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WECC
Electric Reliability and Security for the West

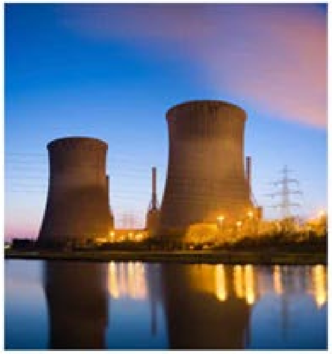
California 2021 Solar PV Events

NERC/WECC Event Analysis and Engineering

Ryan Quint, Rich Bauer, NERC
James Hanson, Curtis Holland, WECC

Industry Webinar – May 2022

RELIABILITY | RESILIENCE | SECURITY

Opening Remarks

Branden Sudduth
Vice President
Reliability Planning and Performance Analysis

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Introductions

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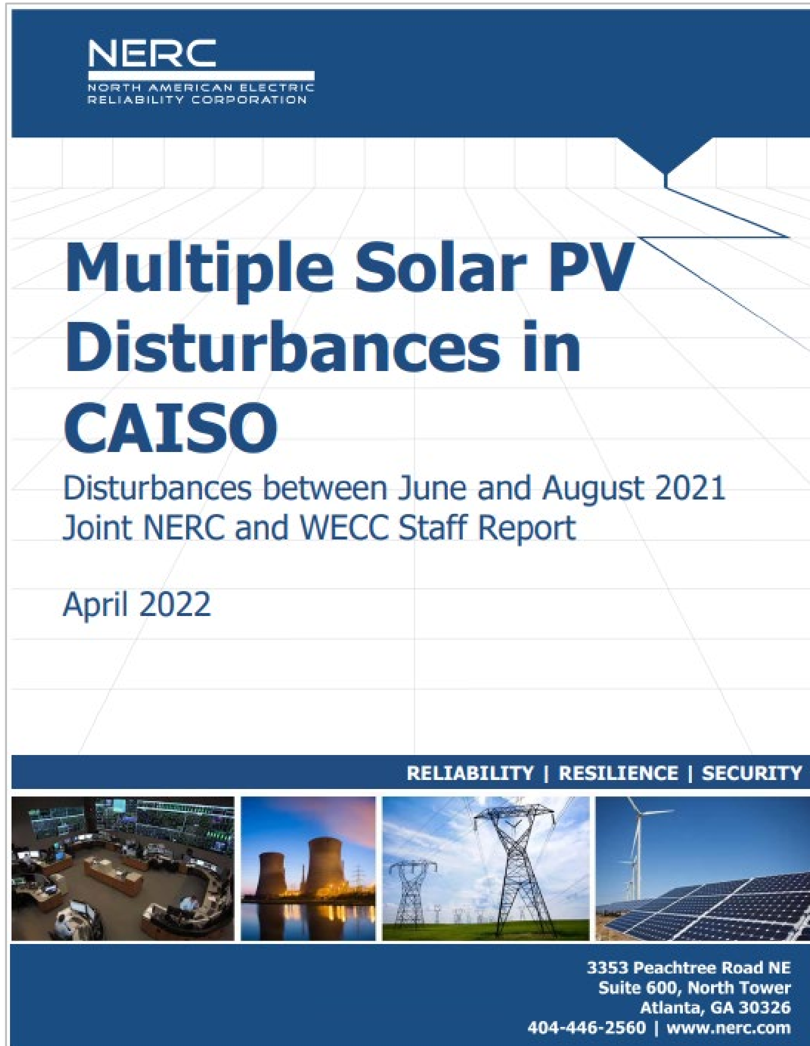
NERC Disturbance Reports and Alerts

CA 2021 Disturbances Report



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Multiple Solar PV Disturbances in CAISO

