Odessa Disturbance Events May 2021 & June 2022

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ESIG Webinar
November 3, 2022

2021 Odessa Disturbance Event Overview

- On May 9, 2021, @ 11:21 AM CDT, Phase-A to ground fault occurred on 345 kV level in the Odessa area
- Fault cleared within 3 cycles, consequentially tripping 192 MW of thermal generation
- Real-Time PMUs recorded voltages as low as 0.72pu on 345 kV, 0.84pu on 138 kV, and 0.54pu on 69 kV
- Voltage remained within "No Trip Zone" of VRT requirements in ERCOT's Nodal Operating Guide
- Non-consequential loss of 1,112 MW of solar generation from 10 different sites occurred following the fault (Only units with >10 MW loss included)
- Frequency dropped to 59.817 Hz and recovered in ~3 minutes
- Categorized as NERC 1i Event - *A non-consequential interruption of inverter type resources aggregated to 500 MW or more not caused by a fault on its inverters, or its ac terminal equipment.*

Inverter Manufacturers Involved in 2021 Odessa Disturbance

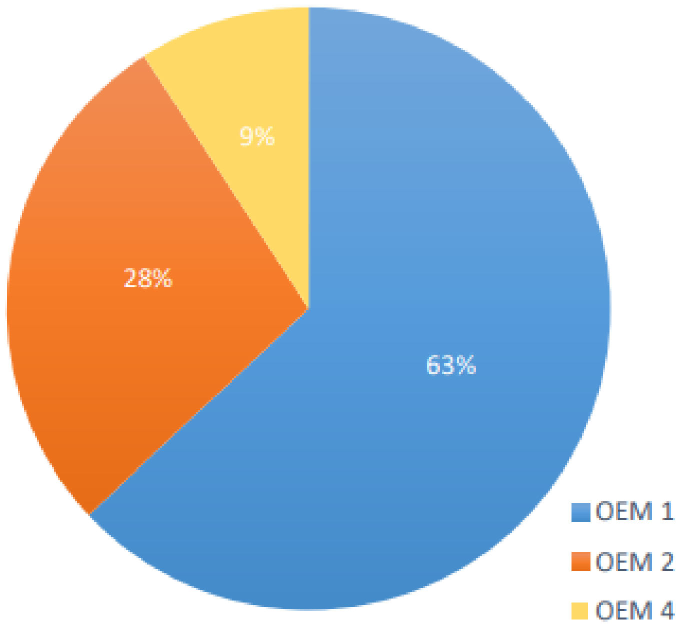


Figure 1.2: Inverter Manufacturers Involved in Disturbance

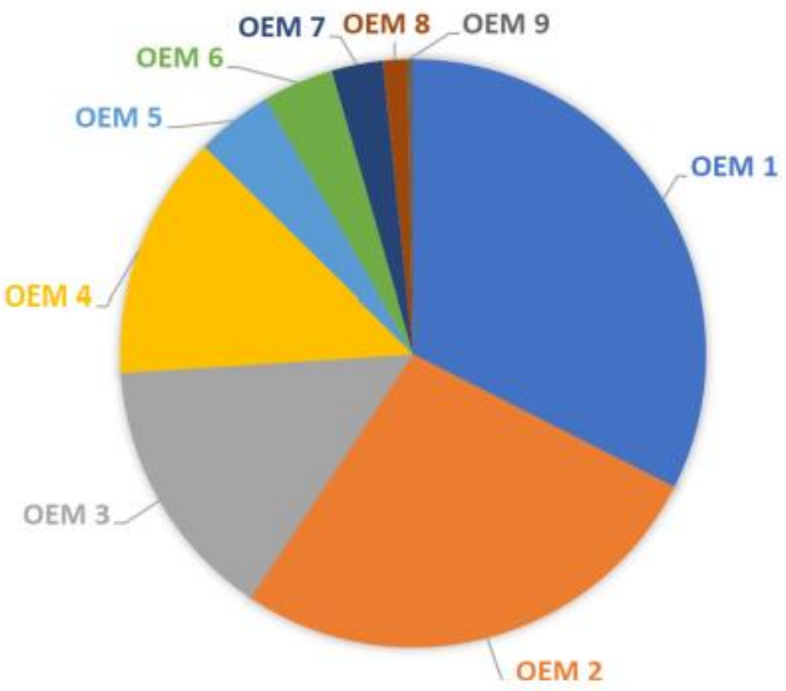


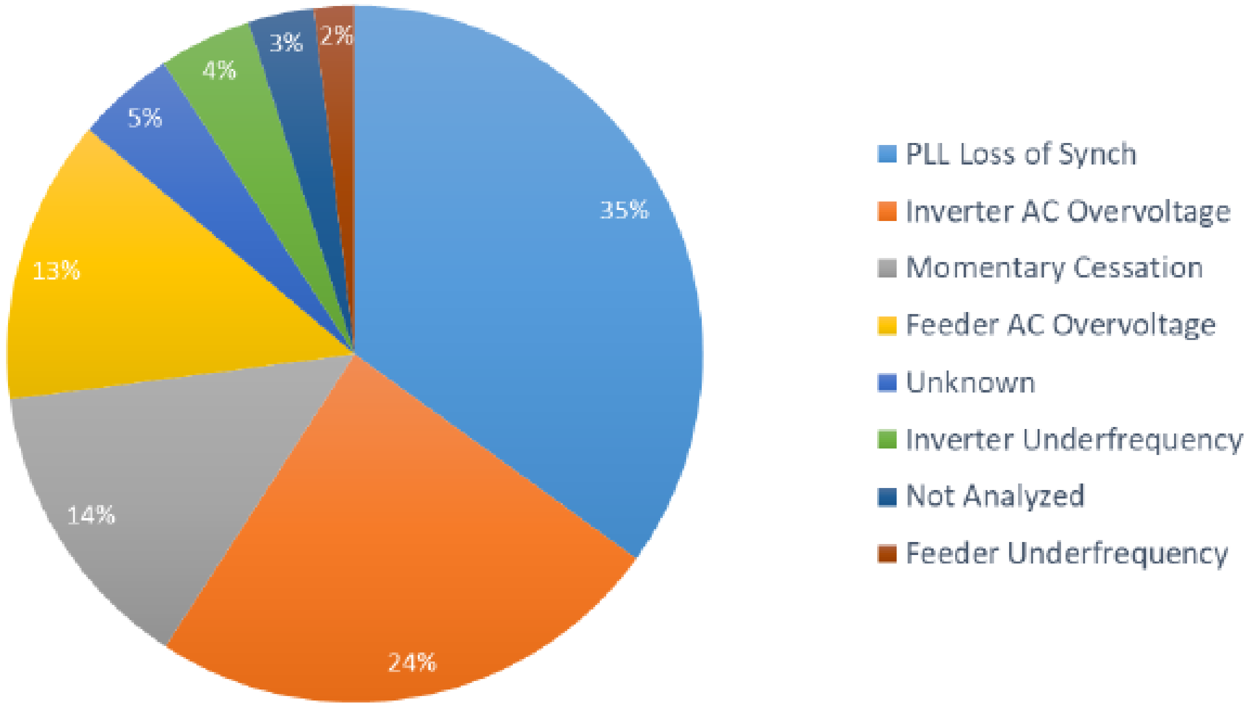
Figure I.2: Capacity Share of BPS-Connected Solar PV Resources by Inverter Original Equipment Manufacturer

