Generation Interconnection Request
GI-2004-2 Restudy
Feasibility and System Impact Study Report

75MW Expansion of the Twin Buttes Wind Generation Facility

Lamar 230kV Substation

Transmission Planning West – Xcel Energy

June 27, 2016

Contents

Executive Summary

The study request for GI-2004-2 was originally received in 2004. The initial request received by Public Service Company of Colorado (PSCo) in 2004 was for the interconnection of a 238MW wind generating facility at PSCo's Lamar 230kV Substation. The Feasibility Study completed in May 2004 and the System Impact Study completed in December 2004 had evaluated the 238MW capacity for Network Resource Interconnection Service (NRIS) as well as Energy Resource Interconnection Service (ERIS). Subsequently, the LGIA executed in 2005 was for a reduced 150MW capacity as ERIS. However, only 75MW was constructed by the Interconnection Customer by installing fifty GE-1.5MW Type-3 wind turbine generators (WTG), which were consistent with the WTG's studied for the original GI-2004-02 request. The resulting 75MW Twin Buttes generating facility has been in commercial operation since 2005.

In 2015, the Interconnection Customer approached PSCo to avail the remaining 75MW capacity under the purview of the existing LGIA. PSCo as Transmission Provider determined that a combined Feasibility & System Impact Restudy is needed to evaluate the proposed 75MW capacity addition for ERIS. Consistent with this objective, the purpose of the GI-2014-2 Restudy is to address the following: (1) identify the maximum allowed output of the proposed 75MW expansion without network upgrades, (2) identify any network upgrades needed to allow the generating facility to operate at full output (i.e. 150MW aggregate output after 75MW addition), and (3) identify the network upgrades needed to address the adverse system impact(s) due to the Gamesa-G9x 2.1MW wind turbine generators proposed for the 75MW capacity addition. The study request is for Energy Resource Interconnection Service only.

The study agreement for GI-2004-2 Restudy was executed on March 18, 2015. The 75MW expansion will be located adjacent to the existing Twin Buttes wind generating facility and interconnect to the Interconnection Customer's existing 230kV tie-line at approximately eight miles from the existing Twin Buttes switching station. Since this is a 75MW expansion for GI-2004-2, the existing POI at Lamar 230kV station remains unchanged. The proposed in-service date of the 75MW expansion is November 1, 2016. The affected parties for this study are Colorado Springs Utilities (CSU), Black Hills Colorado Electric (BHCE) and Tri-State Generation & Transmission Inc. (TSGT).

This request was studied as a stand-alone project, with no evaluations made of other potential new generation requests that may exist in the Generator Interconnection Request queue, other than the resource acquisitions for which Power Purchase Agreements have been signed. The system impact study consisted of steady state power flow contingency analysis and short circuit analysis. The Interconnection Customer has indicated TSGT as the off taker of the 75MW capacity expansion being studied.

The power flow analysis part of the study was performed using 2016 Heavy summer power flow model with heavy south – north flows in the Lamar, Comanche and Midway

area, and full generation dispatch at the existing Lamar Substation. The total generation interconnected at the Lamar Substation in the current system is 447MW. However, the power flow studies indicated that the maximum allowable generation injection capacity is limited to 296MVA. The thermal overloads caused on the CSU system can be mitigated by the Palmer Lake – Monument 115kV line operating procedure. Hence, the replacement of existing Lamar 230/115kV, 100 MVA # T1 transformer with a new 150 MVA transformer has been identified as a Network Upgrade in order to provide the full 75MW ERIS capacity for the 75MW Twin Buttes Expansion.

The transient stability analysis part of the study was performed using a 2016 base case with light loads and heavy wind generation at the Lamar POI. The study was performed for various combinations of wind and DC tie dispatch, for a combined maximum allowable generation injection capacity of 392MW at the Lamar Substation (the new injection limit after replacement of Lamar 230/115kV #T1). Due to the close proximity of the interconnecting generator to the Lamar back-to-back DC tie and the existing wind generation plant – all of which have a common POI at the Lamar 230kV bus – the transient stability study was performed with PSCAD by using detailed three-phase dynamic models for each of them.

The transient stability study did not find any unacceptable dynamic performance (as per FERC Order 661-A) that may be attributable to the 75MW expansion of Twin Buttes generation. Note that it is the responsibility of the Interconnection Customer to ensure that its generating facility is capable of meeting the voltage ride-through and frequency ride-through (VRT and FRT) performance specified in the NERC Reliability Standard PRC-024-2.

GI-2004-2 Restudy ERIS capacity is 0MW ***before*** Network Upgrade (Lamar 230/115kV, 100MVA transformer replacement with 150MVA rated unit)
GI-2004-2 Restudy ERIS capacity is 75MW ***after*** Network Upgrade (Lamar 230/115kV, 100MVA transformer replacement with 150MVA rated unit)

Note – TSGT who is the Transmission Operator of the Lamar 230/115kV, 100MVA#T1 transformer has initiated a capital budget project to replace the transformer with 150 MVA rated unit in order to allow full 75MW ERIS for the Twin Buttes expansion.

Short Circuit

The data related to the fault current levels at the POI contributed by the 75MW expansion was not provided, so a detailed short circuit analysis could not be done. An accurate short circuit analysis will be performed during Facility Study. See Table-1 for the single phase and three phase fault current levels at the Lamar 230kV POI for the current system configuration.

Cost Estimates

The cost for the transmission interconnection (in 2015 dollars):

The total estimated cost of the recommended system improvements to interconnect the project is approximately **$169.4 Thousand** and includes:

- $169.4 thousand for PSCo-Owned, Customer-Funded Interconnection Facilities
- $0 for PSCo-Owned, PSCo-Funded Network Upgrades for Interconnection
- $0 for PSCo Network Upgrades for Delivery to PSCo Loads

This work can be completed in 12 months following receipt of authorization to proceed.

The cost estimates do not currently include costs for upgrading the Lamar 230/115kV, 100MVA #T1 transformer. It is anticipated that the total cost for this transformer will be the responsibility of theInterconnection Customer. This transformer is a shared facility of PSCo and Tri-State (TSGT).

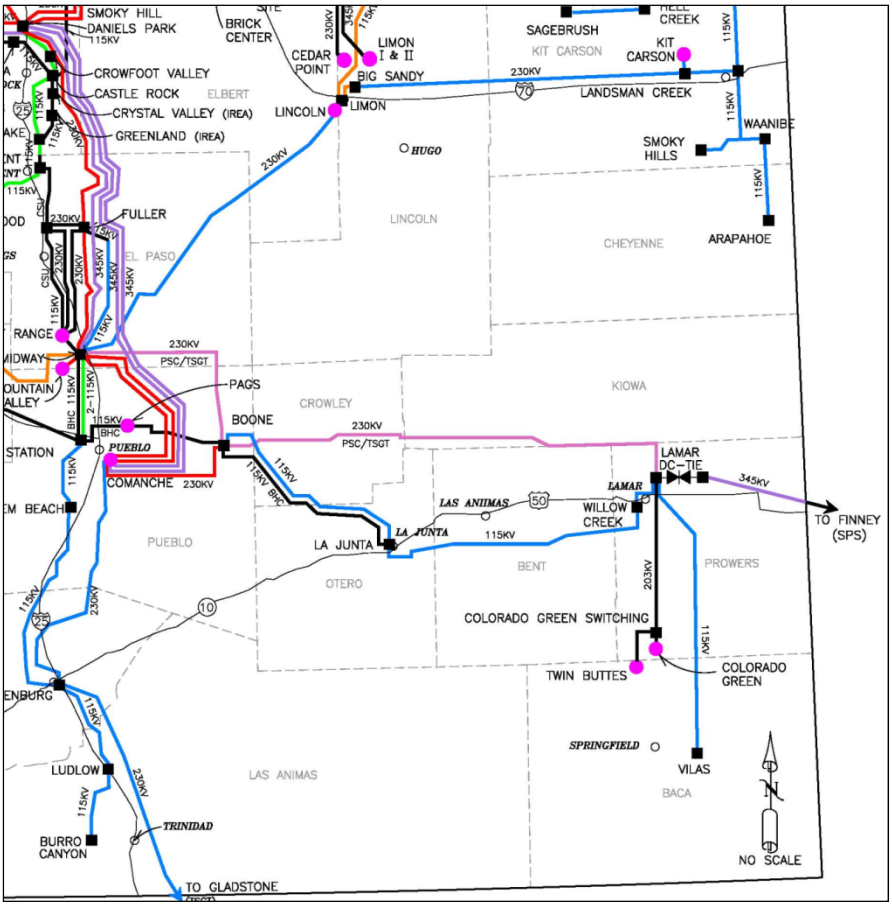

Figure 1 Lamar Substation and Surrounding Transmission System

1.0 Introduction

The study request for GI-2004-2 was originally received in 2004. The initial request was for the interconnection of a 238MW wind farm, the feasibility study for the 238MW interconnection request was completed in May 2004 and System Impact study was completed in December 2004. Post the system impact study completion, in December 2004, the GI capacity was reduced to 150MW. The studies performed in 2004 assumed GI-2004-2 included 1.5MW GE doubly fed induction generators. Out of the 150MW, 75MW capacity is currently interconnected as Twin Buttes generation at PSCo's Lamar 230kV bus. The purpose of the restudy is to evaluate the feasibility of interconnecting the remaining 75MW of the 150MW capacity and also study the impact of the change in the turbines to Gamesa-G9x 2.1MW for the 75MW expansion.

The study agreement for the restudy of GI-2004-2 was executed on March 18, 2015. The geographical location of the 75MW expansion will be adjacent to the existing Twin Buttes wind farm and electrically interconnect to the Customer gen-tie line at approximately eight miles from the existing Twin Buttes switching station. The 75MW expansion will interconnect at the Lamar Substation at the existing POI using the existing customer owned 230kV gen-tie line. The Lamar 230kV POI is shown in Figure 1 above. The proposed in-service date of the 75MW expansion is November 1, 2016. The study request is for an Energy Resource interconnection only.

The study request is for a combined Feasibility and System Impact study. The purpose of the GI-2014-2 Feasibility and System Impact Restudy is to address the following: (1) identify the maximum allowed output of without network upgrades, (2) identify any network upgrades needed to allow the generating facility to operate at full output (i.e. 150MW aggregate output after 75MW addition), and (3) identify the network upgrades needed to address the adverse system impact(s) due to the Gamesa-G9x 2.1MW wind turbine generators proposed for the 75MW capacity addition. The study request is for Energy Resource Interconnection Service only.

The Gamesa-9X 2.1MW wind turbine generator is a doubly-fed induction generator (Type-3) that is asynchronous from the transmission system and has an inverter-connected rotor with automatic voltage control capability. It is expected that these machines will have at least +/- 0.95 power factor capability and be operated in voltage control mode at all times.

Due to the close proximity of the interconnecting generator to the Lamar back-to-back DC tie and the existing wind generation plants, all of which have a common POI at the Lamar 230kV bus; transient stability analysis was performed with PSCAD by using detailed three-phase dynamic models.

Furthermore, it is the responsibility of the Interconnection Customer to ensure that its generating facility is capable of meeting the voltage ride-through and frequency ride-

through (VRT and FRT) performance specified in the NERC Reliability Standard PRC-024-2.

2.0 Study Scope and Criteria

The Feasibility Study consists of steady-state power flow analyses to evaluate the thermal and voltage impacts of the proposed generating plant on the transmission system, as well as determine the adequacy of the generating plant's power factor range (reactive power capability) at the POI.

Feasibility Study Criteria: During system intact conditions, criteria are to maintain transmission system bus voltages between 0.95 and 1.05 per unit of nominal and steady-state power flows below the thermal ratings of all facilities. Operationally, PSCo tries to maintain a transmission system voltage of 1.02 per unit or higher at regulating (generator) buses and 1.0 per unit or higher per unit at transmission load buses in the study area. Following a single or double contingency, transmission system steady state bus voltages must remain within 0.90 - 1.05 per unit, and power flows must remain within 100% of the facility's continuous thermal ratings. Also, voltage deviations should not exceed 5%.

The transient stability study analysis monitored

- Fault dynamic performance and recovery – since the Gamesa PSCAD models include detailed controls and protection system, the ride-through behavior was tested to ensure the windfarm ride-through the disturbances/faults.
- Interactions/Oscillations between the DC link, existing windfarms and the new windfarm post disturbance.

The proposed facility was requested to be studied as Energy Resource only.

Energy Resource Interconnection Service shall mean an Interconnection Service that allows the Interconnection Customer to connect its Generating Facility to the Transmission Provider's Transmission System to be eligible to deliver the Generating Facility's electric output using the existing firm or non-firm capacity of the Transmission Provider's Transmission System on an as available basis. Energy Resource Interconnection Service in and of itself does not convey transmission service.

The affected parties for this study are CSU, TSGT and BHCE.

3.0 Feasibility Study

3.1 Power Flow Study Models

The study was based on 2016HS power flow case created from the WECC 2015HS power flow case released on December 5, 2014. The updates included topology, generation, load and rating updates to the PSCo, TSGT, BHCE, IREA and CSU systems. The second 230/115kV, 150MVA Lamar transformer is modeled. The Lamar 230/115kV, 150MVA#T1 transformer is modeled at 100MVA. BHCE updates included modeling of a fifth 90MW Baculite Mesa Generator connecting to BHCE's Baculite substation.

To assess the impact of the proposed generation on the interconnected transmission system, the generation dispatch in the reference case was adjusted to create a south to north power flow stress on the Comanche – Midway - Jackson Fuller – Daniels Park transmission path. This was accomplished by adopting the generation dispatch described in Table - 8 below. PSCo generation dispatch in the study area (zones 700, 704, 710, 712, 752, 757, 790 and 791) is dispatched such that wind generation is at 85% name plate capacity, solar generation is at 80% name plate capacity and conventional non-coal generation is at 90% name palate capacity, coal generation is dispatched at 100% name plate capacity. The study did not include any generation in the Generation Interconnection queue except resources for which a Power Purchase Agreement (PPA) has been signed.

The Lamar DC tie and existing Wind generation at Colorado Green and Twin Buttes is dispatched such that no thermal violations exist in the benchmark case, which resulted in the combined generation total of 237MW from the Wind farms and the DC tie.

Two power flow cases were created for evaluating the system impact of the proposed generator – the benchmark case and the study case. The study case included the 75MW generation addition at Lamar 230kV POI due to the proposed GI-2004-2 restudy. PSCo's Fort Saint Vrain is used as the sink for the generation addition.

3.2 Power Flow Study Process

In the current system configuration, the total generation interconnected at the Lamar 230kV bus is 447MW (210MW at Lamar DC tie and 237MW of combined generation from Colorado Green and Twin Buttes wind plants). However, the maximum generation injection allowed at any time at the Lamar 230kV bus is limited by the overloads on the Lamar 230/115kV, 100MVA # T1 transformer. Without exceeding the thermal rating of the Lamar 230/115kV, 100MVA #T1 transformer, the maximum allowable generation at Lamar 230kV POI is 237MW. For any injection level above 237MW, the Lamar 230/115kV, 100MVA#T1 transformer overloads above 100% of the thermal rating for the loss of the Lamar230/115kV, 150MVA # T2 parallel transformer.

Contingency power flow studies were completed on the reference power flow case and the study case (power flow case with 75MW expansion of Twin Buttes) using PTI's

PSSE Ver. 33.4.0 program. Results from each of the two cases were compared and the monitoring criteria are to list any new thermal and voltage violations. The PSSE Ver. 33.4.0 ACCC contingency analysis activity was used to perform the load flow contingency analysis. The analysis included various Category B and Category C contingencies. The Category B analysis was performed using bus-bus contingencies and all breaker – breaker contingencies in the study area are run. Category B outages were run in areas 70 and 73 whereas Category C contingencies were studied for zones 700, 704, 705, 709, 712, 752, 757, 790, and 791. The facilities in Zones 700, 704, 710, 712, 752, 757, 790 and 791 were monitored for overloads and voltage violations. The Category C analysis included a selected few worst case contingencies in Zones 704 and 712.

3.3 Power Flow Study Results

The current system configuration limits the existing 447MW available generation at Lamar 230kV Substation to 237MW. Therefore, the maximum allowable generation at Lamar 230kV POI before any network upgrades are performed is only 237MW.

The ER portion of the study determined that the Customer could provide approximately 0MW of energy before network reinforcements for delivery would be required; however, non-firm capacity may occasionally be available depending upon the dispatch of the existing wind generation facilities and the Lamar DC tie schedules such that total injection at Lamar 230kV does not exceed 237MW.

> However, when the identified network upgrades are performed, the injection capacity of the proposed 75MW expansion can be up to 100% as an Energy Resource. The identified network upgrade is *replacement of the Lamar 230/115kV, 100MVA # T1 transformer with a 150MVA rated transformer.*

The results of the single contingency analysis for 237MW total injection at the Lamar 230kV bus are given Table-6. The Cherokee – Federal Ht 115kV# 2 line overload is caused due to reduction in the Fort Saint Vrain generation which is used as system sink and is not attributable to the Lamar 230kV injection.

The Lamar 230/115kV # T1 transformer loading increases from 100% to 111.1% when the GI-2004-2 75MW expansion is added to the case.

The existing thermal overloads on the CSU lines BrairgateS- CottonwoodS 115kV, CottonwoodN-KettleCreekS 115kV and Monument - Flyhorse 115kV line increase when GI-2004-2 75MW expansion is added at Lamar. However, PSCo has an operating procedure to open the Palmer Lake – Monument 115kV line that will mitigate these overloads. The revised line loadings with Palmer Lake – Monument 115kV line open are given in Table-7.

The study did not cause any new voltage violations and none of the existing voltage violations increased. The highest increase seen in voltage range violations is 0.006p.u. and the highest increase seen in voltage deviations is 0.01p.u, so there were no voltage violations attributable to GI-2004-2 Restudy

4.0 Voltage Regulation and Reactive Power Capability

Interconnection Customers are required to interconnect their Large Generating Facilities with Public Service of Colorado's (PSCo) Transmission System in conformance to the *Xcel Energy Interconnection Guidelines for Transmission Interconnected Producer-Owned Generation Greater Than 20MW* (available at http://www.xcelenergy.com/staticfiles/xe/Regulatory/Transmission-Interconnection-Guidelines-Great-20MW.pdf). Wind and solar generating plant interconnections (Variable Energy Resources) must also conform to the performance requirements in FERC Order 661-A. Accordingly, the following voltage regulation and reactive power capability requirements (at the POI) are applicable to this interconnection request:

- To ensure reliable operation, all Generating Facilities interconnected to the PSCo transmission system should adhere to the Rocky Mountain Area Voltage Coordination Guidelines. Accordingly, since the POI for this interconnection request is located within Southeast Colorado Region 4; the applicable ideal transmission system voltage profile range is 1.02 – 1.03 per unit at regulated buses and 1.0 – 1.03 per unit at non-regulated buses.
- Xcel Energy's OATT requires all Interconnection Customers to have the reactive capability to achieve +/– 0.95 power factor at the POI, with the maximum "full output" reactive capability available at all output levels. Furthermore, Xcel Energy requires all Interconnection Customers to have dynamic voltage control and maintain the voltage specified by the Transmission Operator within the limitation of +/– 0.95 power factor at the POI, as long as the generating plant is on-line and producing power.
- It is the responsibility of the Interconnection Customer to determine the type (switched shunt capacitors and/or switched shunt reactors, etc.), the size (MVAR), and the locations (690 V, 34.5kV or 230kV bus etc.) of any additional static reactive power equipment needed within the generating plant in order to have the reactive capability to meet the +/– 0.95 power factor and the 1.02 – 1.03 per unit voltage range standards at the POI. The Interconnection Customer may need to perform additional studies for this purpose.
- It is the responsibility of the Interconnection Customer to ensure that its generating facility is capable of meeting the voltage ride-through and frequency ride-through (VRT and FRT) performance specified in NERC Reliability Standard PRC-024-2.

- The Interconnection Customer is required to demonstrate to the satisfaction of PSCo Transmission Operations prior to the commercial in-service date of the generating plant that it can safely and reliably operate within the required power factor and voltage ranges noted above.

5.0 Transient Stability Study

The Transient Stability Study was performed by the Consultant Electranix Corporation, under the direction of the Interconnection Customer, PSCo (the Transmission Provider), and TSGT(the Affected Party responsible for Network Upgrade and the Transmission Service Requestor). The study was performed using PSCAD/EMTDC V4.6 and E-TRAN V3.

5.1 PSCAD Model

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The Transient Stability study modeled light loads and heavy wind penetration in the Lamar area. Also, Comanche #1 unit was modeled offline. In addition, the following modifications are made to the PSCAD model

- Replace the Lamar 230/115kV #T1 transformer with 150MVA unit.
- The wind turbines are set to control the Colorado Green 230kV bus to 1.02p.u..
- The shunt elements at the 34.5kV bus and 34.5/230kV transformer high side taps are adjusted for a low Q dispatch from the windfarm turbines as well as to maintain nominal voltages at the 34.5kV low voltage buses.
- The two winding 34.5/230kV station transformer for Twin Buttes – II is replaced with a three winding transformer having winding 1 to 2 impedance of 10% (on 75MVA)

The following detailed PSCAD models were used for the study:

- The detailed Gamesa Wind Turbine Models for PSCAD representing the TB2 wind farm. Since the Gamesa PSCAD models include detailed controls and protection system, the ride-through behavior was tested to ensure the windfarm ride-through the disturbances/faults.
- GE Wind Turbine PSCAD Models for Colorado Green and Twin Buttes I. The GE PSCAD models received do not include the farm controllers or central reactive coordination scheme. This is normally acceptable for EMT studies, as the farm controllers are usually relative slow (i.e. seconds response times) – for the PSCAD models, the turbines are essentially each in constant Q control, using a steady state Q value that comes from the power flow (which inherently models the Q it would receive from a central farm controller).
- Lamar HVDC PSCAD Model

5.2 Study Assumptions

The following settings and assumptions are used during this study:

- The system model included in the study is large enough to include the area around Lamar, including the 230kV path to Boone/Comanche/Midway and the parallel 115kV path. The E-TRAN program also computes passive multi-port network equivalents, which were placed at Boone, Midway and Comanche busses.
- Wind farms models are lumped/scaled equivalents, using individual turbine models (scaled by N using the E-TRAN transformer scaling component). The database of models also includes the nearby AC lines, including logic for the application, clearing and reclosing of line faults, plotting of key quantities etc… This ensures a robust method for running/documenting cases, even with multiple power flow scenarios to be studied.
- A generic voltage/farm controller was used for TB2, using a simple PI controller with a conservative 3 second time constant.
- The Detailed Lamar DC link model is a PSCAD version 4.2.1 model with COMPAQ FORTRAN compiled binaries. On the other hand, the GE wind farm models (representing the existing Colorado Green and Twin Butte windfarms) are PSCAD version 4.6 models with INTEL FORTRAN compiled binaries. Similarly, the Gamesa model representing the Twin Buttes II windfarm is also a PSCAD 4.6 model with INTEL FORTRAN compiled binaries. Thus, in order to combine all the models into one PSCAD simulation, the “E-TRAN Plus for PSCAD” Parallel processing tool is used during this study. The PSCAD parallel processing tool allows large PSCAD case to be broken up into many smaller PSCAD cases, so that they can be run on many cpu/cores or onto multiple computers allowing each process to be built with a different version of FORTRAN compilers. This means, each PSCAD case can be different version of PSCAD, use a different FORTRAN compiler, and run at a different simulation time step.
- The Gamesa wind model does not support snapshots, so each run will require simulation of 20 seconds, before applying any faults due to the start-up/initialization process of the Lamar HVDC link model.
- The loads in the nearby area are assumed to be constant PQ loads (i.e. no induction motor loads are modeled, which would depress the voltage longer during the fault recovery). Thus, this study assumes worst case post fault voltages/overshoots, which is considered as a conservative approach.

- For the contingency analysis, faults are applied at 20.1 seconds of the simulation and the breaker opening/fault clearing time for 115 and 230kV lines is considered as 4 cycles. Note that the outage of the Lamar-Boone 230kV line is not considered as a contingency during this study, thus, the transfer trip information (i.e. the communication time delays involved, the HVDC link power order reduction levels, and the time to transfer trip the 230kV lines from Lamar to the wind farms), are not modified in the existing Lamar HVDC link PSCAD model.

5.3 PSCAD Study Methodology

The total injection capacity at Lamar 230kV POI is limited to 392MW after the replacement of the Lamar 230/115kV, 100MVA#T1 with 150MVA capable unit. The study simulated three different dispatch scenarios containing different DC/existing wind MW amounts, with the combined injection equal to 392MW.

- **Dispatch Scenario 1: DC Tie = +210MW; Wind = 107MW (CG) + 75MW (TB2)**
- **Dispatch Scenario 2: DC Tie = +105MW; Wind = 212MW (CG+TB1) + 75MW (TB2)**
- **Dispatch Scenario 3: DC Tie = 0MW; Wind = 237MW (CG+TB1) + 75MW (TB2)**

For each scenario, the following contingencies are simulated

Table 1 – List of Contingencies

3ph Fault Location	Facility Tripped	Lamar Transfer Trip Initiated?	Lamar DC Tie Power Order Reduction Initiated?
Lamar 115kV Bus	Lamar 230/115kV Xfmr T1	No	No
Lamar 115kV Bus	Lamar – Willow Creek 115kV Line	No	No
Willow Crk 115kV Bus	Lamar – Willow Creek 115kV Line	No	No
Boone 230kV Bus	Boone – Midway 230kV Line	No	No
Boone 230kV Bus	Boone - Comanche 230kV Line	No	No

All simulations are performed for 30 seconds with faults being applied at 20.1 seconds (approximately 15 seconds is required for the PSCAD Lamar HVDC model to reach steady state). Also, all the simulations are starting from time zero, since the Gamesa wind model does not support snapshots.

The simulation time steps used were as follows:

- 20 µsec for the PSCAD case with the Lamar DC link model
- 10 µsec for the PSCAD case with the Gamesa TB2 model

- 10 µsec for the PSCAD case with the GE models.

The study results are reviewed, looking for oscillatory or unstable responses, unwanted operation of protections systems, over-voltage/under-voltage conditions, interactions between the DC link and windfarms etc.

The transmission line is represented in the power flow using R, X, B in pu on 100MVA base – this default data is converted into PSCAD as a Bergeron traveling wave model and will have a reasonable frequency response (much better than a PI equivalent circuit). The Bergeron representation will not have the correct damping however, and the frequency of dominant resonances can be shifted. Therefore, 115/230kV lines around the study area (specifically the 230 and 115kV paths between Lamar and Boone) are modeled using detailed frequency dependent line models. All remaining transmission lines in the kept system were represented using Bergeron travelling wave model based on PSS/E power flow data. Extremely short lines (or lines where B was not entered in the power flow) were represented with PI sections.

5.4 Transient Stability Analysis Results

It was observed that the existing GE wind units trip under several contingencies, just after the fault is applied (typically, within the first cycle after the application of the fault). It is concluded that the tripping of the GE windfarm model is due to the activation of DC overvoltage protection. During this remote fault condition, the older generation of GE turbines go into ride-through mode, but they cannot transmit any real power (i.e. the voltage at the AC bus is 0.0 so the AC power delivered will be zero). The VSC HVDC converter in the turbines have a power balance – i.e. in steady state, the real power into the rotor side converter will be equal to the real power out of the grid side converter. Since the grid power is 0.0, this means that the DC voltage shoots up very high (i.e. more power in vs out), causing this DCOV protection to activate.

It is important to note that the tripping of the GE units causes significant loss of real power (depending on the scenario considered - 107MW, 212MW and 237MW respectively for the three scenarios). This sudden loss of real power generation was observed to produce an over voltage condition just after the fault is cleared. Since the 3 phase to ground faults are considered, and the induction motor loads in the nearby area are not modeled, this voltage overshoot can be significant.

The AC over voltage (OV) that occurs was observed to occur due to four factors:

1. The HVDC link commutation-failure event (and filterMVARs left on once the HVDC MVAR absorption temporarily goes away)
2. The inherent I*I*X (I squared X) reduction of MVARs absorbed by the 230 and 115kV systems when the total MW from wind and HVDC is reduced temporarily after a fault (permanently - if the GE units trip).

3. The dynamic VAR control behavior of the existing and new turbines.
4. Shunt capacitors (for the wind farms and HVDC link).

Item 1 is a pre-existing issue and not affected by the addition of TB2.

The OV contribution from Item 2 is a function of the total pre-fault power level exported out of Lamar (i.e. the total of wind + HVDC power) – this is limited to 392MW (assuming the 2nd 230/115 transformer at Lamar is in-service) regardless of whether TB2 is added or not.
For Item 3, the TB2 turbines were observed to go to 0 MVARs during a fault (this is observable in system plots/traces) - in which case they do not contribute to a post-fault OV.
Item 4 is a case where any shunt caps in-service will contribute to the dynamic post-fault OV – TB2 does utilize shunt capacitors (so therefore can contribute to this aspect of the post-fault ACOV), however the capacitors are out-of-service for all three scenarios. The study result sensitivity to these shunt caps has not been exhaustively investigated (some of the shunt caps in the existing Colorado Green and Twin Buttes 1 were in-service depending on the scenario, but not all.) The shunt dispatch and the 34.5/230kV transformer tap settings for the three scenarios are shown below.

Scenario 1
CG -west - all shunts out-of-service
CG -east - all shunts out-of-service
TB - no shunts in the model
TB2 - all shunts out-of-service
all transformers have nominal tap settings

Scenario 2
CG -west - all shunts out-of-service
CG -east - all shunts out-of-service
TB - no shunts in the model
TB2 - all shunts out-of-service
CGE/CGW/TB transformers have 1.0187 off nominal tap on 230kV side
TB2 transformer has 1.05 off nominal tap on 230kV side

Scenario 3
CG -west - all shunts out-of-service
CG -east - 13MVAr shunt in-service
TB - no shunts in the model
TB2 - all shunts out-of-service
CGE/CGW/TB transformers have 1.0187 off nominal tap on 230kV side
TB2 transformer has 1.02 off nominal tap on 230kV side

Also note that, in all cases, all windfarms are controlling the Colorado Green 230kV bus (PSSE bus 70700) to 1.02pu

The tripping of the HVDC link and the TB2 windfarm occur when the post fault AC voltage exceeds a threshold value. There is an accompanying delay time for the HVDC link before tripping. However, the TB2 windfarm trips almost instantly once the local 690V bus voltage exceeds 1.2pu. This is in line with the simulation traces, where anytime the 690V bus voltage exceeds 1.2pu during the fault recovery, the TB2 is tripped.

For those cases, where only the existing wind farms are tripped during the fault (i.e. "fail[7]" marked in the results table) under the system intact conditions, the simulations were repeated with the TB2 windfarm out of service. It was observed that these five simulations without TB2 exhibit somewhat similar behavior to that of TB2 in-service cases (i.e. existing windfarms are still tripping during the fault).

The results of the simulations are summarized in Table-3 and plots are given in Appendix – B.

Table 3 - PSCAD Stability Study Results

3ph Fault Location	Facility Tripped	Lamar Transfer Trip Initiated?	Lamar DC Tie Power Order Reduction Initiated?	Scenario 1 DC=210E2W CG+TB1=107MW TB2=75MW	Scenario 2 DC=105E2W CG+TB1=212MW TB2=75MW	Scenario 3 DC=0 CG+TB1=237MW TB2=75MW
Lamar 115kV Bus	Lamar 230/115kV Xfmr T1	No	No	fail[8*]	pass[1]	pass[1]
Lamar 115kV Bus	Lamar – Willow Creek 115kV Line	No	No	pass[1]	fail[7] fail[7] (with TB2 Off)	pass[1]
Willow Crk 115kV Bus	Lamar – Willow Creek 115kV Line	No	No	fail[2*]	pass[1]	pass[1]
Boone 230kV Bus	Boone – Midway 230kV Line	No	No	pass[1]	fail[7] fail[7] (with TB2 Off)	fail[7] fail[7] (with TB2 Off)
Boone 230kV Bus	Boone – Comanche 230kV line	No	No	pass[1]	fail[7] fail[7] (with TB2 Off)	fail[7] Fail[9] (with TB2 Off)

* - trips occur due to OVs above 1.2 pu at the turbine 690V location - tests are ongoing with the manufacturers to investigate possible solutions

Note	Lamar HVDC	Existing GE Wind at CG and TB1	New Gamesa Wind at TB2	
1	Recovered	Recovered	Recovered	
2	Recovered	Tripped	Tripped	
3	Tripped	Tripped	Tripped	
4	Recovered	Recovered	Recovered	Sustained post-fault oscillations from HVDC
5	Tripped	Tripped	Recovered	
6	N/A	Tripped	Recovered	
7	Recovered	Tripped	Recovered	

8	Recovered	Recovered	Tripped	
9	Tripped	Tripped	N/A	

6.0 Conclusion

The Feasibility Study concludes that the Interconnection Service capacity is limited by the overloads on the Lamar 230/115kV, 100MVA transformer.

The Transient Stability study did not find any unacceptable dynamic performance violations (as per FERC Order 661-A) that may be attributable to the 75MW expansion of Twin Buttes generation.

GI-2004-2 Restudy ERIS capacity is 0MW before Lamar 230/115kV, 100MVA transformer replacement with 150MVA capable.

GI-2004-2 Restudy ERIS capacity is 75MW after Lamar 230/115kV, 100MVA transformer replacement with 150MVA capable

Furthermore, it is the responsibility of the Interconnection Customer to ensure that its generating facility is capable of meeting the voltage ride-through and frequency ride-through performance specified in the NERC Reliability Standard PRC-024-2.

Note that the provided cost estimates do not include costs for upgrading the transformer. It is anticipated that the total cost for this transformer will be the responsibility of the Interconnection Customer. This transformer is a shared facility of PSCo and Tri-State (TSGT).

7.0 Short Circuit

The calculated short circuit levels and Thevenin system equivalent impedances for the Lamar 230kV bus for the current system configuration are tabulated below. The customer must provide detailed model along with GSU data in order to verify the breaker over duty limits. Short circuit analysis will be performed during Facilities Study.

Table 1 – Short Circuit Parameters at the Lamar 230kV POI

System Condition	Three-Phase Fault Level (Amps)	Single-Line-to-Ground Fault Level (Amps)	SLG X/R	3 Phase X/R
System Intact	2241.8	1742.95	9.3745	8.4579

8.0 Costs Estimates and Assumptions

Scoping level cost estimates for Interconnection Facilities and Network/Infrastructure Upgrades for Delivery (+/- 30% accuracy) were developed by Public Service Company

of Colorado (PSCo) / Xcel Energy (Xcel) Engineering. The cost estimates are in 2015 dollars with escalation and contingency included. AFUDC is not included. Estimates are developed assuming typical construction costs for previous completed projects. These estimates include all applicable labor and overheads associated with the siting support, engineering, design, material/equipment procurement, construction, testing and commissioning of these new substation and transmission line facilities. This estimate does not include the cost for any other Customer owned equipment and associated design and engineering.

The estimated total cost for the required upgrades is **$169,400.** Figure 2 below represents a conceptual one-line of the proposed interconnection into the 230kV bus at the Lamar Transmission Substation. These estimates do not include costs for any other Customer owned equipment and associated design and engineering. Note that the provided cost estimates do not include costs for upgrading the transformer. It is anticipated that the total cost for this transformer will be the responsibility of the Interconnection Customer. This transformer is a shared facility of PSCo and Tri-State (TSGT). The following tables list the improvements required to accommodate the interconnection and the delivery of the Project generation output. The cost responsibilities associated with these facilities shall be handled as per current FERC guidelines. System improvements are subject to change upon a more detailed and refined design.

Table 3 – PSCo Owned; Customer Funded Transmission Provider Interconnection Facilities

Element	Description	Cost Est. (Thousands)
Lamar 230kV Transmission Substation	Interconnect Customer to tap the existing, customer owned 230kV transmission line that interconnects at the Lamar 230kV Transmission Substation (into the 230kV bus). The new equipment includes: • Transmission line communications, station controls, line relaying and testing upgrades	**$169.4**
	Total Cost Estimate for PSCo-Owned, Customer-Funded Interconnection Facilities	**$169.4**
Time Frame	**Site, design, procure and construct**	**12 Months**

Table 4 - PSCo Owned; PSCo Funded Interconnection Network Facilities

Element	Description	Cost Estimate (Millions)
	N/A	

Table 5 – PSCo Network Upgrades for Delivery

Element	Description	Cost Est. (Millions)
	N/A	

Cost Estimate Assumptions

- Scoping level project cost estimates for Interconnection Facilities and Network/Infrastructure Upgrades for Delivery (+/- 30% accuracy) were developed by PSCo / Xcel Engineering.
- Estimates are based on 2015 dollars (appropriate contingency and escalation included).
- AFUDC has been excluded.
- Labor is estimated for straight time only – no overtime included.
- Lead times for materials were considered for the schedule.
- The Wind Generation Facility is not in PSCo's retail service territory. Therefore, no costs for retail load (distribution) facilities and metering required for station service are included in these estimates.
- PSCo / Xcel (or our Contractor) crews will perform all construction, wiring, testing and commissioning for PSCo owned and maintained facilities.
- The estimated time to site, design, procure and construct the interconnection and network delivery facilities is approximately 12 months after authorization to proceed has been obtained.
- A CPCN will not be required for the interconnection and network delivery facilities construction.
- The Customer will be required to design, procure and install a Load Frequency/Automated Generation Control (LF/AGC) RTU at their Customer Substation.
- Customer will string OPGW fiber into substation as part of the transmission line construction scope.
- No new substation land will need to be acquired

Figure B - One-Line of Proposed GI-2004-2 75MW expansion at Lamar 230kV POI

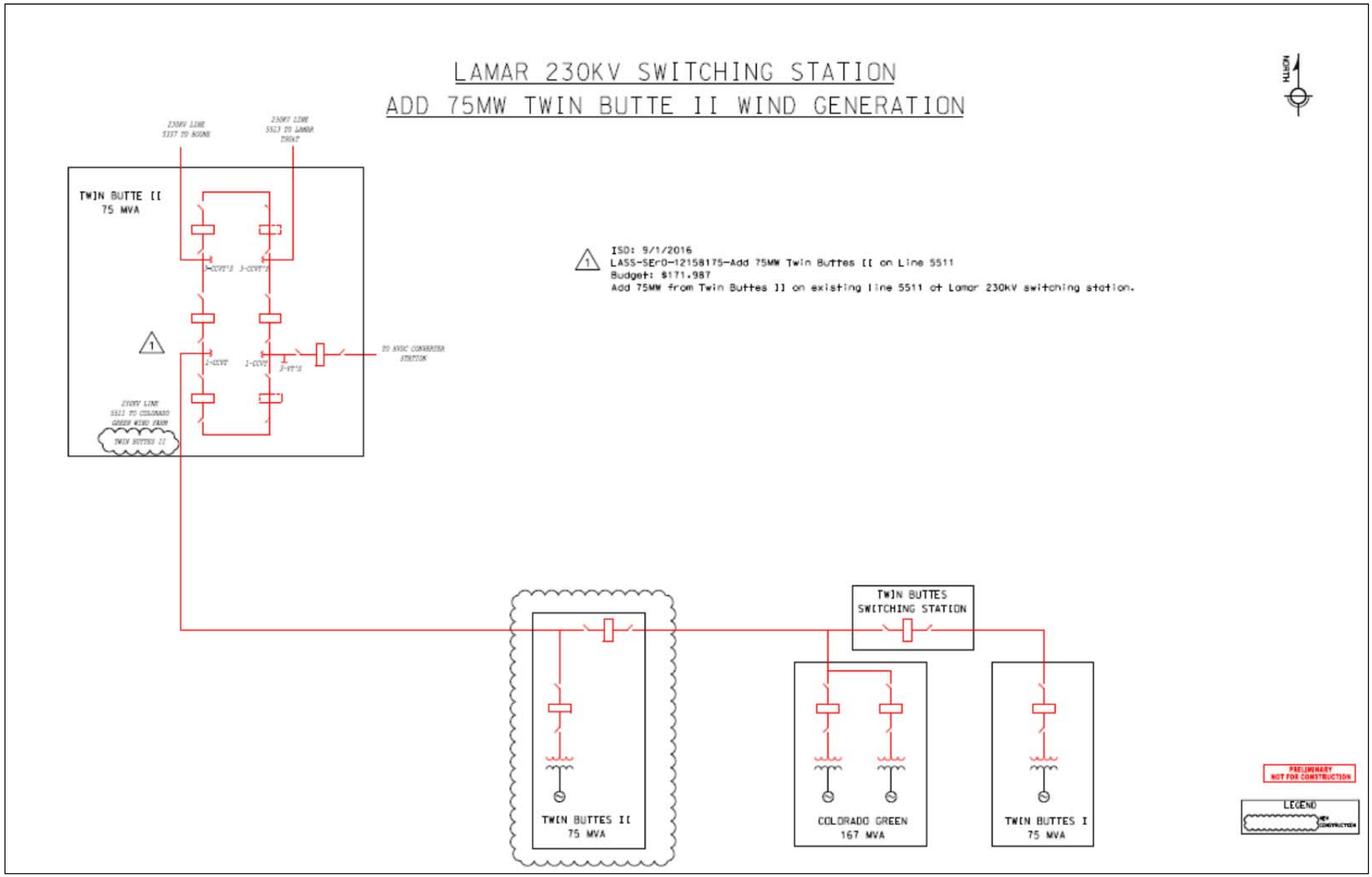


Table 6 – Summary of Thermal Violations from Single Contingency Analysis

				Branch Contingency Loading Without GI-2004-2 Restudy		Branch Contingency Loading With GI-2004-2 Restudy			
Monitored Facility (Line or Transformer)	**Type**	**Owner**	**Branch RatingMVA (Norm/Emer)**	**N-1 FlowMVA**	**N-1 Flow % of Rating**	**N-1 FlowMVA**	**N-1 Flow % of Rating**	**% Change**	**NERC Cat B Contingency**
Cherokee-Federal Ht 115kV#2	Line	PSCo	139/153	140.4	101%/91.8%	141.8	102%/92.7%	1%	Cherokee – Federal ht - Semper
Lamar 230/115kV # T1	Xfmr	PSCo/ TSGT	100/100	100	100%/100%	111.1	111.1%/111.1%	11.1%	Lamar 230/115kV # 2
BrairgateS – CottonwoodS 115kV	Line	CSU	162/180	175	108%/97.2%	178.2	110%/99%	2%	Cottonwood N - Kettle Creek S 115kV
Cottonwood N - Kettle Creek S 115kV	Line	CSU	150/192	160.5	107%/83.6%	165	110%/86%	3%	BrairgateS – CottonwoodS 115kV
Monument – Flyhorse 115kV	Line	CSU	120/120	116.4	97%/97%	122.4%	102%/102%	5%	Daniels Park – Fuller 230kV

Table 7 – Summary of Thermal Violations from Single Contingency Analysis with Palmer Lake – Monument 115kV line open

				Branch Contingency Loading Without GI-2004-2 Restudy		Branch Contingency Loading With GI-2004-2 Restudy			
Monitored Facility (Line or Transformer)	**Type**	**Owner**	**Branch RatingMVA (Norm/Emer)**	**N-1 FlowMVA**	**N-1 Flow % of Rating**	**N-1 Flow MVA**	**N-1 Flow % of Rating**	**% Change**	**N-1 Contingency Outage**
Cherokee-Federal Ht 115kV#2	Line	PSCo	139/153	140.4	101%/91.8%	141.8	102%/92.7%	1%	Cherokee – Federal ht - Semper
Lamar 230/115kV # T1	Xfmr	PSCo/ TSGT	100/100	100	100%/100%	111.1	111.1%/111.1 %	11.1%	Lamar 230/115kV # 2
BrairgateS – CottonwoodS 115kV	Line	CSU	162/180	150.5	86%/83.6%	155	87%/86.1%	1%	Cottonwood N - Kettle Creek S 115kV
Cottonwood N - Kettle Creek S 115kV	Line	CSU	150/192	124.5	83%/64.8%	126	84%/65.6%	1%	BrairgateS – CottonwoodS 115kV
Monument – Flyhorse 115kV	Line	CSU	120/120	50.4	42%/42%	52.8	44%/44%	2%	Daniels Park – Fuller 230kV

Table 8 – Summary of Thermal Violations from Category-C Contingency Analysis Without Palmer Lake Series Reactor.

