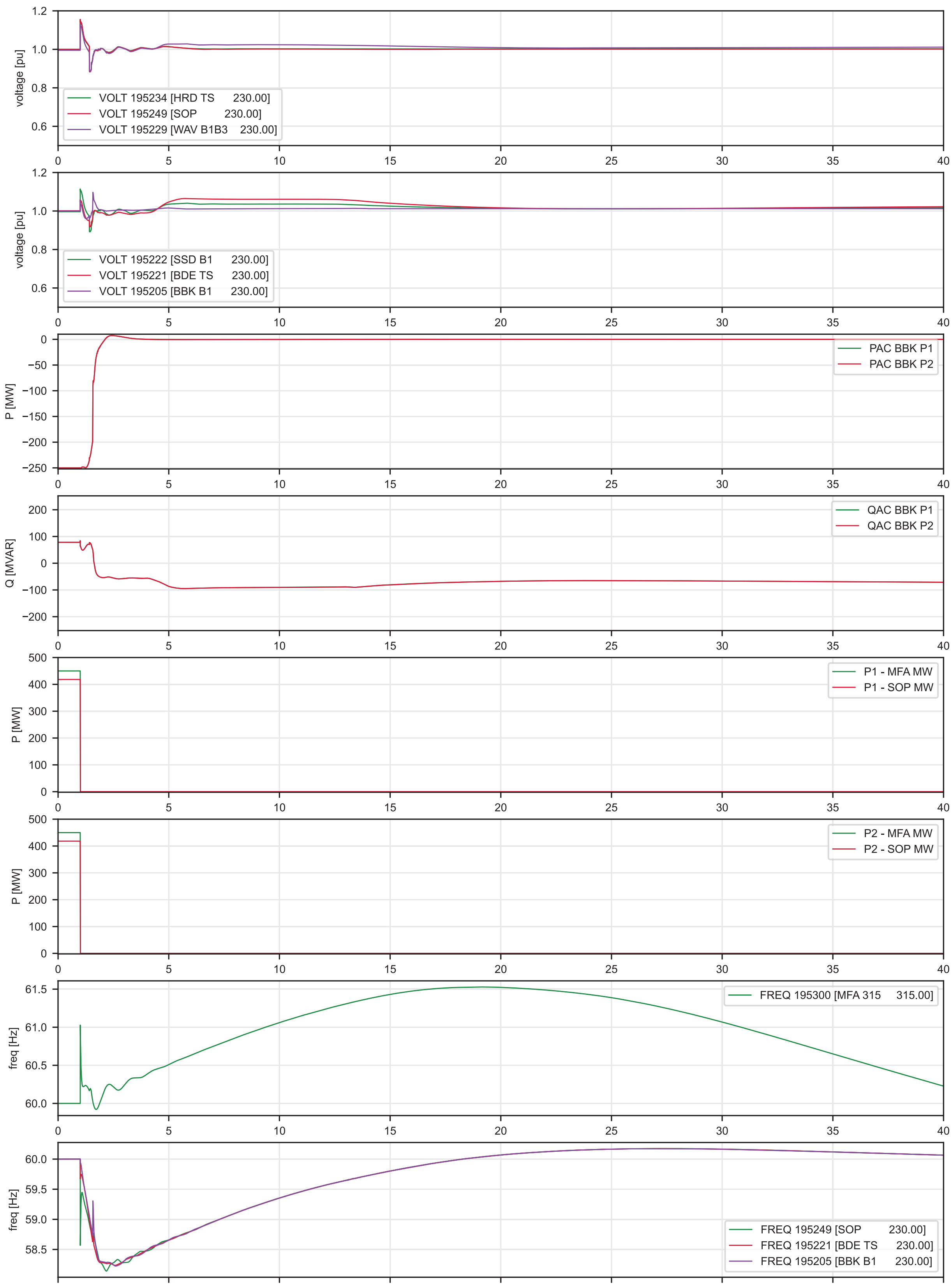
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1250 MW - ML 0 MW / ML Runbacks Inactive / ML F/C Inactive - No LIL restarts enabled



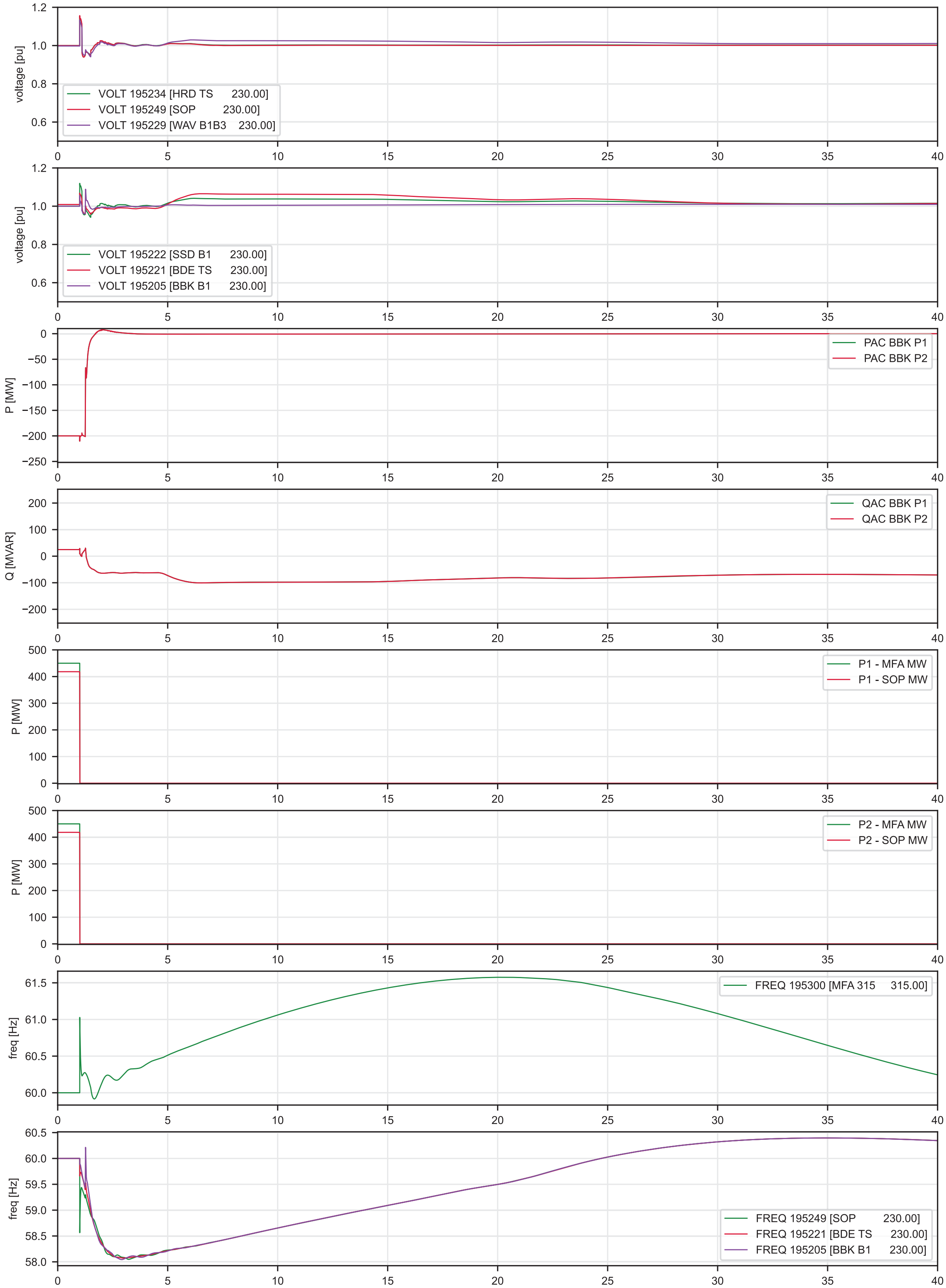
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1000 MW - ML 500 MW - No LIL restarts enabled



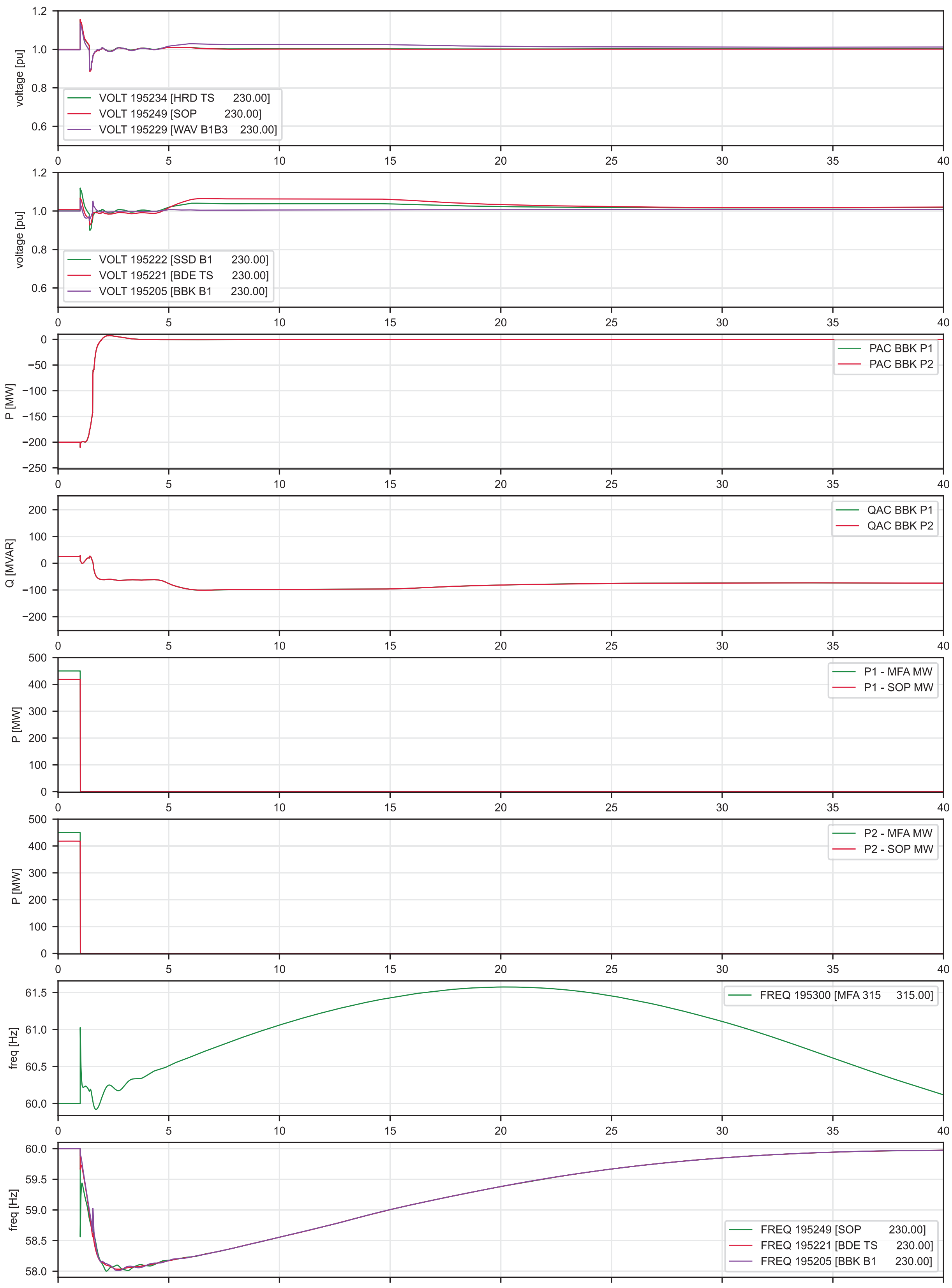
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1000 MW - ML 500 MW - One LIL restart enabled



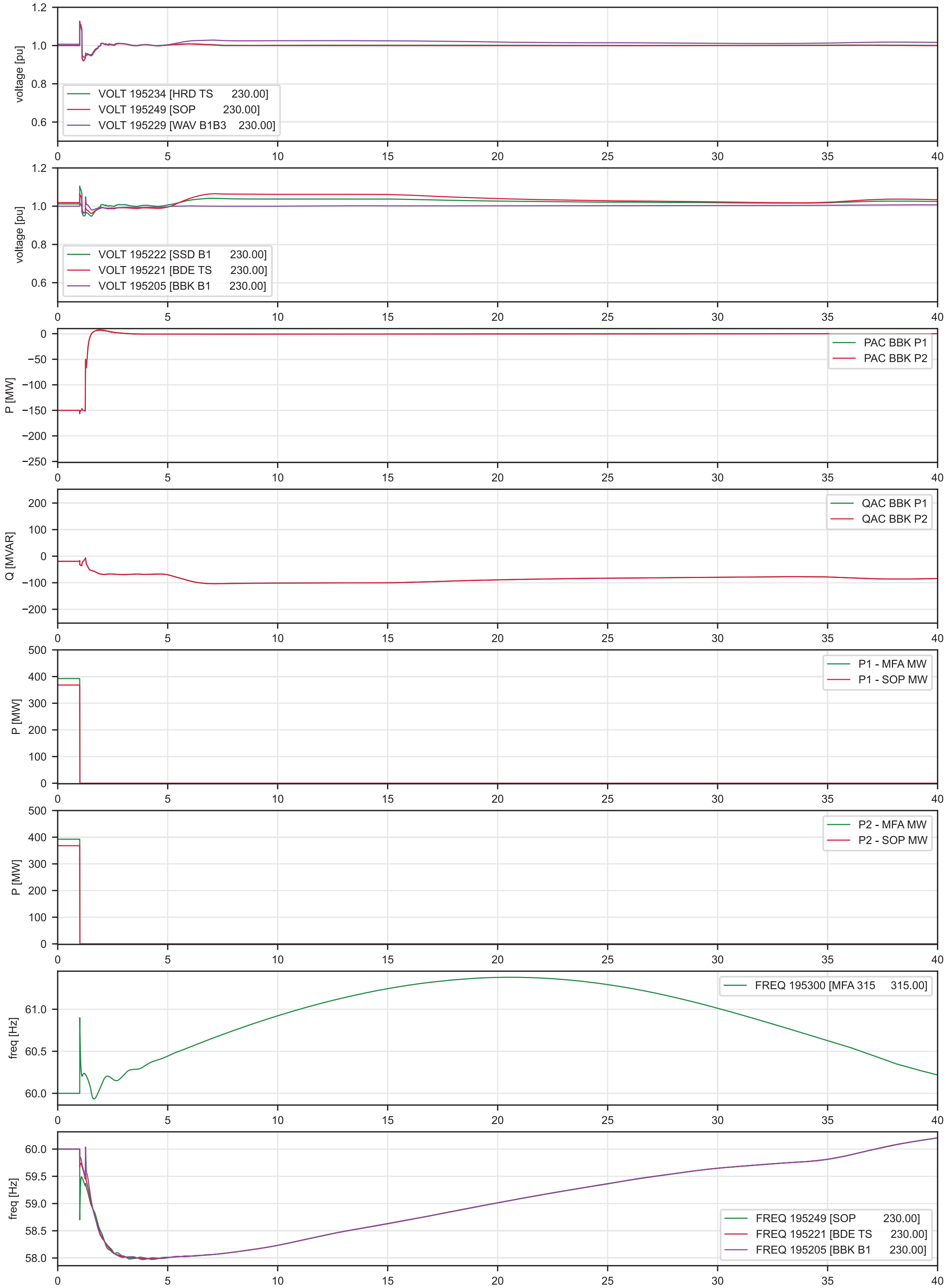
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1000 MW - ML 400 MW - No LIL restarts enabled



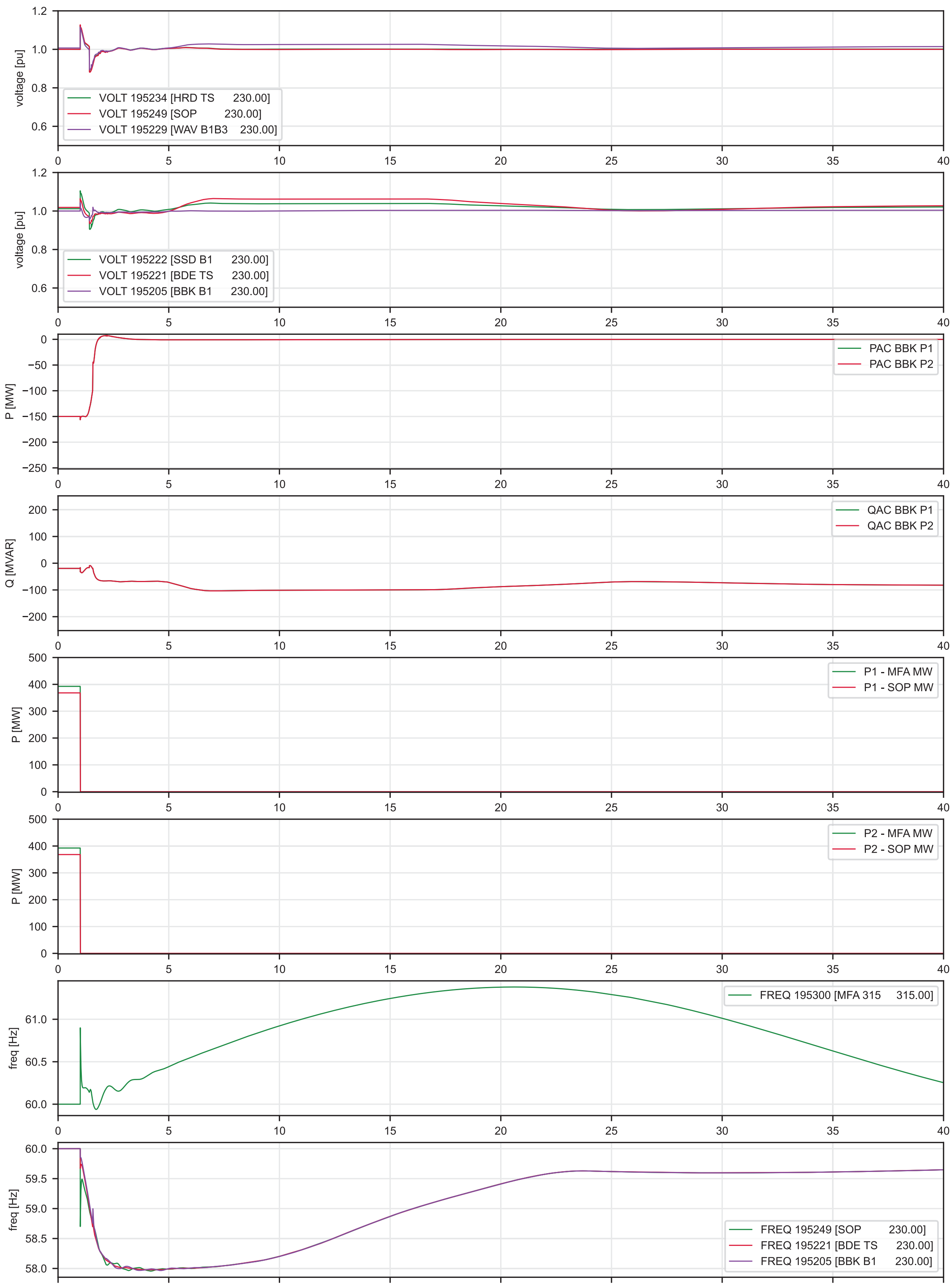
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1000 MW - ML 400 MW - One LIL restart enabled



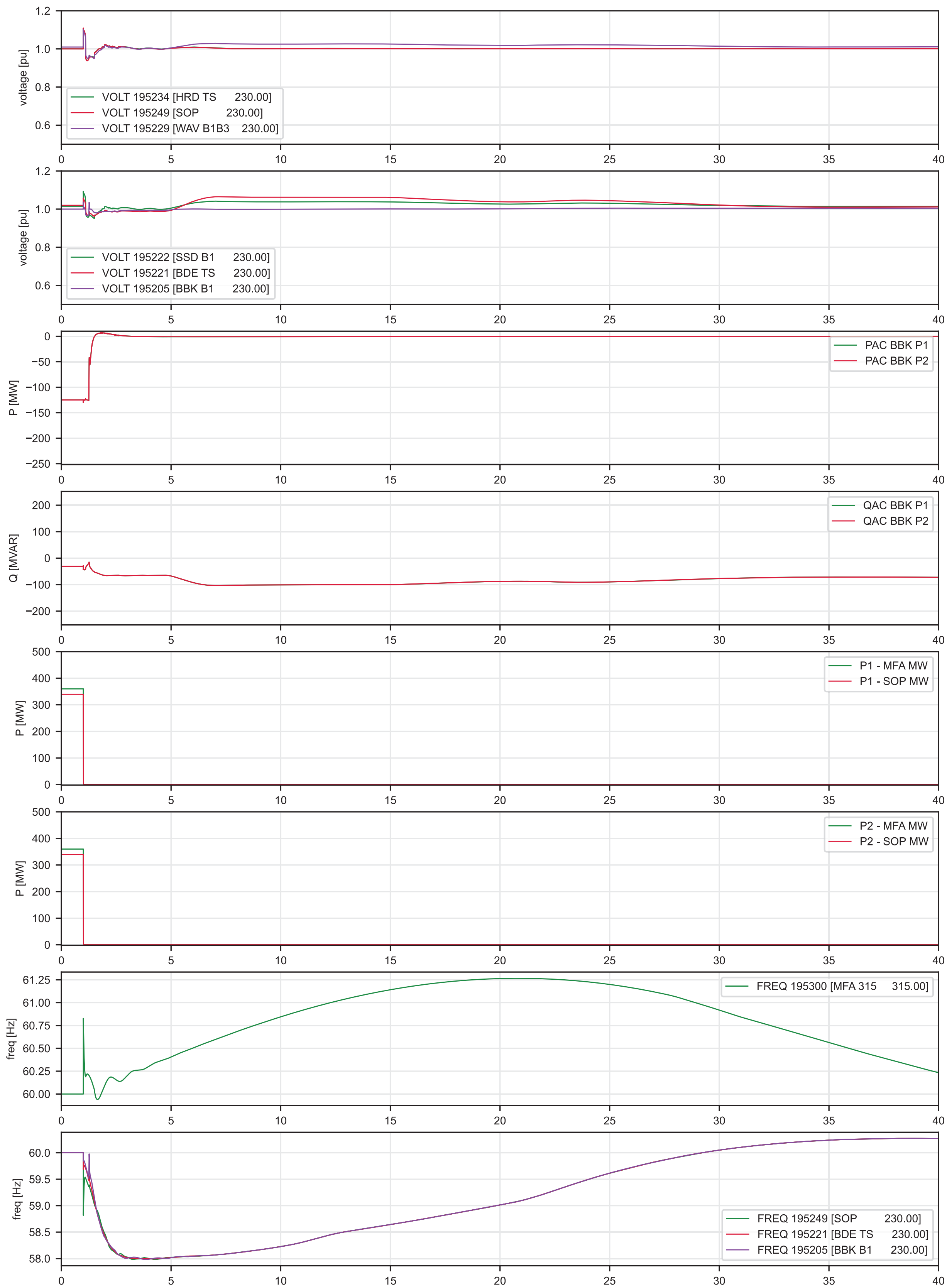
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1000 MW - ML 300 MW - No LIL restarts enabled



