NERC
NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

2022 Odessa Disturbance

Texas Event: June 4, 2022

Joint NERC and Texas RE Staff Report

December 2022

RELIABILITY | RESILIENCE | SECURITY

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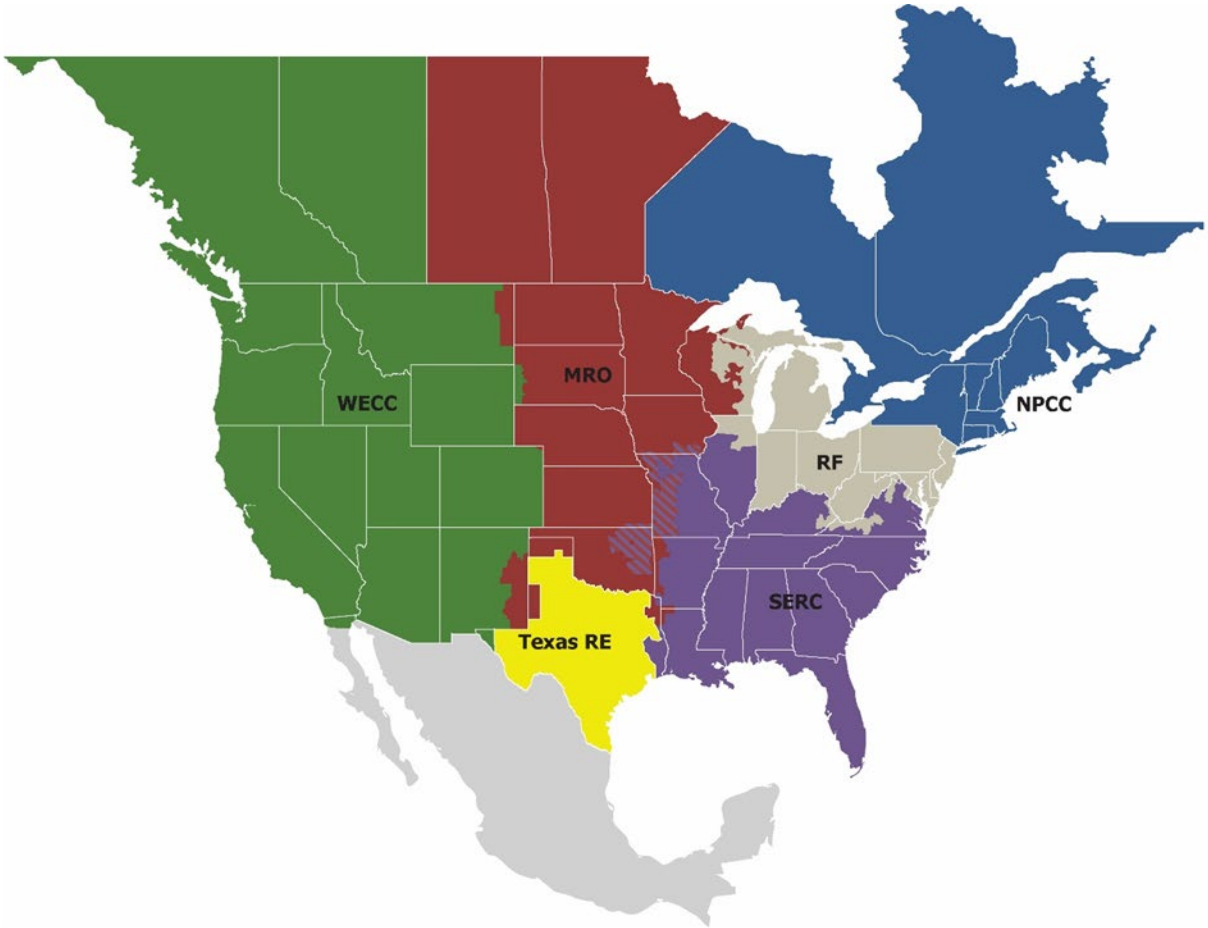
Preface

Electricity is a key component of the fabric of modern society and the Electric Reliability Organization (ERO) Enterprise serves to strengthen that fabric. The vision for the ERO Enterprise, which is comprised of NERC and the six Regional Entities, is a highly reliable, resilient, and secure North American bulk power system (BPS). Our mission is to assure the effective and efficient reduction of risks to the reliability and security of the grid.

Reliability | Resilience | Security
Because nearly 400 million citizens in North America are counting on us

The North American BPS is made up of six Regional Entity boundaries as shown in the map and corresponding table below. The multicolored area denotes overlap as some load-serving entities participate in one Regional Entity while associated Transmission Owners (TO)/Operators (TOP) participate in another.



MRO	Midwest Reliability Organization
NPCC	Northeast Power Coordinating Council
RF	ReliabilityFirst
SERC	SERC Reliability Corporation
Texas RE	Texas Reliability Entity
WECC	WECC

Executive Summary

The ERO Enterprise continues to analyze disturbances that involve the widespread reduction of inverter-based resources in order to identify systemic reliability issues, support affected Generator Owners (GO), and share key findings and recommendations with industry for increased awareness and action. Refer to NERC *Quick Reference Guide: Inverter-Based Resource Activities* for more details on all aspects of work in this area.[1]

The ERO continues to stress the need for industry action in multiple areas to address the systemic reliability risks posed by inverter-based resource performance issues. Multiple disturbances that involve the widespread reduction of solar photovoltaic (PV) resources have occurred in California and Texas. This report provides a comprehensive assessment of a widespread loss of solar PV and synchronous generation caused by a normally cleared fault in the Texas Interconnection that occurred on June 4, 2022 (referred to herein as the "2022 Odessa Disturbance"). This event is unique in that NERC and Texas RE analyzed a nearly identical event that occurred just over one year prior at the same location. This event is a perfect illustration of the need for immediate industry action to ensure reliable operation of the BPS with increasing penetrations of inverter-based resources. The unexpected and unplanned loss of generation (both synchronous and inverter-based) poses an increasing and significant risk to BPS reliability.

Takeaway

The event was categorized as a Category 3a event in the NERC Event Analysis Process. The concurrent and unexpected tripping of synchronous generation in addition to the abnormal reduction of power from many solar PV facilities poses a ***significant*** risk to BPS reliability. The combined loss of generation nearly exceeded the Texas Interconnection Resource Loss Protection Criteria. These types of concurrent and unexpected losses in generation pose a significant risk to BPS reliability when many of the underlying causes of abnormal performance are systemic in nature, should be captured in system planning assessments or interconnection studies, and are not mitigated in a timely manner.

The 2022 Odessa Disturbance was categorized as a Category 3a event in the NERC Event Analysis Process due to the magnitude of generation loss.[2] The Electric Reliability Council of Texas (ERCOT) provided an extensive brief report that documented the performance of each facility. ERCOT led the solicitation of requests for information (RFI) immediately after the event occurred, coordinated with affected entities, and collected data for analysis. NERC and Texas RE worked closely with ERCOT to analyze the data and RFI responses from affected GOs whose facilities experienced a notable reduction in power during the event. ERCOT collaboratively engaged the impacted TOs to gather additional information and corroborate data with other sources.

This disturbance further illustrates a growing and significant risk to BPS reliability. The size of this disturbance nearly exceeded the Texas Interconnection Resource Loss Protection Criteria[3] defined in NERC BAL-003 that is used to establish the largest credible contingency for frequency stability in an Interconnection. Furthermore, this disturbance involved the abnormal performance of multiple solar PV facilities and synchronous generating facilities. These types of concurrent and unexpected losses in generation pose a significant risk to BPS reliability when many of the underlying causes of abnormal performance are systemic in nature, should be captured in system planning assessments or interconnection studies, and are not mitigated in a timely manner. As the penetration of solar PV resources (and all inverter-based resources) continues to grow rapidly in the ERCOT footprint and in many areas of North America, it is paramount that these inverter-based resource performance issues are proactively and immediately addressed.

While solar PV penetration was only at 15% of the total generation mix for this event, the size of the event nearly exceeded system design criteria. Future solar PV penetrations of much higher levels are expected in the near-term, and they could pose a significant risk of widespread outages if performance issues are not mitigated.

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[1] https://www.nerc.com/pa/Documents/IBR_Quick%20Reference%20Guide.pdf

[2] NERC Event Analysis Program: https://www.nerc.com/pa/rrm/ea/Pages/EA-Program.aspx

[3] https://www.nerc.com/pa/Stand/Reliability%20Standards/BAL-003-2.pdf

The **Introduction** section of this report provides details regarding the initiating event, overall performance of the BPS-connected generation fleet during the event, and additional relevant details. **Chapter 1** provides a detailed review of the key findings and establishes the supporting evidence and technical basis for the recommendations that are laid out in **Chapter 4**. A detailed comparison of the 2021 and 2022 Odessa events as well as a review of the mitigation actions taken after the 2022 Odessa Disturbance is located in **Chapter 2**. **Chapter 3** focuses on an assessment of ERCOT performance validation, modeling, and study findings that also support the recommendations in **Chapter 4**. **Appendix A** provides a detailed analysis of the affected facilities.

Overview of Disturbances

At 12:59:25 p.m., Central Time on June 4, 2022, a surge arrestor failed at a synchronous generation facility in Odessa, Texas, causing a B-phase-to-ground fault on the 345 kV system. The fault cleared in three cycles, disconnecting part of the plant that was carrying 333 MW. Other units in the plant unexpectedly tripped for an additional immediate loss of 202 MW.[4] A separate synchronous generation facility in South Texas over 450 miles away lost an additional 309 MW. In total, 844 MW of synchronous generation tripped at the time of the disturbance. In addition, 1,711 MW of inverter-based resources from many different facilities also unexpectedly reduced power output due to the protection and controls at each site. Therefore, the normally-cleared single-line-to-ground fault resulted in a total loss of 2,555 MW of generation, and system frequency dropped to 59.7 Hz. The total responsive reserve service available at the time of the disturbance was 2,442 MW. Total responsive reserve service deployed was 2,343 MW with 1,116 MW from load resources[5] and 1,227 MW from generation. **Table ES.1** shows active power reductions by resource type.[6]

Table ES.1: Reductions of Output by Unit Type

Plant Type	Reduction [MW]
Synchronous Generation Plants	844
Solar PV Plants	1,711
Total	**2,555**

A subsequent fault occurred 10 seconds later on a failed reclose attempt; however, there was no significant reduction of any additional solar PV or synchronous generation.

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[4] Part of the plant ramped down over the course of multiple minutes that resulted in a total loss of 829 MW for this plant. Only the initial active power reduction (202 MW + 333 MW = 535 MW) at the time of the fault was counted in the total reduction for this plant.

[5] Load resources in ERCOT are capable of providing ancillary services for the ERCOT system and/or energy in the form of demand response and are registered with ERCOT as such.

[6] Active power reductions are based on the best available information by combining supervisory control and data acquisition (SCADA) data, digital fault recorder data, digital relay data, phasor measurement unit data, and any other relevant information from the analysis. Aggregate quantities reported throughout the document are based on best available information.

Expected Mitigations to Address Abnormal Solar PV Performance Issues

GOs at both synchronous generation facilities were able to deploy mitigations to eliminate the causes of tripping at each site. ERCOT has been diligently working with GOs of affected solar PV facilities to develop and implement mitigation plans to eliminate the unexpected causes of reduction observed in both the 2021 and 2022 Odessa disturbances. ERCOT has worked collaboratively with the GOs and equipment manufacturers to determine suitable performance enhancements at each facility. Table ES.2 shows the expected effectiveness of the proposed mitigations.

Table ES.2: Effect of Proposed Mitigations

Plant Type	Reduction [MW]	Mitigated Reductions [MW]*
Solar PV Plants	1,711	1,633

* Assumes the mitigations stop unexpected or abnormal reductions during ride-through events and that these actions are implemented on-site. Does not include potential additional underlying ride through deficiencies.

Key Findings and Recommended Actions

Based on the findings of this disturbance report and in the context of past disturbance reports for inverter performance issues, the ERO recommends the following actions:

- **There is an immediate need for all GOs, especially the affected GOs in this event, to mitigate abnormal performance issues in the Texas Interconnection.**
  ERCOT has been responsive to seeking mitigations for the risks identified in this event and past events while working with stakeholder groups and affected entities. The affected GOs in the ERCOT footprint should mitigate any abnormal performance issues identified in the 2021 or 2022 Odessa disturbances (as well as any additional smaller disturbances reported by ERCOT) and have evidence of accurate facility modeling when compared to actual facility performance and as-built control settings and parameters. ERCOT should fully leverage its interconnection requirements and any other rules or protocols to ensure that all GOs are compliant with those requirements and rules. ERCOT should immediately report any entities to NERC and FERC that have not mitigated the performance issues identified (or that have not developed plans to mitigate them) in the 2021 Odessa Disturbance within a reasonable time frame.

- **The risk profile for inverter-based resource performance issues needs to be elevated, and immediate ERO Enterprise risk-based compliance activities are needed in this area.**
  Inverter performance issues continue to be a systemic risk to BPS reliability as resource loss events grow in frequency and magnitude across multiple Interconnections. Coupled with the unexpected loss of synchronous generating resources, the inability of inverter-based resources to reliably ride through BPS faults and support the BPS with essential reliability services poses a significant risk to BPS reliability. The ERO Enterprise will fully leverage all possible risk-based compliance mechanisms to ensure that GOs, Generator Operators (GOP), TOs, Transmission Planners (TP), Planning Coordinators (PC), and Reliability Coordinators (RC) are compliant with all aspects of the NERC Reliability Standards. In particular, all NERC Reliability Standards related to modeling, reliability studies (interconnection studies,[7] long-term planning studies, and operations planning studies), and resource performance will be considered by Compliance Monitoring and Enforcement staff.

- **There is an immediate need for NERC standards enhancements to address inverter-based resource performance issue identification, analysis, and mitigation.**
  NERC has analyzed multiple widespread solar PV loss events across multiple Interconnections and has noted that most GOs are not conducting adequate assessments of resource performance. Furthermore, GOs are not proactively mitigating performance issues in a timely manner. The NERC Inverter-Based Resource Performance Subcommittee (IRPS) has developed a Standard Authorization Request (SAR) based on findings

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[7] Interconnection studies per FAC-002 requirements.

from the *2021 Odessa Disturbance Report*, which proposes a new NERC Reliability Standard that requires all Bulk Electric System (BES) inverter-based resource GOs to identify and analyze abnormal performance issues and develop mitigations to any abnormal performance issues identified. In addition, the proposed standard would authorize the TOP, RC, or Balancing Authority to require GOs to conduct these assessments if they identify abnormal performance issues for any BES resource. This standard is a critical step in developing a risk mitigation for these systemic inverter issues. The proposed SAR should be endorsed by the Reliability and Security Technical Committee (RSTC) and fast-tracked. It is critical that enhancements to NERC Reliability Standards keep pace with the rapid growth of inverter-based resources and the potential risks that may be posed under such rapid change.

- **There is an immediate need for a performance-based, comprehensive generator ride-through standard.** NERC staff submitted a SAR to the NERC Standards Committee that proposed the complete overhaul of PRC-024-3 and replacing it with a performance-based comprehensive ride-through standard that ensures generators remain connected to the BPS during system disturbances. That SAR was endorsed by the NERC Standards Committee in April 2022. Project 2020-02 was recast to begin developments of the replacement for PRC-024-3. The 2022 Odessa Disturbance reiterates the criticality and strong need for this standard enhancement, and NERC wholly supports the expeditious development and approval of this enhanced standard by industry. The standard needs sufficient clarity and specificity to ensure all associated failure modes during ride-through events are accounted for in the standard.

- **One or more Level 2 NERC alerts will be issued to understand the extent of inverter performance issues and modeling deficiencies.** Based on the findings of the 2021 and 2022 Odessa disturbances, NERC will develop one or more NERC alerts to understand the extent of inverter performance risks and modeling deficiencies as well as to gather necessary data to conduct further BPS reliability risk assessments across the ERO footprint for the currently installed fleet. The alert will include recommended mitigating actions and questions to industry that will be used to help conduct additional analyses and develop further mitigations to emerging risks to the BPS as more inverter-based resources are commissioned.

- **There is a need for electromagnetic transient (EMT) modeling requirements and accurate EMT models for all BPS-connected inverter-based resources.** Industry needs to recognize that these studies will become increasingly necessary to identify and mitigate BPS reliability performance issues and should immediately prepare for the increased study workload. Both the 2021 and 2022 Odessa disturbances stress the importance of EMT modeling and studies for growing levels of BPS-connected inverter-based resources. The NERC IRPS submitted a SAR regarding the inclusion of EMT modeling and studies in specific NERC FAC, MOD, and TPL standards. Project 2022-04 is underway to begin the development of applicable standard modifications. NERC strongly supports all TPs and PCs establish clear EMT modeling requirements and detailed model quality checks for all submitted models. EMT modeling and studies during the interconnection study process are necessary to ensure reliable performance and ride-through for newly connecting inverter-based resources.

- **A comprehensive model quality review should take place.** NERC believes that a comprehensive model quality review is needed to ensure that inverter-based resource models are accurate, that these models have passed rigorous model quality checks, and that the GO has provided the TP with sufficient documentation (including verification of as-built control and protection settings) so these entities can make a determination of the model quality and fidelity. NERC will develop a project plan and strategy for executing this model quality review process while working across the ERO Enterprise and with industry as needed.

- **The significant need for updates to the FERC *pro forma* generator interconnection agreements and procedures should be reiterated.**
  NERC submitted detailed comments[8] to the Federal Energy Regulatory Commission (FERC) Notice of Proposed Rulemaking regarding proposed reforms to the *pro forma* interconnection agreements and procedures.[9] In those comments, NERC reiterated that performance issues identified in NERC disturbance reports stem from a lack of interconnection requirements[10] or that the models used to conduct reliability studies are not reflective of the as-built equipment (modes of operation, controls, settings, and protections). NERC has multiple standards projects underway to address these reliability risk issues; however, issues pertaining to analysis, studies, or commissioning activities should be incorporated into enhancements of the FERC *pro forma* interconnection agreements and procedures.

- **Improvements to commissioning practices for inverter-based resources should occur.**
  Findings from essentially all past inverter-based resource events analyzed by the ERO Enterprise show that the abnormal performance issues observed during real-time operation are not being addressed in the interconnection processes implemented by the TO, TP, and PC. Repeated abnormal performance issues across many inverter-based resources is clear evidence that those facilities are not being configured to give the same performance as was studied in the interconnection process. Improvements are needed to ensure that the plant is commissioned to match exactly what was studied during the interconnection process with all gaps or discrepancies clearly documented and analyzed by the TO prior to commercial operation.

- **Key findings and recommendations from this event will be included in the NERC comments regarding the FERC Notice of Proposed Rulemaking directing NERC to enhance the NERC Reliability Standards related to inverter-based resource issues.**[11]
  FERC recently issued two key items regarding future work pertaining to inverter-based resources; the first was an order directing NERC to develop a plan to register the entities that own and operate inverter-based resources, and the second was a Notice of Proposed Rulemaking to direct NERC to develop Reliability Standards for inverter-based resources that cover data sharing, model validation, planning and operational studies as well as performance requirements. NERC will be including the key findings and recommendations from this event in its comments to the Notice of Proposed Rulemaking and will consider them as well in their efforts related to the inverter-based resource registration activities.

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[8] https://www.nerc.com/FilingsOrders/us/NERC%20Filings%20to%20FERC%20DL/Interconnection%20NOPR%20Comments%20RM22-14.pdf

[9] Including the Large Generator Interconnection Agreement and Procedures and Small Generator Interconnection Agreement and Procedures

[10] Including performance, modeling (and model quality) and studies requirements

[11] https://www.ferc.gov/news-events/news/ferc-proposes-ibr-standards-registration-improve-grid-reliability

Introduction

Description of Analysis Process

ERCOT first observed the reduction of solar PV resources across multiple facilities. The event met the criteria for a Category 3a event per the NERC Event Analysis Program due to the total MW loss of solar and conventional plants exceeding 2,000 MW. NERC, Texas RE, and ERCOT mutually agreed to develop an ERO disturbance report to share the key findings and recommendations from the analysis with industry. ERCOT solicited RFIs to affected entities and also held follow-up calls with those entities, Texas RE, and NERC to gain any additional information to perform root cause analysis. Follow-ups focused primarily on facilities that reduced power output by more than 10 MW.

Predisturbance Operating Conditions

Figure I.1 shows the total ERCOT solar PV generation profile for June 4, 2022. The disturbance occurred at 12:59:25 p.m. Central, when solar was at its peak output for the day. The disturbance is clearly visible in the total solar PV power output. The unexpected reduction and abnormal performance of solar PV resources and synchronous generation across a large geographic area of the ERCOT footprint presents significant BPS reliability concerns. Most of the affected solar PV facilities were located in the West Texas area; affected synchronous generation was located in West Texas and South Texas.

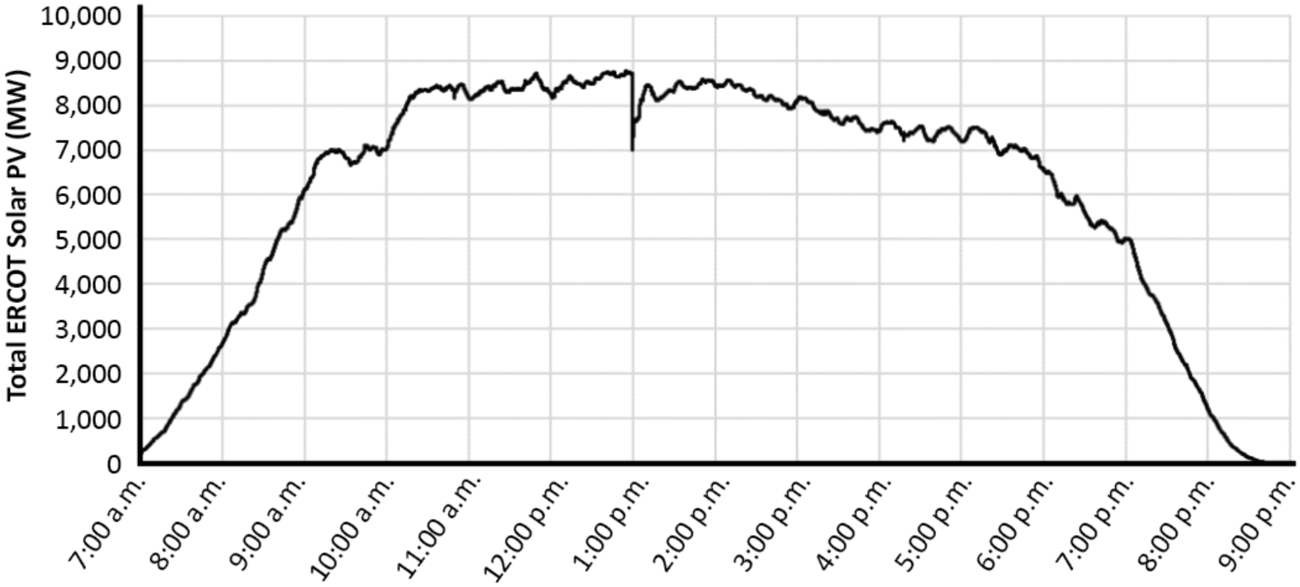

Figure I.1: ERCOT Solar PV Profile for June 4, 2022

Synchronous generation, wind, and solar PV resources comprised 74%, 10%, and 16% of total generation prior to the disturbance, respectively (see **Table I.1**). At the time of the event, the ERCOT footprint included about 8,660 MW of solar PV resources with an additional 3,010 MW in the commissioning process. There is projected to be as much as 28,850 MW by the end of 2023 based on solar PV resources with signed interconnection agreements in the ERCOT generation interconnection queue. This is a slightly higher projection of installed solar PV resources by end of 2023 than previously predicted in the *2021 Odessa Disturbance Report*.