				Branch N-2 Loading Without GI-2004-2 Restudy		Branch N-2 Loading With GI-2004-2 Restudy			
Monitored Facility (Line or Transformer)	**Type**	**Owner**	**Branch RatingMVA (Norm/Emer)**	**N-1 Flow MVA**	**N-1 Flow % of Rating**	**N-1 Flow MVA**	**N-1 Flow % of Rating**	**% Change**	**NERC Cat C Contingency**
Airport Park – Baculite 115kV	Line	BHCE	195/195	195	100%/100%	198.7	101.9%/101.9%	1.9%	Baculite – West Station 115kV#1 &2
Baculite – Northridge 115kV	Line	BHCE	119/119	120.3	101.1%/101.1%	124.4	104.5%/104.5%	3.4%	Baculite – West Station 115kV#1 &2
Daniels Park – Fuller 230kV	Line	PSCo	478/478	511.5	107%/107%	535.4	112%/112%	5%	Comanche – Daniels Park 345kV #1&2
Fountain Valley – DesertCov 230kV	Line	BHCE	115/115	121.7	105.8%/105.8%	129.5	112.6%	6.8%	MidwayBR 230kV breaker failure
Fountain Valley – MidwayBR 115kV	Line	BHCE	115/115	120.3	104.6%/104.6%	128.11	111.4%/111.4%	6.8%	MidwayBR 230kV breaker failure
Midway 230/115kV #T1	Xfmr	PSCo	97/97	101	104.1%/104.1%	106.6	109.9%/109.9%	5.8%	Comanche – Daniels Park 345kV #1&2
MidwayPS-Midway BR 230kV	Bus tie	WAPA/ PSCo	430/478	468.7	109%/98%	496.7	115.5%/103.9%	6.5%	Comanche – Daniels Park 345kV #1&2
Palmer Lake – Monument 115kV	Line	PSCo	120/120	148.9	124.1%/124.1%	155.8	129.9%/129.9%	5.8%	Comanche – Daniels Park 345kV #1&2
Monument – FlyhorseN 115kV	Line	CSU	120/120	156.6	130.5%/130.5%	163.8	136.5%/136.5%	6%	Comanche – Daniels Park 345kV #1&2
Waterton – Martin2tap 115kV	Line	PSCo	125/138	128.4	102.7%/93%	131.4	105.1%/95.2%	2.4%	Sodalake 230kV Breaker Failure
BrairigateS-CottonwoodS 115kV	Line	CSU	162/180	191.3	118.1%/106.3%	194.9	120.3%/108.3%	2.2%	Cottonwood North Bus outage
CottonwoodN-KettlecreekS 115kV	Line	CSU	150/192	147.2	98.1%/76%	150.5	100.3%/78.4%	2.2%	Cottonwood South Bus outage
BlackForest Tap – BLK SQMV 115kV	Line	CSU	81/81	121.6	150.2%/150.2%	124.3	153.4%/153.4%	3.2%	Cottonwood 115kV tie breaker outage
BLk SQMV – Fuller 115kV	Line	CSU	143/143	214.8	150.2%/150.2%	219.4	153.4%/153.4%	3.2%	Cottonwood 115kV tie breaker outage
Fountain S-RD_Nixon 115kV	Line	CSU	195/212	229.7	117.8%/108.3%	232.0	119%/109.4%	1.2%	KelKer 230kV Tie breaker outage

Table 9- Generation Dispatch of Major Generating Units in the Study Area (MW is Gross Value)

PSCo:

Bus	LF ID	MW
Comanche PV	S1	102
Comanche	C1	360
Comanche	C2	365
Comanche	C3	805
Lamar DC Tie	DC	0
Fountain Valley	G1	36
Fountain Valley	G2	36
Fountain Valley	G3	36
Fountain Valley	G4	36
Fountain Valley	G5	36
Fountain Valley	G6	36
Colorado Green	1	81
Colorado Green	2	81
Twin Butte	1	75
Jackson Fuller	W1	200
Comanche PV	S1	120
Alamosa CT	G1	0
Alamosa CT	G2	0
Cogentrix	S1	25.5
Greater Sandhill	S1	14.5
Blanca Peak	S1	19.5
SLV Solar	S1	44.2

BHE:

Bus	LF ID	MW
BUSCHWRTG1	G1	3.6
BUSCHWRTG2	G2	3.6
E Canon	G1	0
PP_MINE	G1	0
Pueblo Diesels	G1	0
Pueblo Plant	G1	0
Pueblo Plant	G2	0.0
R.F. Diesels	G1	0.0
Airport Diesels	G1	0.0
Canyon City	C1	0
Canyon City	C1	0
Baculite 1	G1	90
Baculite 2	G1	90
Baculite 3	G1	40.0
Baculite 3	G2	40.0
Baculite 3	S1	20
Baculite 4	G1	40.0

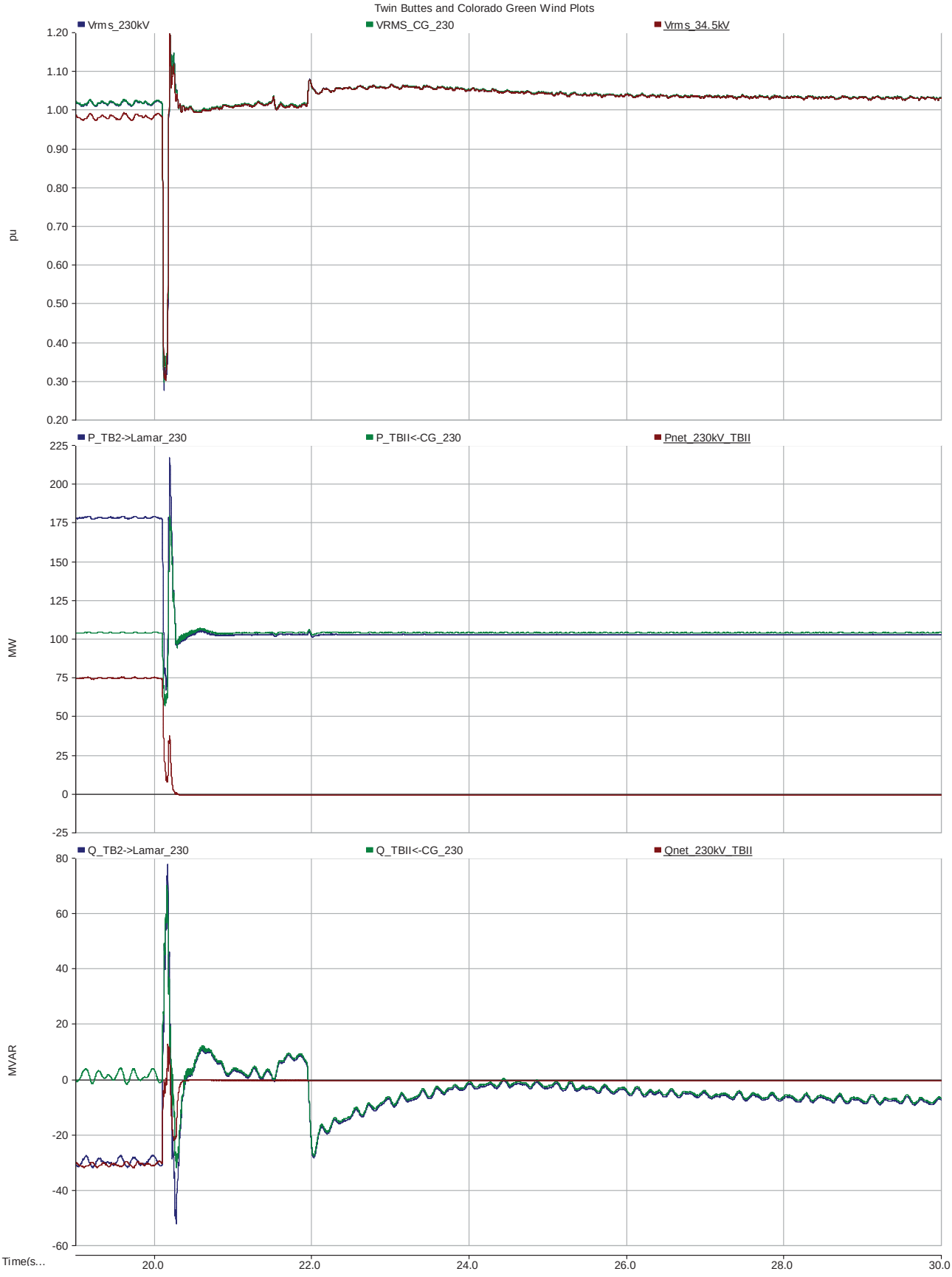
Baculite 4	G2	40.0
Baculite 4	S1	20
Baculite 5	G1	90

CSU:

Bus	LF ID	MW
Birdsale1	1	0.0
Birdsale 2	1	0.0
Birdsale 3	1	0.0
RD_Nixon	1	225.39
Tesla	1	13.2
Drake 5	1	49.65
Drake 6	1	83.19
Drake 7	1	138.03
Nixon CT 1	1	0.0
Nixon CT 2	1	0.0
Front Range CC 1	1	120.4
Front Range CC 2	1	120.8
Front Range CC 3	1	120.0

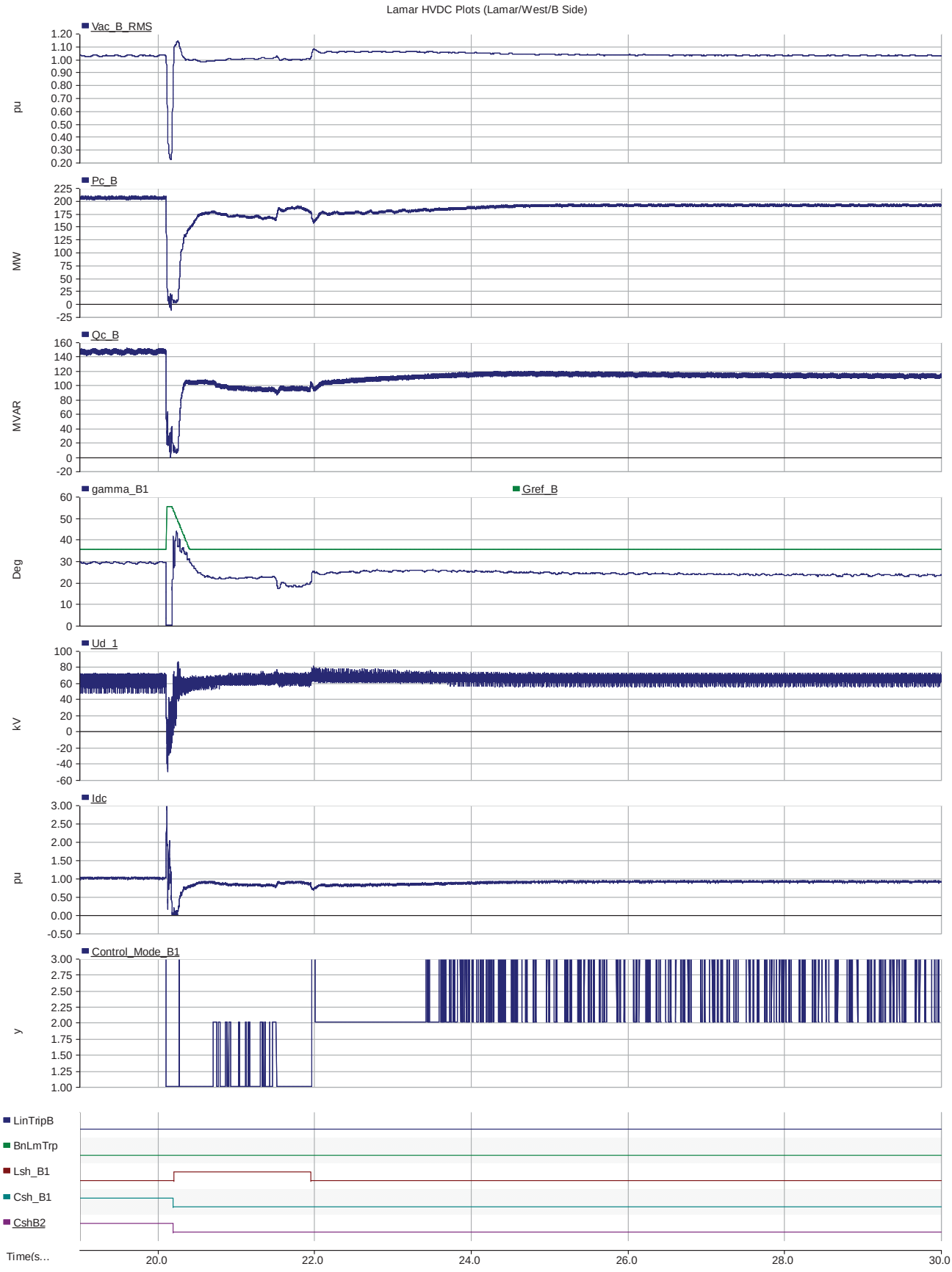
Appendix B – Transient Stability Plots

F1_S1 plots



Twin Buttes II Wind PSCAD Studies
- 2016 Loadflow (Formal BaseCase with two Lamar 230/115 Transformers etc)
- Wind: CG1/2: 107 MW, TB1: 0 MW, TBII: 75 MW
- Lamar HVDC 210 MW E2W
- Updated GE Wind Farm Models (plus slower ramp rate of 1 pu/sec) - received on May 4th, 2016
- TB2 farm controller with ACUV Reset of QOrder to Gamesa turbines
- LTC Tap changer added to TB2 transformer

Fault 1 - LLLG fault at Lamar 115kV bus - and subsiquent tripping of the Lamar 230/115 kV TF1.



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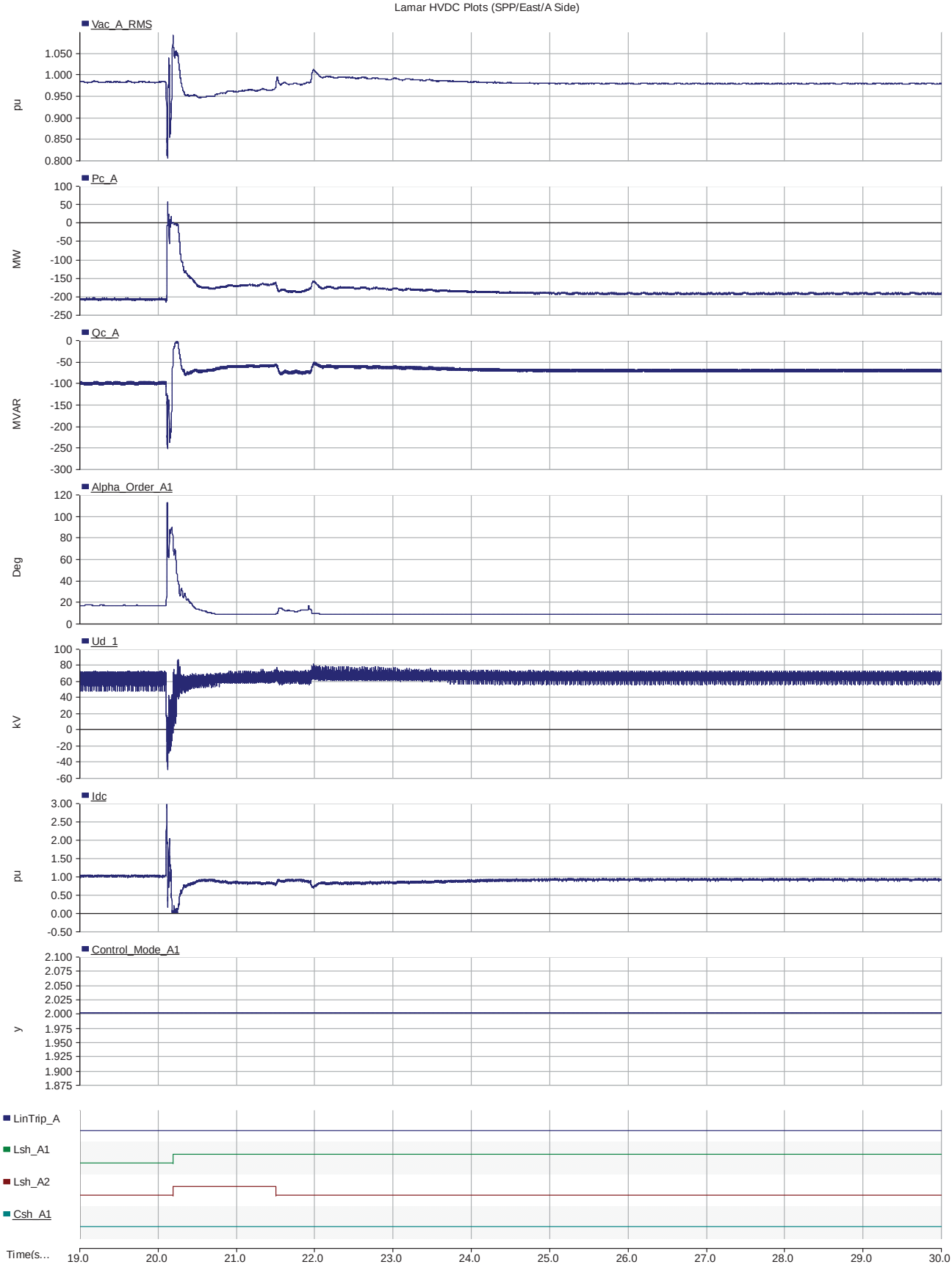

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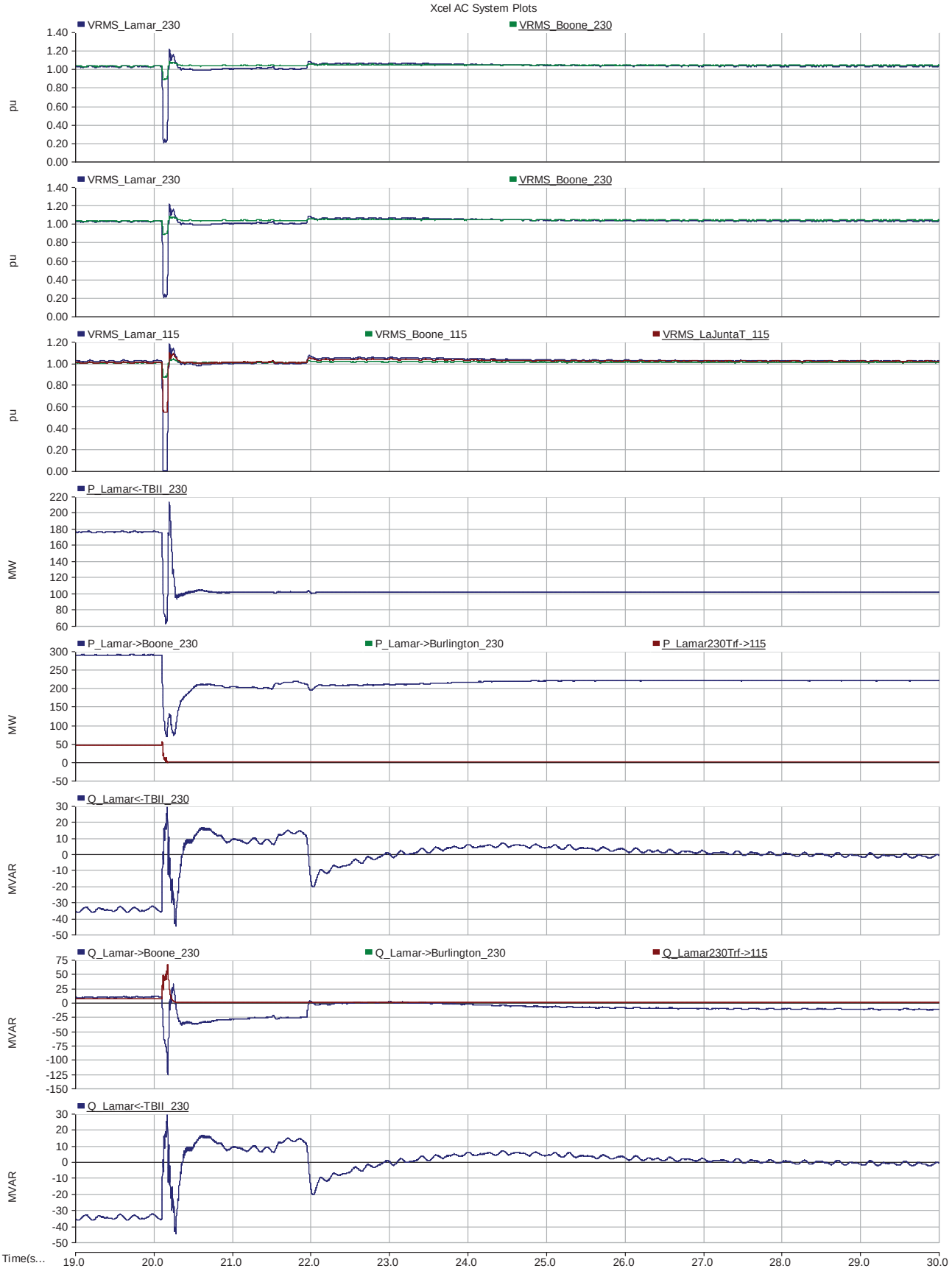

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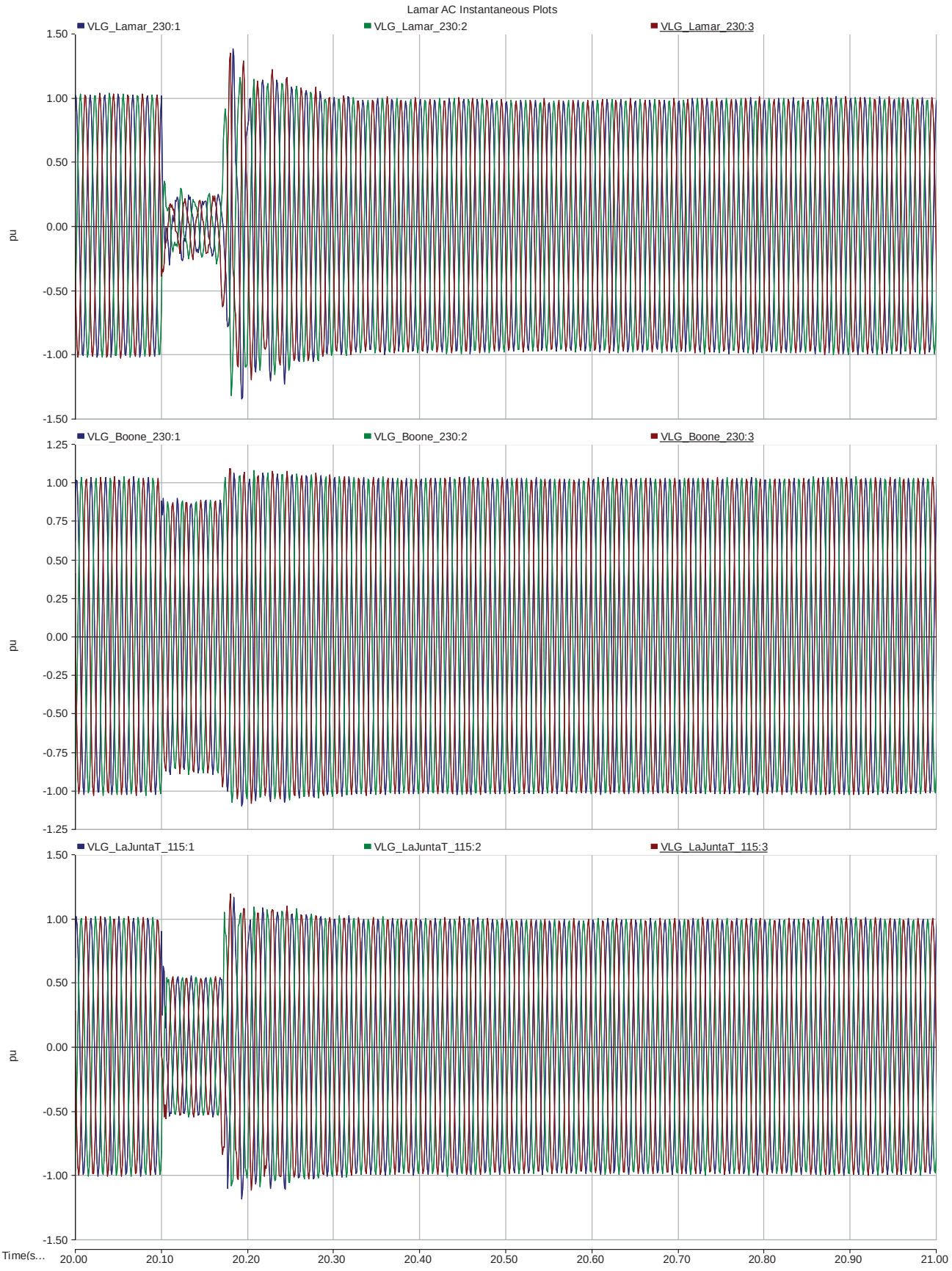

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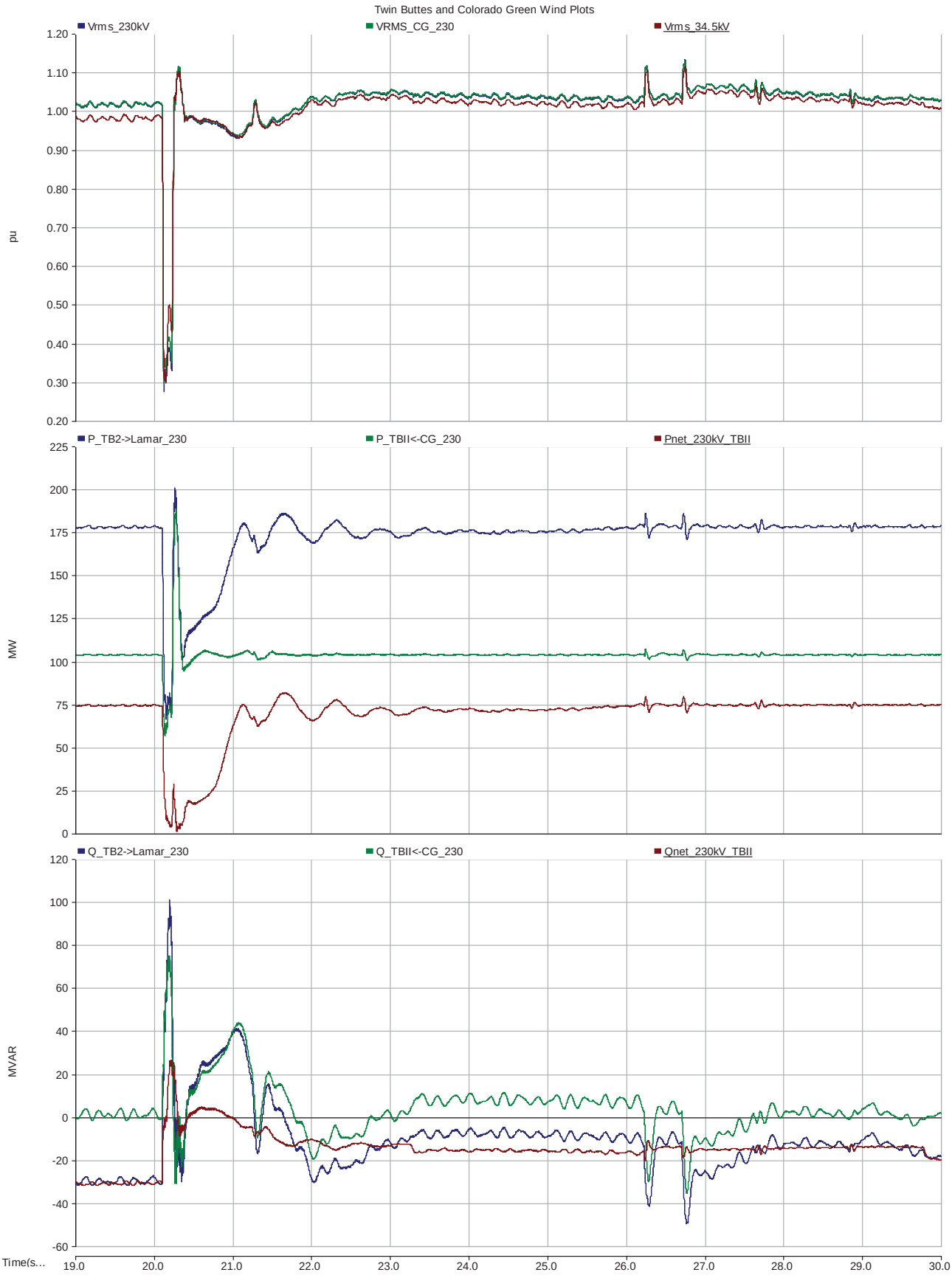
F2_S1 plots



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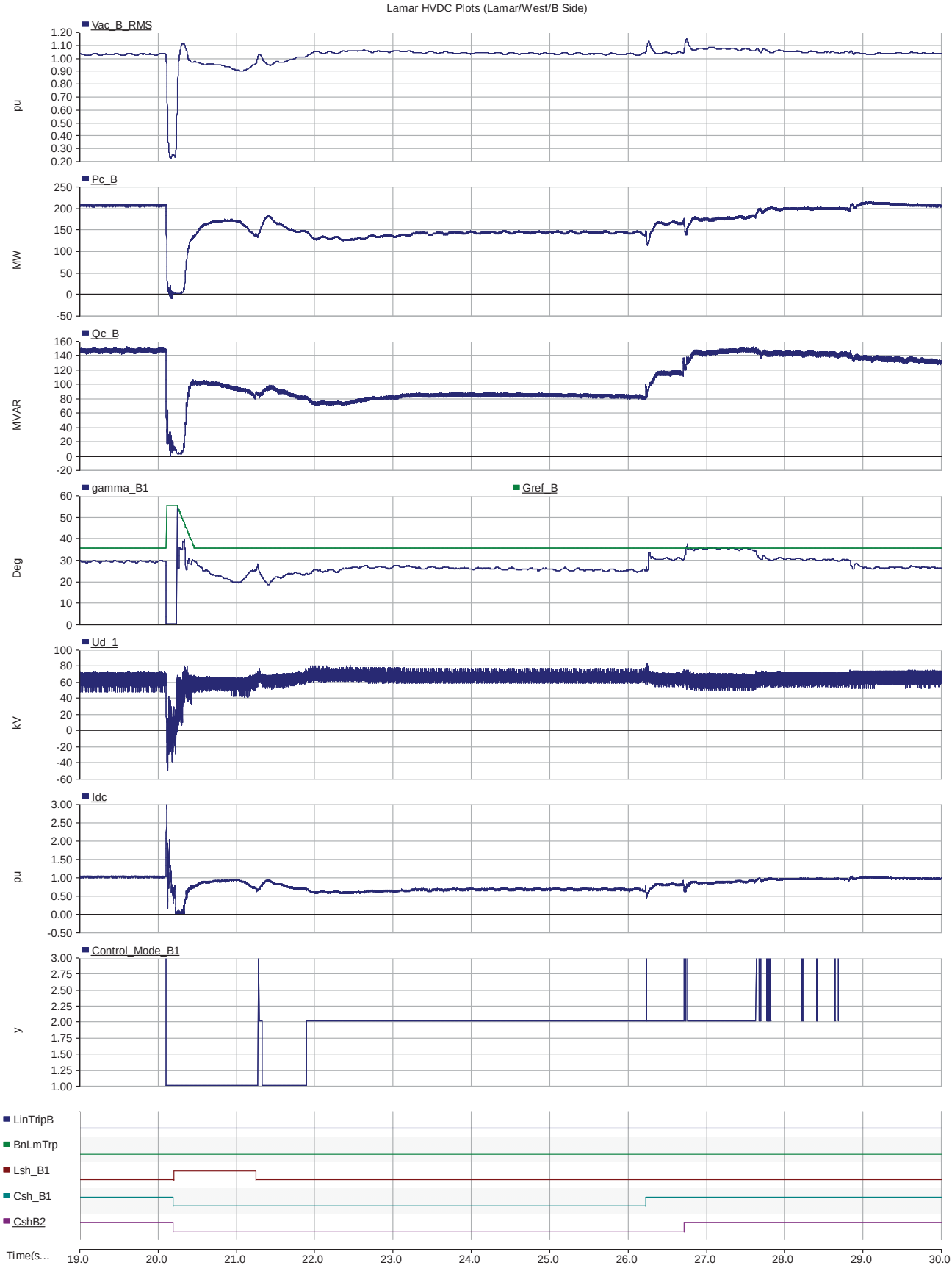
Fault 2 - LLLG fault at Lamar 115kV bus on the line to Willow Creek- and subsiquent tripping of the line.



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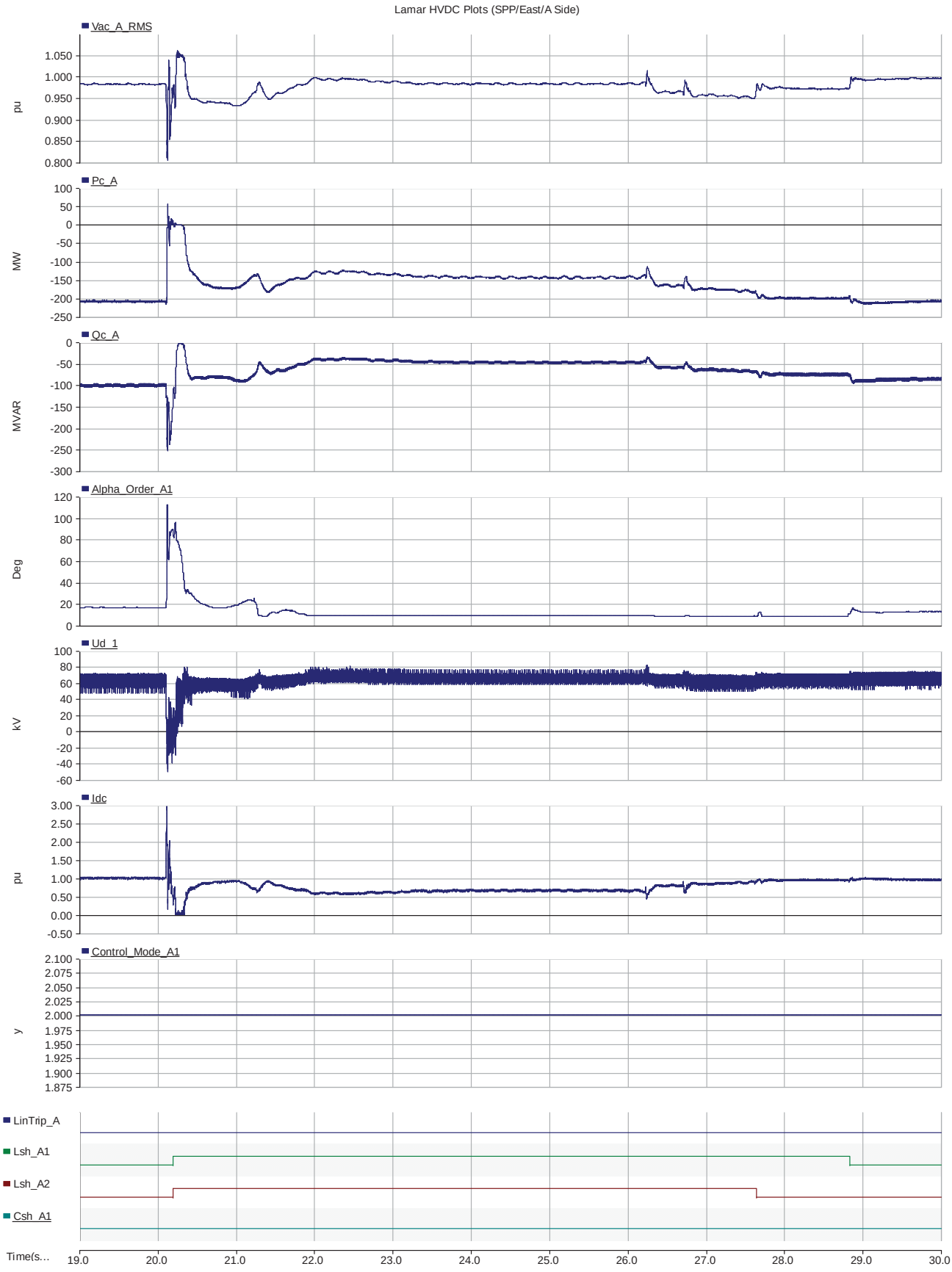

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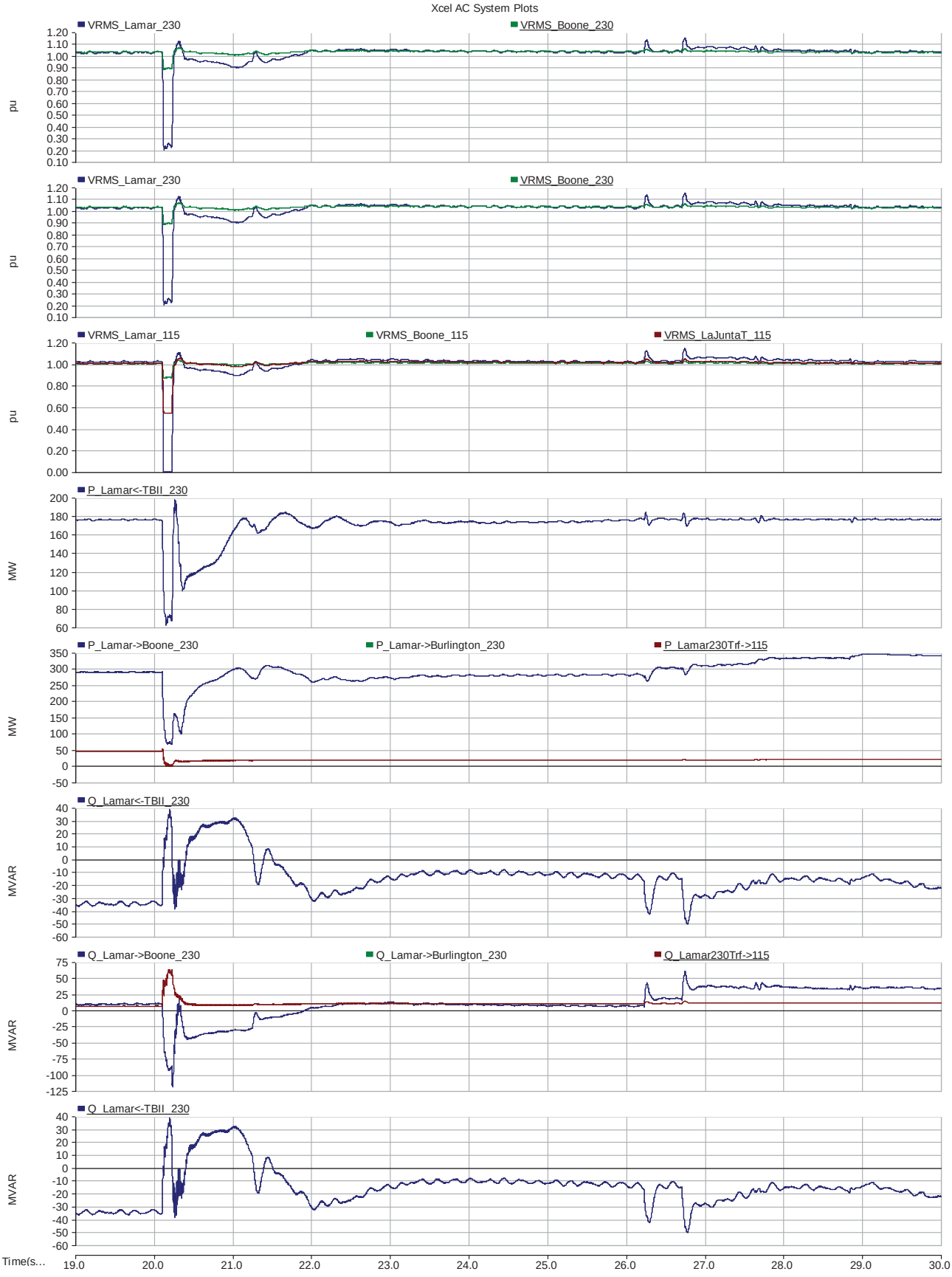

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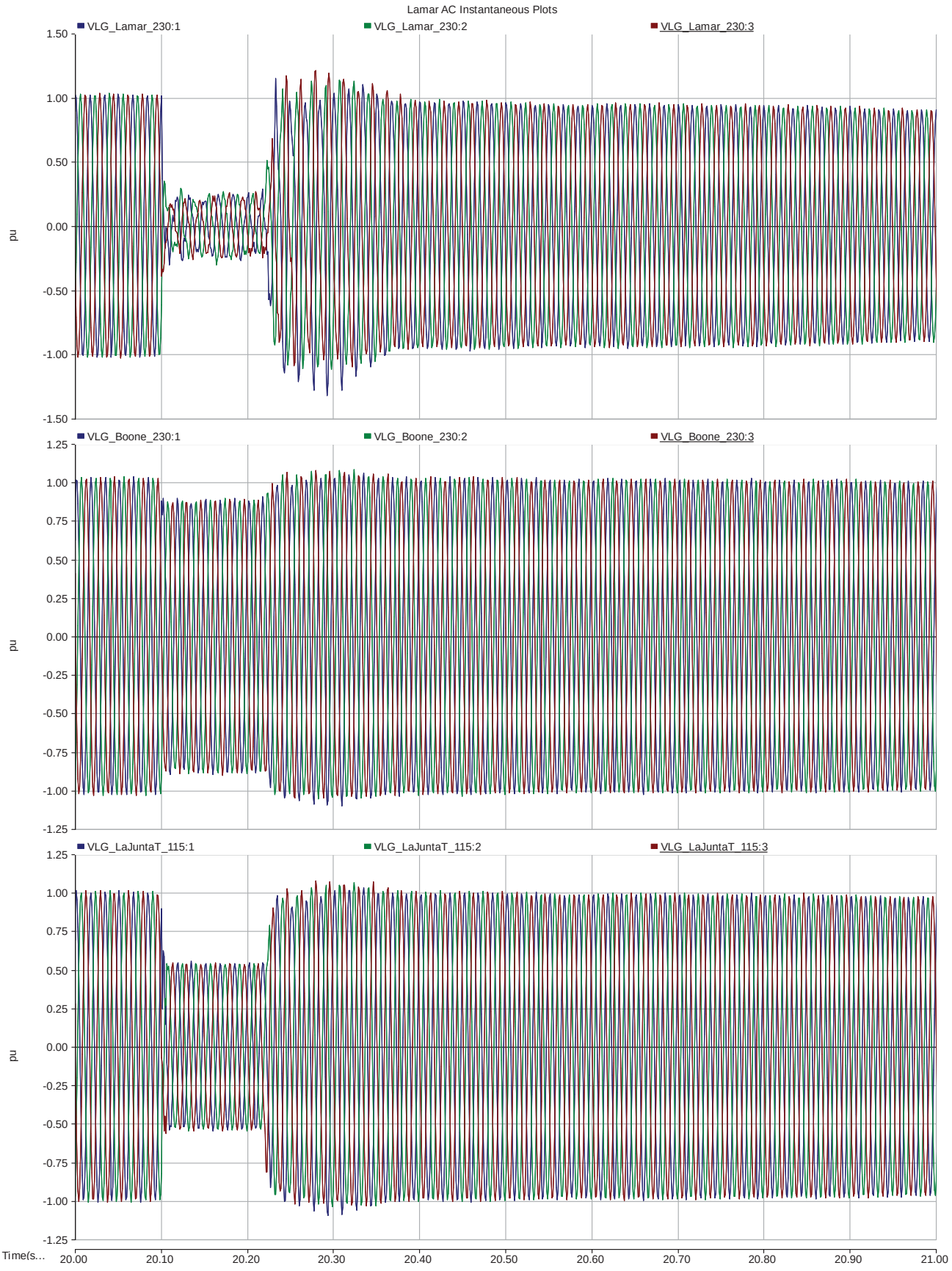

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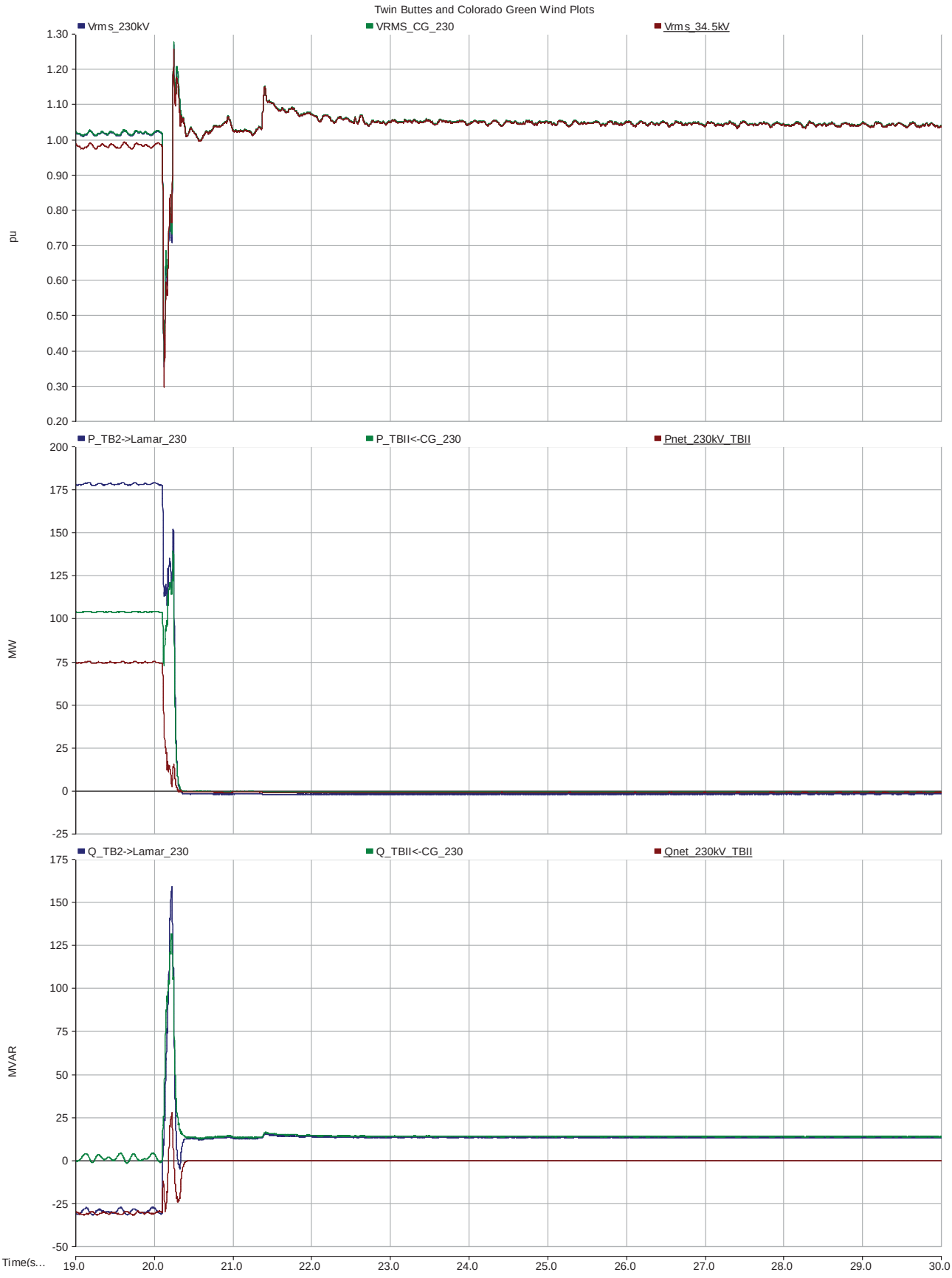
F3_S1 plots