*charts and tables from NERC Event Report - https://www.nerc.com/pa/rrm/ea/Documents/Odessa_Disturbance_Report.pdf

Causes of Solar PV Reduction – 2021 Odessa

Table 1.1: Causes of Reduction

Cause of Reduction	Reduction [MW]
PLL Loss of Synchronism	389
Inverter AC Overvoltage	269
Momentary Cessation	153
Feeder AC Overvoltage	147
Unknown	51
Inverter Underfrequency	48
Not Analyzed	34
Feeder Underfrequency	21



PLL Loss of Synchronism

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- Two solar facilities – reductions of 239 MW and 150 MW
- Attributable to one inverter OEM
- Identified in multiple prior events analyzed by NERC
- Systemic concern for facilities with this inverter type
- Existing facilities with this inverter OEM were likely susceptible to tripping
- Inverters issue fault code and shut down for 5-minute timeout
- Default setting of 20 degree voltage phase angle shift
- Inverter OEM removed this trip function from inverters at existing facilities only upon request; shipping newer inverters with function disabled
- PLL Loss of Synchronism has been disabled at all facilities with this inverter type in ERCOT since 2021 Odessa event

AC Overvoltage – Inverter Level

Table 1.1: Causes of Reduction	
Cause of Reduction	Reduction [MW]
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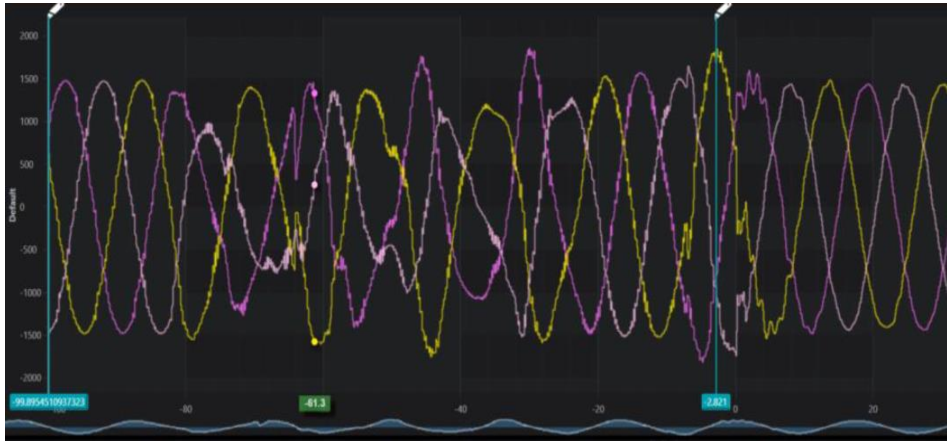

- Two solar facilities – reductions of 205 MW and 64 MW
- POI high resolution data shows voltage within PRC-024-3 and ERCOT NOG voltage "no trip" curve (<1.2 pu)
- Inverter experiences spikes (instantaneous peak) above 1.3 pu at terminals
- OEM states overvoltage settings cannot be modified for any existing facilities due to inverter protection
- AC overvoltage tripping for this OEM will likely continue to occur in future
- Identified in nearly all solar PV disturbances analyzed by NERC
- Potential corrective action is to reduce k-factor of DVC within inverter to reduce reactive injection
- Both facilities performed PSCAD studies on reduced k-factor and saw improvement

AC Overvoltage – Feeder-Level

Table 1.1: Causes of Reduction	
Cause of Reduction	Reduction [MW]
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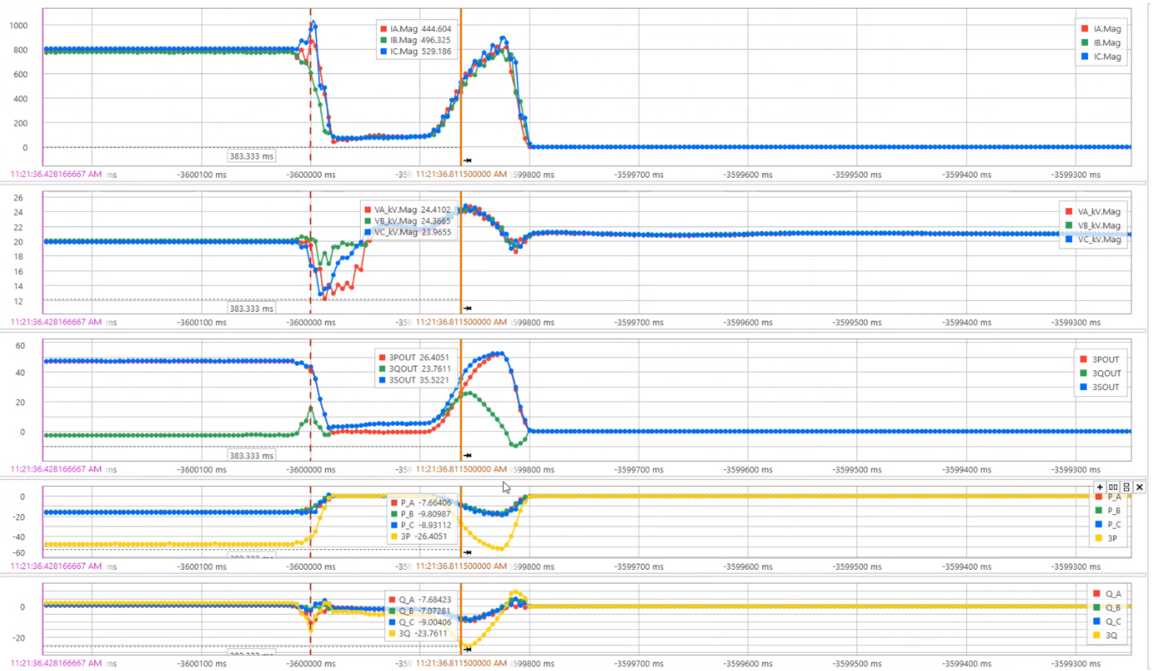

- Voltage driven high by reactive current injection after fault cleared and voltage recovered
- All feeder protection at one facility set to trip on instantaneous phase ac overvoltage
- Set at 1.2 pu – directly on PRC-024-3 and ERCOT NOG VRT curves
- Review team questioned need for this feeder-level protection
- Plant personnel unable to clarify what the voltage protection was protecting at the feeder level
- Plant has since disabled feeder level overvoltage protection – concern that inverter protection could trip for similar event