Table I.1: Predisturbance Resource Mix

BPS Operating Characteristic	MW	Percentage
Internal Net Demand	55,436	-
Solar PV Output	8,740	15.8%
Wind Output	5,742	10.4%
Synchronous Generation	40,744	73.5%

*ERCOT was importing 210 MW

Figure I.2 shows the share of BPS-connected solar PV resources by inverter manufacturer around the time of this disturbance. Inverter manufacturers involved in this event (and in the 2021 Odessa Disturbance) include Toshiba Mitsubishi-Electric Industrial Systems Corporation (TMEIC), Power Electronics, and KACO.[12] The majority of abnormal performance (e.g., tripping) is attributed to the two largest manufacturers by installed capacity.

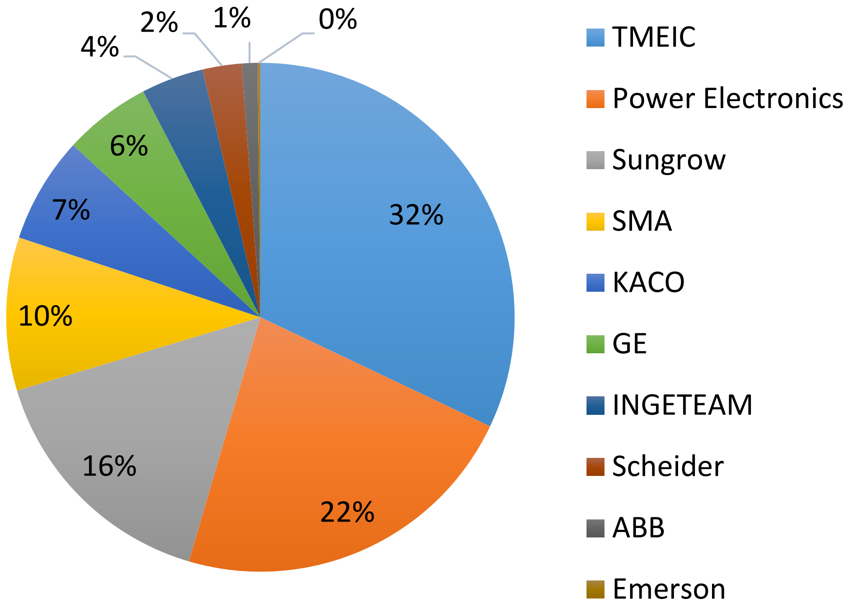

Figure I.2: Capacity Share of BPS-Connected Solar PV Inverter Manufacturers

Disturbance Overview

At 12:59:25 p.m., a B-phase-to-ground fault occurred on the 345 kV bus when a lightning arrestor failed at a synchronous generation plant near Odessa, Texas. Protective relaying cleared the fault in about three cycles by opening the far-end transmission breaker and the three generator step-up transformer circuit breakers. At the same time, generator protection on the neighboring unit misoperated due to current transformer saturation, resulting in additional synchronous generation tripping and runback. A total of 535 MW of generation tripped at this location. In addition, a synchronous generation plant in South Texas also tripped due to loss of excitation from an automatic voltage regulator in the incorrect operating mode (manual versus automatic), resulting in an additional loss of 309 MW. A total of 844 MW of synchronous generation was lost due to the normally cleared fault. In addition,

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[12] KACO is no longer in the business of manufacturing large-scale solar inverters.

approximately 1,711 MW of power reduction occurred at multiple inverter-based resources in West Texas. At 12:59:35 p.m., a failed reclose attempt occurred, resulting in another normally cleared fault.

Voltages in the area were depressed as a result of the fault. The perturbation in system voltages and phase angles resulted in widespread reduction of BPS-connected solar PV resources; no solar PV resources were de-energized as a direct consequence of protective relaying removing the faulted BPS elements from service. Rather, controls and protection within the plant caused the reduction in output for all affected inverter-based facilities.

Location of Disturbance and Affected Facilities

The fault occurred in the Odessa, Texas, area within the ERCOT footprint. Multiple solar PV facilities were identified as exhibiting unreliable performance. All affected solar PV facilities are within or near the West Texas part of ERCOT. Figure I.3 shows the geographic location of the fault and the affected solar PV facilities. The blue and red circles represent synchronous generators and solar PV facilities, respectively, that abnormally responded to the fault. The size of the circle illustrates the relative size of reduction.

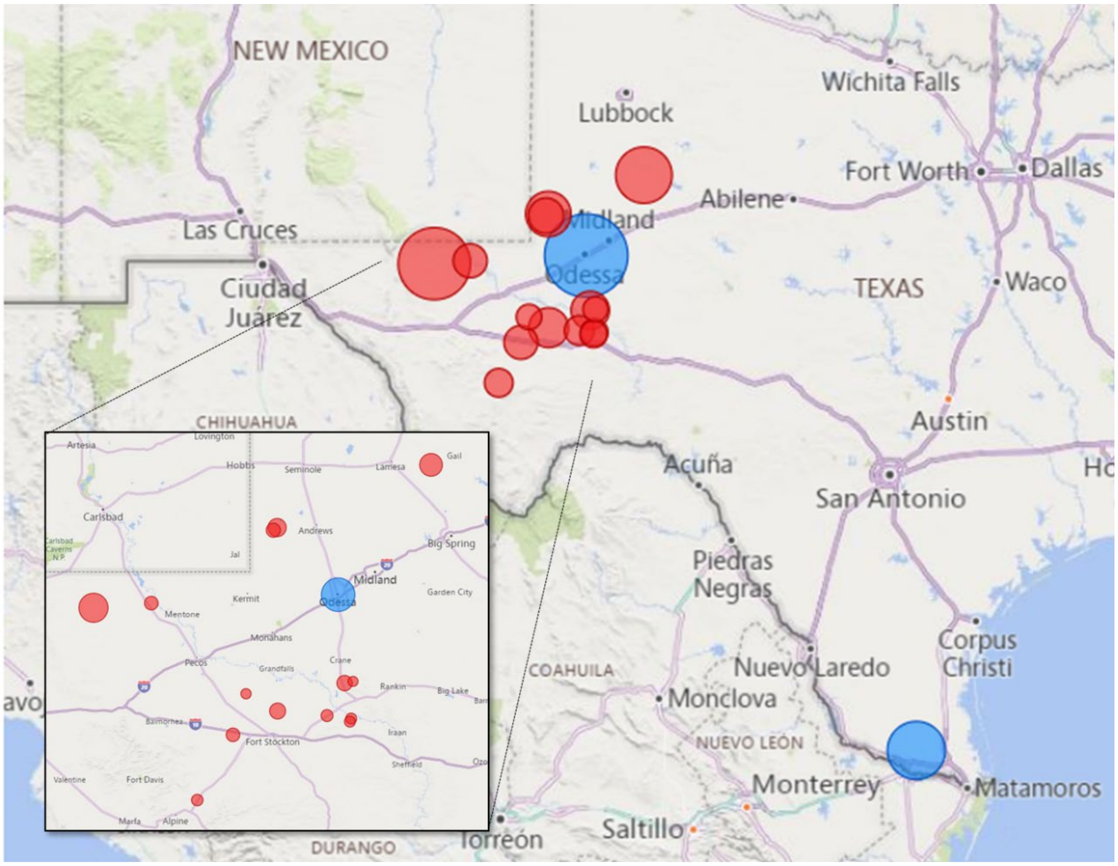

Figure I.3: Map of the Fault Location and Affected Solar PV and Synchronous Generators

Figure I.4 shows the reduction in solar PV resources reported by ERCOT SCADA data. As with past analysis of inverter-based resource disturbances, reductions captured by SCADA likely differ from information captured with higher resolution monitoring equipment. Discrepancies may exist between this value and others reported in this disturbance report; however, the reduction in solar PV output captured by SCADA provides a relative indicator of the impact of each disturbance.

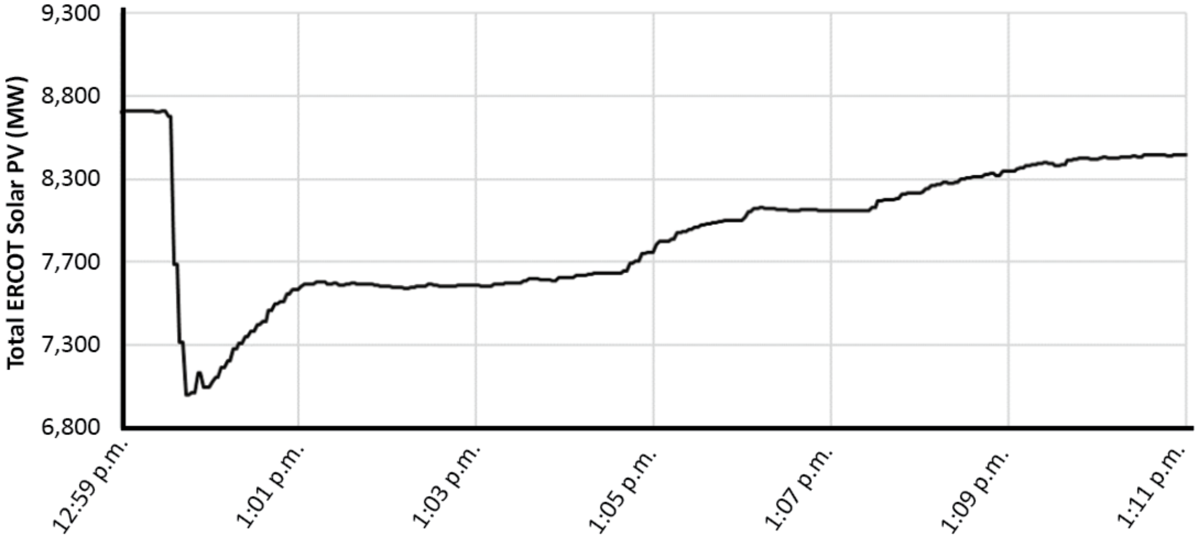

Figure I.4: ERCOT BPS-Connected Solar PV Generation during Disturbance [Source: ERCOT]

There were no notable changes in net load quantities that would be attributable to distributed energy resources (DER) tripping and ERCOT did not perform any analysis to evaluate DER performance.

The loss of generation caused system frequency to fall from around 60.01 Hz to 59.70 Hz. A total of 1,116 MW of end-use loads participating in ERCOT's load resources program[13] provide responsive reserve service that is automatically deployed in response to the frequency drop. End-use loads participating in ERCOT's load resources program are set to automatically disconnect when frequency hits 59.70 Hz. This ancillary service market product is used to stabilize system frequency for large frequency excursions to avoid frequency from reaching emergency underfrequency load shedding thresholds beginning at 59.3 Hz.

Synchronous generation levels were relatively high during this time, so system inertia and high rate-of-change-of-frequency conditions were not a concern. The time from the event start to the frequency nadir was measured at approximately three seconds.

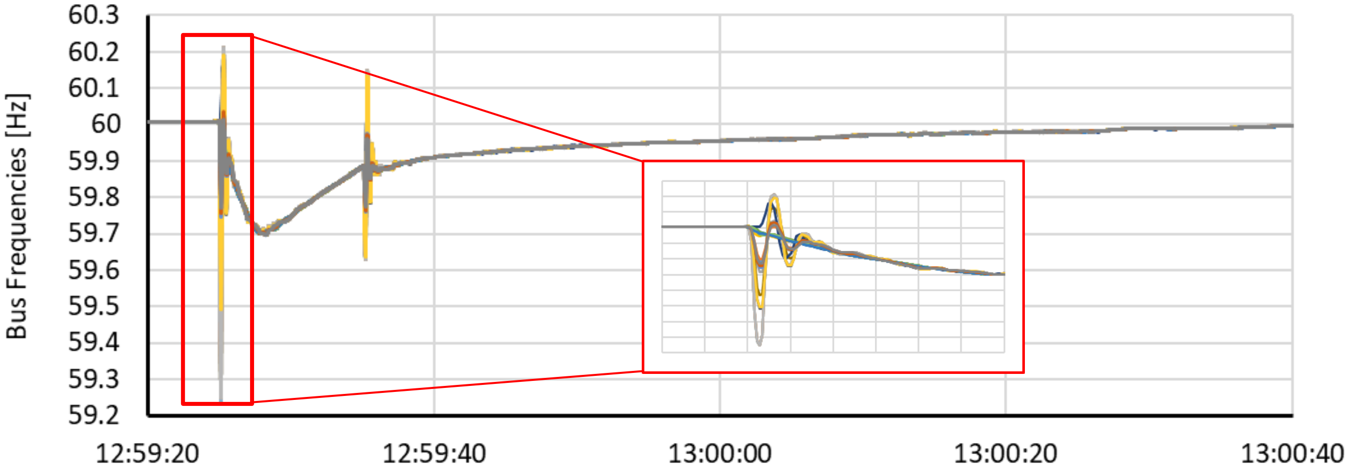

Figure I.5: ERCOT System Frequency

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[13] Load resources in ERCOT are interruptible loads capable of providing ancillary service and/or energy in the form of demand response. Load resources are required to deploy by underfrequency relay set at 59.7 Hz and to deploy within 10 minutes after a manual deployment instruction from ERCOT.

Chapter 1: Detailed Findings from Disturbance Analysis

ERCOT facilitated data requests to all affected facilities and held follow-up calls with Texas RE, NERC, and affected GOs and GOPs. NERC, Texas RE, and ERCOT also engaged the equipment manufacturers directly to better understand the root causes of abnormal performance. Refer to **Appendix A** for details regarding each affected facility and refer to **Chapter 2** for a comparison of the 2021 and 2022 Odessa disturbances. This chapter provides the key findings from this analysis.

Overview of Solar PV Abnormal Performance Issues

A significant number of solar PV resources responded to the BPS fault event in an abnormal and unreliable manner. Many solar PV sites reduced power output by more than 10 MW. The unexpected reduction in solar PV power output for this event totaled 1,711 MW. A majority of these sites were also involved in the 2021 Odessa Disturbance as well; the remaining sites were either off-line during the 2021 event, rode through that event, or were in commissioning and not yet on-line at the time. Many of the solar PV resources that responded abnormally were large BES facilities over a large geographic area in the West Texas footprint. **Table 1.1** shows a comparison of the causes of abnormal solar PV performance for the 2021 and 2022 Odessa disturbances. **Figure 1.1** shows a graphical representation of the causes of reduction for the 2022 Odessa Disturbance.[14]

Table 1.1: Causes of Solar PV Active Power Reductions

Cause of Reduction	Odessa 2021 Reduction [MW]	Odessa 2022 Reduction [MW]
Inverter Instantaneous AC Overcurrent	–	459
Passive Anti-Islanding (Phase Jump)	–	385
Inverter Instantaneous AC Overvoltage	269	295
Inverter DC Bus Voltage Unbalance	–	211
Feeder Underfrequency	21	148*
Unknown/Misc.	51	96
Incorrect Ride-Through Configuration	–	135
Plant Controller Interactions	–	146
Momentary Cessation	153	130**
Inverter Overfrequency	–	–
PLL Loss of Synchronism	389	–
Feeder AC Overvoltage	147	–
Inverter Underfrequency	48	–
Not Analyzed	34	–

* In addition to inverter-level tripping (not included in total tripping calculation.)
** Power supply failure

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[14] Note that the values will not add up to the total aggregate size of the event because some facilities involved multiple causes of tripping (i.e., inverter-level and feeder-level).

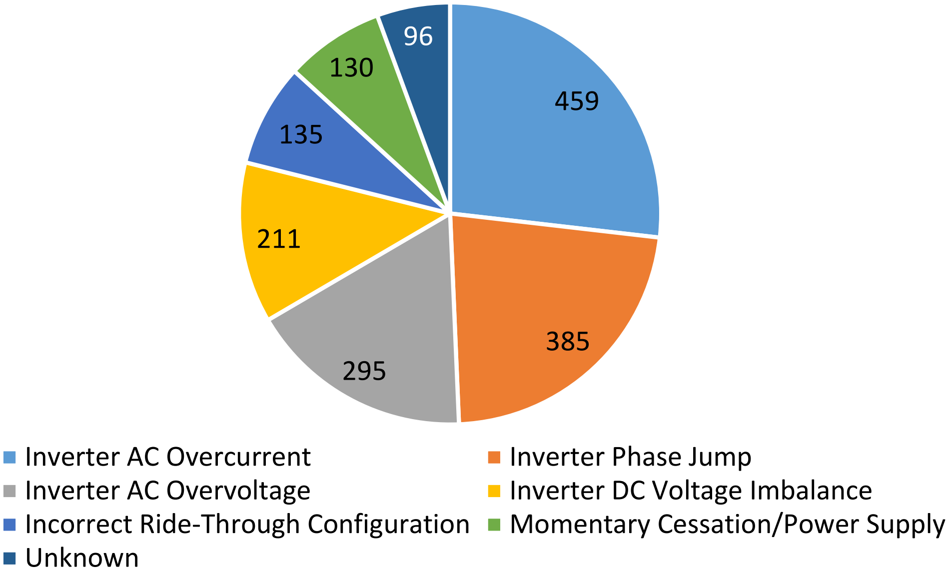

Figure 1.1: Causes of Solar PV Reduction

Figure 1.2 shows the share of solar PV inverter equipment manufacturers involved in the 2021 and 2022 Odessa disturbances. Only three manufacturers were involved in both events, showing systemic performance issues for those manufacturers. KACO is no longer in the business of manufacturing large-scale inverters. TMEIC and Power Electronics are actively involved in the production of inverters for large-scale solar PV power plants across all Interconnections, and they are the two largest equipment manufacturers by market share in the Texas Interconnection.

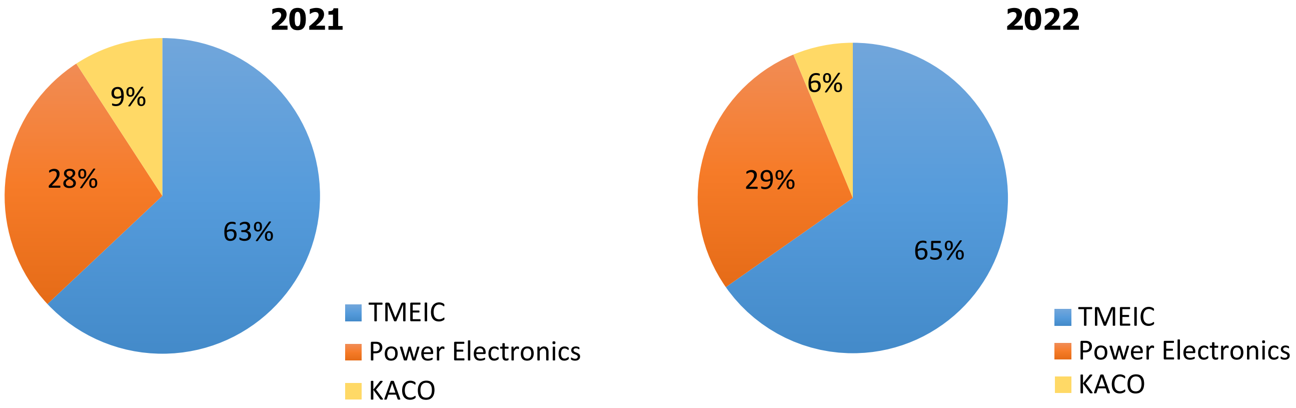

Figure 1.2: Inverter Manufacturers Involved in Odessa Disturbances in 2021 and 2022

The following sections will describe the root causes of abnormal solar PV resource performance and outcomes from follow-up discussions with equipment manufacturers and affected GOs.

Inverter Instantaneous AC Overcurrent Tripping

The largest solar PV reduction in this event was caused by inverter ac overcurrent tripping that was observed across three different inverter manufacturers. One manufacturer is now out of business, so the settings were not obtainable. Tripping of inverters by another manufacturer was not entirely confirmed due to inverter logs being overwritten. The third manufacturer, and largest contributor to the overall reduction, has two levels of instantaneous ac overcurrent protection at 1.4 pu (minor fault) and 1.5 pu (major fault) of rated ac current.[15] These trip levels are not adjustable. The overcurrent protection is used to protect insulated-gate bipolar transistors from equipment failures, so it does not involve any time delay. Tripping typically occurs within 0.2 ms; however, the ac overcurrent protection is operating for external BPS grid faults due to the controls programmed in the inverter power electronics.

Figure 1.3 and **Figure 1.4** show inverter-level oscillography data recorded at a single inverter at one of the facilities that experienced tripping. When the fault occurs, the voltage waveform is slightly distorted during the fault and the terminal voltage is reduced slightly. The inverter current also fluctuates somewhat but well within inverter ratings. During the fault, the phase and magnitude of inverter terminal voltage changed rapidly. As the inverter attempted to respond to this change, inverter ac current was driven above its rating and tripped on instantaneous ac overcurrent exceeding the trip threshold.

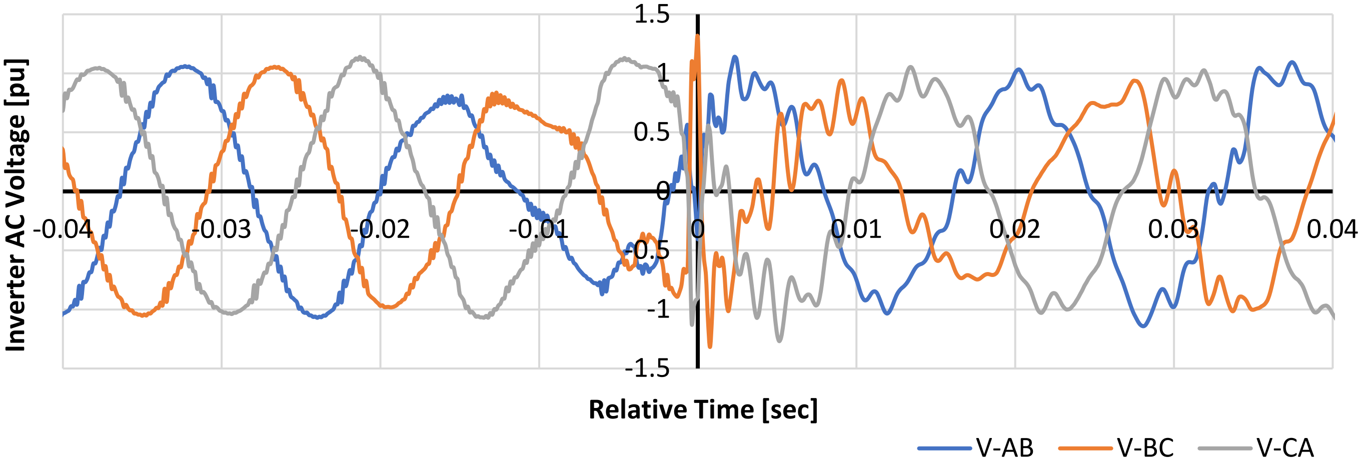

Figure 1.3: Inverter-Level High Speed Oscillography Voltage Data

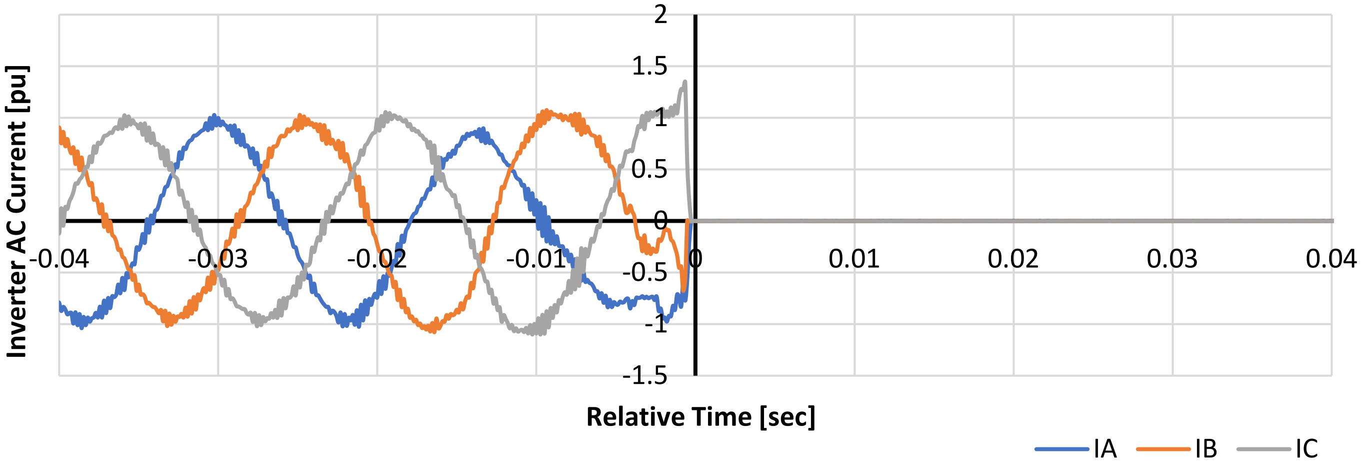

Figure 1.4: Inverter-Level High Speed Oscillography Current Data

The inverter manufacturer has developed a software algorithm that modifies inverter switching logic during overcurrent events. Presently, large changes in terminal voltage will drive excessively high ac currents that result in tripping. The new software algorithm will result in less change in ac current during large changes in ac voltage; the

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[15] This inverter manufacturer uses “major” and “minor” faults to differentiate fault codes. The fault codes have different thresholds and different restoration times. Some may allow automatic restart with different times; some may require manual restart by a technician.

update for this requires inverter manufacturer personnel to be on-site to modify inverter firmware and parameters. Testing has been performed by the equipment manufacturer on a hardware-in-the-loop setup with actual control boards. However, the update is still in the study phase with the inverter manufacturer and not yet ready for complete rollout to all facilities. The inverter manufacturer stated that they plan to only make changes to facilities that request the update and do not have any plans to proactively update or mitigate this risk on their end. Therefore, NERC strongly recommends that all GOs with these inverters seek immediate updates (when available) to their in-service inverters to mitigate the possibility of unexpected and abnormal tripping for BPS faults. The inverter manufacturer is planning to integrate these improvements for next-generation inverters.