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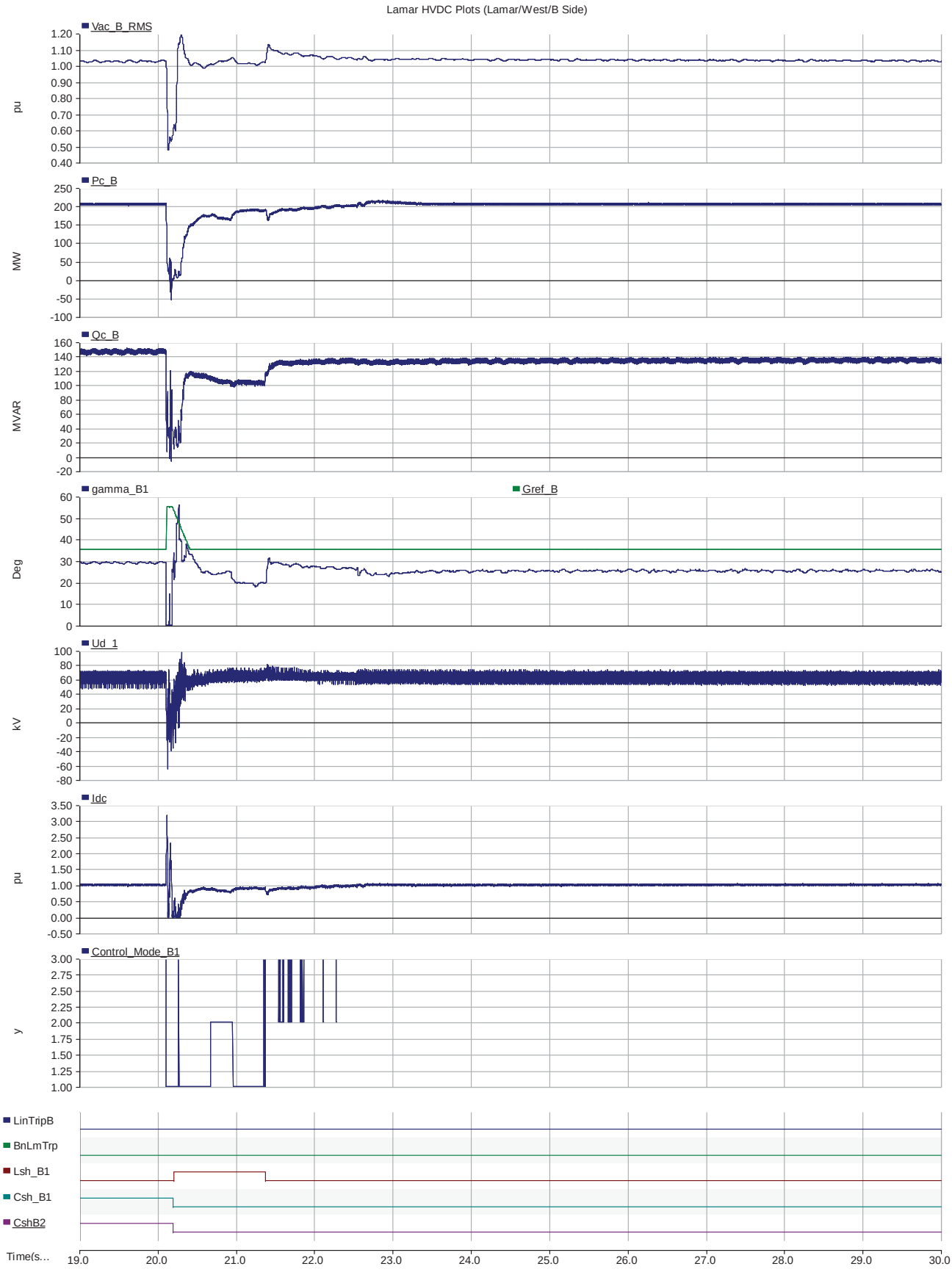

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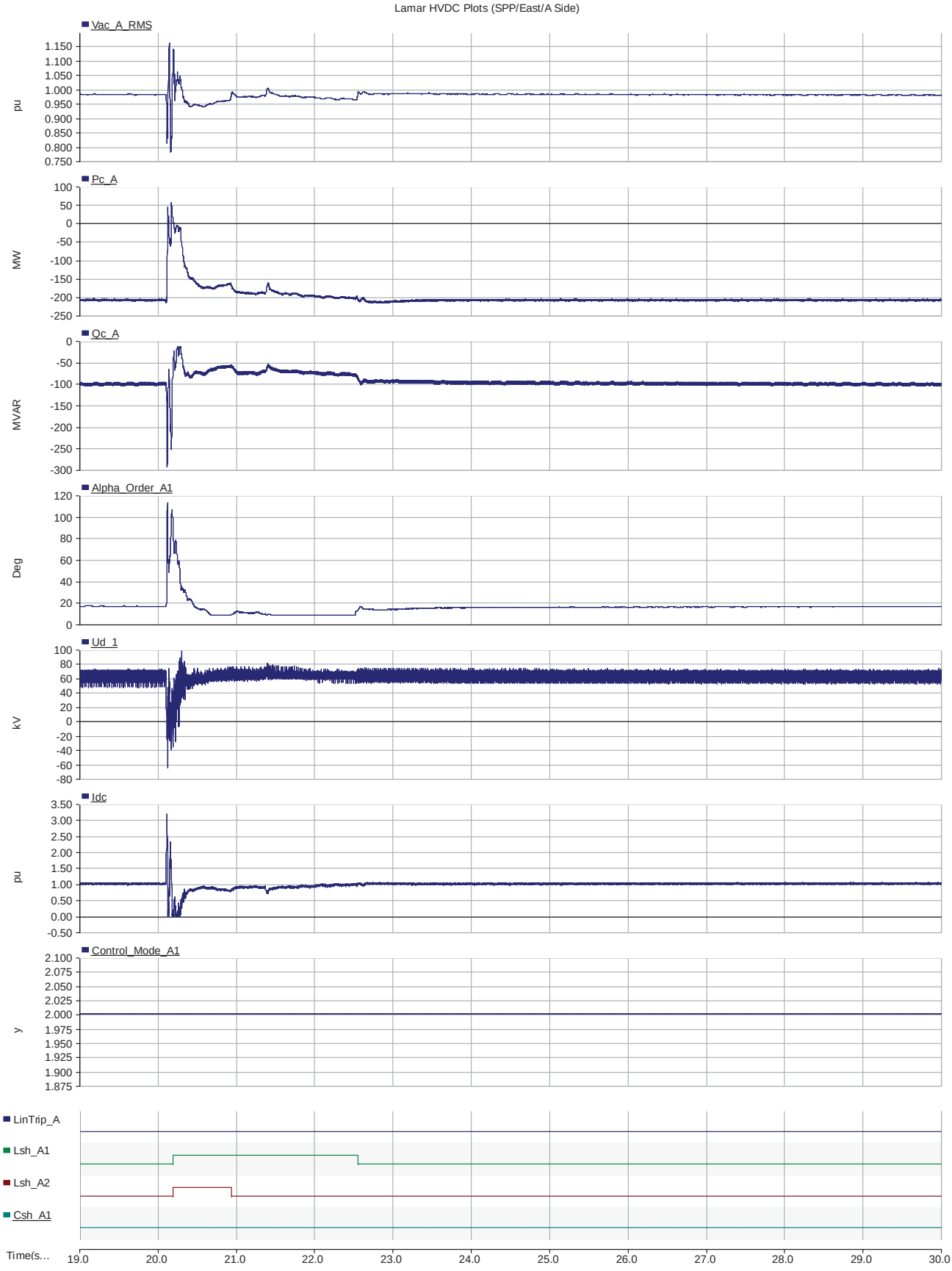

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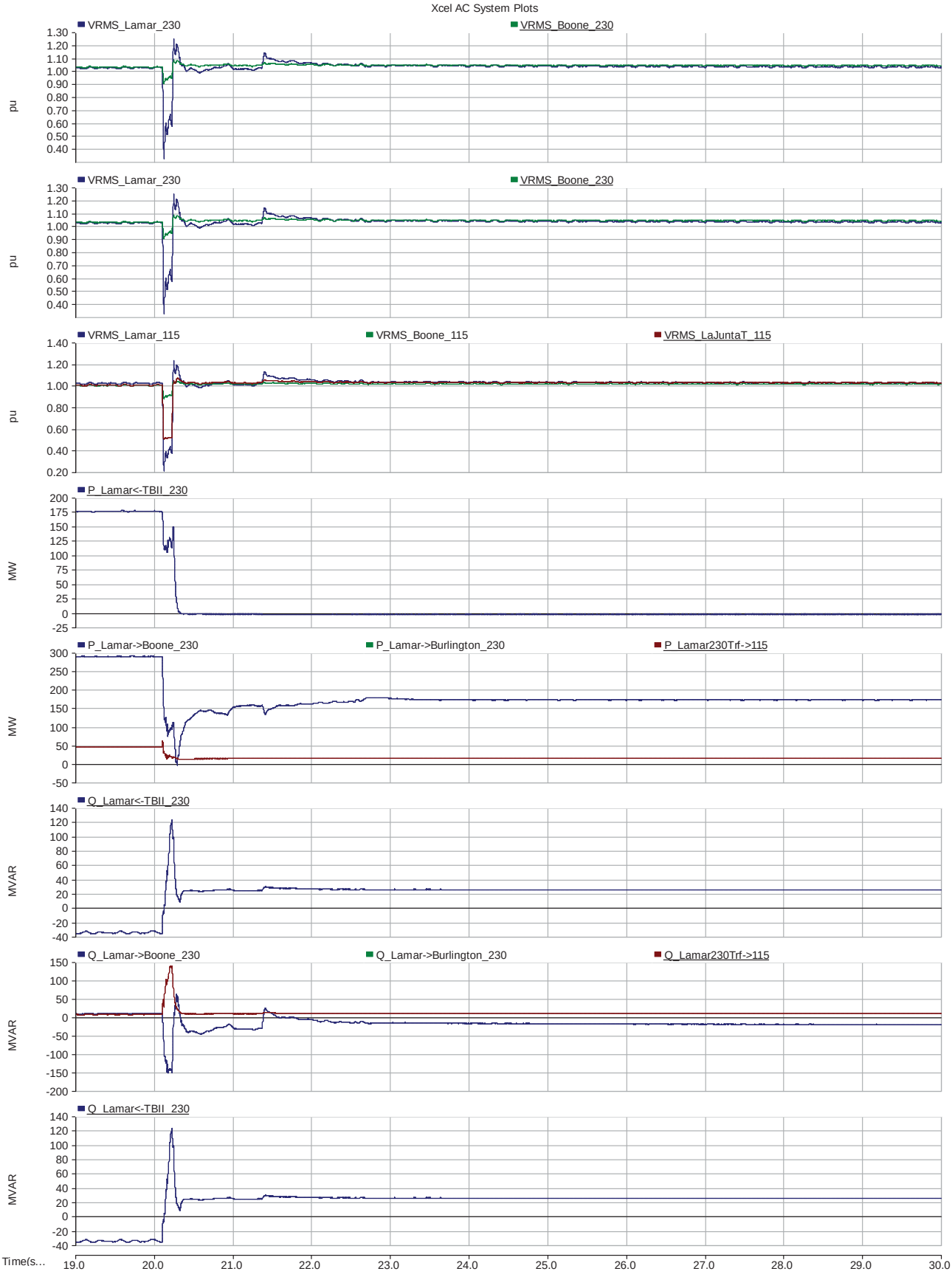
Fault 3 - LLLG fault at Willow Creek 115kV bus on the line to Lamar- and subsiquent tripping of the line.



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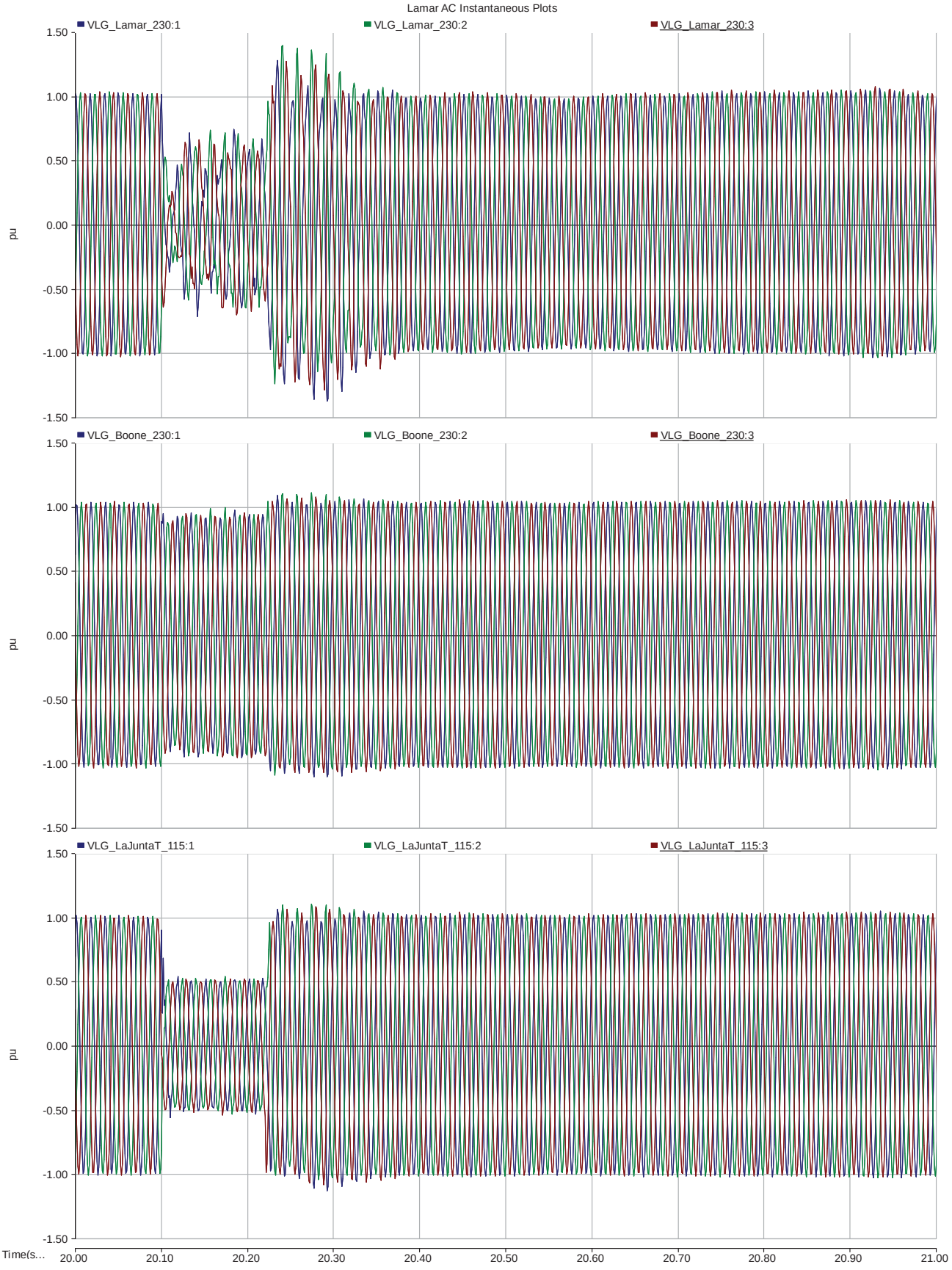

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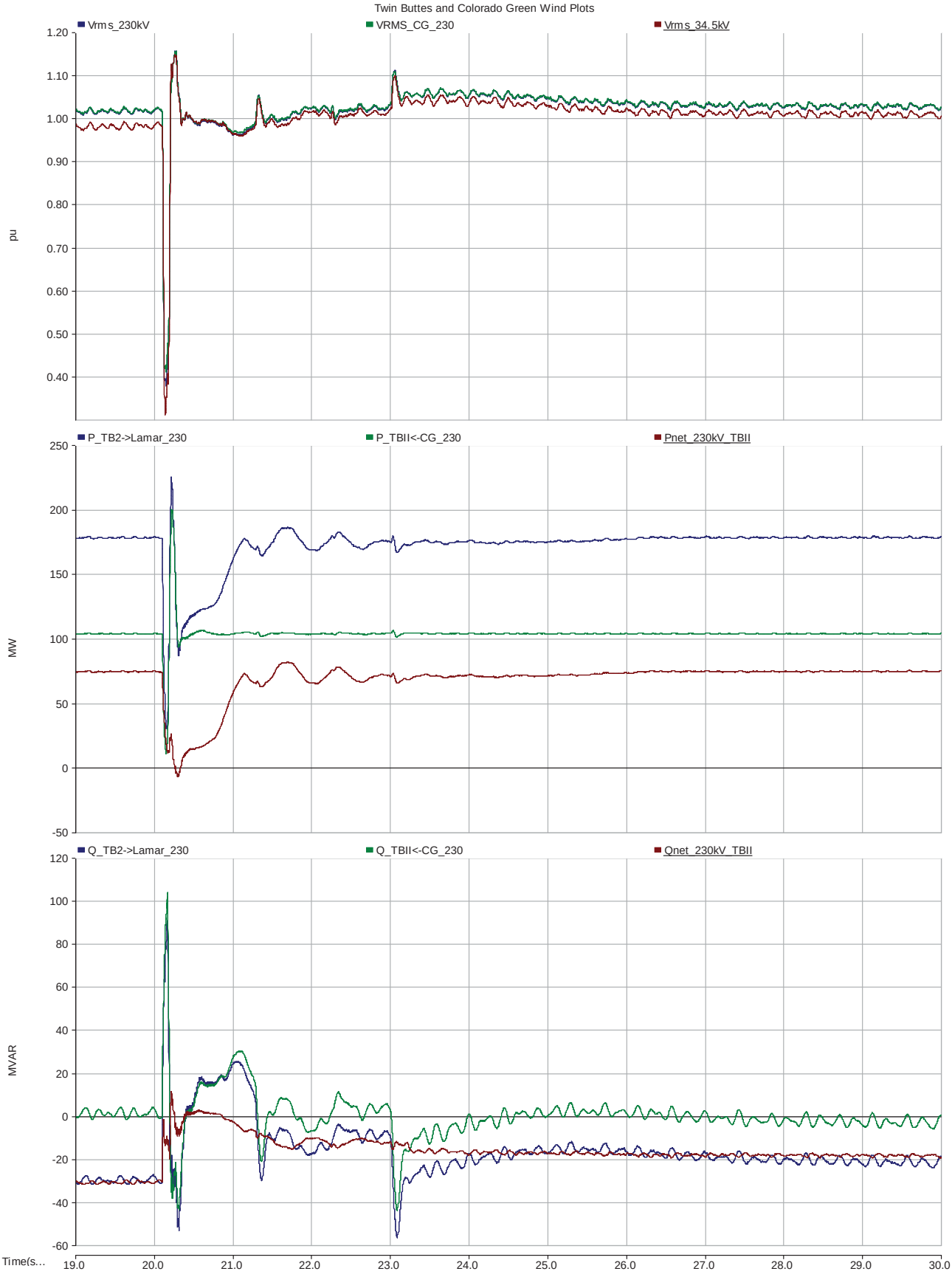
F4_S1 plots



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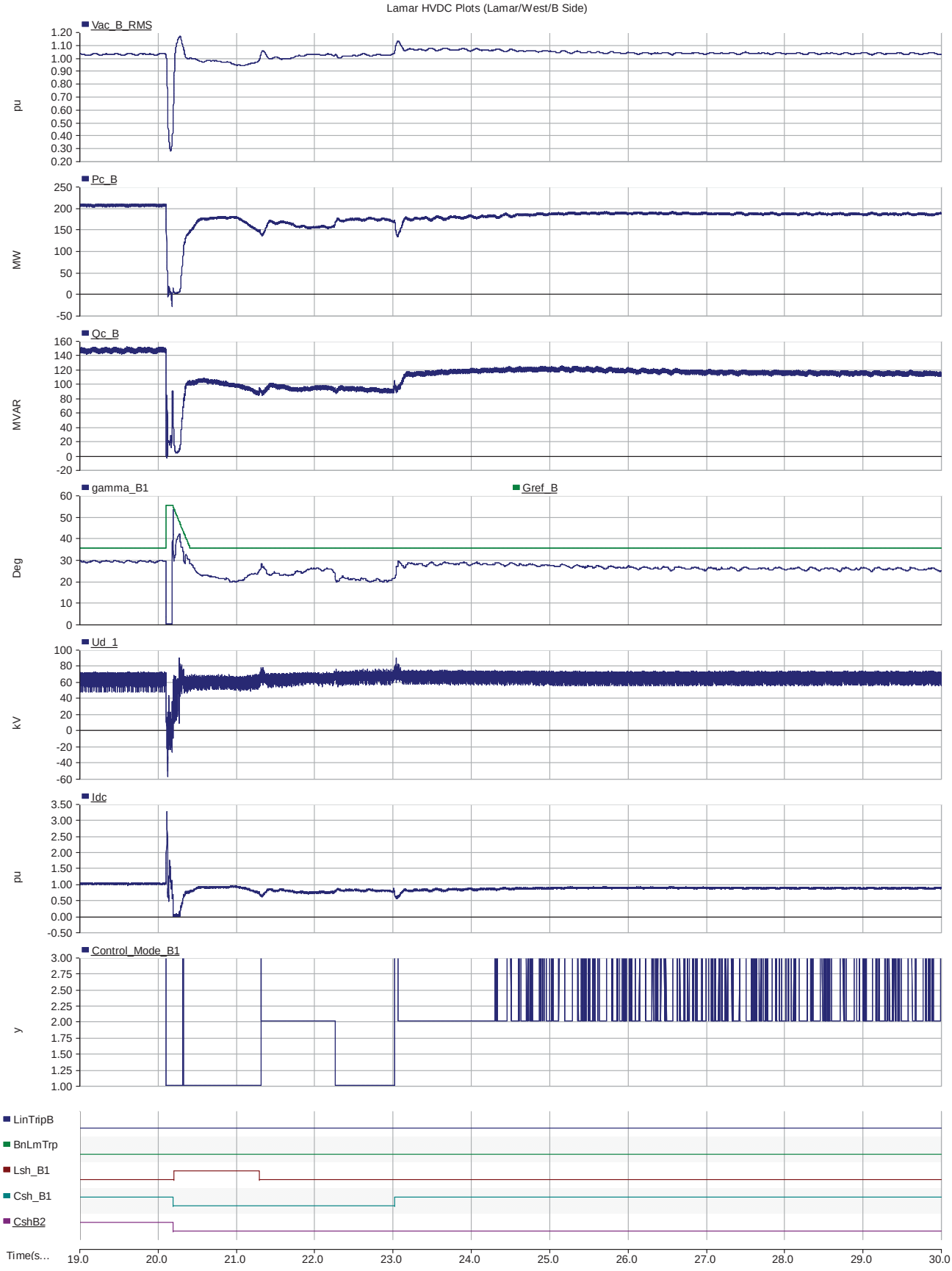
Fault 4 - LLLG fault at Boone 230kV bus on the line to Midway - and subsiquent tripping of the line.



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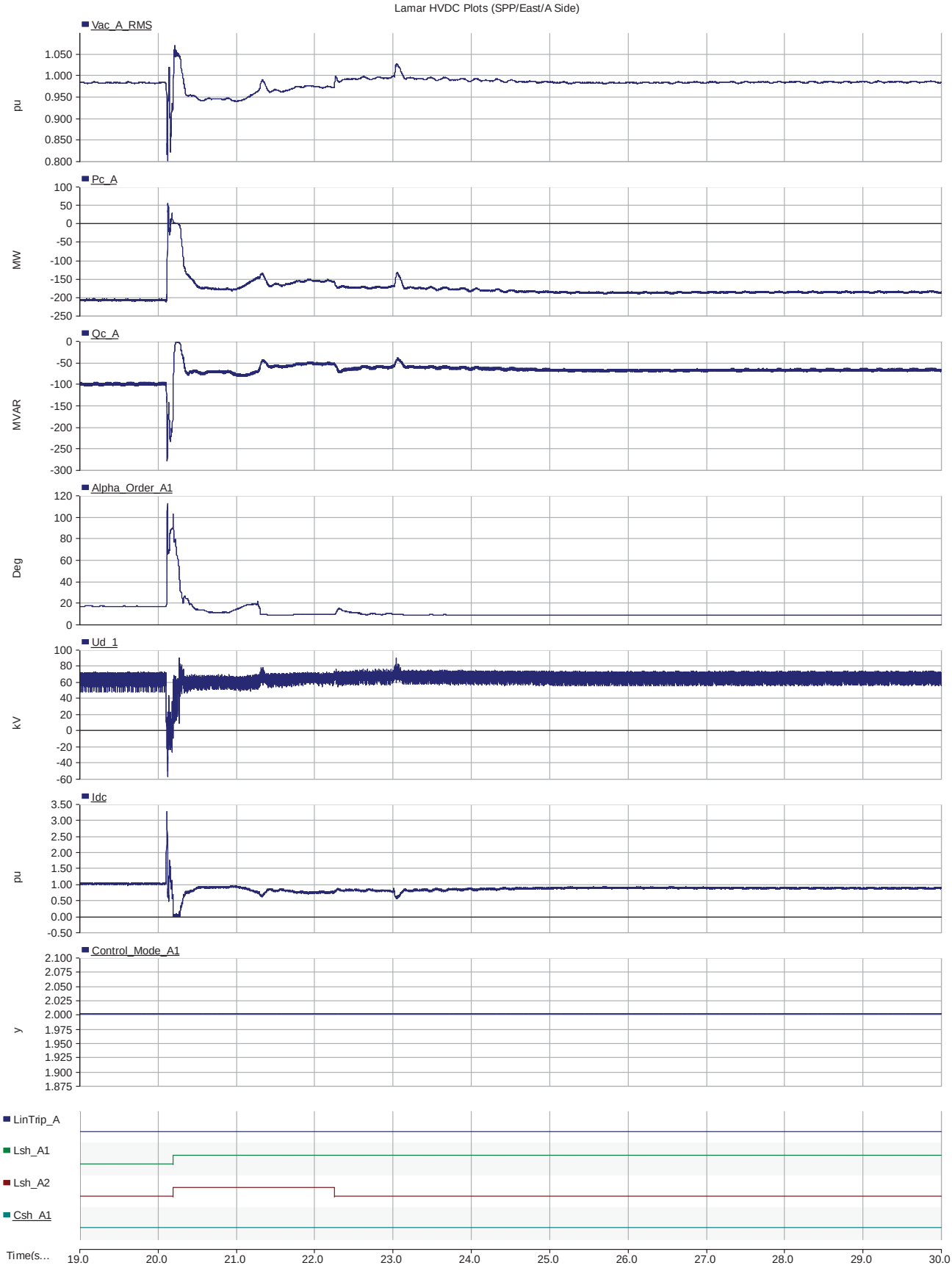

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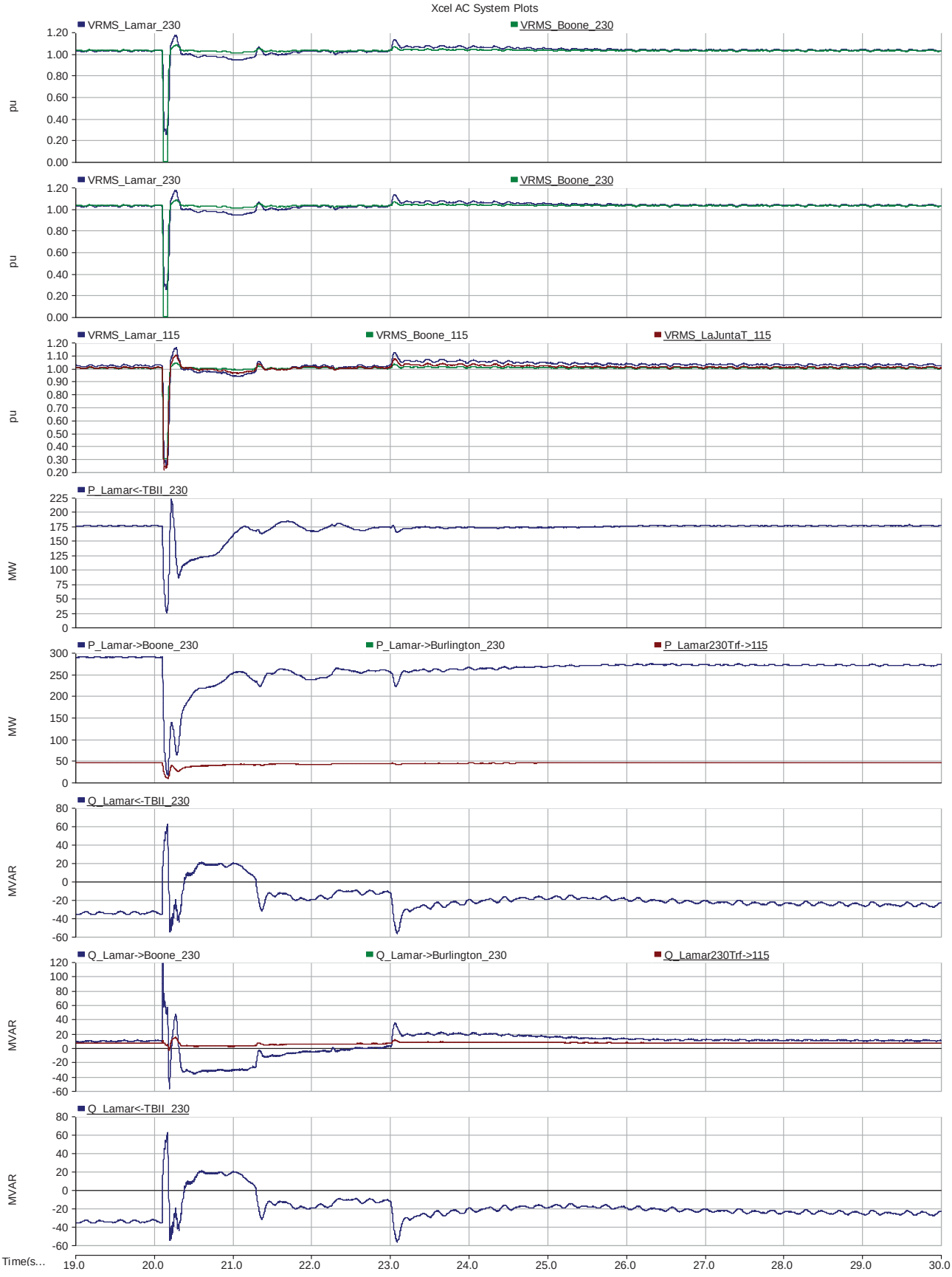

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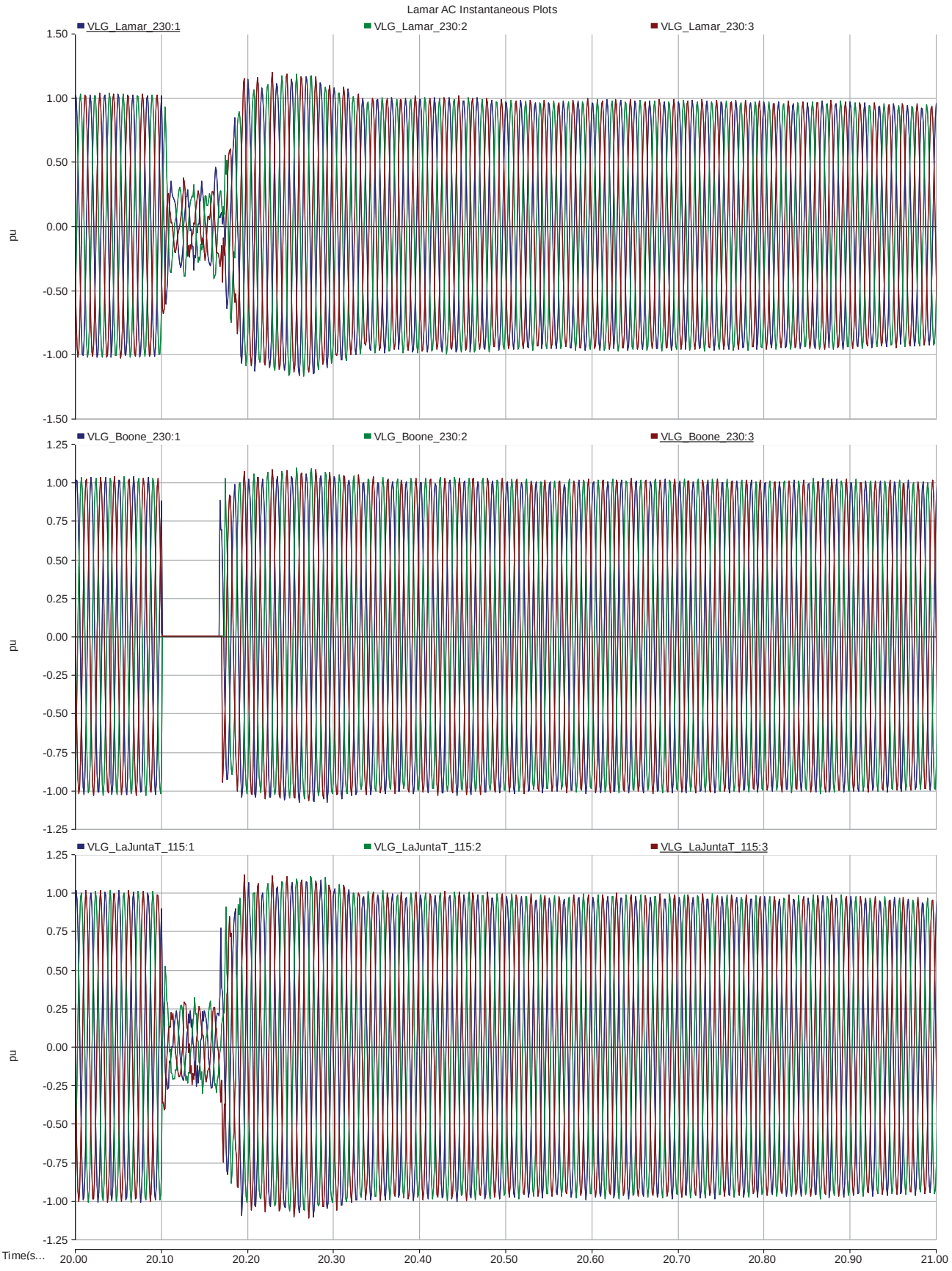

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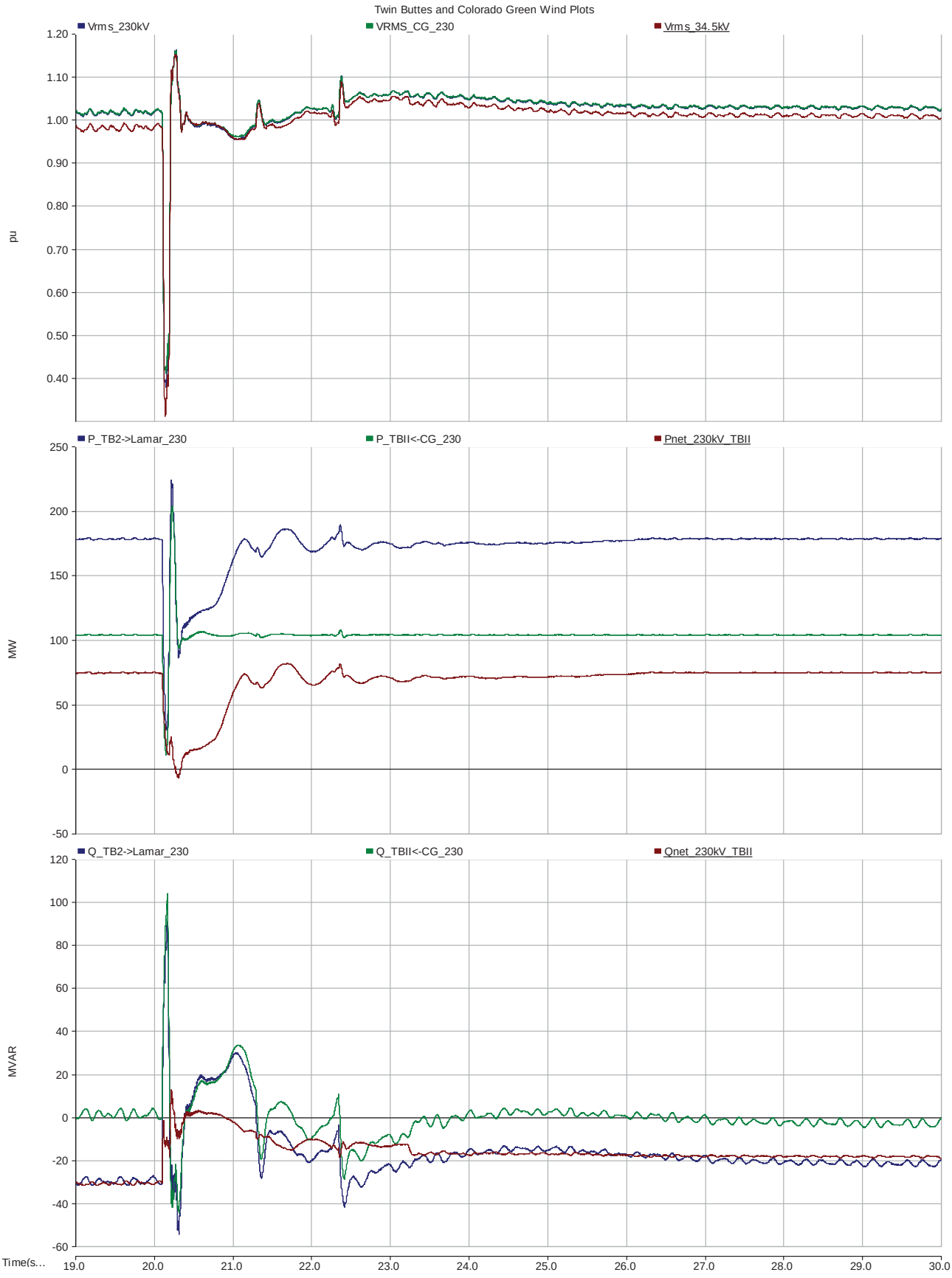
F5_S1 plots



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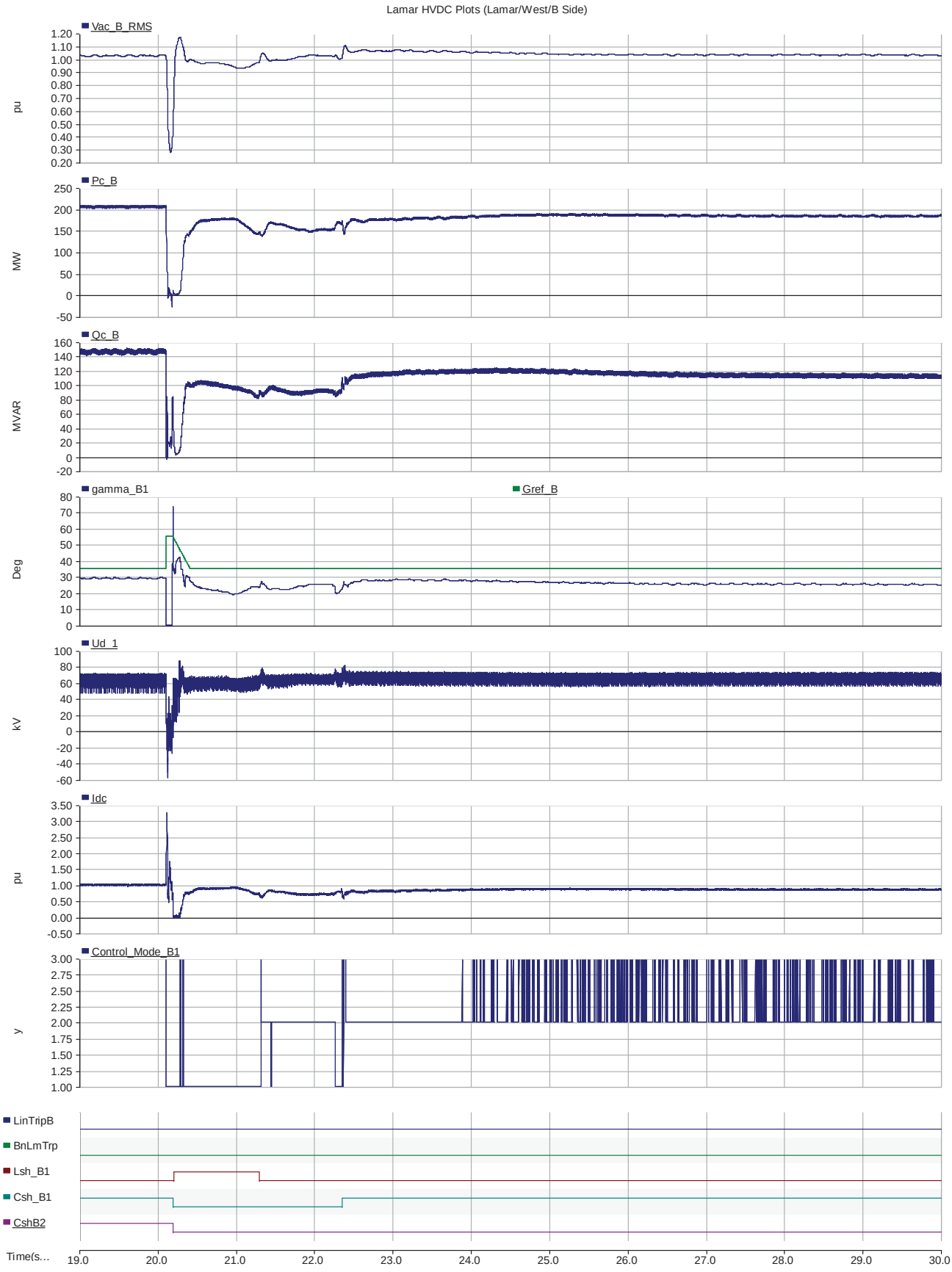

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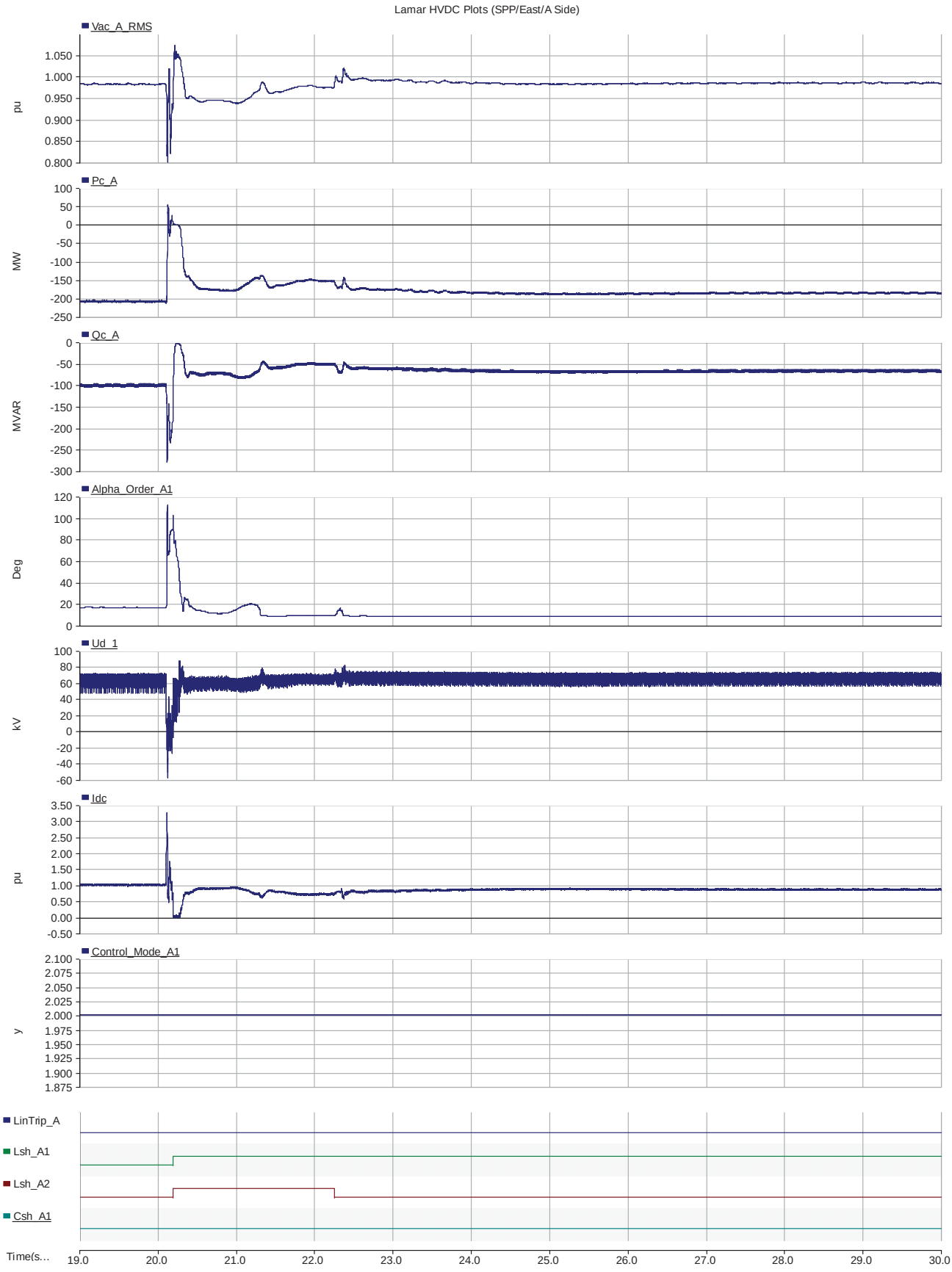

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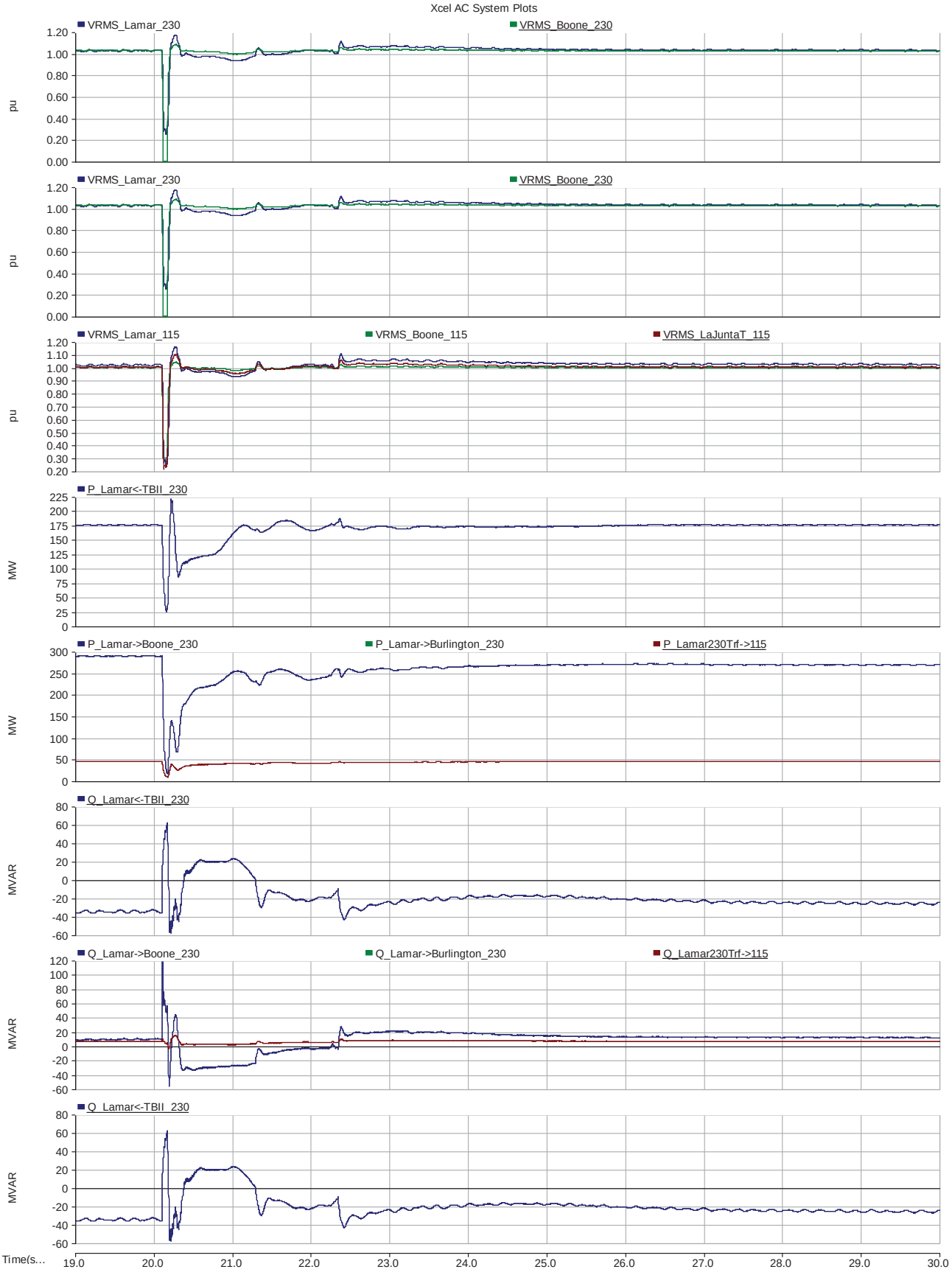