Disturbances between June and August 2021
Joint NERC and WECC Staff Report

April 2022

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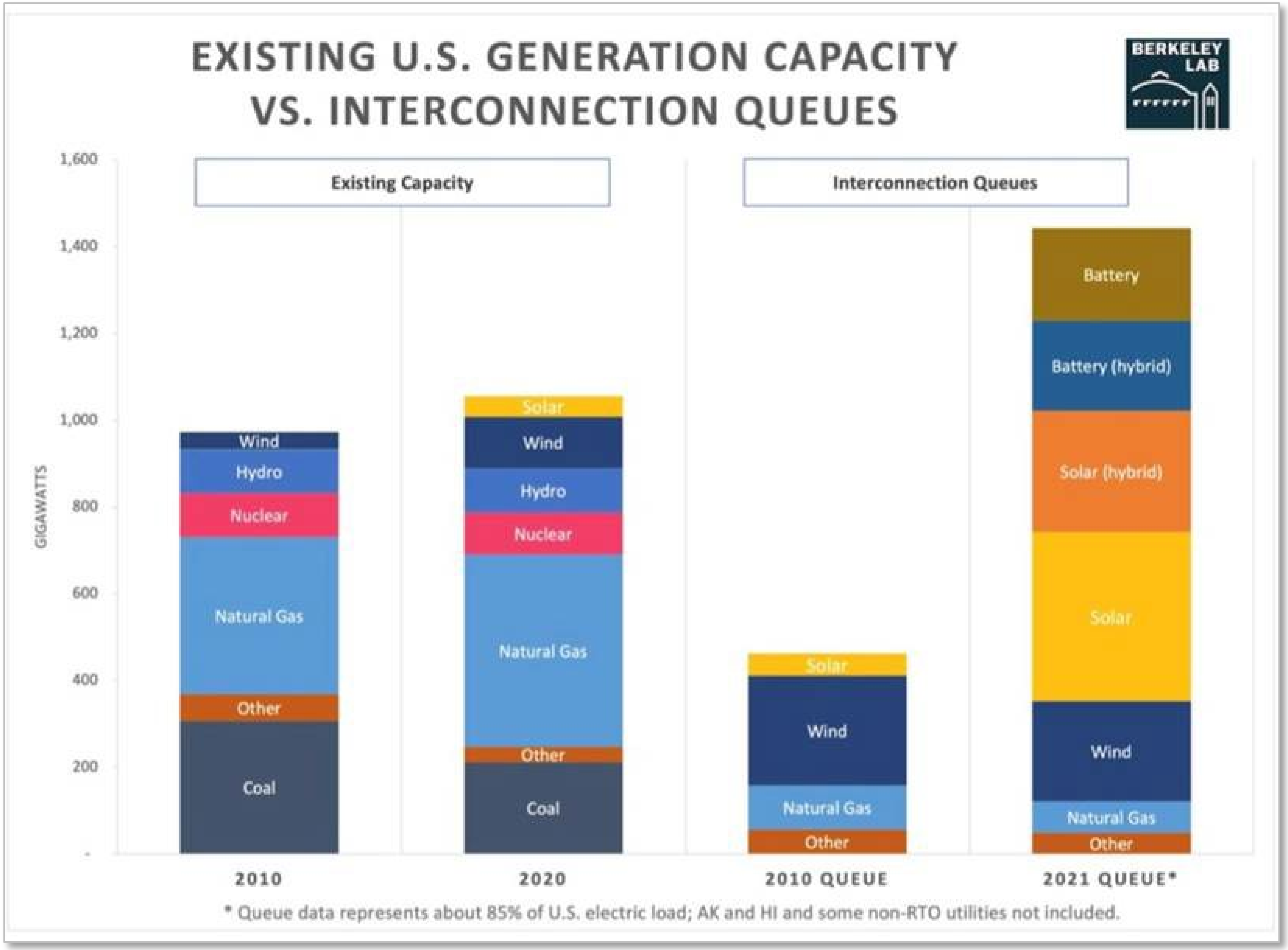
3353 Peachtree Road NE
Suite 600, North Tower
Atlanta, GA 30326
404-446-2560 | www.nerc.com