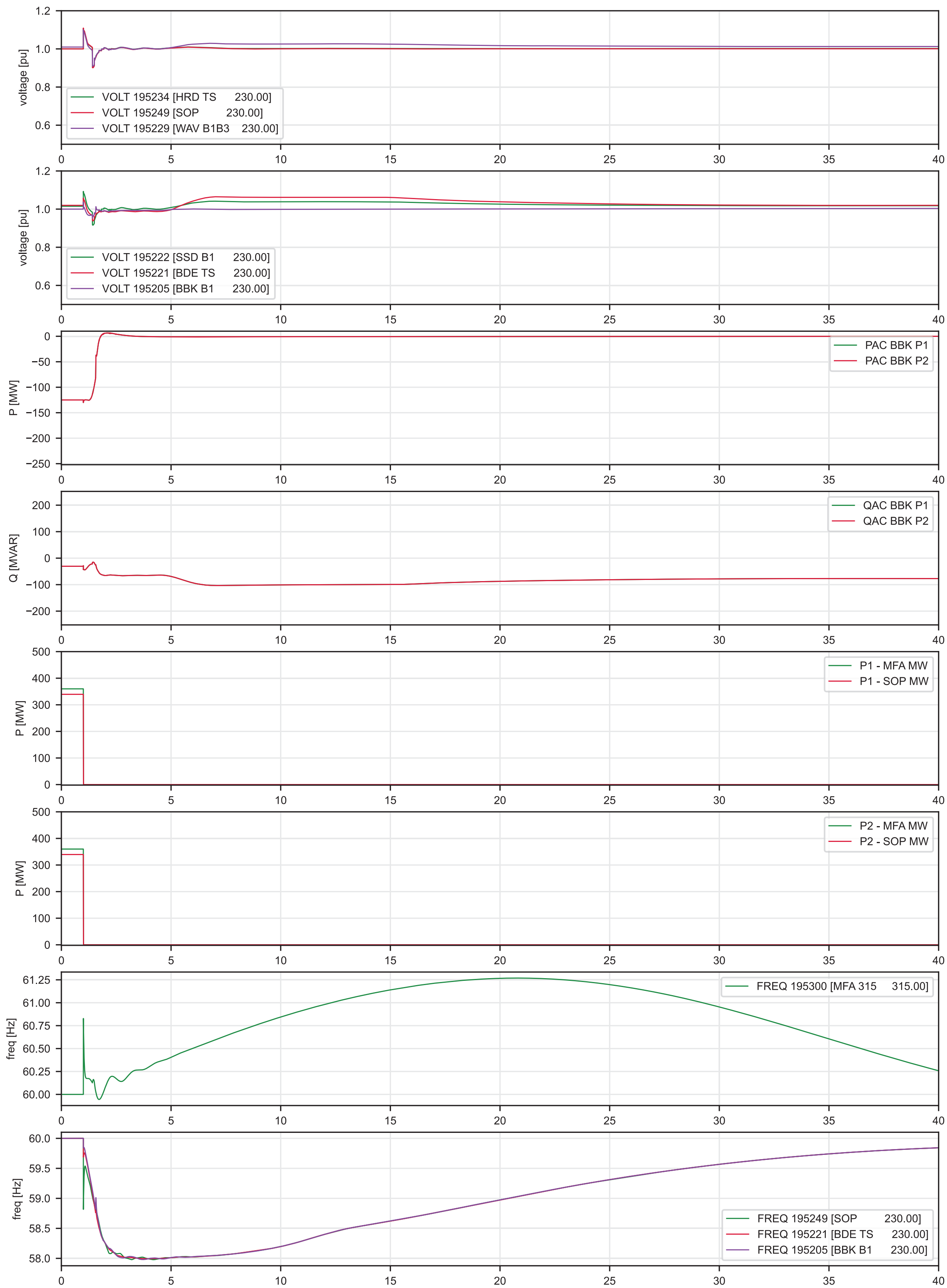
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1000 MW - ML 300 MW - One LIL restart enabled



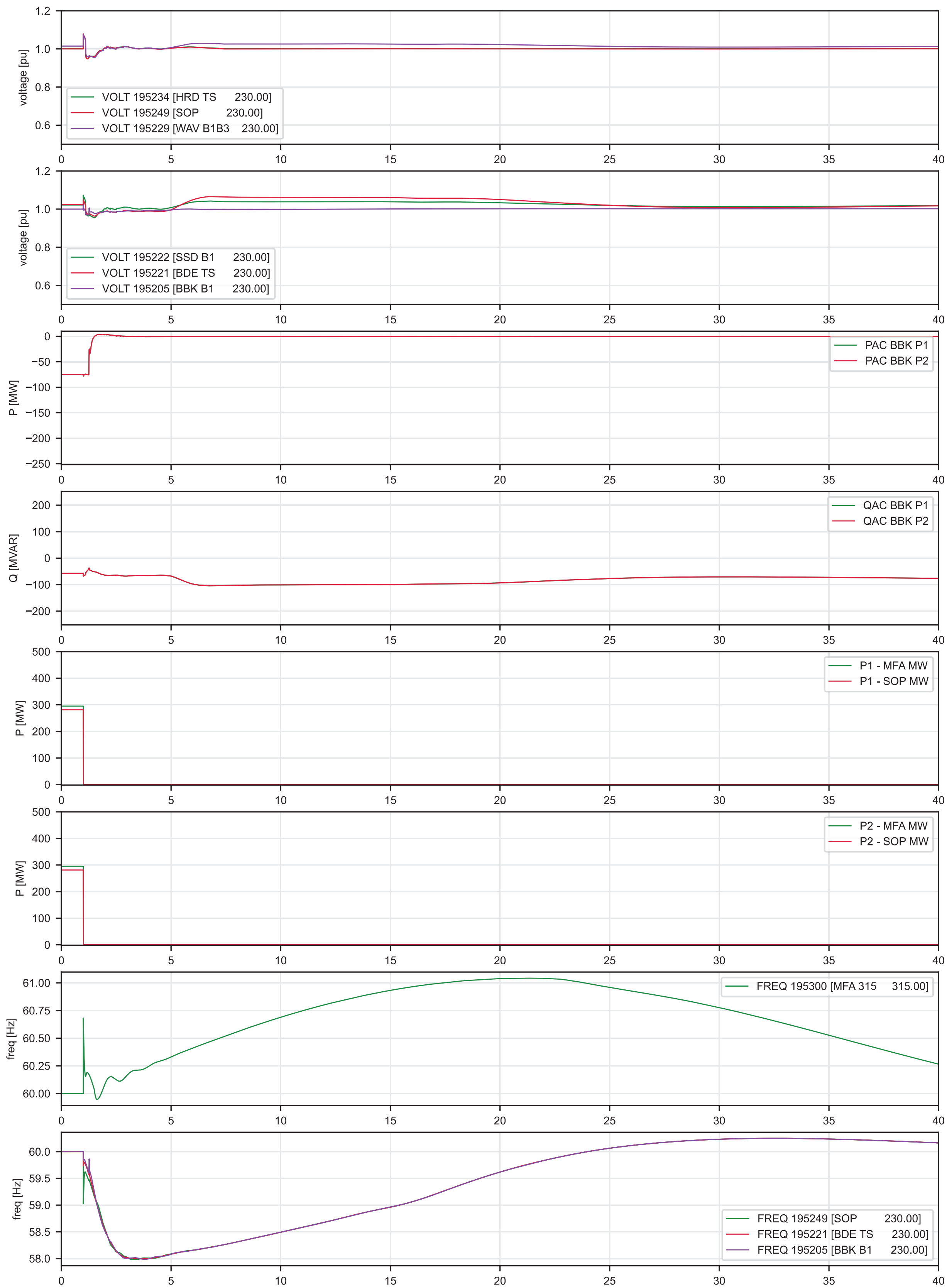
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1000 MW - ML 250 MW - No LIL restarts enabled



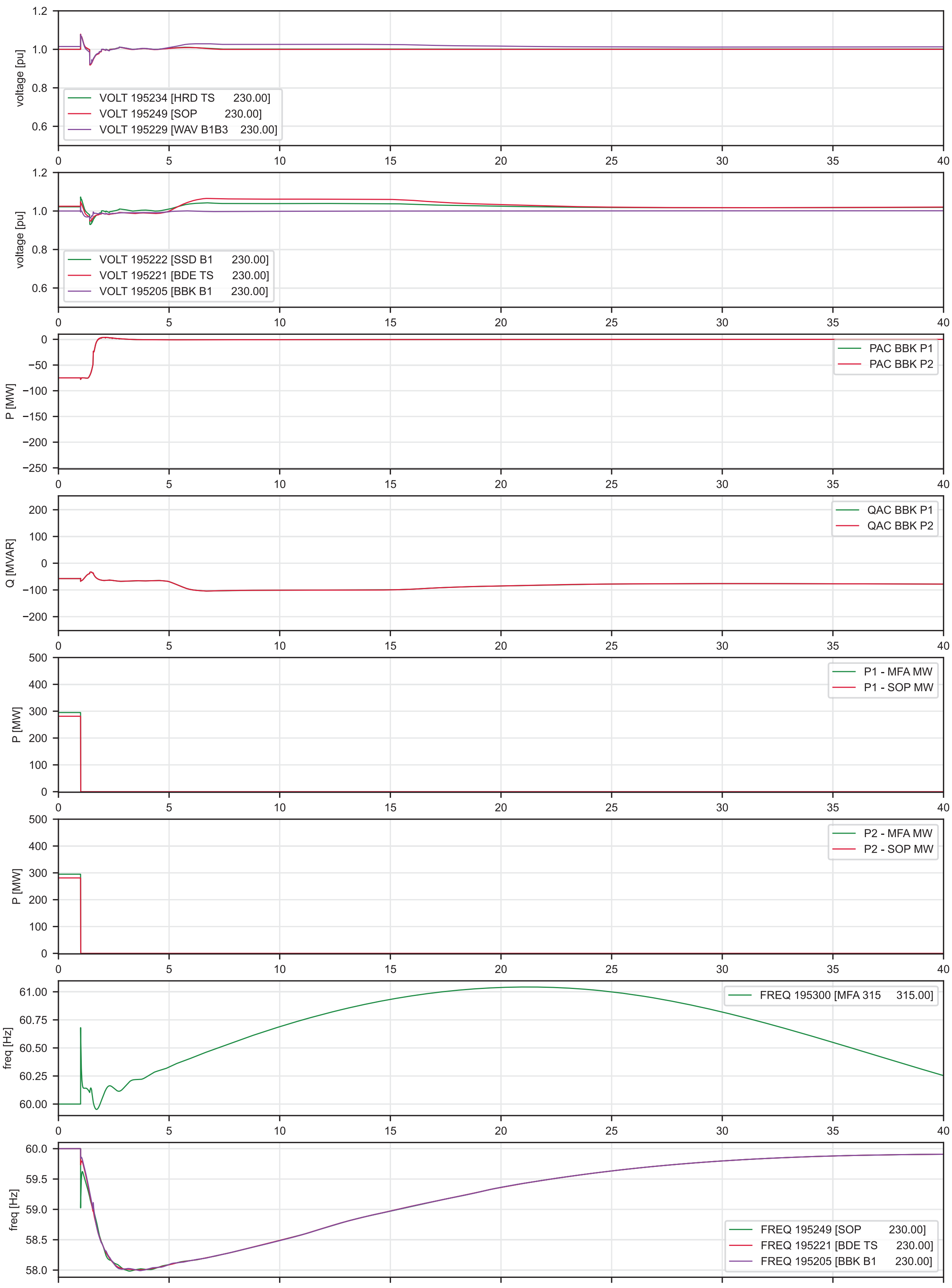
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1000 MW - ML 250 MW - One LIL restart enabled



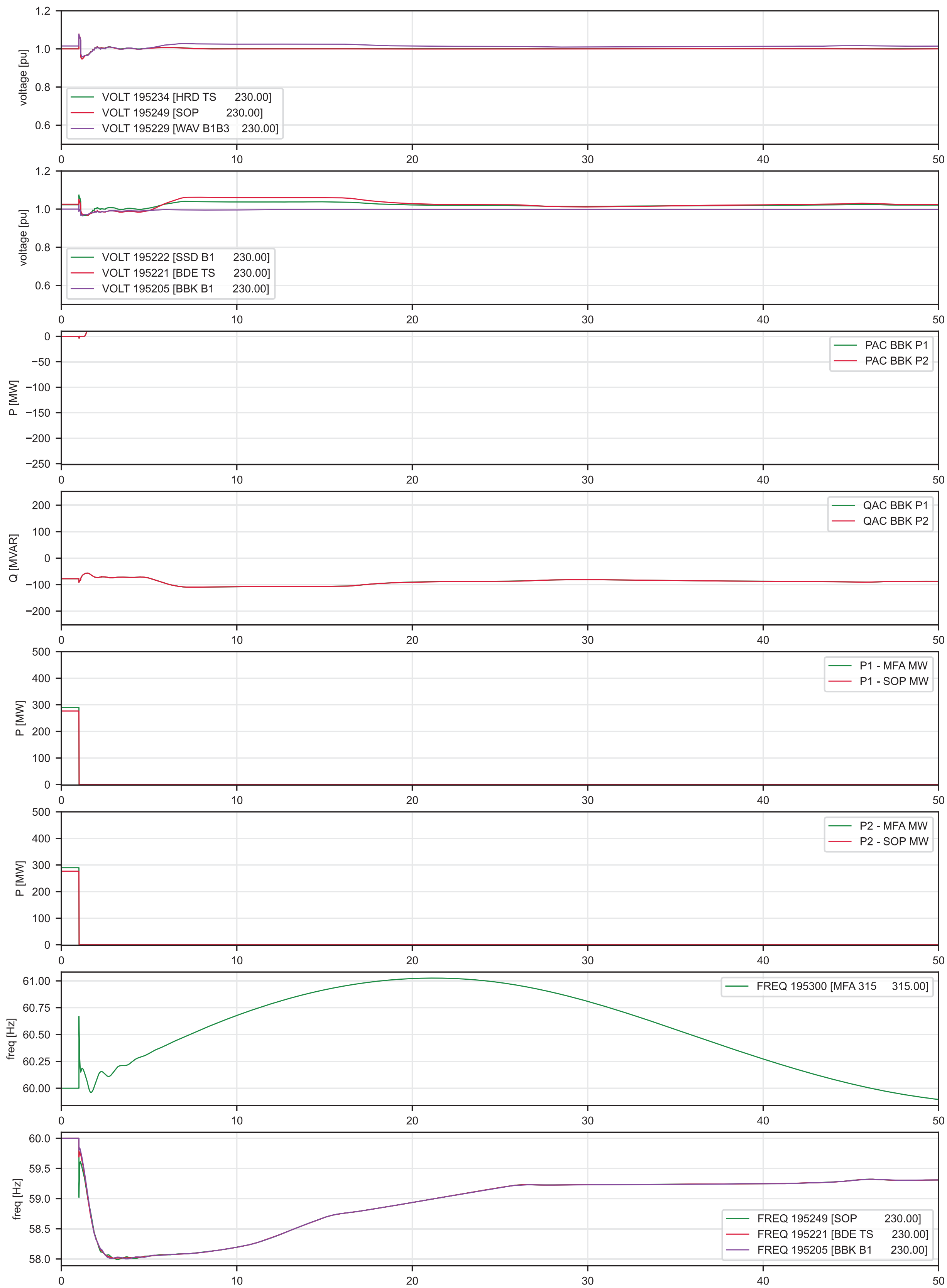
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1000 MW - ML 150 MW - No LIL restarts enabled



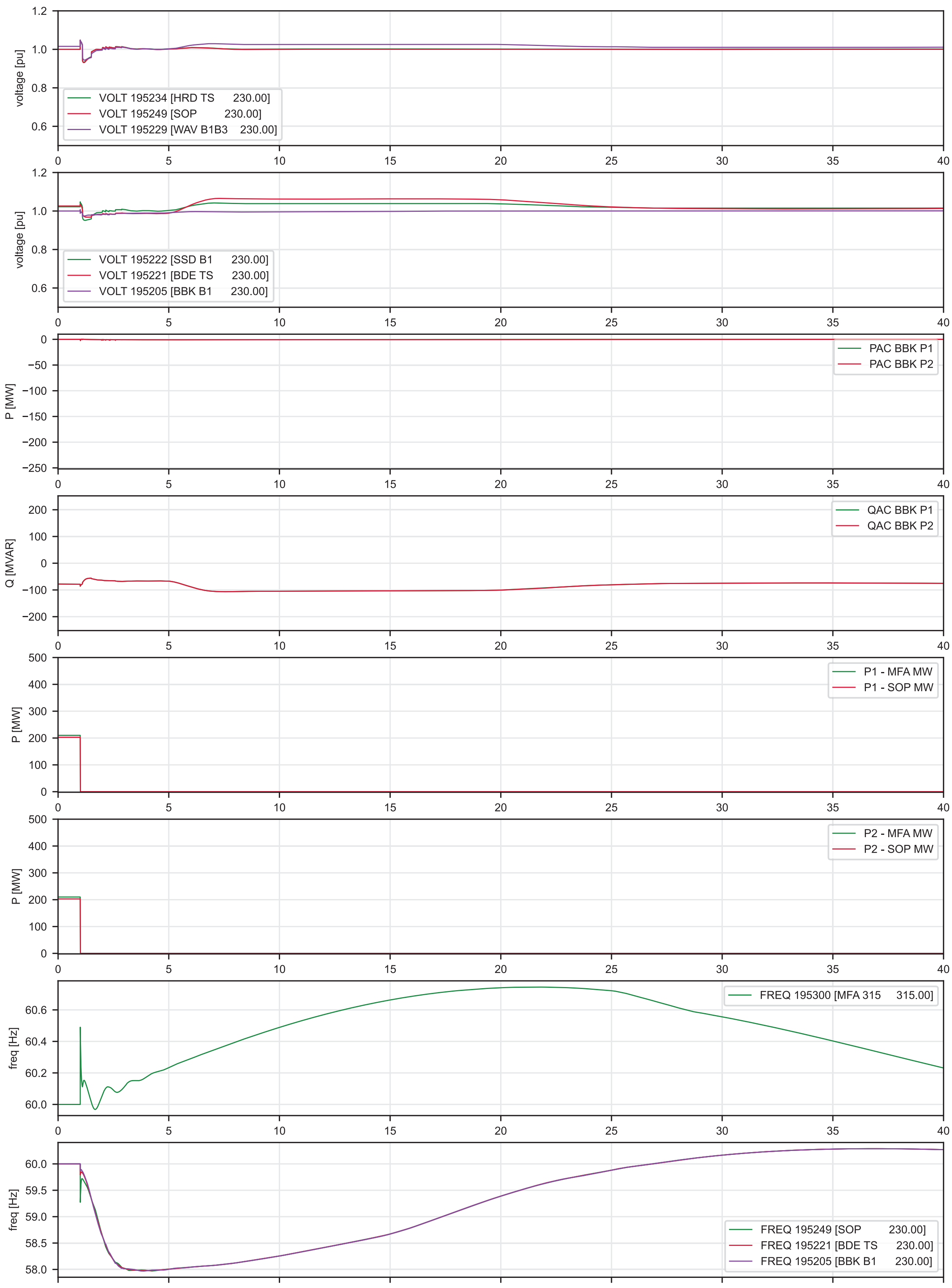
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1000 MW - ML 150 MW - One LIL restart enabled



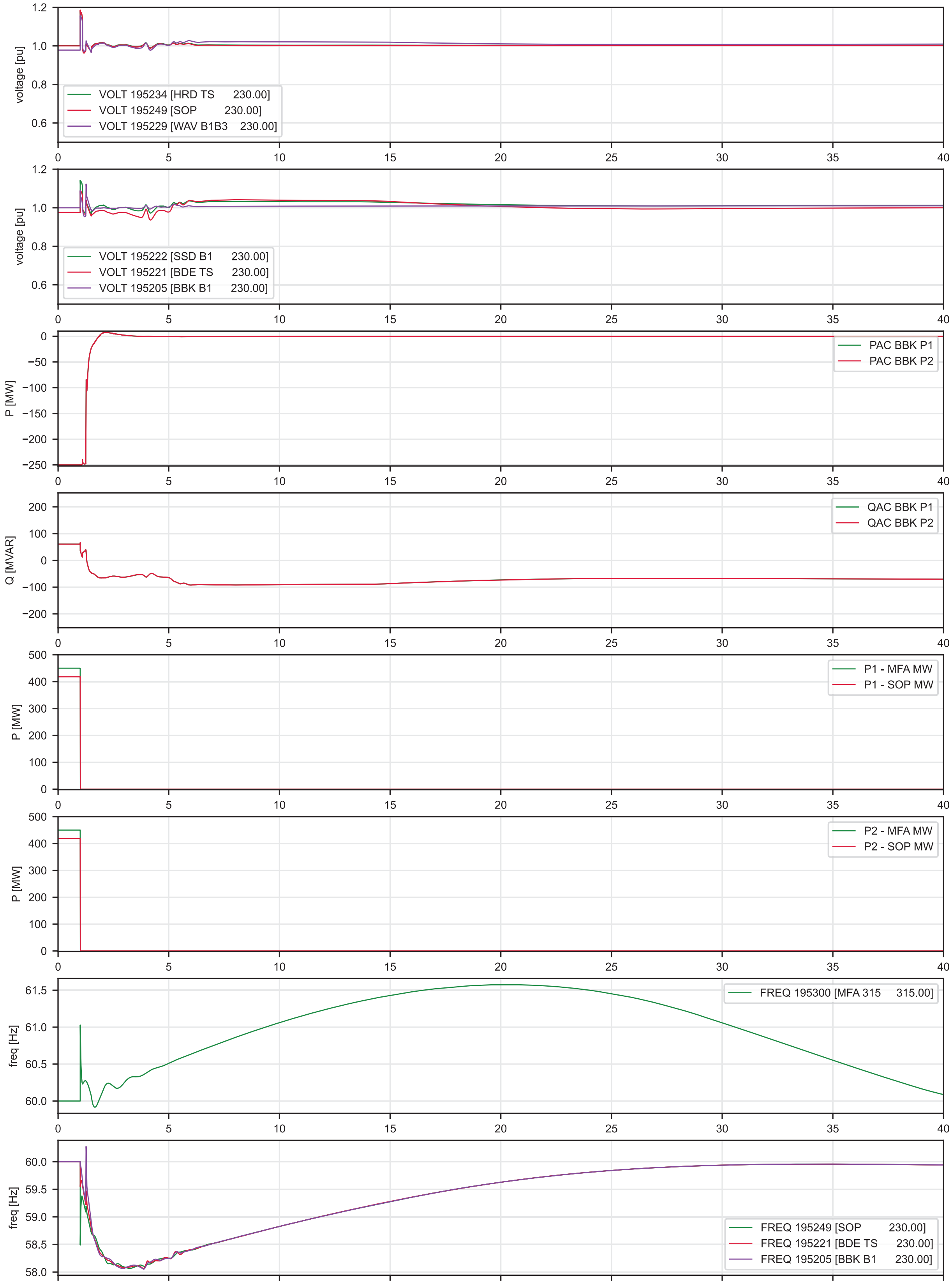
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1000 MW - ML 0 MW / ML Runbacks Inactive / ML F/C Active - No LIL restarts enabled