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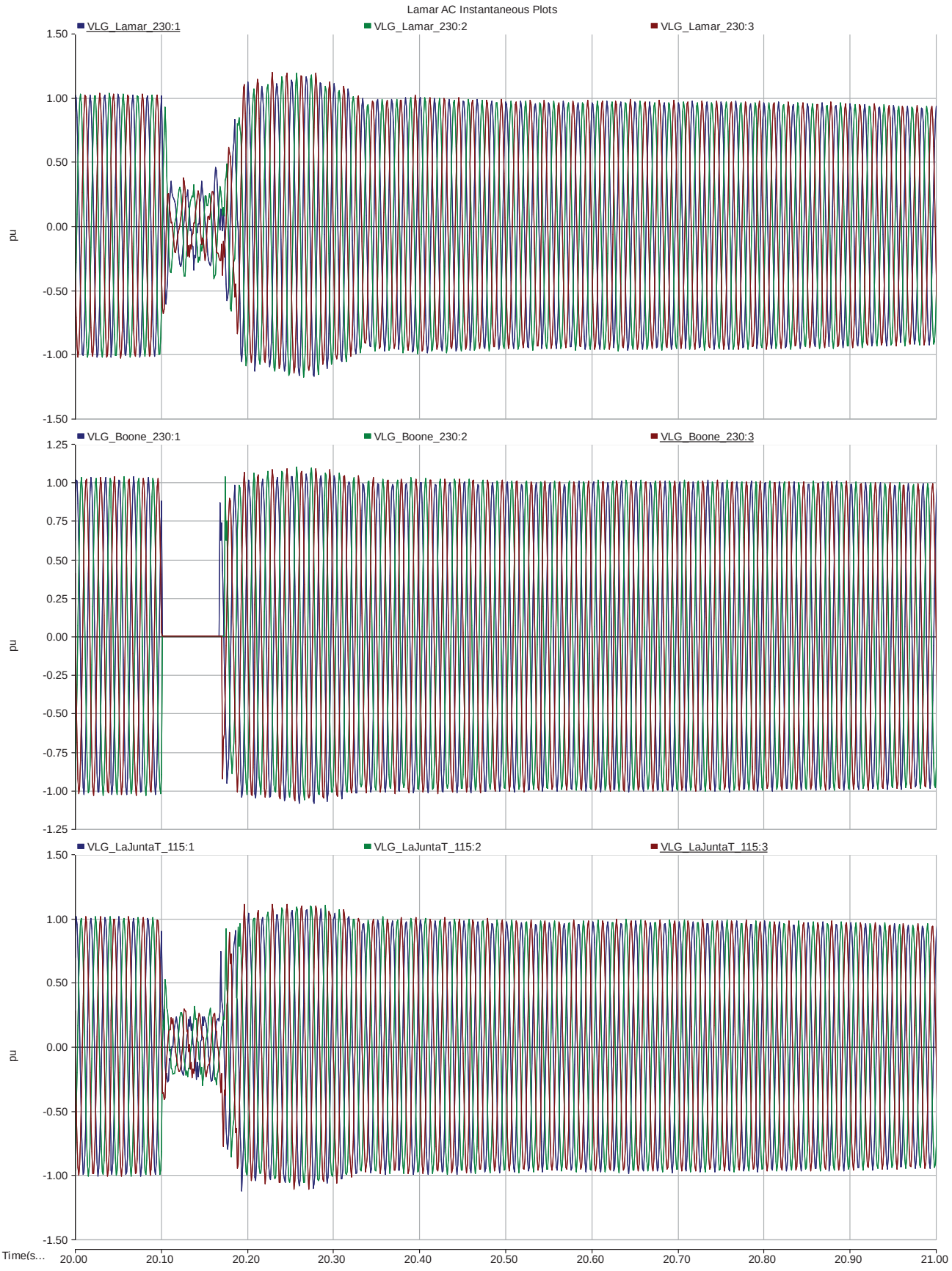

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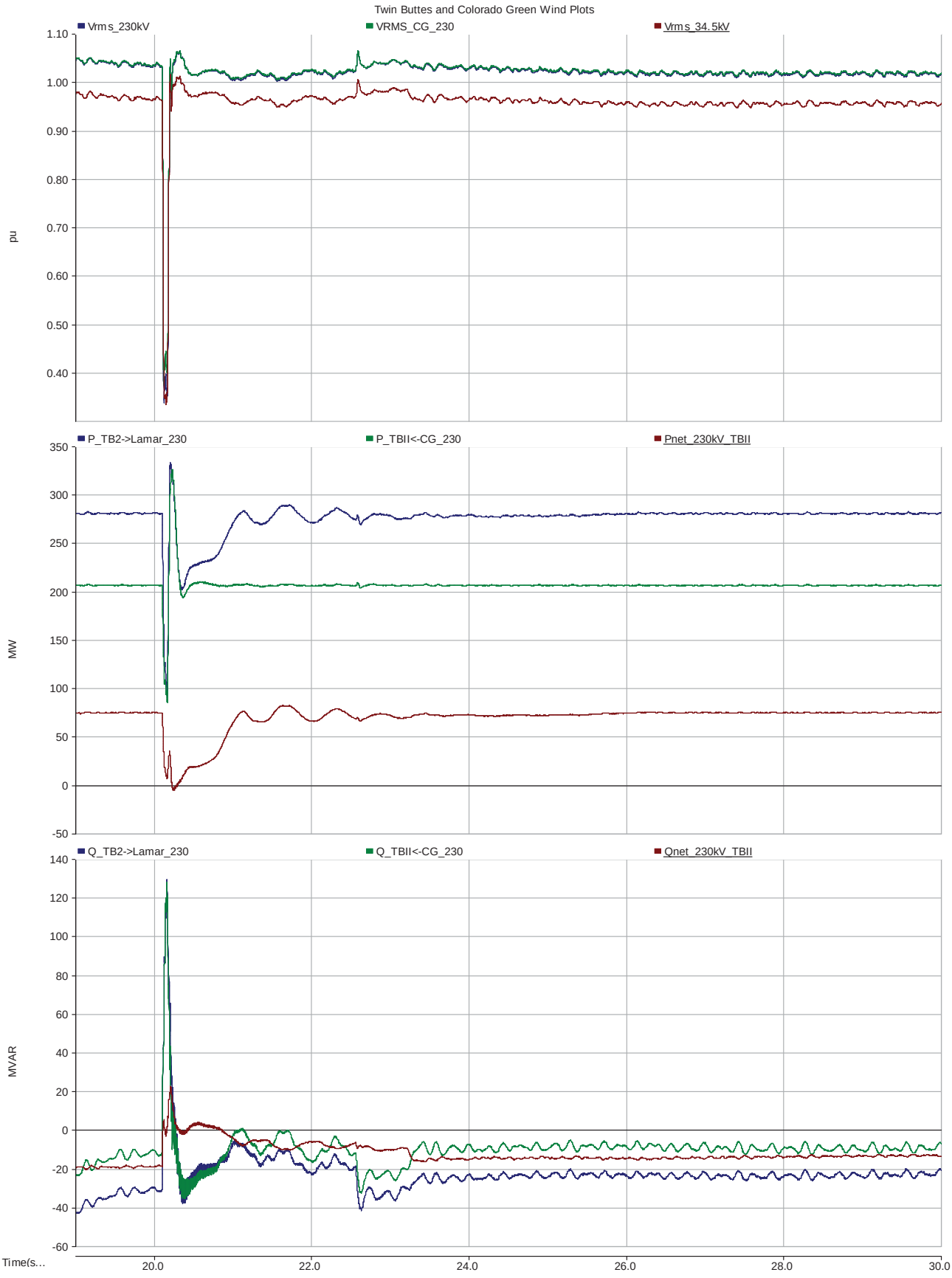
F1_S2 plots



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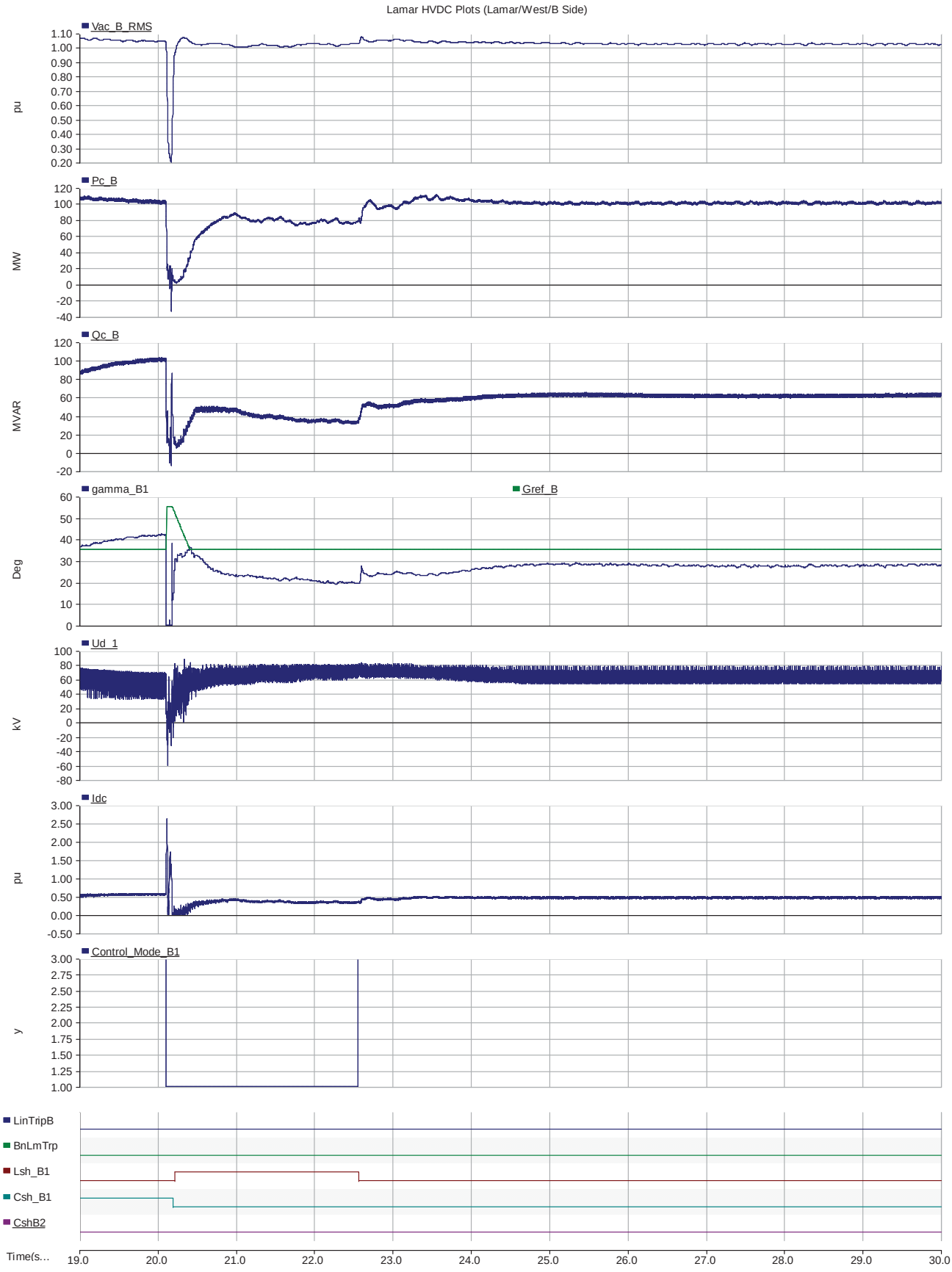

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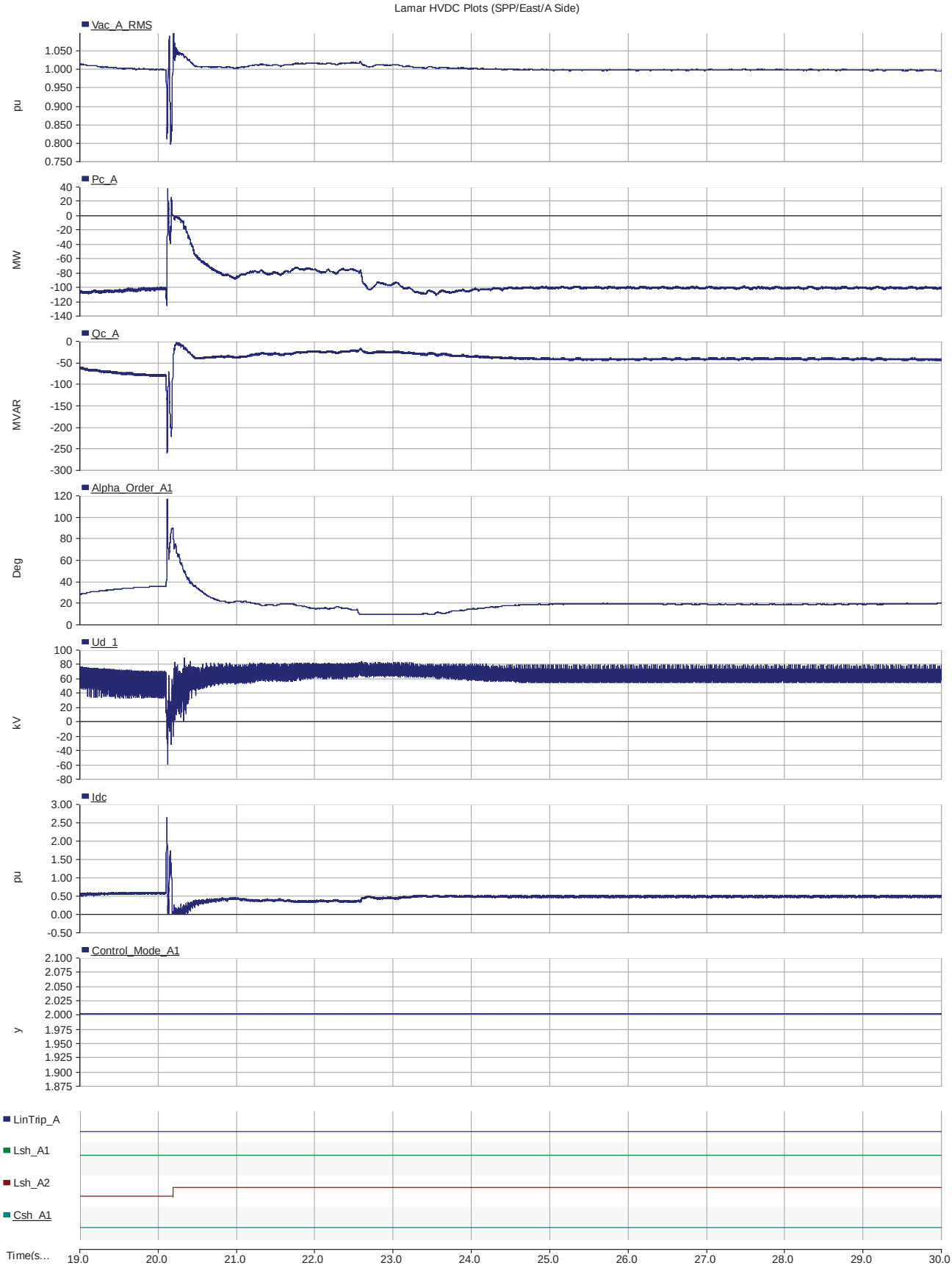

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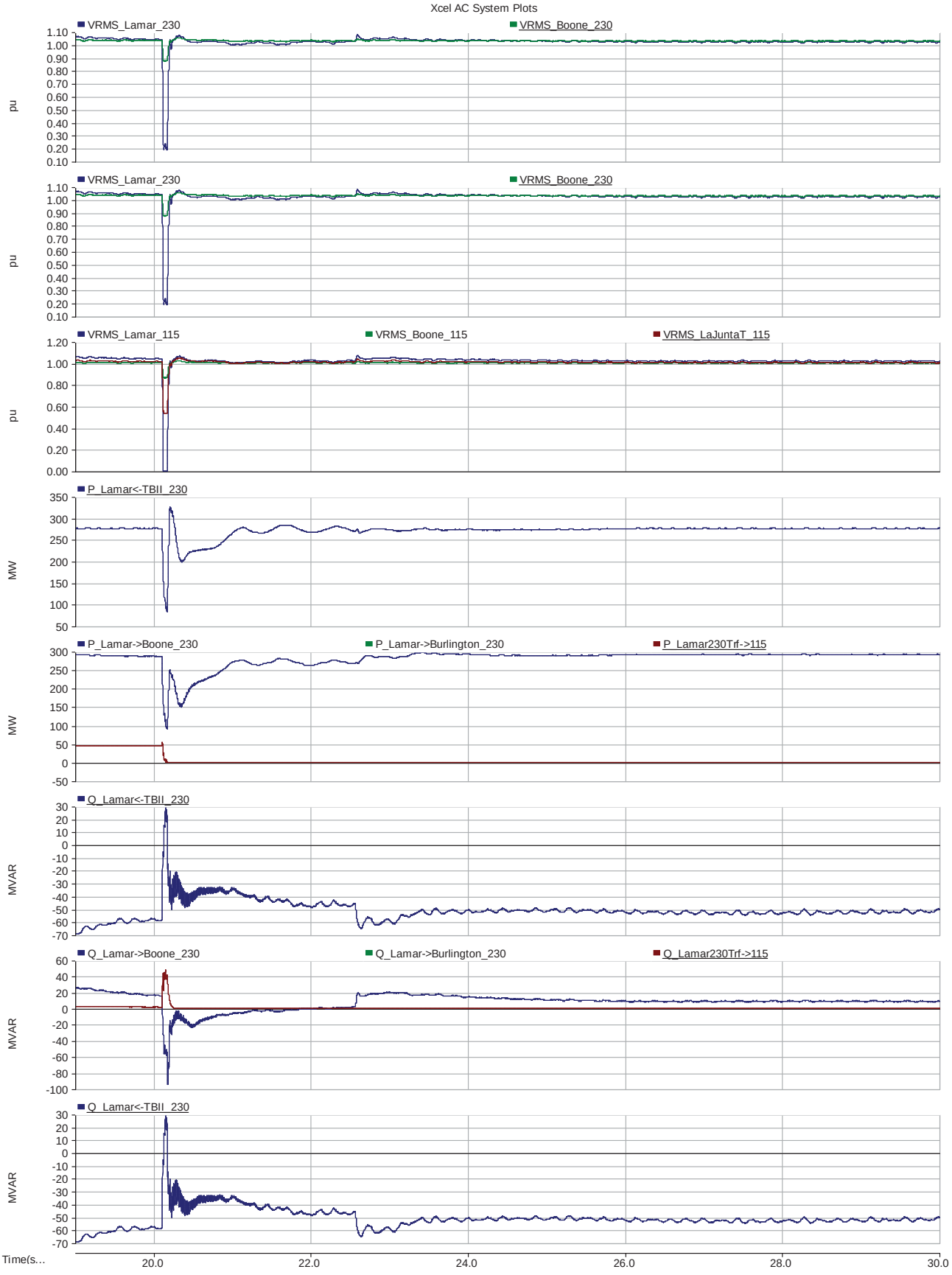

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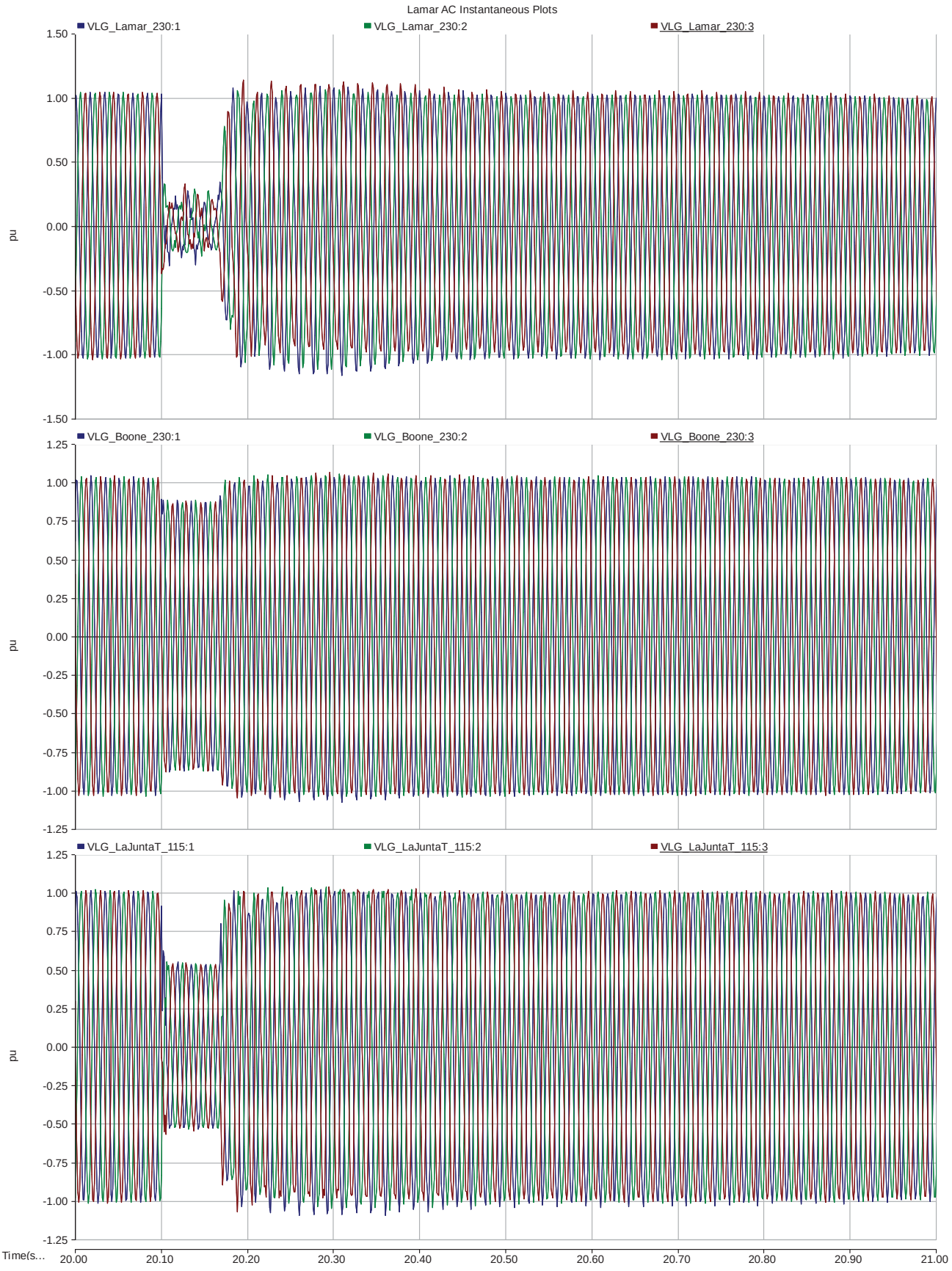

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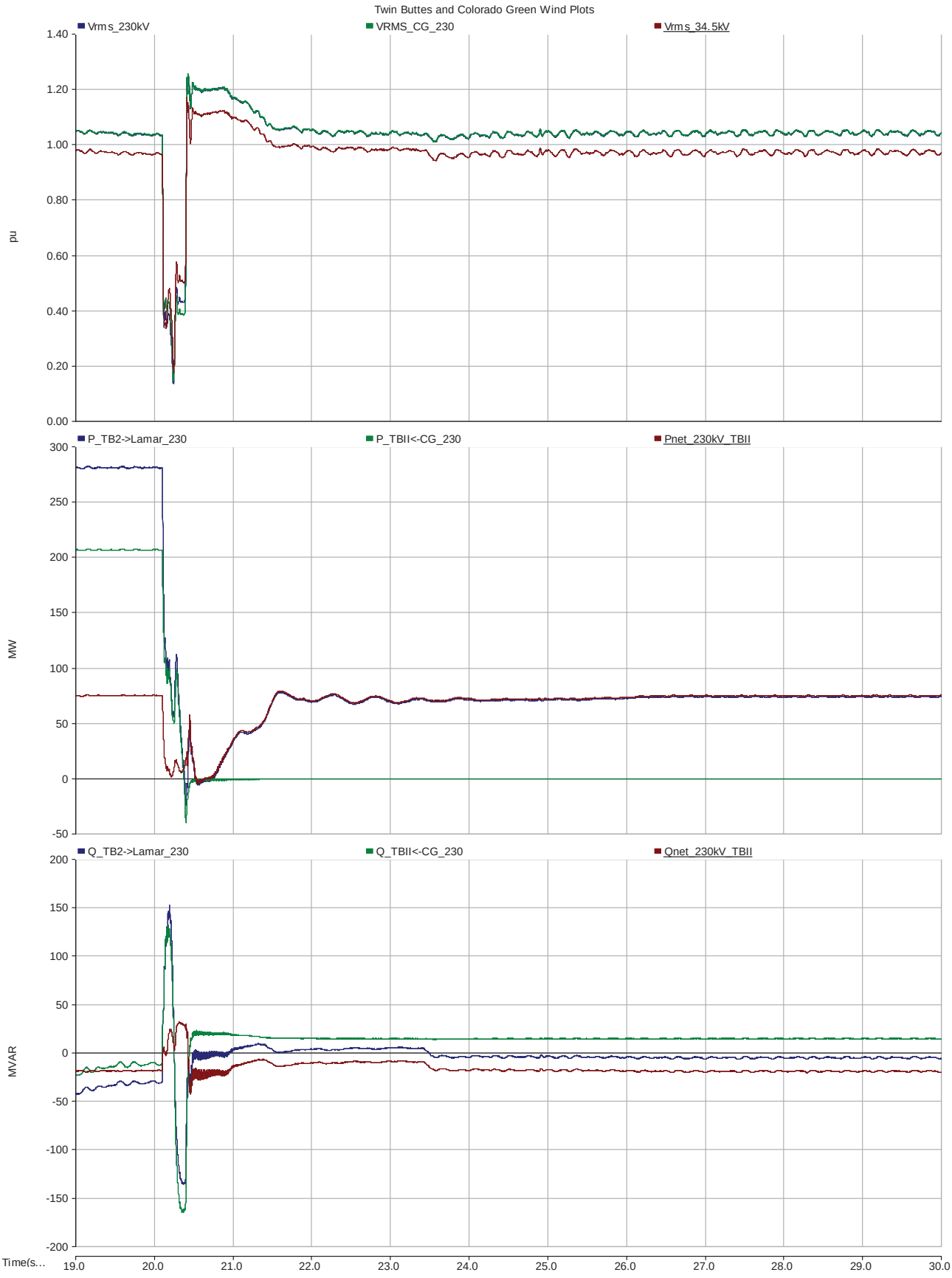
F2_S2 plots



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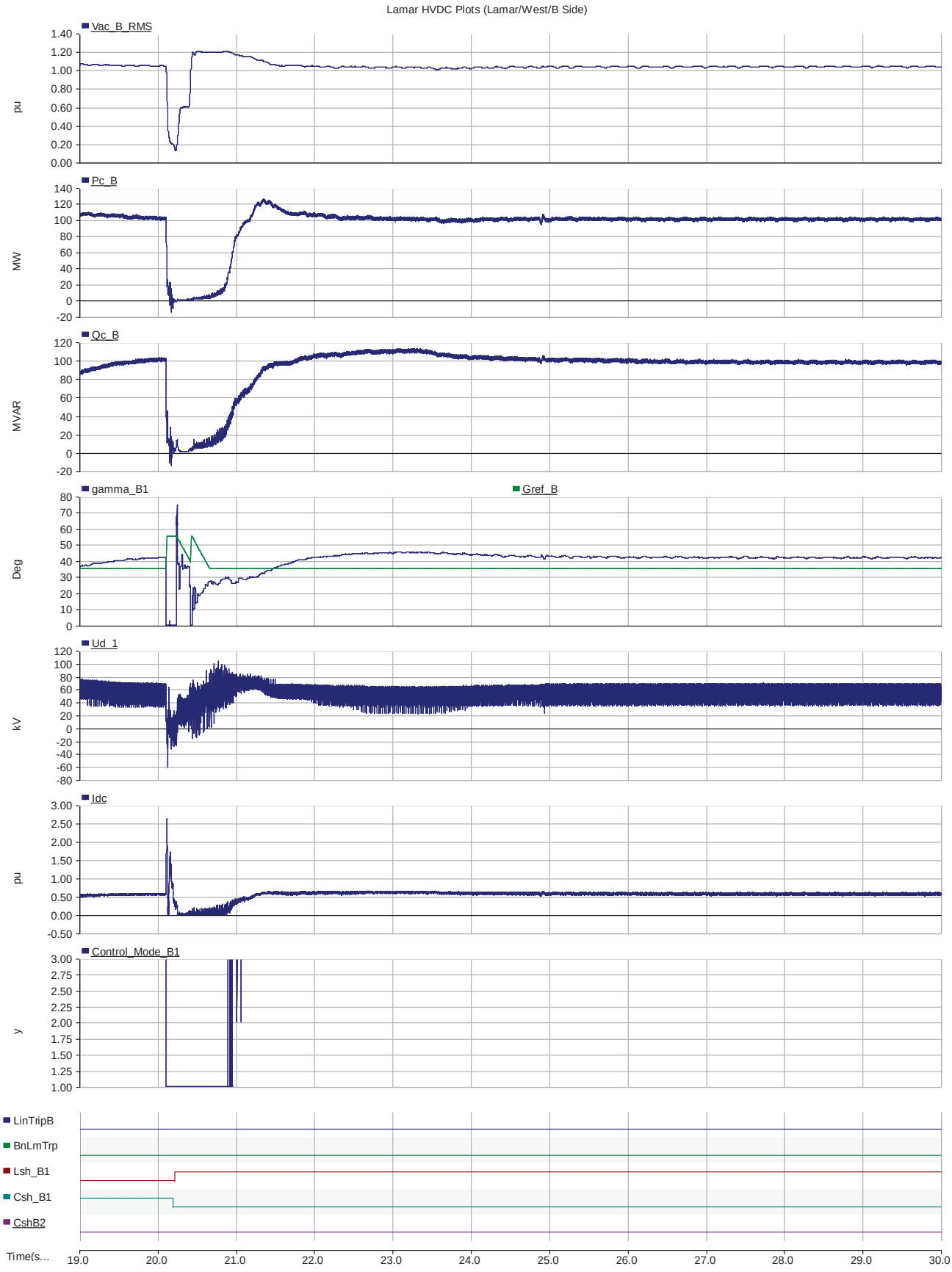

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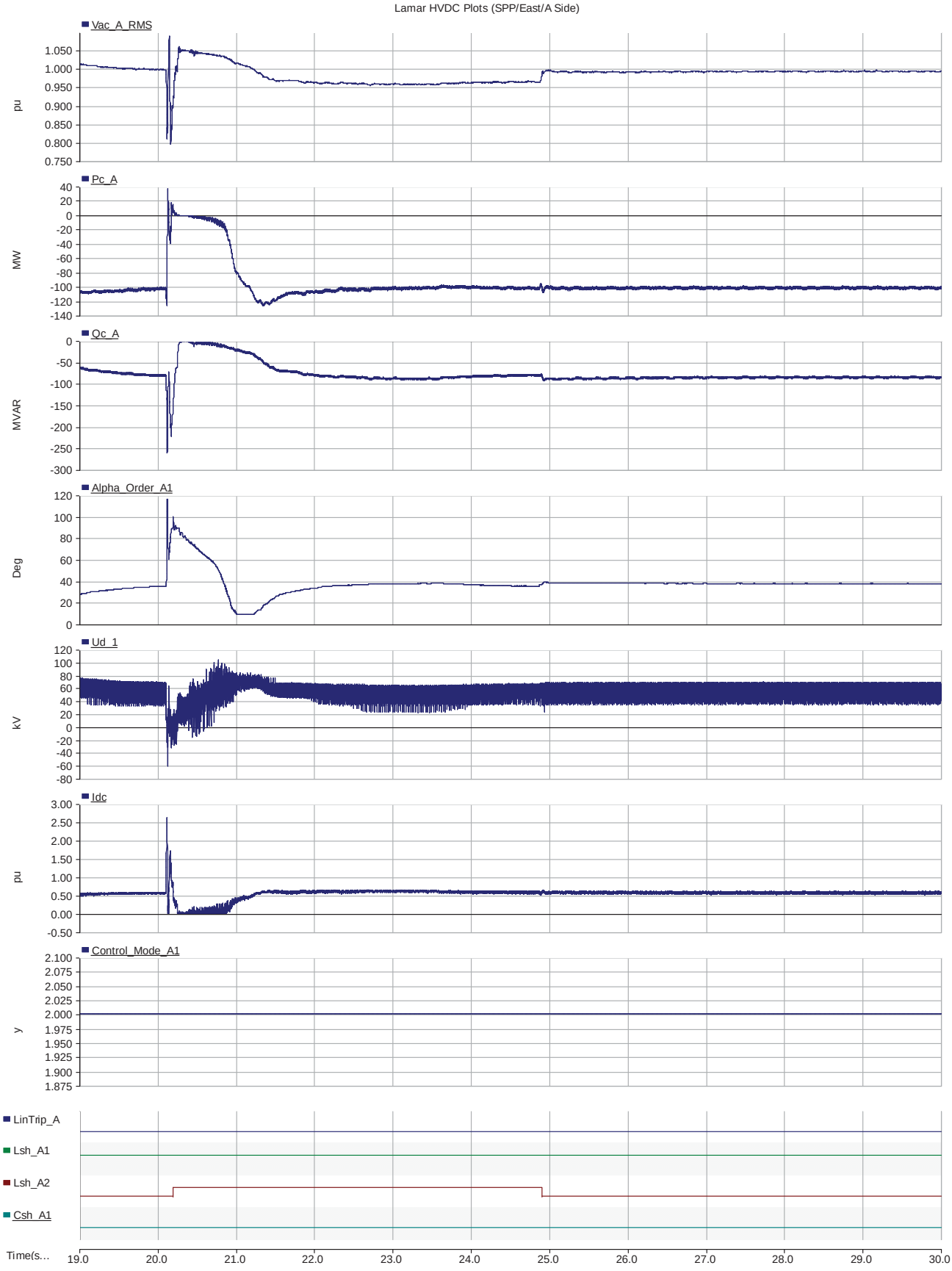

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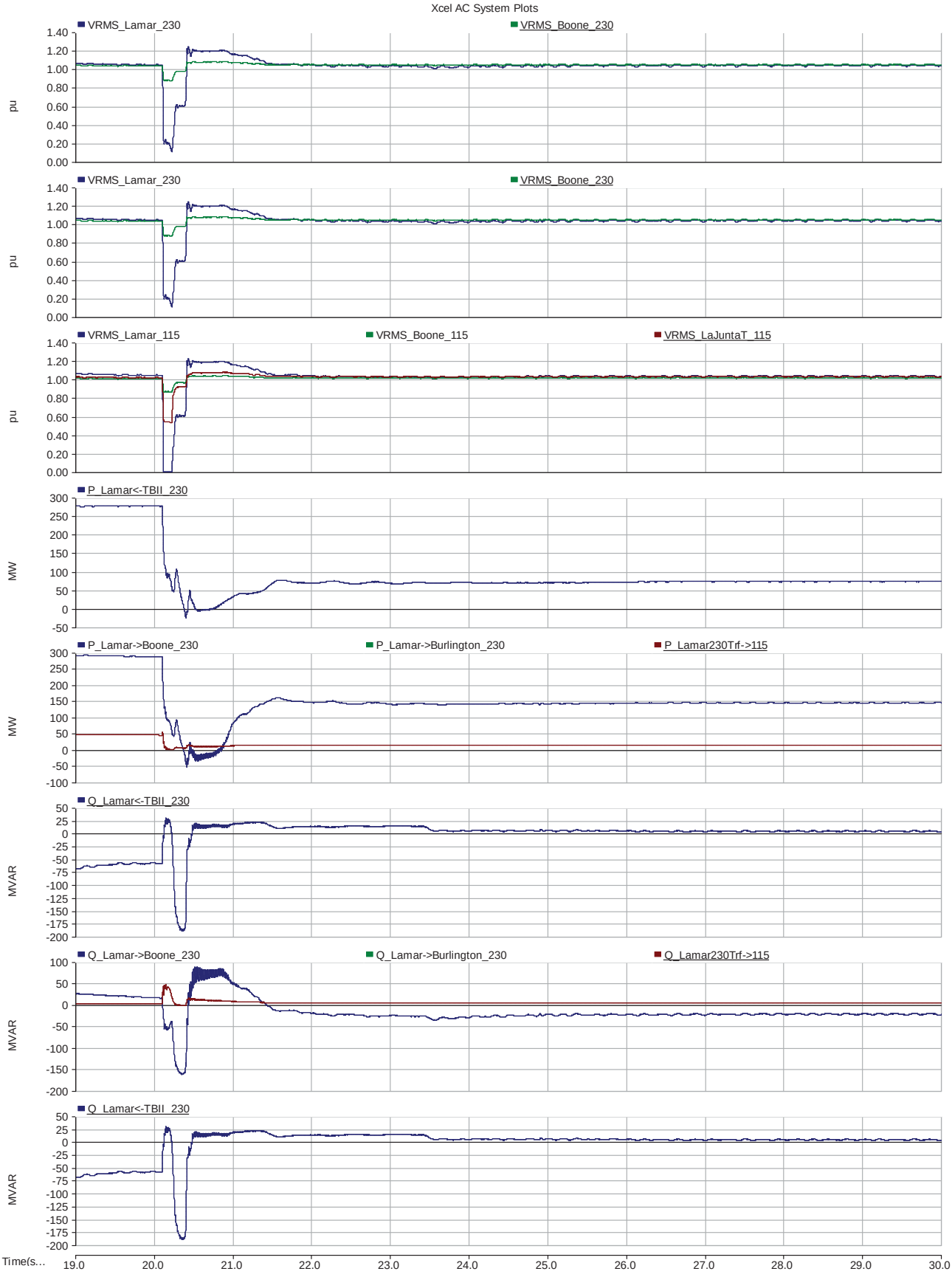

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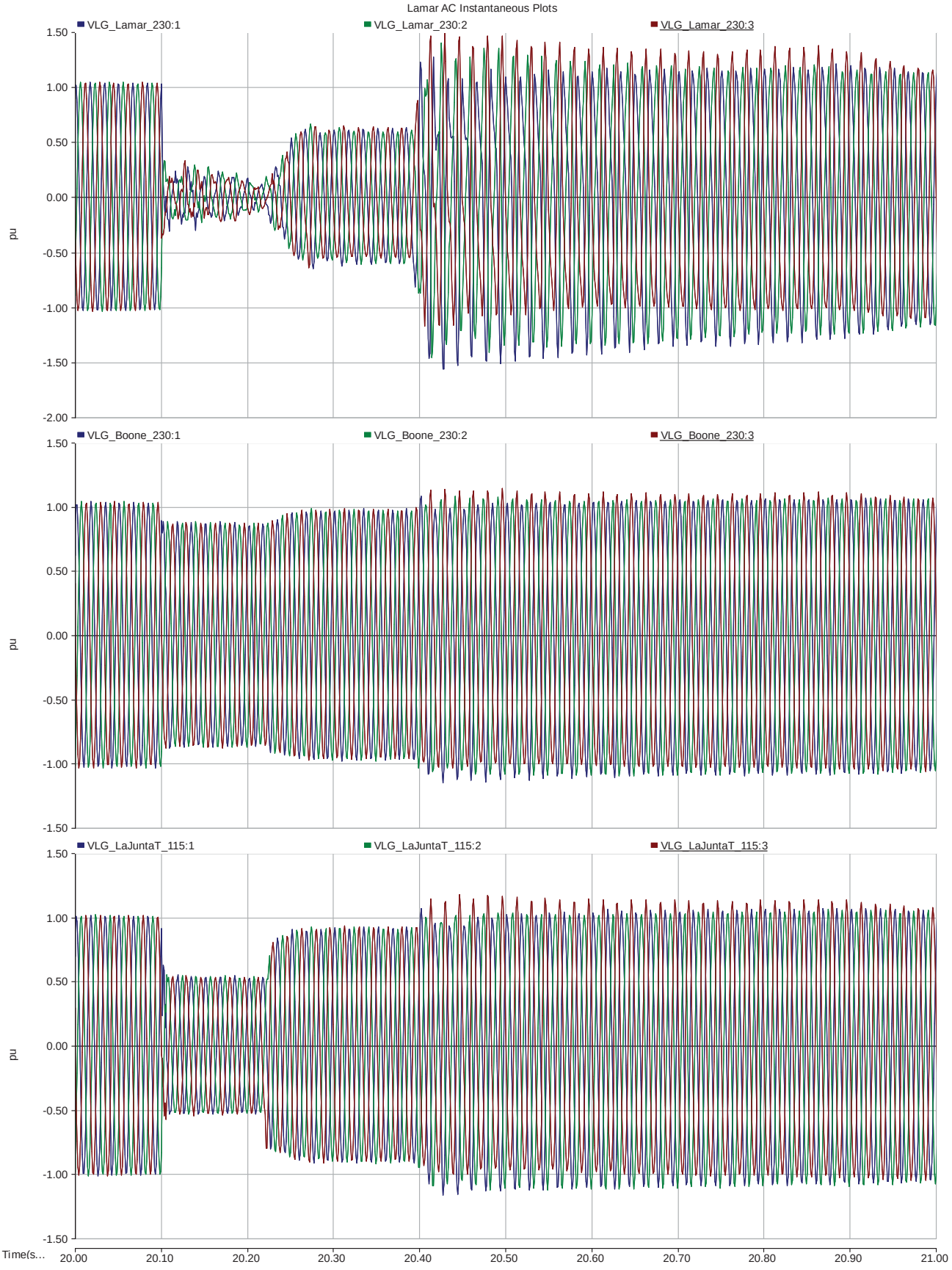

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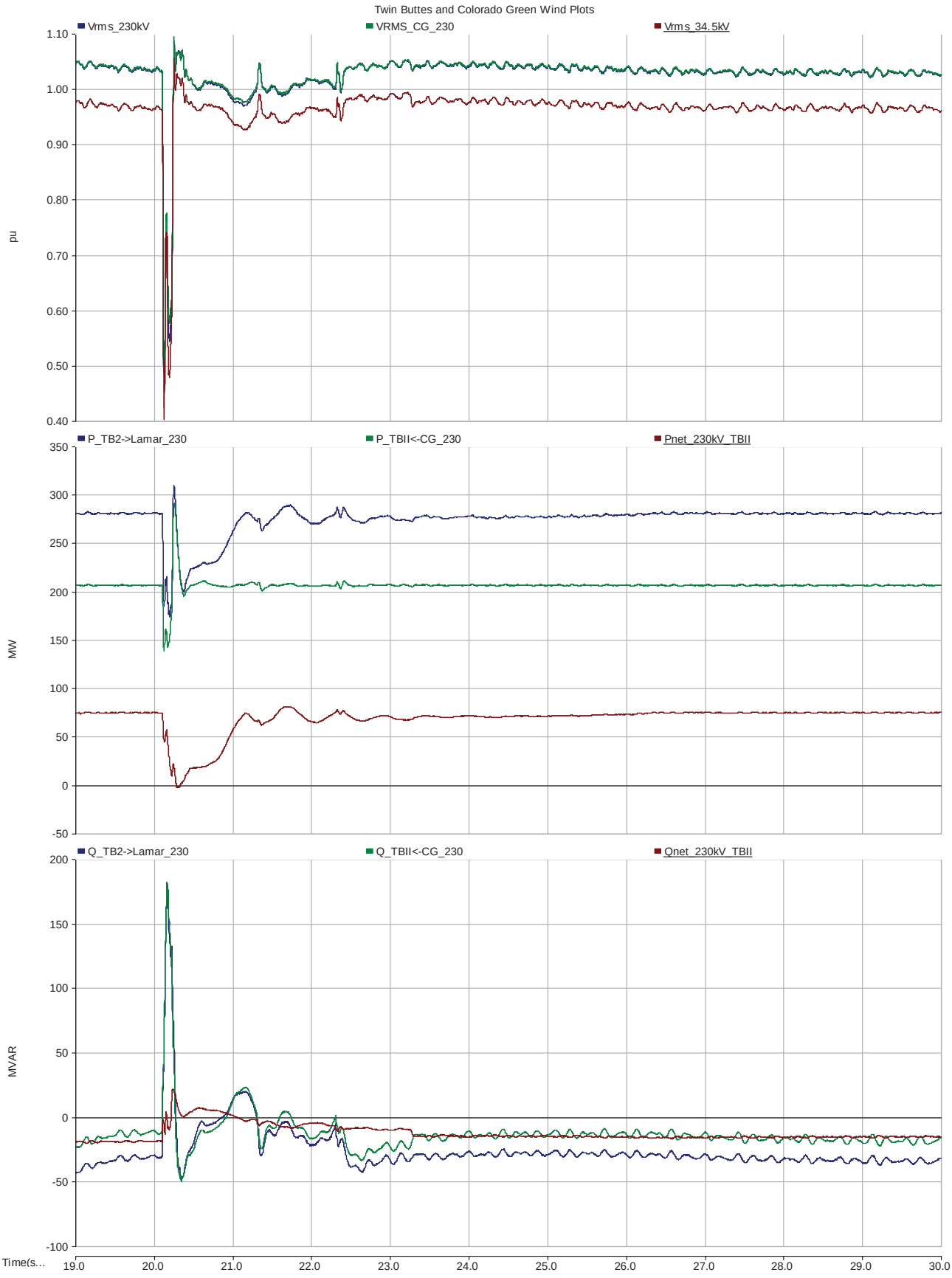
F3_S2 plots