https://www.nerc.com/pa/rrm/ea/Pages/CAISO-2021-Disturbance-Report.aspx

Interconnection Queues



Source: LBNL

Overview of Disturbances
and
Causes of Generation Reductions

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Analysis Process

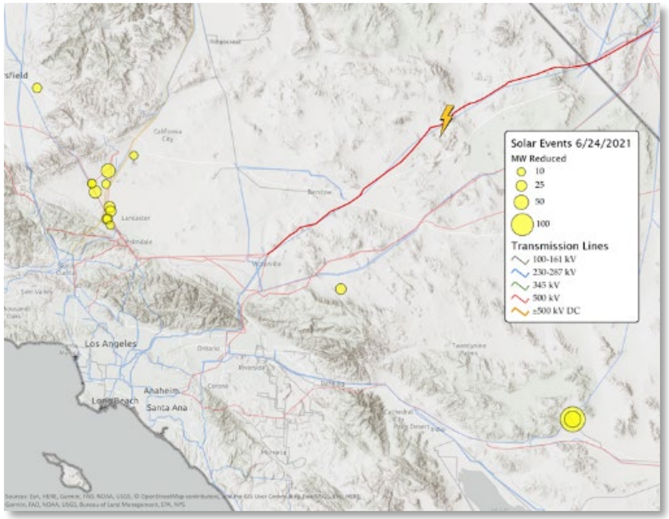
- Situational awareness tools identified disturbances – WECC and NERC low frequency alarms coincident with fault events
- WECC and CAISO confirmed widespread solar PV reduction coincident with fault
- Categorized as NERC Event Analysis Program Category 1i event
- CAISO provided Brief Reports for each events, identifying resources involved
- WECC initiated RFIs to affected facilities – follow-up discussions needed to identify root causes of reduction for most facilities
- NERC and WECC engaged affected generator owners for facilities that reduced output **more than 10 MW**

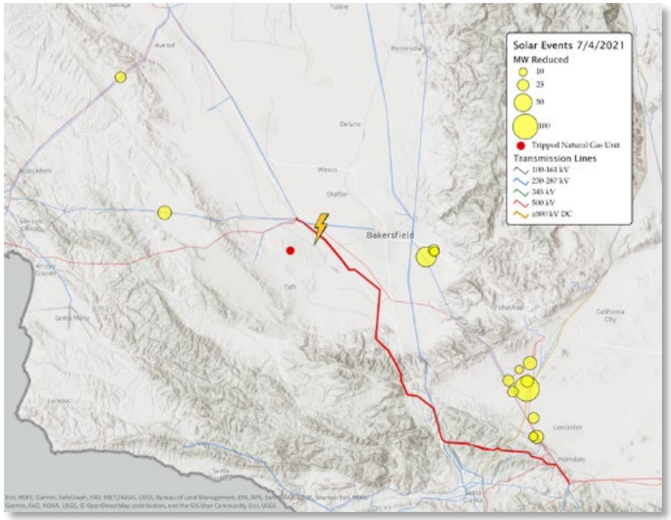
Overview of Events

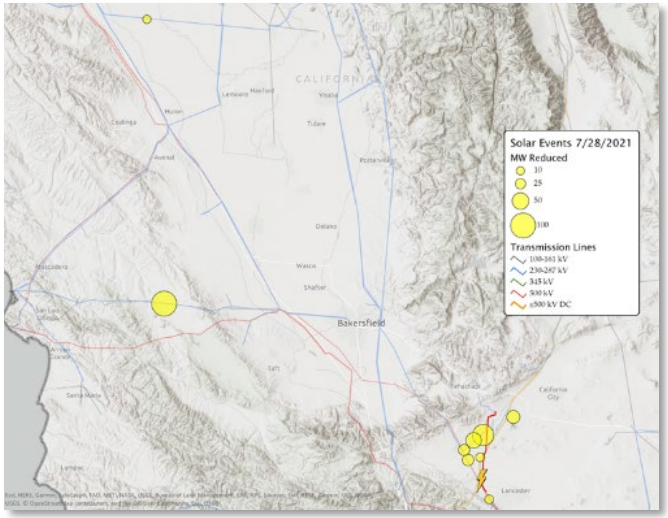
Table ES.1: Overview of Disturbances		
Disturbance and Name	**Initiating Fault Event**	**Description of Resource Loss***
June 24, 2021 "Victorville"	Phase-to-Phase Fault on 500 kV Line	Loss of 765 MW of solar PV resources (27 facilities) Loss of 145 MW of DERs
July 4, 2021 "Tumbleweed"	Phase-to-Phase Fault on 500 kV Line	Loss of 605 MW of solar PV resources (33 facilities) Loss of 125 MW at natural gas facility Loss of 46 MW of DERs
July 28, 2021 "Windhub"	Single-Line-to-Ground Fault on 500 kV Circuit Breaker	Loss of 511 MW of solar PV resources (27 facilities) Loss of 46 MW of DERs
August 25, 2021 "Lytle Creek Fire"	Phase-to-Phase Fault on 500 kV Line	Loss of 583 MW of solar PV resources (30 facilities) Loss of 212 MW at natural gas facility Loss of 91 MW at a different natural gas facility