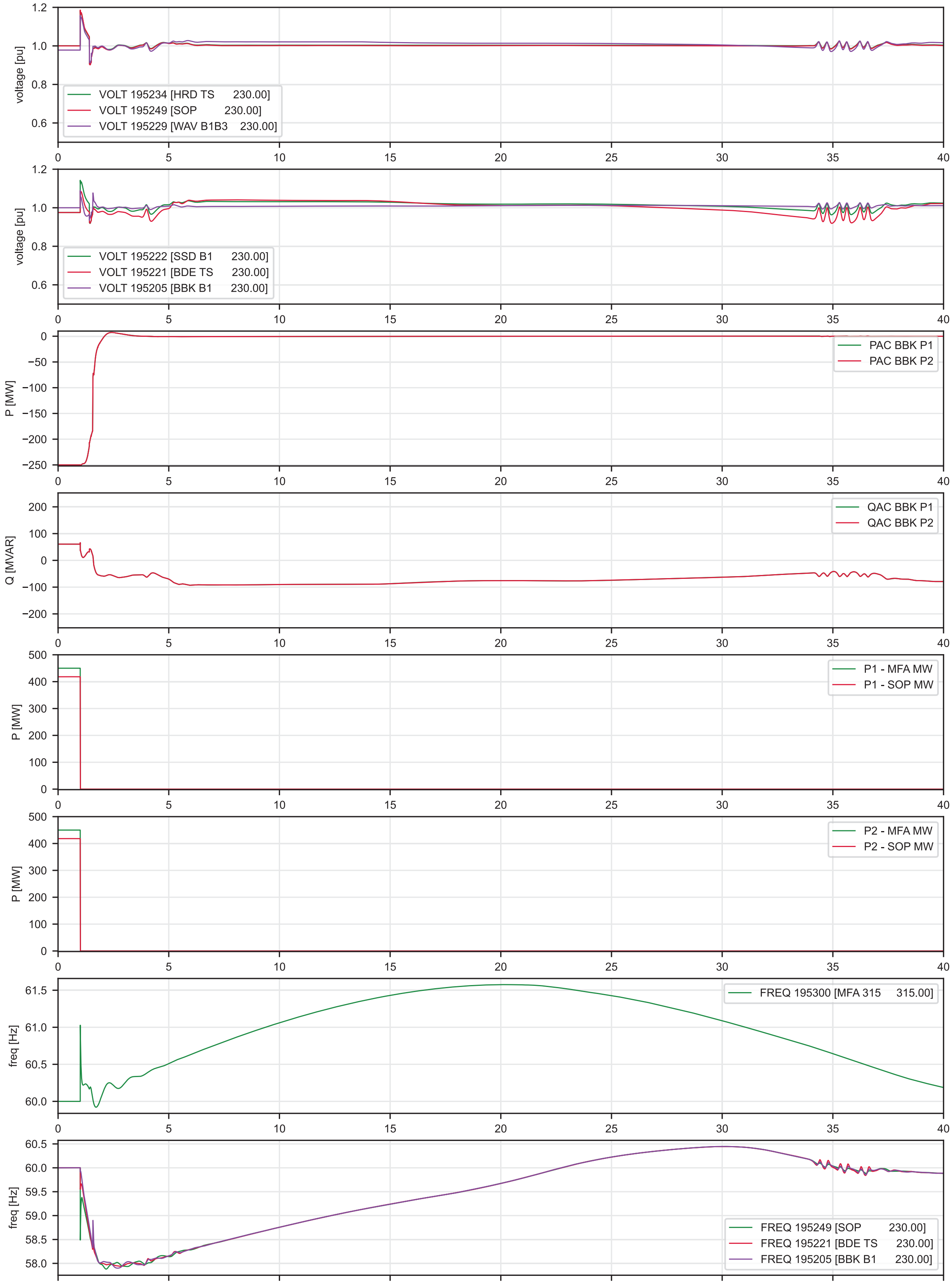
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 1000 MW - ML 0 MW / ML Runbacks Inactive / ML F/C Inactive - No LIL restarts enabled



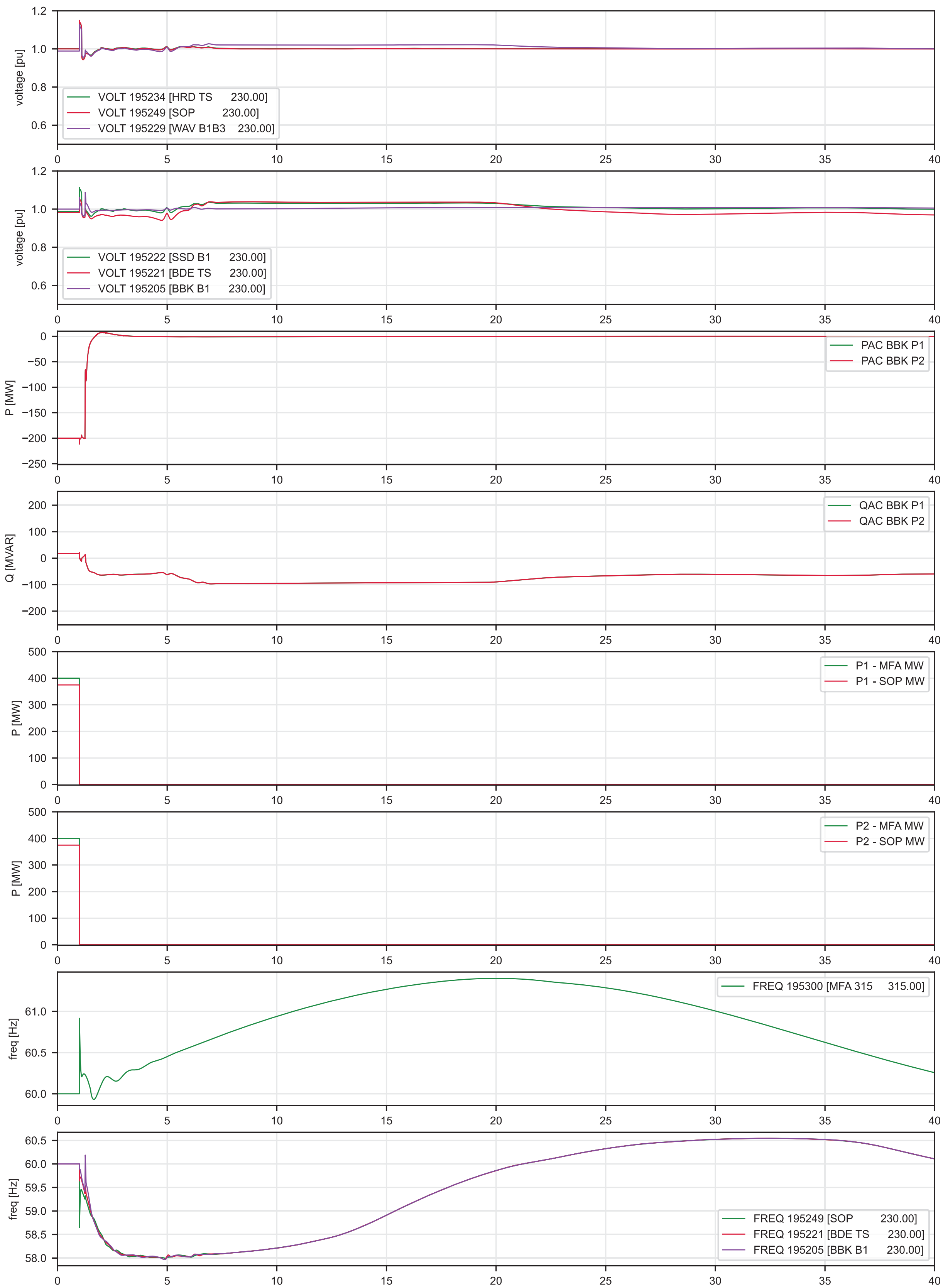
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 750 MW - ML 500 MW - No LIL restarts enabled



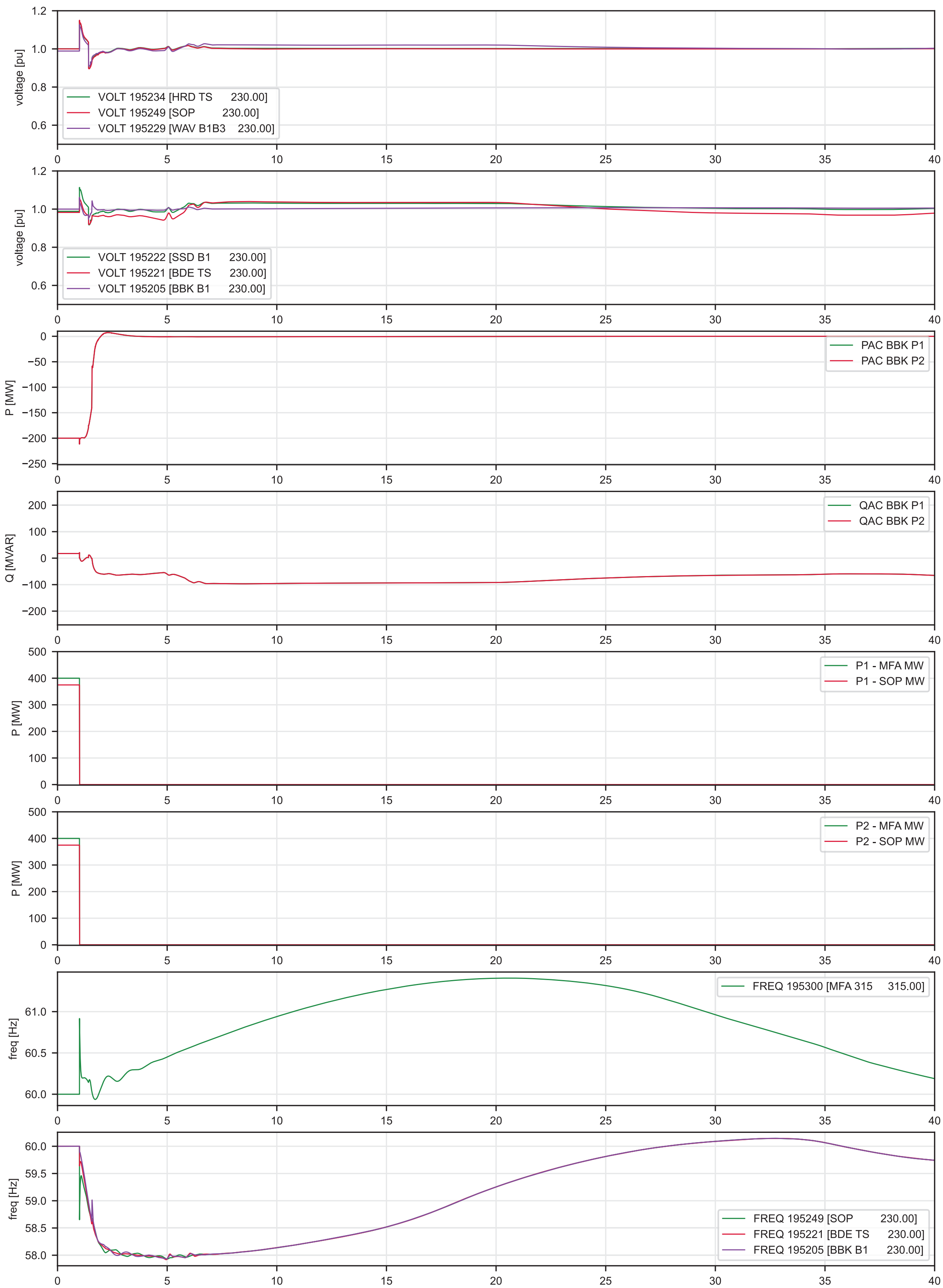
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 750 MW - ML 500 MW - One LIL restart enabled



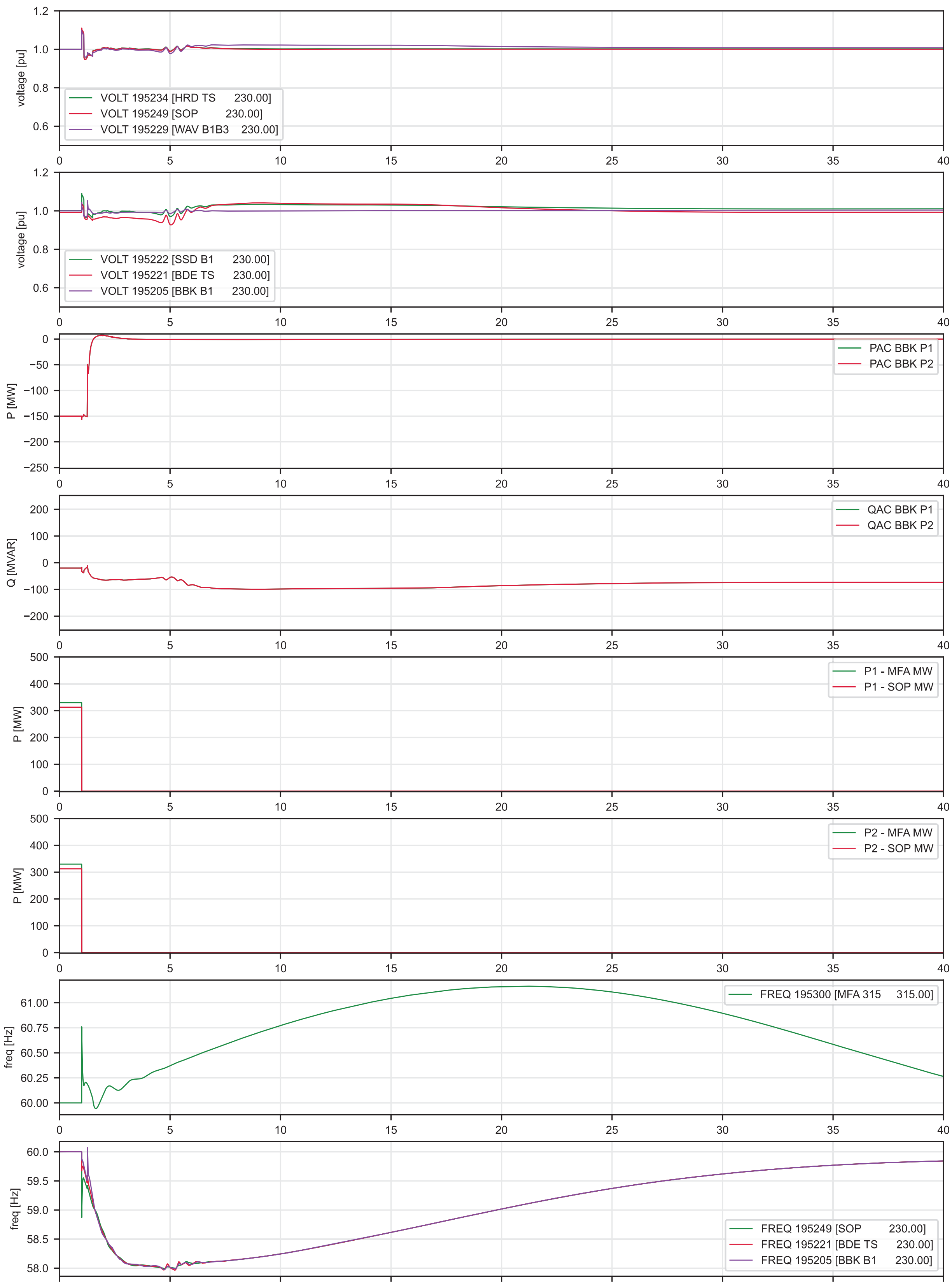
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 750 MW - ML 400 MW - No LIL restarts enabled



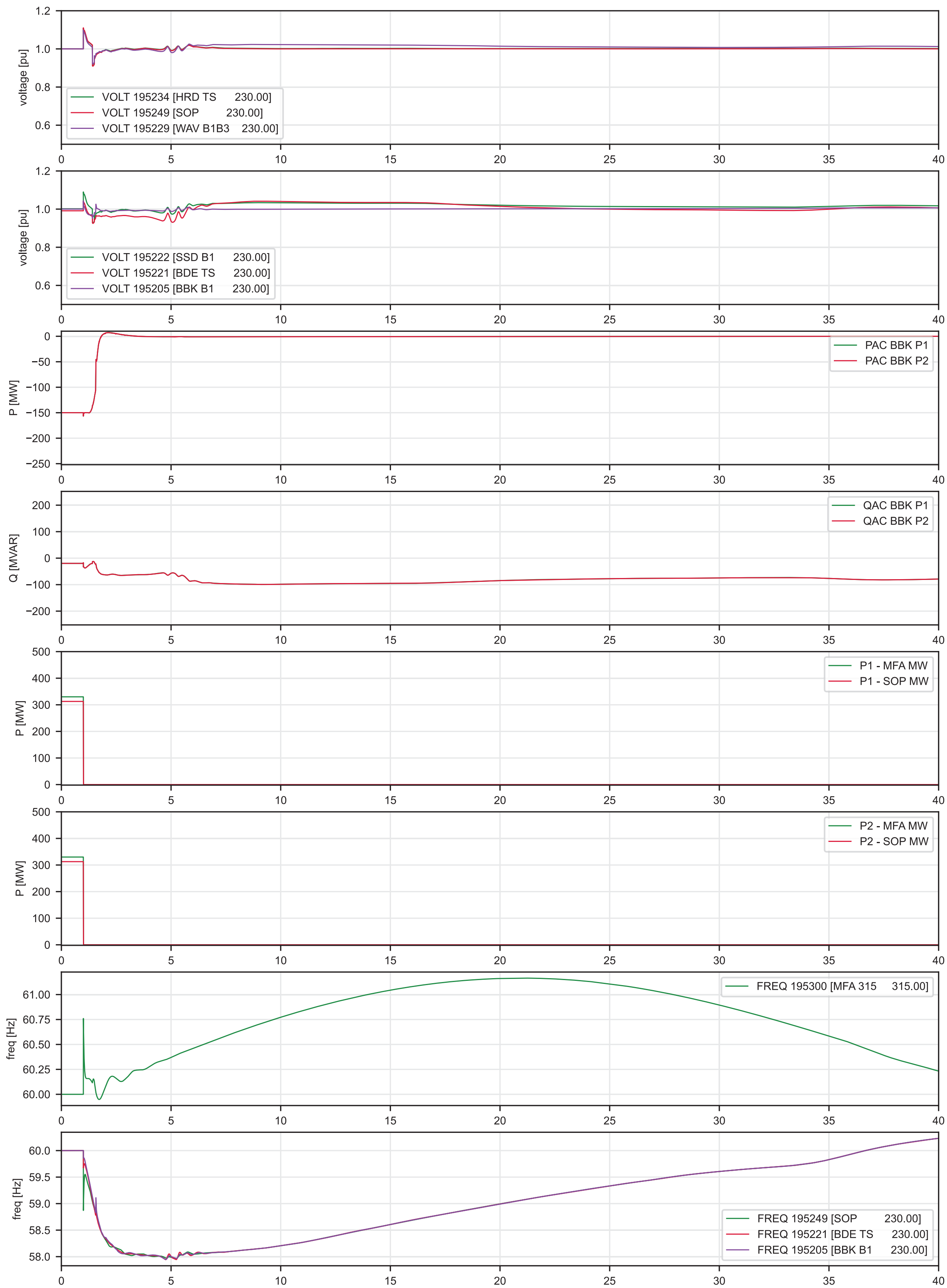
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 750 MW - ML 400 MW - One LIL restart enabled



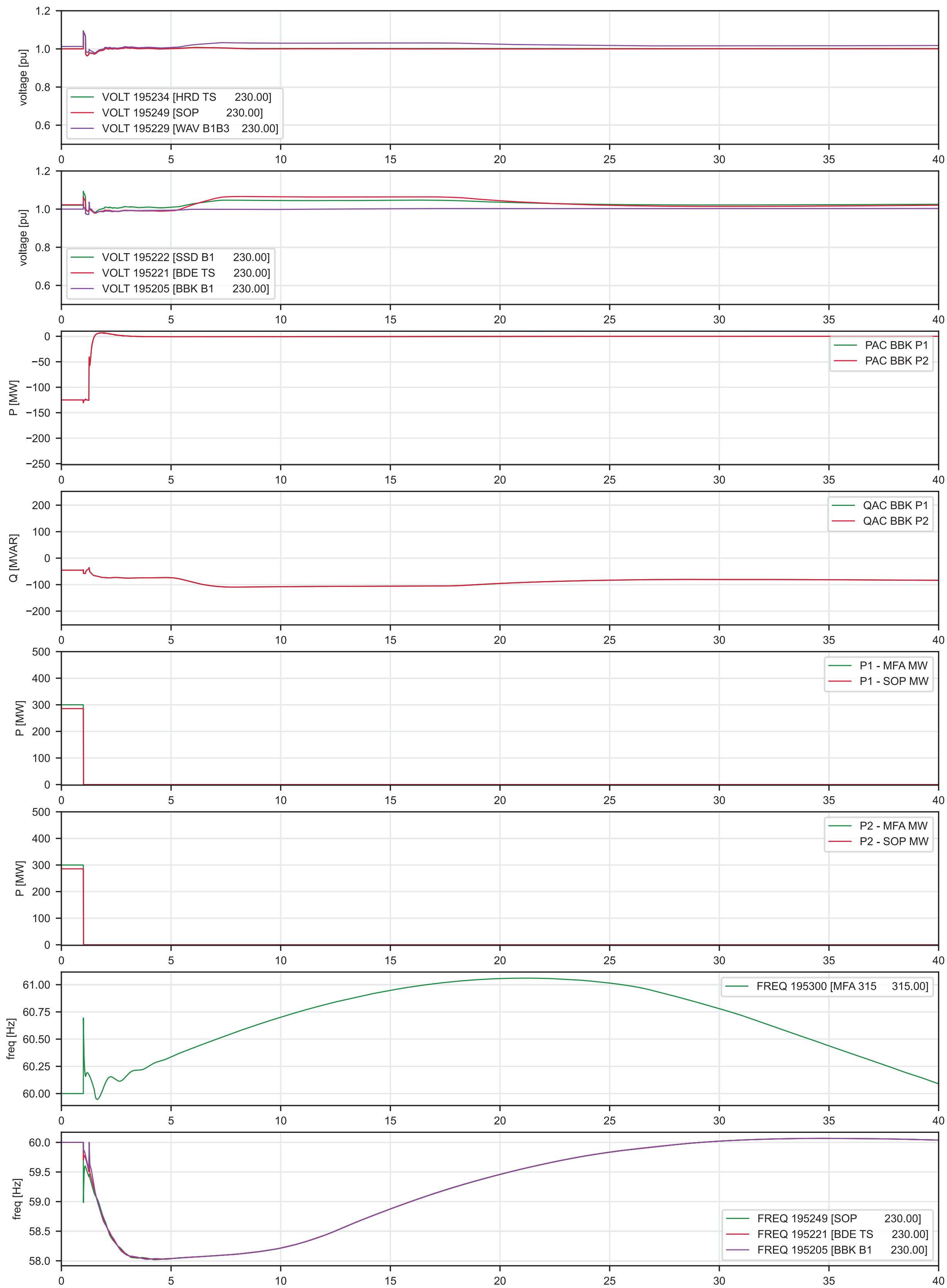
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 750 MW - ML 300 MW - No LIL restarts enabled