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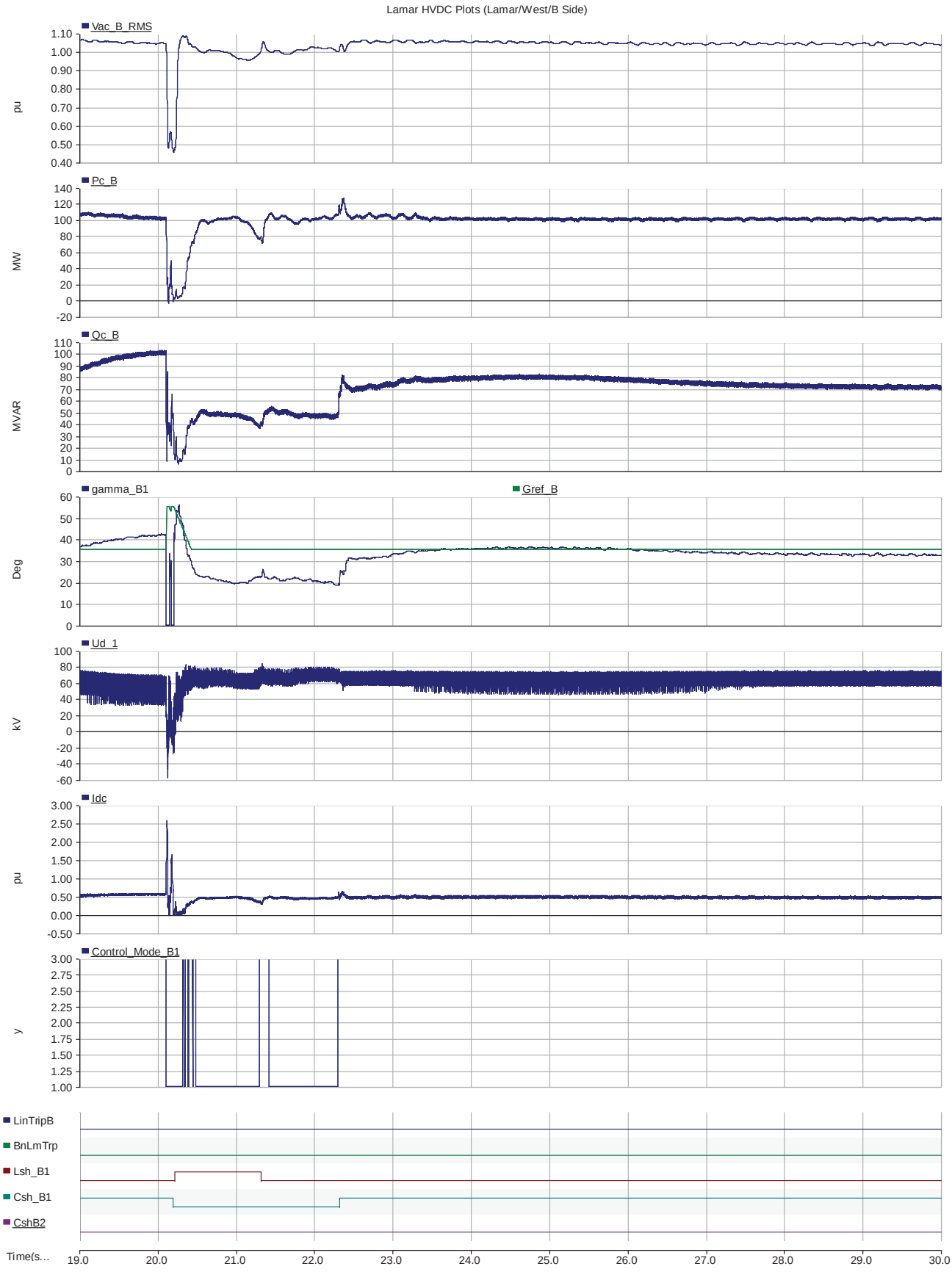

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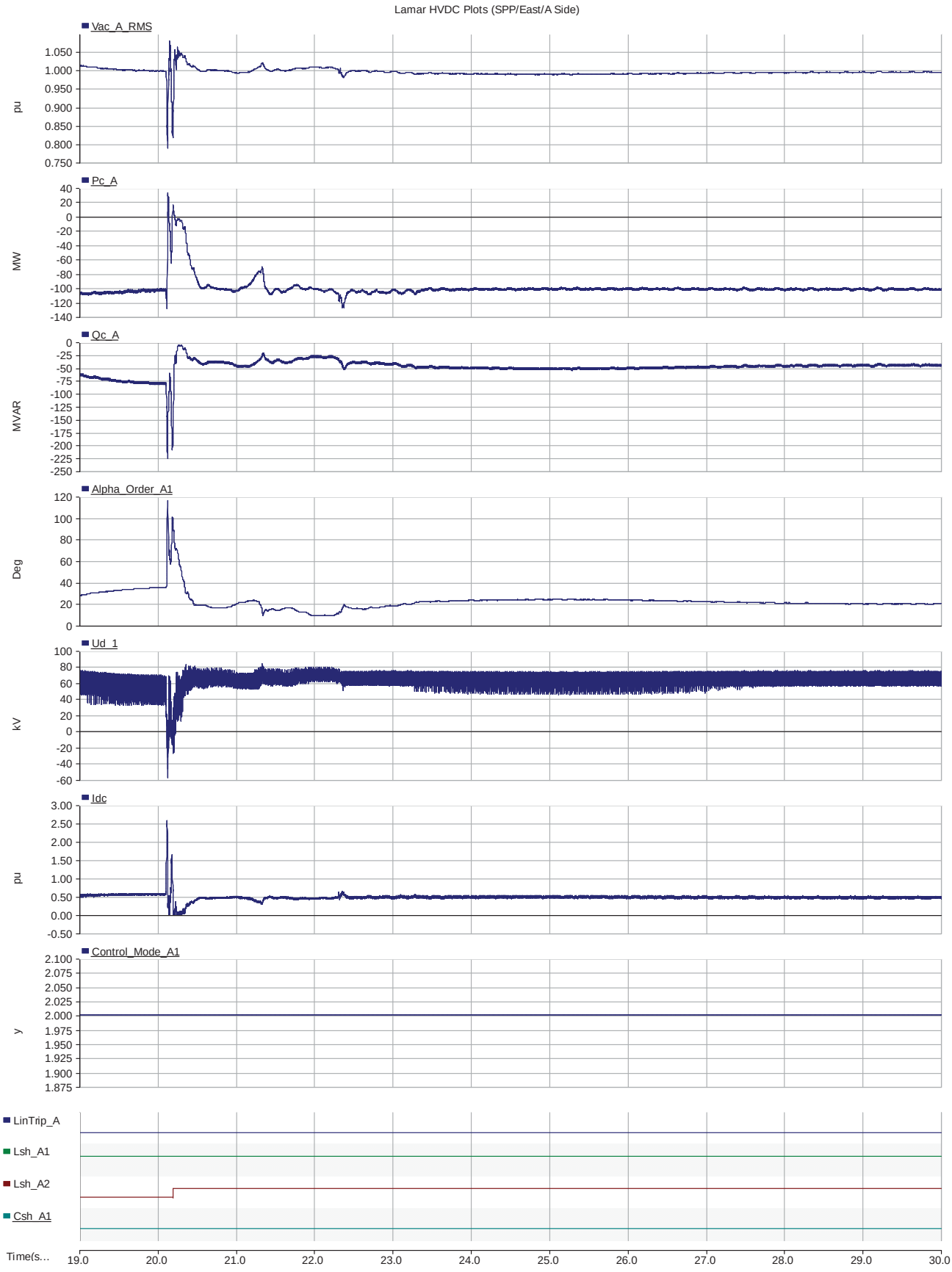

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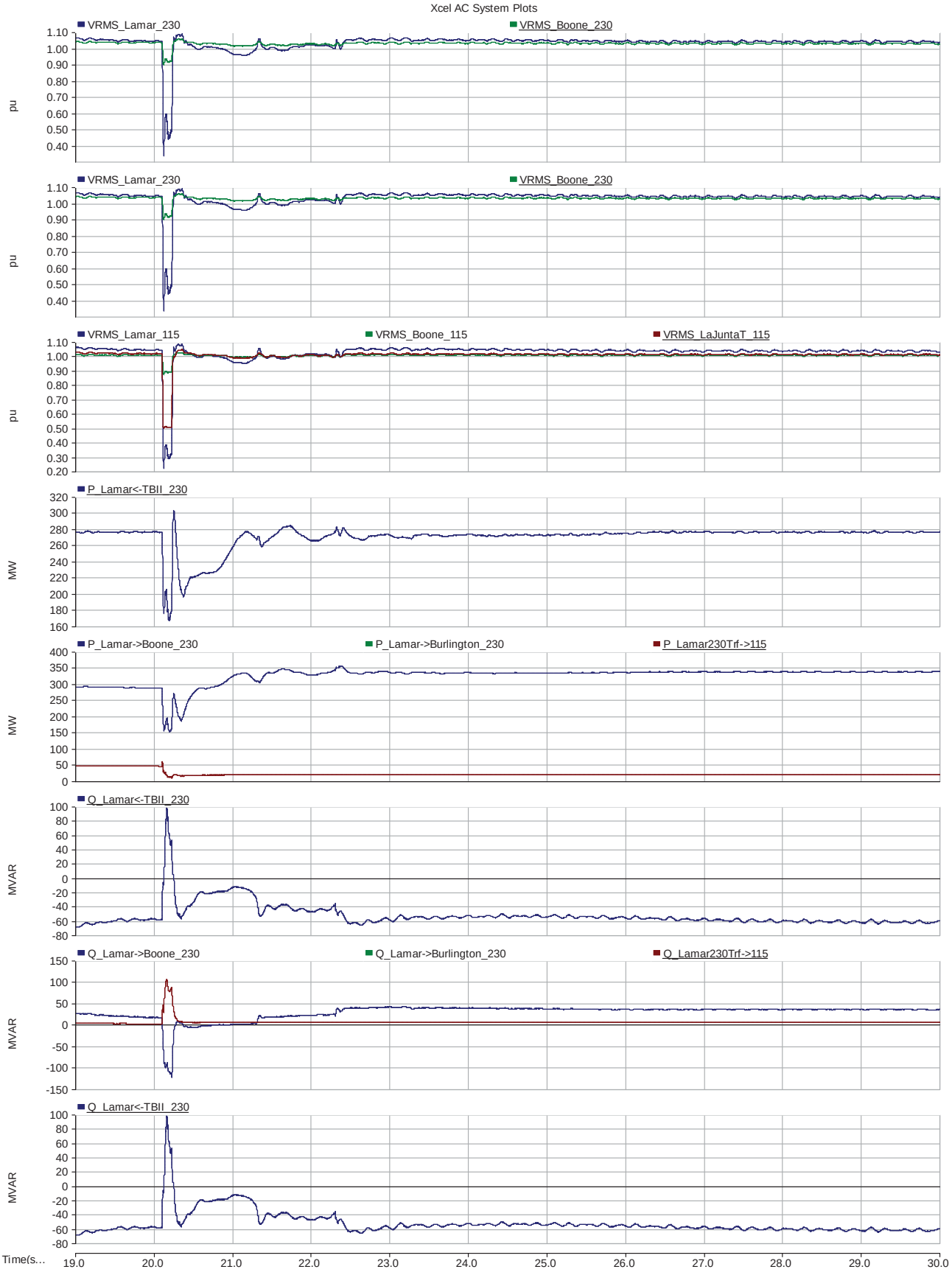

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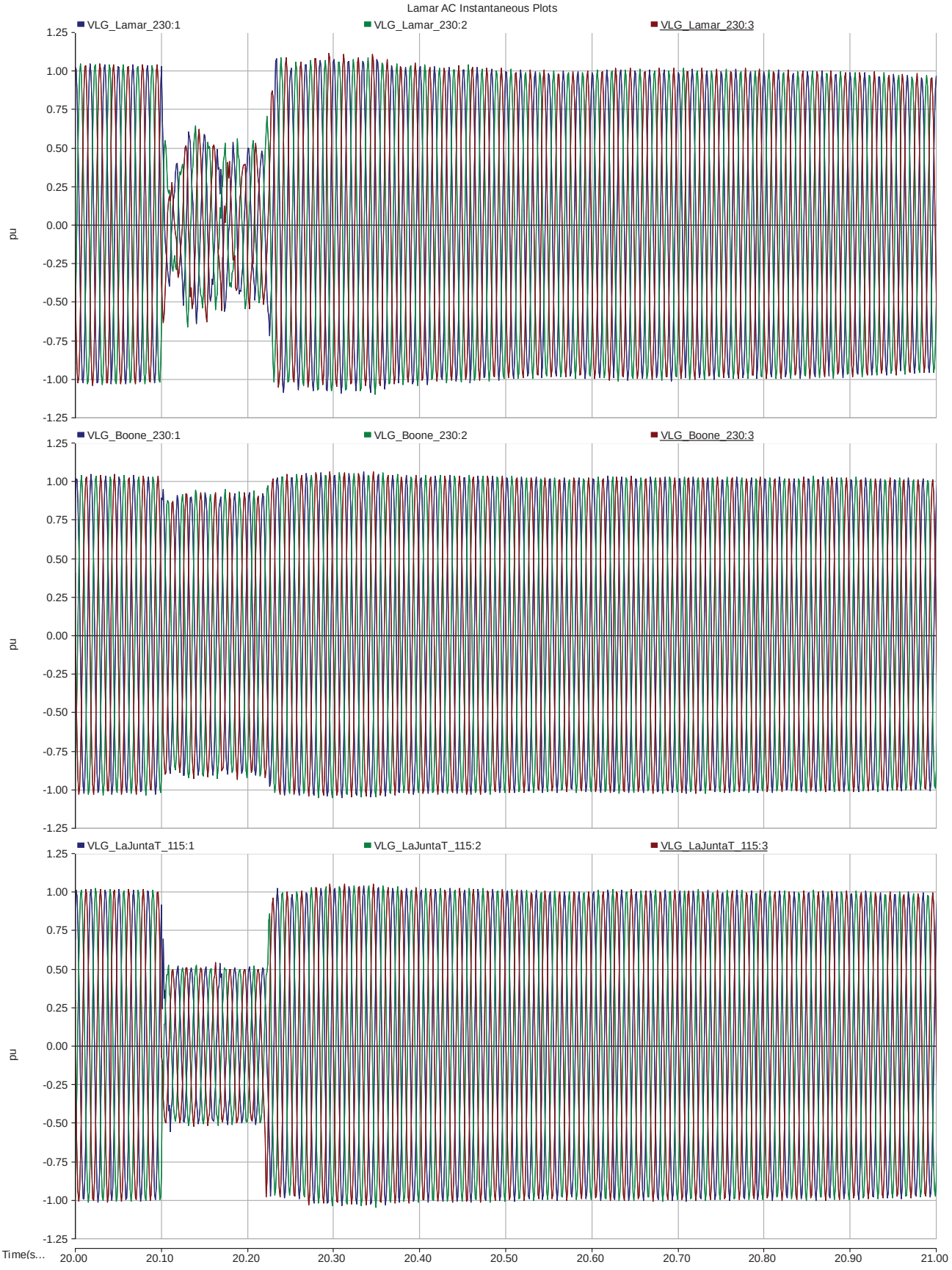

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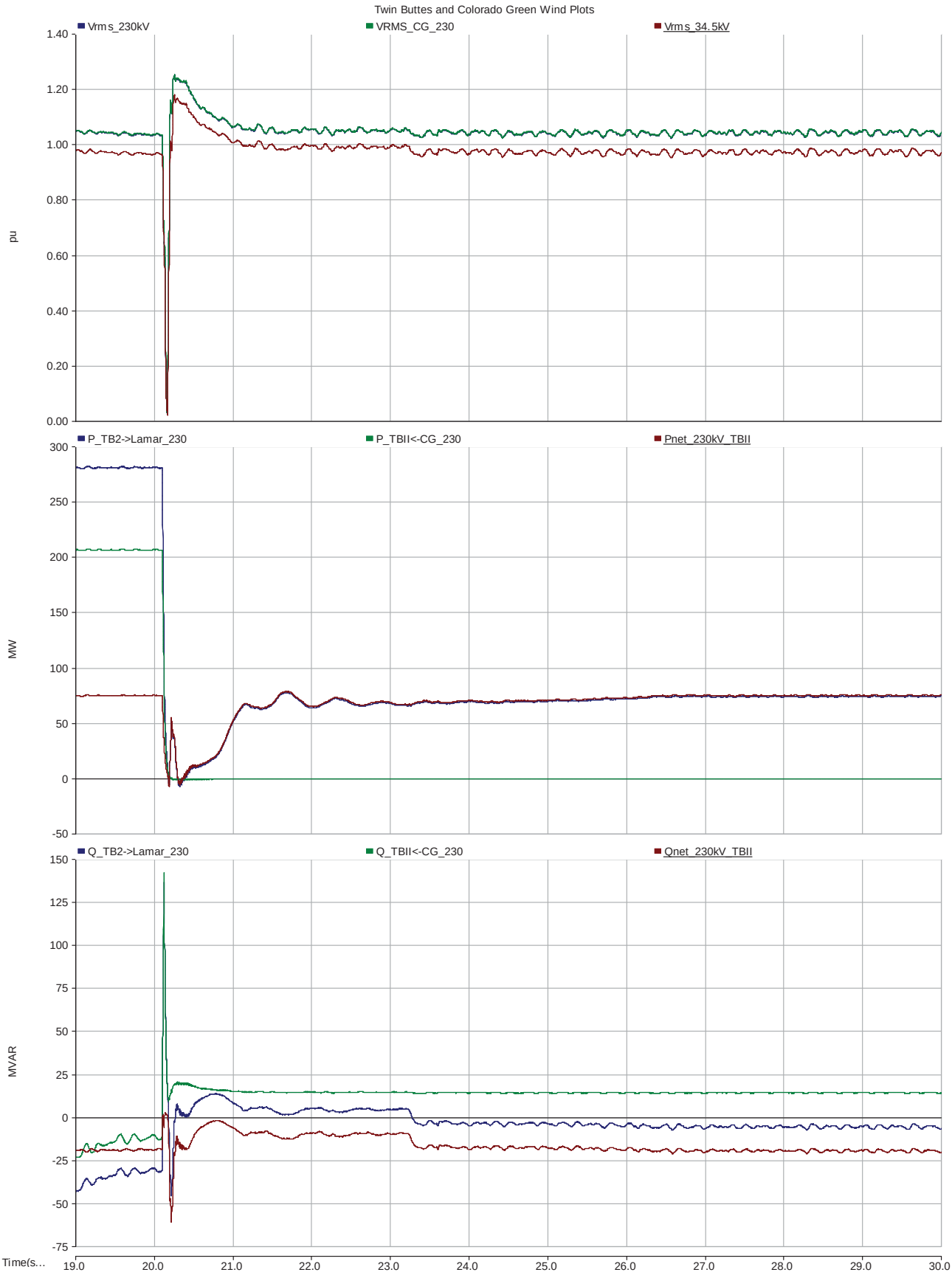
F4_S2 plots



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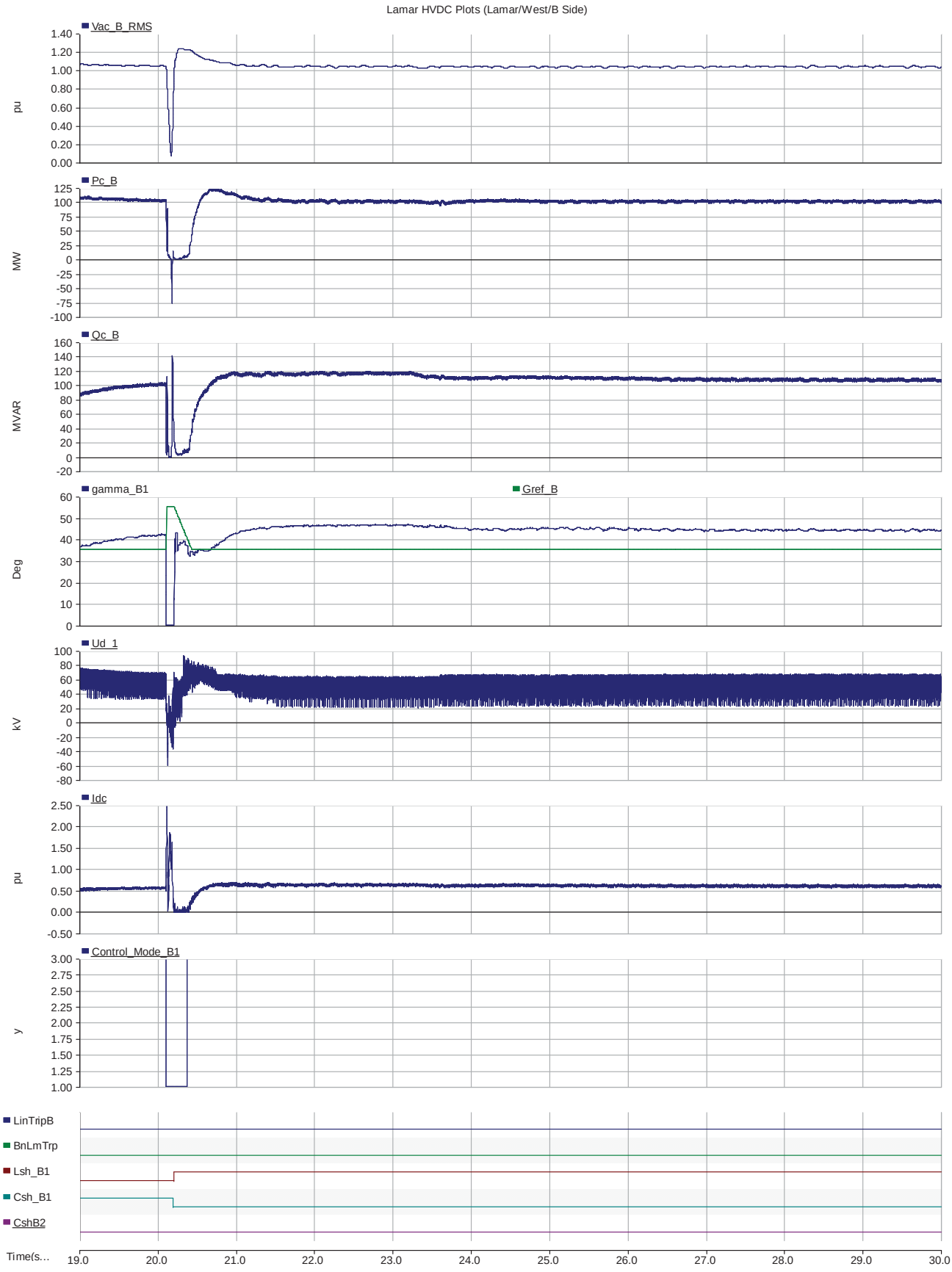
Fault 4 - LLLG fault at Boone 230kV bus on the line to Midway - and subsiquent tripping of the line.



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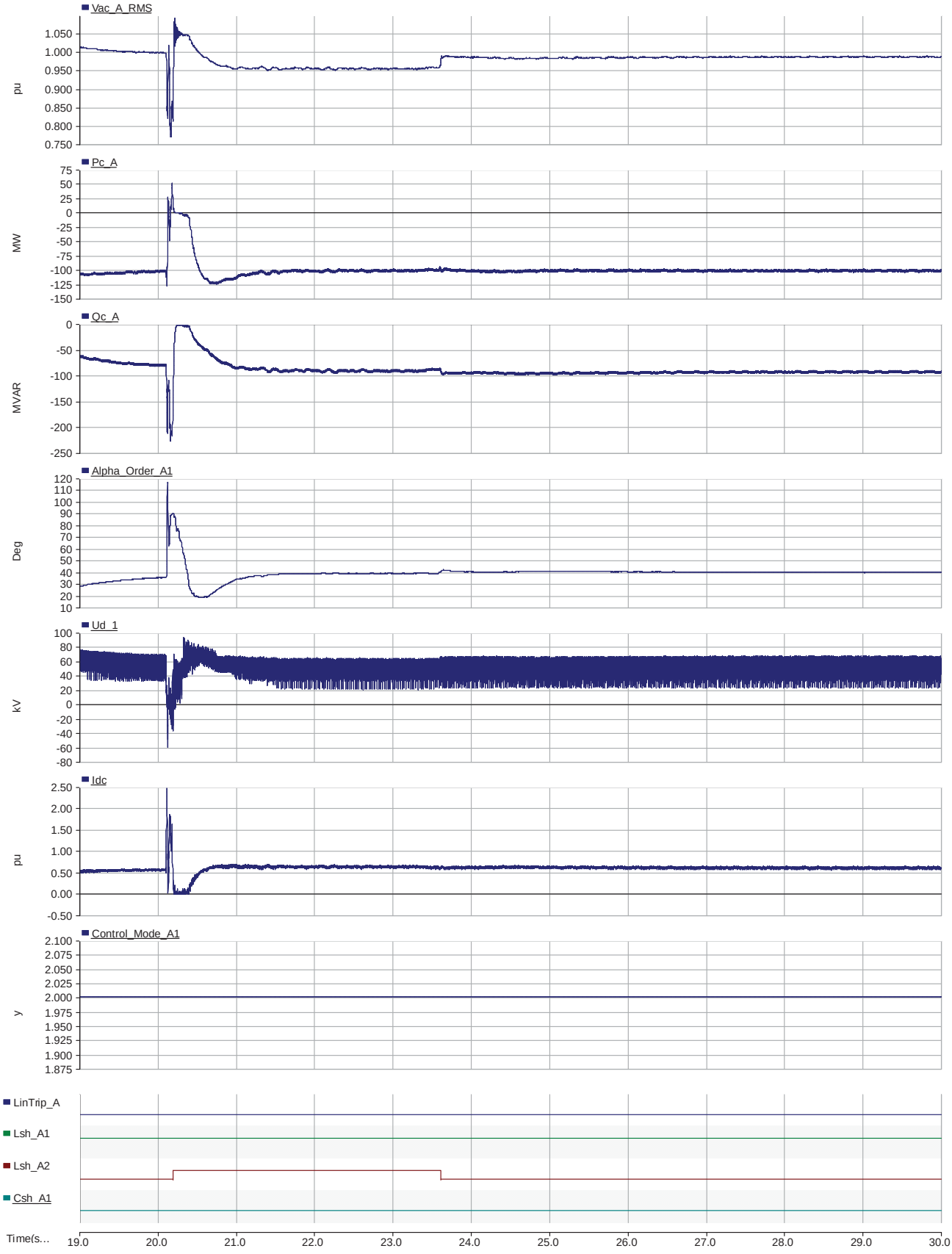
Lamar HVDC Plots (SPP/East/A Side)



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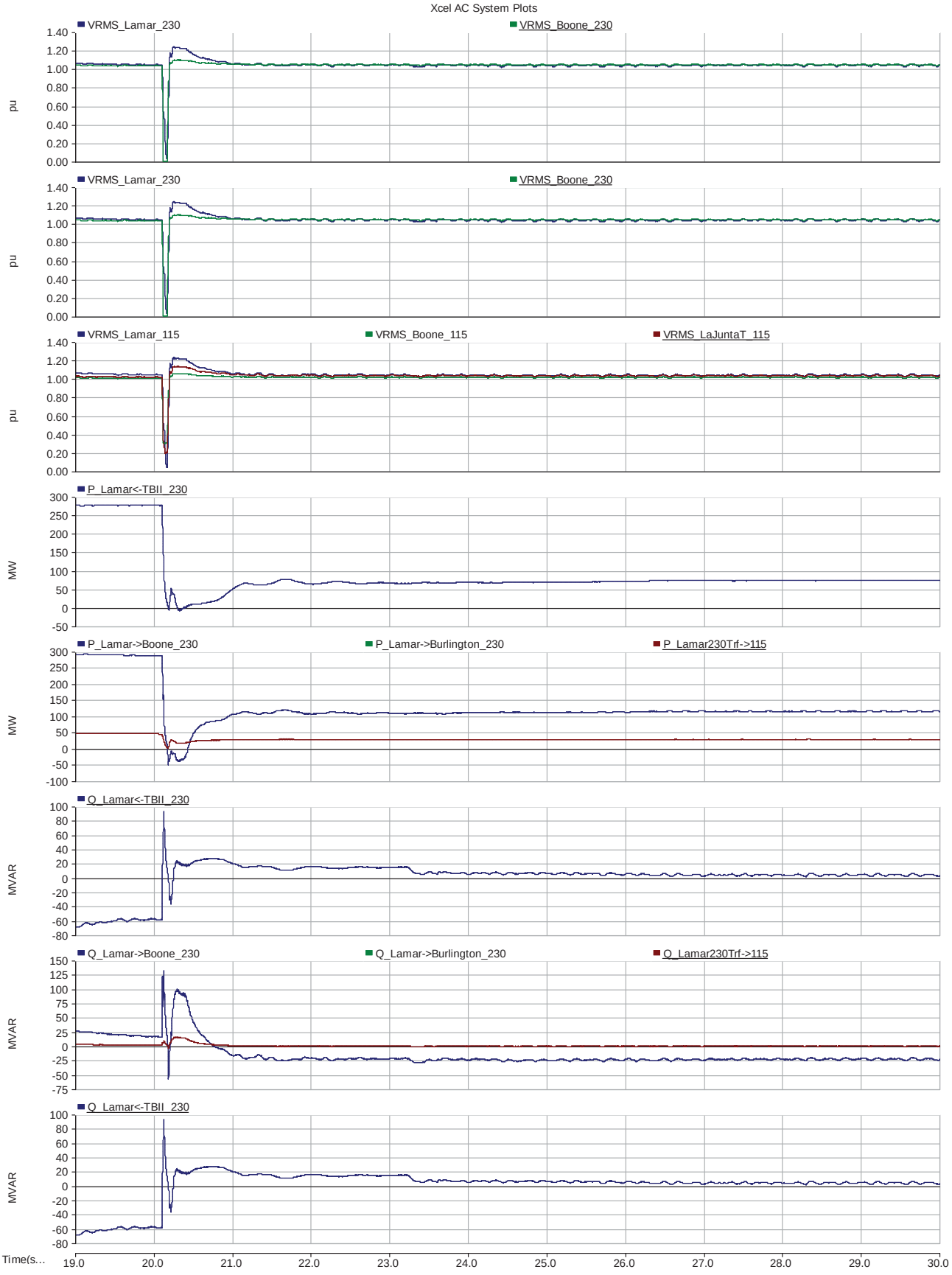

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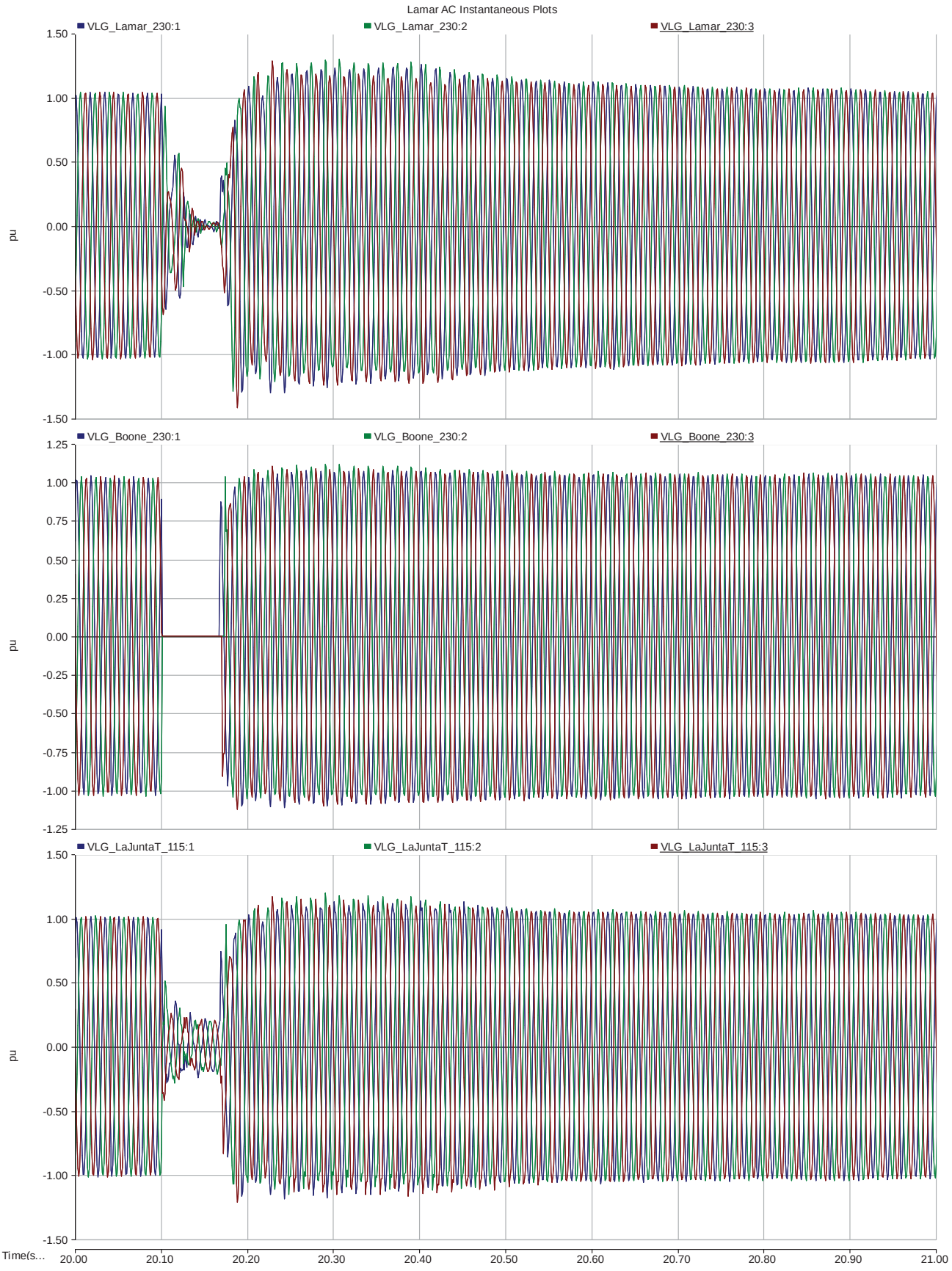

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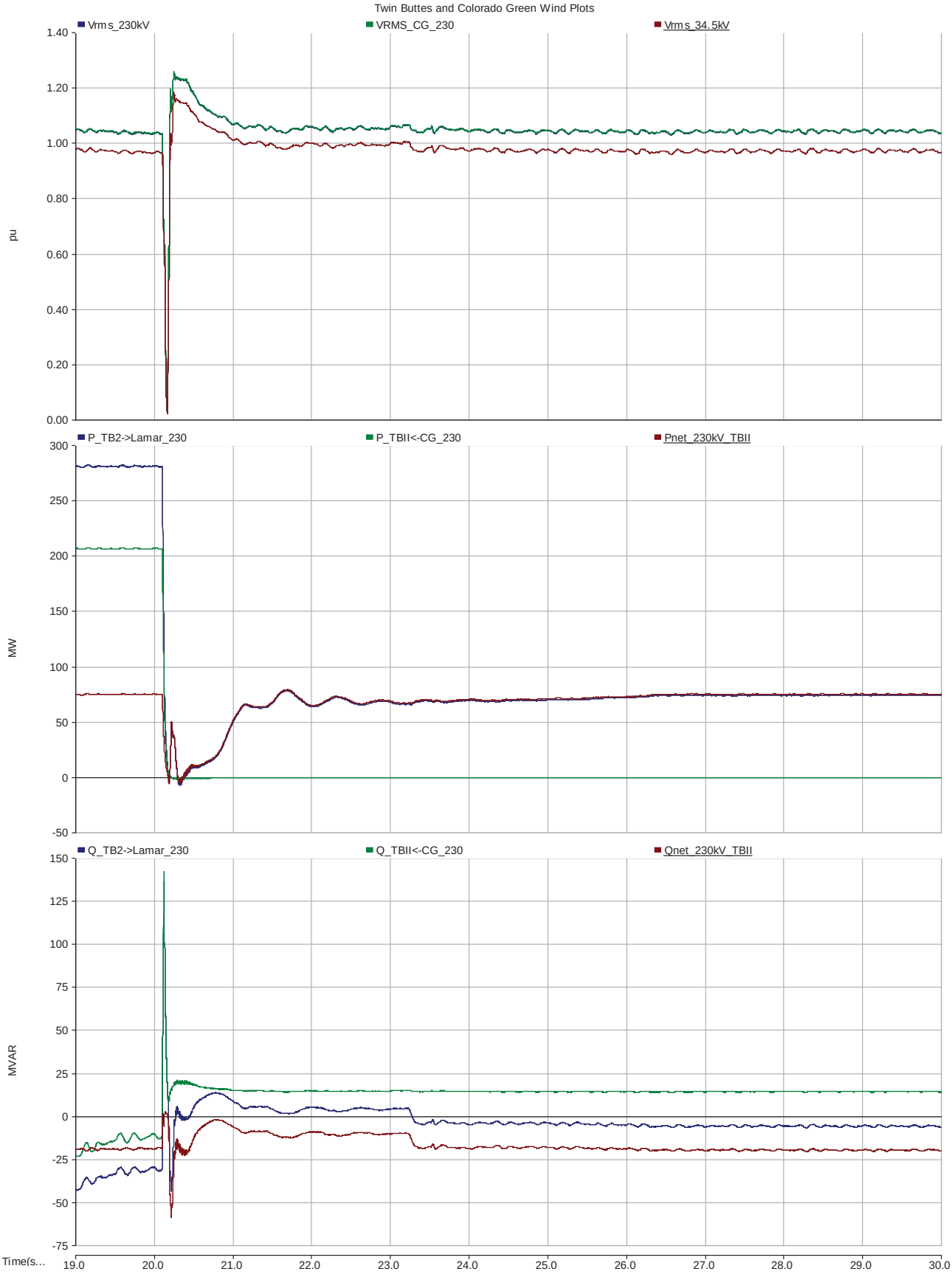
F5_S2 plots



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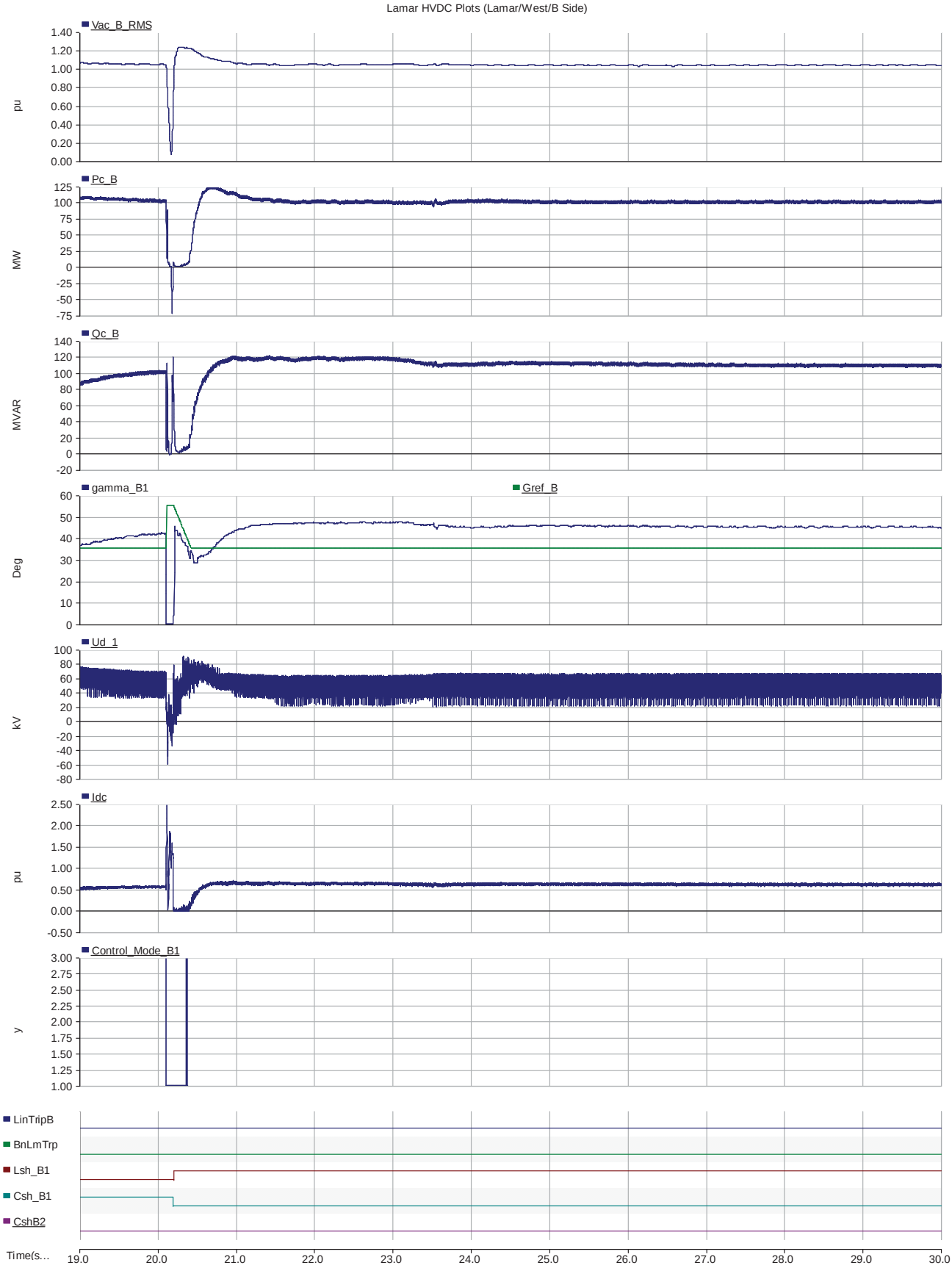
Fault 5 - LLLG fault at Boone 230kV bus - and subsiquent tripping of the Boone - Comanche 230kV line.