Changes to dynamic models, particularly EMT models, will be needed when these changes are made to reflect the new inverter control strategy implemented in the inverters. Therefore, all GOs making changes to these inverters should submit updated EMT models to their respective TP and PC to ensure accurate models are maintained and that the GO is compliant with all applicable NERC Reliability Standards.

It is believed that this cause of tripping was not widely observed in past events because this inverter manufacturer had a preemptive phase lock loop (PLL) loss of synchronism tripping enabled at most facilities that was highly sensitive and would trip the inverters for normal BPS faults. This protection has since been disabled at many facilities since it is essentially unrelated to any actual inverter-level ratings or equipment limits.

Passive Anti-Islanding (Phase Jump) Tripping

The largest reduction of solar PV output during the 2021 Odessa Disturbance was caused by two large plants tripping entirely due to PLL loss of synchronism tripping with one of the plants being furthest from the fault (upwards of 250 miles away). The report highlighted NERC guidance[16] published years prior that stated "PLL loss of synchronism should not result in inverter tripping…[because]…the PLL is able to resynchronize to the grid within a couple electrical cycles and should be able to immediately return to expected current injection." Additional guidance also stated that TOs should establish a dialogue with interconnecting GOs to understand the means in which the inverters may trip on instantaneous changes in phase angle either due to fault events or line switching events. The *2021 Odessa Disturbance Report* also highlighted that this cause of tripping is outside the scope of the PRC-024-3 standard and that it should be mitigated with a comprehensive ride-through standard.[17]

During discussions with the inverter manufacturer during the 2021 Odessa Disturbance, they determined that PLL loss of synchronism protection was causing unnecessary tripping of inverters for BPS faults. Therefore, the manufacturer now disables this protective function by default in all new inverters. ERCOT has confirmed that updates have been made at all BPS-connected facilities of this manufacturer in their footprint; however, this protection may still be enabled in other existing inverters. GOs will need to request disabling the protection to ensure ride-through during BPS faults.

In the 2022 Odessa Disturbance, inverters did not trip on PLL loss of synchronism since many of those protections had been disabled; however, the inverters from this same manufacturer tripped on passive anti-islanding function, which misinterpreted the grid phase angle shift upon fault recovery as an islanding signature.[18] The protection compares the angle difference between inverter voltage and current phasors, and operates for a change larger than 15 degrees within 500 ms.

NERC Reliability Guideline: *BPS-Connected Inverter-Based Resource Performance*, published in 2018, specifically stated that passive anti-islanding protection should be disabled for all BPS-connected inverter-based resources since

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[16] https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Inverter-Based_Resource_Performance_Guideline.pdf
https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline_IBR_Interconnection_Requirements_Improvements.pdf

[17] NERC subsequently submitted a SAR to ensure ride-through performance issues are mitigated in a timely manner.

[18] This specific inverter manufacturer refers to this inverter protective function as "phase jump protection."

this is predominantly a distribution-centric form of protection that is not appropriate for the BPS. The protection is prone to false tripping for situations that involve large, rapid changes in phase angle as well as during high rate-of-change-of-frequency conditions. However, this inverter manufacturer has been installing inverters across North America with this form of protection enabled at the vast majority (if not all) BPS-connected facilities. This poses a relatively significant risk to BPS reliability as this protection is likely to misoperate for normal, expected BPS faults.

NERC, Texas RE, and ERCOT all strongly recommended that this form of protection be disabled at all BPS-connected solar PV facilities. ERCOT further corroborated this statement with local TOs to ensure they do not rely on this form of protection in any way. The TOs also strongly recommended that this protection be disabled so as to not cause inadvertent tripping. The inverter manufacturer has stated they will be disabling the passive anti-islanding protection upon request from GOs and will likely be disabling the protection as a default for future installations, and it has an increased threshold value in cases where an entity keeps it enabled. NERC strongly recommends that all GOs of BPS-connected solar PV facilities reach out to their respective inverter manufacturer to ensure that any passive (and active) anti-islanding protection is set appropriately (and ideally disabled).

Inverter Instantaneous AC Overvoltage Tripping

Inverter instantaneous ac overvoltage tripping is a persistent and recurring cause of unexpected tripping of BPS-connected inverter-based resources. NERC has documented the cause of this tripping in detail in the *2021 Odessa Disturbance Report* and has issued strong recommendations that inverters used on the BPS be designed, constructed, and tested rigorously to ensure they can withstand expected instantaneous spikes in voltage that occur during normally cleared BPS faults. NERC also highlighted inadequacies in PRC-024-3 since the standard allows for instantaneous tripping at fairly low overvoltage levels.[19] The PRC-024-3 curves are intended as point of interconnection (POI) voltage measurements, not inverter terminal voltage measurements; however, industry has not developed standardized methods to ensure inverter-level protections are sufficient for various dynamic (sub-cycle) POI voltage levels during faults. This would require extensive EMT modeling and studies for each interconnecting facility; NERC has strongly recommended that these types of studies be conducted for future interconnections to avoid systemic inverter tripping concerns that should be identified during interconnection studies.

In the 2022 Odessa Disturbance, one large facility with two units had many inverters trip on instantaneous ac overvoltage protection. The protection was set at 1.25 pu for 0.2 ms. Inverter overvoltage conditions occur upon fault clearing as observed in inverter terminal voltages captured with inverter oscillography data (see **Figure 1.5**). Terminal voltage is depressed during the fault and then rises very rapidly at fault clearing. At the time of fault clearing, the inverter ac current had recovered (see **Figure 1.6**) and was injecting a significant amount of reactive current (see **Figure 1.7**). The large injection of reactive current, based on measurements taken during fault conditions, and the near-instantaneous recovery of terminal voltage results in high inverter terminal voltage conditions and the inverters subsequently trip themselves off-line. The cause of this tripping is attributed to the inverter control strategy regarding its injection of active and reactive current during and immediately following BPS faults (i.e., dynamic reactive power K-factor settings) in addition to the inverter overvoltage trip settings.

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[19] The PRC-024-3 curves are intended to use RMS filtered voltage measurements; however, the standard does not preclude an entity or equipment manufacturer from using instantaneous peak quantities at those same voltage levels. This has resulted in inverter protections set outside the curve yet highly susceptible to tripping.

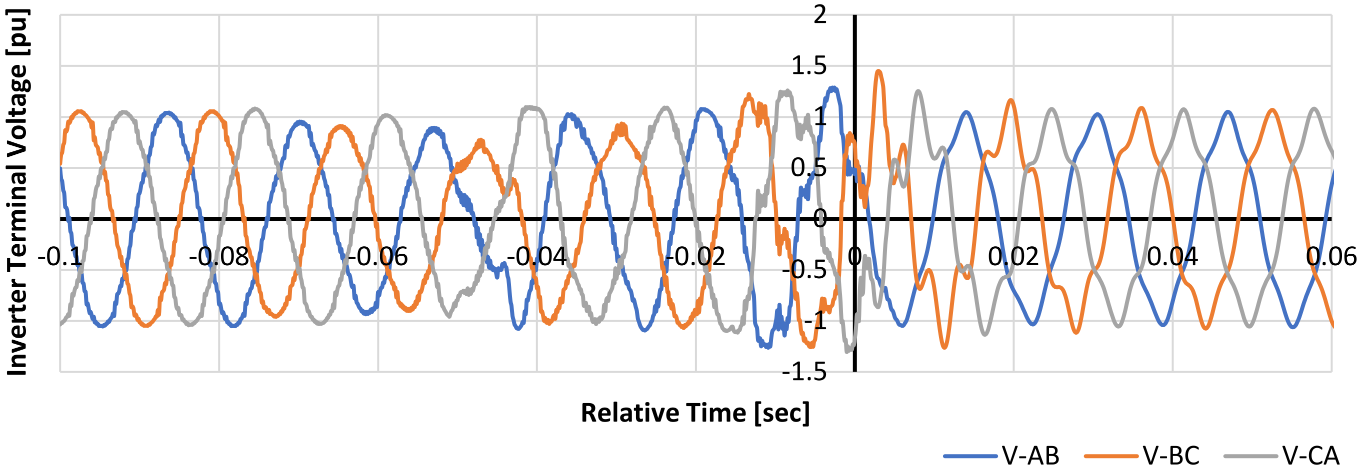

Figure 1.5: Inverter-Level High Speed Oscillography Voltage Data

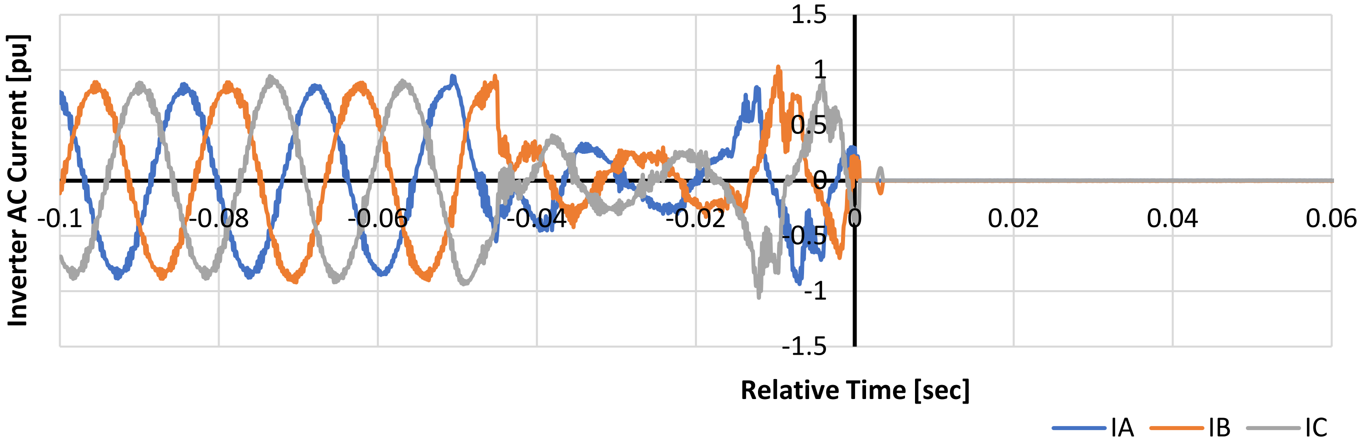

Figure 1.6: Inverter-Level High Speed Oscillography Current Data

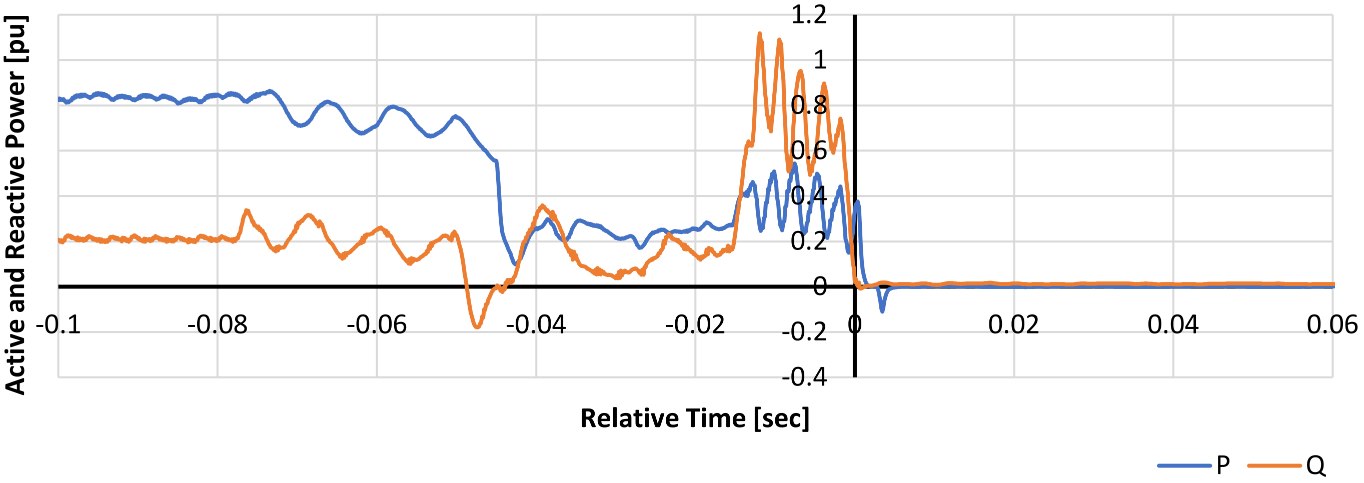

Figure 1.7: Inverter-Level High Speed Oscillography Active and Reactive Power Data

The inverter manufacturer developed an update to inverter protection settings that extends the ac overvoltage protection as shown in Figure 1.8. The changes involve modifications to both the default user-settable ac overvoltage protection settings as well as the inverter protection settings only available to the equipment manufacturer (i.e., not user-settable). Therefore, these updates require an inverter manufacturer field technician on-site to modify internal inverter protection settings so that they are more reflective of actual equipment capability. The modified settings have been tested using EMT modeling as well as in the field. The inverter manufacturer has stated that the settings are generally suitable down to moderate short circuit strength levels but will require detailed EMT modeling to ensure ride-through capability for low short circuit strength network conditions.

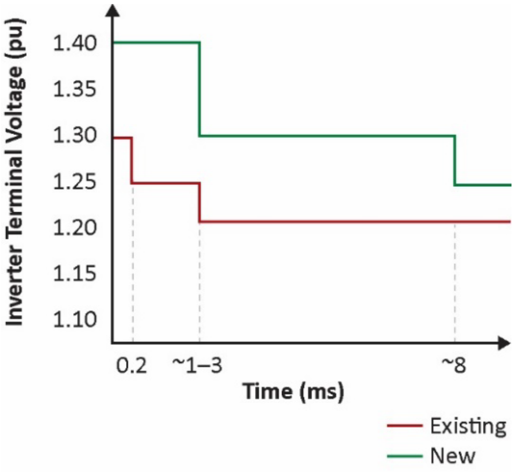

Figure 1.8: Existing and Proposed Inverter AC Overvoltage Protection Settings

Inverter DC Voltage Unbalance Tripping

Inverter dc voltage unbalance tripping was observed at three separate facilities with the same inverter make yet all different models of inverters. This cause of tripping was also observed in California in 2021 for the same types of inverters.[20] Tripping occurs when a large voltage difference between positive and negative terminals on the inverter dc bus is measured (|V(P)–V(N)| > Threshold). Unbalanced (negative sequence) voltage on the ac side of the inverter can cause a ripple on the dc bus that must be managed by inverter inner control loops. If these loops are not sufficiently fast enough to respond to grid fault events, the dc-side ripple may surpass the trip threshold and cause inverter tripping for ac-side faults.

NERC and WECC identified that a firmware upgrade was available for existing solar PV facilities after the 2021 solar PV disturbances in California. The firmware upgrade reconfigures the way that inner controls respond and enables much faster and tighter control of inverter module currents in response to grid disturbances. The research team at the inverter manufacturer has stated that this firmware upgrade will likely reduce the tendency of inverters tripping on dc voltage imbalance issues if deployed.

It is clear that these firmware upgrades were not rolled out between 2021 and 2022, and the upgrades should be implemented immediately to mitigate any unnecessary inverter tripping. The inverter manufacturer informed NERC, Texas RE, and ERCOT that they are rolling this update out fleet-wide for specific models of inverters with the Texas Interconnection being the top priority. ERCOT should ensure that all facilities with inverters from this manufacturer have updated their firmware to mitigate these performance issues as quickly as possible. All GOs should check with their inverter manufacturer to ensure that unexpected dc voltage unbalance tripping is not a concern.

The inverter manufacturer informed NERC, Texas RE, and ERCOT that no changes being made to the dc bus controls will affect the EMT models supplied by the manufacturer for existing facilities. This inverter manufacturer does not

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[20] https://www.nerc.com/pa/rrm/ea/Documents/NERC_2021_California_Solar_PV_Disturbances_Report.pdf

model dc bus controls in their EMT models and assumes an ideal voltage source on the dc bus. There are also no dc bus protections modeled.

Feeder Underfrequency Tripping

Feeder protective relaying was configured with underfrequency trip settings of 57.5 Hz with an instantaneous (0.0 sec) timer. Instantaneously measured frequency was the primary contributor to erroneous widespread solar PV tripping in the Blue Cut Fire event in Southern California of August 2016,[21] and NERC subsequently issued multiple guidelines and an alert with strong recommendations to eliminate its use. PRC-024-2 was modified to clarify this issue as well. However, it is clear that industry is not adhering to the recommendations or clarifications set forth in the guidelines, alert, or modifications to the standard. This finding further strengthens the need for a performance-based comprehensive ride-through standard to replace the existing PRC-024-3.

Furthermore, NERC has recognized through discussions with affected GOs that the protections are not set based on equipment ratings. Rather, protection settings are simply compared to requirements set in PRC-024 or any other local interconnection requirements and are set wider than those requirements with no technical basis for their use. Discussions clearly demonstrated that some GOs and consultants were unfamiliar with the actual equipment ratings of the assets in the plant and could not demonstrate how their protection systems were coordinated with those ratings. The focus was simply on adjusting the protections within a range of adjustability to ensure compliance with any necessary requirements. PRC-024-3 sought to clarify this misconception; however, it is not being adhered to by industry.

Unknown Tripping

Multiple solar PV facilities tripped for unknown reasons, attributed to issues including inverter firmware issues and internal inverter logs being overwritten. There were no systemic causes of lack of data or information in this event other than the majority of these facilities have legacy KACO inverters installed.

Incorrect Ride-Through Configuration

One facility had all inverters misconfigured with low voltage ride through settings disabled. The mode was also incorrectly set such that all inverters would go to zero active power output when entering ride-through mode (configured to occur below 0.9 pu voltage), and the reactive power would change proportionally based on the change in voltage with a K-factor control. The GO identified that the inverters were misconfigured during its investigation of the facility; the GO changed all inverters to a mode that allows for both active and reactive power injection during ride-through operation.

Momentary Cessation and Power Supply Failure

One facility has inverters that were previously configured with momentary cessation. Based on the 2019 NERC alert, the GO modified all inverters at the facility to eliminate momentary cessation. However, these inverters are not equipped with uninterruptible power supplies; they rely on momentary cessation during low voltage conditions to mitigate tripping issues caused by hardware limitations. The manufacturer stated that the two options available to correct this issue are as follows:

- Turn momentary cessation back on with settings around 0.9 pu voltage threshold and a 200 ms delay to start recovery with a 500%/second recovery ramp rate.
- Leave momentary cessation disabled and install uninterruptible power supplies on the inverters so that the facility can provide dynamic reactive power support during faults. However, the inverter manufacturer could not confirm that this option would guarantee effective ride-through performance for large phase angle changes or a high rate-of-change-of-frequency such as what was experienced for both Odessa disturbances.

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[21] https://www.nerc.com/pa/rrm/ea/Pages/1200-MW-Fault-Induced-Solar-Photovoltaic-Resource-Interruption-Disturbance-Report.aspx

NERC strongly recommends installing inverter uninterruptible power supplies to avoid the need for momentary cessation. This is a plant design choice and not a legitimate reason for the facility to not be able to provide dynamic reactive power support (i.e., an essential reliability service) as most all other plants do.

Reactive Power Support K-Factor Modifications

At least one major solar PV inverter manufacturer has stated that they believe their inverters may have challenges riding through normal BPS faults with a voltage ride-through dynamic reactive power support proportional "K-factor"[22] larger than 1. Due to this limitation, the manufacturer has been changing the K-factor to a value of 1 (default K-factor is typically set to the maximum option of 2). While changes to the K-factor can be an appropriate change when mitigating a weak grid or subsynchronous resonance stability issues (in conjunction with other control changes), changes to these gains with the intent to only reduce current injection to avoid triggering overvoltage protection is not desirable and should not be considered an acceptable mitigation strategy to ensure ride-through performance. Reducing k-factor and thus dynamic reactive support and reactive current injection during and immediately after faults could impact voltage stability and may be harmful to reliability of the BPS.

Decreasing K-factor values will reduce reactive power contribution during fault ride-through but may overly limit the resource's ability to deliver its dynamic reactive capability to support the BPS during and immediately following the fault. It is more appropriate to address the underlying issue which is that the reactive current injection based on RMS voltage causes instantaneous overvoltage beyond the inverter self-protection limit due to fast voltage recovery upon fault clearance. Inverter manufacturers should reevaluate their design criteria and mitigate erroneous tripping by ensuring that the inverter does not drive itself past its own protection limits when providing grid support during fault ride-through. TPs and PCs should develop clear and firm performance requirements for reactive support during and post fault. Manufacturers should design their equipment and self-protection to be capable of meeting those requirements without exceeding inverter capabilities. Generator owners should perform, with inverter manufacturer support, detailed tuning of voltage ride-through K-factor along with other inverter and plant-level controller parameters should be performed to optimize the support of the grid without triggering inverter protection.

Other Findings

In addition to the detailed findings described in this chapter, there are multiple findings that will help close existing gaps in the interconnection process prior to commercial operation to support BPS reliability. The abnormal performance issues observed by all affected solar PV facilities should have been identified during the interconnection study process, during plant design, or during commissioning. The occurrence (and systemic recurrence) of performance issues demonstrates a failure of the interconnection studies, commissioning practices, and periodic plant performance review.

Key Takeaway

The abnormal performance issues observed by all affected solar PV facilities should have been identified during the interconnection study process, during plant design, or during commissioning. The occurrence (and systemic recurrence) of performance issues demonstrates a failure of the interconnection studies, commissioning practices, and periodic plant performance review.

Need for Improvements to Factory Acceptance Testing and Unit Model Validation

Improvements to both inverter-based resource equipment capabilities and the representation of those capabilities in dynamic models are critical for sufficiently analyzing BPS reliability impacts when inverter-based resources are connected to the BPS. ERCOT has implemented an inverter-based resource unit model validation requirement that provides evidence that the EMT model for the resource is a sufficiently accurate representation of the facility. While

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[22] K-factor is a proportional control that relates the amount of reactive power support based on the deviation of voltage from nominal. For example, K-factor of 1 results in 100% reactive power injection at 0.0 pu voltage; K-factor of 2 results in 100% reactive power injection at 0.5 pu voltage.

this new requirement in ERCOT is very important, there is room for improvement in order to increase the capabilities and accuracy of inverter-based resource models.