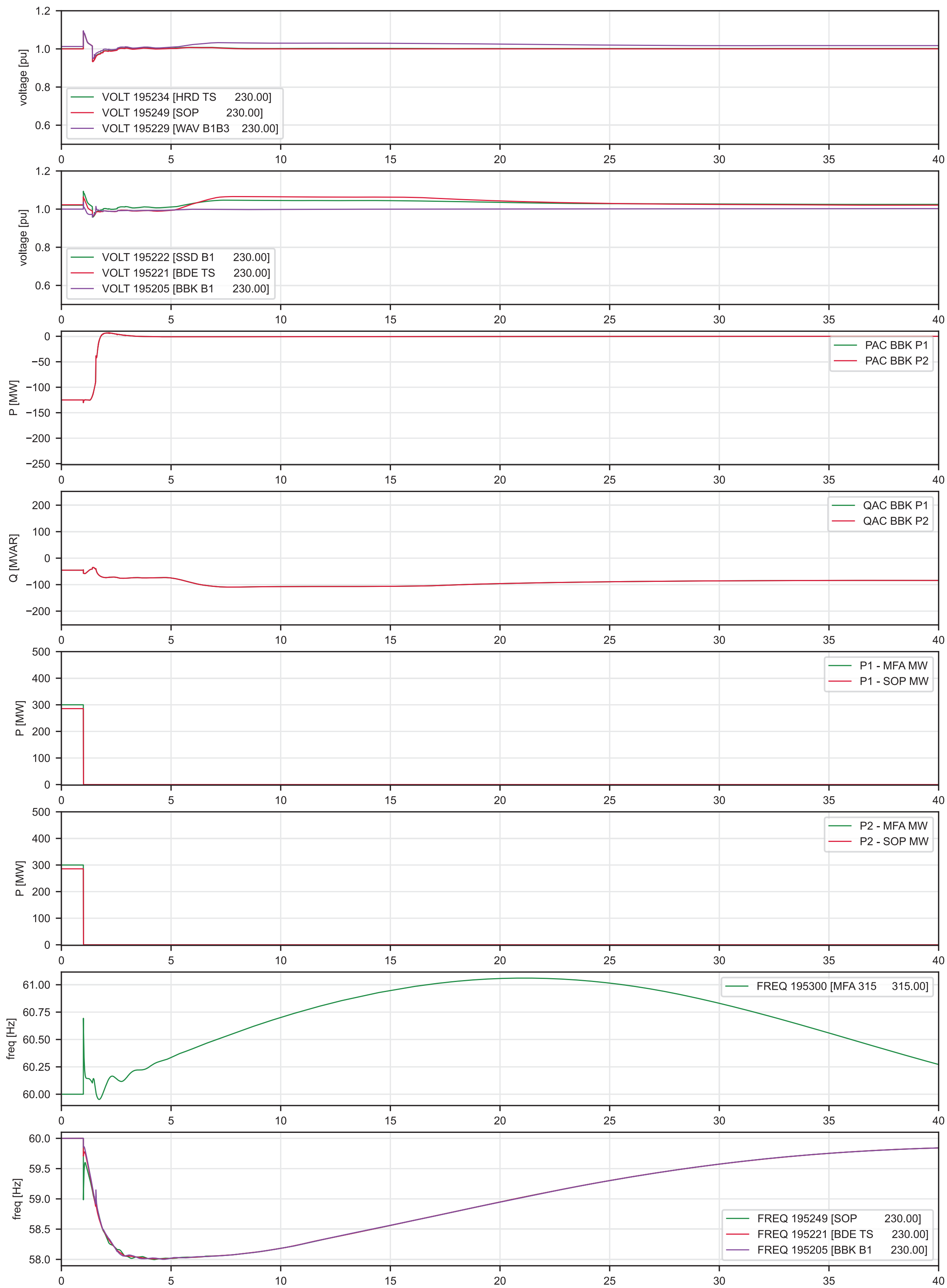
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 750 MW - ML 300 MW - One LIL restart enabled



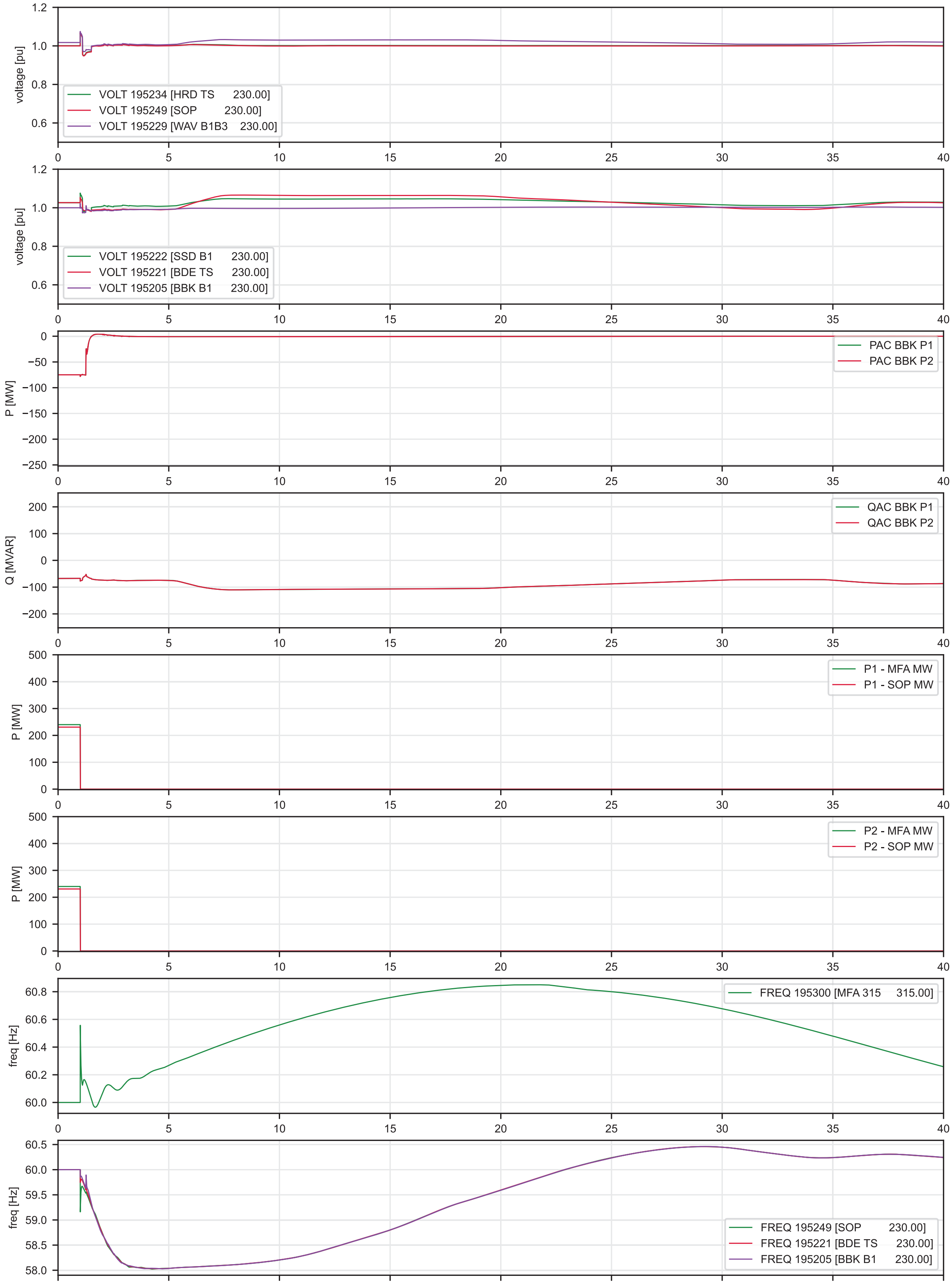
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 750 MW - ML 250 MW - No LIL restarts enabled



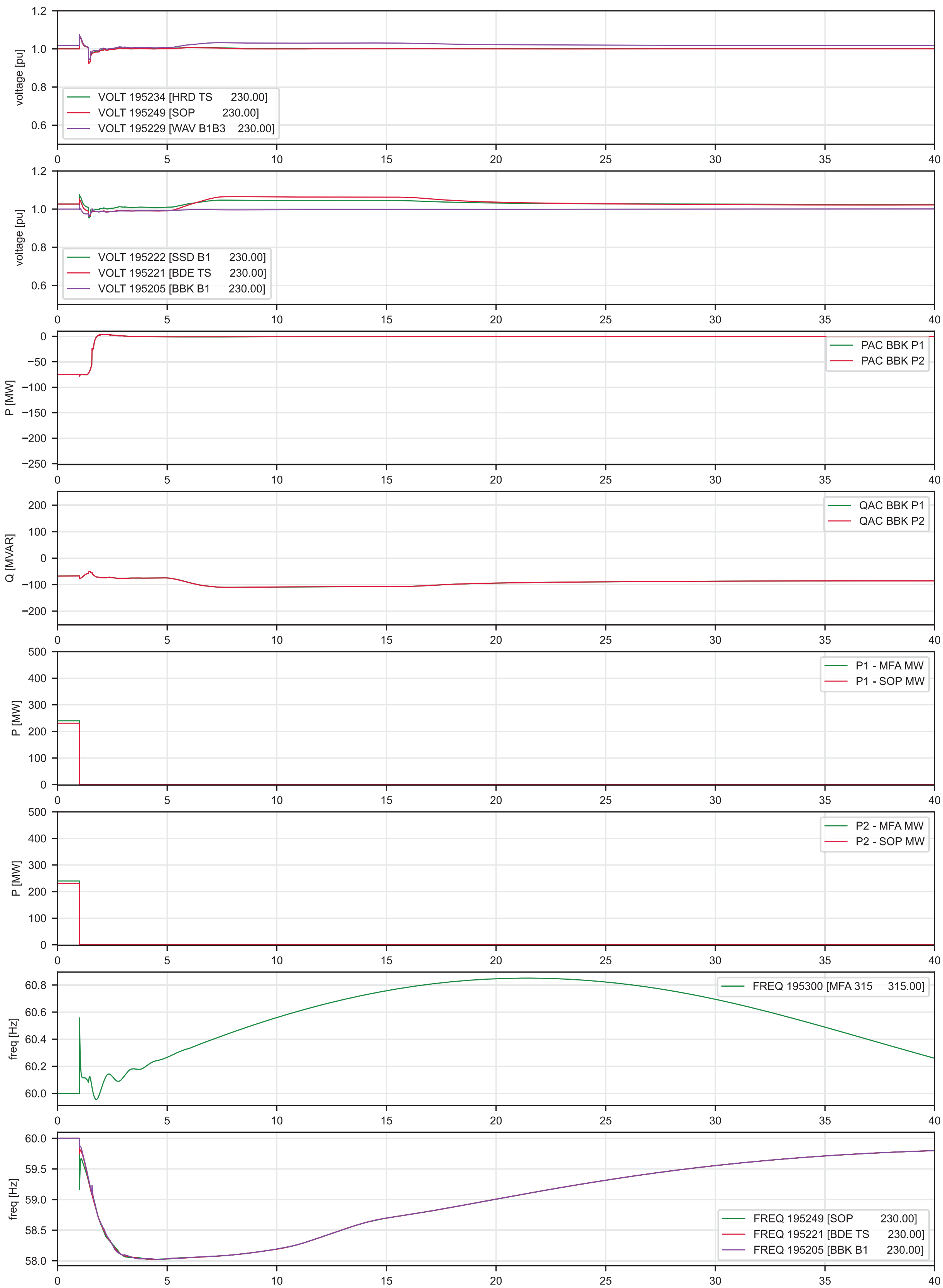
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 750 MW - ML 250 MW - One LIL restart enabled

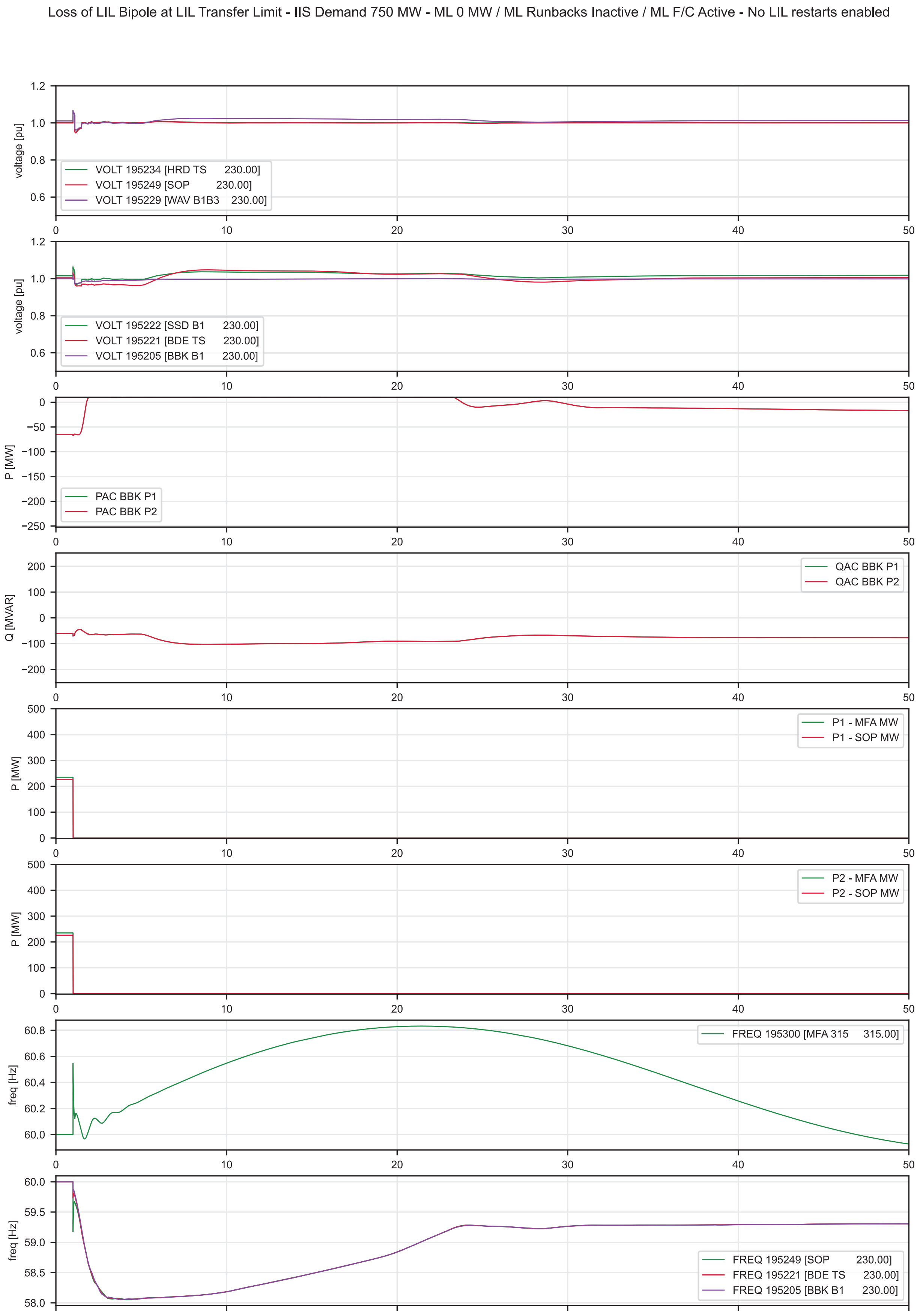


Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 750 MW - ML 150 MW - No LIL restarts enabled

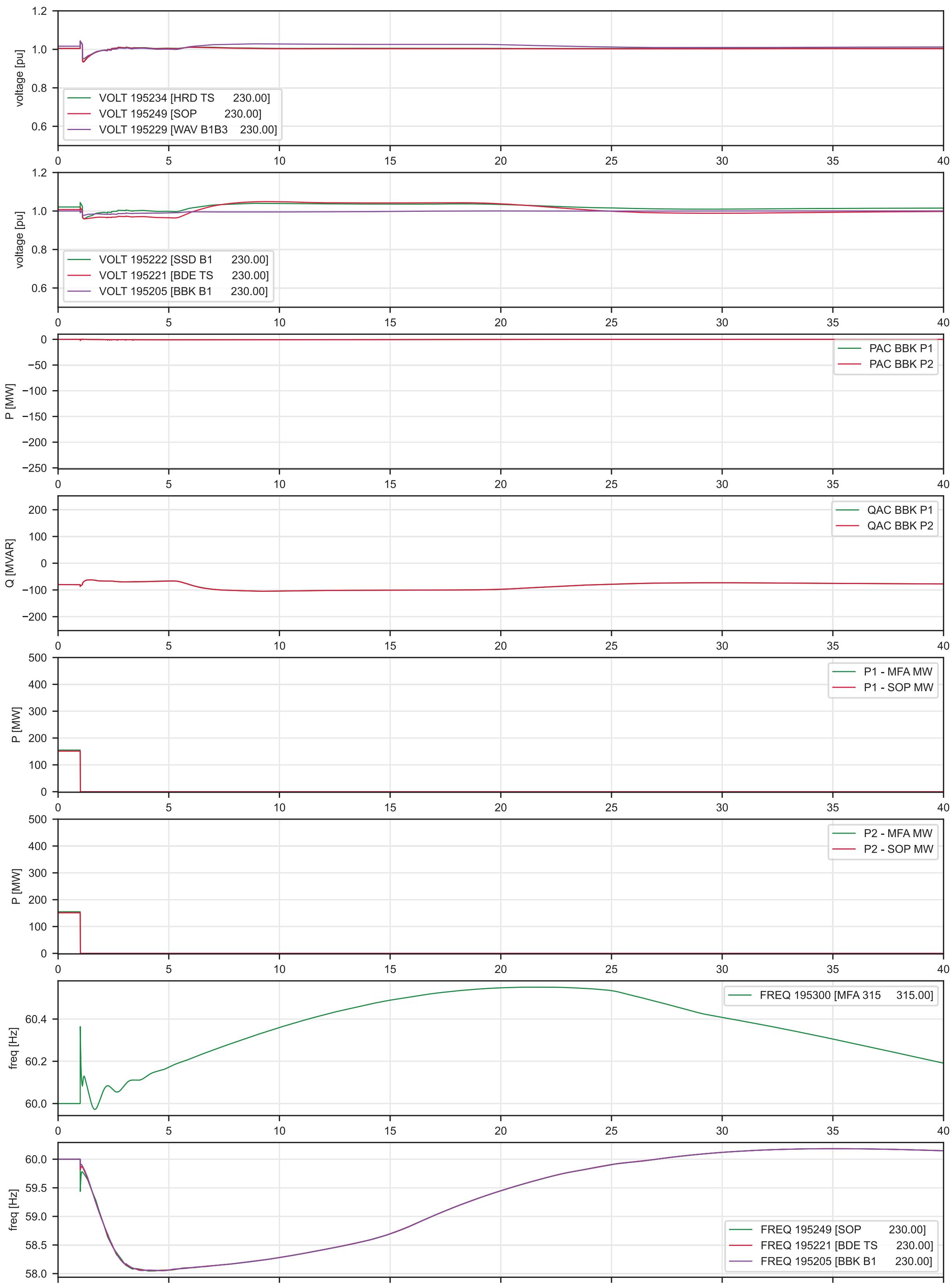


Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 750 MW - ML 150 MW - One LIL restart enabled

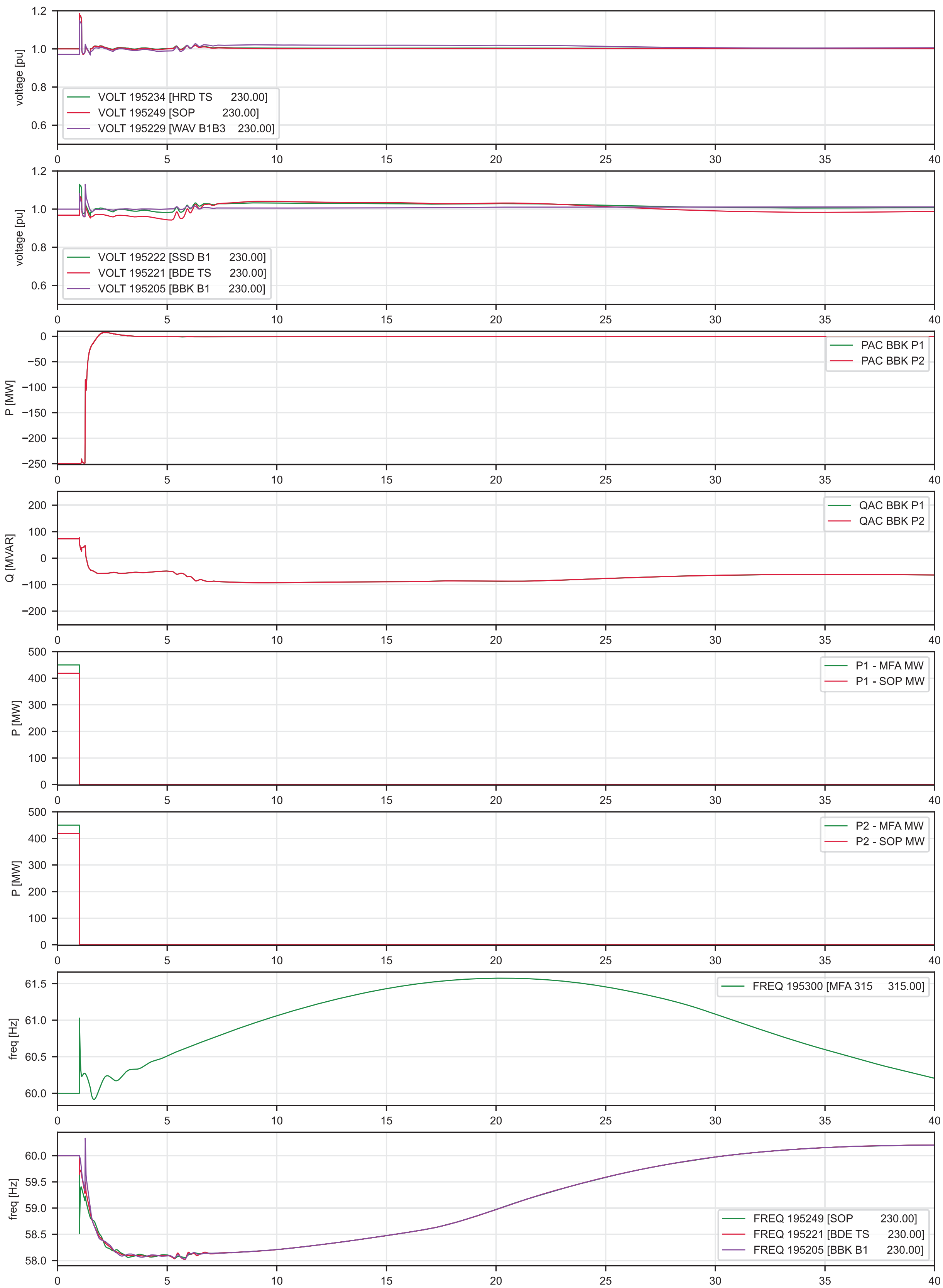


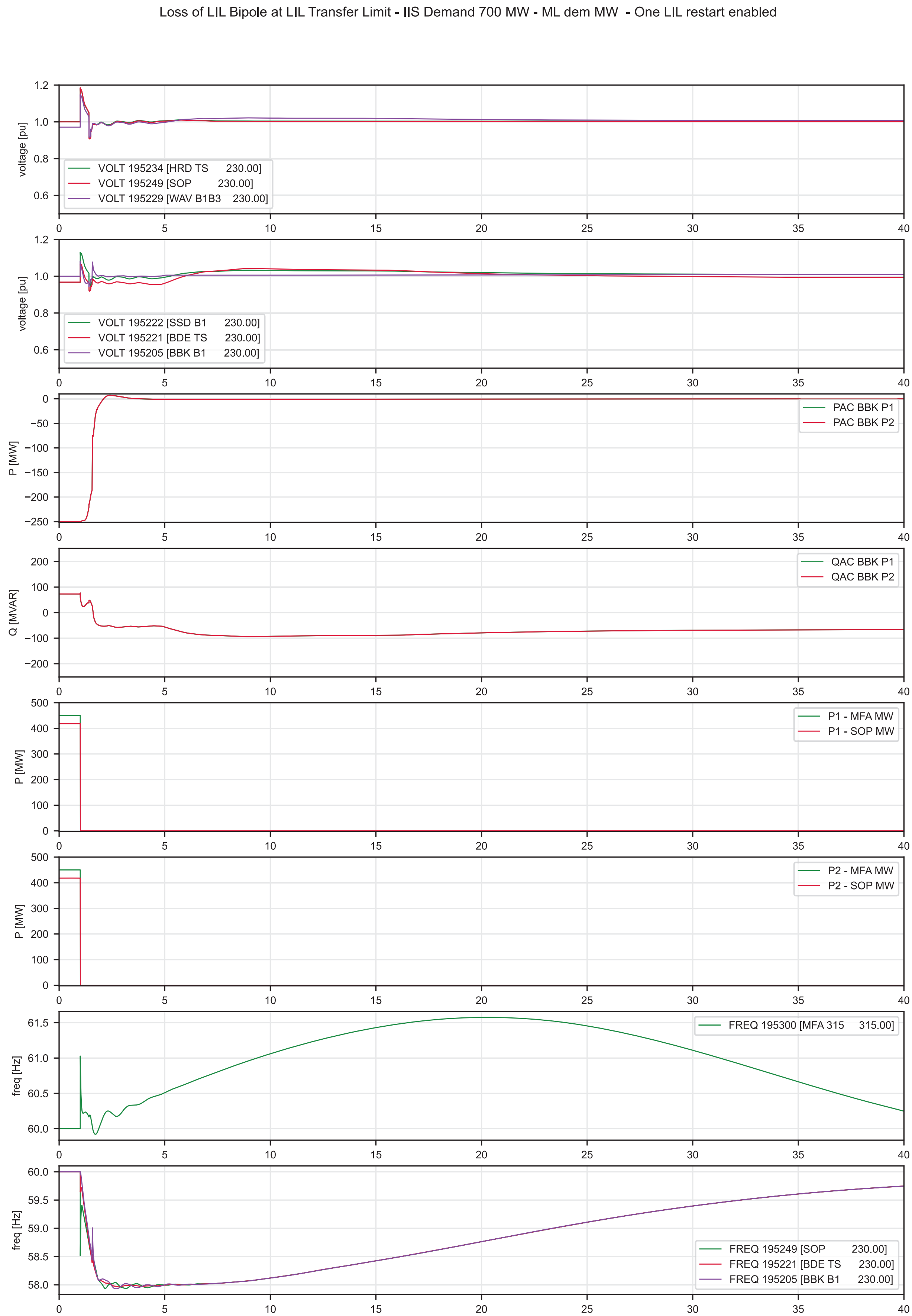

Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 750 MW - ML 0 MW / ML Runbacks Inactive / ML F/C Active - No LIL restarts enabled
voltage [pu]
VOLT 195234 [HRD TS 230.00]
VOLT 195249 [SOP 230.00]
VOLT 195229 [WAV B1B3 230.00]
VOLT 195222 [SSD B1 230.00]
VOLT 195221 [BDE TS 230.00]
VOLT 195205 [BBK B1 230.00]
P [MW]
PAC BBK P1
PAC BBK P2
Q [MVAR]
QAC BBK P1
QAC BBK P2
P1 - MFA MW
P1 - SOP MW
P2 - MFA MW
P2 - SOP MW
freq [Hz]
FREQ 195300 [MFA 315 315.00]
FREQ 195249 [SOP 230.00]
FREQ 195221 [BDE TS 230.00]
FREQ 195205 [BBK B1 230.00]

Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 750 MW - ML 0 MW / ML Runbacks Inactive / ML F/C Inactive - No LIL restarts enabled

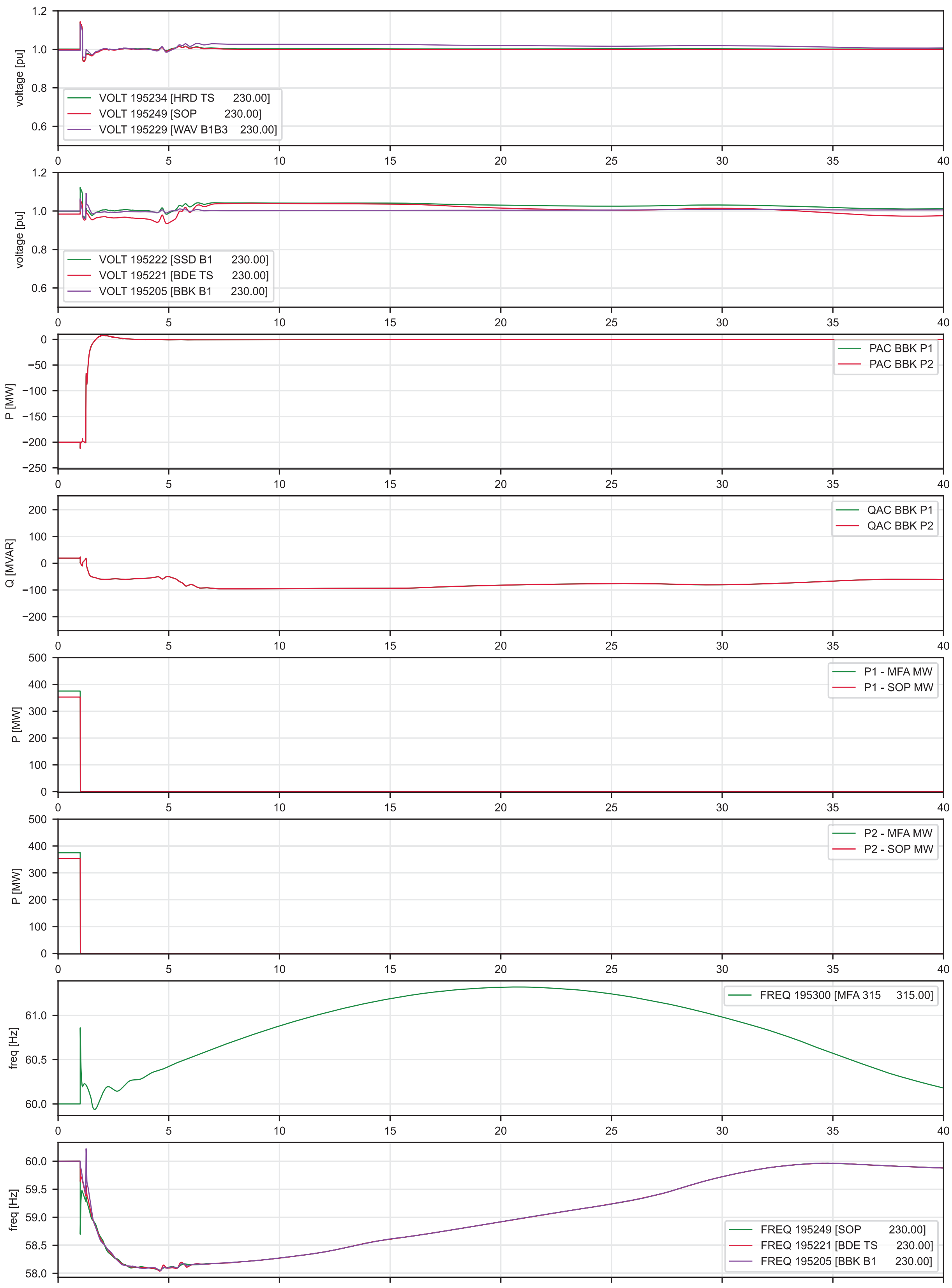


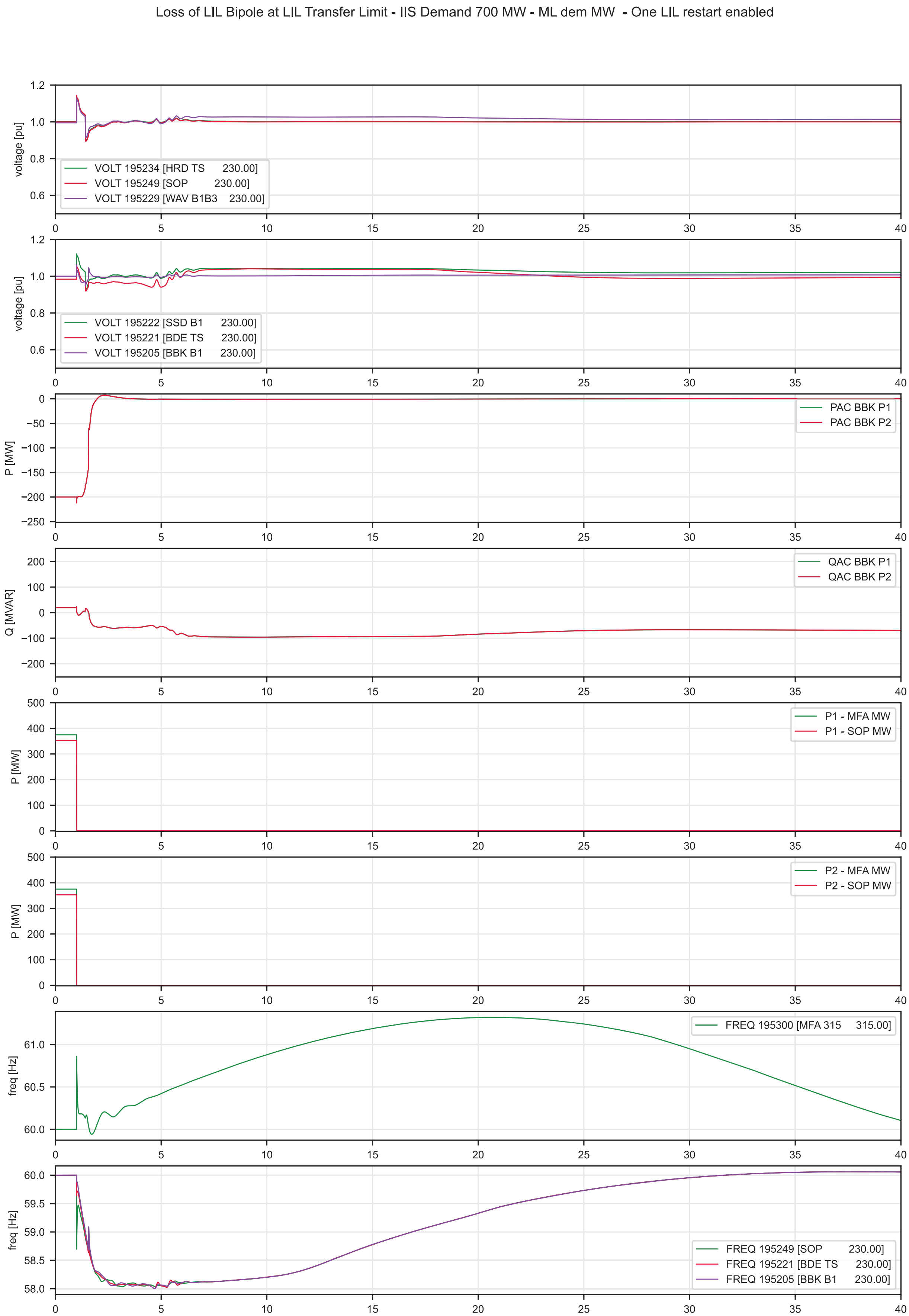
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 700 MW - ML dem MW - No LIL restarts enabled

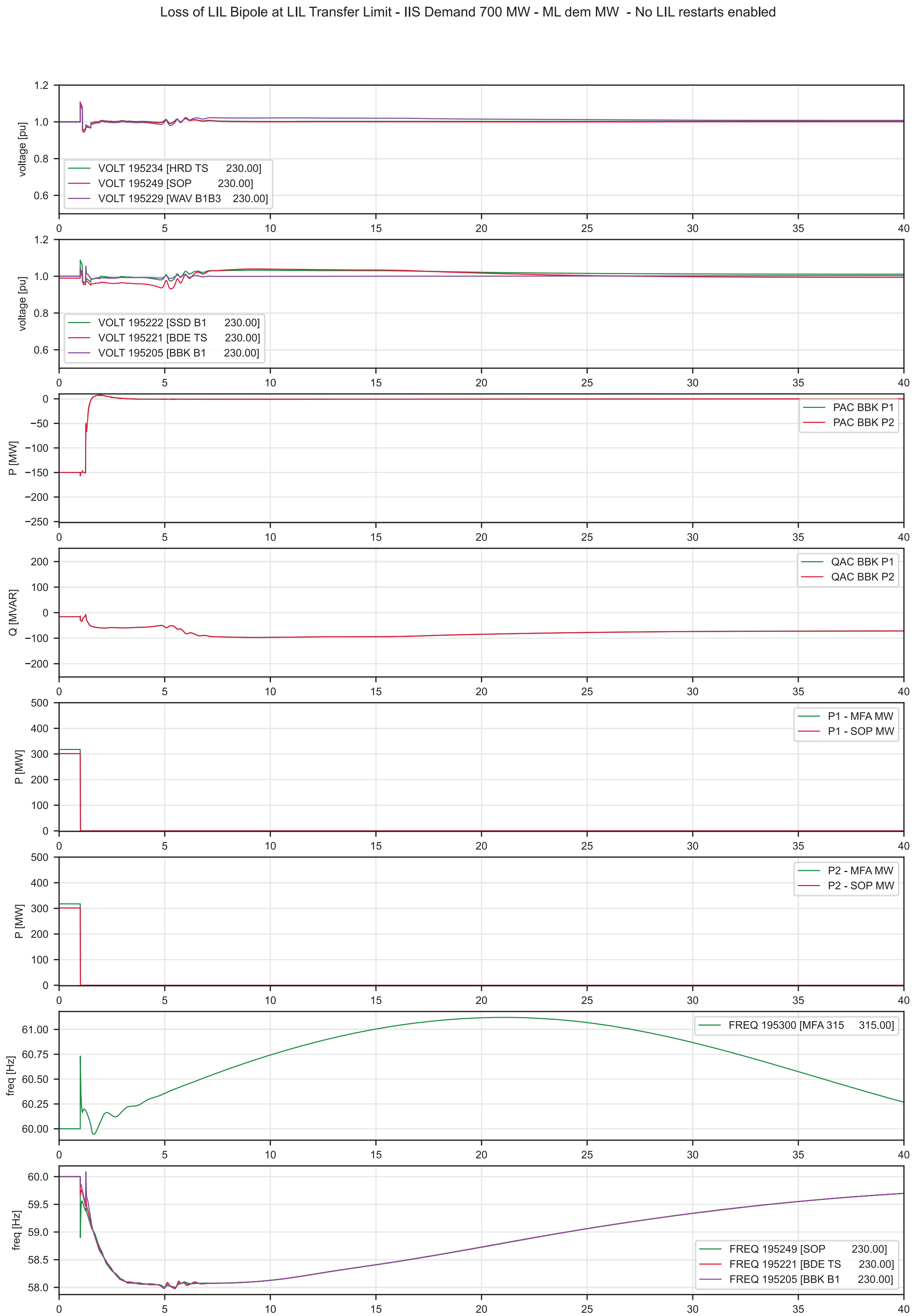



Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 700 MW - ML dem MW - One LIL restart enabled
voltage [pu]
VOLT 195234 [HRD TS 230.00]
VOLT 195249 [SOP 230.00]
VOLT 195229 [WAV B1B3 230.00]
VOLT 195222 [SSD B1 230.00]
VOLT 195221 [BDE TS 230.00]
VOLT 195205 [BBK B1 230.00]
P [MW]
PAC BBK P1
PAC BBK P2
Q [MVAR]
QAC BBK P1
QAC BBK P2
P1 - MFA MW
P1 - SOP MW
P2 - MFA MW
P2 - SOP MW
freq [Hz]
FREQ 195300 [MFA 315 315.00]
FREQ 195249 [SOP 230.00]
FREQ 195221 [BDE TS 230.00]
FREQ 195205 [BBK B1 230.00]

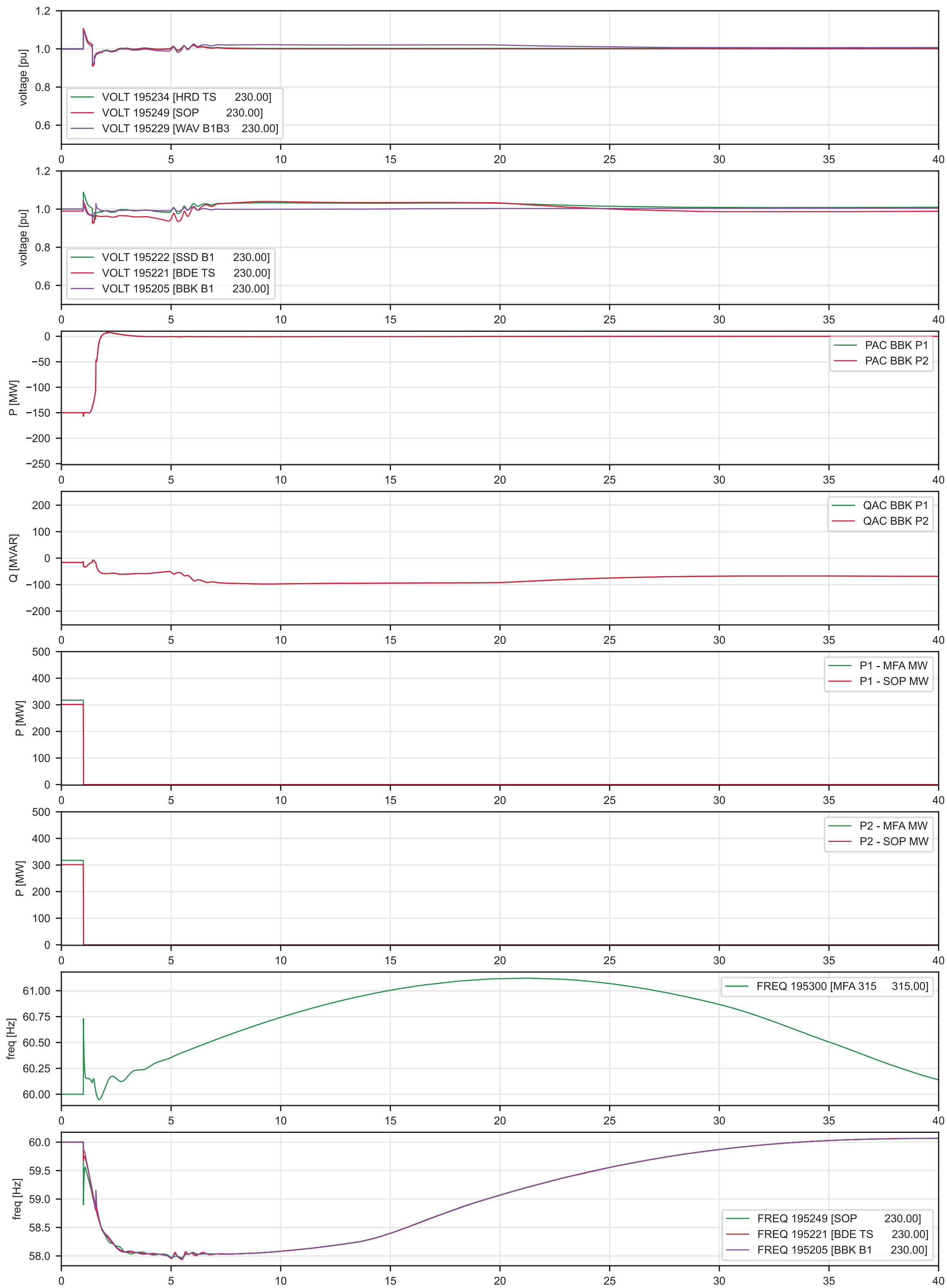
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 700 MW - ML dem MW - No LIL restarts enabled



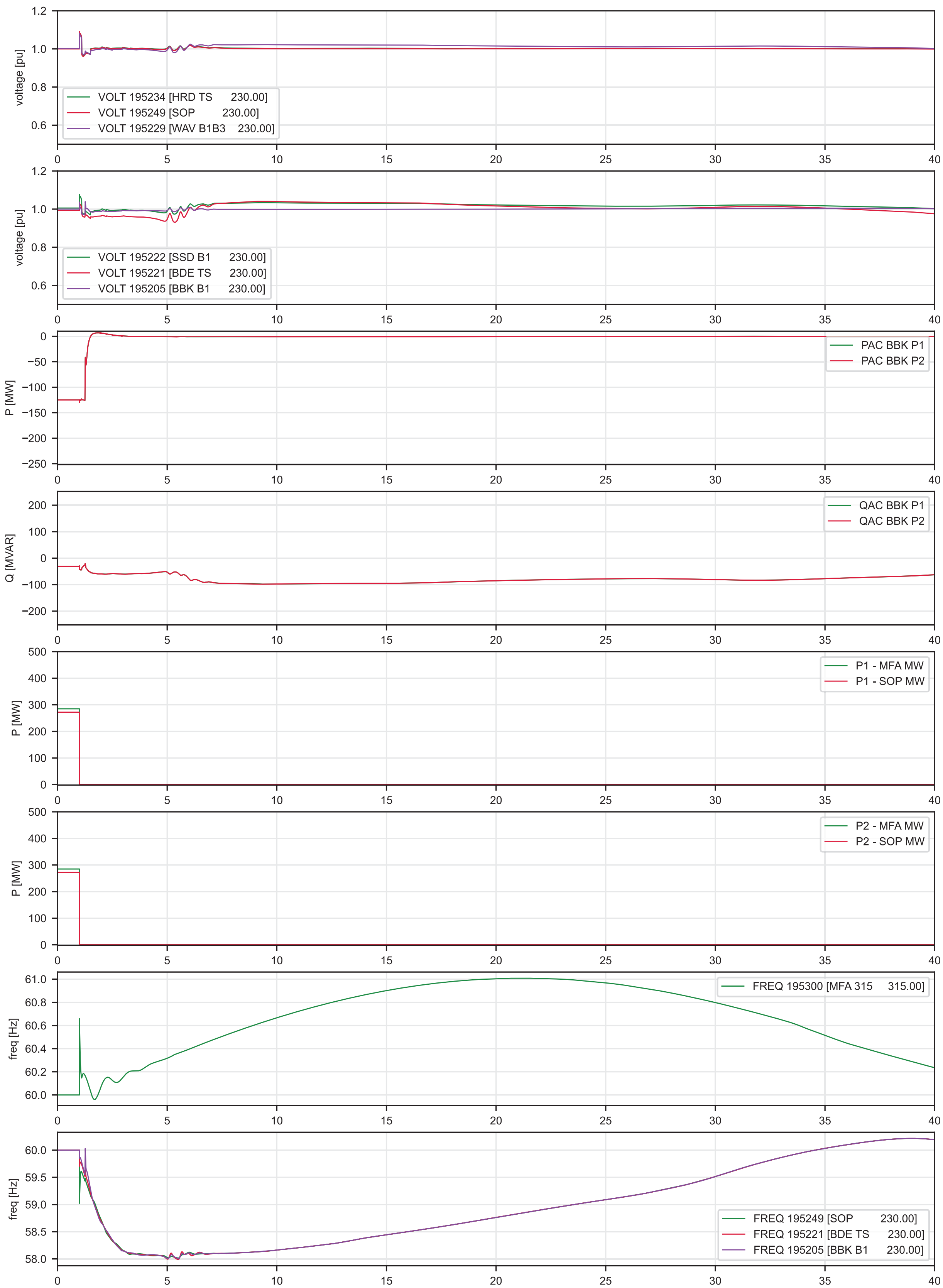

Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 700 MW - ML dem MW - One LIL restart enabled
voltage [pu]
VOLT 195234 [HRD TS 230.00]
VOLT 195249 [SOP 230.00]
VOLT 195229 [WAV B1B3 230.00]
voltage [pu]
VOLT 195222 [SSD B1 230.00]
VOLT 195221 [BDE TS 230.00]
VOLT 195205 [BBK B1 230.00]
P [MW]
PAC BBK P1
PAC BBK P2
Q [MVAR]
QAC BBK P1
QAC BBK P2
P [MW]
P1 - MFA MW
P1 - SOP MW
P [MW]
P2 - MFA MW
P2 - SOP MW
freq [Hz]
FREQ 195300 [MFA 315 315.00]
freq [Hz]
FREQ 195249 [SOP 230.00]
FREQ 195221 [BDE TS 230.00]
FREQ 195205 [BBK B1 230.00]


Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 700 MW - ML dem MW - No LIL restarts enabled
voltage [pu]
VOLT 195234 [HRD TS 230.00]
VOLT 195249 [SOP 230.00]
VOLT 195229 [WAV B1B3 230.00]
VOLT 195222 [SSD B1 230.00]
VOLT 195221 [BDE TS 230.00]
VOLT 195205 [BBK B1 230.00]
P [MW]
PAC BBK P1
PAC BBK P2
Q [MVAR]
QAC BBK P1
QAC BBK P2
P1 - MFA MW
P1 - SOP MW
P2 - MFA MW
P2 - SOP MW
freq [Hz]
FREQ 195300 [MFA 315 315.00]
FREQ 195249 [SOP 230.00]
FREQ 195221 [BDE TS 230.00]
FREQ 195205 [BBK B1 230.00]