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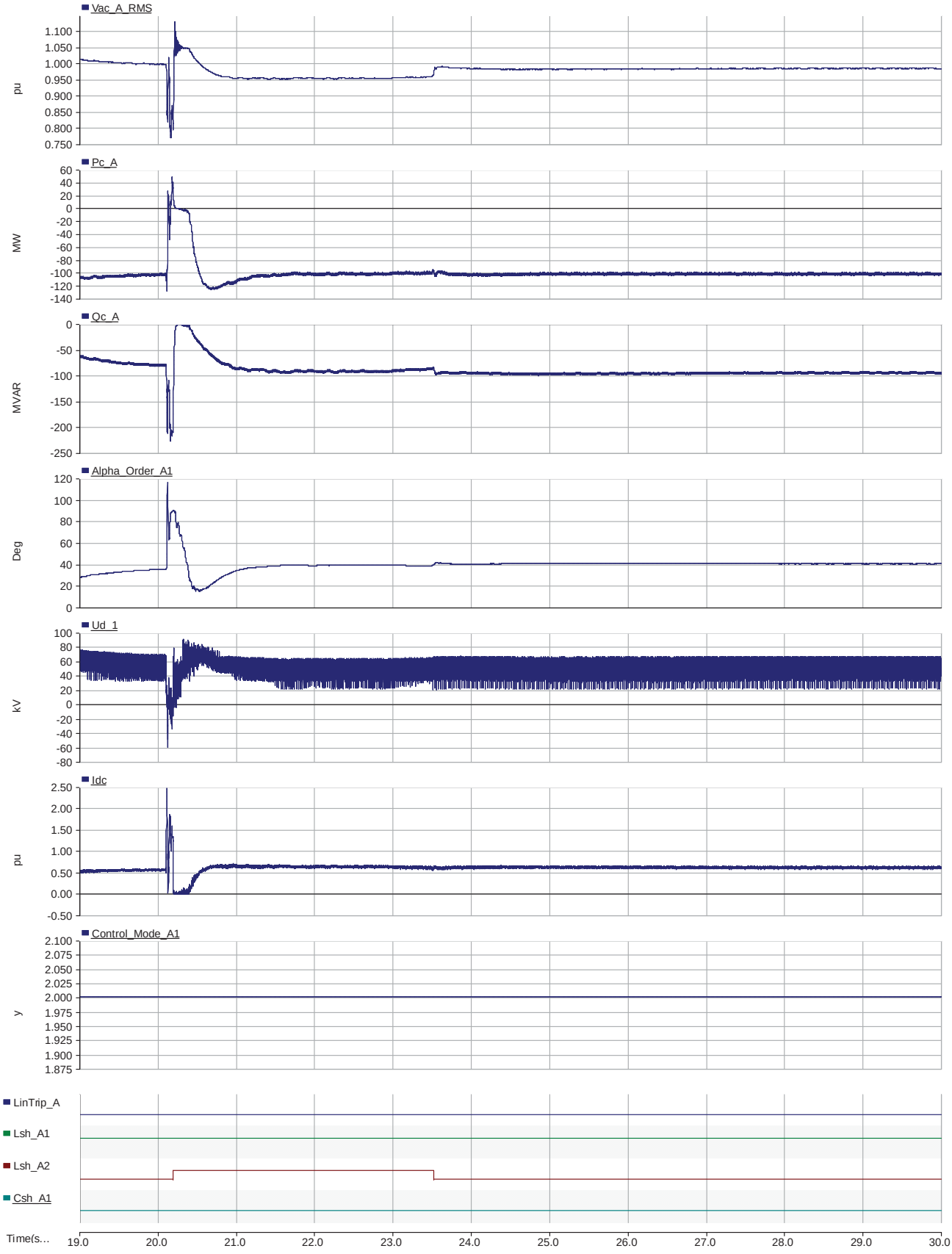

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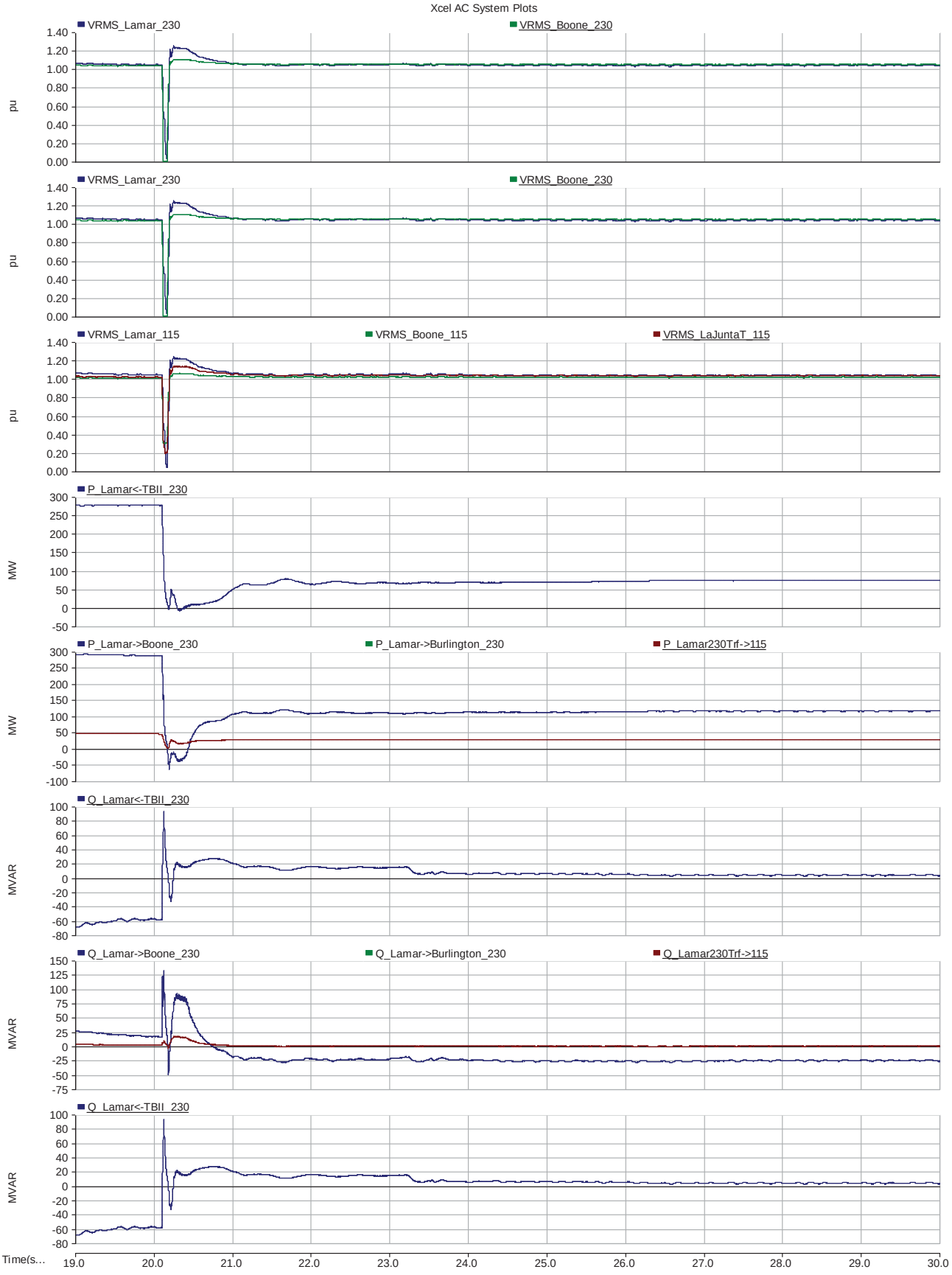

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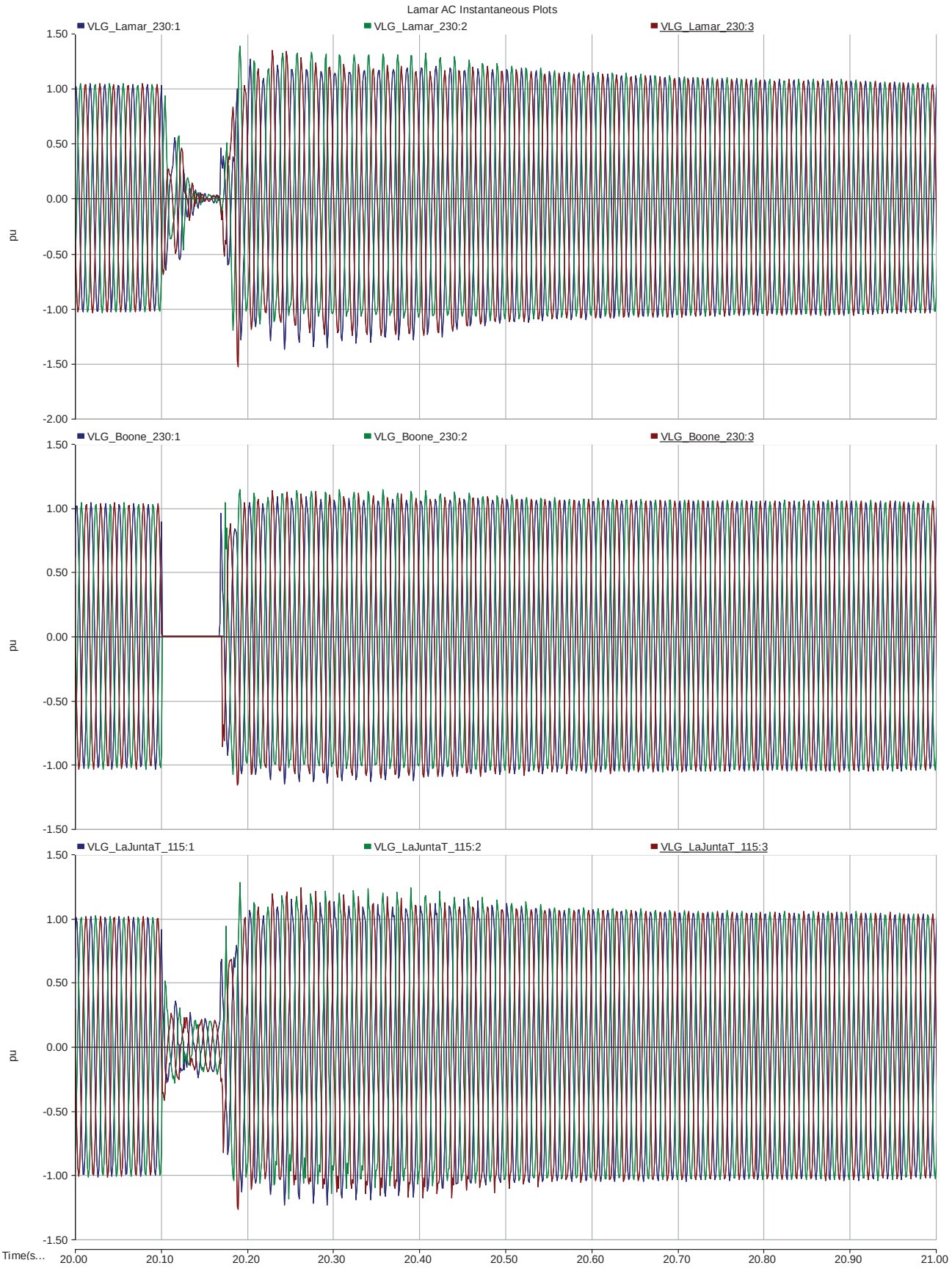

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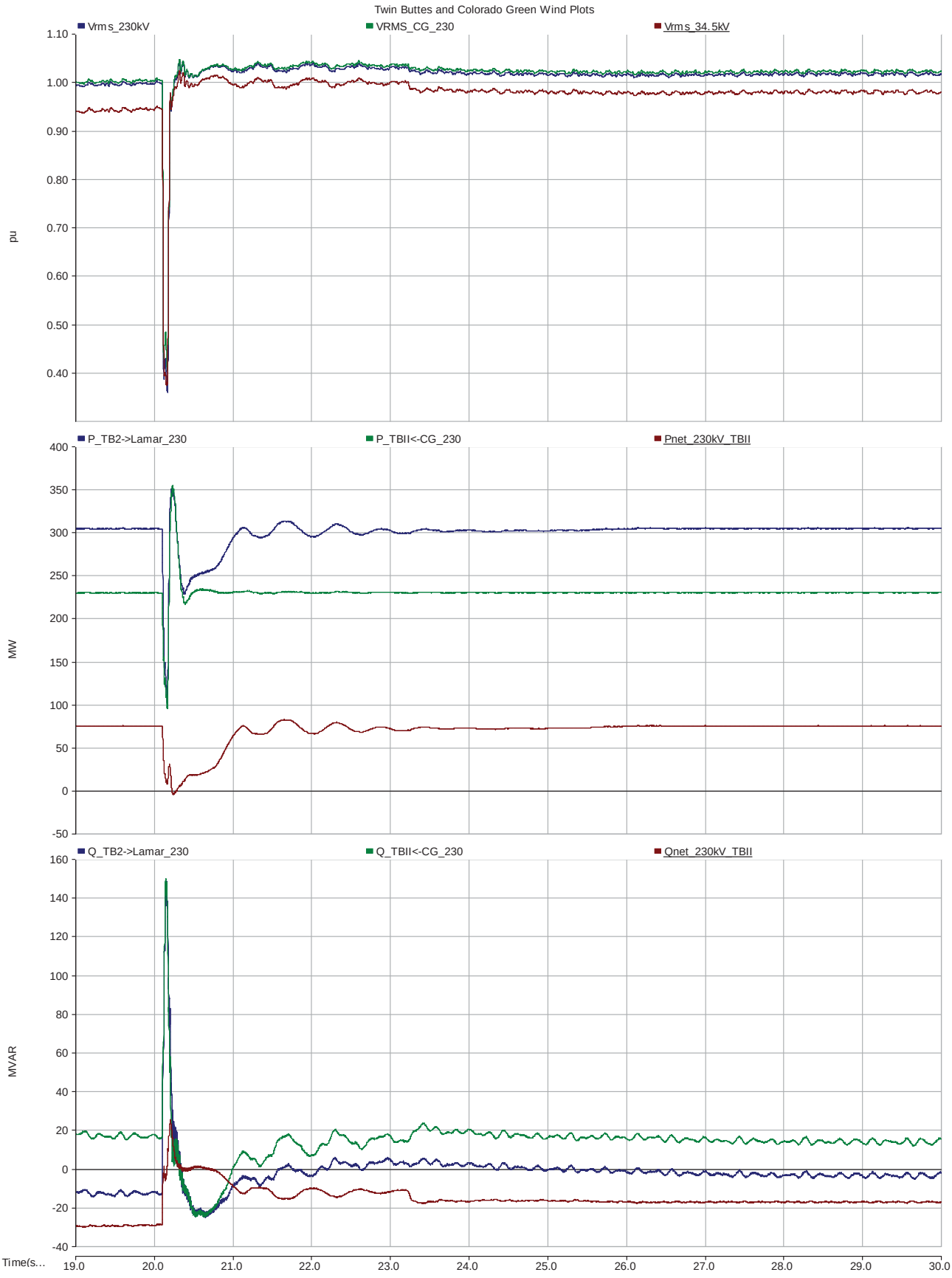
F1_S3 plots



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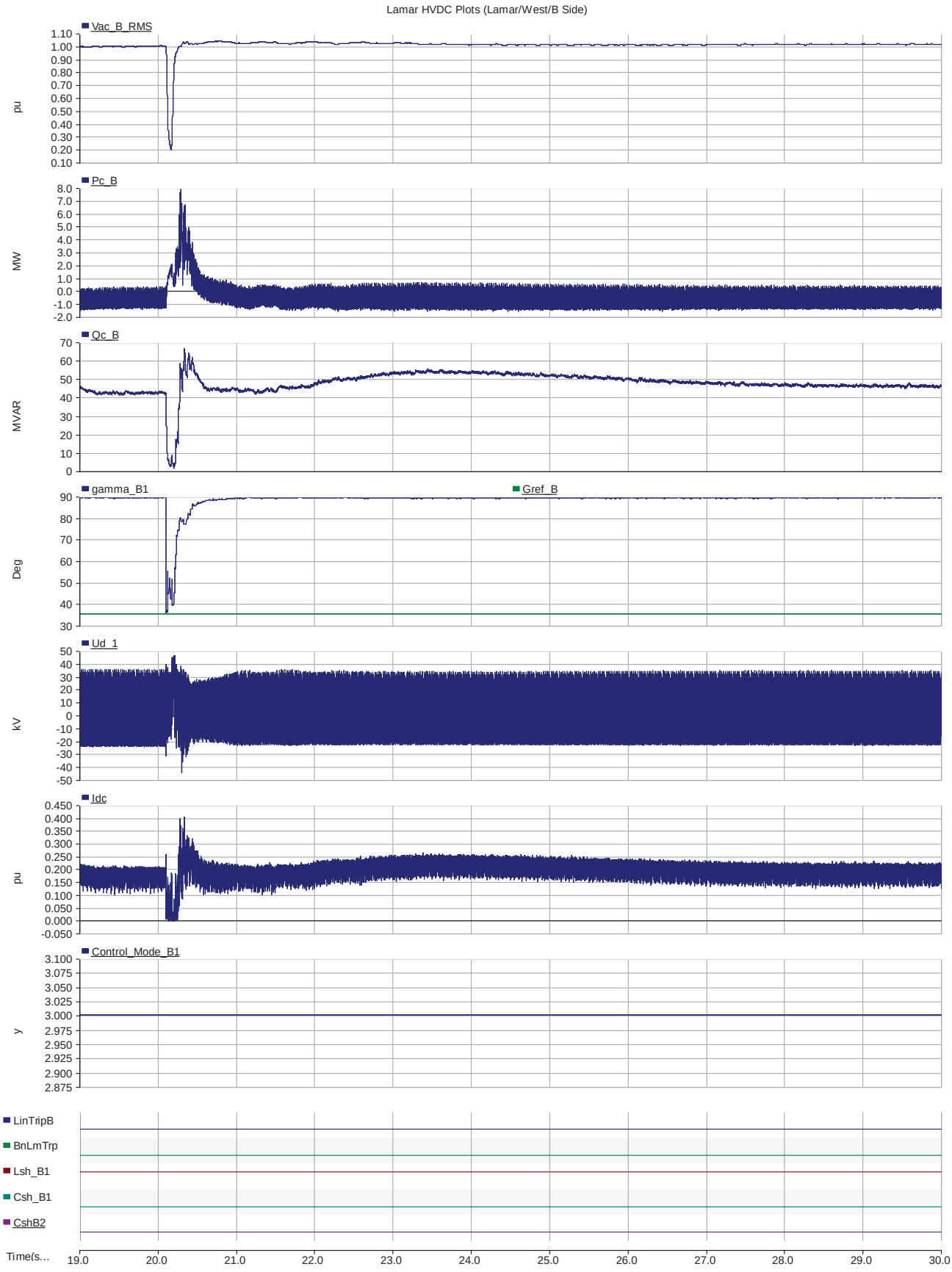

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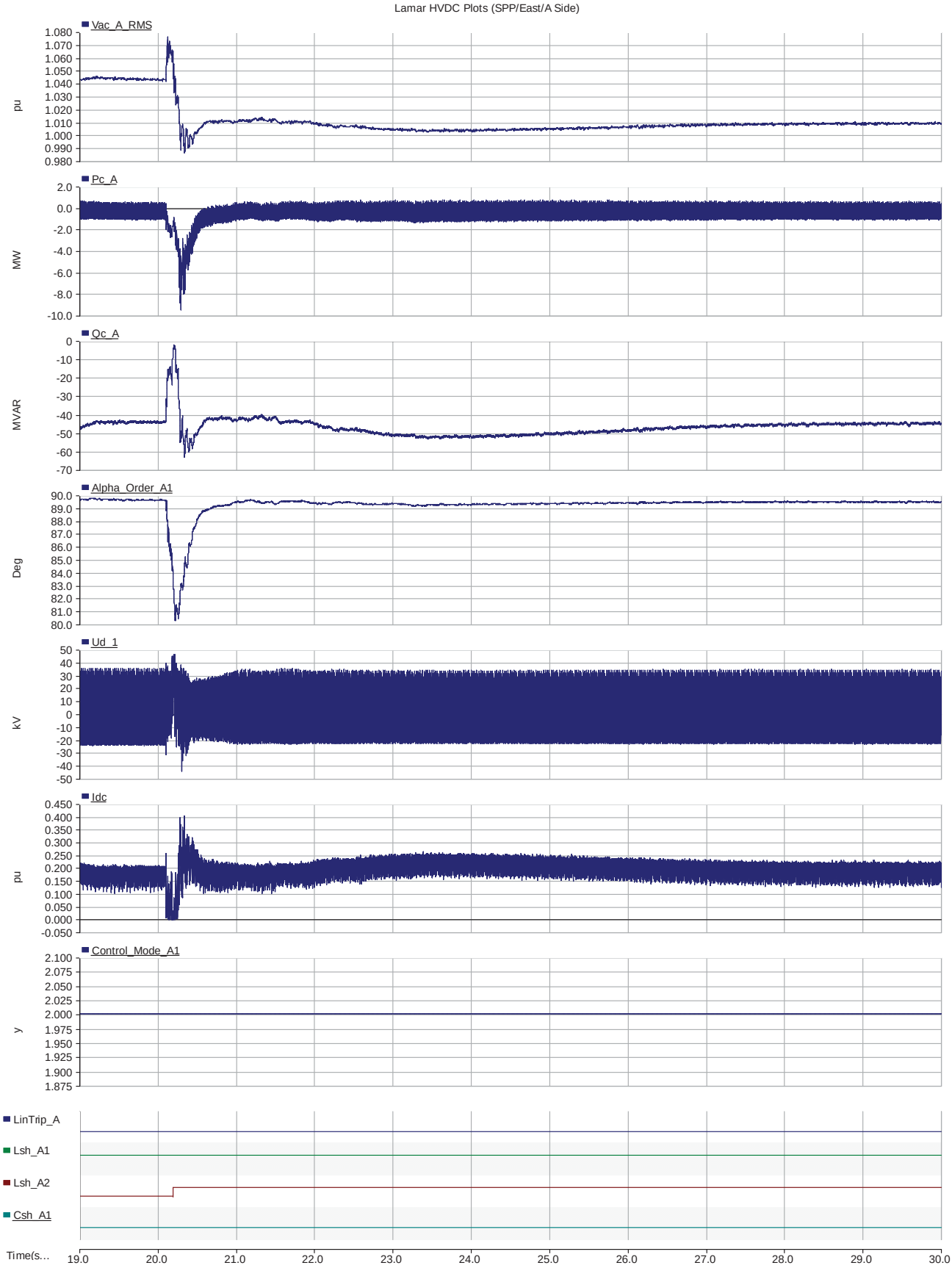

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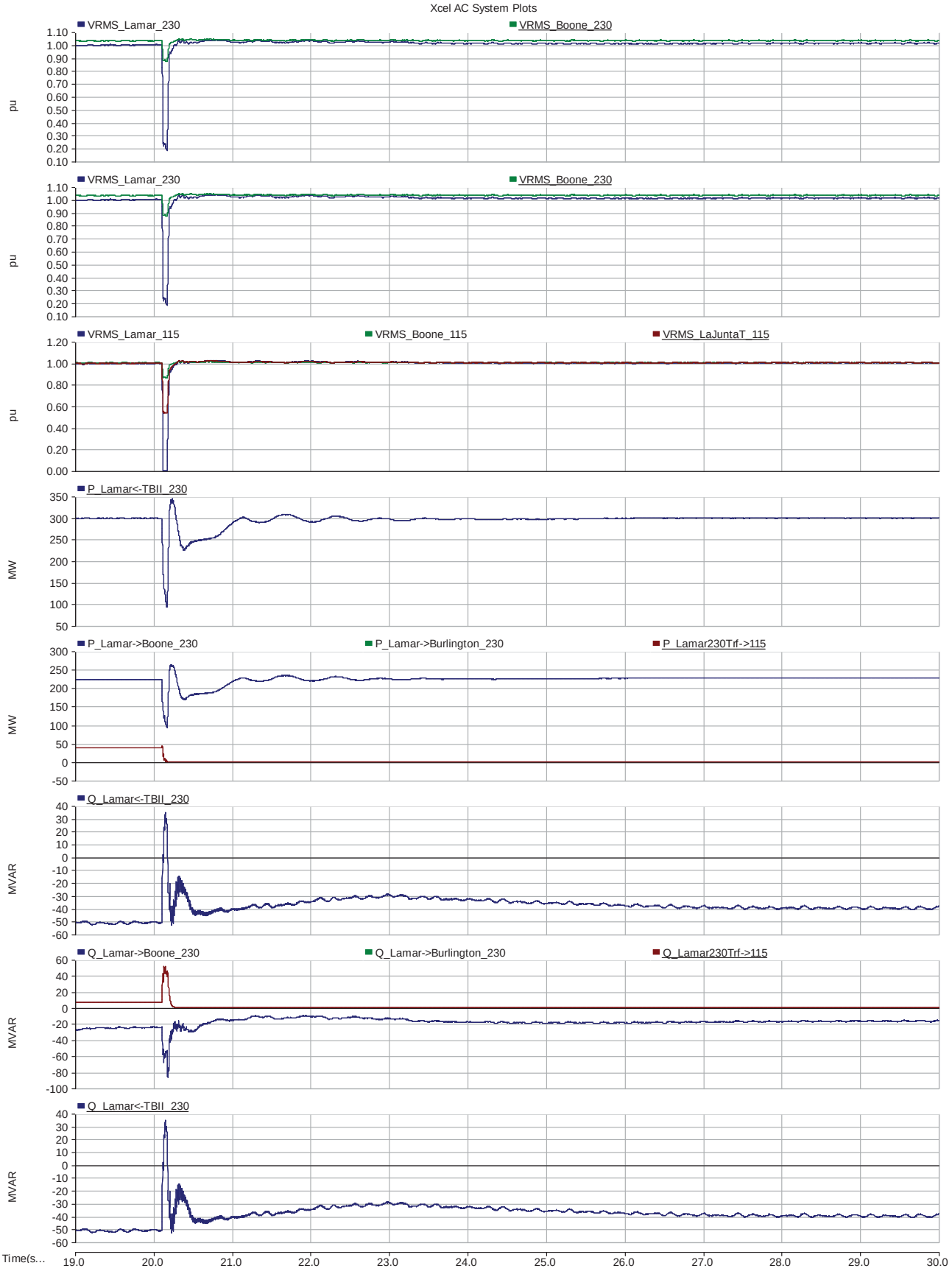

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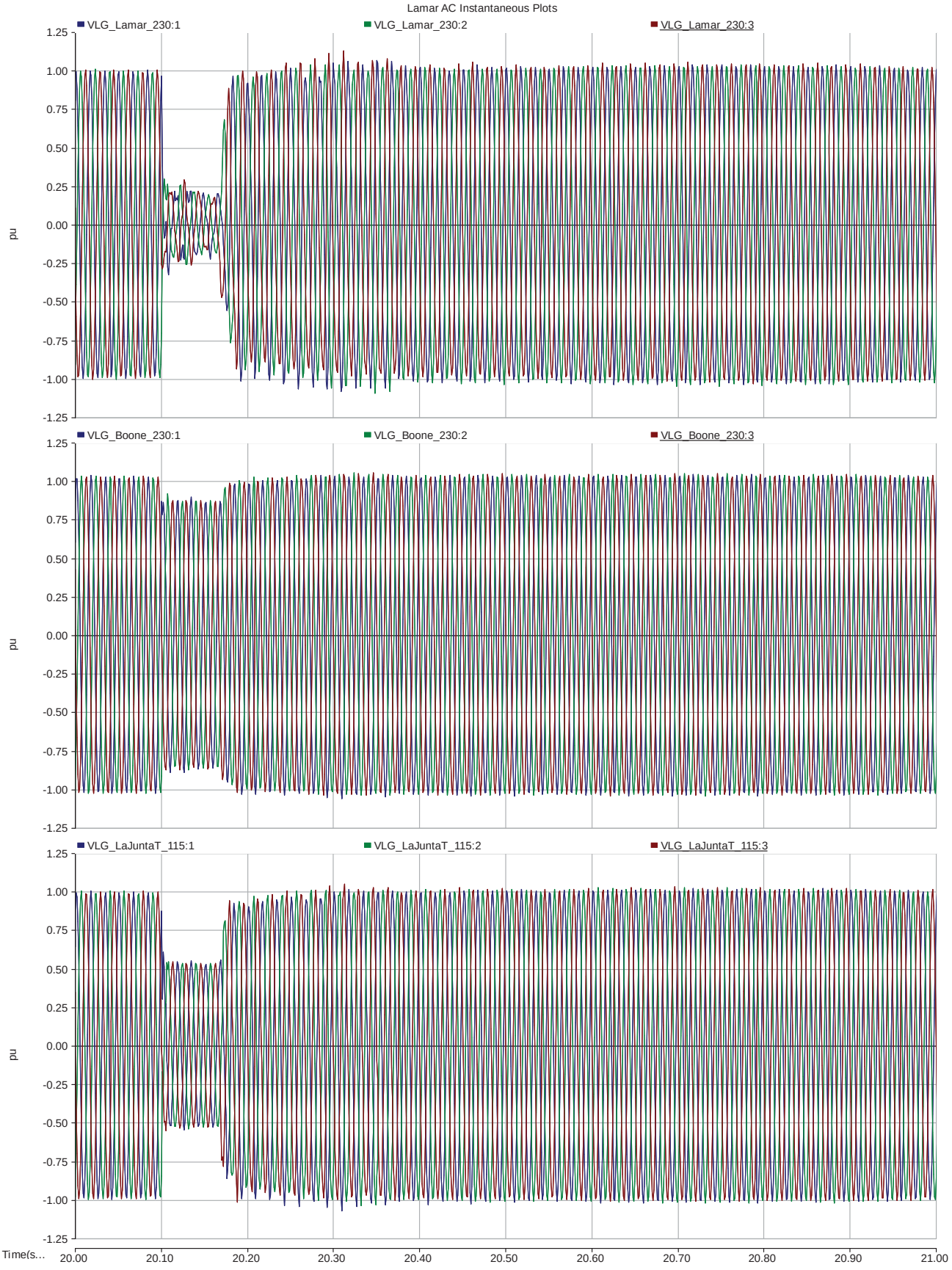

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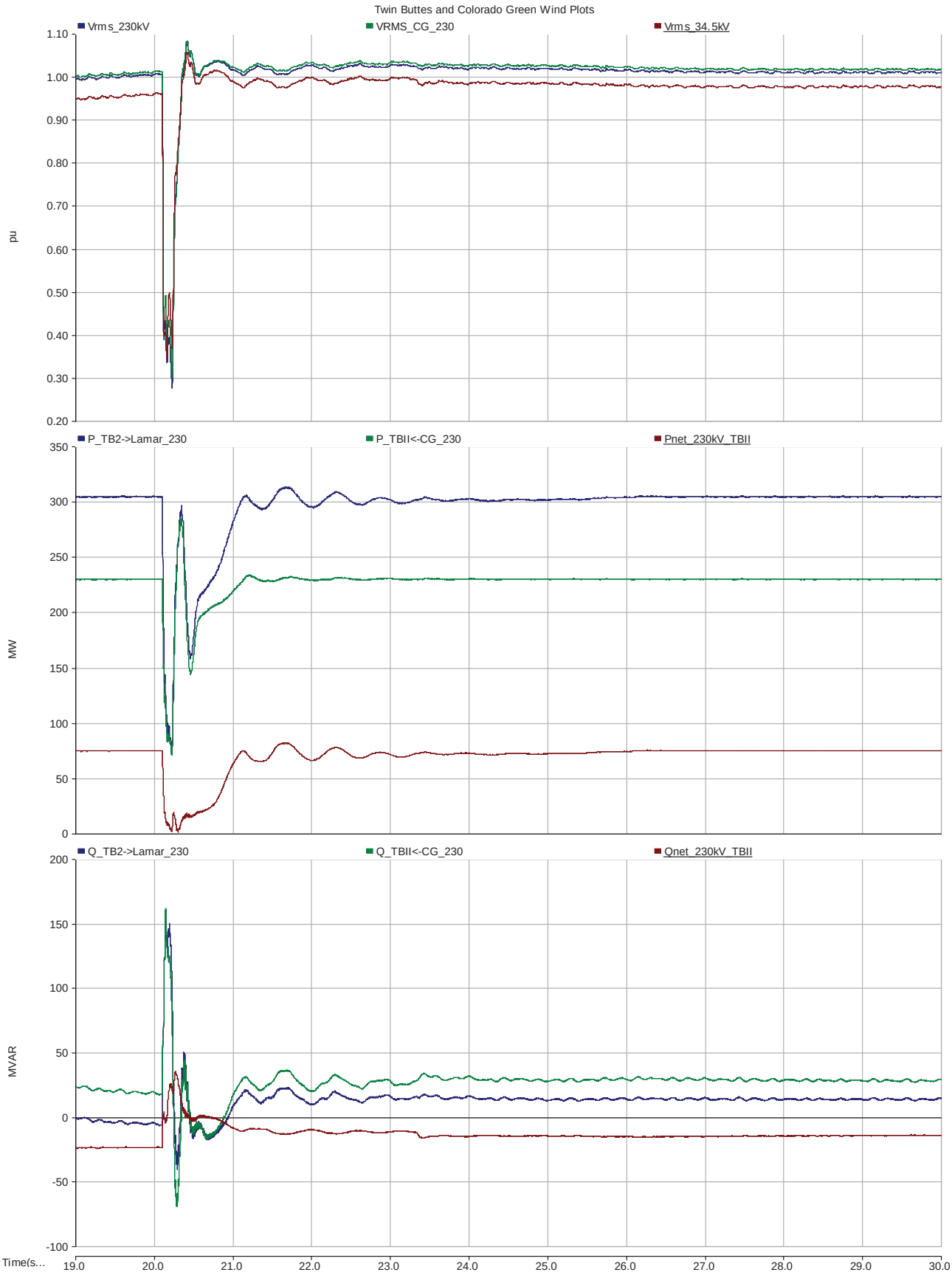
F2_S3 plots



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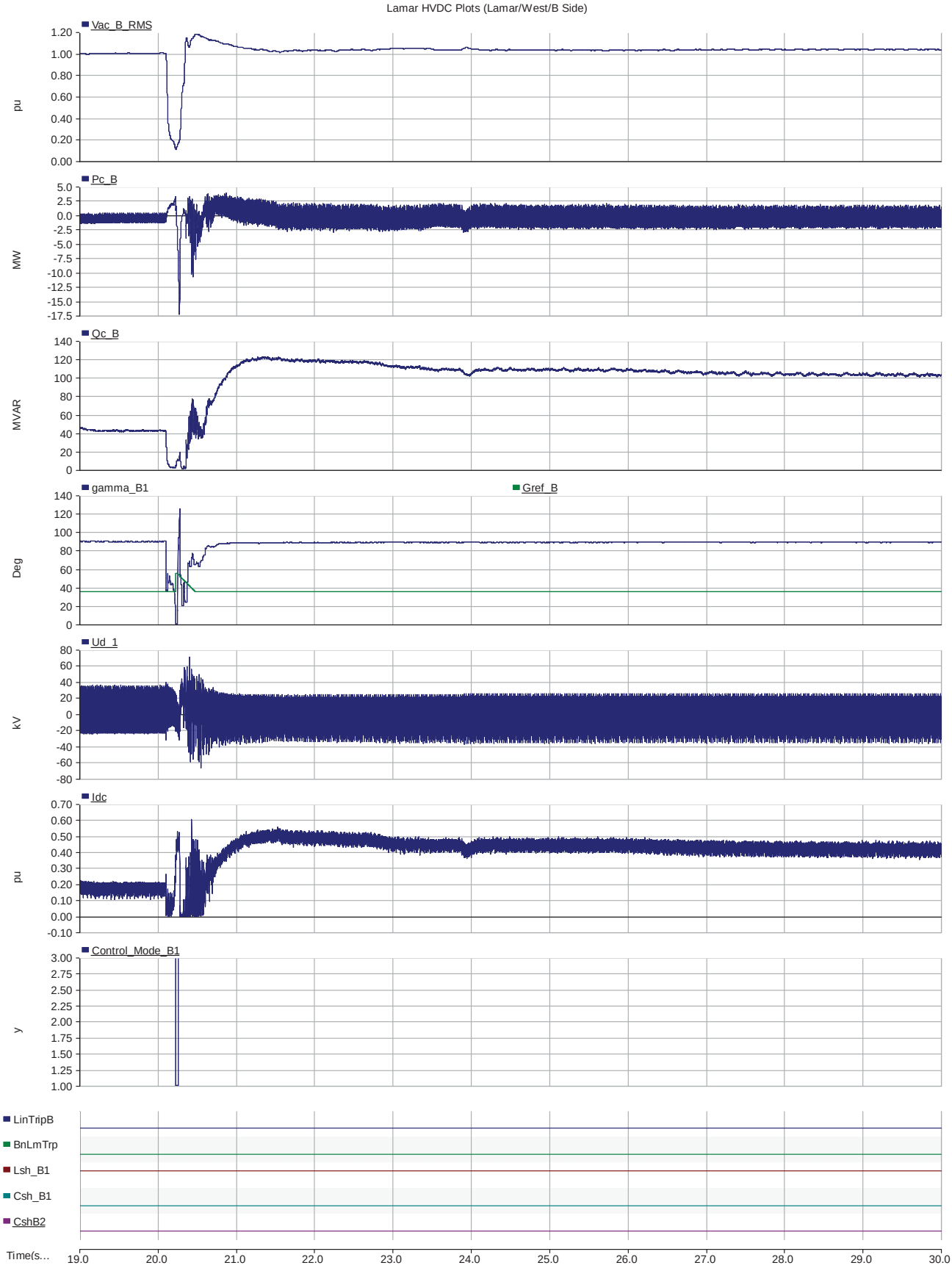

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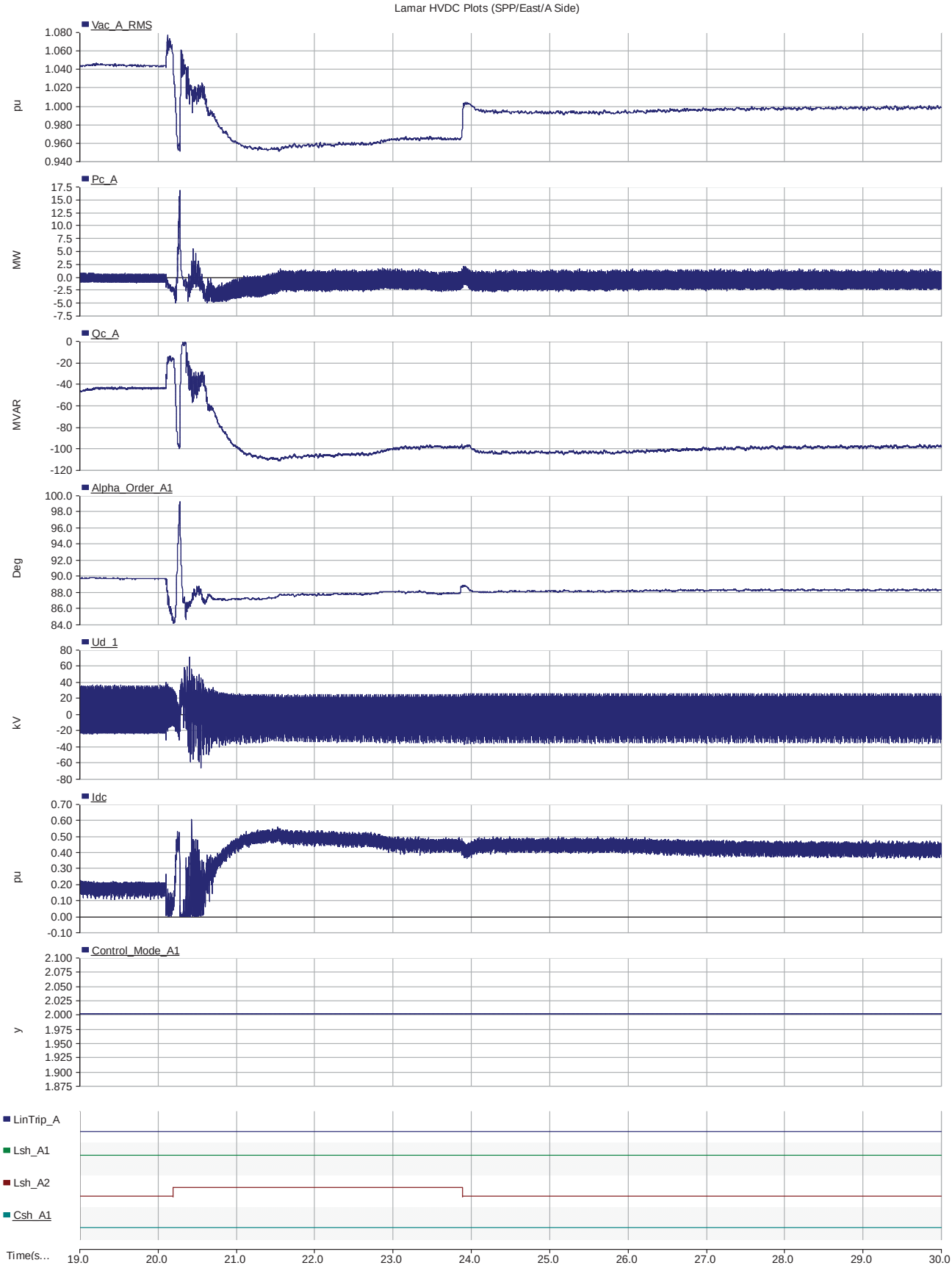

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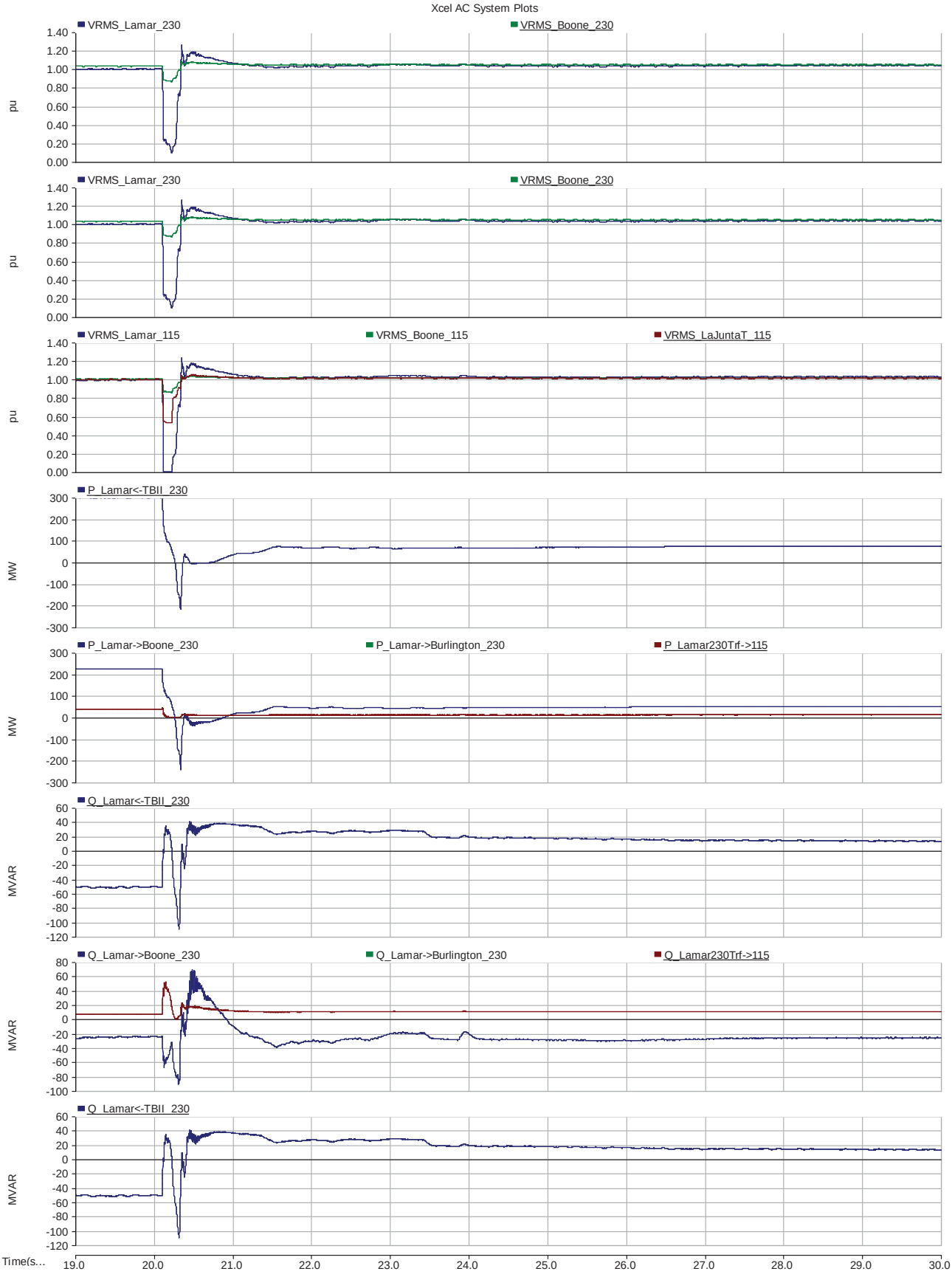

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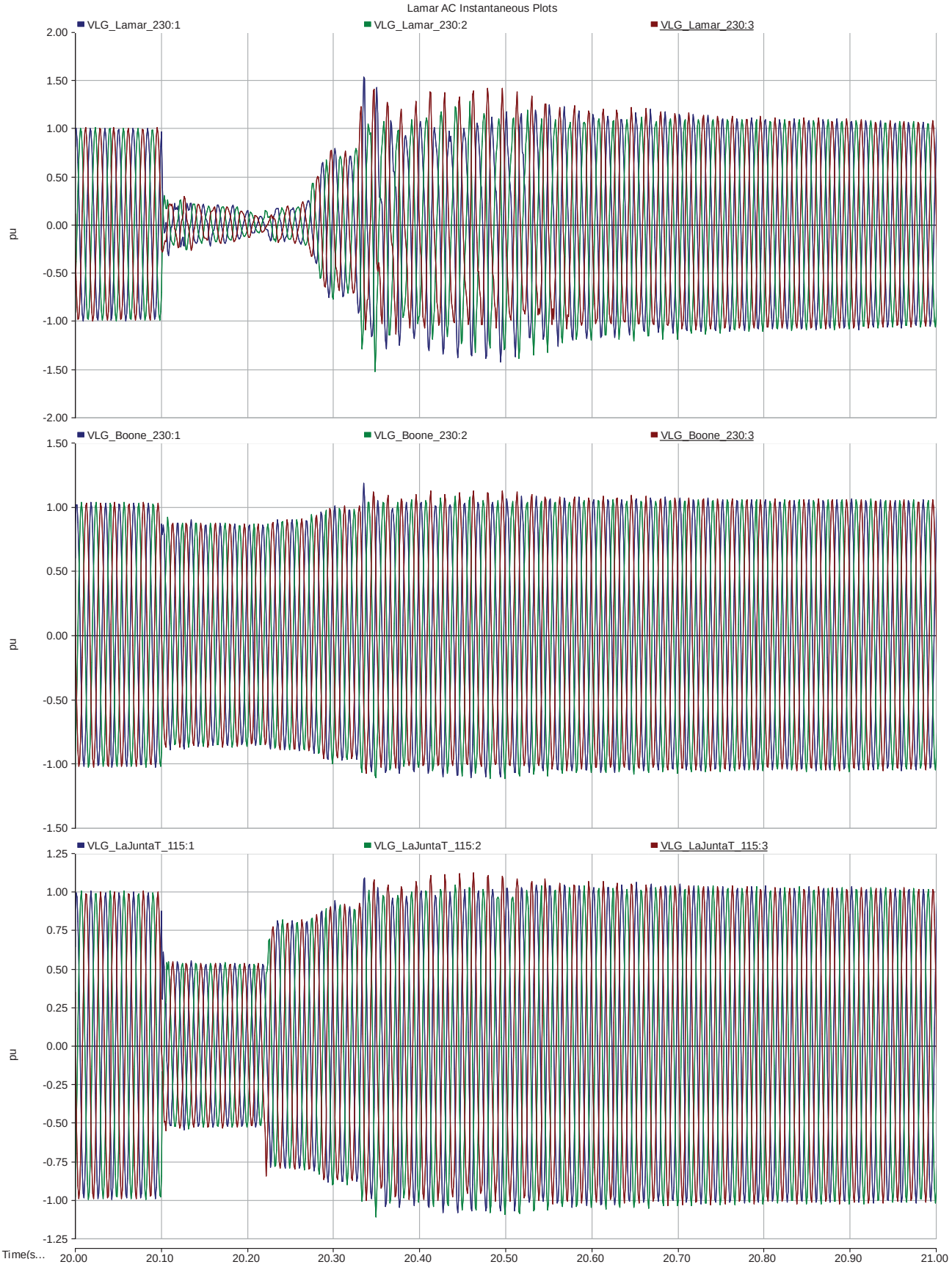