Momentary Cessation

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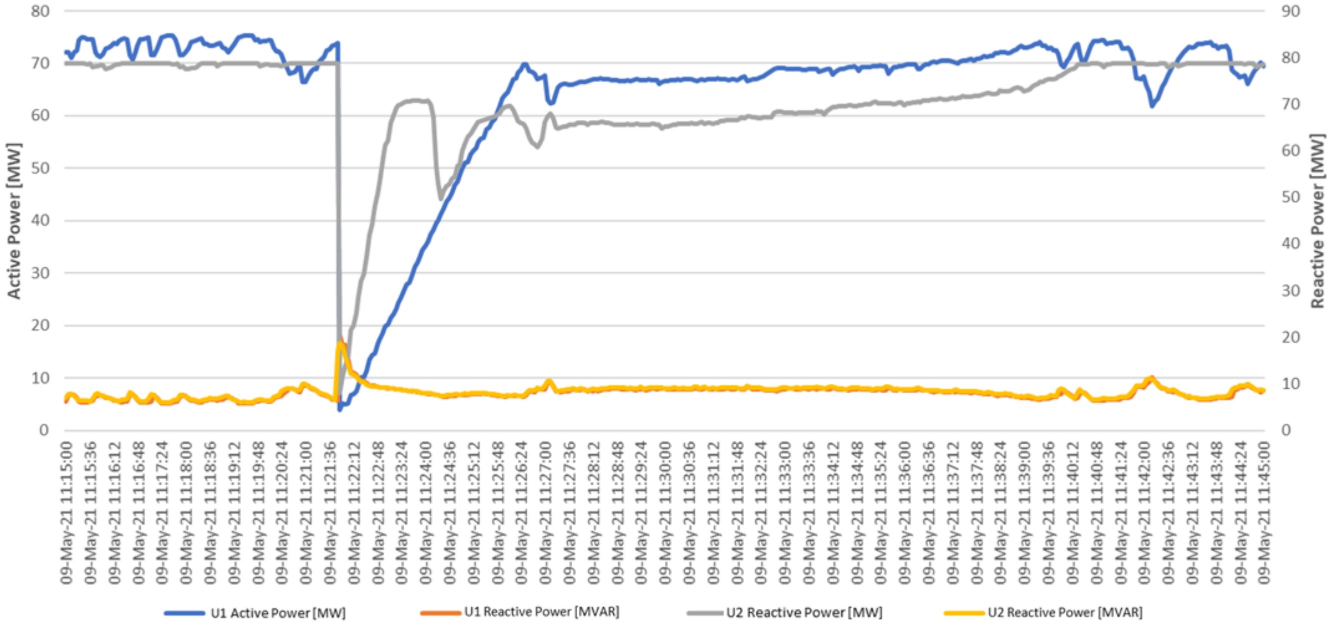

- Legacy inverters at one plant – momentary cessation below 0.9 pu voltage
- Inverters should recover to predisturbance output relatively quickly (<1 sec) when voltage recovers
- Plant-level controller interactions – slowed recovery to BA ramp rate limits
- Not appropriate use of these limits; negatively impacting system stability
- Not meeting recommended performance in NERC reliability guidelines
- Plant has replaced PPC since 2021 Odessa event to improve recovery time

Underfrequency – Inverter and Feeder

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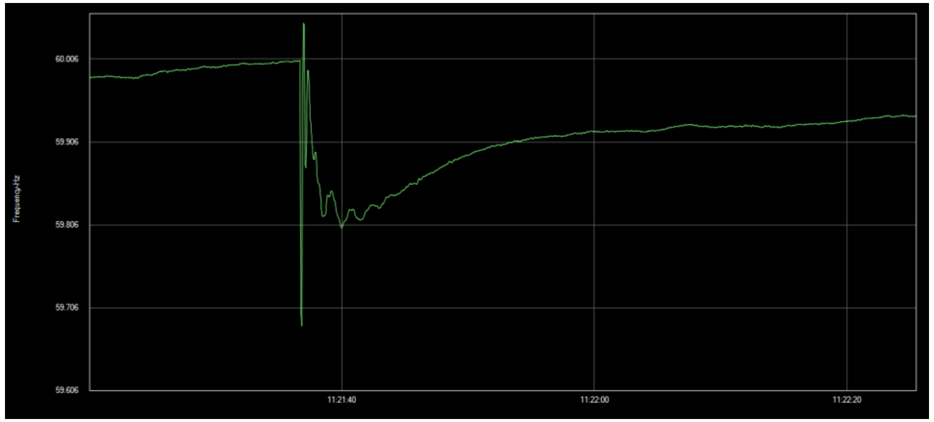


- Inverter-Level Underfrequency:
  - One facility had all inverters trip on "grid underfrequency" below 58.2 Hz
  - Grid frequency did not fall outside of the PRC-024-3 boundaries – low frequency of 59.8 Hz
  - Inverters likely erroneously tripped on a poorly measured or calculated frequency signal during fault conditions
  - Facility modified settings but not until after Odessa 2022

- Feeder-Level Underfrequency:
  - One feeder-level relay operated on frequency below 57.5 Hz
  - NERC followed up with relay OEM to perform root cause analysis
  - Newer relay version used at this facility, set with very fast measurement window
  - Relay OEM modifying adjustable window to eliminate problem – at least 5-cycle measurement window
  - Facility has modified settings but not until after Odessa 2022

Other

Table 1.1: Causes of Reduction	
Cause of Reduction	**Reduction [MW]**
PLL Loss of Synchronism	389
Inverter AC Overvoltage	269
Momentary Cessation	153
Feeder AC Overvoltage	147
Unknown	51
Inverter Underfrequency	48
Not Analyzed	34
Feeder Underfrequency	21