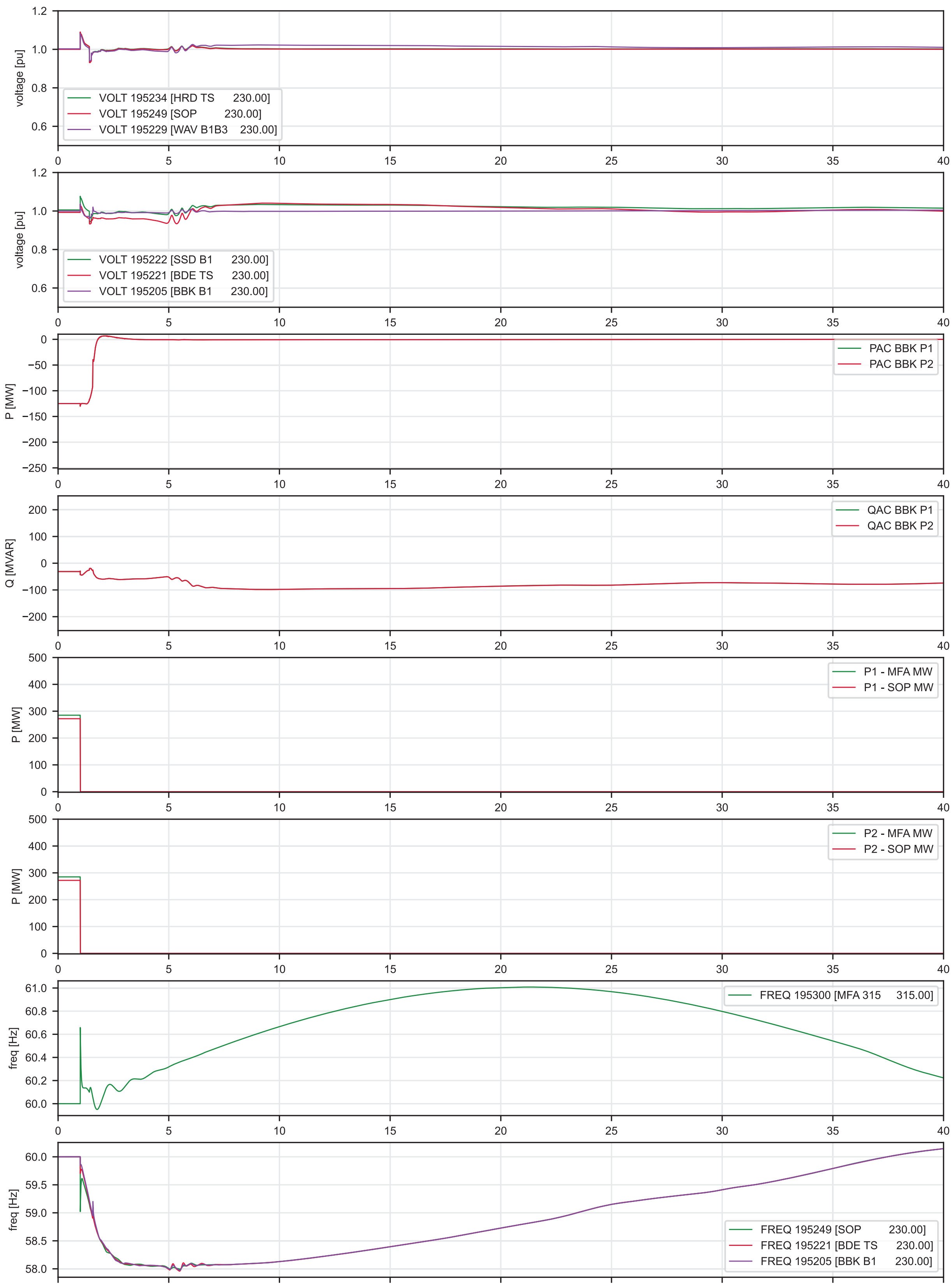
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 700 MW - ML dem MW - One LIL restart enabled



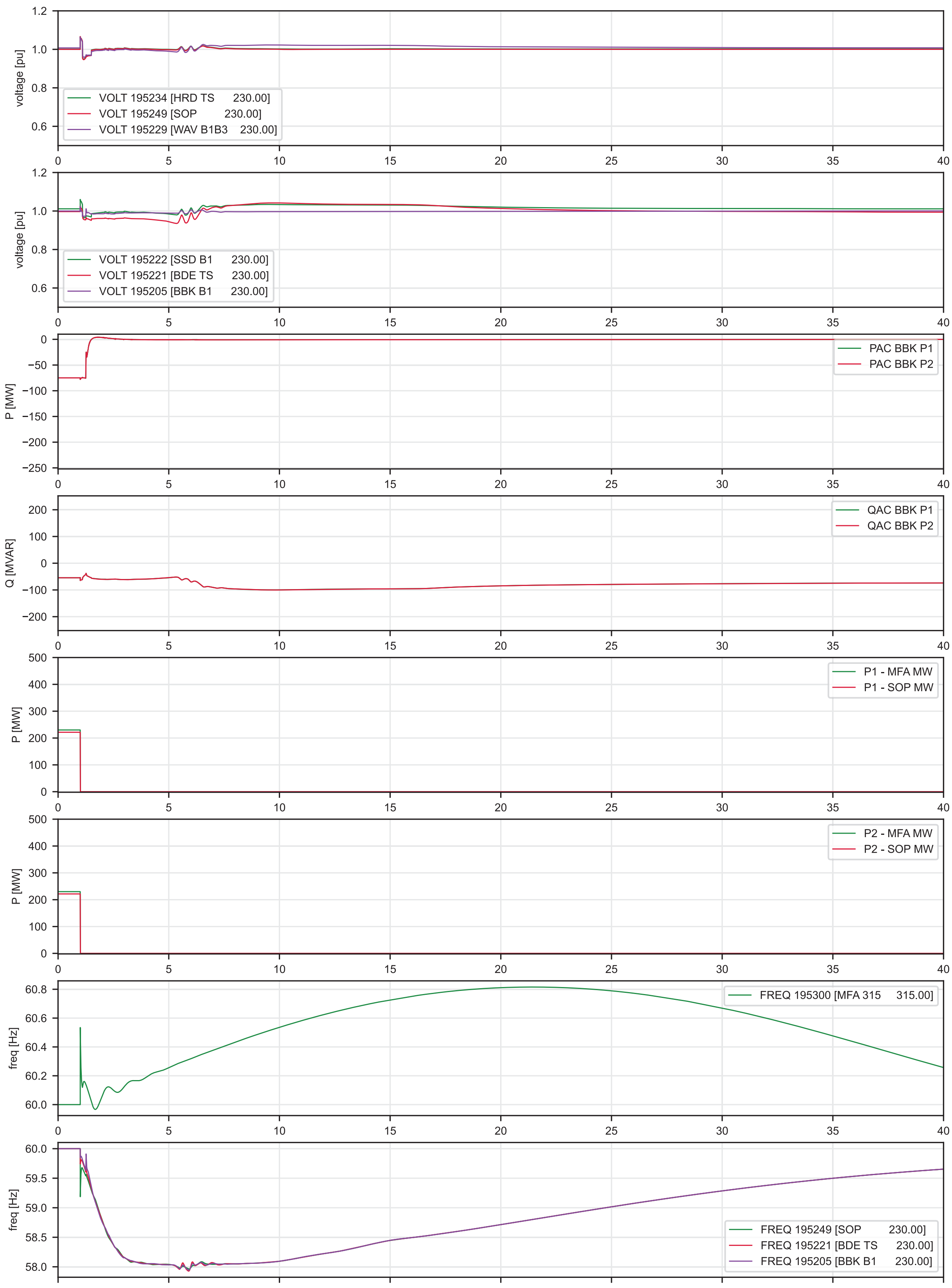
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 700 MW - ML dem MW - No LIL restarts enabled



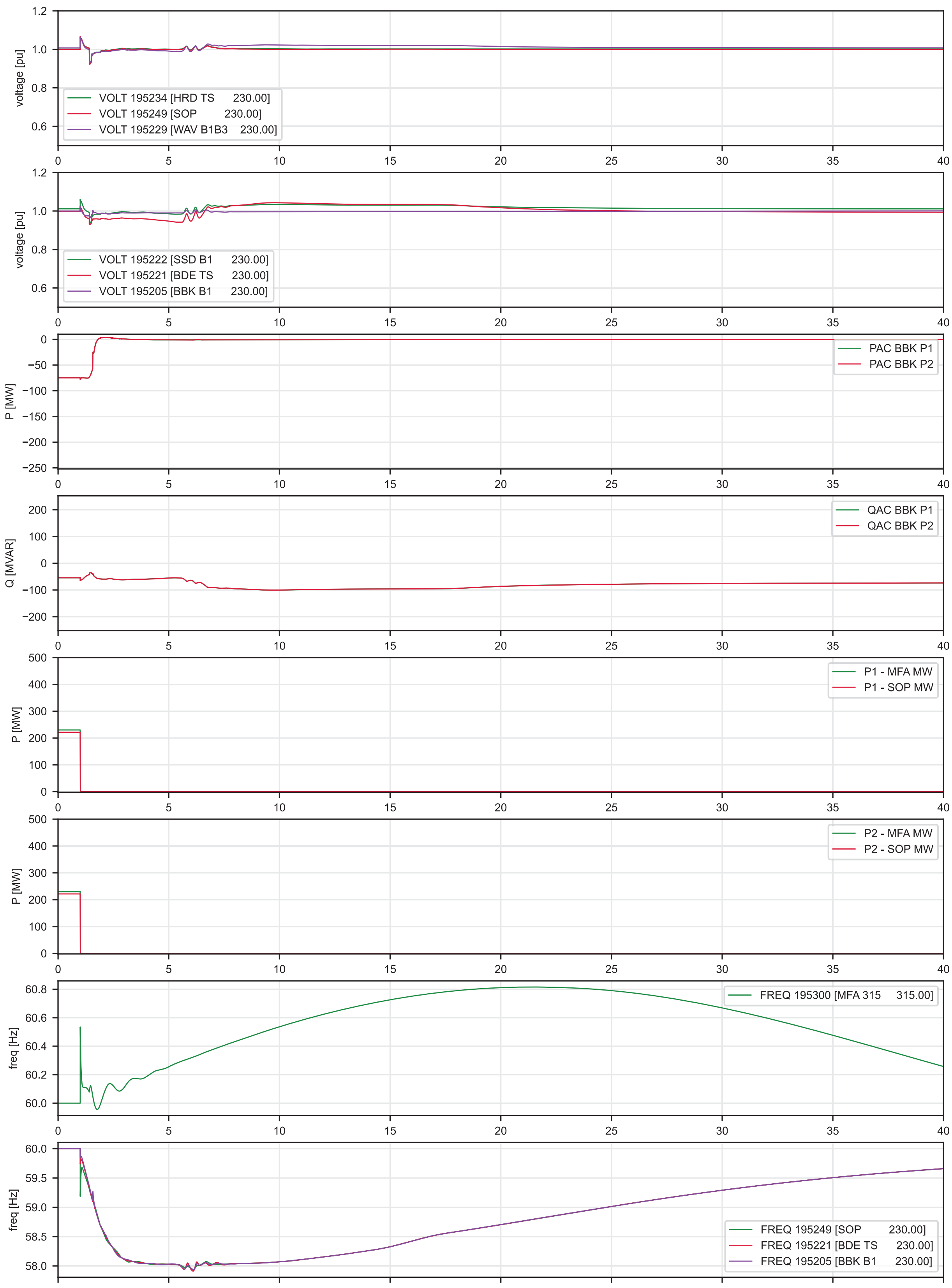
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 700 MW - ML dem MW - One LIL restart enabled



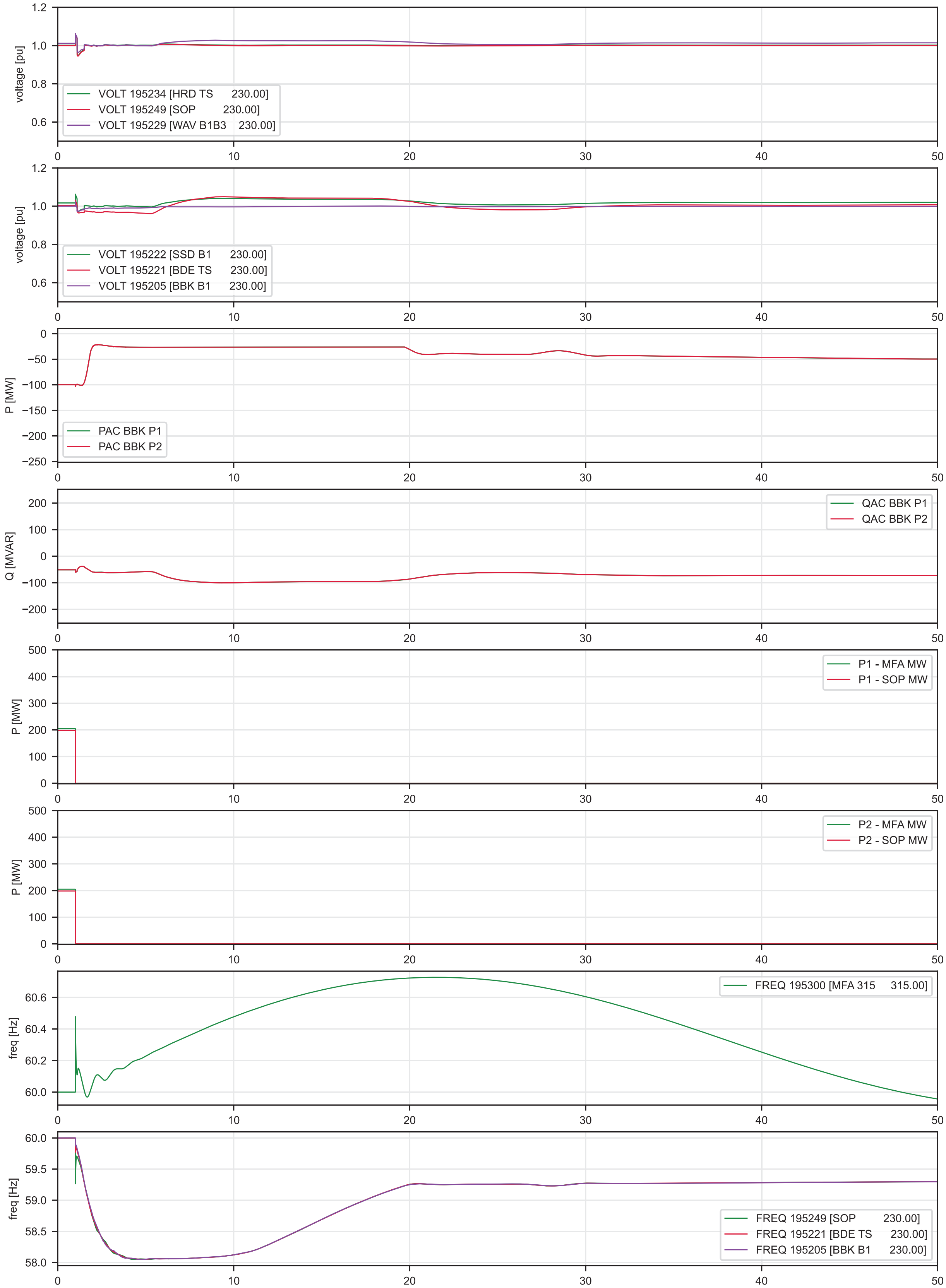
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 700 MW - ML dem MW - No LIL restarts enabled



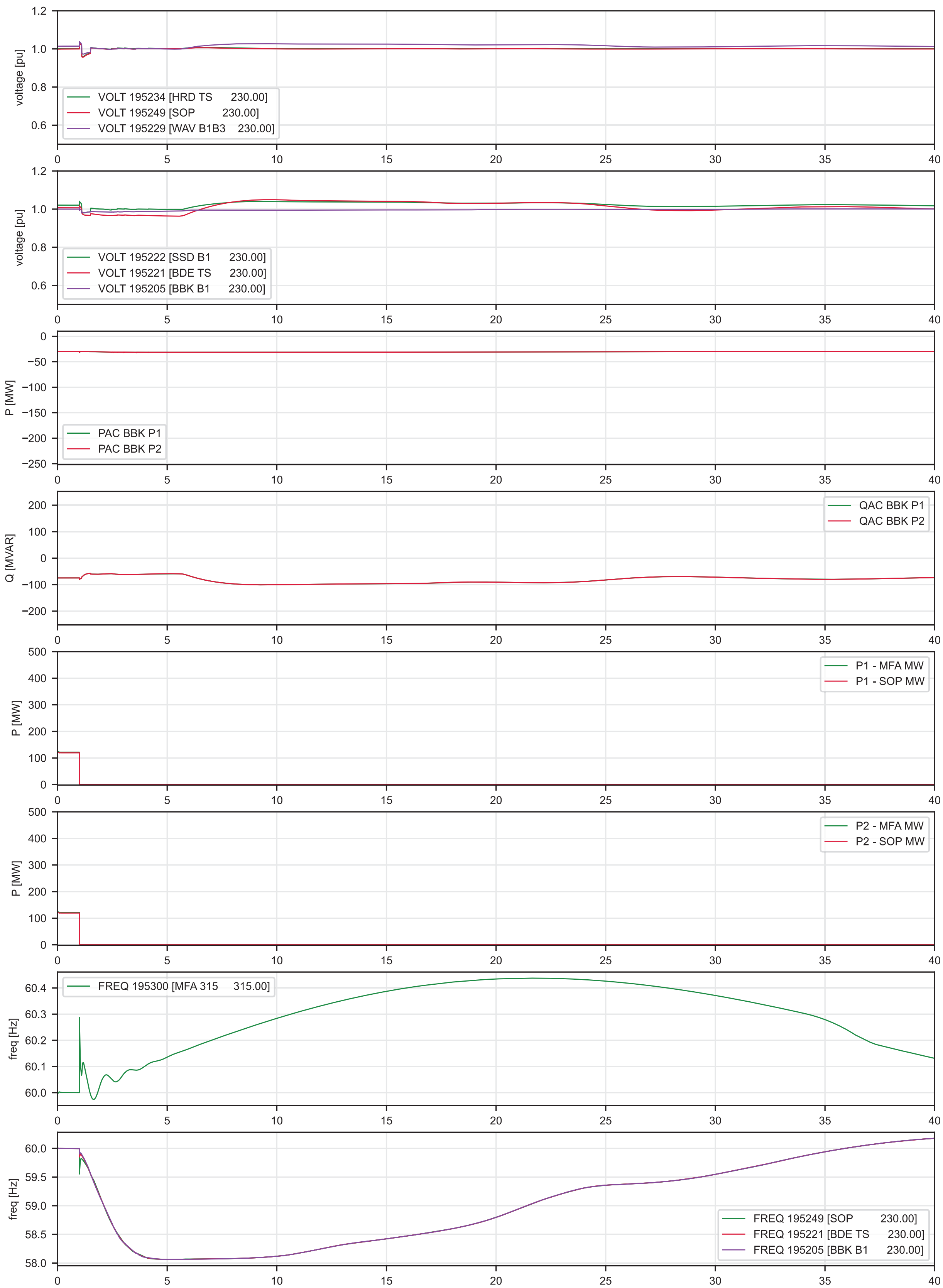
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 700 MW - ML dem MW - One LIL restart enabled



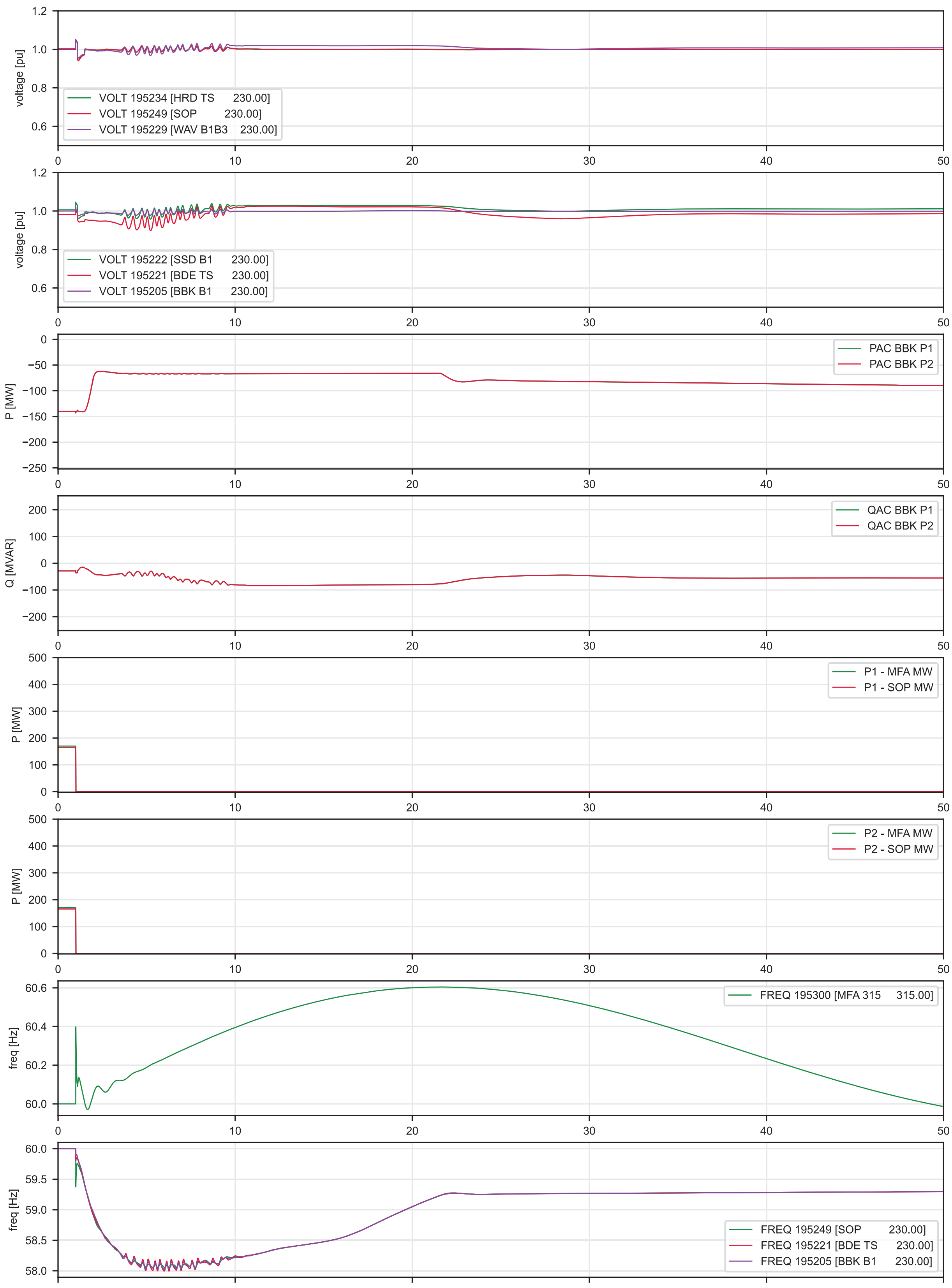
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 600 MW - ML 0 MW / ML Runbacks Inactive / ML F/C Active - No LIL restarts enabled