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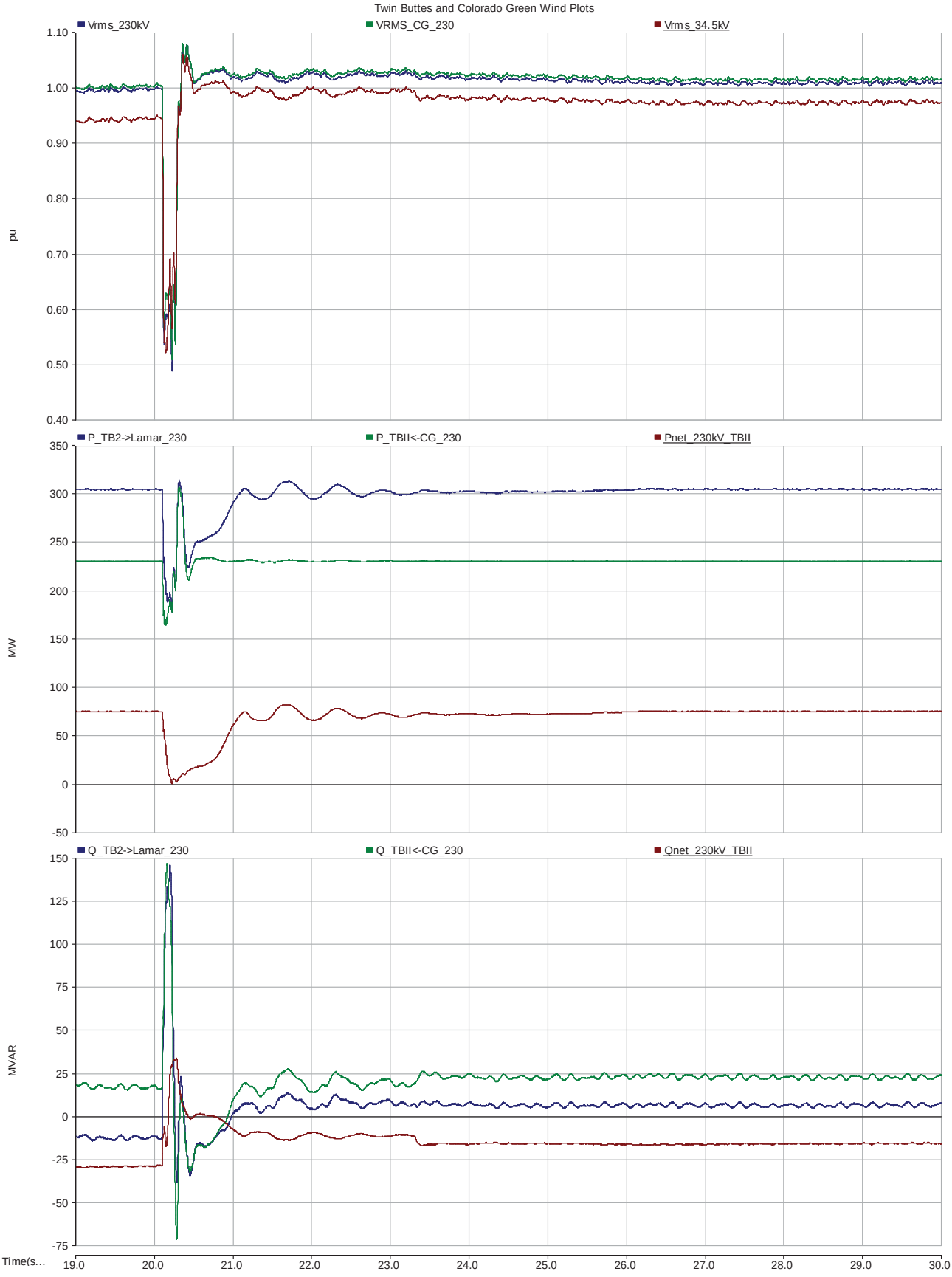
F3_S3 plots



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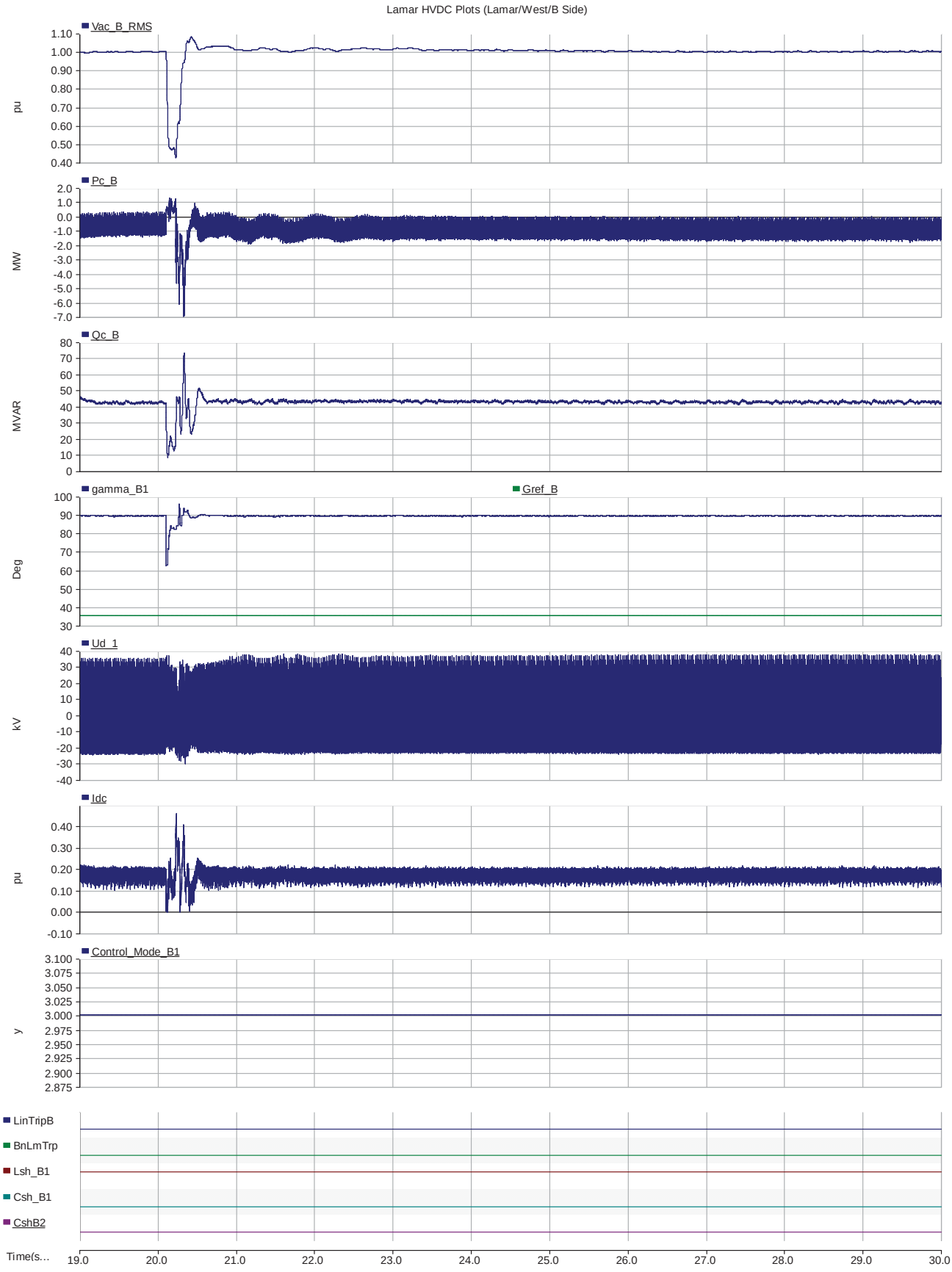

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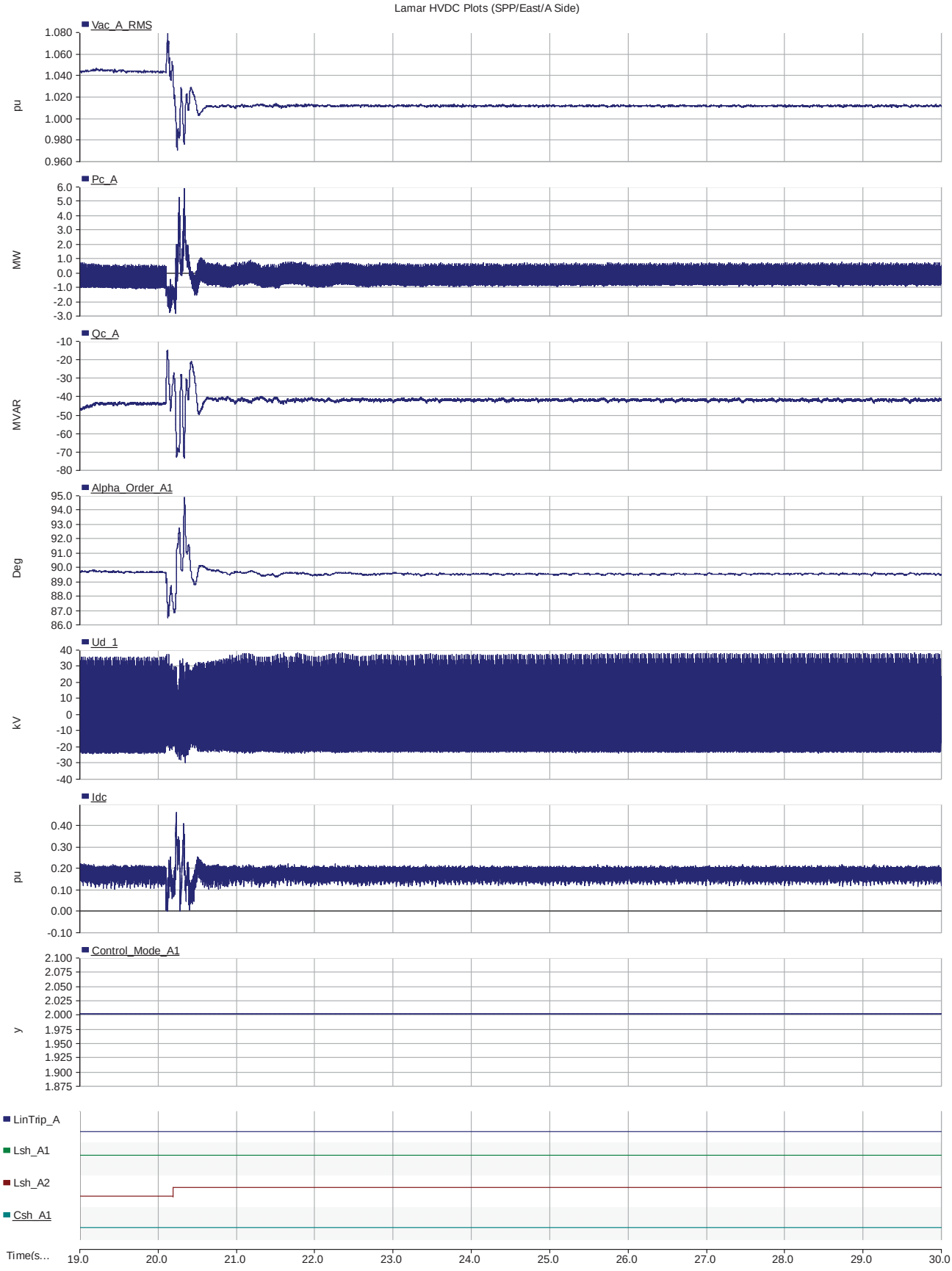

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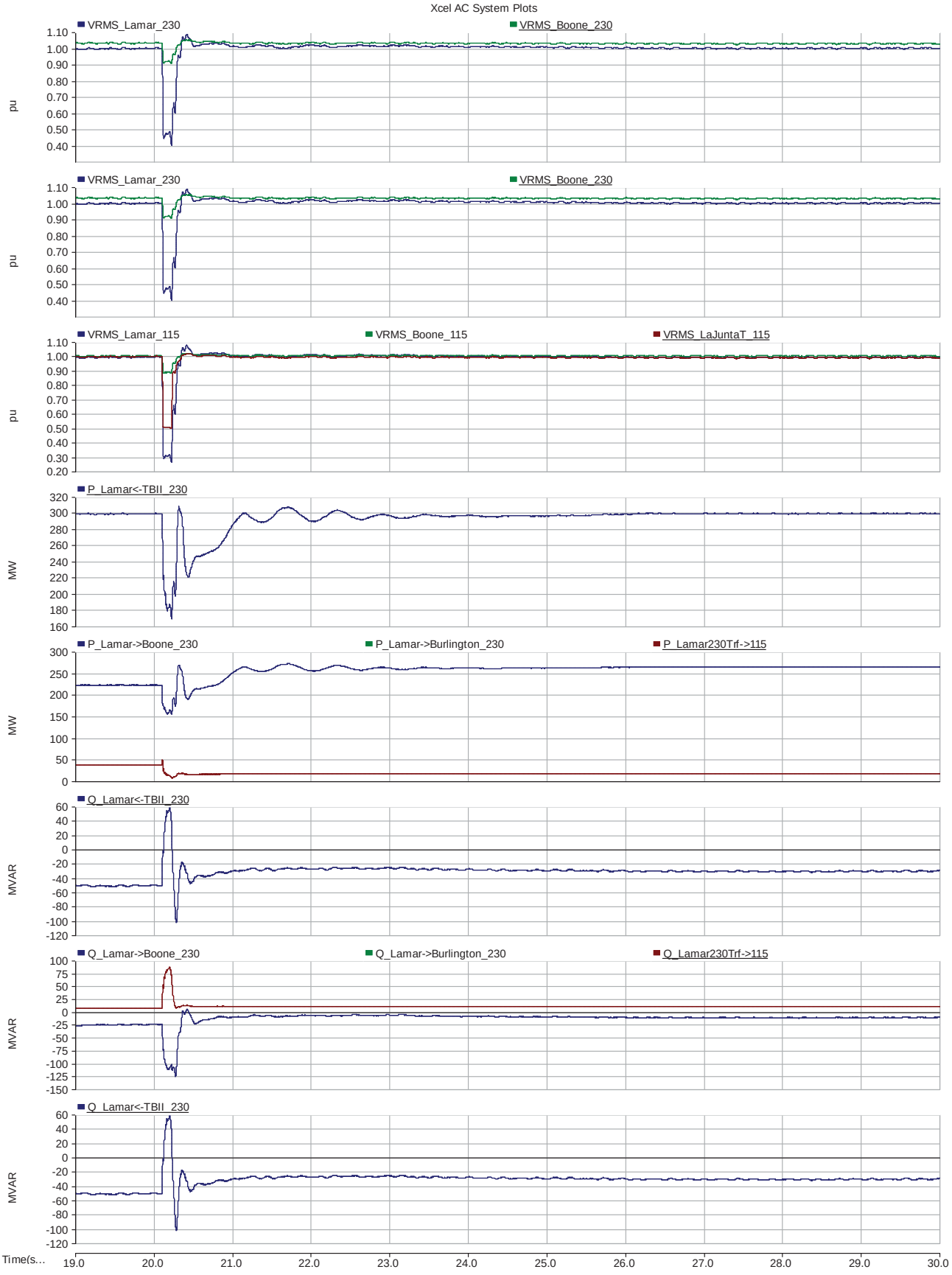

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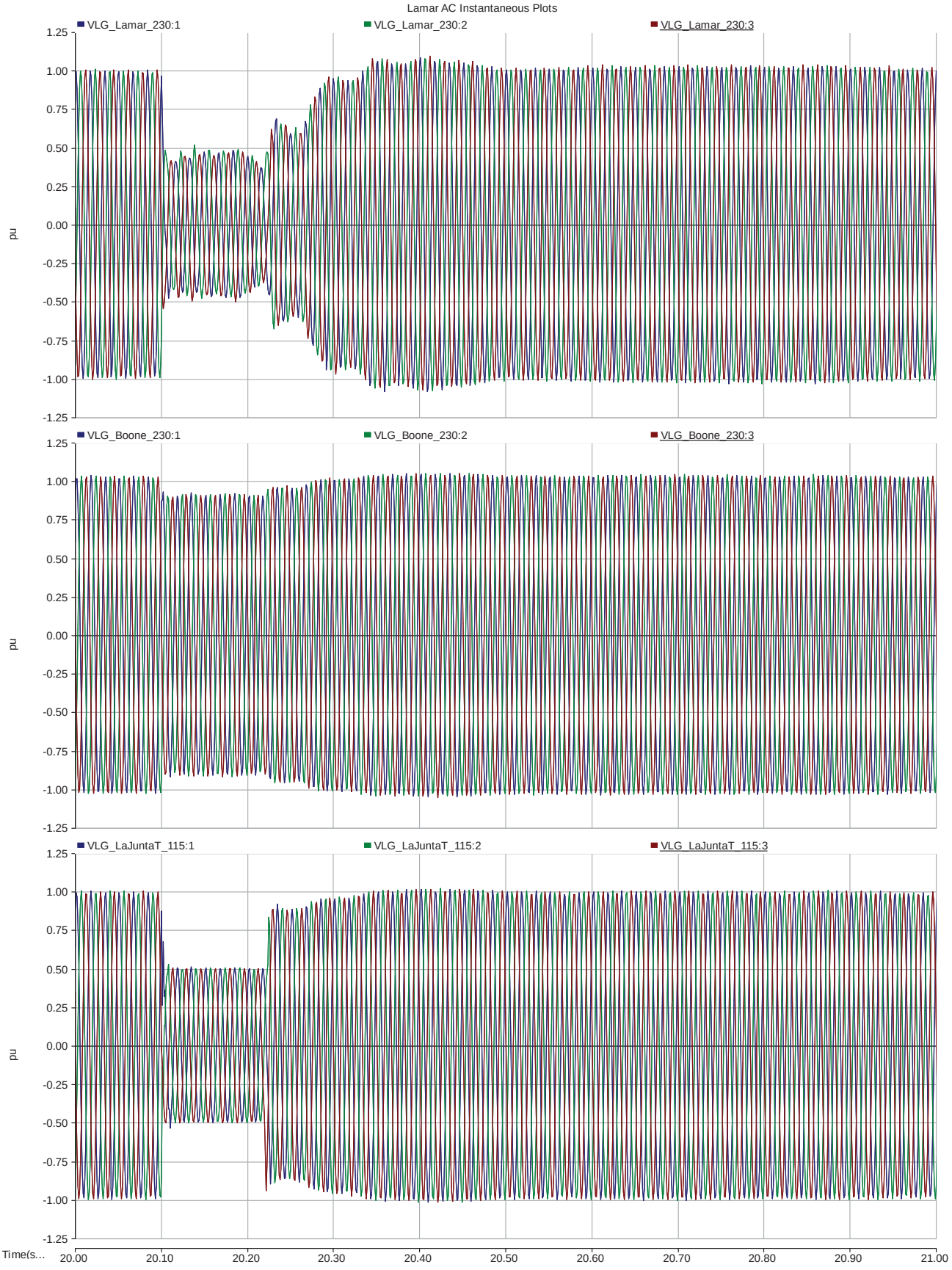

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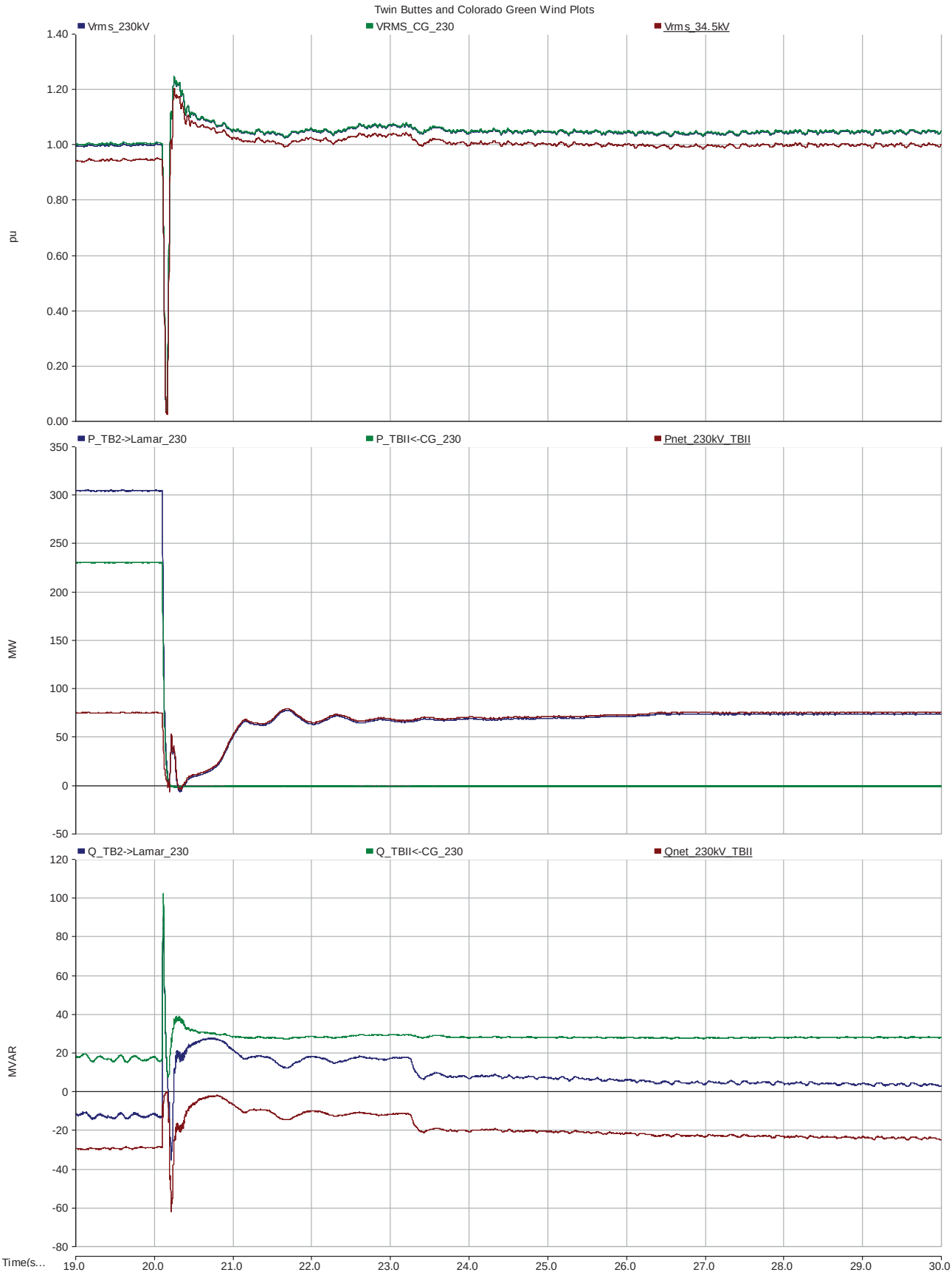
F4_S3 plots



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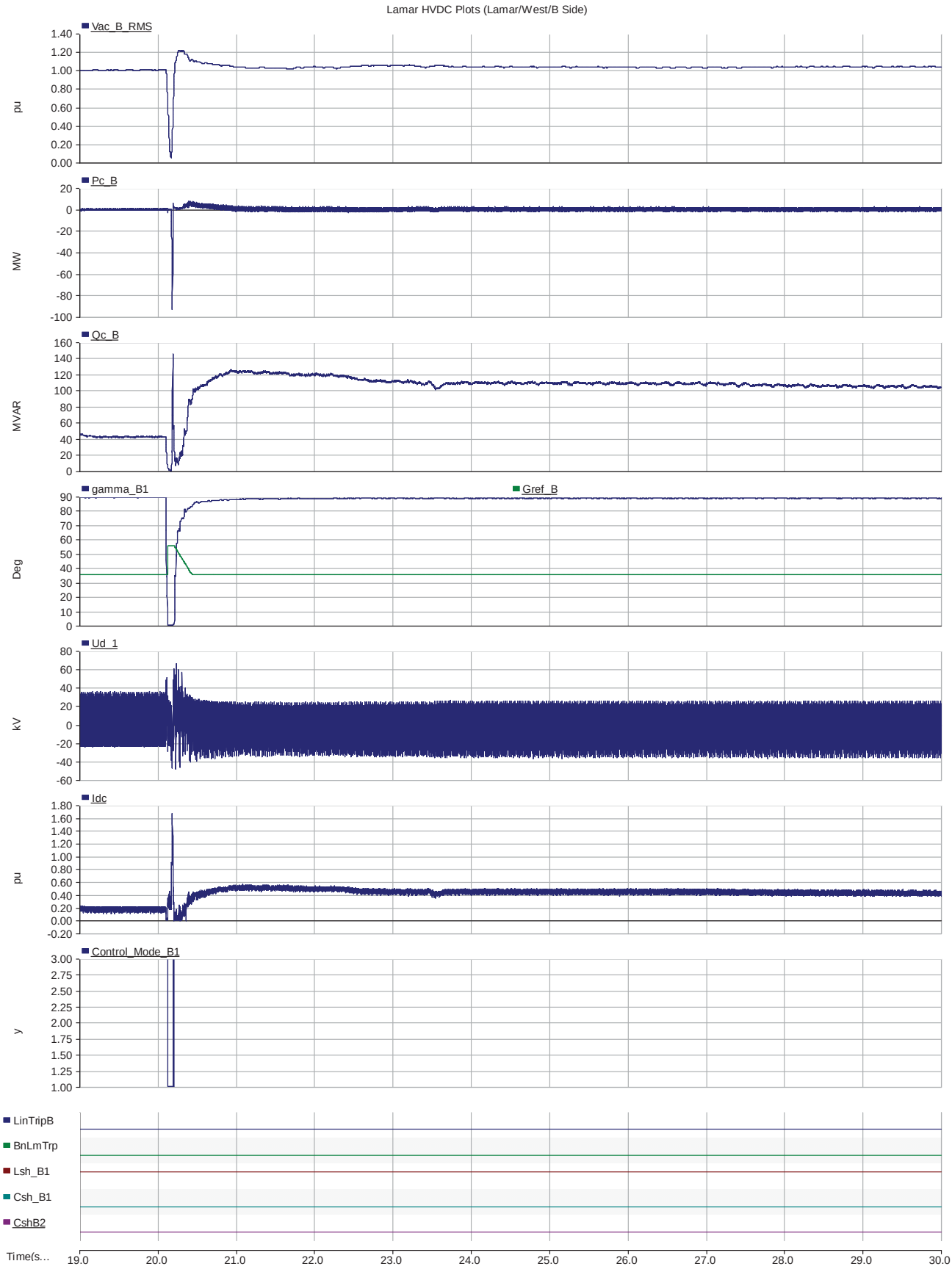
Fault 4 - LLLG fault at Boone 230 bus on the line to Midway.



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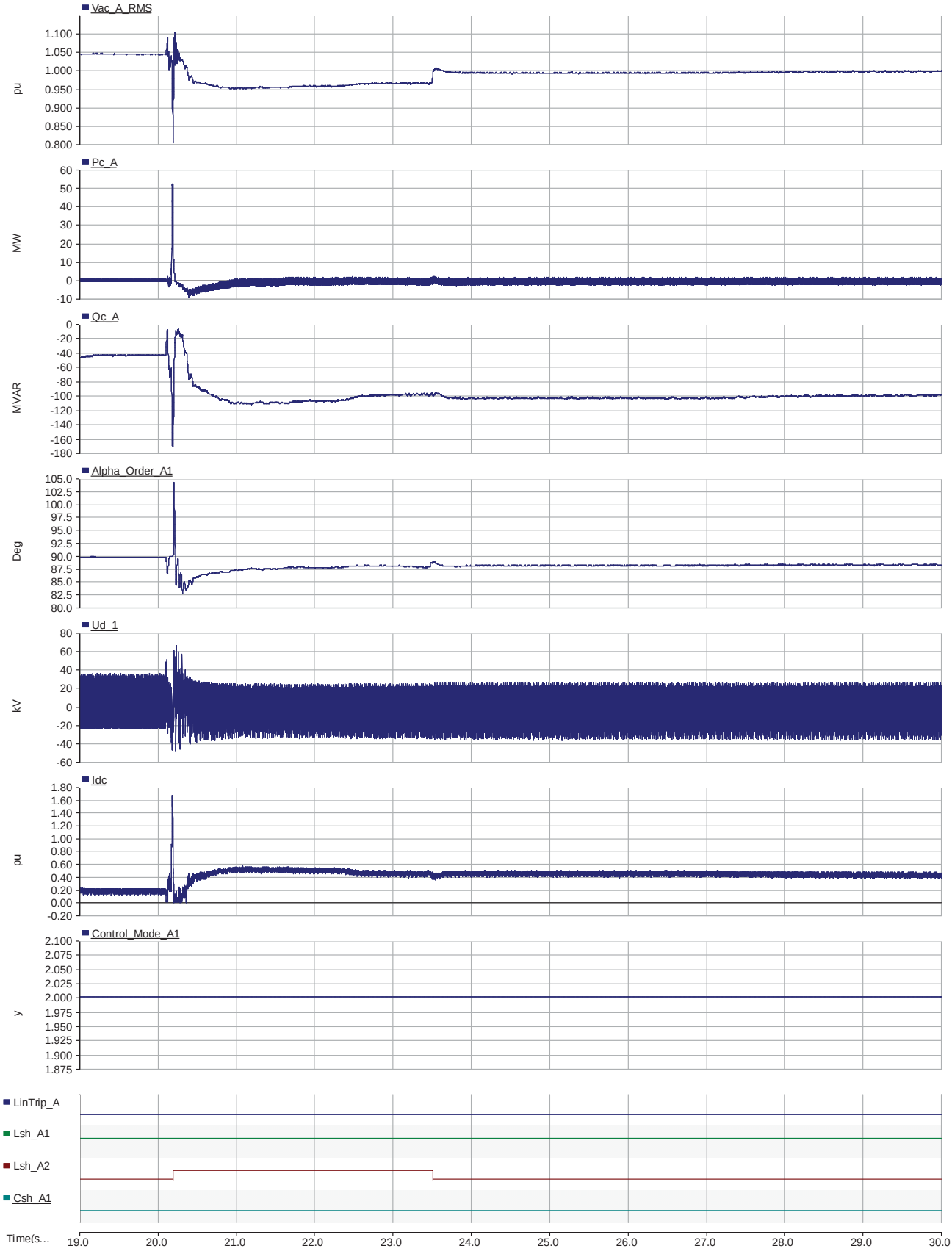
Lamar HVDC Plots (SPP/East/A Side)



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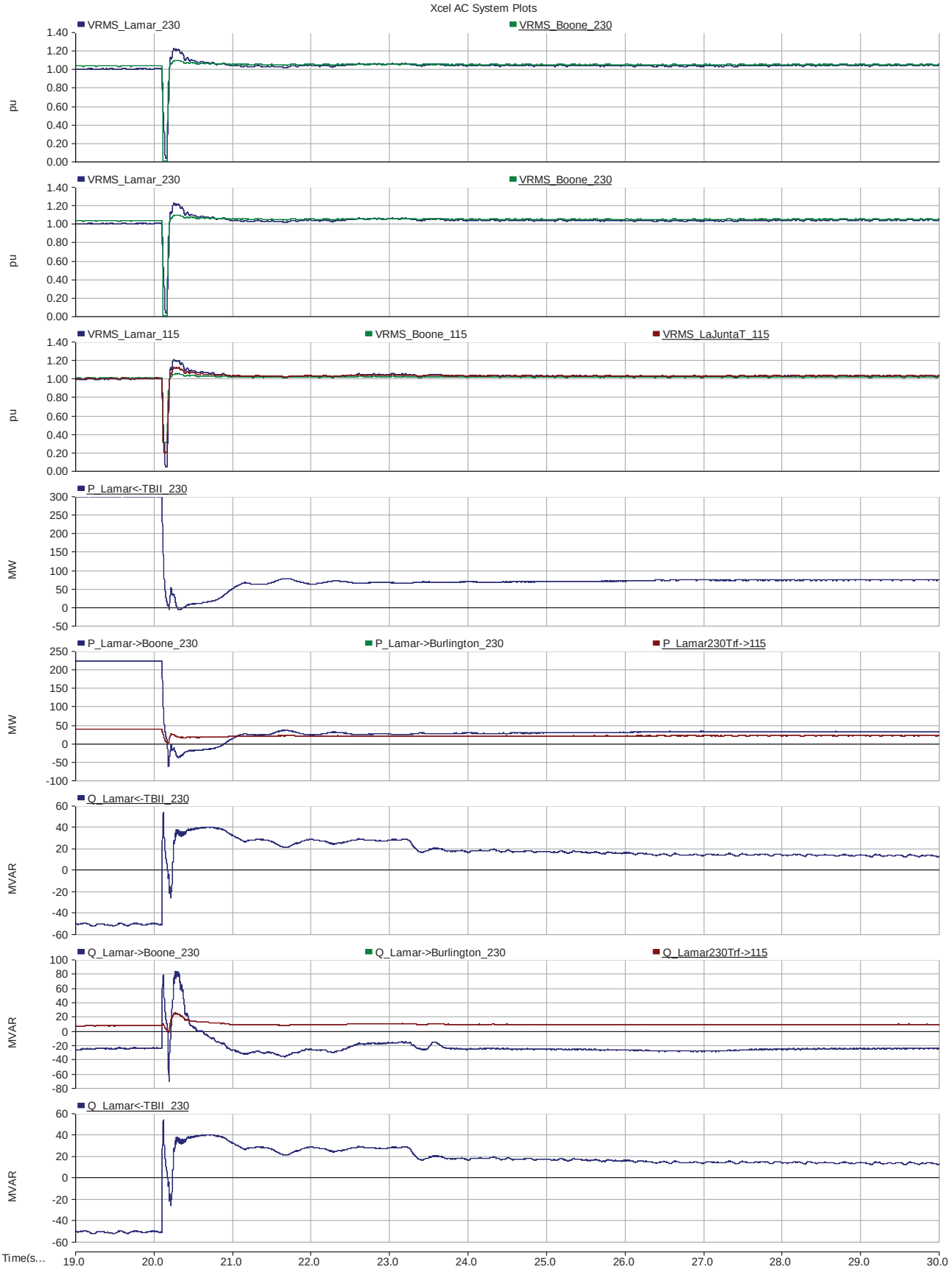

Twin Buttes II Wind PSCAD Studies
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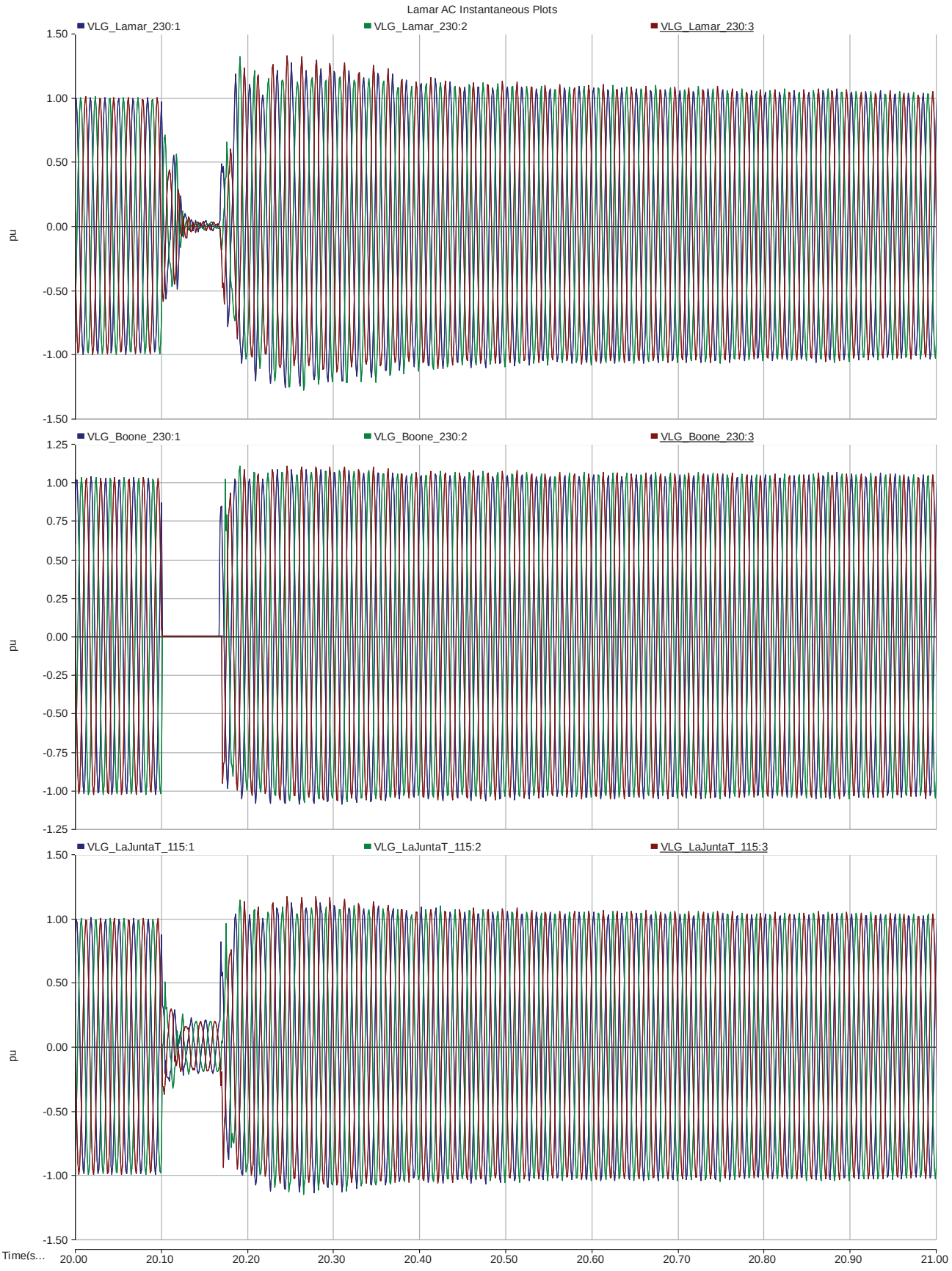

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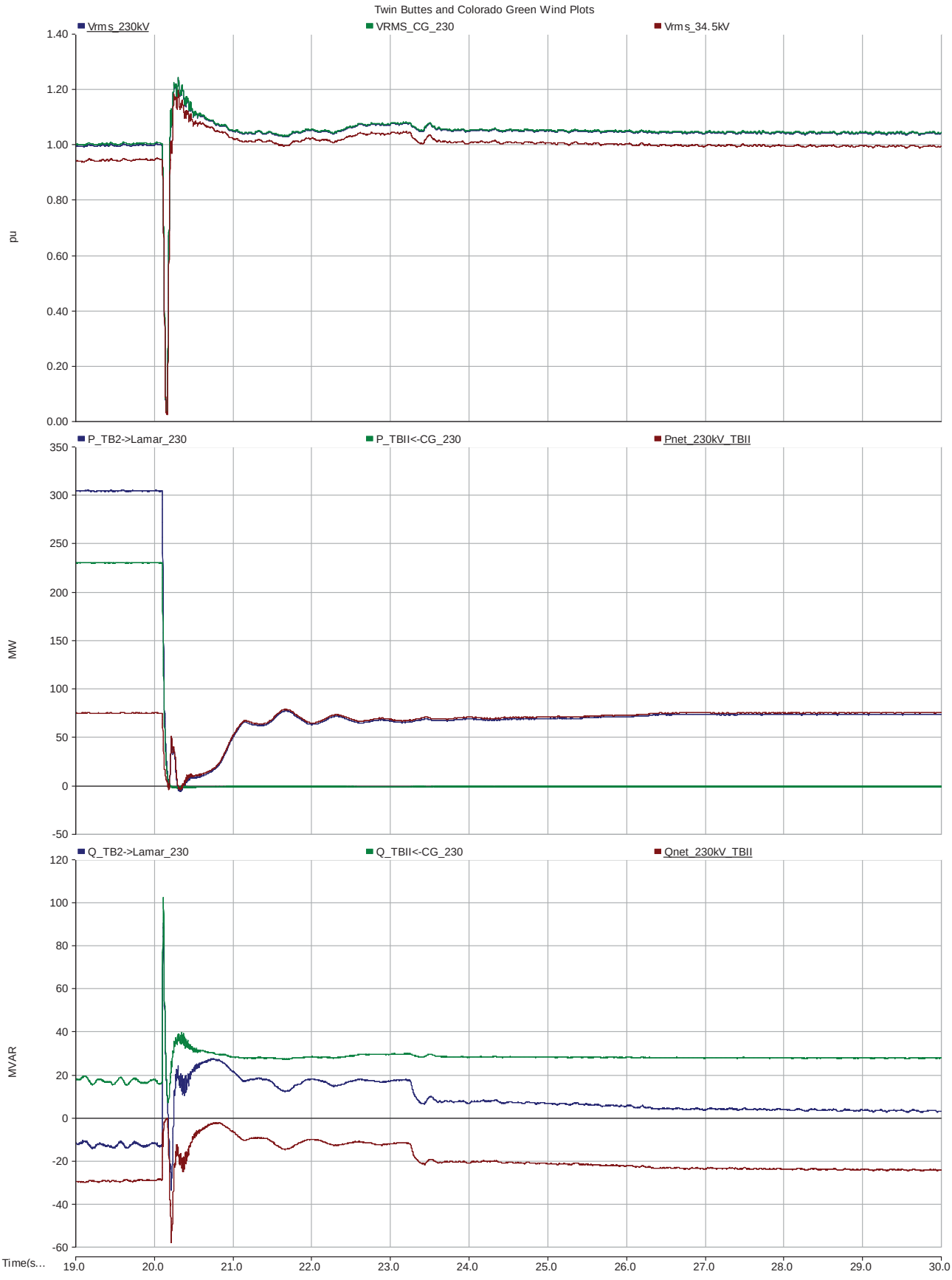
F5_S3 plots



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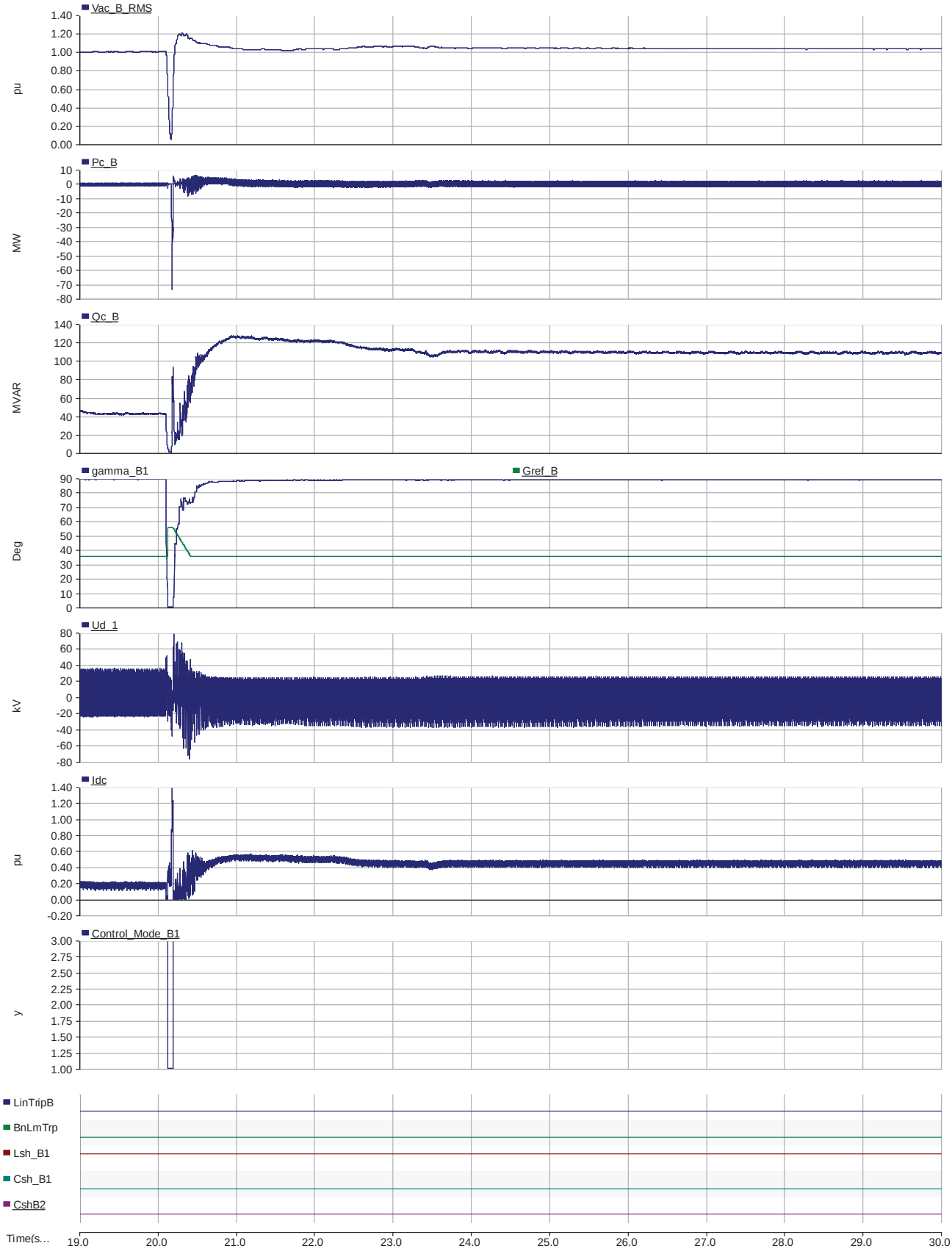

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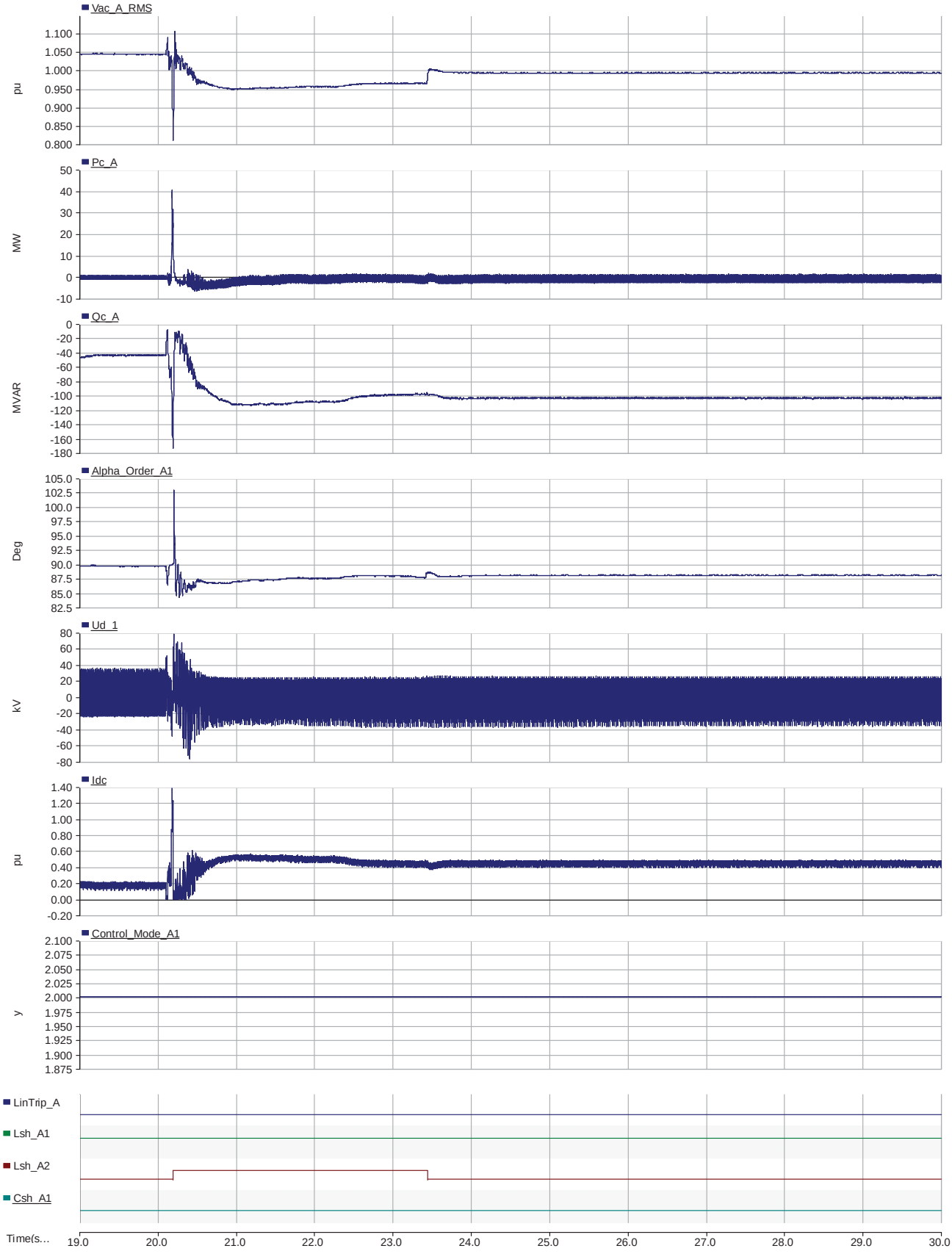
Lamar HVDC Plots (SPP/East/A Side)