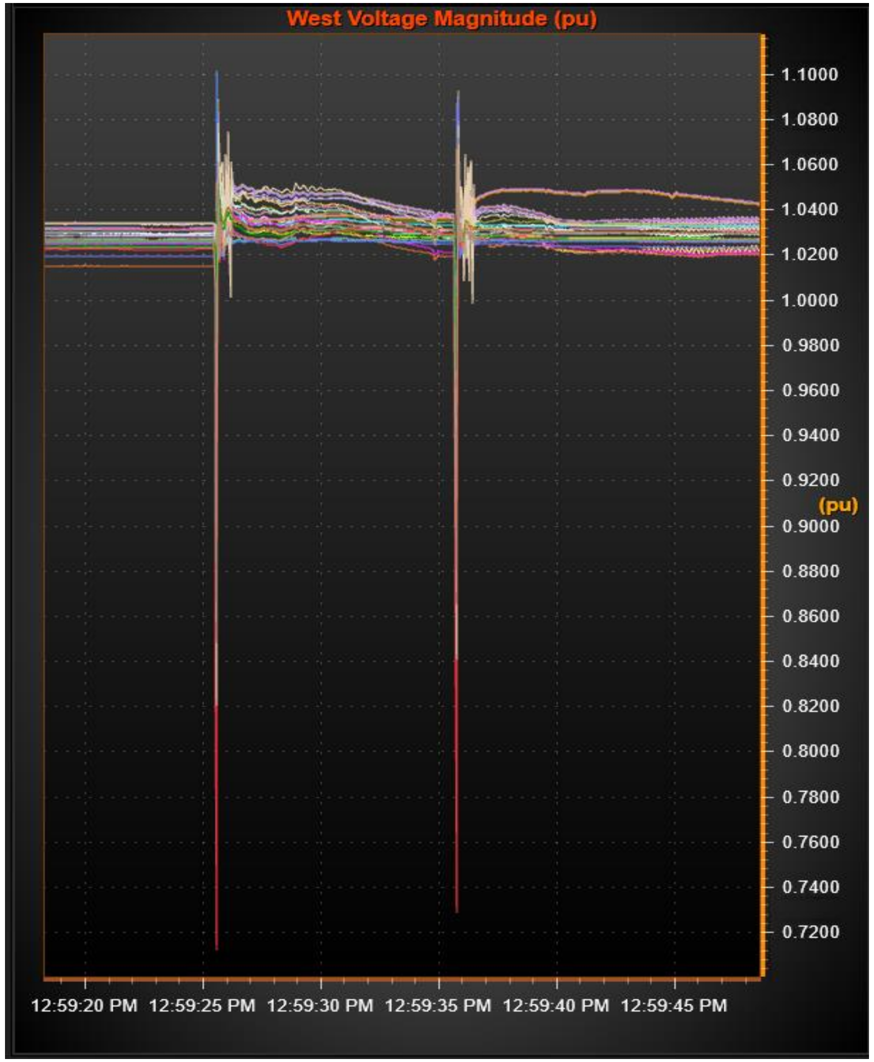
- Unknown Cause (51 MW):
  - Two facilities had insufficient data to perform any useful root cause analysis; the cause of reduction remains unknown.
  - OEM out of business
  - Poor inverter logging capabilities and lack of high-resolution data

- Not Analyzed (34 MW):
  - All other combined reductions in solar PV output (not meeting ERO Enterprise analysis threshold) accounted 34 MW

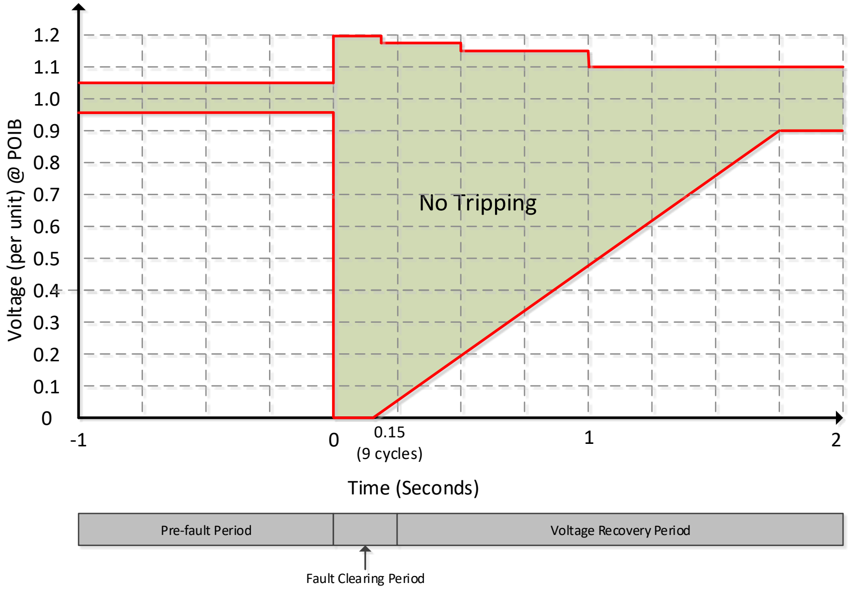
2022 Odessa Disturbance Event Overview

- On June 4, 2022, @ 12:59 PM CDT, Phase-B to ground fault occurred due to lightning arrestor failure in the Odessa area
- Fault cleared within 3 cycles, consequentially tripping off 542 MW of thermal generation
- Additional 309 MW lost from combined cycle plant in South Texas
- Non-consequential loss of 1,709 MW of solar generation from 14 different sites following the fault
- Combined loss of 2,560 MW of generation
- 1,116 of Load Resources provided Responsive Reserve Service automatically
- Frequency dropped to ~59.7 Hz when LR deployed and recovered in 80 seconds
- Categorized as NERC Cat 3a event (generation loss > 2000 MW)

Real Time PMU Voltages



- ERCOT has ~200 PMUs streaming real time data
- Lowest recorded voltage of 0.714pu from PMU in Odessa area on 345 kV line
- Highest recorded voltage of 1.102pu from PMU in Del Rio area on 138 kV line
- Fault cleared in ~3 cycles
- Attempted reclose ~10 seconds later
- Within VRT “No Tripping” zone in NOG 2.9.1