At present, the majority of the ERCOT unit model validation tests are made up of small signal disturbance and fault events. Additional hardware in the loop tests for large disturbance behavior can be conducted by the equipment manufacturer and supplied to the developer/GO for submittal and verification by the TP and PC as part of the interconnection process (and definitely) prior to the commercial operation date. If certain protection functions are not able to be replicated in either the hardware-in-the-loop or EMT model space, these tests would still provide benefit with a clear description of the limitations of the resource and the models.

In addition to a more robust suite of unit model validation tests, the same accuracy requirements should be applied to the model used in the positive sequence dynamic modeling space. A comparison between the performance of actual products, EMT models, and positive sequence dynamic models will provide evidence of model accuracy across the board and uncover model deficiencies. This evidence is an important step towards more accurate modeling across all domains and provides a necessary picture of limitations in each model (which is currently not well understood by the TP or PC).

Need for Improved Commissioning Processes

The failure to predict these widespread inverter-based resource reductions is evidence of a significant gap between the representation of the facilities (i.e., the model used to study possible reliability impacts and allow interconnection) and how the facility was configured prior to commercial operation. Improvements need to be made to the commissioning process such that there is validation and verification that the model used to study the facility's impact on the BPS is indeed representative of the facility's as-built parameters and performance before commercial operation. A new facility should not be allowed to enter commercial operation until there is sufficient evidence that the facility's as-built performance and installed control parameters match when compared to the model used throughout the interconnection process. BPS reliability depends on the accuracy, fidelity, and integrity of the models used to study the impacts that the interconnecting facility will have on the BPS. Any discrepancies between the studies conducted and plant configuration should be addressed prior to commercial operation through additional verification steps during trial operation.

The risk to project development timeline can be mitigated through additional due diligence throughout the interconnection and design process. GOs should ensure that all studies performed for their facility include models that are as representative of the facility as possible. GOs and developers can reduce project risks during the interconnection and commissioning process by ensuring that the models and as-built settings match throughout the entire process; any changes to planned equipment should be reported to the transmission entity immediately. This includes, but is not limited to, updating powerflow model representations as the site design matures, including all controlled equipment and their parameters in the powerflow model (e.g., load tap changers, medium voltage shunt control) as well as ensuring that all dynamic model parameters are set to match the proposed as-built parameters as accurately as possible. The use of user-defined EMT and positive sequence models along with support from equipment manufacturers throughout the site design and interconnection process will help mitigate any project timeline delays that could potentially be caused by additional verification and validation.

Chapter 2: Comparison and Follow-Up of Odessa Disturbances

This chapter shows a comparison of the 2021 and 2022 Odessa disturbances since the initiating event for each was nearly identical. The goal is to illustrate the key differences between the events as well as to highlight the work that has been done by ERCOT and the affected GOs to mitigate performance issues. This chapter will also identify areas for improvement in terms of BPS-connected solar PV plant performance moving forward.

Comparison of 2021 and 2022 Odessa Disturbance Causes of Reduction

Key Takeaway
The majority of solar PV facilities involved in the 2021 Odessa Disturbance were also involved in the 2022 Odessa Disturbance. Some facilities made changes to mitigate the causes of reductions after the first event but subsequently tripped on other unexpected forms of protection in the second event.

After the 2021 Odessa Disturbance, ERCOT initiated a regional Inverter-Based Resource Task Force[23] to coordinate with inverter-based resource GOs and GOPs as well as TOs, TOPs, inverter-based resource vendors and equipment manufacturers, and other interested parties. That group meets on a monthly basis to discuss the findings of the disturbances analyzed by ERCOT and any necessary mitigating actions to eliminate abnormal performance issues. The ERCOT Inverter-Based Resource Task Force is an excellent example of industry responding to the identified risk as well as developing and deploying risk mitigations to address the issues. **Table 2.1** shows the cause of reduction for each affected plant in the 2021 Odessa Disturbance and the corrective actions made to the facilities before the 2022 Odessa Disturbance occurred. **Table 2.1** also shows the cause of reduction for the 2022 Odessa Disturbance to illustrate the different causes of reductions. The following are key findings from this comparison:

- The majority of solar PV facilities involved in the 2021 Odessa Disturbance were also involved in the 2022 Odessa Disturbance. Only one solar PV facility was able to deploy mitigating actions between events that resulted in appropriate ride-through performance; this plant is over 250 miles from the initiating fault location. This raises significant concerns for the capability of solar PV facilities to ride-through normally-cleared BPS faults to support the BPS with essential reliability services.
- Some solar PV facilities that tripped on PLL loss of synchronism or inverter ac overvoltage protection in the 2021 Odessa Disturbance tripped on passive anti-islanding (voltage phase jump) protection in the 2022 Odessa Disturbance. Any one of multiple layers of protective functions within the inverter can result in tripping, and these need to be comprehensively studied with EMT models.
- Corrective actions to address unnecessary feeder-level tripping from the 2021 Odessa Disturbance resulted in the same facilities uncovering inverter-level protection and control issues in the 2022 Odessa Disturbance.

Table 2.1: Causes of Tripping and Changes Made Between Events

Plant	Odessa 2021 Cause of Reduction	Changes Made to Affected Plant	Odessa 2022 Cause of Reduction
Plant A	Unknown	None	Not involved
Plant B	PLL loss of synchronism tripping	PLL loss of synchronism protection function disabled in all inverters	Passive anti-islanding (voltage phase jump)
Plant C and Plant D	Inverter instantaneous ac overvoltage tripping	None; EMT modeling to explore decreasing reactive power support (K-factor setting) in progress during 2022 Odessa Disturbance	Passive anti-islanding (voltage phase jump)

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[23] https://www.ercot.com/committees/ros/ibrtf

Table 2.1: Causes of Tripping and Changes Made Between Events

Plant	Odessa 2021 Cause of Reduction	Changes Made to Affected Plant	Odessa 2022 Cause of Reduction
Plant E	Feeder instantaneous underfrequency tripping	None by 2022 Odessa Disturbance; has since increased feeder relay frequency measurement window to 10 cycles	Inverter ac overvoltage
Plant F	Inverter instantaneous underfrequency tripping	None by 2022 Odessa Disturbance; has since increased frequency measurement window to 2 seconds	Unknown (Inverter logs overwritten)
Plant G and Plant H	PLL loss of synchronism tripping	PLL loss of synchronism protection function disabled in all inverters	Not involved
Plant I and Plant J	Inverter instantaneous ac overvoltage tripping	None by 2022 Odessa Disturbance; EMT modeling for decreasing k-factor in progress during 2022 Odessa Disturbance; have since decreased reactive power support (K-factor setting) from 2 to 1 and increased overvoltage threshold from 1.25 pu to 1.4 pu	Passive anti-islanding (voltage phase jump)
Plant K and Plant L	Momentary cessation with slow recovery due to plant controller interactions	Replaced plant-level controller and implemented logic to speed recovery	Momentary cessation/loss of inverter auxiliary power
Plant M	Feeder instantaneous ac overvoltage tripping	Disabled all feeder breaker overvoltage protection	Low voltage ride-through mode disabled; slow inverter ramp rate
Plant N and Plant O	Unknown	None	Unknown

Follow-Up Activities since 2022 Odessa Disturbance

ERCOT has worked with all GOs of solar PV facilities involved in the 2022 Odessa Disturbance to ensure that mitigating measures are being implemented to address the unreliable performance issues observed during the event. An overview of mitigating measures for each facility are provided in Table 2.2. The following are key findings from this comparison:

- ERCOT has followed up extensively with every affected facility to seek corrective actions to mitigate future performance issues.
- Inverter manufacturers have been developing mitigating actions to address the causes of reduction that occurred at multiple facilities. These corrections include the following:
  - Disabling passive anti-islanding protection or increasing trip thresholds
  - Increasing ac overvoltage protection settings closer to equipment ratings
  - Lengthening frequency protection timers to avoid tripping on instantaneous spikes in frequency calculations
  - Deploying inverter firmware updates to mitigate possible dc bus voltage imbalance issues

  - Enabling appropriate fault ride-through modes of operations
  - Modifying fault ride-through settings to ensure stable inverter response
- GOs and inverter manufacturers are decreasing reactive power injection (an essential reliability service to the BPS) to ensure reliable inverter ride-through capability. These corrections appear to be occurring without sufficient system-wide analyses to fully vet their impacts to the BPS.

Table 2.2: Changes Made After 2022 Odessa Disturbance

Plant	Odessa 2022 Cause of Reduction	Changes Made After 2022 Odessa Disturbance
Plant B	Passive anti-islanding (voltage phase jump)	Passive anti-islanding disabled and high voltage ride through trip thresholds increased for all inverters in September 2022. Dynamic reactive power K-factor will be decreased from 2 to 1 at a later date after additional studies.
Plant C	Passive anti-islanding (voltage phase jump)	None. GO has developed mitigation plan but is waiting on inverter manufacturer to schedule dates for implementation. Changes include changing dynamic reactive power K-factor from 2 to 1, increasing overvoltage protection trip threshold from 1.25 to 1.4, increasing overvoltage tripping timers, updating firmware to mitigate overcurrent protection issues, and increasing passive anti-islanding protection setting from 15 to 35 degrees.
Plant E and Plant U	AC overvoltage	Passive anti-islanding trip threshold will be increased from 15 degrees to 35 degrees. Dynamic reactive power K-factor will be changed from 2 to 1 (reducing dynamic reactive support) to attempt to stabilize current injection during faults. Inverter instantaneous ac overvoltage protection will be increased from 1.25 pu to 1.4 pu. These changes should be completed by mid-December 2022. Awaiting inverter manufacturer approval to change ac overcurrent protection settings (requires inverter updates).
Plant F	Unknown (inverter logs overwritten)	Increased time duration of inverter frequency protection (UF<57.5 Hz; UF>61.8 Hz) from 60 ms to 2,000 ms.
Plant I and Plant J	Passive anti-islanding (voltage phase jump)	Passive anti-islanding trip threshold increased from 15 to 35 degrees. Dynamic reactive power K-factor changed from 2 to 1 (reducing dynamic reactive support) to attempt to stabilize current injection during faults. Inverter instantaneous ac overvoltage protection increased from 1.25 pu to 1.4 pu. These changes have been completed. Awaiting inverter manufacturer approval to change ac overcurrent protection settings (requires inverter updates).
Plant V	DC bus voltage unbalance	Firmware upgrade to all inverters to mitigate dc voltage imbalance issue has been provided by inverter manufacturer and will be implemented no later than end of November 2022.

Table 2.2: Changes Made After 2022 Odessa Disturbance

Plant	Odessa 2022 Cause of Reduction	Changes Made After 2022 Odessa Disturbance
Plant K and Plant L	Momentary cessation (loss of auxiliary power)	Low voltage ride-through settings modified. GO expects the plant to return from momentary cessation to predisturbance output within 1 sec for voltages below 0.9 pu. Plant will likely fail to ride through (i.e., trip) for events involving large phase angle changes or high rate-of-change-of-frequency as observed in both the 2021 and 2022 Odessa disturbances.
Plant M	Low voltage ride through mode disabled, slow inverter recovery	Voltage ride-through mode enabled. Thresholds for low and high voltage set to 0.9 pu and 1.15 pu, respectively. Fastest ac overvoltage protection increased to 1.35 pu with delay of 0.5 seconds. Ride-through mode control changed to reduce the active power reduction with reactive power K-factor changed to 1.
Plant N and Plant O	Unknown	Increased all frequency trip thresholds to 5-second delay. Widened voltage trip settings to 1.30 pu for 0.06 sec, 1.10 pu for 5 seconds, 0.9 pu for 5 seconds, and 0.1 pu for 1 second. Settings changes completed in September 2022. Inverter manufacturer is currently working on improving logging capabilities and will be implemented by end of 2022.
Plant P	Inverter instantaneous ac overcurrent	None. GO has stated that the inverter manufacturer claims there are no corrective actions for these overcurrent limits and will not share protection logic.
Plant Q	Inverter instantaneous ac overcurrent	Memory cards will be replaced with higher capacity cards to enable better inverter logging. Implementation date is not yet determined. No additional performance improvements planned by GO at this time.
Plant R	Inverter instantaneous ac overcurrent	Passive anti-islanding trip threshold will be increased from 15 degrees to 35 degrees. Dynamic reactive power K-factor will be changed from 2 to 1 (reducing dynamic reactive support) to attempt to stabilize current injection during faults. Inverter instantaneous ac overvoltage protection will be increased from 1.25 pu to 1.4 pu. These changes should be completed by mid-December 2022. Awaiting inverter manufacturer approval to change ac overcurrent protection settings (requires inverter updates).
Plant S	Inverter dc voltage imbalance	Firmware upgrade to all inverters to mitigate dc voltage imbalance issue has been provided by inverter manufacturer implemented in August 2022.
Plant T	Inverter instantaneous ac overcurrent	Passive anti-islanding trip threshold will be increased from 15 degrees to 35 degrees. Dynamic reactive power K-factor will be changed from 2 to 1 (reducing dynamic reactive support) to attempt to stabilize current injection during faults. Inverter instantaneous ac overvoltage protection will be increased from 1.25 pu to 1.4 pu. These changes should be completed by mid-December 2022. Awaiting inverter manufacturer approval to change ac overcurrent protection settings (requires inverter updates).

Chapter 3: Modeling Assessment

This chapter focuses specifically on modeling practices and challenges for the affected solar PV facilities in the 2022 Odessa Disturbance. The findings are also applicable to inverter-based resources across all Interconnections. Key findings and recommendations in this report highlight that industry faces *significant* dynamic modeling challenges; while this event involved solar PV resources, the same challenges exist for other inverter-based resources.

NERC continues to provide strong recommendations to industry to enhance interconnection requirements, modeling requirements, and model quality checks to ensure that dynamic models used to represent these facilities during interconnection studies, long-term planning studies, and operations planning studies are representative of the actual installed equipment. Local TO interconnection requirements per NERC FAC-001 and FAC-002 should be established to address these known modeling difficulties. The generic nature of the provided models, the lack of user-defined models validated by the equipment manufacturer, the absence of EMT model quality checks, and the overall poor accuracy and fidelity of the models all contributed to the 2022 and 2021 Odessa disturbances.

Key Takeaway
Significant deficiencies exist for inverter-based resources both in positive sequence and EMT models. This includes the use of standard library models that cannot match actual inverter controls, incorrect parameterization of the models, insufficient model fidelity (i.e., missing protections or controls), and lack of model quality checks.

This chapter highlights that shortcuts were taken during the interconnection study process such that ERCOT could not ensure that high-quality models are used throughout, leading to potential performance issues that go unnoticed until significant widespread reliability issues arise. This leaves the BPS prone to unknown and unexpected performance issues that could include unreliable ride-through performance, unstable operation in low short circuit strength networks, and subsynchronous control interactions as well as other issues. NERC has recommended enhancements to the FERC generator interconnection agreements and procedures to support reliable connection of inverter-based resources to the BPS. NERC also recognizes that ERCOT will need to implement similar updates leveraging their corresponding market rules and protocols.

Review of Modeling Capabilities

Multiple types of inverter tripping have been identified in the 2022 Odessa Disturbance and discussed in past NERC disturbance reports on solar PV resource loss events.[24] **Table 3.1** shows the causes of inverter tripping and whether these causes of tripping can even be modeled in positive sequence and EMT simulations.

Table 3.1: Solar PV Tripping and Modeling Capabilities and Practices

Cause of Reduction	Can Be Accurately Modeled in Positive Sequence Simulations?	Can Be Accurately Modeled in EMT Simulations?
Inverter Instantaneous AC Overcurrent	No	Yes
Passive Anti-Islanding (Phase Jump)	Yes[a]	Yes
Inverter Instantaneous AC Overvoltage	No	Yes
Inverter DC Bus Voltage Unbalance	No	Yes
Feeder Underfrequency	No[b]	No[c]
Incorrect Ride-Through Configuration	Yes	Yes

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[24] https://www.nerc.com/pa/rrm/ea/Pages/Major-Event-Reports.aspx

Table 3.1: Solar PV Tripping and Modeling Capabilities and Practices

Cause of Reduction	Can Be Accurately Modeled in Positive Sequence Simulations?	Can Be Accurately Modeled in EMT Simulations?
Plant Controller Interactions	Yes[d]	Yes[e]
Momentary Cessation	Yes	Yes
Inverter Overfrequency	No[b]	Yes
PLL Loss of Synchronism	No	Yes
Feeder AC Overvoltage	Yes[f]	Yes
Inverter Underfrequency	No[b]	Yes

[a] This is based on a proper representation of the PLL dynamics and possible implementation issues in the software platforms.
[b] This is due to the instantaneous nature of this specific protective function as it was configured.
[c] This is due to very limited protective relay models in EMT currently.
[d] This requires the use of a user-defined model from the equipment manufacturer(s) and detailed model development.
[e] This requires representation of time delays between inverters, plant controller, and other controlled devices.
[f] This protection uses a filtered RMS quantity with zero time delay. This is a correction to the *2021 Odessa Disturbance Report* Table 2.1.

The following are observations and key takeaways from **Table 3.1**:

- **The Need for EMT Simulations to Study Inverter-Based Resource Ride-Through Performance**
  There are nuances to positive sequence modeling practices and inherent limitations with positive sequence simulation platforms; EMT studies are needed to adequately assess ride-through performance, including the potential operation of protections and controls of inverter-based resources moving forward. While mitigating the abnormal performance issues would address ride-through performance, the lack of representations of these controls and protections lead to simulations that are unable to identify reliability issues before real-time operation. This leads to possible systemic BPS reliability issues that can pose a significant risk.

- **Inverter Instantaneous AC Overcurrent and Inverter Instantaneous AC Overvoltage**
  These inverter-level protective functions cannot be accurately modeled in positive sequence models since they operate on instantaneous phase quantities. They are typically hardcoded and not available to the model user in EMT models; therefore, the equipment manufacturer must attest that the EMT model includes these protections in the model and that they are enabled.

- **DC-Side Bus Protection**
  NERC confirmed with one major inverter manufacturer involved in the 2022 Odessa Disturbance that dc-side bus protections are not modeled in the positive sequence or EMT models provided to the GO and submitted to the TP and PC. Representation of the dc bus and associated protections in EMT models is a crucial component of EMT model quality and accuracy; not representing this component in the model is a significant deficiency in the accuracy of the EMT model and its ability to identify potential tripping issues.

- **Feeder-Level Protection Modeling**
  NERC has highlighted that feeder-level frequency and voltage protection have tripped multiple plants in past events and that those protective functions may be unnecessary. The majority of tripping is due to instantaneous time delays in relay settings. Regardless, any operational feeder-level protection should be modeled (where possible) in both the EMT and positive sequence models. In positive sequence simulations, instantaneous frequency calculations can cause erroneous model tripping during simulated faults; however, there is also evidence that feeder and substation protection devices also show spikes in frequency that have

the ability to erroneously activate the protection.[25] In EMT simulations, instantaneous protection can be represent but requires accurate models supplied and verified by the equipment manufacturers. This may include verified EMT models of protective relays from the relay manufacturers for specific types of protection where applicable.

Inverter Manufacturer Input on Modeling Capabilities

NERC requested additional information from the two inverter manufacturers that constituted the majority of abnormal performance issues for the 2022 Odessa Disturbance. For the purposes of this discussion, inverter-based resource controller deficiencies and plant protective relaying were not considered; the follow-up focused specifically on inverter-level tripping and controls and whether the dynamic models (both positive sequence and EMT) can recreate the disturbance. The following are key observations from discussions with both manufacturers:

- **Inability of Positive Sequence Simulations to Capture Potential Causes of Tripping**
  Positive sequence simulations inherently cannot (and/or do not) capture the instantaneous phase quantities used in inverter protections (e.g., ac overcurrent and ac overvoltage protection). They also do not represent complicated PLL logic (e.g., passive anti-islanding protection) nor do they represent the dc bus (e.g., dc voltage imbalance protection). Therefore, ride-through performance issues caused by inadvertent protection operation generally cannot be studied with positive sequence simulations.

- **Standard Library Model Inadequacy**
  Both manufacturers highlighted that the positive sequence standard library models have significant limitations in their ability to represent inverter controls and protections. Beyond those listed above, the standardized block diagram representation of highly complex controls fails to accurately represent the possible modes of operation and control strategies used in the inverters. Inverter manufacturers highly recommend and strongly support the use of detailed user-defined models for inverter-based resources for this reason. They also support general improvements to user-defined model usability and support software vendor enhancements to handling user-defined models so that users are not dealing with case crashing and challenges from past industry experience working with user-defined models.

- **EMT Modeling Capabilities**
  EMT modeling practices were mixed across manufacturers with some protections modeled and others not modeled. Discussions with the manufacturers highlighted the following key points:
  - All ac-side protections either are already modeled or could be modeled relatively easily. This includes ac overcurrent protection ac overvoltage protection, anti-islanding protection, etc. NERC strongly recommends that these protection functions and settings be represented and enabled in EMT models for use in ride-through studies. They should match the equipment installed (or planned to be installed) in the field.
  - DC-side modeling is limited based on current practices. DC-side protection is not modeled because the dc bus is generally represented as an ideal dc voltage source, and dc-side dynamics are generally ignored; however, the dc side could be represented more explicitly if desired by industry. NERC recommends EMT models be enhanced to better represent the dc bus and possible dc bus protections that could trip the inverters.
  - Both manufacturers were up front in stating that model requirement documents generally lack any specificity regarding what should and should not be modeled, leaving modeling expectations unclear and

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[25] Balance of plant protections, even if instantaneous, should be represented in positive sequence and EMT models where applicable. For example, spikes in positive sequence simulations may spuriously trip instantaneous frequency protection; however, identification of this possible occurrence would result in an evaluation of whether that instantaneous frequency tripping is even necessary and will improve ride-through performance by setting protections based on actual equipment capabilities.

ambiguous.[26] This reinforces NERC's strong recommendations for more explicit and clear modeling requirements industry-wide. Interconnection requirements should explicitly state expectations for protections and controls. Model quality checks must be thoroughly conducted throughout the interconnection study process. Any projects not meeting the requirements or model quality checks should not be allowed interconnection until the models match actual performance and are verified by the manufacturers.

Additional Insights from Inverter Manufacturers Regarding Model Quality

Technical discussions with inverter manufacturers provided useful insights on their experience working with GOs, developers, TOs, TPs, and PCs throughout the interconnection process and in the handling of post-commissioning updates. The following are key points and recommendations for industry regarding improving model quality efforts:

- **There is a need for clearer and more explicit modeling and performance requirements.**
  Inverter manufacturers need to be able to justify any resources spent on enhancing model quality. For example, many protective functions that are not currently modeled in the EMT model space are not missing due to technical limitations; they have not been implemented due to a lack of explicit requirements from GOs that would be passed thorough by requirements set by TPs and PCs.

  All TPs and PCs should create explicit and detailed requirements for product performance, model quality, and model validation and verification. This will allow equipment manufacturers to justify these necessary model quality and fidelity updates as there would be a regulatory need. Industry cannot rely on "best practice" and hope that correct model features are added by equipment manufacturers.

- **There is a need to address failures in the commissioning process that lead to models not matching the actual commissioned facility.**
  The equipment manufacturers lose significant visibility during the interconnection process. Many times, once the equipment models are provided to the developer/GO, the final models that include tuned parameters or enabled features are not incorporated into the commissioning process. This creates an environment where the representation of the facility that is used throughout the interconnection study process does not match the parameters and features that are commissioned on-site. Due to this disconnect and the lack of site-specific modeling as a tool for facility design, many inverter-based resources are commissioned with default settings that are likely not represented in the model. This leads to widespread inaccuracies in the models used to plan and operate a reliable BPS. This is a significant reliability issue facing the industry presently. Industry needs to ensure that detailed EMT and positive sequence modeling is performed throughout the interconnection process and that these models are continuously updated to reflect changes in the control parameters that affect the performance of the inverter-based resource.