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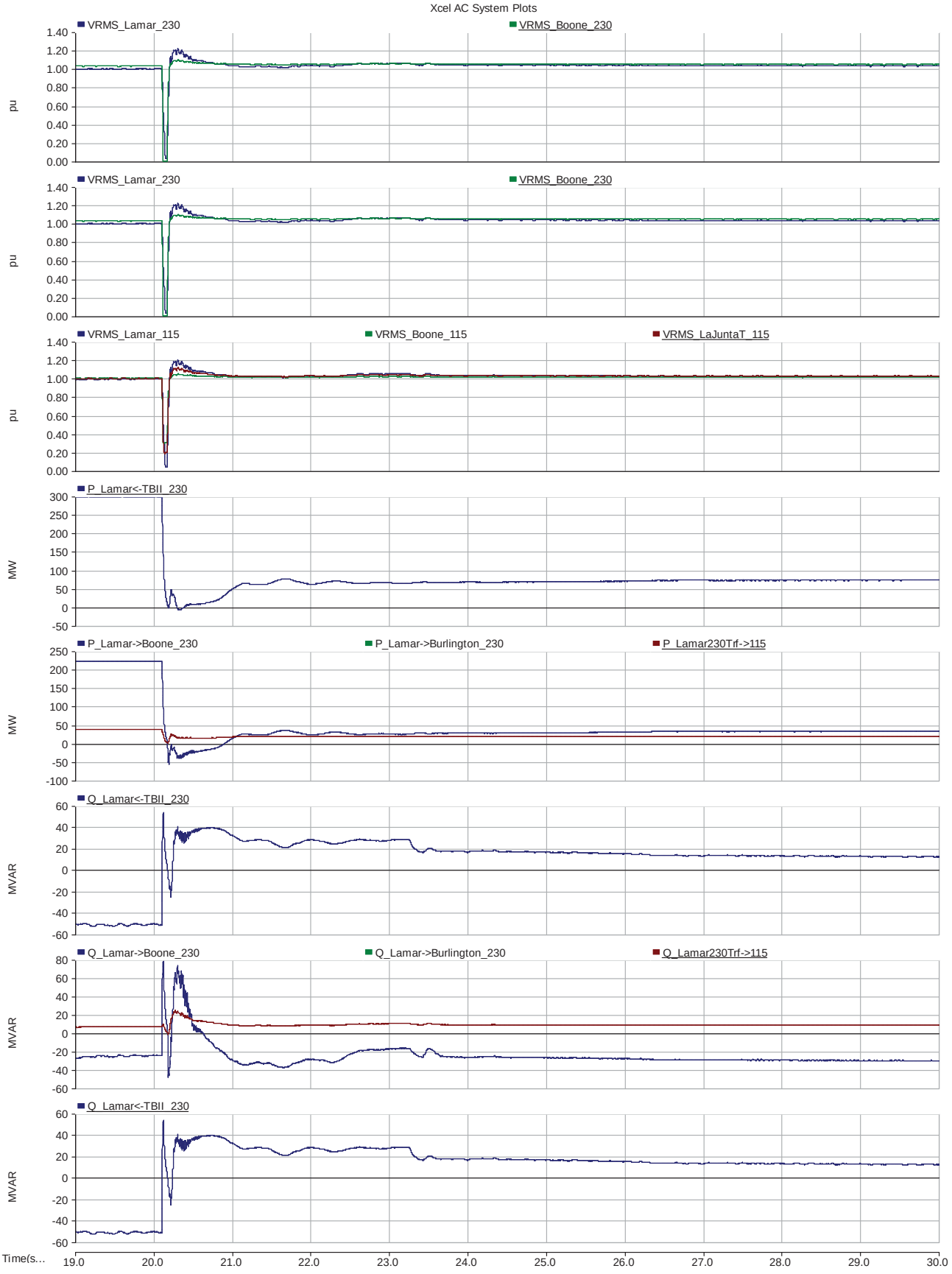

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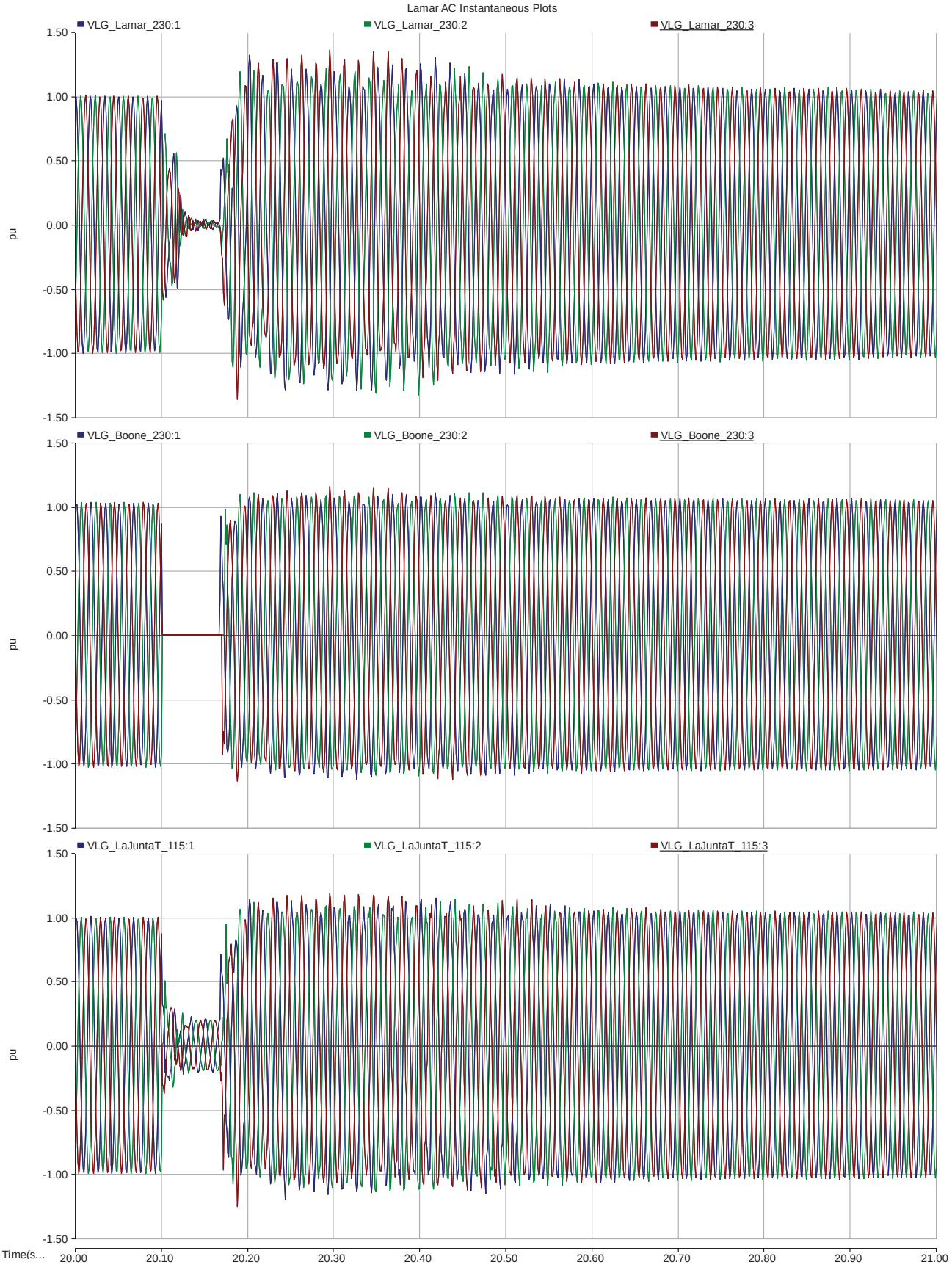

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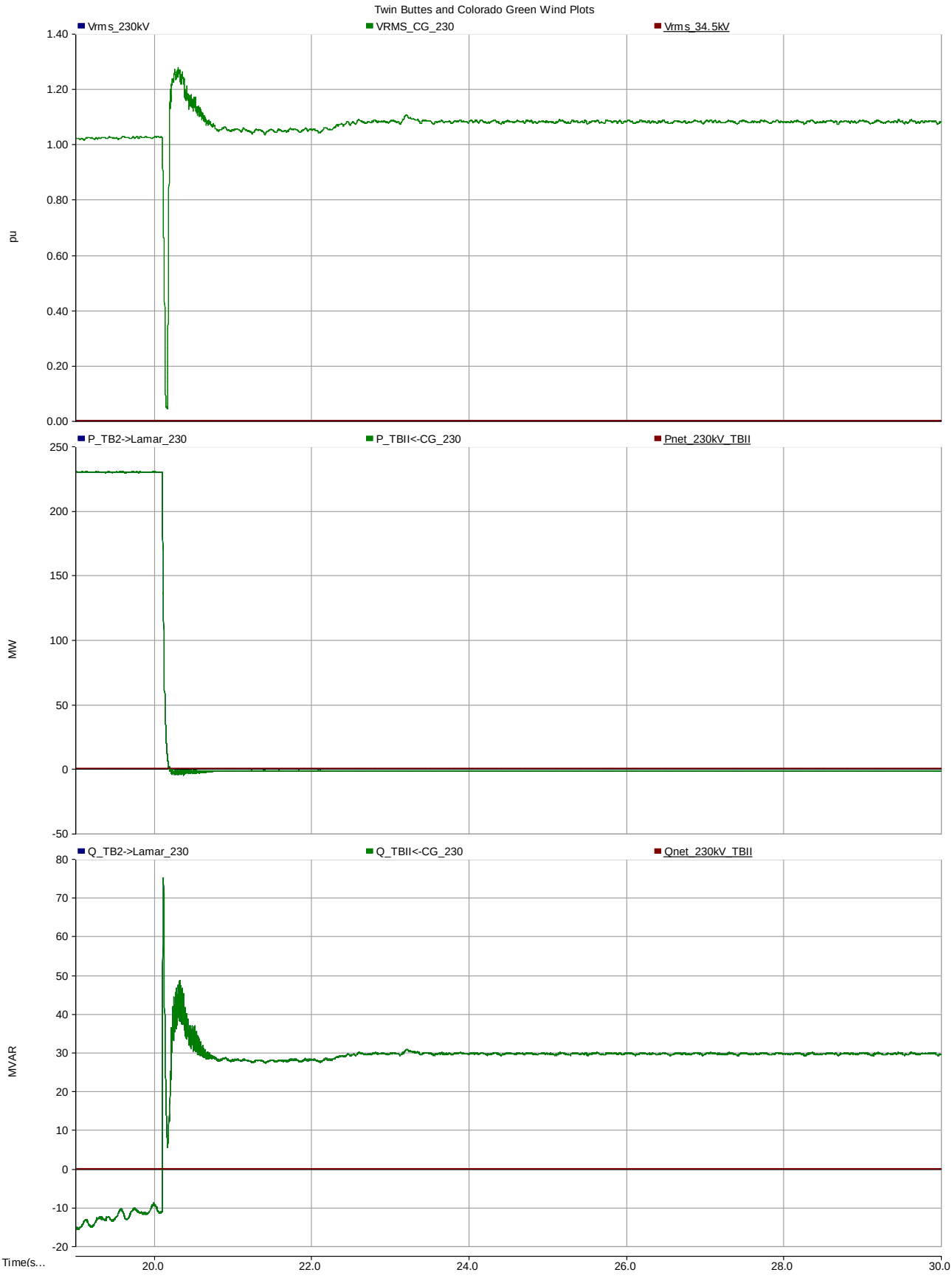

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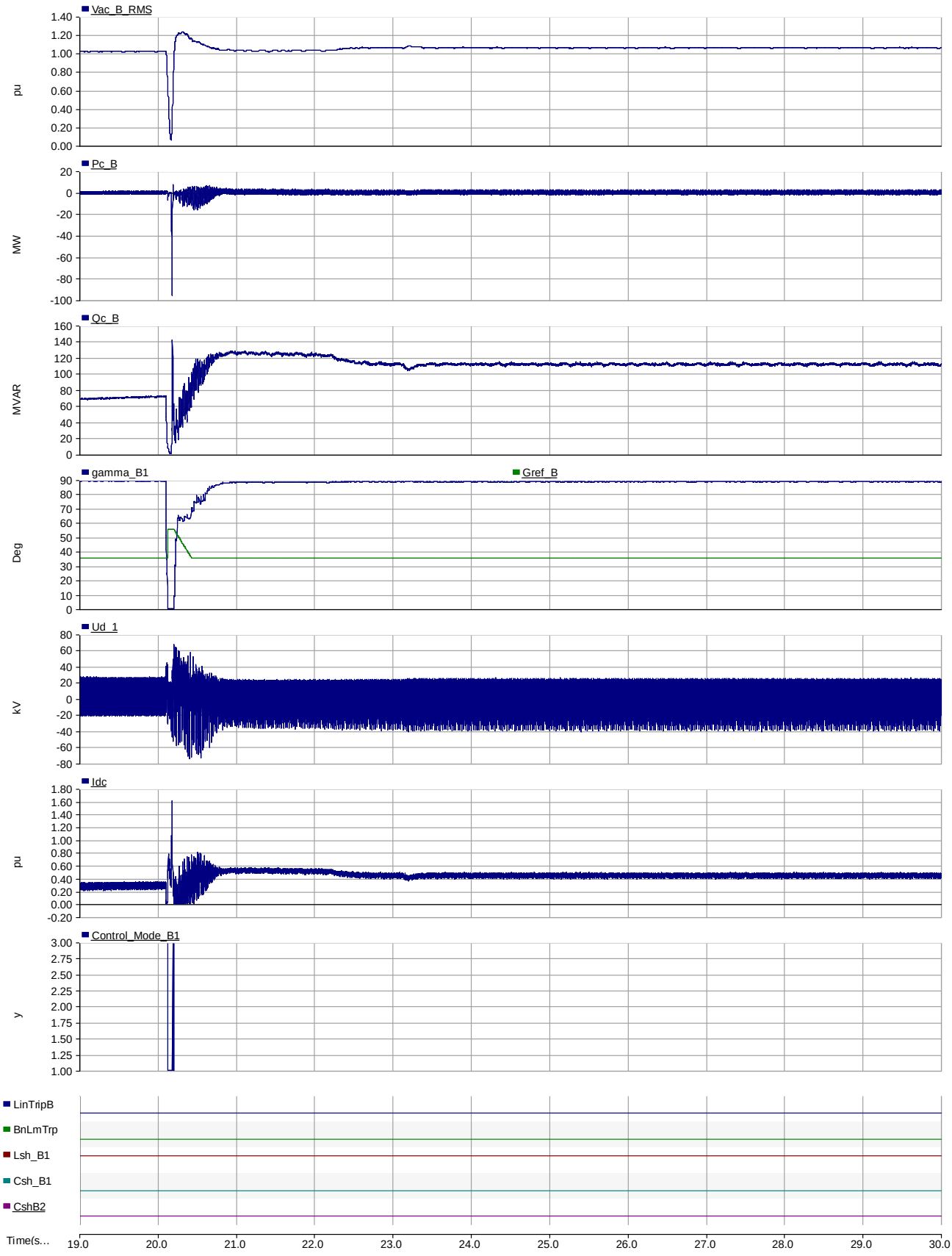

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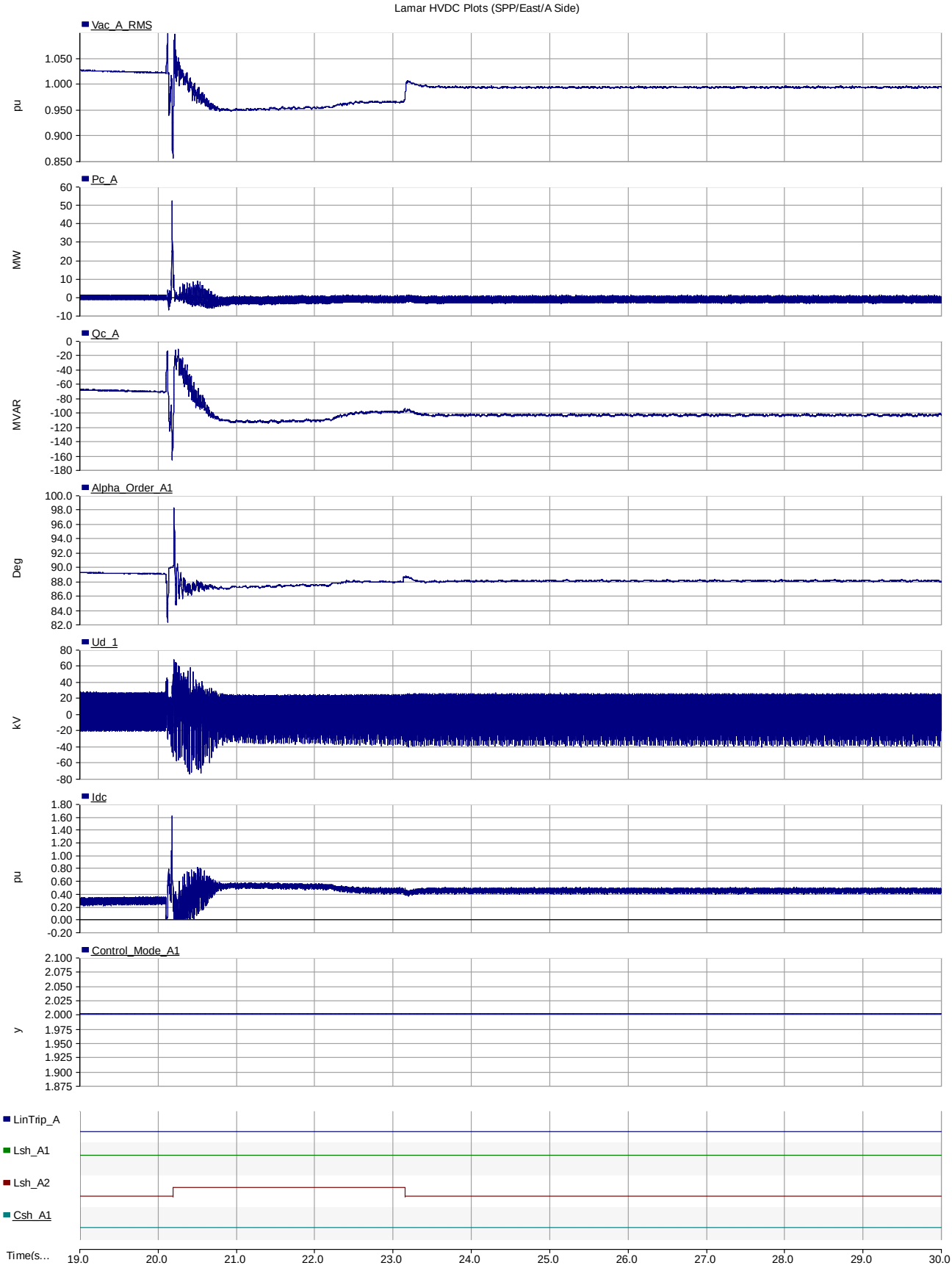

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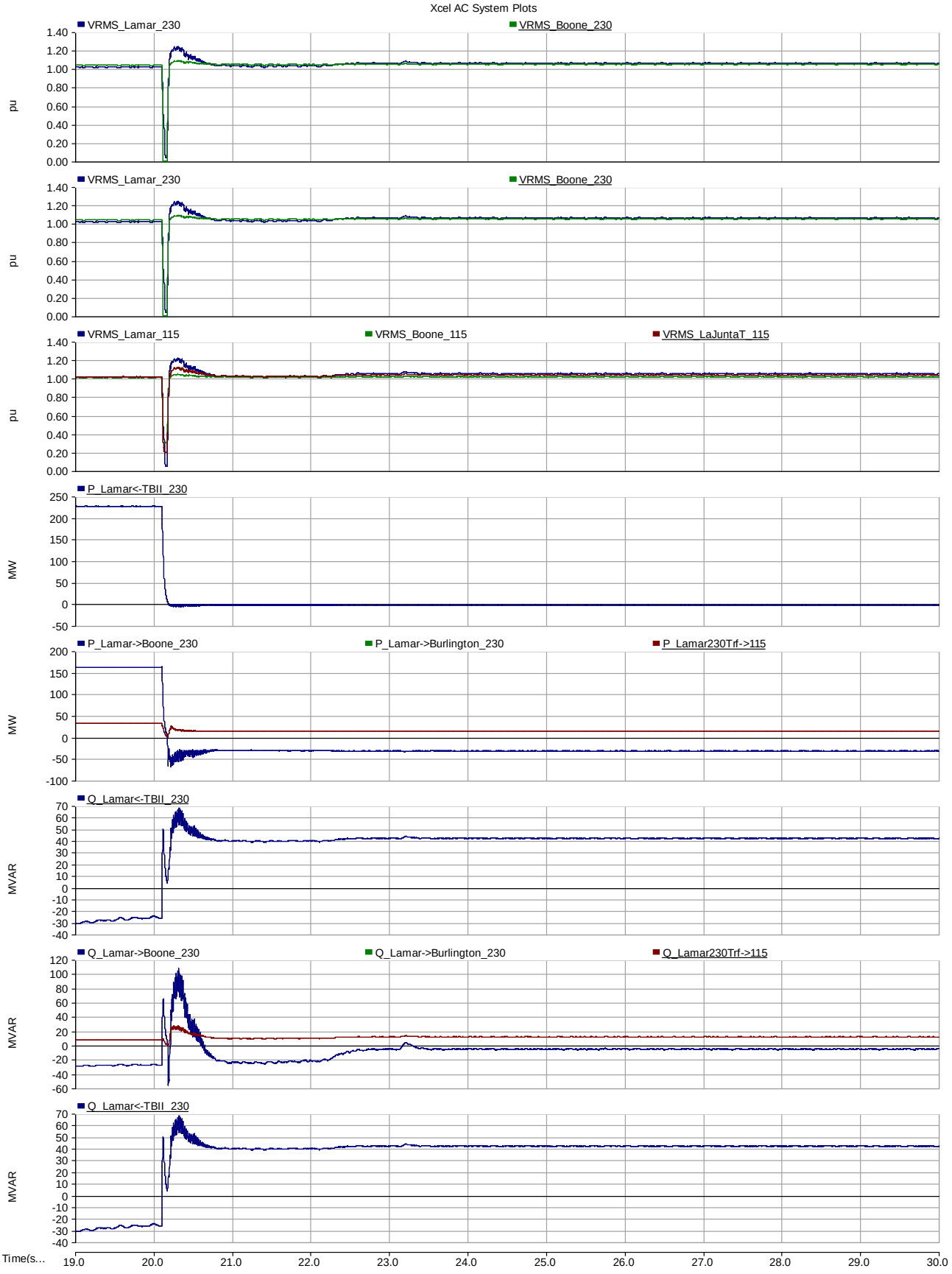

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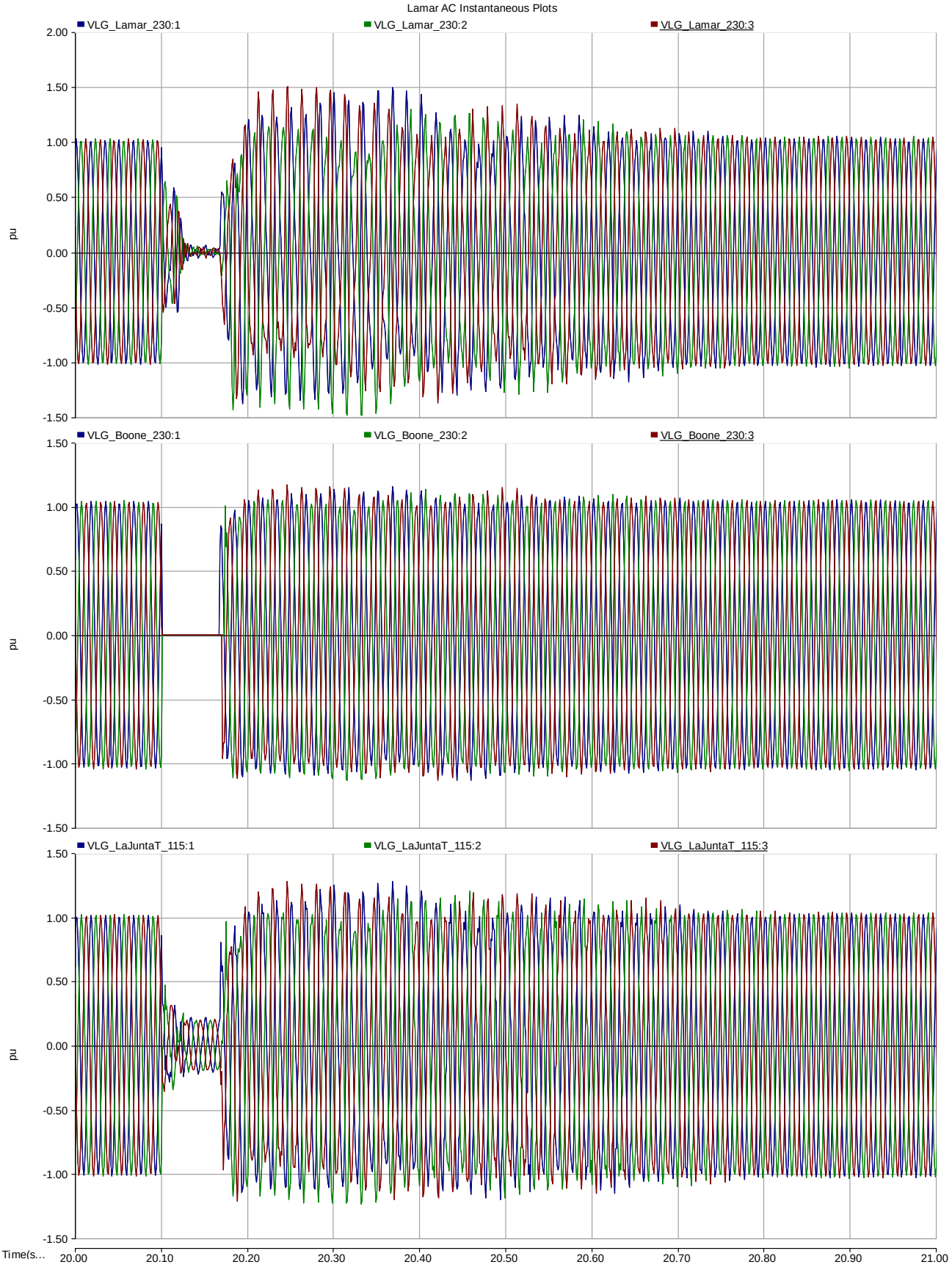

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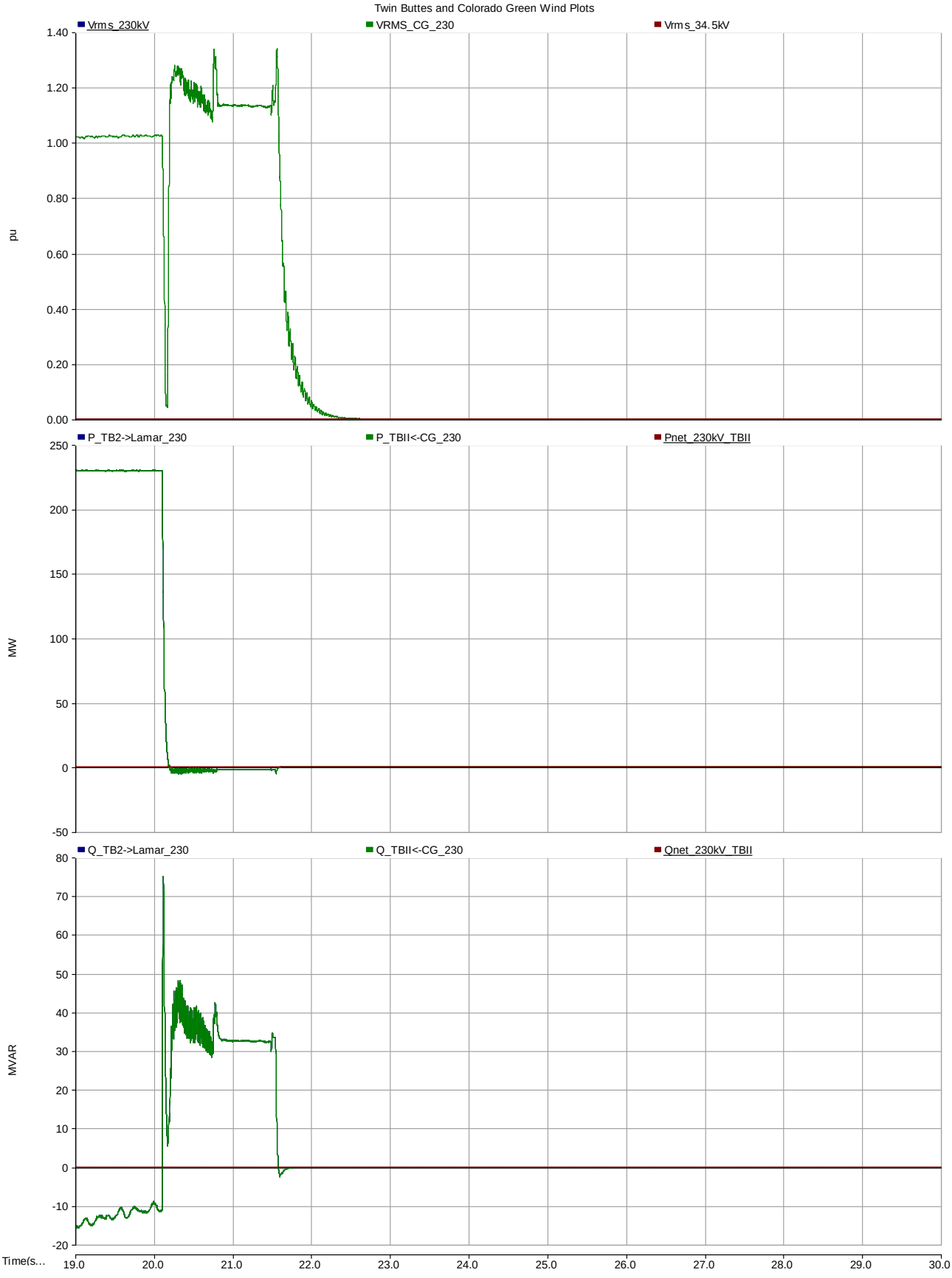

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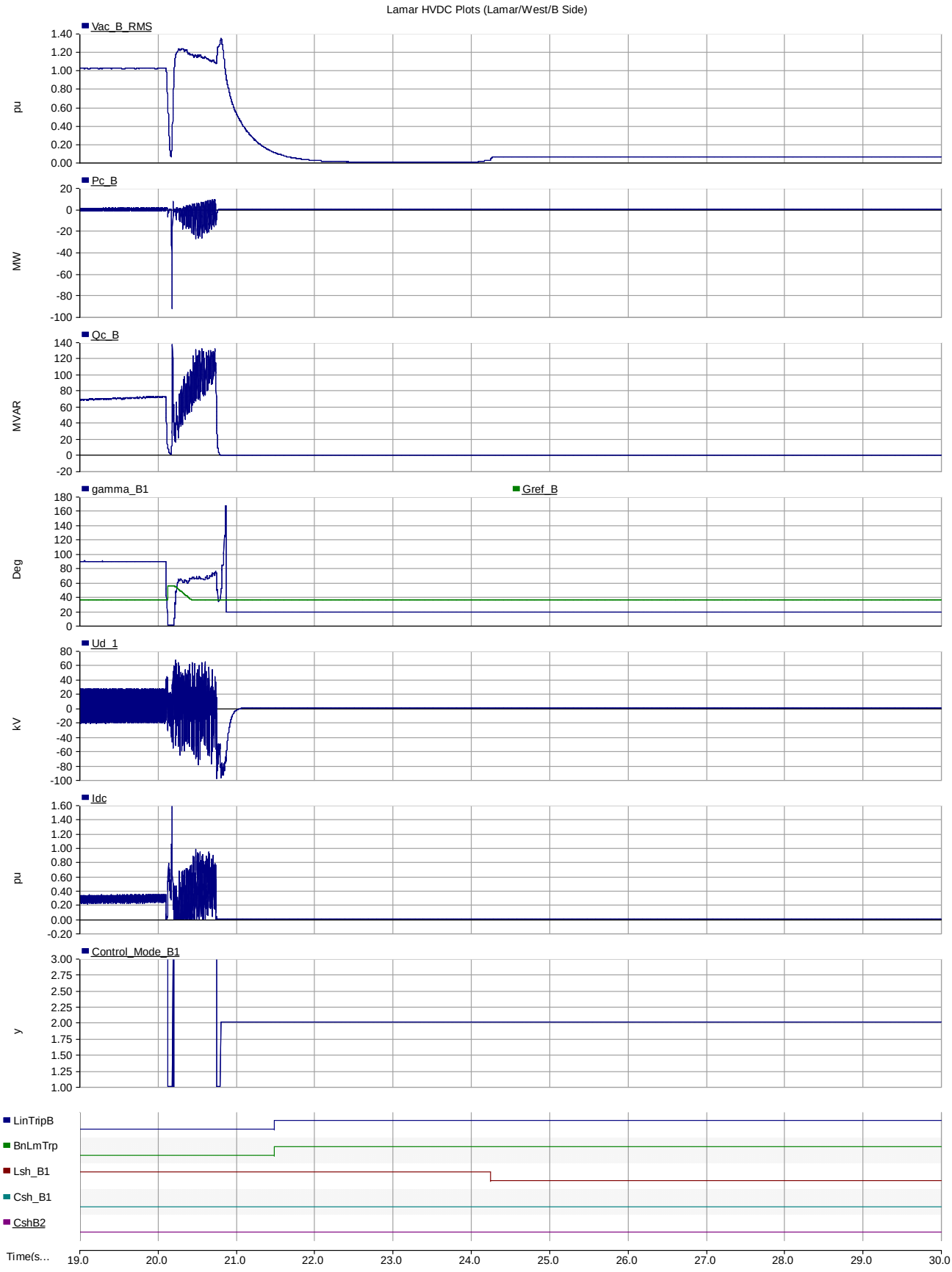

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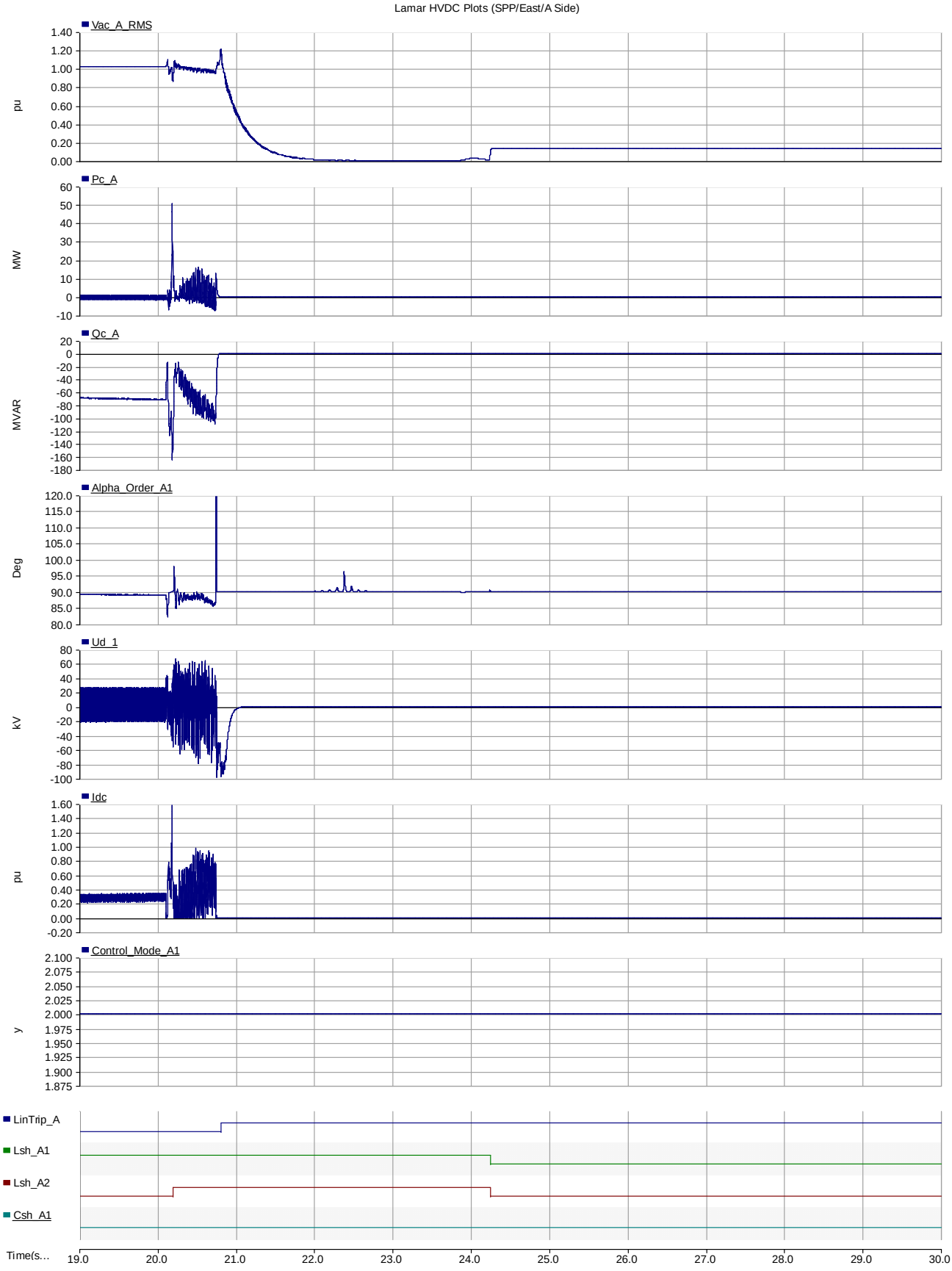

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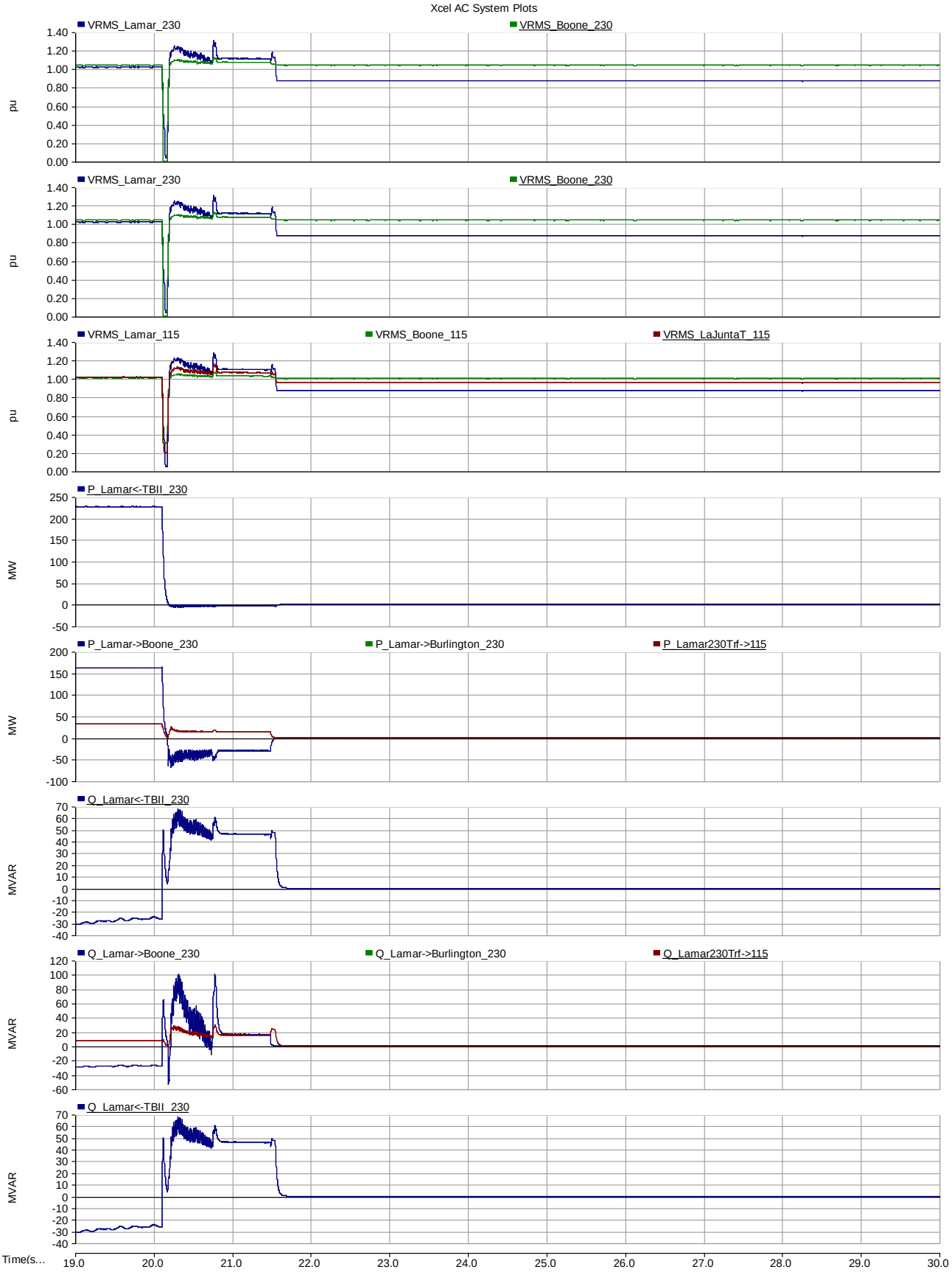

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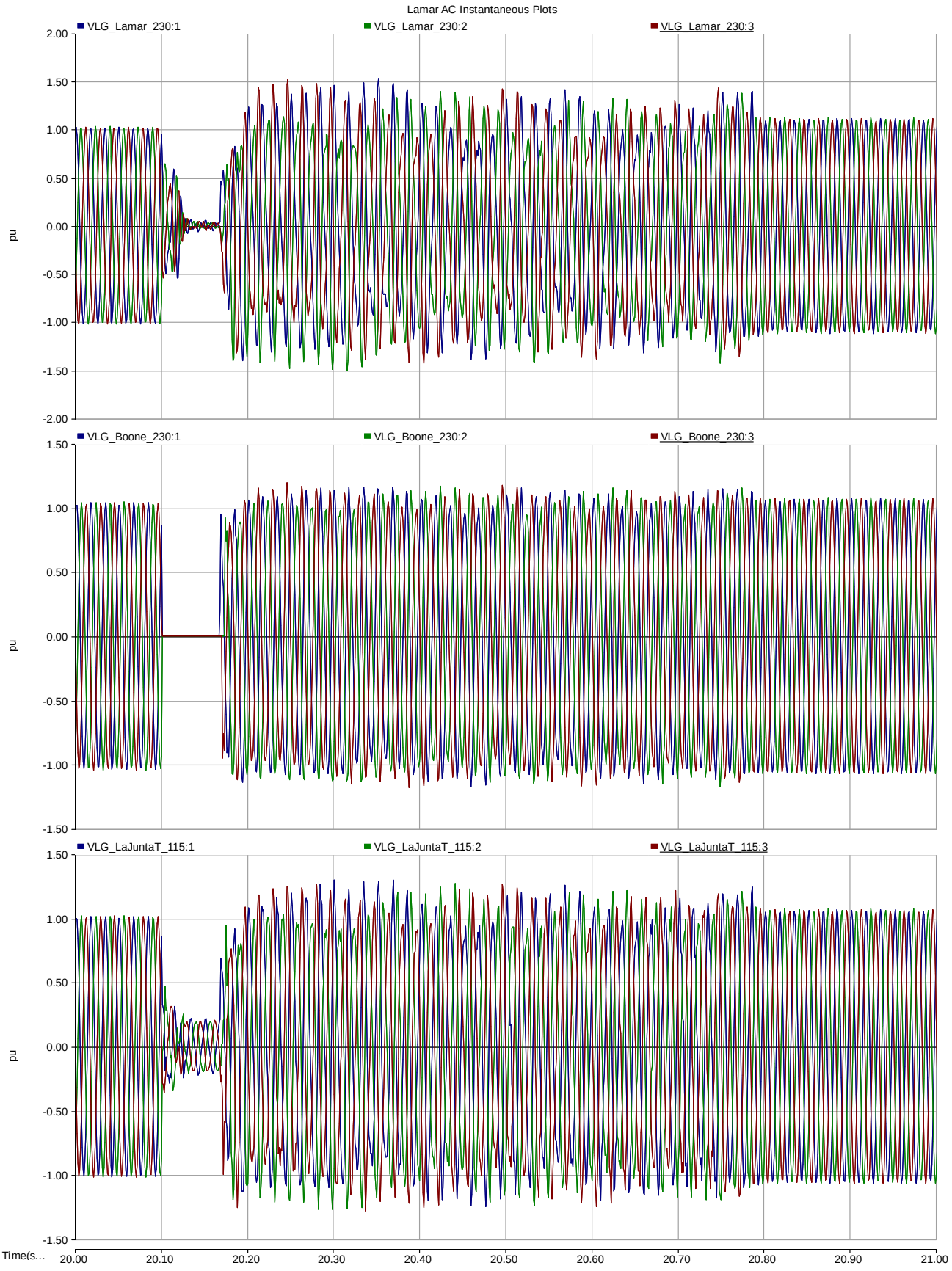

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