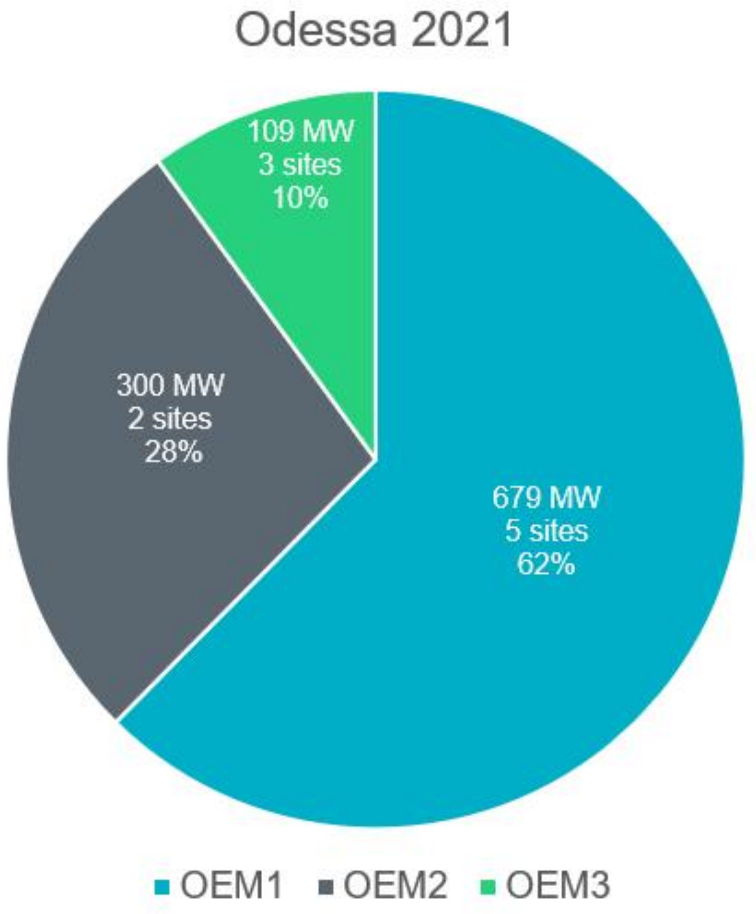
Real Time PMU Frequency

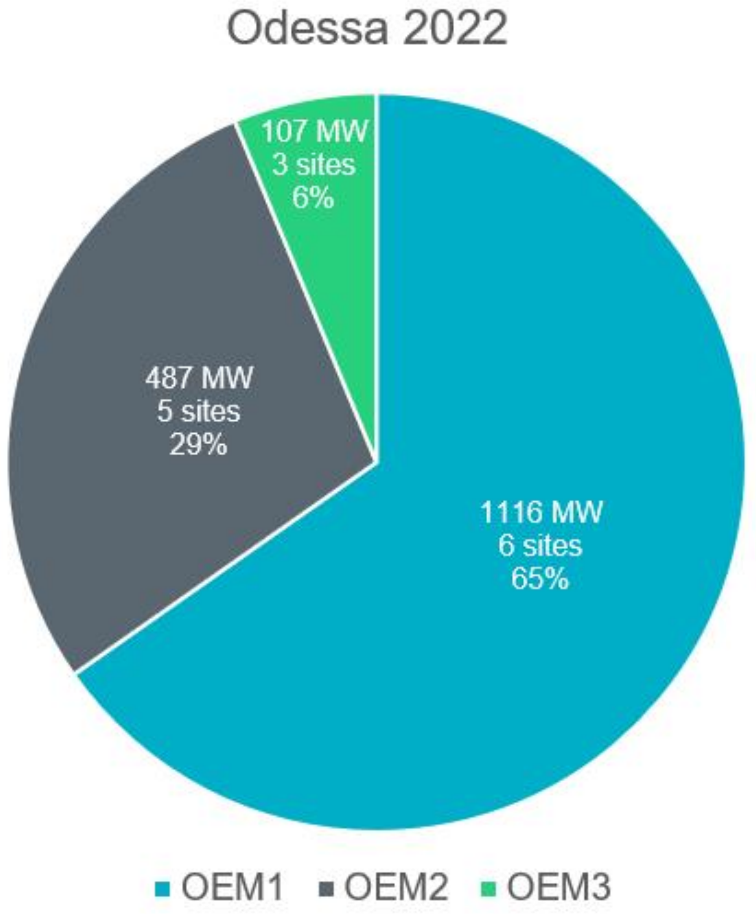
- Most PMUs lowest freq. of 59.7 Hz after loss of generation
- Single PMU near Laredo had lowest freq. of 59.62 Hz
- Couple other PMUs in South Texas dipped below 59.7 Hz
- Local frequencies during fault conditions measured as low 58.83 Hz and high as 60.26 Hz in Far West Texas
- Protection settings should measure frequencies over >5 cycles to prevent unnecessary tripping

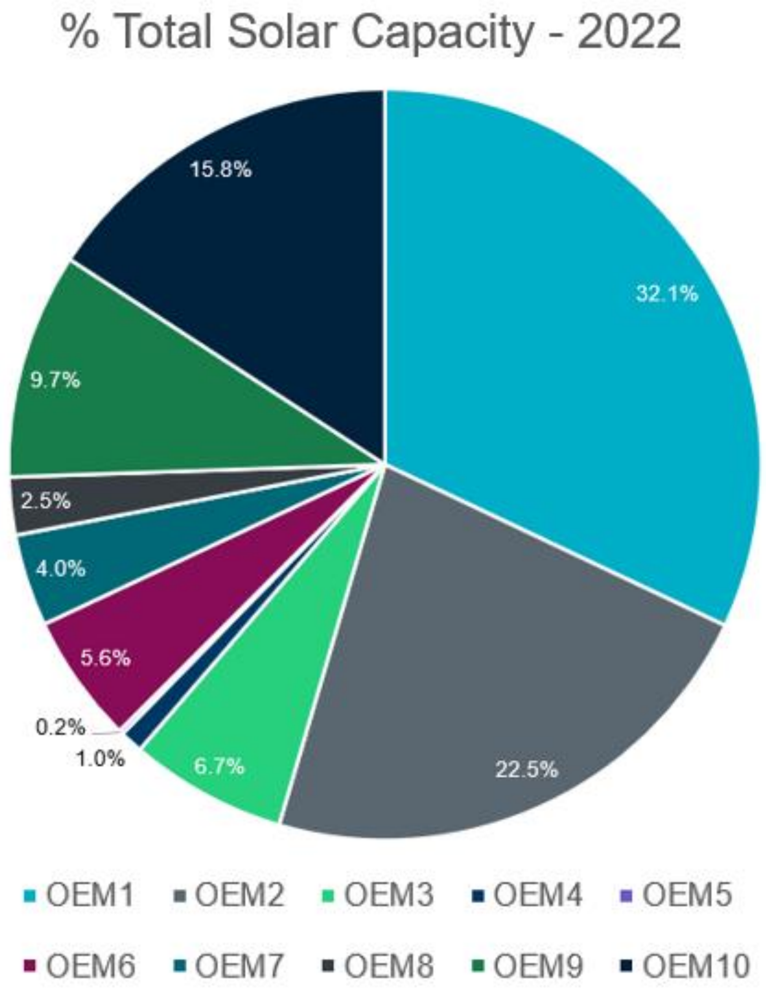
Frequency Range	Delay to Trip
Above 59.4 Hz	No automatic tripping (Continuous operation)
Above 58.4 Hz up to And including 59.4 Hz	Not less than 9 minutes
Above 58.0 Hz up to And including 58.4 Hz	Not less than 30 seconds
Above 57.5 Hz up to And including 58.0 Hz	Not less than 2 seconds
57.5 Hz or below	No time delay required

Frequency Range	Delay to Trip
Below 60.6 Hz down to and including 60 Hz	No automatic tripping (Continuous operation)
Below 61.6 Hz down to and including 60.6 Hz	Not less than 9 minutes
Below 61.8 Hz down to and including 61.6 Hz	Not less than 30 seconds
61.8 Hz or above	No time delay required