Key Takeaway
Inverter manufacturers highlighted that many of the modeling and study issues stem from a lack of clear modeling requirements. They also emphasized a disconnect during the commissioning process that likely leads to inaccurate models due to insufficient "true up" during commissioning and trial operation. Lastly, the manufacturers strongly advocated for the use of user-defined models (where necessary) since the standard library models often have deficiencies in accurately representing the inverter controls.

- **There is a need for model submission requirement updates to allow for user-defined models.**
  Inverter manufacturers prefer to use their verified and user-defined models since these models can significantly reduce the risk to facility designs and support a reliable BPS. Current model submission requirements across the industry either strongly imply that user-defined models are not accepted or

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[26] The most recent ERCOT EMT model guideline checklist includes specificity for model quality and fidelity: https://www.ercot.com/files/docs/2021/04/20/Model_Quality_Guide.zip

completely disallow them. These requirements are a detriment to model quality and hinder detailed and informed facility design decisions and interconnection studies.

Updating industry model submission requirements to accept user-defined EMT and positive sequence models verified by the equipment manufacturers for local reliability studies (including interconnection studies), with detailed usability requirements, will allow for increased model quality and more accurate facility representation. Any user-defined models that are not usable by the TP and PC should be grounds for denial of the project proceeding towards interconnection or possible curtailment during real-time operations.

Types of Models Submitted to ERCOT by GOs

Table 3.2 and Table 3.3 show the positive sequence and EMT models supplied by GOs for the affected solar PV facilities. GOs supplied an EMT model for all sites, and all but one provided a standard library representation of the facility in positive sequence (the other site using a user-defined model).

Table 3.2: Positive Sequence Models for Affected Facilities

Resource	Standard Library Model	User-Defined Model
Solar PV	13	1

Table 3.3: EMT Models for Affected Facilities

Resource	Available EMT Model	No EMT Model
Solar PV	14	0

The use of standard library positive sequence models in combination with a lack of EMT model quality checks and performance validation are root causes for performance issues not being identified during studies. This leads to unexpected performance issues showing up during real-time operations that should have been identified during the interconnection study process. The use of standard library models severely inhibits the ability to accurately represent the performance, as-left configurations, or protections necessary to ensure reliability of the BPS.[27]

ERCOT should perform a comprehensive review of dynamic models for all solar PV facilities with a focus on obtaining site-specific and equipment manufacturer-verified EMT and positive sequence models that include all necessary controls, settings, and protections. GOs should be required to provide verification reports that show that all parameters affecting facility performance and ride-through capability are captured in the model. Model benchmarking between the EMT and positive sequence models should also be required. This system review should include all measures necessary to mitigate abnormal inverter-based resource performance issues when compared to their representation in the model space, and the GO should prepare and submit evidence to ERCOT. This will allow ERCOT to receive verified, validated, and benchmarked EMT and positive sequence models to be used throughout the interconnection and long-term planning processes. The burden of evidence should reside with the GO to ensure that proper dialogue between the GO and equipment manufacturers is occurring and that any gaps between model and product performance are mitigated before final model submission to ERCOT (or documented thoroughly such that these gaps are clear to planning engineers).

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[27] ERCOT does not require the use of standard library models and has always allowed GOs to submit user-defined models. ERCOT has also cautioned GOs when representing inverter-based resources with the standard library models: https://www.ercot.com/files/docs/2021/04/20/Model_Quality_Guide.zip

Plant-Specific Model Review

Table 3.4 illustrates the ability of each plant dynamic model (positive sequence and EMT) to recreate the causes of tripping or abnormal performance identified during the 2022 Odessa Disturbance. NERC and Texas RE did not conduct a detailed review of the dynamic models provided to ERCOT by the GOs; rather, Table 3.4 shows ERCOT's response regarding whether the dynamic models can even represent the cause of reduction given software tool limitations, inverter and balance of plant equipment manufacturer modeling practices, and the accuracy of the models provided when compared to each facility. ERCOT has conducted individual positive sequence model validation for the plants listed in Table 3.4 with a "*" using phasor measurement unit playback methods. None of the positive sequence models showed any notable or abnormal power reduction for the played-in signals. Furthermore, no unit-level EMT model verification was performed.

Table 3.4: Review of Solar PV Facilities

Facility ID	Reduction [MW]	Cause of Reduction	Positive Sequence Model Capable?	EMT Model Capable?
Plant B	133	Inverter phase jump (passive anti-islanding) tripping.	Unknown*	Unknown
Plant C	56	Inverter phase jump (passive anti-islanding) tripping.	Unknown	Unknown
Plant E	159	Inverter ac overvoltage tripping.	Unknown*	Unknown
Plant U	136	Inverter ac overvoltage tripping; feeder underfrequency tripping.	Unknown	Unknown
Plant F	46	Unknown.	Unknown	Unknown
Plant I	196	Inverter phase jump (passive anti-islanding) tripping.	Unknown	Unknown
Plant J	106	Inverter dc voltage imbalance tripping.	Unknown	Unknown
Plants K + L	130	Momentary cessation/inverter power supply failure.	Unknown	Unknown
Plant M	146	Inverter dc voltage imbalance tripping; incorrect inverter ride through configuration.	Unknown	Unknown
Plant N	35	Unknown.	Unknown	Unknown
Plant O	15	Unknown.	Unknown	Unknown
Plant P	10	Inverter ac overcurrent tripping.	Unknown*	Unknown
Plant Q	12	Inverter ac overcurrent tripping.	Unknown	Unknown
Plant R	261	Inverter ac overcurrent tripping.	Unknown*	Unknown
Plant S	94	Inverter dc voltage imbalance tripping.	Unknown*	Unknown
Plant T	176	Inverter ac overcurrent tripping; feeder underfrequency tripping.	Unknown*	Unknown

Some causes of reduction cannot be replicated in the positive sequence simulation domain due to inherent limitations in the software tools (refer to Table 3.1). However, some of the causes of reduction can and should be able to recreate the abnormal performance issues. Table 3.4 shows that ERCOT cannot confirm whether any of the models supplied by GOs are sufficient to represent the causes of reduction that occurred during the 2022 Odessa

Disturbance. The lack of confidence in the dynamic models submitted and the inaccuracies in those models that preclude them from replicating any causes of reduction are a symptom of the following underlying issues:

- Positive sequence standard library models are often used that do not include specific manufacturer controls or protections that often cause abnormal performance issues.
- Generic models are used with default model parameters during the interconnection study process that are never updated after interconnection agreements are signed.
- Models supplied by equipment manufacturers do not include specific protections enabled in the product installed in the field, leaving gaps in understanding of the actual equipment's ride-through performance
- Models supplied during the interconnection study process are not "trued up" at the time of commissioning with changes being made during commissioning that do not reflect what was studied (i.e., lack of validation of as-left settings).

Table 3.4 also indicates that ERCOT is unsure whether the supplied EMT models are able to replicate the abnormal performance issues even though nearly all causes of reduction can be accurately modeled in the EMT model space. As highlighted in the *2021 Odessa Disturbance Report*, ERCOT has enhanced their model quality checks (described below in more detail) but is uncertain about the quality of models for existing plants while that process is implemented. NERC has previously stated and will reiterate here that extensive EMT model quality checks must be conducted throughout the interconnection study process to ensure that the model accurately reflects all controls, modes of operation, and protections that could affect the electrical output of the facility. Model developers (i.e., equipment manufacturers) should ensure that protections and controls are accurately represented (where applicable), and the TP and PC should require sufficient documentation from the GO to verify model quality. Commissioning practices should also add an additional layer of defense to "true up" any differences between what was studied and what was installed in the field. Proof of this "true up" should be provided by the GO to the TO, TP, and PC prior to commercial operation; any discrepancies should be addressed prior to commercial operation as part of the interconnection process.

ERCOT Model Quality and Validation Process

The *2021 Odessa Disturbance Report*[28] provides a description of the ERCOT model quality and validation process. ERCOT stated that model quality gaps for affected facilities are partly due to their interconnection prior to the applicable date of ERCOT's most recent requirement changes. As discussed in more depth in that report, some model quality gaps are partly due to the applicability of recent requirement changes, but these gaps are primarily driven by other factors. The use of standard library models precludes ERCOT from accurately studying the affected facilities' performance due to missing protective functions and missing vendor-specific controls. In addition to the use of standard library models, analysis of this disturbance clearly shows a failure to sufficiently represent the as-left facility configurations. NERC strongly recommends that GOs submit quality facility models, either EMT or positive sequence that have been verified to be accurate.

ERCOT has not validated the EMT models; therefore NERC cannot ascertain whether the EMT models submitted by GOs of affected facilities are able to recreate the reductions. ERCOT was able to perform model verification tests on positive sequence models but did not observe the power reductions. This is an artifact of the implementation timeline and applicability of updates to the ERCOT Model Validation Process as described in PGRR-085.[29] The updated process was effective as of March 1, 2021; however, it is only applicable for newly interconnecting plants. Parameter verification is required for all resources by March 2023 and is intended to ensure plant-specific settings are reflected in the models submitted by the GO.

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[28] https://www.nerc.com/pa/rrm/ea/Documents/Odessa_Disturbance_Report.pdf

[29] https://www.ercot.com/files/docs/2021/02/12/085PGRR-12_Board_Report_020921.doc

To illustrate this challenge, Plant M involved in this 2022 Odessa Disturbance was responsible for a reduction of 146 MW that was driven by disabled low voltage ride-through logic and improperly set voltage ride-through thresholds. Plant M provided evidence for the positive sequence model quality check, and ERCOT deemed the plant performance acceptable. The acceptance of the model through the model quality check process, given that every inverter was misconfigured, demonstrates a failure of the model verification process to identify gaps or shortcomings in model accuracy.

For most of the effected facilities, the observed inverter protection systems, threshold, time limits, and hardcoded response logic were not included in the current EMT or positive sequence models provided by the GO (in coordination with the equipment manufacturer). It also does not appear that sufficient model validation and verification was performed in either the EMT or positive sequence domains. This is a significant modeling gap, particularly in the EMT models, as these models are expected to provide such detail in order to identify these potential tripping issues during ride-through simulation tests conducted during interconnection studies. NERC strongly recommends the inclusion of unbalanced faults in the ERCOT EMT model quality test as well as explicit requirements for EMT models to include the ac-side and dc-side protective functions that are enabled at the facility.

EMT models should be provided to ERCOT in conjunction with model parameter verification reports and performance validation reports that compare the installed facility and the specific product’s performance. GOs should ensure that all EMT models submitted to ERCOT reflect the latest as-built or issued-for-construction parameters and performance features subject to the maturity of the facility. For facilities in commercial operation, full parameter verification against an EMT model verified by the equipment manufacturers should be provided as well as a performance benchmark report that compares the verified EMT model and the positive sequence model.

ERCOT did note that none of the EMT models provided were tested for model quality. While this is partly due to the effective date of the requirements, a detailed review and model quality assessment for both EMT and positive sequence models is recommended. NERC strongly recommends that ERCOT follow up with NERC and Texas RE with a detailed assessment of EMT model quality for its BPS-connected inverter-based resource fleet after the effective dates are in place. In particular, the model quality assessment should determine whether the EMT models that GOs provide are site-specific and reflect the actual equipment installed at the facility. Any discrepancies should be corrected immediately. Once the EMT models have been verified against as-built parameters, and the facility performance is deemed appropriate, these EMT models should be used to validate the positive sequence model through a detailed gap analysis.

In addition to closing the gaps in inverter-based resource model quality, ERCOT should also consider a system-wide validation of all models. The *2021 Odessa Disturbance Report* also made recommendations for a system-wide model validation effort[30] to identify models that do not match installed equipment. At present, ERCOT has no plans to conduct a system-wide model validation effort, but NERC makes the same recommendation for this 2022 Odessa event as it is clear that the same deficiencies that lead to the 2021 event are still present in the models used for reliability analysis.

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[30] This would include analyzing the accuracy of the overall ERCOT system model to recreate an actual grid disturbance, such as the 2021 or 2022 Odessa disturbances, to identify dynamic models with deficiencies that need to be corrected.

EMT Model Quality Requirements Improvements

Key Takeaway
Model quality tests intended to check model accuracy are mixed with plant performance tests against interconnection requirements. This appears to incentive inaccurate models that pass performance criteria and disincentives model accuracy throughout the interconnection process.

ERCOT stated that their model quality tests are intended to demonstrate reasonable model performance when compared to the ERCOT performance requirements rather than actually confirming model accuracy compared to as-built facilities. This creates a process where model performance is significantly more important than a model that accurately represents the facility, innately encouraging developers, equipment manufacturers, and GOs to submit a model that simply passes all necessary tests. In order to properly mitigate the gaps in model accuracy produced by this process, ERCOT should focus on obtaining positive sequence and EMT models verified by the equipment manufacturer and confirm that they contain accurate reflections of the controls, settings, and protections installed (or to be installed) on-site. This will help ensure that parameter changes made in the dynamic model to meet ERCOT performance requirements are possible in the actual facility and are able to be mapped back to the facility either during commissioning or through facility parameter updates. ERCOT should report any facilities with inaccurate models (or unwillingness to update modeling deficiencies) to NERC and Regional Entity Compliance Assurance teams in a timely manner.

ERCOT Review of Changes to Inverter Based Resources

ERCOT stated that they are not approving mitigation actions at the affected facilities before those changes are being made in the field nor are they studying the reliability impacts of those changes before they are made. ERCOT only requires that the mitigation plans submitted to ERCOT meet current performance requirements. ERCOT stated that it is in the GO's scope to set facility controls and protection settings such that they meet ride-through and performance requirements. Once mitigation plans are implemented at the facility, ERCOT requires new models be submitted that reflects the changes made. Those models will then be used in future system reliability studies.

ERCOT has not defined qualified changes per the recently approved NERC FAC-002-4.[31] Changes to facilities that affect the electrical output during a disturbance should be studied for potential BPS reliability impacts prior to the change being made in the field. Requirement 1.2 of NERC FAC-002-4 requires analysis of adherence to applicable NERC Reliability Standards, regional and TO planning criteria, and facility interconnection requirements. Modifications, such as protection and control setting changes, should be deemed qualified changes by ERCOT (and all TPs and PCs) and should be studied prior to changes made in the field. NERC also recommends that GOs (in coordination with their equipment manufacturers) provide ERCOT with sufficient evidence of the effectiveness of the mitigation plans, showing before and after performance of the equipment in the simulations (ideally hardware-in-the-loop testing).

As mitigations are deployed for future events, the sequence for determining corrective actions should be improved to ensure that mitigations do not cause other adverse effects. The event analysis, determination of mitigating actions, coordinating with asset owners, updating dynamic models, validating model quality, conducting reliability studies, and approving the changes all require significant resources to complete; this puts a significant strain on ERCOT as the ISO/RTO, especially when EMT studies are needed. New processes may be needed to expedite this process; operating procedures, such as curtailments or other measures to ensure reliable operation of the BPS, may also be needed in cases where entities are not providing updated models or mitigation plans quickly enough.

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[31] https://www.nerc.com/pa/Stand/Project_202005_Modifications_to_FAC001_and_FAC002_/FAC-002-4_final%20Ballot_clean.pdf

Chapter 4: Recommendations and Actions Needed

Table 4.1 provides a list of recommendations and actions needed by applicable entities based on the key findings from this disturbance analysis in the context of prior events analyzed by the ERO Enterprise.

Table 4.1: Recommendations and Actions Needed

Recommendations	Applicability
NERC Standards Enhancements to Address Performance Gaps for Inverter-Based Resources	
Reiteration of Necessary NERC Standards Enhancements Related to Performance As highlighted in the 2021 Odessa Disturbance, enhancements are needed to NERC Reliability Standards immediately to address gaps in BES inverter-based resource performance. These enhancements include the following: • **Ride-Through Standard to Replace PRC-024-3** Ensuring BES resources remain connected to support the BPS during grid disturbances is an essential reliability service. The magnitude and breadth of tripping, reduction, and abnormal performance observed at solar PV facilities (and synchronous generators) in the 2022 Odessa Disturbance signify a significant reliability risk facing the industry. Newly interconnecting solar PV resources continue to operate in an unreliable manner and NERC standards updates are necessary to address any performance issues. NERC Project 2020-02[32] is addressing this issue based on the SAR submitted by NERC after these same issues were highlighted in the 2021 Odessa Disturbance. The gravity and importance of enhancing this standard to a comprehensive ride-through standard are amplified given the size of the 2022 Odessa Disturbance.	Project 2020-02 Standard Drafting Team
• **Performance Validation Standard Needed** The NERC IRPS has developed a SAR that proposes that inverter-based resource GOs identify, analyze, and mitigate any identified abnormal performance issues. The SAR also recommends giving TOPs, RCs, and Balancing Authorities the flexibility and authority to initiate this analysis based on any abnormal performance issues observed from transmission-side measurements. As NERC has highlighted multiple times, GOs are not proactively addressing performance issues, and further regulatory action is necessary to ensure that systemic issues are mitigated proactively by GOs rather than waiting for these events to elevate to a system-wide problem that could pose significant risks to the overall BPS. NERC strongly recommends this SAR be endorsed and approved on a fast-track to get mitigations in place as quickly as possible.	NERC RSTC, NERC IRPS
• **Monitoring Data** ERCOT and the GOs in the Texas Interconnection have extensive data that is critical for root cause analysis. This data includes plant-level high resolution oscillography data, plant SCADA data, and inverter-level sequence of events recording (e.g., fault codes) and oscillography data. These types of measurements should be standard across industry for the purposes of event analysis and reducing the risk to plant performance. The IRPS submitted a SAR, and Project 2021-04[33] is working on enhancements to PRC-002-2 to ensure this type of data is available at BES resources.	Project 2021-04 Standard Drafting Team

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[32] https://www.nerc.com/pa/Stand/Pages/Project_2020-02_Transmission-connected_Resources.aspx

[33] https://www.nerc.com/pa/Stand/Pages/Project-2021-04-Modifications-to-PRC-002-2.aspx

Table 4.1: Recommendations and Actions Needed	
Recommendations	**Applicability**
The NERC RSTC should ensure the effective facilitations of SARs to address any outstanding issues.	
NERC Standards Enhancements to Address Modeling and Studies Gaps for Inverter-Based Resources	
Reiteration of Necessary NERC Standards Enhancement Related to Modeling and Studies This disturbance further emphasizes the criticality of modeling and studying enhancements to ensure sufficient technical analysis is conducted during the interconnection study process and planning assessments. Necessary enhancements include the following: • **EMT Modeling and Model Quality Checks** As stated in the 2021 Odessa Disturbance, NERC strongly recommends enhancements to NERC standards to incorporate EMT modeling requirements and quality checks for all submitted models as well as EMT studies to ensure reliable operation of the BPS with increasing levels of inverter-based resources. Project 2022-04[34] is developing enhancements to the NERC FAC, MOD, and TPL standards to incorporate these enhancements.	Project 2022-04 Standard Drafting Team
• **Enhancements to NERC FAC-001 and FAC-002 Regarding Enforceability of Interconnection Requirements and Interconnection Studies** The NERC FAC-001 and FAC-002 standards should be enhanced to add clarity regarding necessary steps to ensure interconnection requirements are met at commercial operation and that interconnection studies have adequate checks and balances to avoid modeling errors throughout. Industry continues to highlight the inability of actually enforcing interconnection requirements. Significant updates are needed to NERC FAC-001 and FAC-002 to enable TOs, TPs, or PCs to identify non-conformance with interconnection requirements, seek mitigations to address identified issues, and report any entities that persistently fail to meet interconnection requirements to the ERO Enterprise. The NERC disturbance analyses continue to highlight that insufficient model quality checks are done throughout the interconnection study process to avoid discrepancies between modeled and actual performance. In particular, current plant commissioning practices appear to have significant shortfalls for ensuring plant configuration matches TP, PC, and TO expectations (based on studies). Requirements related to plant commissioning should also be considered. Controls should be established to ensure plant modifications (e.g., firmware upgrades or settings changes) do not cause abnormal performance issues or other unintentional consequences.	NERC RSTC, NERC IRPS
NERC Alerts	
NERC Assurance of Inverter-Based Resource Performance While NERC standards enhancements are underway, NERC will issue an alert to ensure concise recommendations for mitigating possible performance issues are provided to GOs and that sufficient data is provided to understand extent of condition regarding inverter	GOs, TPs, PCs, equipment manufacturers

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[34] https://www.nerc.com/pa/Stand/Pages/Project2022-04EMTModeling.aspx

Table 4.1: Recommendations and Actions Needed

Recommendations	Applicability
performance risks. The alert will encompass all past performance issues identified by the ERO Enterprise since there appears to be latent control and protection issues that could adversely impact BPS reliability.	
NERC Assurance of Model Quality Industry should perform a comprehensive review of the parameterization of all positive sequence and EMT models representing inverter-based resources. NERC will issue an alert to ensure that all GOs of inverter-based resources provide adequate proof that the dynamic models match actual equipment controls, settings, and protections. Any discrepancies shall be reported to the ERO Enterprise and to TPs and PCs so they can ensure corrective actions are implemented. Detailed model verification reports should illustrate appropriate mapping between all as-built and modeled controls, settings, and protections. Equipment manufacturers will need to be engaged in this process to ensure appropriate analysis and comparison of models and installed equipment settings.	GOs, TPs, PCs, equipment manufacturers
Additional Industry Activities	
Model Quality and Model Validation All TOs, TPs, and PCs should significantly enhance their modeling requirements with model quality checks and model validation practices. Model quality checks should ensure that the dynamic models adequately represent the as-built facility and that the dynamic models have sufficient fidelity to represent necessary protections and controls (as applicable based on simulation type). Updates currently being made to NERC MOD-026 aim to close current modeling gaps; however, further model validation is necessary in order to increase BPS reliability. Industry should perform model quality checks with a verified as-built EMT model by performing small signal site testing, replicating the tests in the model space, and comparing the model response to the site-tested response. Once a quality EMT model has been validated against the facility response, the EMT model should be subjected to more severe testing that cannot be performed in the field, including fault ride-through tests specified to capture the causes of reduction in this report. Industry should then use this quality EMT model as a benchmark for performing a gap analysis between the positive sequence, EMT model, and site performance.	TOs, GOs, GOPs, developers, equipment manufacturers
Study Qualified Changes Prior to Implementation Per NERC FAC-002, NERC strongly recommends that all TPs and PCs ensure that all qualified changes encompass any changes to equipment that can alter the electrical output of the facility. These changes should be studied by the TP and PC prior to implementation in the field by the GO or developer; this ensures that all potential adverse BPS reliability impacts are identified via simulations rather than identified in real-time operation.	TPs, PCs
Adoption of Reliability Guidelines NERC continues to strongly recommend that the recommendations set forth in NERC reliability guidelines are comprehensively adopted by Industry. GOs, GOPs, developers, and equipment manufacturers should adopt the performance recommendations provided in the NERC reliability guidelines. TOs, TPs, and PCs should establish or improve interconnection requirements and study processes for BPS-connected inverter-based resources.	TOs, GOs, TPs, PCs, developers, equipment manufacturers

Table 4.1: Recommendations and Actions Needed

Recommendations	Applicability
Improvements to FERC Large Generation Interconnection Process Significant improvements are needed to the FERC generator interconnection procedures and agreements to address issues pre-commissioning that are outside the purview of NERC reliability standards. Aligning the interconnection agreements and procedures with the recommendations outlined in NERC disturbance reports and ongoing NERC standards enhancements will help support a more streamlined interconnection process.	FERC
ERCOT Recommended Actions	
ERCOT Improvement to Interconnection Process ERCOT should prioritize making improvements to their interconnection process in an effort to close known gaps in model quality. ERCOT should focus on using user-defined EMT and positive sequence models verified by the original equipment manufacturers in tandem throughout the interconnection process. Both the EMT and positive sequence models should be verified against designed parameters with any gaps clearly explained such that ERCOT is aware of all model limitations. Prior to commercial operation, ERCOT should ensure that as-commissioned equipment settings and protections match those that were used throughout the interconnection study process. Any discrepancies should be clearly documented by the GO, reviewed by ERCOT, and “trued up” prior to commercial operation.	ERCOT
ERCOT Adoption of Reliability Guideline Content As stated in multiple NERC reports and guidelines, ERCOT (and all TOs, TPs, and PCs) should comprehensively adopt any applicable recommendations contained in the NERC reliability guidelines to ensure mitigating actions are put in place to prevent these types of issues in the future. Many of the performance issues in this event could have been mitigated if appropriate modeling and performance requirements were established and conformance with those requirements was enforced. NERC reliability guidelines (and other resources, such as IEEE 2800-2022) provide additional specificity and clarity that can help enhance existing performance requirements established by TOs, TPs, and/or PCs.	ERCOT
ERCOT Follow-Up with all Inverter-Based Resources in Texas Interconnection ERCOT should continue its strong stakeholder outreach and education programs to ensure all GOs and GOPs of inverter-based resources in the Texas Interconnection are implementing mitigating actions to address reliability issues. This may include enforcing its comprehensive ride-through requirements and model quality checks.	ERCOT
ERCOT System Model Validation Effort NERC strongly recommends ERCOT conduct a system model validation effort by using both positive sequence and EMT models to ensure that those models reflect as-commissioned equipment settings and can accurately recreate system events. This activity will help improve model quality and ensure that the models can identify future performance issues on the ERCOT system.	ERCOT

Appendix A: Detailed Review of Affected Facilities

This appendix describes the causes of abnormal performance at each affected facility that reduced power output during the 2022 Odessa Disturbance.