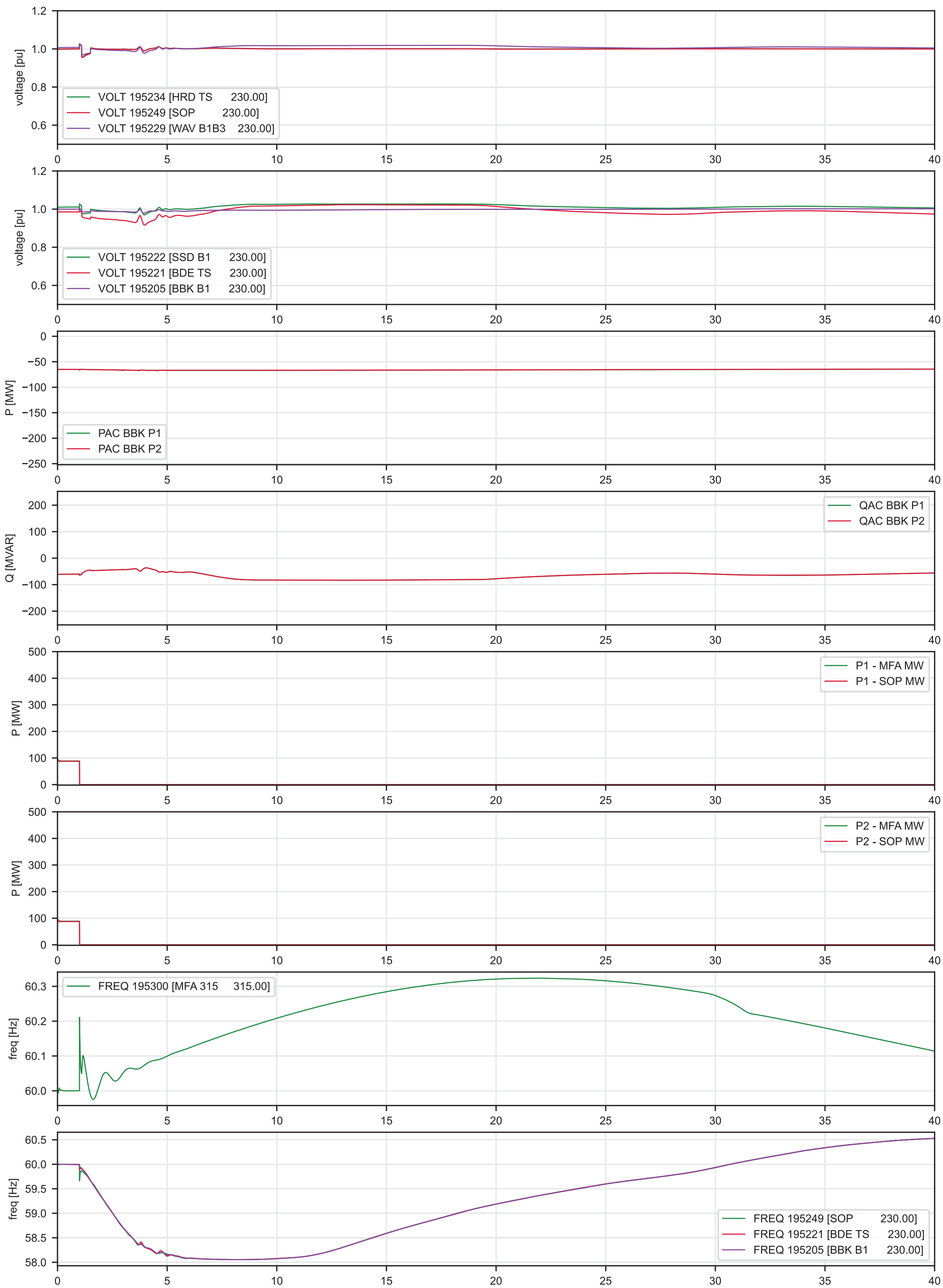
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 600 MW - ML 0 MW / ML Runbacks Inactive / ML F/C Inactive - No LIL restarts enabled



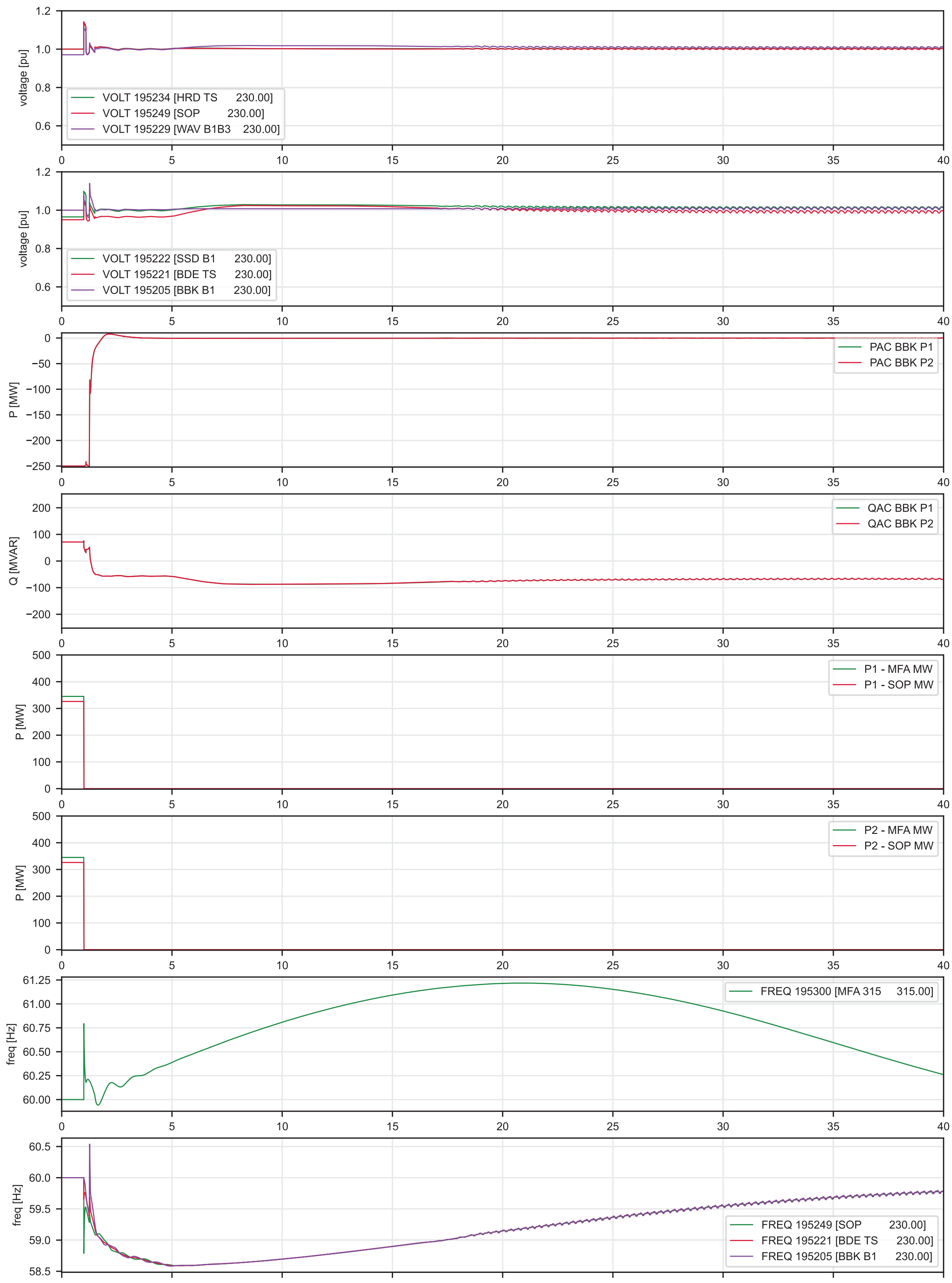
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 450 MW - ML 0 MW / ML Runbacks Inactive / ML F/C Active - No LIL restarts enabled



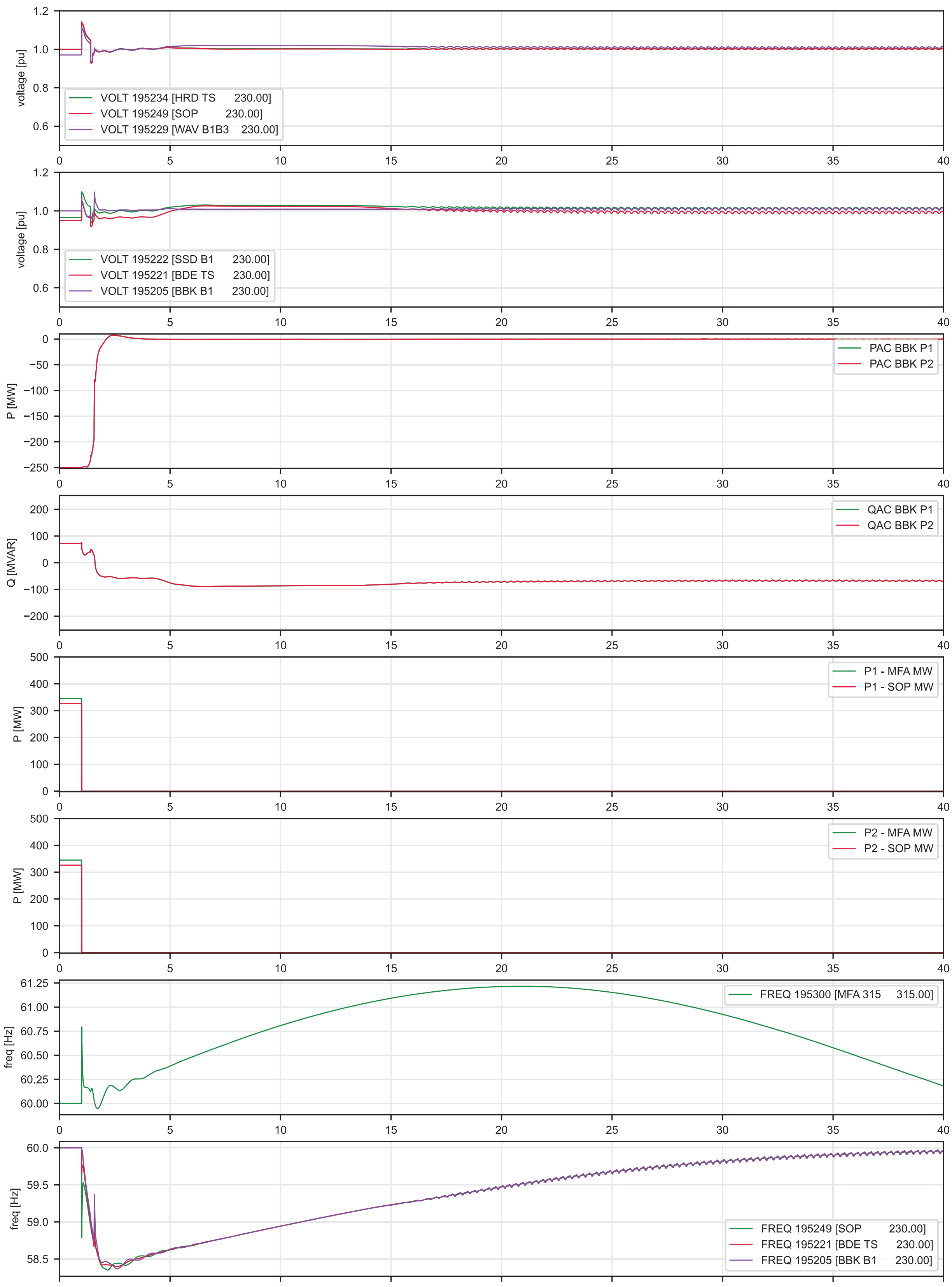
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 450 MW - ML 0 MW / ML Runbacks Inactive / ML F/C Inactive - No LIL restarts enabled

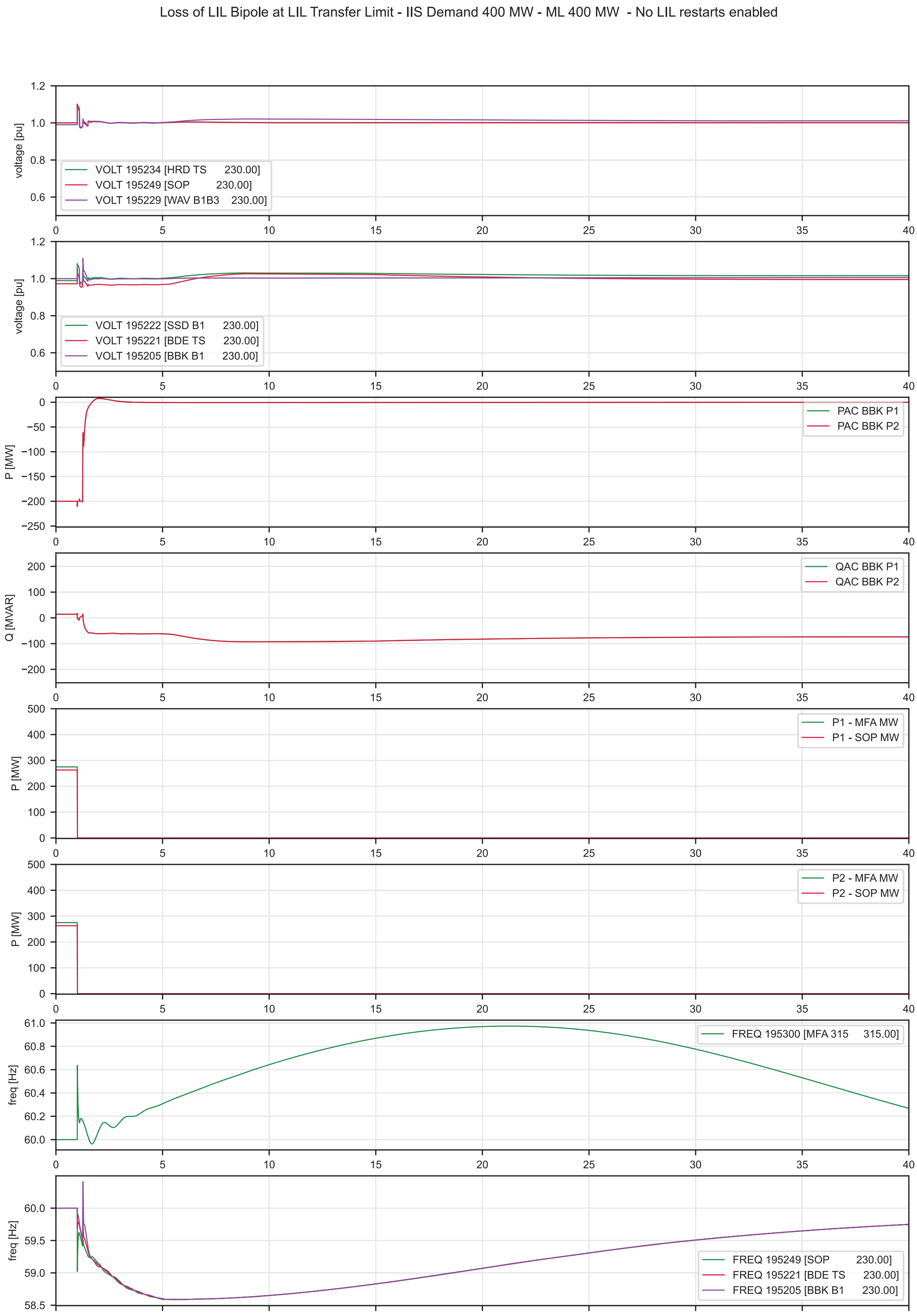


Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 400 MW - ML 500 MW - No LIL restarts enabled

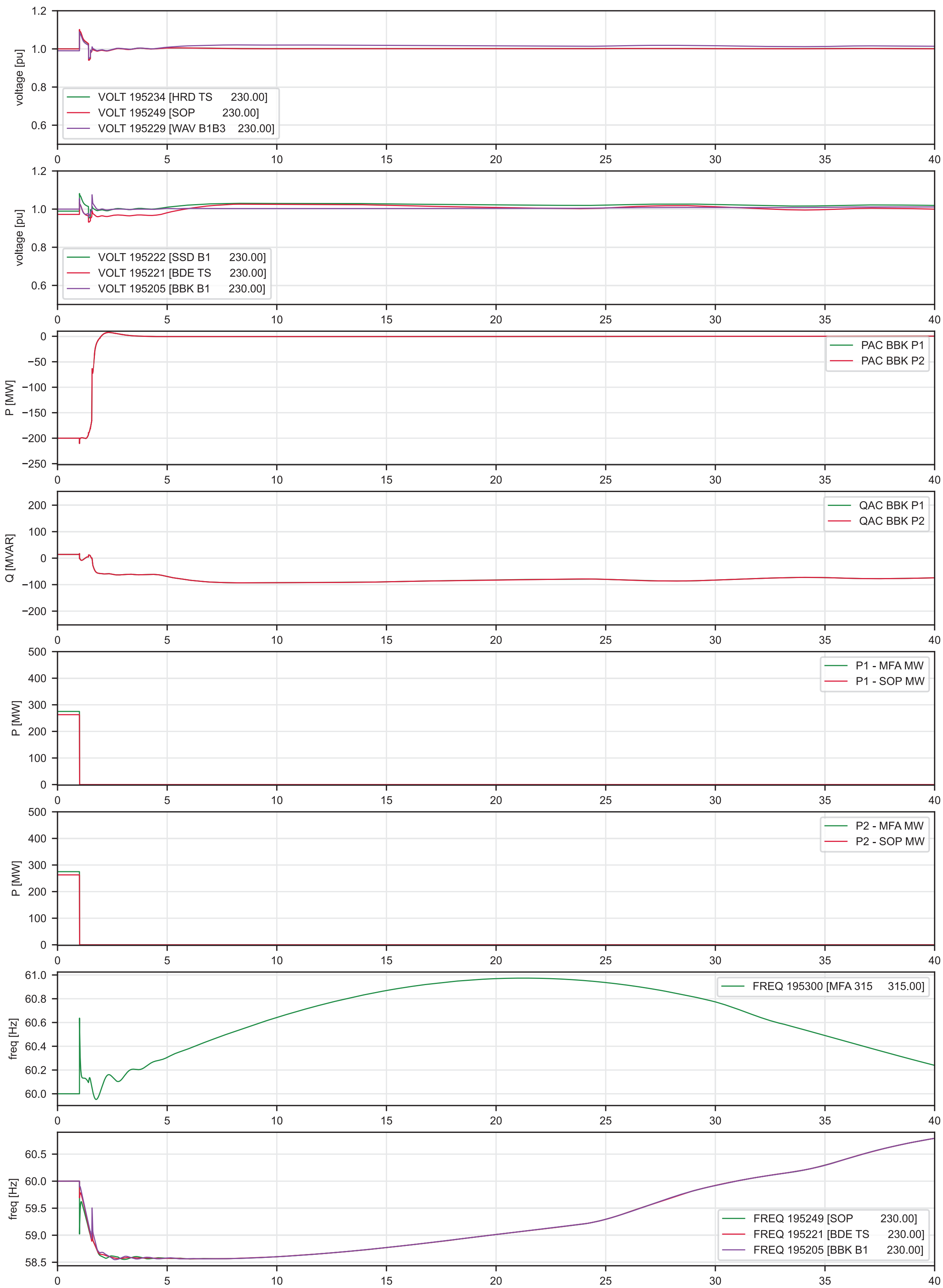


Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 400 MW - ML 500 MW - One LIL restart enabled

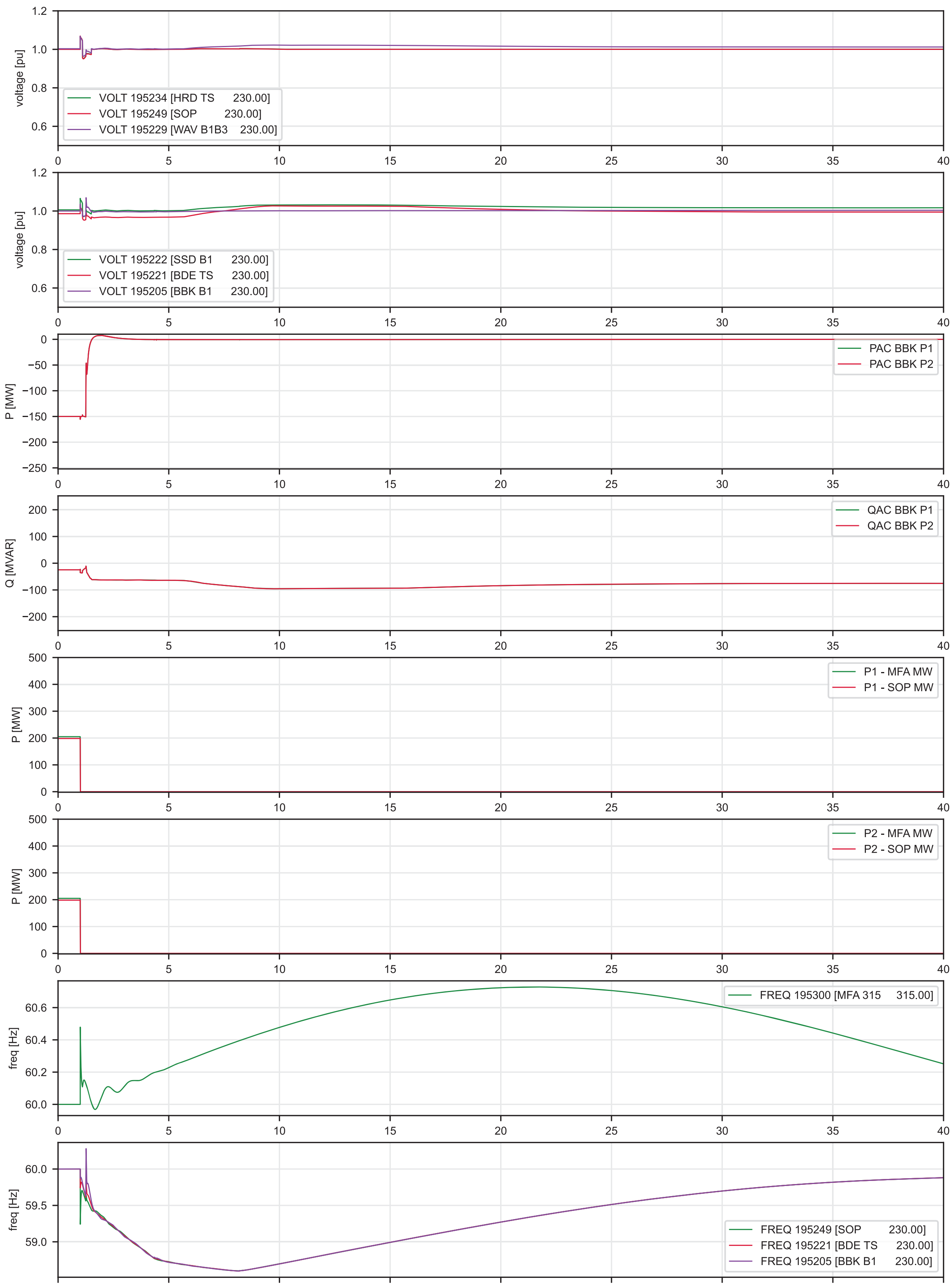



Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 400 MW - ML 400 MW - No LIL restarts enabled
voltage [pu]
VOLT 195234 [HRD TS 230.00]
VOLT 195249 [SOP 230.00]
VOLT 195229 [WAV B1B3 230.00]
VOLT 195222 [SSD B1 230.00]
VOLT 195221 [BDE TS 230.00]
VOLT 195205 [BBK B1 230.00]
P [MW]
PAC BBK P1
PAC BBK P2
Q [MVAR]
QAC BBK P1
QAC BBK P2
P1 - MFA MW
P1 - SOP MW
P2 - MFA MW
P2 - SOP MW
freq [Hz]
FREQ 195300 [MFA 315 315.00]
FREQ 195249 [SOP 230.00]
FREQ 195221 [BDE TS 230.00]
FREQ 195205 [BBK B1 230.00]