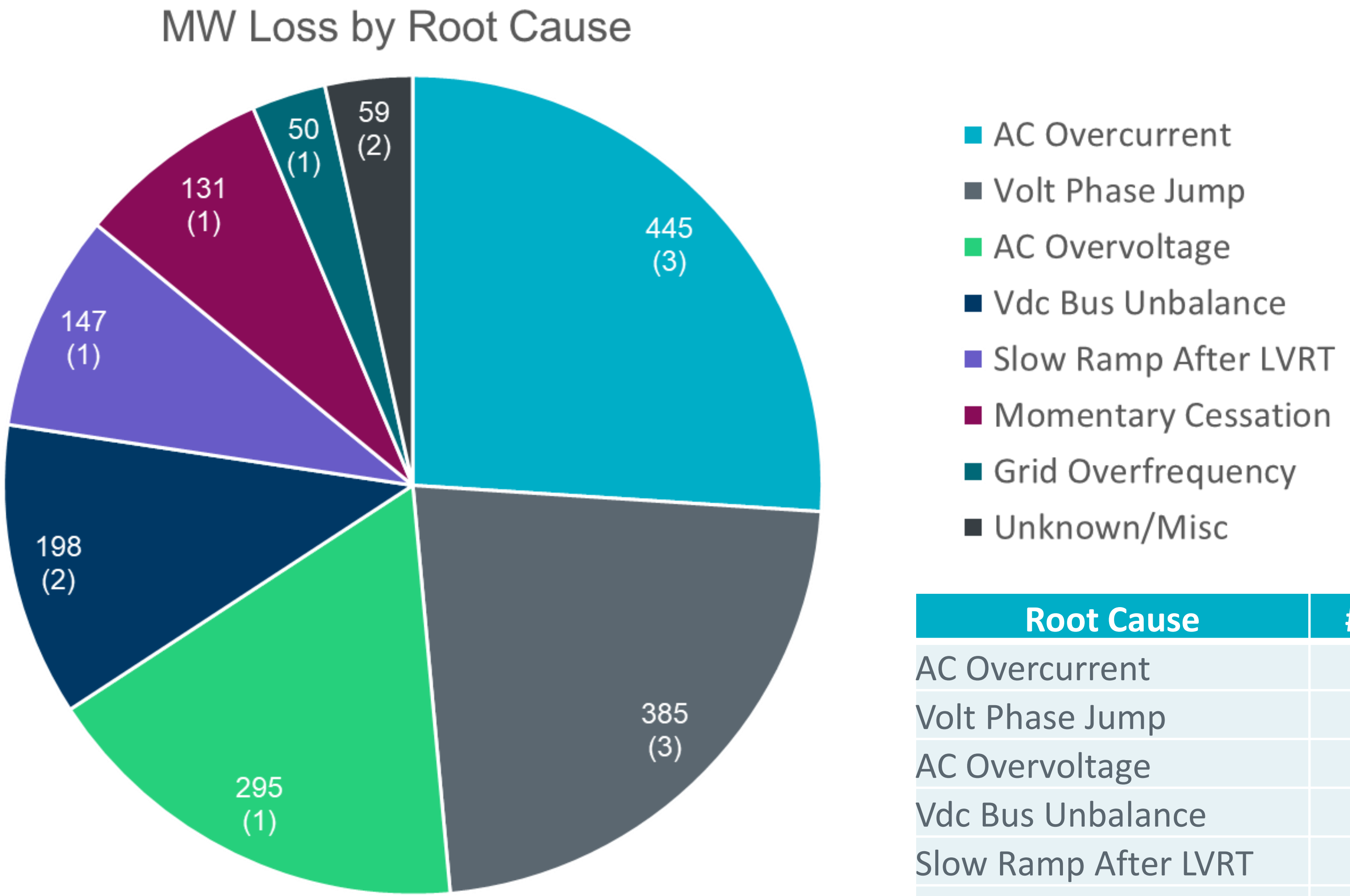
MW Loss per Inverter Type and Capacity







Causes of Solar PV Reduction – 2022 Odessa



Root Cause	# Affected Facilities	MW Loss
AC Overcurrent	3	445
Volt Phase Jump	3	385
AC Overvoltage	1	295
Vdc Bus Unbalance	2	198
Slow Ramp After LVRT	1	147
Momentary Cessation	1	131
Grid Overfrequency	1	50
Unknown/Misc	2	59

AC Overcurrent Protection

Root Cause	# Affected Facilities	MW Loss
AC Overcurrent	3	445
Volt Phase Jump	3	385
AC Overvoltage	1	295
Vdc Bus Unbalance	2	198
Slow Ramp After LVRT	1	147
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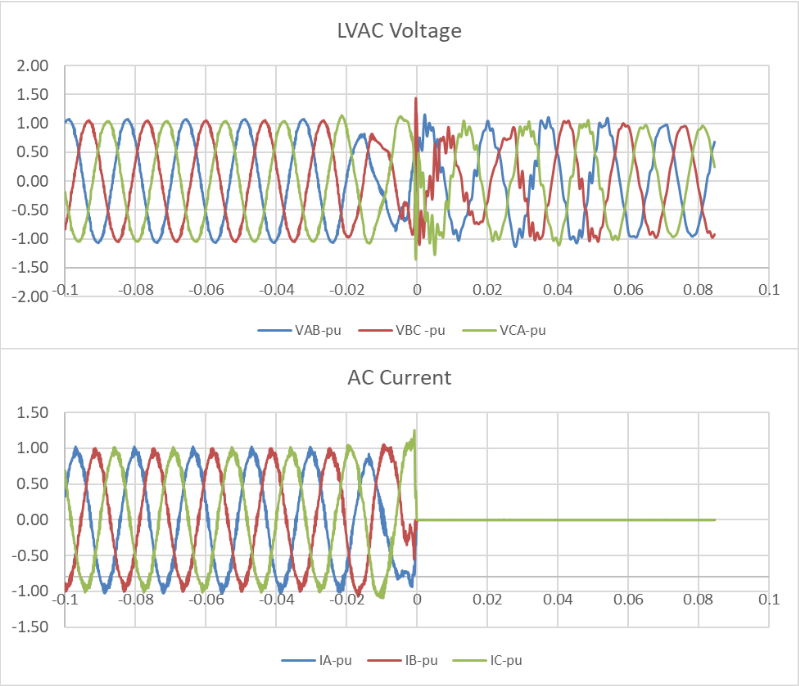

- **2 plants with OEM1 inverters (259 and 176 MW loss)**
  - Both plants in commissioning during 2021 Odessa
  - All inverters tripped on either AC Overcurrent Low (140% of rated current) or High (150% of rated current)
  - Overcurrent caused by distorted voltages and instantaneous current spikes during fault conditions
  - Protection prevents damage to insulated-gate bipolar transistors within inverter – cannot be increased
  - OEM developed and currently testing potential upgrade to prevent overcurrent during this type of event
- **1 plant with OEM3 inverters (10 MW loss)**
  - 7 of 79 inverters tripped – OEM out of business and unable to provide analysis/corrective actions

Volt Phase Jump

Root Cause	# Affected Facilities	MW Loss
AC Overcurrent	3	445
Volt Phase Jump	3	385
AC Overvoltage	1	295
Vdc Bus Unbalance	2	198
Slow Ramp After LVRT	1	147
Momentary Cessation	1	131
Grid Overfrequency	1	50
Unknown/Misc	2	59

- Anti-islanding protection primarily used in distribution to protect lineman
- Protection not needed for BPS
- Anti-islanding protection required for UL 1741 certification

- **3 plants with OEM1 inverters for combined loss of 385 MW**
  - Plants had all inverters trip on Fault Code 221: Volt Phase Jump – occurs when expected phase angle deviates > 15 degrees
  - OEM confirmed it is not needed for inverter protection
  - OEM recommends either extending threshold to 35 degrees or disabling protection altogether
  - Up to GO to choose and authorize OEM to extend threshold or disable setting
  - Already extended or disabled at 2 plants; 3rd plant will be extending threshold
  - 2 plants tripped on inverter AC overvoltage and 1 plant tripped on PLL Loss of Synchronism in Odessa 2021