Affected Solar PV Facilities

Table A.1 provides a high-level overview of the solar PV facilities involved in the event and followed by additional details for each specific facility.

Table A.1: Review of Solar PV Facilities

Facility ID	Capacity [MW]	Reduction [MW]	POI Voltage [kV]	In-Service Date	Cause of Reduction
Plant B	152	133	138	June 2020	Inverter phase jump (passive anti-islanding) tripping.
Plant C	126	56	345	November 2020	Inverter phase jump (passive anti-islanding) tripping.
Plant E	162	159	138	May 2021	Inverter ac overvoltage tripping.
Plant U	143.5	136	138	August 2021	Inverter ac overvoltage tripping; feeder underfrequency tripping.
Plant F	50	46	69	September 2017	Unknown.
Plants I & J	304	196	345	June 2020	Inverter phase jump (passive anti-islanding) tripping.
Plant V	253	106	345	July 2021	Inverter dc voltage imbalance tripping.
Plants K & L	157.5	130	138	September 2016	Momentary cessation/inverter power supply failure.
Plant M	155	146	138	March 2018	Inverter dc voltage imbalance tripping; incorrect inverter ride through configuration.
Plant N	110	35	138	March 2017	Unknown.
Plant O	50	15	138	November 2016	Unknown.
Plant P	157.5	10	138	August 2017	Inverter ac overcurrent tripping.
Plant Q	255	12	138	December 2020	Inverter ac overcurrent tripping.
Plant R	268	261	138	June 2021	Inverter ac overcurrent tripping.
Plant S	100	94	138	December 2019	Inverter dc voltage imbalance tripping.
Plant T	187	176	138	September 2021	Inverter ac overcurrent tripping; feeder underfrequency tripping.
TOTAL		**1,711**			

* Naming convention of facilities is a continuation of the 2021 Odessa Disturbance; therefore, plant numbering is not necessarily alphanumeric but does match the labeling used in the 2021 Odessa Disturbance.

Plant B (Inverter Manufacturer: TMEIC)

Plant B is a 152 MW facility connected to the 138 kV network that went into commercial operation in June 2020. The plant reduced output by 133 MW during the event (see **Figure A.1**). All inverters in the plant tripped on voltage phase jump protection that acts as passive anti-islanding protection for this specific inverter manufacturer. The inverters tripped and automatically returned to service with a preprogrammed time delay of five minutes.

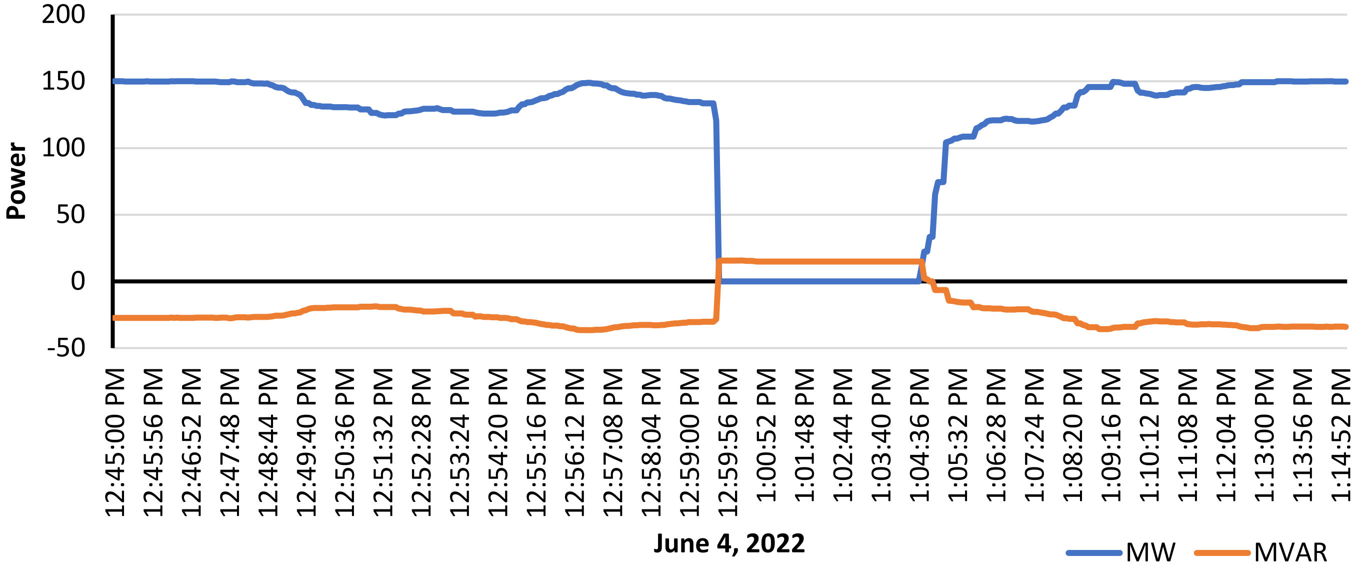

Figure A.1: Plant Active and Reactive Power at POI

Plant C (Inverter Manufacturer: TMEIC)

Plant C is a 258.5 MW facility connected to the 345 kV network that went into commercial operation in November 2020. The plant reduced output by 56 MW during the event (see **Figure A.2**). All inverters in the plant tripped on voltage phase jump protection that acts as passive anti-islanding protection for this specific inverter manufacturer. The inverters tripped and automatically returned to service with a pre-programmed time delay of five minutes.

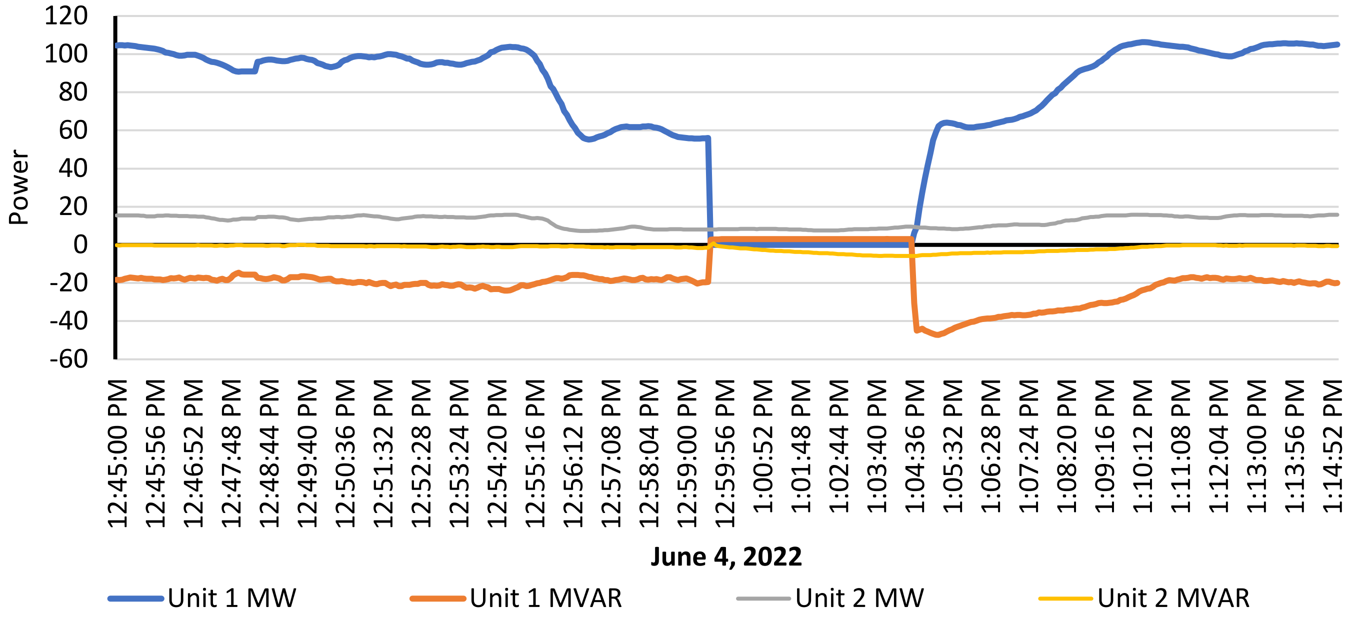

Figure A.2: Plant Active and Reactive Power at POI

Plant E and Plant U (Inverter Manufacturer: TMEIC)

Plant E is a 162 MW facility connected to the 138 kV network that went into commercial operation in May 2021. Plant E reduced power output from 159 MW to 0 MW when the fault occurred (see **Figure A.3**). All inverters tripped on instantaneous ac overvoltage protection set at 1.25 pu. This is considered a "minor" fault by the manufacturer so the inverters initiated an automatic restart about 25 seconds after the fault. The inverters returned to predisturbance output 1.5 minutes after the fault. The oscillography data at the POI (see Figure A.4) and the inverter-level oscillography data (see **Figure A.5**) show that the inverters were injecting reactive current upon fault clearing, which very likely lead to overvoltage conditions.

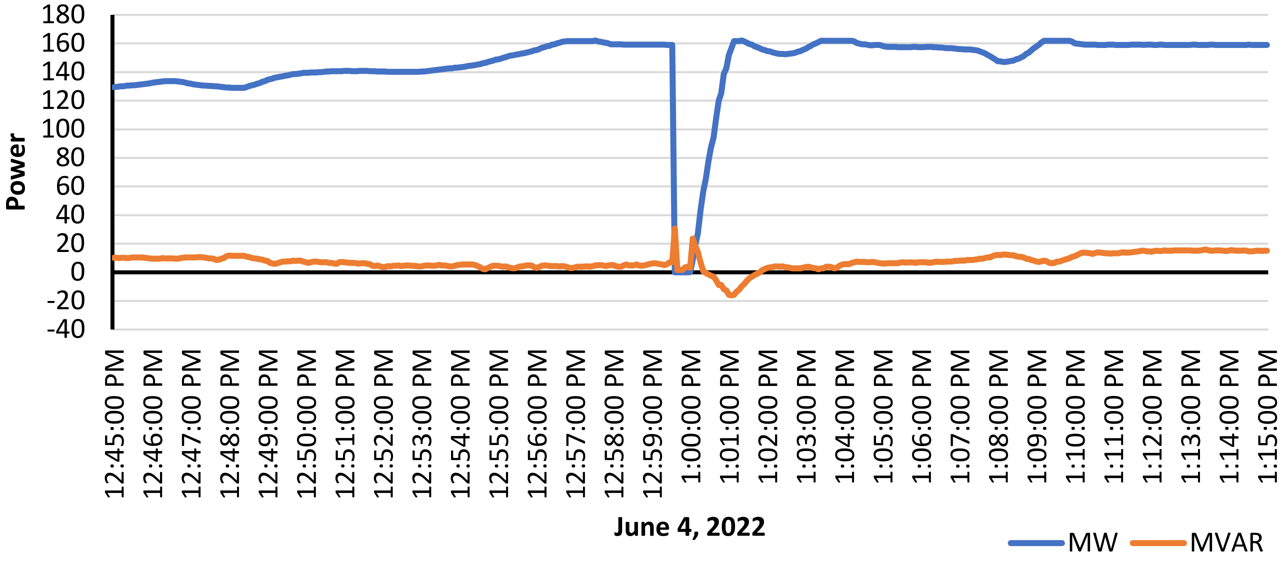

Figure A.3: Plant Active and Reactive Power at POI

Figure A.4: Plant Oscillography Data at POI

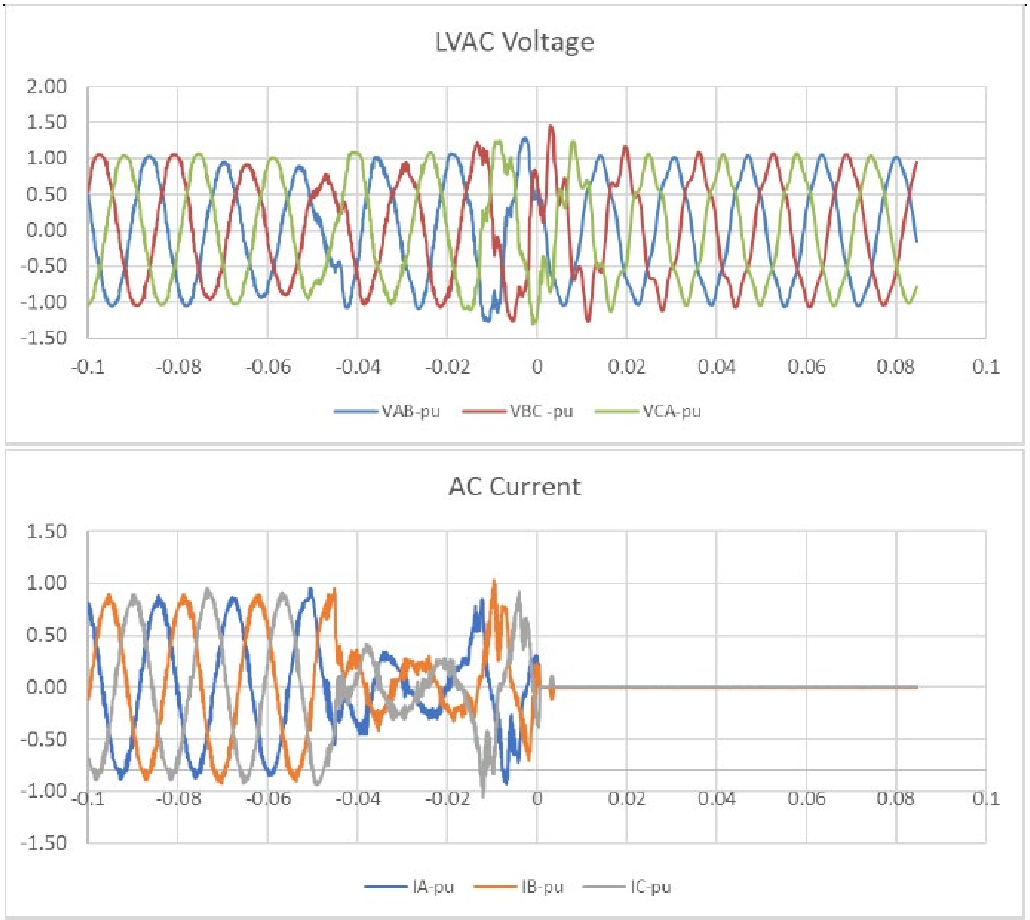

Figure A.5: Inverter Oscillography Voltage and Current Data [Source: Inverter Manufacturer]

Plant U is a 143.5 MW facility connected to the 138 kV network that went into commercial operation in August 2021. Plant U reduced power output from 136 MW to 0 MW when the fault occurred (see Figure A.6). Inverters tripping at this facility is attributed to the following:

- **Inverter Instantaneous Overvoltage Tripping (136 MW):** All inverters tripped on instantaneous ac overvoltage protection set at 1.25 pu (see **Figure A.7**). These inverters automatically restarted after about 15 seconds and ramped back up to predisturbance levels about 1.5 minutes after the fault.
- **Feeder-Level Instantaneous Underfrequency Tripping (102 MW):**[35] This facility has feeder-level voltage and frequency protective relaying configured on each collector line in the plant. The feeder protective relays were configured with a 57.5 Hz trip threshold with a 0.0 second timer, making them highly susceptible to erroneous tripping. Multiple feeders tripped and were out of service for about three hours.

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[35] This tripping was in addition to the inverter-level tripping; hence, double-counting of tripping quantities.

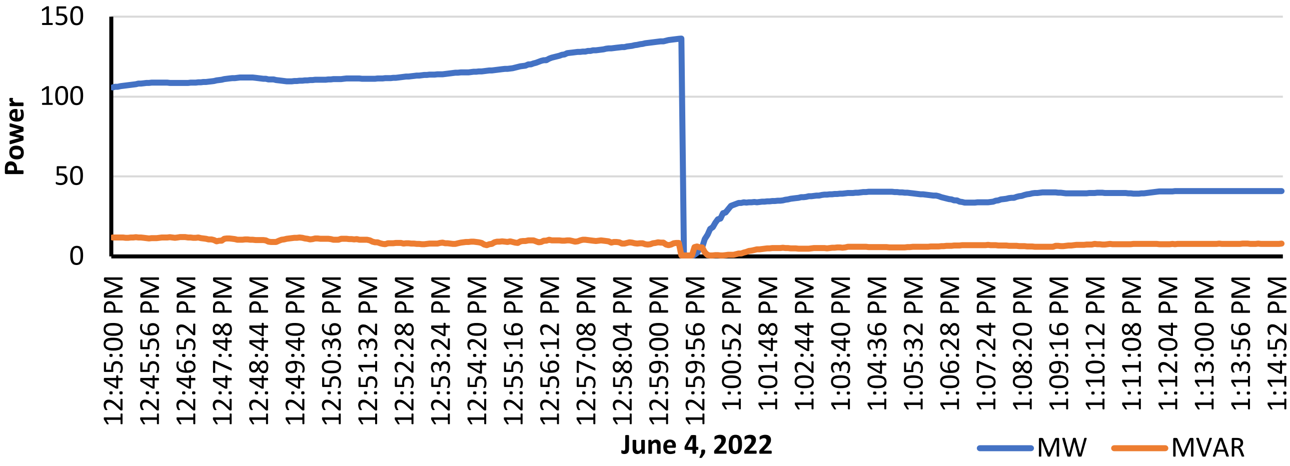

Figure A.6: Plant Active and Reactive Power at POI

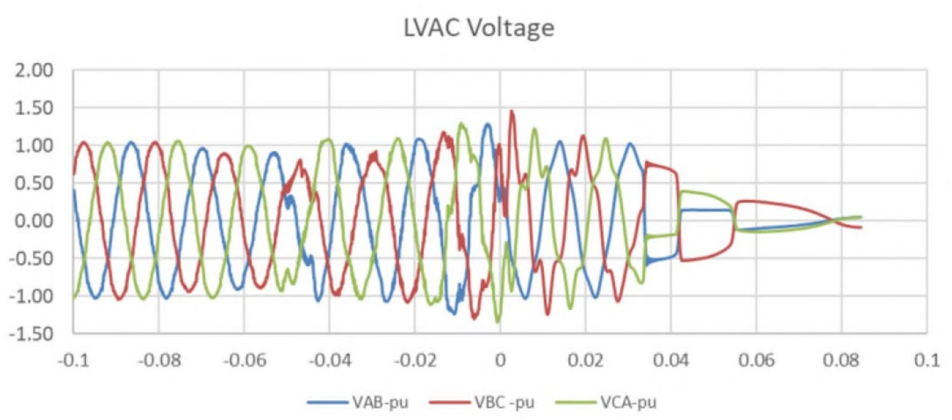

Figure A.7: Inverter Oscillography Voltage Data [Source: Inverter Manufacturer]

Plant F (Inverter Manufacturer: KACO)

Plant F is a 50 MW facility connected to the 69 kV network that went into commercial operation in April 2017. The plant reduced output by 49 MW during the event (see **Figure A.8**). The GO was unable to provide any useful information from the inverters regarding the cause of tripping because the inverter internal logs were overwritten by subsequent commands and events.

The GO has worked with the OEM service provider (Siemens) to modify the following:

- Frequency trip settings to trip only when frequency is below 57 Hz or above 63 Hz for 30 seconds
- AC overvoltage protection settings increased to 1.35 pu for 60 ms

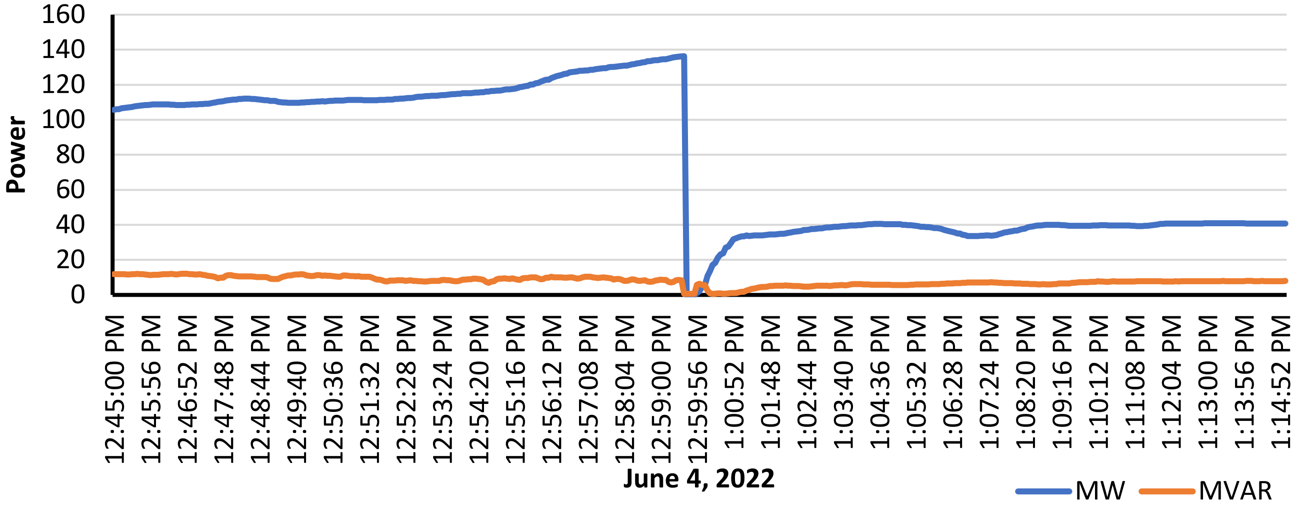

Figure A.8: Plant Active and Reactive Power at POI

Plant I and Plant J (Inverter Manufacturer: TMEIC)

Plant I and Plant J Unit #1 and Unit #2 are 154 MW and 150 MW resources, respectively, connected to the 345 kV network that went into commercial operation in June 2020. Unit #1 reduced active power by 74 MW and recovered 5 minutes later. Unit #2 reduced power output by 122 MW and recovered about 14 minutes later. The combined reduction of active power for the facility is 196 MW (see Figure A.9 and Figure A.10). Both units at the facility have the same inverter make and model and are connected to the same POI bus. All inverters tripped on voltage phase jump protection used as a passive anti-islanding protection for this specific inverter manufacturer. The GO and inverter manufacturer were unable to determine why the units recovered over different time scales.