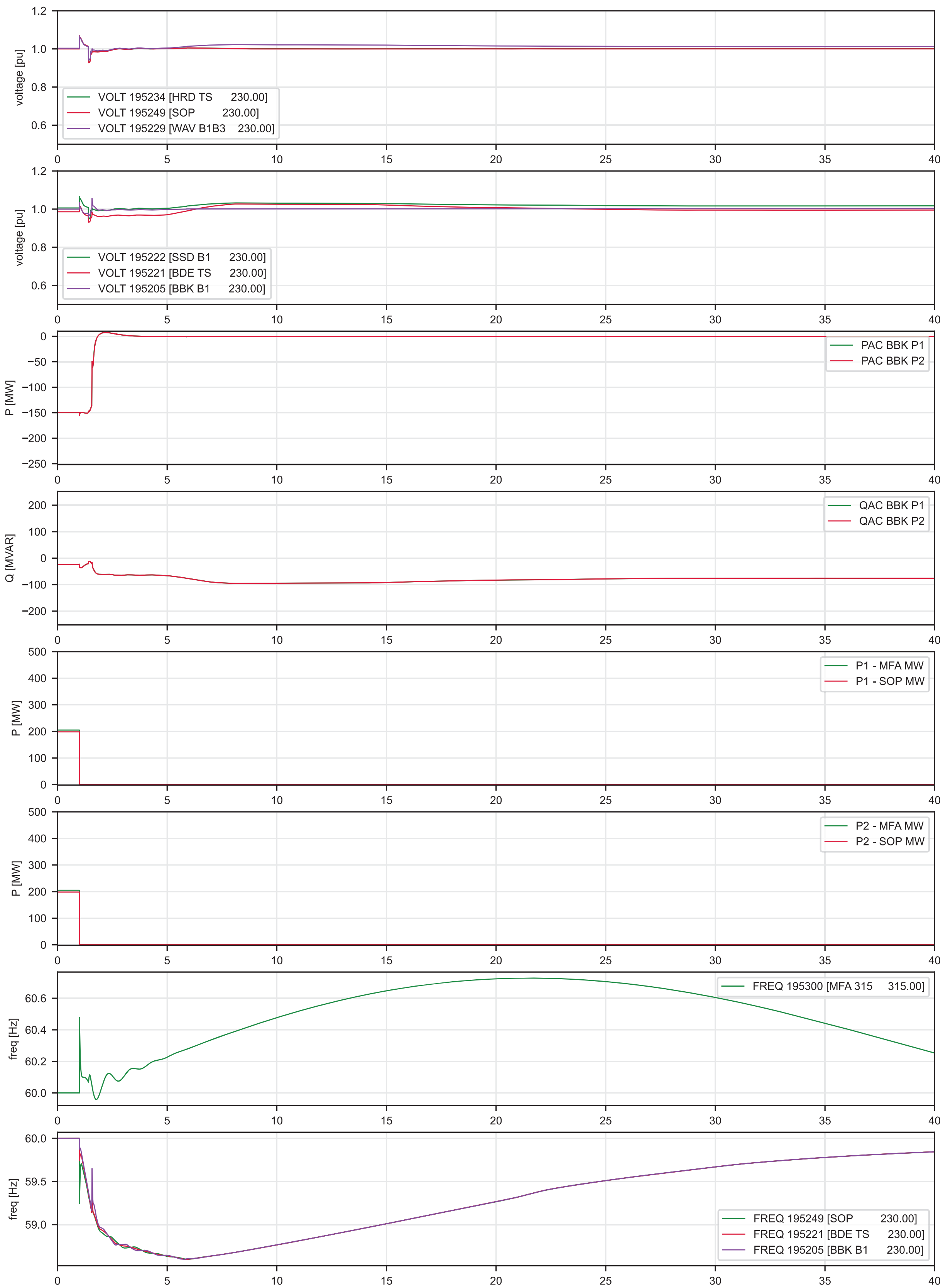
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 400 MW - ML 400 MW - One LIL restart enabled

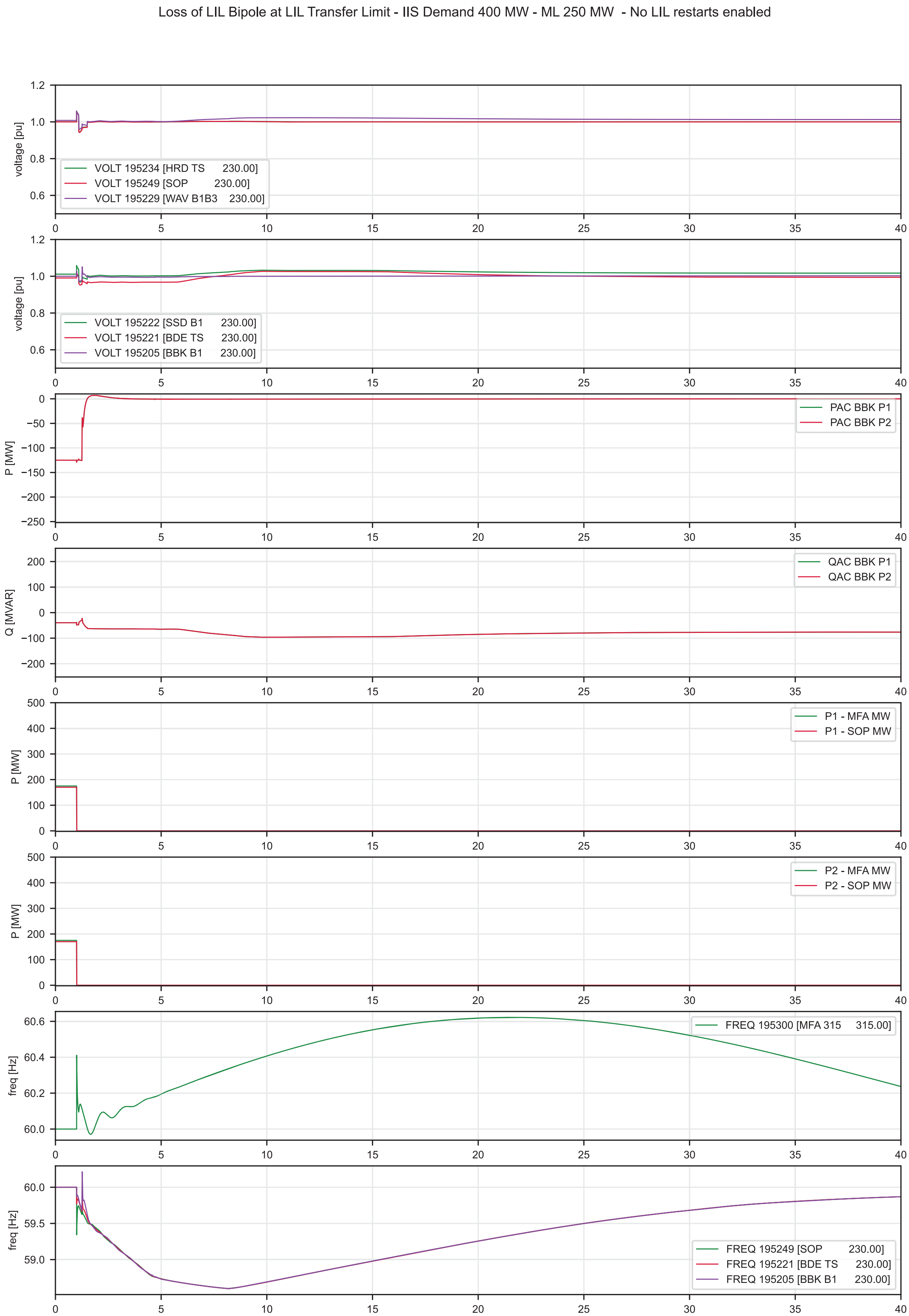


Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 400 MW - ML 300 MW - No LIL restarts enabled

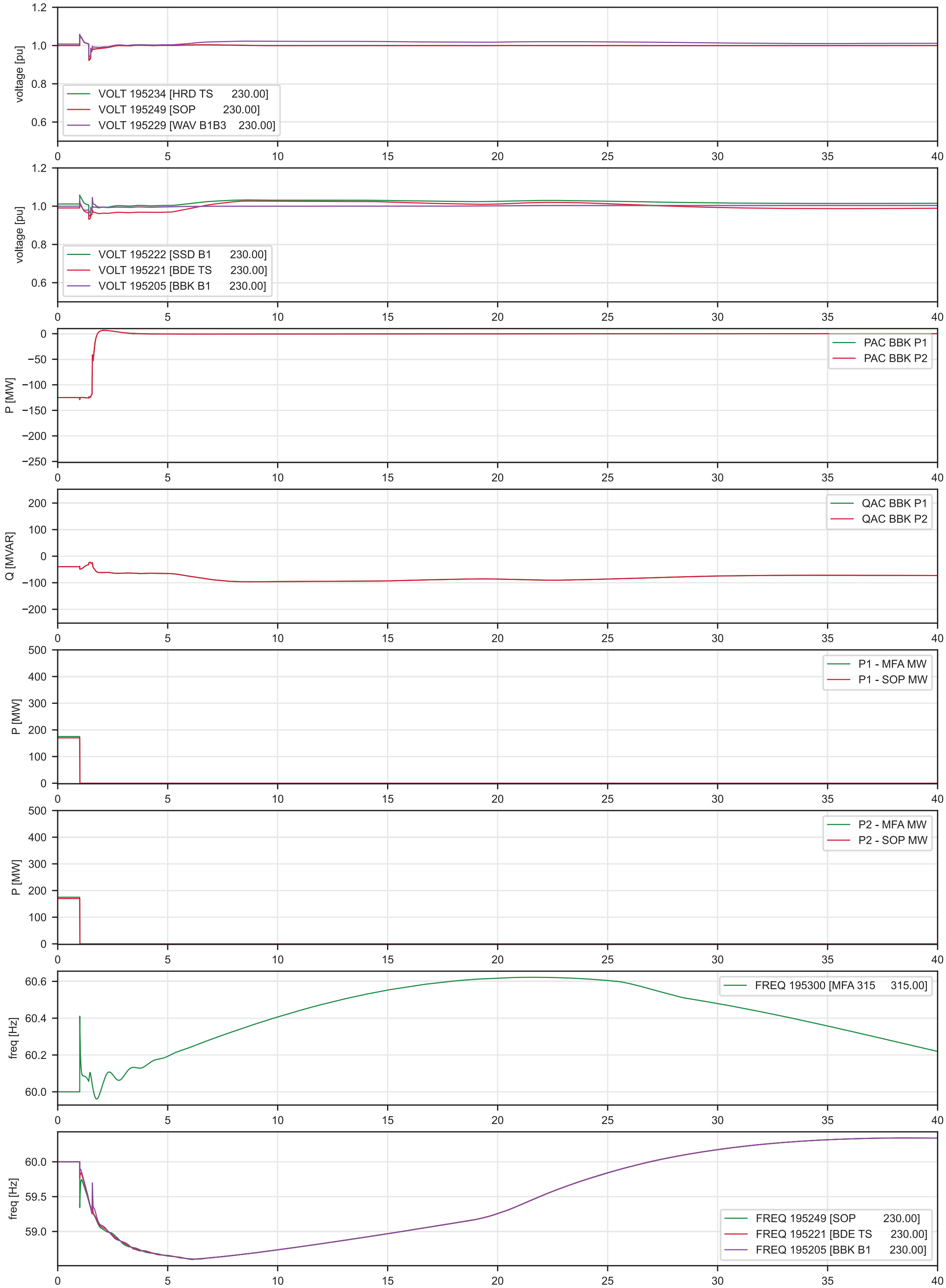


Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 400 MW - ML 300 MW - One LIL restart enabled

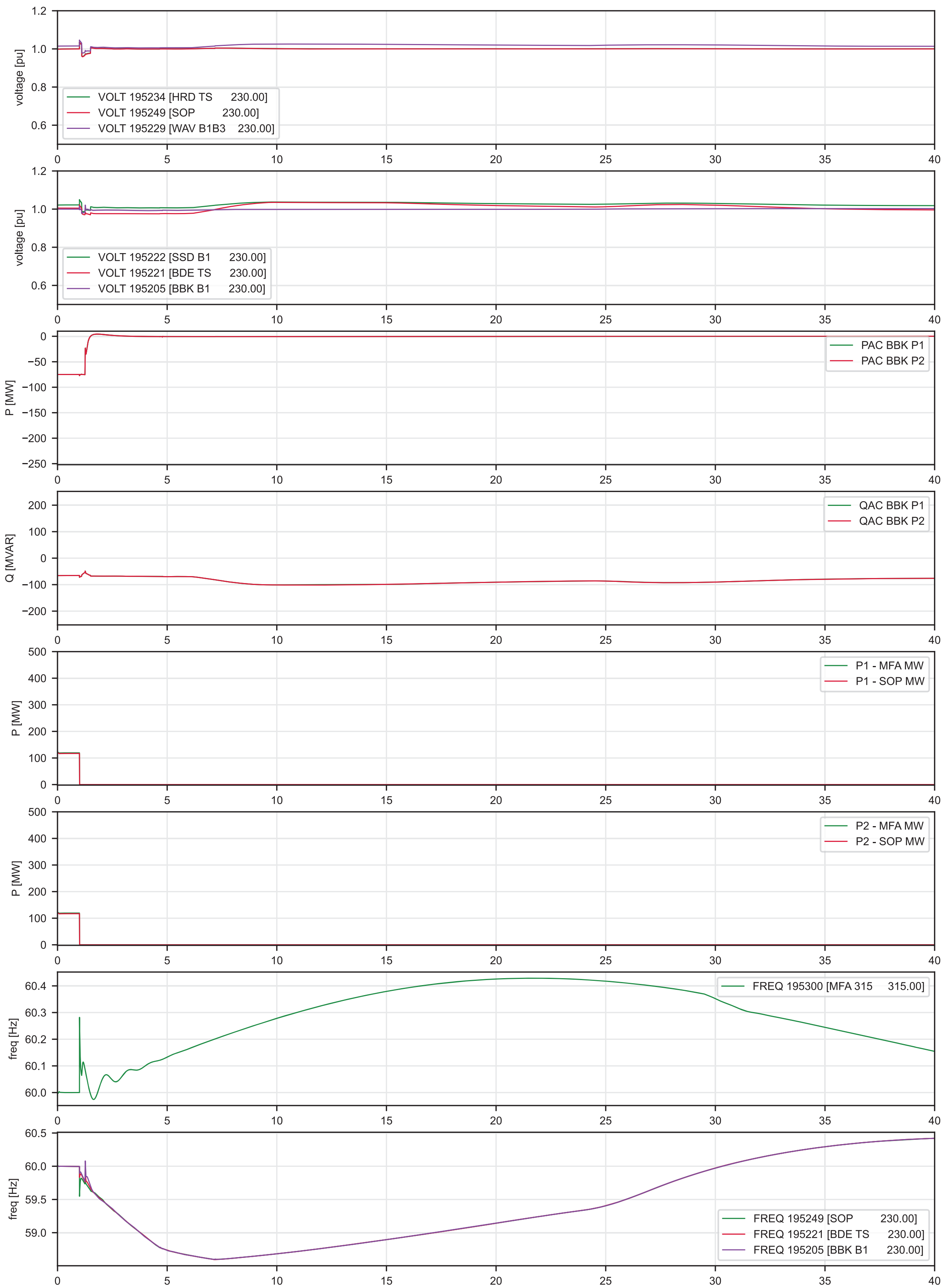



Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 400 MW - ML 250 MW - No LIL restarts enabled
voltage [pu]
VOLT 195234 [HRD TS 230.00]
VOLT 195249 [SOP 230.00]
VOLT 195229 [WAV B1B3 230.00]
VOLT 195222 [SSD B1 230.00]
VOLT 195221 [BDE TS 230.00]
VOLT 195205 [BBK B1 230.00]
P [MW]
PAC BBK P1
PAC BBK P2
Q [MVAR]
QAC BBK P1
QAC BBK P2
P1 - MFA MW
P1 - SOP MW
P2 - MFA MW
P2 - SOP MW
freq [Hz]
FREQ 195300 [MFA 315 315.00]
FREQ 195249 [SOP 230.00]
FREQ 195221 [BDE TS 230.00]
FREQ 195205 [BBK B1 230.00]

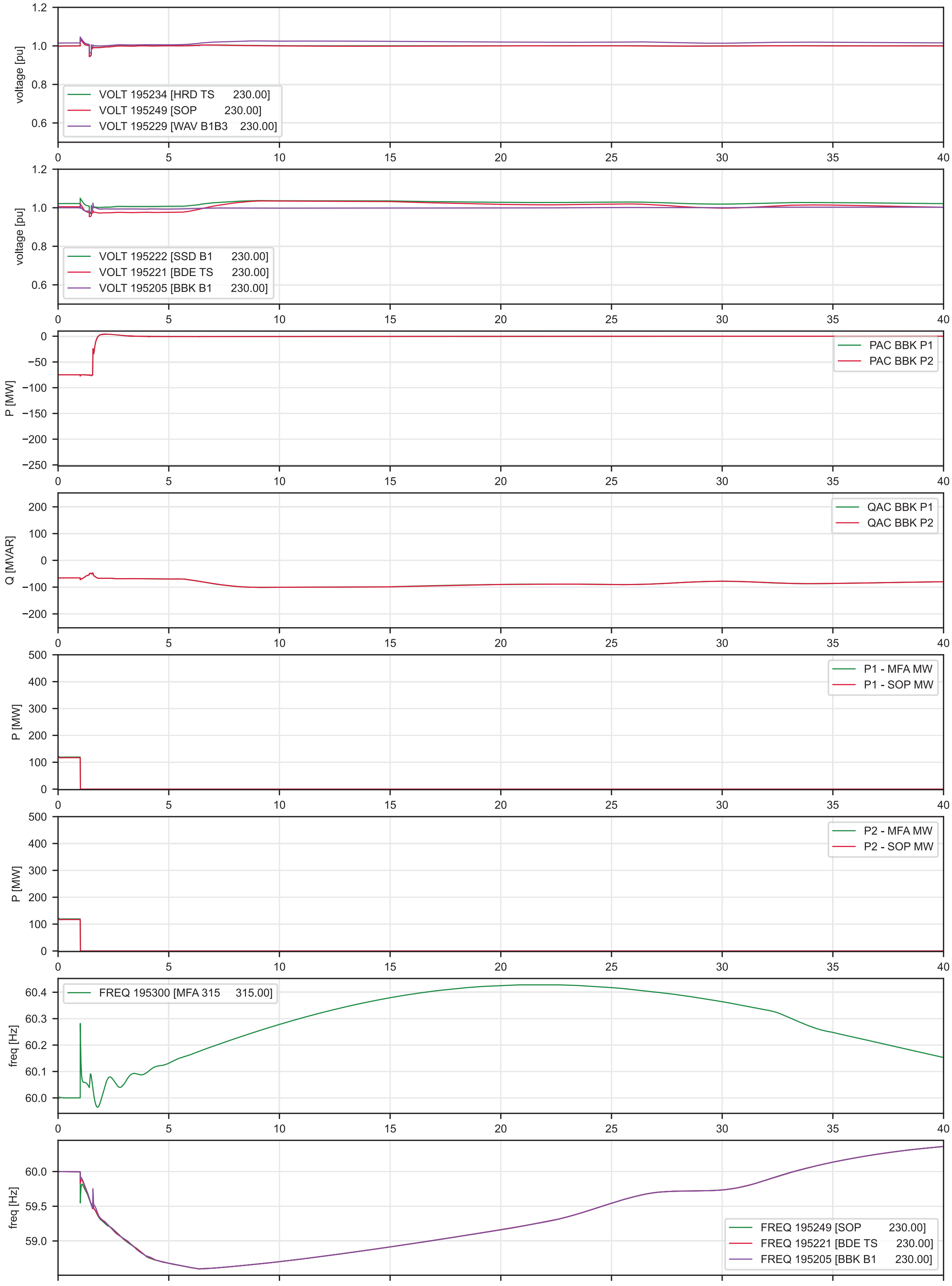
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 400 MW - ML 250 MW - One LIL restart enabled



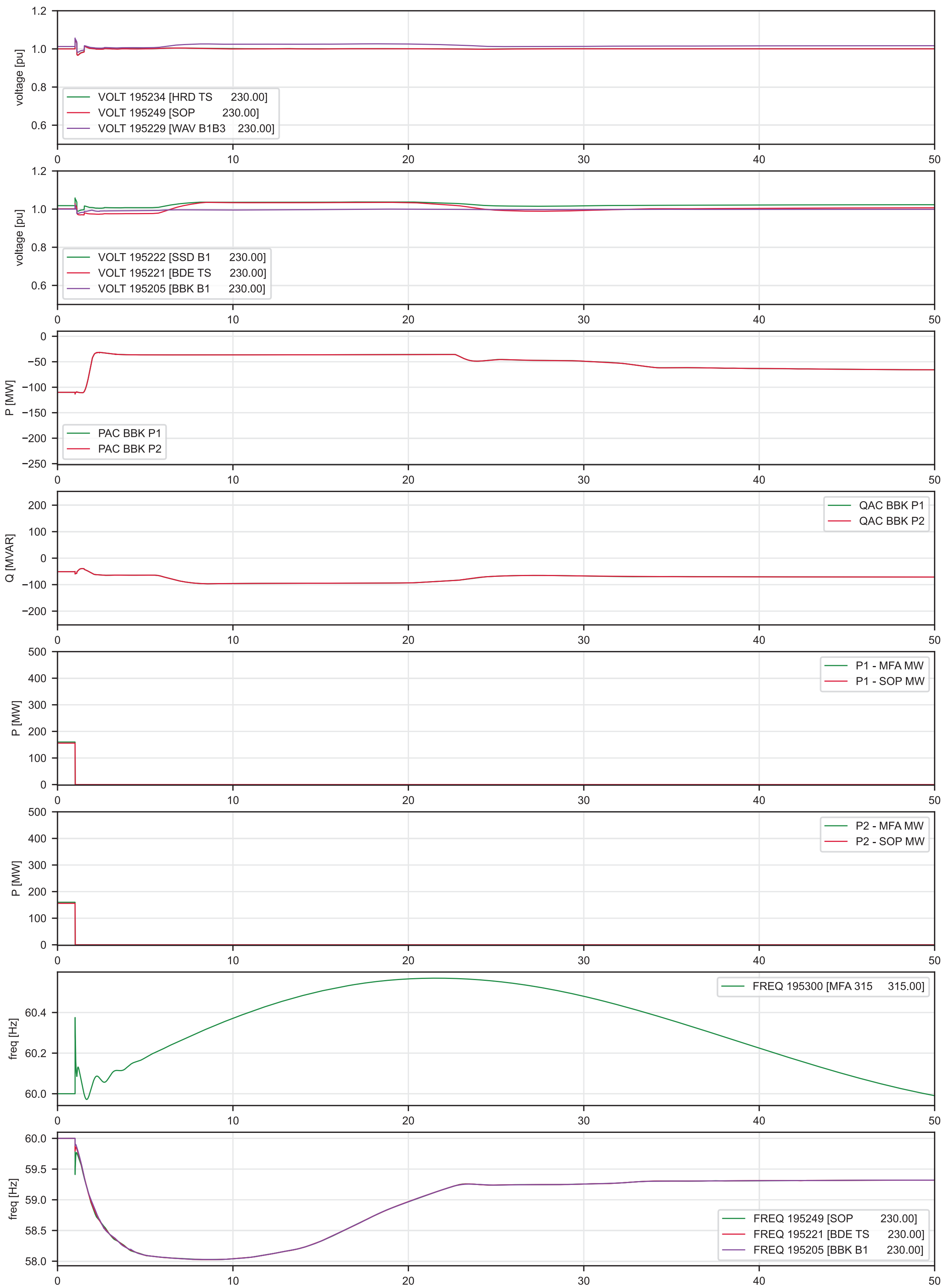
Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 400 MW - ML 150 MW - No LIL restarts enabled



Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 400 MW - ML 150 MW - One LIL restart enabled



Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 400 MW - ML 0 MW / ML Runbacks Inactive / ML F/C Active - No LIL restarts enabled



Loss of LIL Bipole at LIL Transfer Limit - IIS Demand 400 MW - ML 0 MW / ML Runbacks Inactive / ML F/C Inactive - No LIL restarts enabled