AC Overvoltage – Inverter Terminals

Root Cause	# Affected Facilities	MW Loss
AC Overcurrent	3	445
Volt Phase Jump	3	385
AC Overvoltage	1	295
Vdc Bus Unbalance	2	198
Slow Ramp After LVRT	1	147
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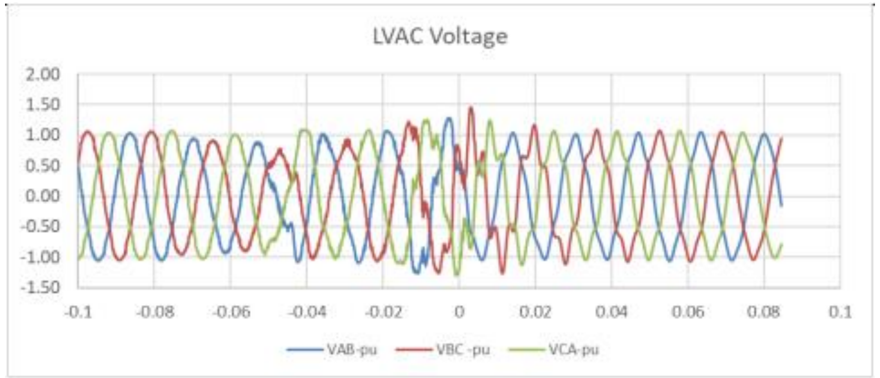

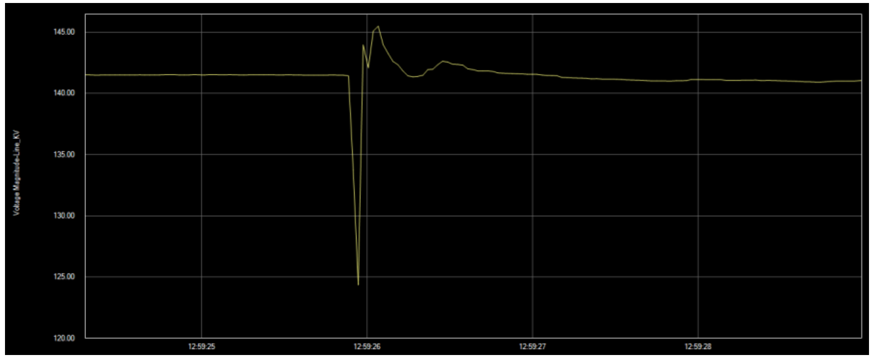

- **1 Plant with OEM1 inverters**
  - Had feeder breaker trip on underfrequency during 2021 Odessa event
  - All inverters tripped on Instant AC Overvoltage in which inverter trip occurs in 1-3 ms when voltage exceeds 1.25pu
  - Inverter terminal voltage reached > 1.3pu during event, but high side of GSU only reached 1.056 pu per PMU data provided by RE – likely caused by reactive injection once fault has cleared
  - Plant had two feeder breakers trip on underfrequency < 57.5 Hz; have adjusted breaker underfrequency settings since event
  - OEM has identified potential solutions – increasing fast overvoltage protection to 1.4 pu and reducing k-factor to reduce reactive injection causing high voltage at inverter terminals

Vdc Bus Unbalance

Root Cause	# Affected Facilities	MW Loss
AC Overcurrent	3	445
Volt Phase Jump	3	385
AC Overvoltage	1	295
Vdc Bus Unbalance	2	198
Slow Ramp After LVRT	1	147
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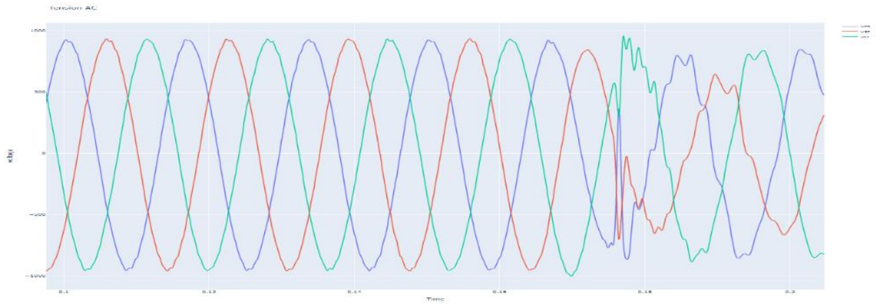

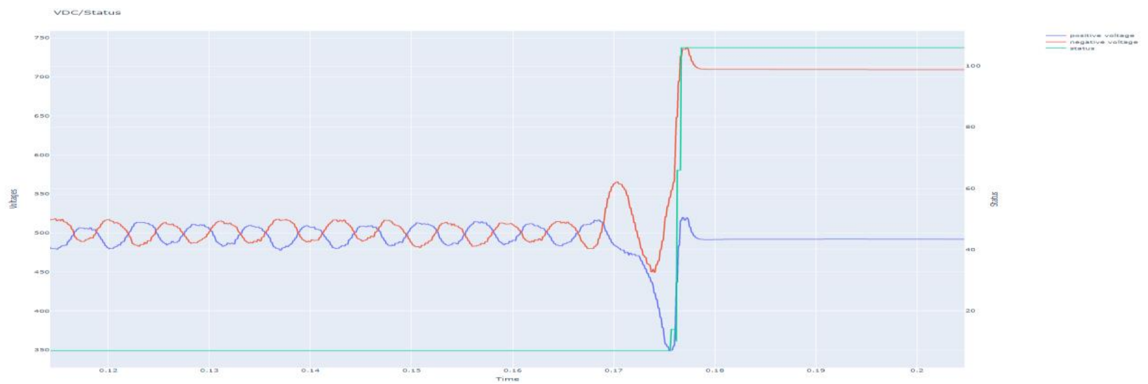

- **2 plants with OEM2 inverters (neither plant involved in 2021 Odessa event)**
  - Fault Code for Vdc Unbalance occurs when DC-side positive and negative bus voltage differ by > 100 V (minor) or > 200 V (major) for 1 ms
  - AC voltage phase became unbalanced faster than controls could regulate DC-side due to disturbance
  - Plants and OEM claim protection operated correctly and required for equipment protection – potential DC short
  - Issue seen in previous events and OEM was already working on fix
  - Software update currently available to improve DC regulation response time and ride-through capabilities
  - One plant has already implemented software upgrade; Second plant scheduled in November