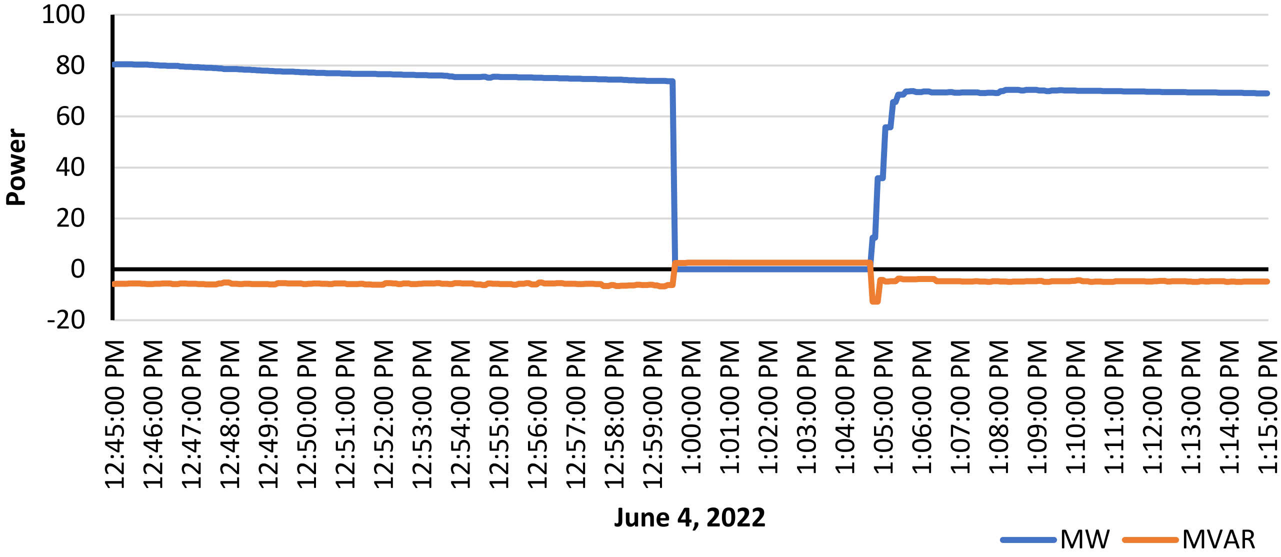

Figure A.9: Plant Active and Reactive Power at POI

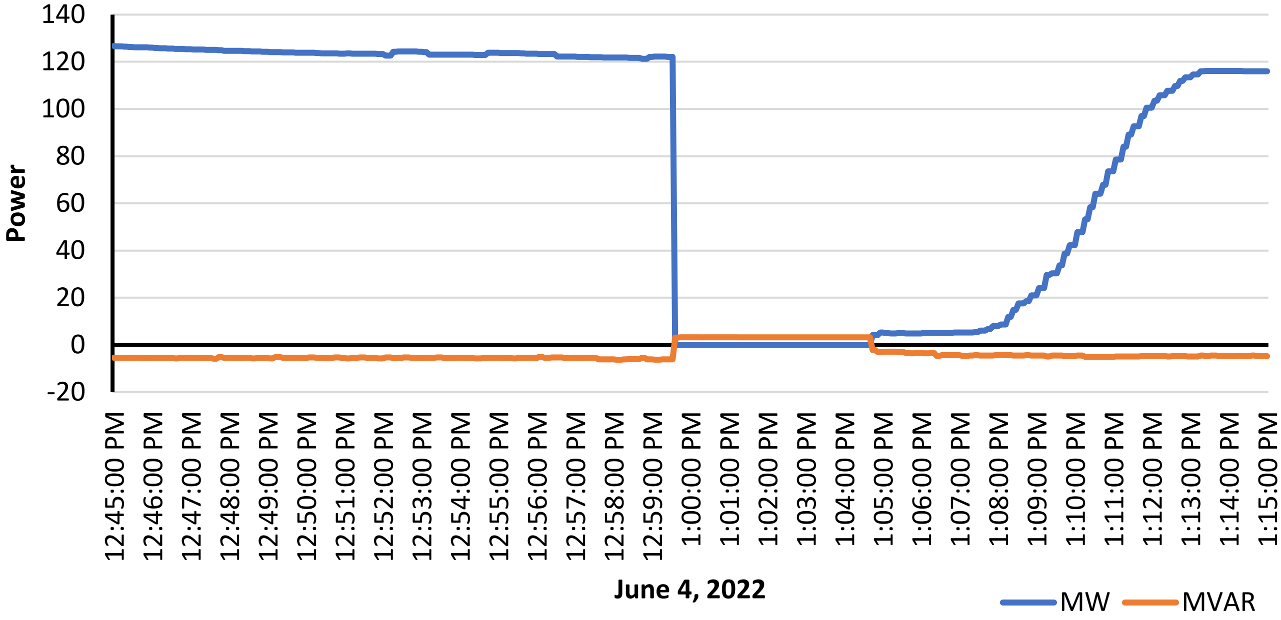

Figure A.10: Plant Active and Reactive Power at POI

Plant V (Inverter Manufacturer: Power Electronics)

Plant J Unit #1 and Unit #2 are 126.5 MW and 126.4 MW resources, respectively, connected to the 345 kV network that went into commercial operation in July 2021. Unit #1 rode through the disturbance[36] and Unit #2 reduced power output by 106 MW and remained off-line until the following day (see Figure A.11). All affected inverters tripped on dc voltage imbalance caused by ac-side voltage phase angle changes that the inverter control could not regulate fast enough to control dc bus voltages.

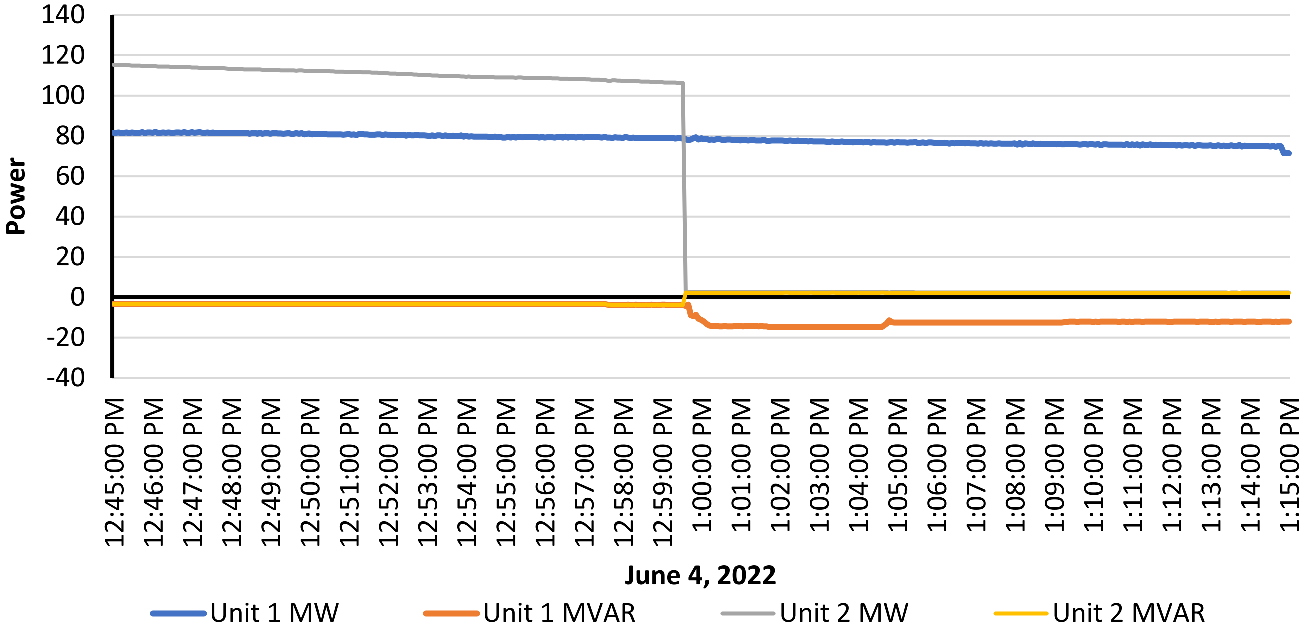

Figure A.11: Plant Active and Reactive Power at POI

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[36] Active power dropped to 0 MW during and immediately after the fault but recovered to pre-disturbance output within about 1 second.

Plant K and Plant L (Inverter Manufacturer: Power Electronics)

Plant K and Plant L are a combined 157.5 MW facility connected to the 138 kV network that went into commercial operation in September 2016. Plant K reduced active power by 62 MW (see **Figure A.12**), and Plant L reduced output by 68 MW (see **Figure A.13**), totaling a 130 MW reduction. Both plants recovered in about 1.5 minutes.

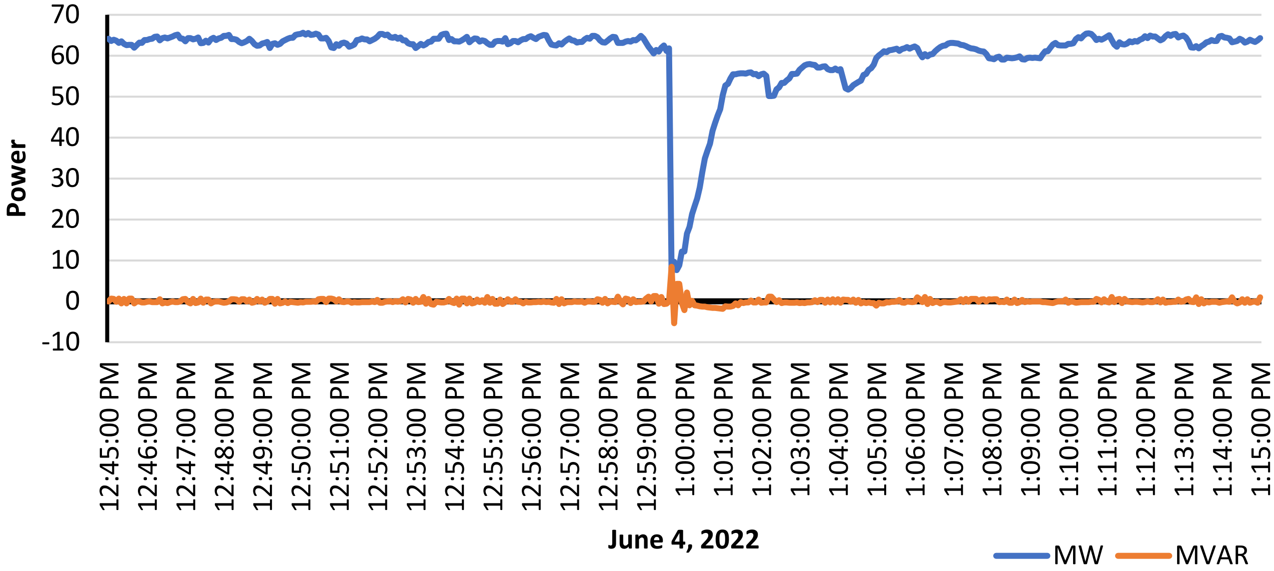

Figure A.12: Plant Active and Reactive Power at POI

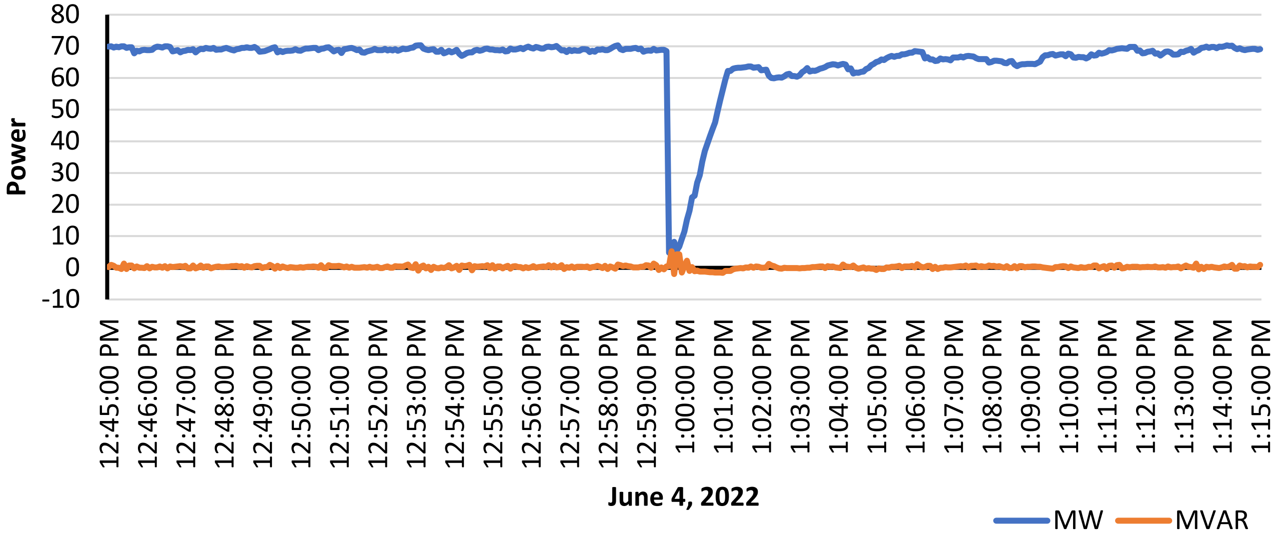

Figure A.13: Plant Active and Reactive Power at POI

These plants were also involved in the 2021 Odessa Disturbance and entered momentary cessation with plant-level controller interactions that precluded the inverters from returning to predisturbance output in a suitable time.[37] In follow-up discussions, the GO stated that the facility had actually turned off momentary cessation in 2019 following the NERC alerts; however, the inverter manufacturer informed the team that at low voltages, these inverters can have inverter power supplies fail (i.e., there are no uninterruptible power supplies). So the options are to perform either of the following:

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[37] The inverters had momentary cessation settings with 0.9 pu voltage threshold and a 200 ms delay to start recovery with a 500% per second recovery ramp rate. However, the plants required multiple minutes to return to predisturbance output.

- Turn momentary cessation back on with settings around 0.9 pu voltage threshold and a 200 ms delay to start recovery with a 500% per second recovery ramp rate.
- Leave momentary cessation disabled and install uninterruptible power supplies on the inverters so the facility can provide dynamic reactive power support during faults. However, the manufacturer cannot verify that this solution will ensure ride-through for large phase jumps or high rate-of-change-of-frequency, such as those experienced in either Odessa event.

NERC strongly recommends implementing necessary improvements to the inverters so that they can ride through grid faults and provide dynamic reactive power support. If this requires the addition of uninterruptible power supplies at this facility to mitigate this risk, then these mitigating measures should be deployed. There is no technical basis for the inverters not to have uninterruptible power supplies so that they can effectively ride through grid disturbances to support the BPS.

These facilities also appear to be exhibiting delayed recovery to predisturbance output. The GO and equipment manufacturer are unable to determine a root cause because this facility has poor logging capability at the inverters. This could be plant controller interactions after momentary cessation or could be some anomalous delays in inverter-level recovery after possible power supply failure.

Plant M (Inverter Manufacturer: Power Electronics)

Plant M is a 155 MW facility connected to the 138 kV network that went into commercial operation in March 2018. The plant reduced power output from 146 MW to 0 MW when the fault occurred (see Figure A.14). The causes of reduction include the following:

- **Inverter DC Voltage Unbalance Tripping (11 MW)**
  Three inverters tripped on dc voltage unbalance and remained off-line for 30 seconds.
- **Incorrect Ride-Through Configuration (135 MW)**
  All inverters at the facility had low voltage ride-through disabled. Inverters were programmed to provide zero active power during low voltage ride through events (configured to occur below 0.9 pu voltage).
- **Plant-Level Controller Interactions (146 MW)[38]**
  Given that inverter low voltage ride-through was disabled, the plant controller interacted with the inverter response and resulted in abnormal plant response after fault clearing (see Figure A.15). The plant has since corrected the inverter and plant controller settings to mitigate this issue.

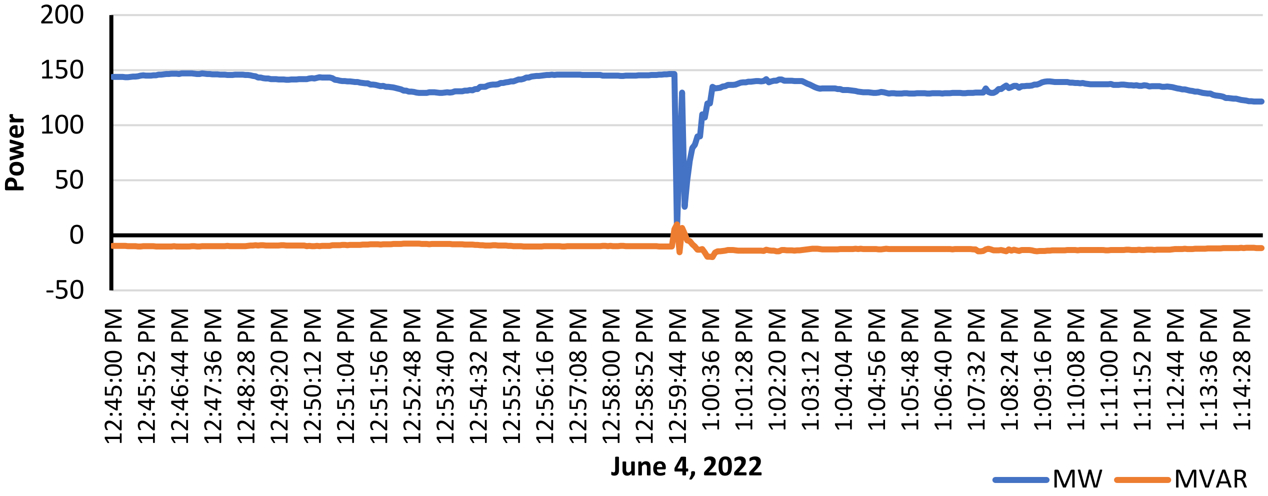

Figure A.14: Plant Active and Reactive Power at POI

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[38] This tripping was in addition to the inverter-level tripping; hence the double-counting of tripping quantities.

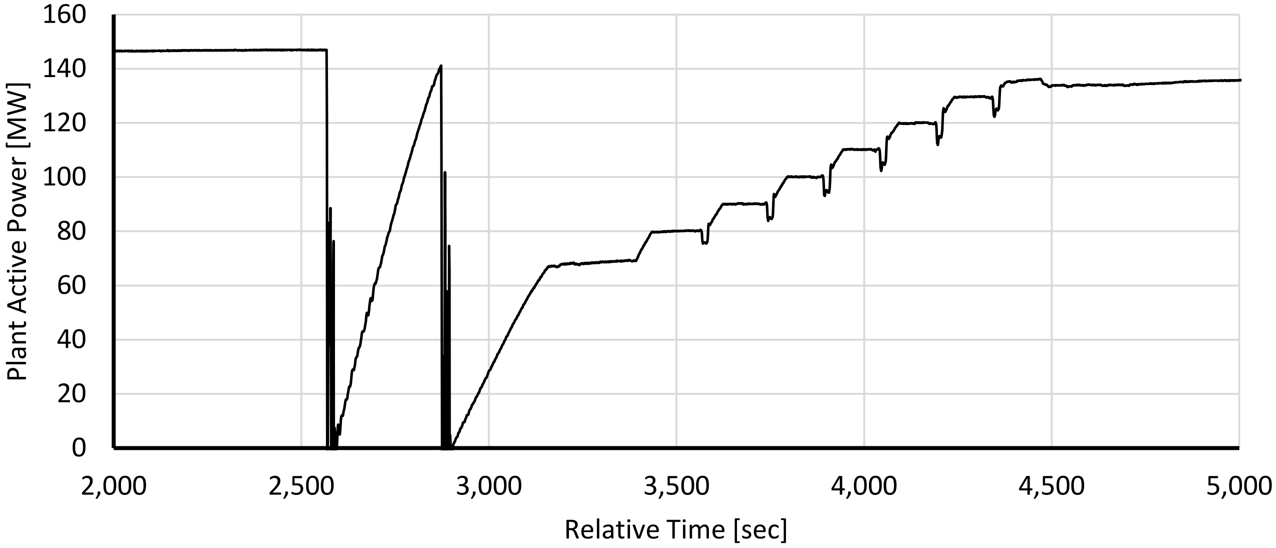

Figure A.15: Plant-Level Controller Interactions

The GO disabled feeder-level overvoltage protection after the *2021 Odessa Disturbance Report* findings were disseminated, which eliminated this risk of tripping. Inverter low voltage ride-through operating modes have been changed from zero active current support to a mode that provides both active and reactive current during faults that is proportional to voltage, which is more aligned with expected performance. Inverter overvoltage protection settings have also been expanded to 1.35 pu with a time duration of 0.5 seconds. The GO enabled low voltage ride-through settings and expects the plant to recover to predisturbance output with no interactions and within 1 second of a fault occurring.

Plant N and Plant O (Inverter Manufacturer: KACO)

Plant N and Plant O are a combined 160 MW facility connected to the 138 kV network that went into commercial operation in March 2017 and November 2016, respectively. Plant N reduced power output by 35 MW (see **Figure A.16**) and Plant O reduced power output by 15 MW (see **Figure A.17**) when the fault occurred.

The inverters initially indicated that tripping was caused by overfrequency settings at 60.6 Hz for 600 seconds, which the grid did not experience. Upon further inspection, the GO determined that field technicians updating inverter human-machine interface (HMI) software inadvertently changed the fault code table/registry. This resulted in incorrectly mapped fault codes; therefore, the actual cause of inverter tripping at this facility is unknown.

NERC, Texas RE, and ERCOT stressed during follow-up discussions with the GO that inverter protection settings should be based on equipment ratings. The GO has worked with the equipment manufacturer service provider (Siemens) to develop and implement expanded frequency and voltage ride-through settings based on equipment tolerances.