Slow Ramp After LVRT

Root Cause	# Affected Facilities	MW Loss
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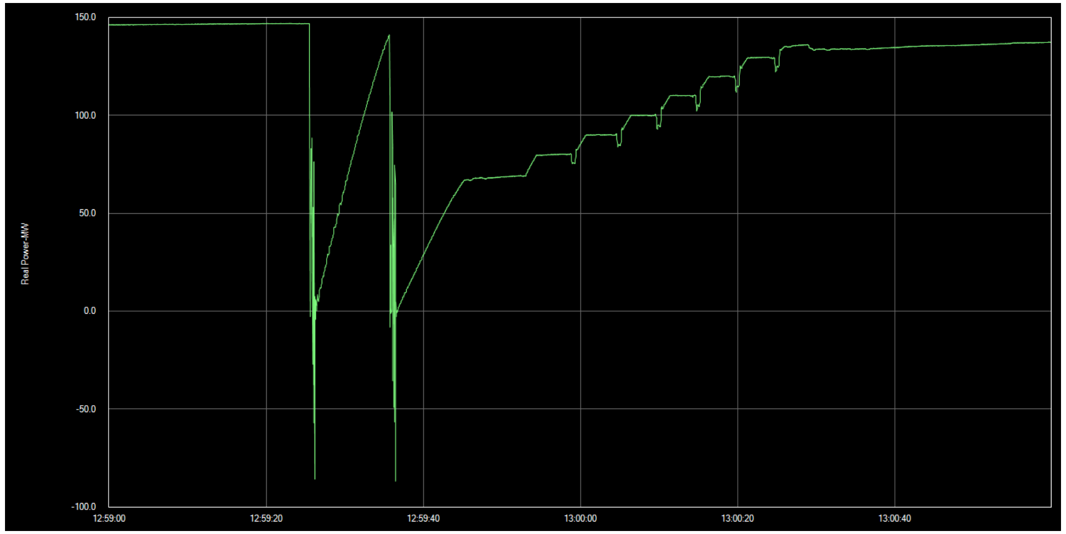

- **1 plant with OEM2 inverters**
  - Provides 100% reactive current during LVRT and did not recover quickly (~10 sec) upon fault clearing
  - Issue identified during Odessa 2021 event analysis but primary cause during 2021 event was feeder breaker tripping on underfrequency (since disabled)
  - Plant has adjusting settings to:
    - ➢Change LVRT/HVRT mode to provide consistent active power as well as required reactive power
    - ➢Change fast overvoltage protection trip settings to 1.35pu with 0.5 sec delay
  - LVRT mode disabled during 2022 event – caused slow response due to PPC interactions
  - LVRT now enabled and all inverter setting changes complete
  - PSCAD modeling required to determine cause of oscillations

Momentary Cessation

Root Cause	# Affected Facilities	MW Loss
AC Overcurrent	3	445
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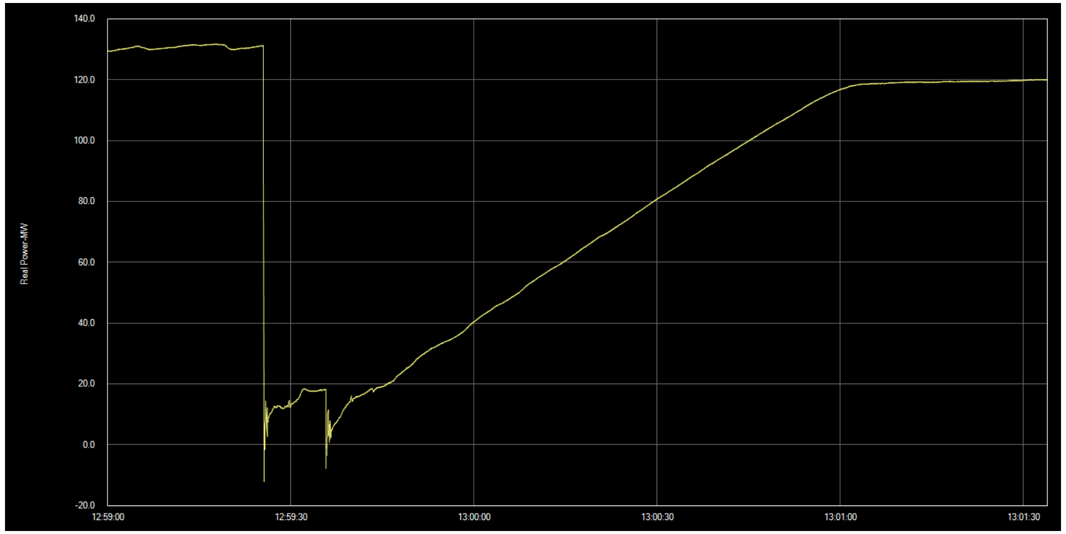

- **1 plant with OEM2 inverters**
  - Previously thought momentary cessation could not be disabled but discovered it was disabled during 2022 event
  - Inverters reduced output due to loss of auxiliary power during 2022 event
  - Legacy inverters with limiting logging capabilities – difficult to identify corrective actions to improve response
  - Unclear whether voltage drop or phase jump caused initial active power loss
  - One potential corrective action is to install UPS for each inverter – unclear if this would allow inverters to ride-through large phase jump
  - Momentary cessation reenabled to allow quicker return after fault clearing – cannot provide reactive
  - Potentially may not be able to meet current VRT requirements with current inverters

Grid Overfrequency / Unknown

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- **1 plant with OEM3 inverters**
  - All inverters tripped on Grid Overfrequency Fault Code
  - Plant acknowledged that conditions for overfrequency trip of 60.6 Hz for 600 sec were not met
  - Fault code table/ registry likely provided wrong fault code – root cause of inverter tripping unknown
  - Possibly tripped on underfrequency below 57.5 Hz – was set to instantaneous trip
  - OEM and GO changed FRT and VRT settings to reflect equipment tolerances - all frequency settings now with 5 second measurement window and VRT settings extended
  - OEM updating software to fix logging issues

Unknown / Miscellaneous

Root Cause	# Affected Facilities	MW Loss
AC Overcurrent	3	445
Volt Phase Jump	3	385
AC Overvoltage	1	295
Vdc Bus Unbalance	2	198
Slow Ramp After LVRT	1	147
Momentary Cessation	1	131
Grid Overfrequency	1	50
Unknown/Misc	2	59

- **1 plant with OEM2 inverters (12 MW loss)**
  - Had 2 inverters trip due to high internal temperature and 3 inverters trip to IGBT overcurrent
  - Unable to identify corrective actions due to logging issues – replaced SD cards

- **1 plant with OEM3 inverters (47 MW loss)**
  - Most inverters went into standby mode and restart after 6-miute timeout
  - Inverter fault codes overwritten so root cause unknown
  - Inverters tripped during 2021 event for grid underfrequency
  - Protection settings for fast underfrequency (<57.5 Hz) have been updated since the 2022 event – extended to 2-second delay
  - OEM and GO developing new FRT and VRT settings based on equipment tolerances
  - Plant needs to improve logging capabilities

Summary of ERCOT Activities in Response to Odessa Events

- Drafting NOG Revision to improve FRT and VRT requirements for IBRs using IEEE 2800 Standard as guideline
  - ➢ Meeting with OEMs to determine what proportion of fleet can meet new requirements

- Continue following up with facilities involved in Odessa events so that corrective actions are implemented – possibly complete by EOY

- Reach out to facilities with same inverters not involved in events to recommend preventative actions

- Analyze smaller events similar to Odessa events (system fault + IBR MW reduction) to identify and mitigate abnormal IBR performance during events

- Validating models of affected facilities compared to PMU and DFR data and requiring GOs to ensure models reflect actual resource performance

- Requiring affected facilities to resubmit dynamic models upon implementation of corrective actions

Questions?