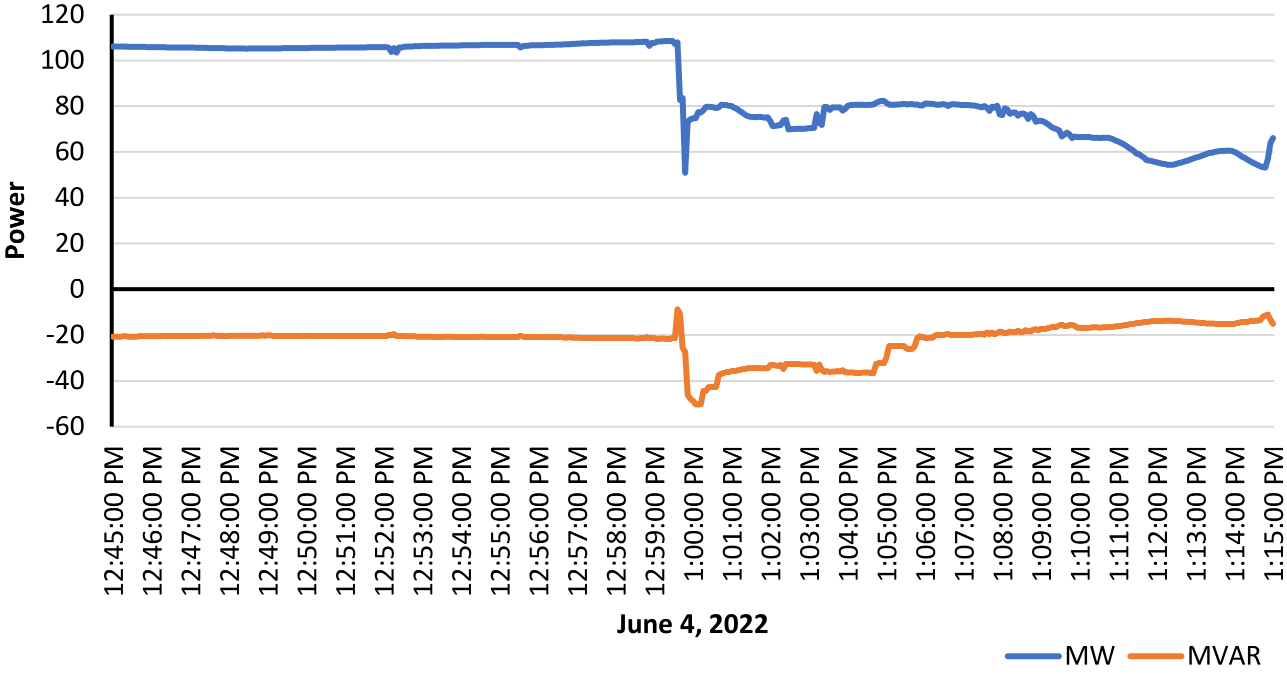

Figure A.16: Plant Active and Reactive Power at POI

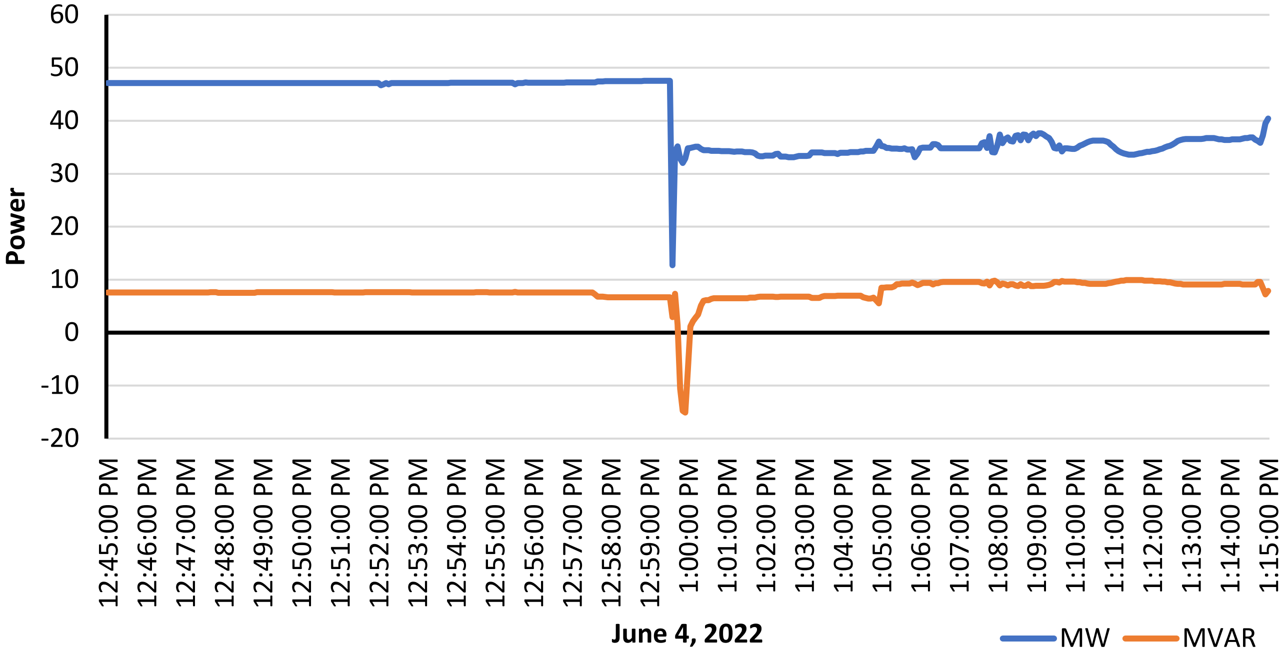

Figure A.17: Plant Active and Reactive Power at POI

Plant P (Inverter Manufacturer: KACO)

Plant P is a 157.5 MW facility connected to the 138 kV network that went into commercial operation in August 2017. Seven inverters tripped due to ac overcurrent protection for a 10 MW reduction (see Figure A.18). The GO was unable to determine the settings for ac overcurrent since the equipment manufacturer that is now out of business.

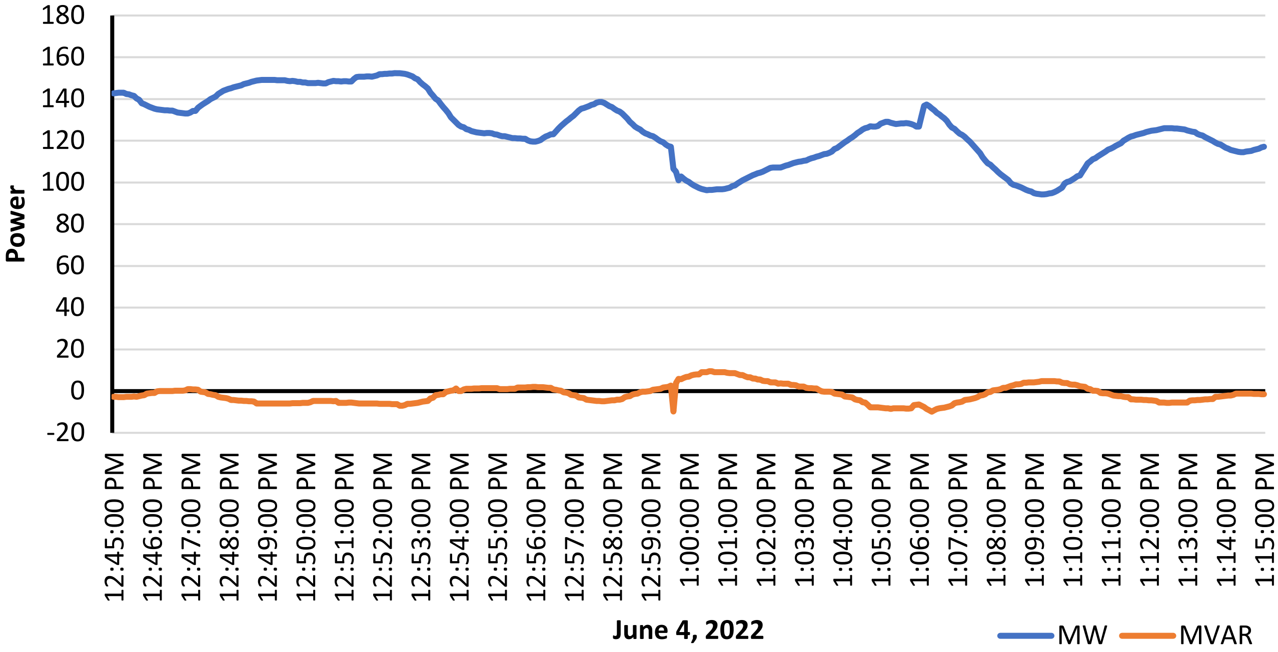

Figure A.18: Plant Active and Reactive Power at POI

Plant Q (Inverter Manufacturer: Power Electronics)

Plant Q is a 255 MW facility connected to the 138 kV network that went into commercial operation in December 2020. The plant reduced output by 12 MW (see **Figure A.19**), likely attributed to some inverters tripping on ac overcurrent protection; however, information provided by the GO was not comprehensive.

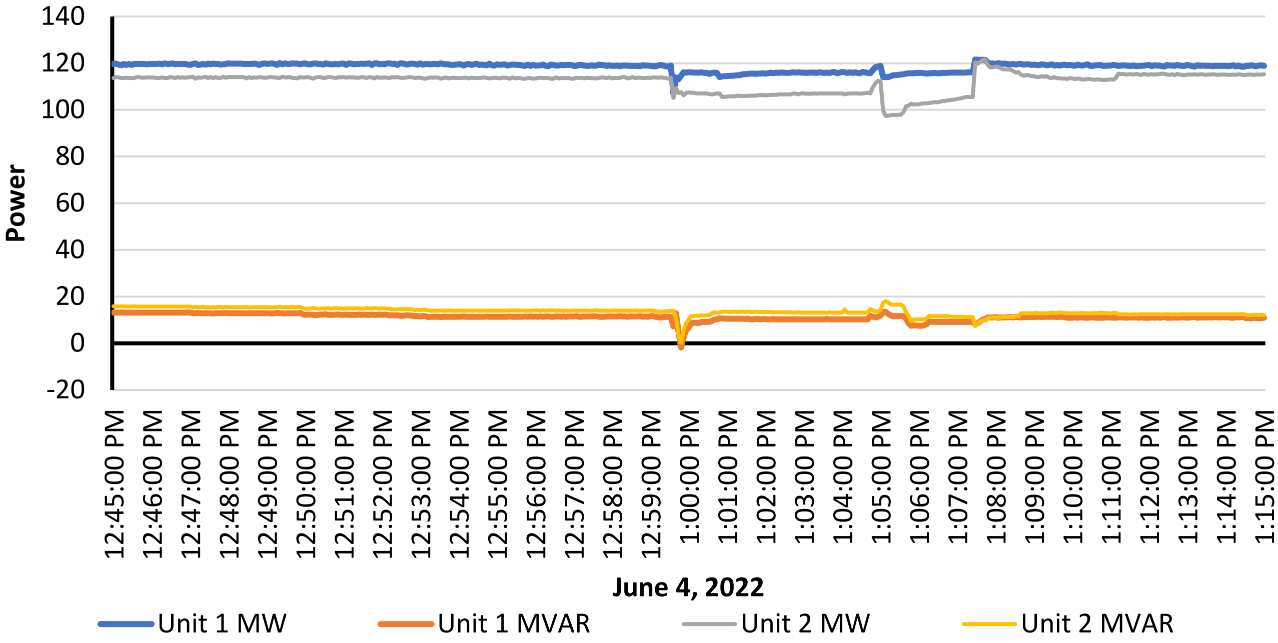

Figure A.19: Plant Active and Reactive Power at POI

Plant R (Inverter Manufacturer: TMEIC)

Plant R is a 268 MW facility connected to the 138 kV network that went into commercial operation in June 2021. Unit #1 reduced output by 134 MW (see **Figure A.20**) and Unit #2 reduced output by 127 MW (see **Figure A.21**). Inverters tripped on ac overcurrent protection with "minor" and "major" faults at 1.4 pu and 1.5 pu of rated ac current. Inverters that tripped on the minor fault code began restarting in about 10 seconds and recovered in 1.5 minutes. Inverters that tripped on the major fault code about 5 minutes after the fault and recovered in 6.5 minutes.

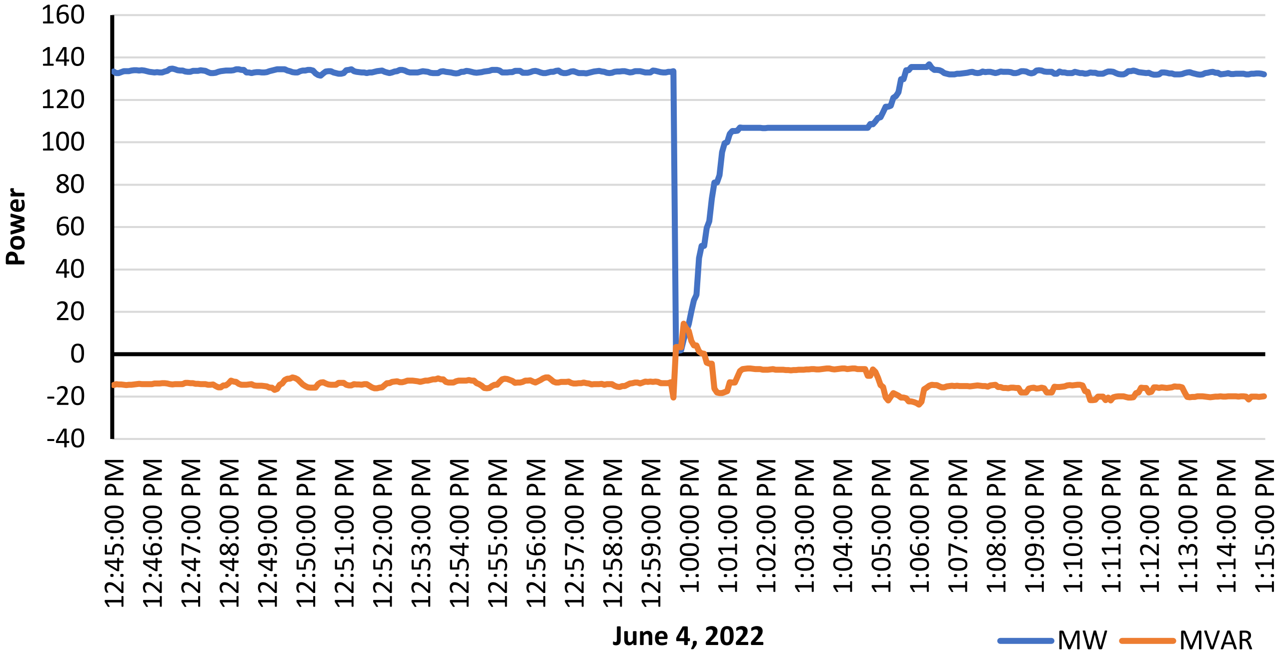

Figure A.20: Plant Active and Reactive Power at POI

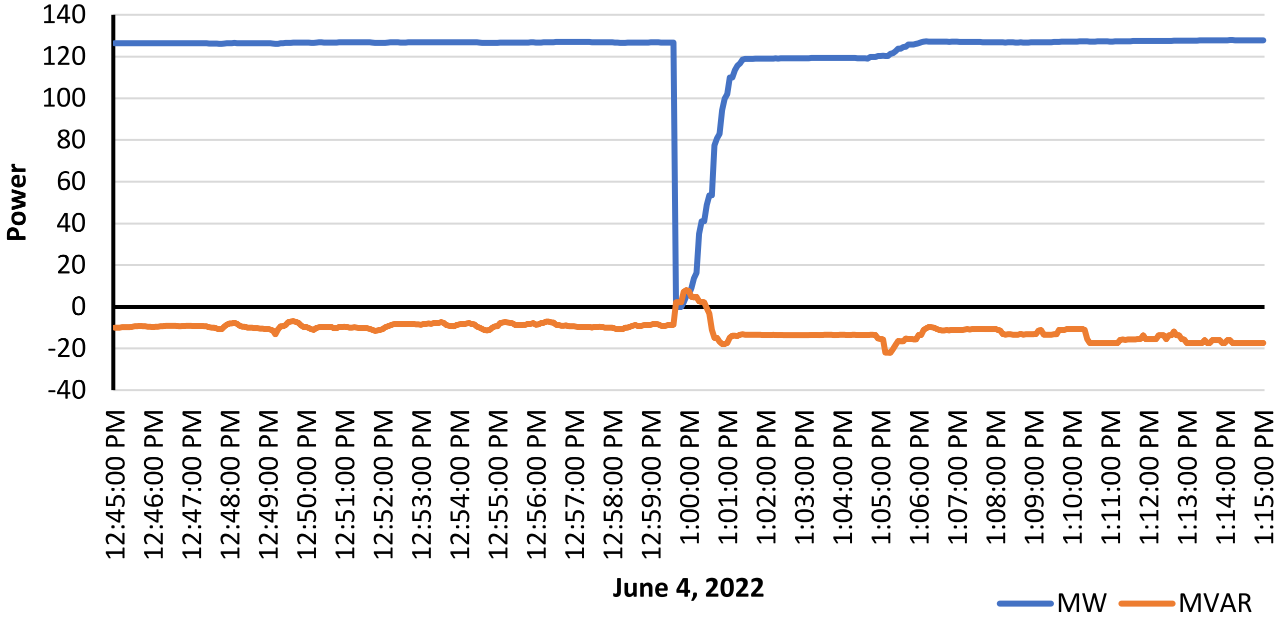

Figure A.21: Plant Active and Reactive Power at POI

Plant S (Inverter Manufacturer: Power Electronics)

Plant S is a 100 MW facility connected to the 138 kV network that went into commercial operation in December 2019. The plant reduced power output by 94 MW when the fault occurred (see Figure A.22). Tripping was attributed to dc voltage unbalance tripping. Some inverter (68 MW) tripped and remained off-line for an extended period of time due to a major fault code; some inverters tripped on a minor fault code (26 MW) and recovered in about 7 minutes.

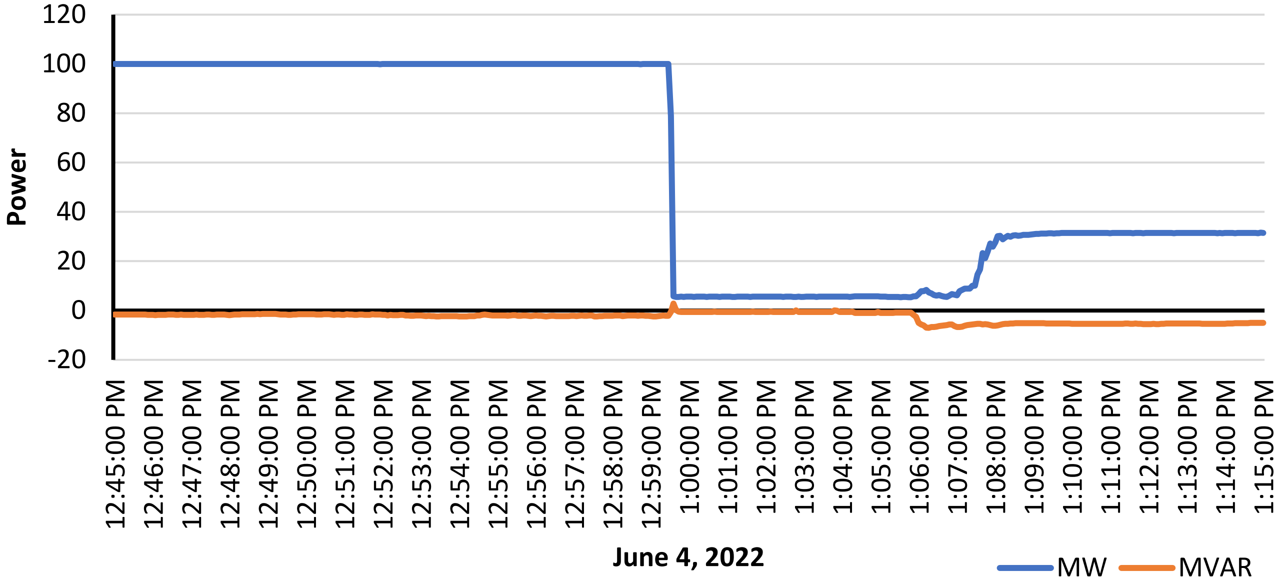

Figure A.22: Plant Active and Reactive Power at POI

Plant T (Inverter Manufacturer: TMEIC)

Plant T is a 187 MW facility connected to the 138 kV network that went into commercial operation in September 2021. The plant reduced output from 176 MW to 0 MW during the event (see Figure A.23). The causes of abnormal performance include the following:

- **Inverter Instantaneous AC Overcurrent Tripping (176 MW)**
  The inverters at this facility have a hardcoded "minor" and "major" instantaneous ac overcurrent trip threshold of 1.4 pu and 1.5 pu of rated current, respectively. Inverters that tripped on the minor fault code recovered to full output in 1.5 minutes; inverters that tripped on the major fault code recovered in about 7 minutes. Some inverters also experienced an instantaneous ac overvoltage fault code at 1.25 pu; however, the inverters tripped first on instantaneous ac overcurrent protection.

- **Feeder-Level Instantaneous Underfrequency Tripping (46 MW)**[39]
  This facility has feeder-level voltage and frequency protective relaying configured on each collector line in the plant. The feeder protective relays were configured with a 57.5 Hz trip threshold with a 0.0-second timer, which is highly susceptible to erroneous tripping.[40] One feeder tripped and was out of service for almost 8 hours.

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[39] This tripping was in addition to the inverter-level tripping; hence, double-counting of tripping quantities.

[40] https://www.nerc.com/pa/rrm/ea/Pages/1200-MW-Fault-Induced-Solar-Photovoltaic-Resource-Interruption-Disturbance-Report.aspx

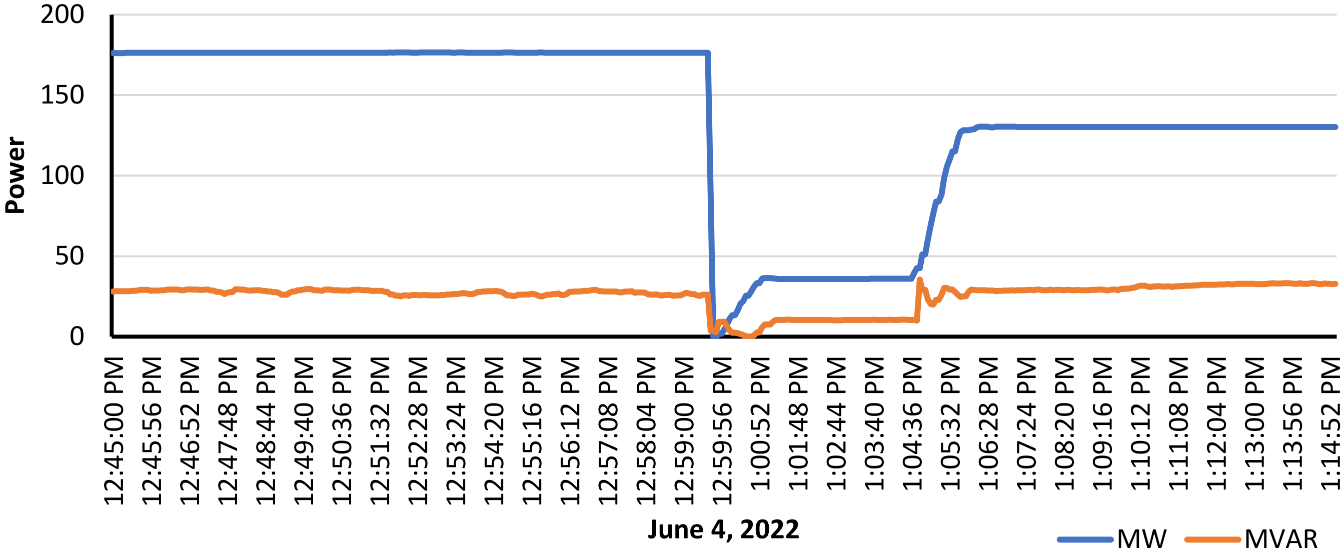

Figure A.23: Plant Active and Reactive Power at POI

The GO modified its feeder voltage and frequency protection to expand the trip thresholds and avoid using instantaneous trip timers. ERCOT is ensuring that inverter software updates are made to the facility to eliminate the instantaneous ac overcurrent tripping.

Affected Synchronous Generation Facilities

The following sections briefly describe key findings from the analysis of synchronous generation facilities that tripped during this event.

Synchronous Generation Plant near Odessa

A failed surge arrestor caused the initiating fault at the synchronous generation facility near Odessa, TX. Surge arrestor failure at this same facility was also the cause of the 2021 Odessa Disturbance. The fault consequentially resulted in the reduction of 333 MW from multiple units.

When the fault occurred, the transformer differential protection misoperated due to current transformer saturation on the neighboring unit. This immediately tripped 202 MW, and then two other units consequently ramped down over the course of multiple minutes for a total reduction of 496 MW. The GO changed the transformer differential current transformer ratio and updated protection settings to eliminate this risk moving forward.

The total loss of generation at this facility at the time of the fault was 535 MW; however, the total loss caused by the fault (including the complete ramp down of units) was 829 MW.

Tripping at Synchronous Generation Facility in South Texas

A natural gas turbine at a combined-cycle facility in South Texas (over 450 miles away) tripped on loss of excitation during the fault, causing the steam turbine to run back due to lack of steam. This resulted in 309 MW of lost generation at this facility. Following the event, the GO/GOP and equipment manufacturer investigated the incident and determined that the automatic voltage regular on one of the combustion turbines, which was upgraded in 2020, was inadvertently placed in manual mode when returned to service. The automatic voltage regular sends a signal to the distributed control system to indicate whether it is in automatic or manual mode; however, the logic in the distributed control system did not give the operator the correct automatic voltage regular status, leading the plant to incorrectly believe the unit was operating in automatic mode. The unit ultimately tripped when more reactive power was absorbed during the disturbance on the system. The units tripped on Zone 2 loss of field protection in the excitation system.

Appendix B: List of Contributors

This disturbance report was published with the contributions of the following individuals. NERC gratefully acknowledges Texas RE, ERCOT, and the affected TOs, TOPs, GOs, and GOPs. Coordination between all affected entities was crucial for the successful analysis of this disturbance and publishing of this report. NERC would also like to acknowledge the continued engagement and support of the inverter manufacturers to ensure that the mitigating measures being developed are pragmatic and implemented in a timely manner. Lastly, members of the NERC IRPS continue to support NERC in its mission to ensure reliable operation of the BPS with rapidly increasing levels of inverter-based resources.

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