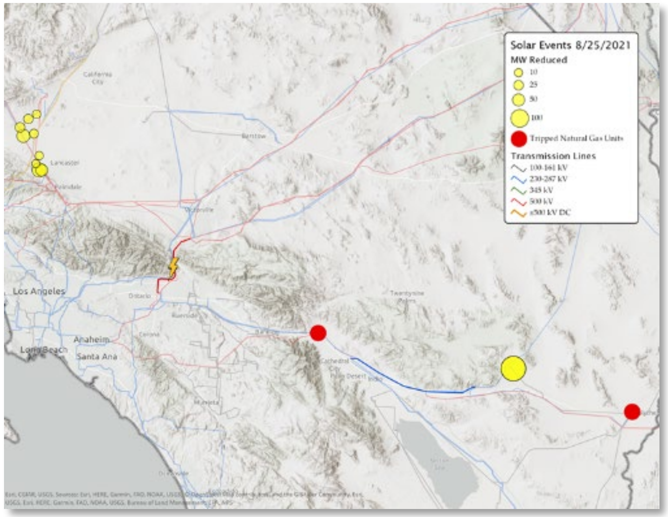
* All events occurred in afternoon (12:00 and 4:00 p.m. Pacific)

Four Events in California in 2021









CAISO Predisturbance Operating Conditions

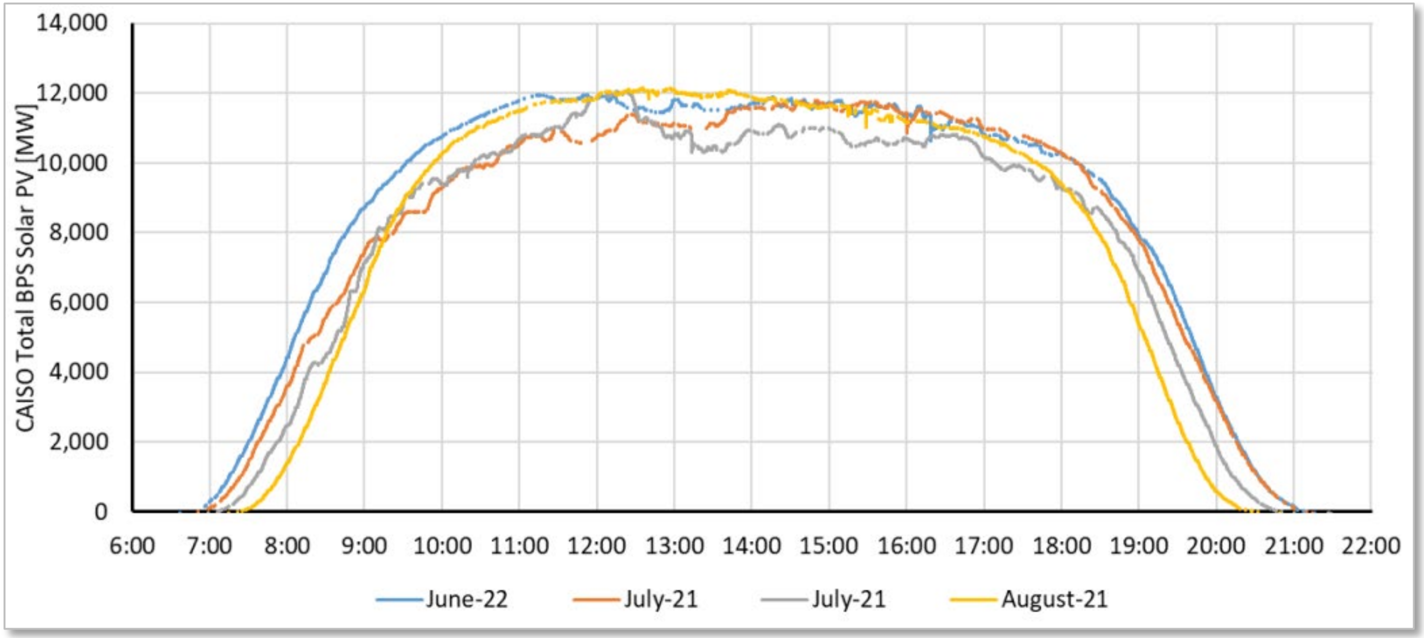
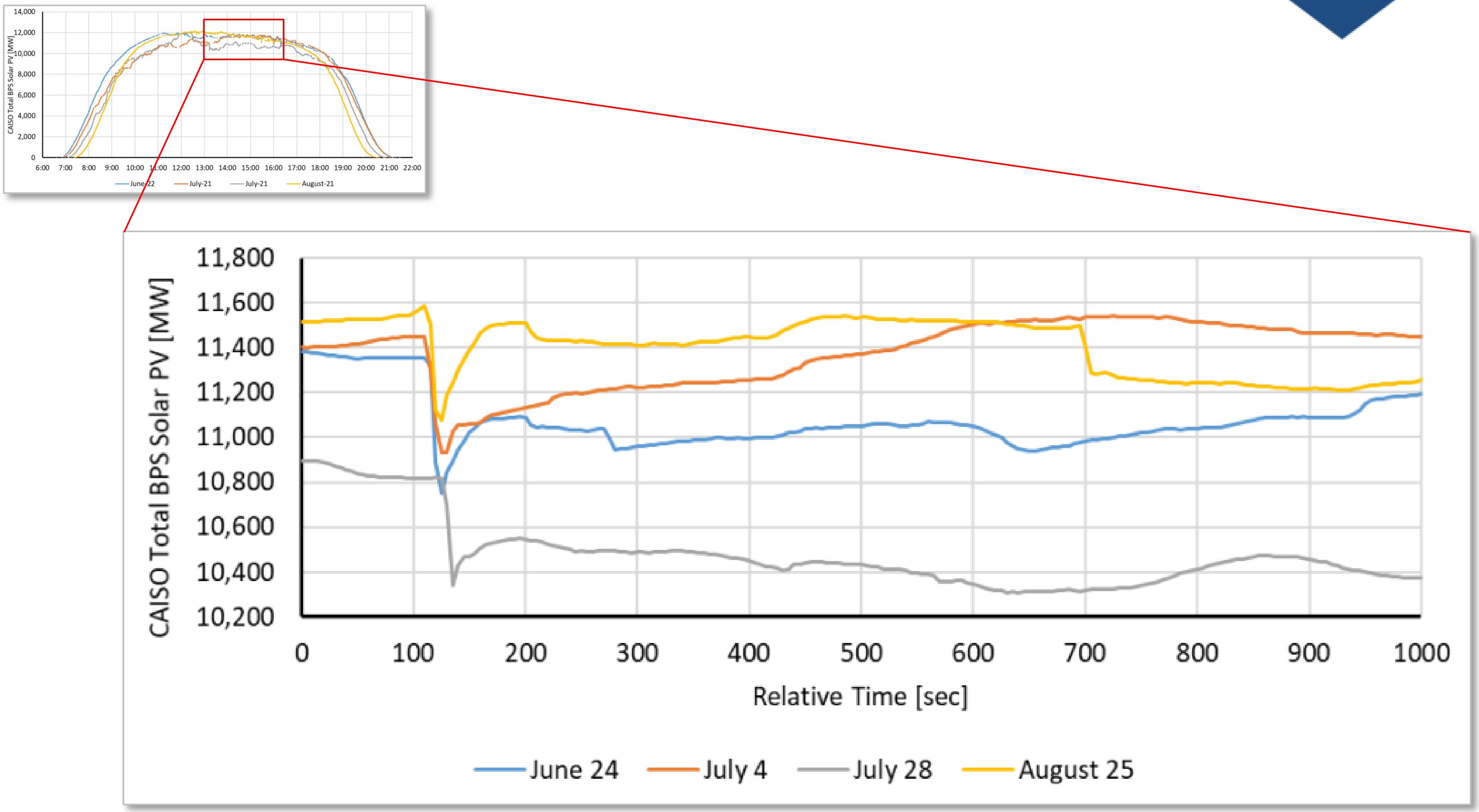
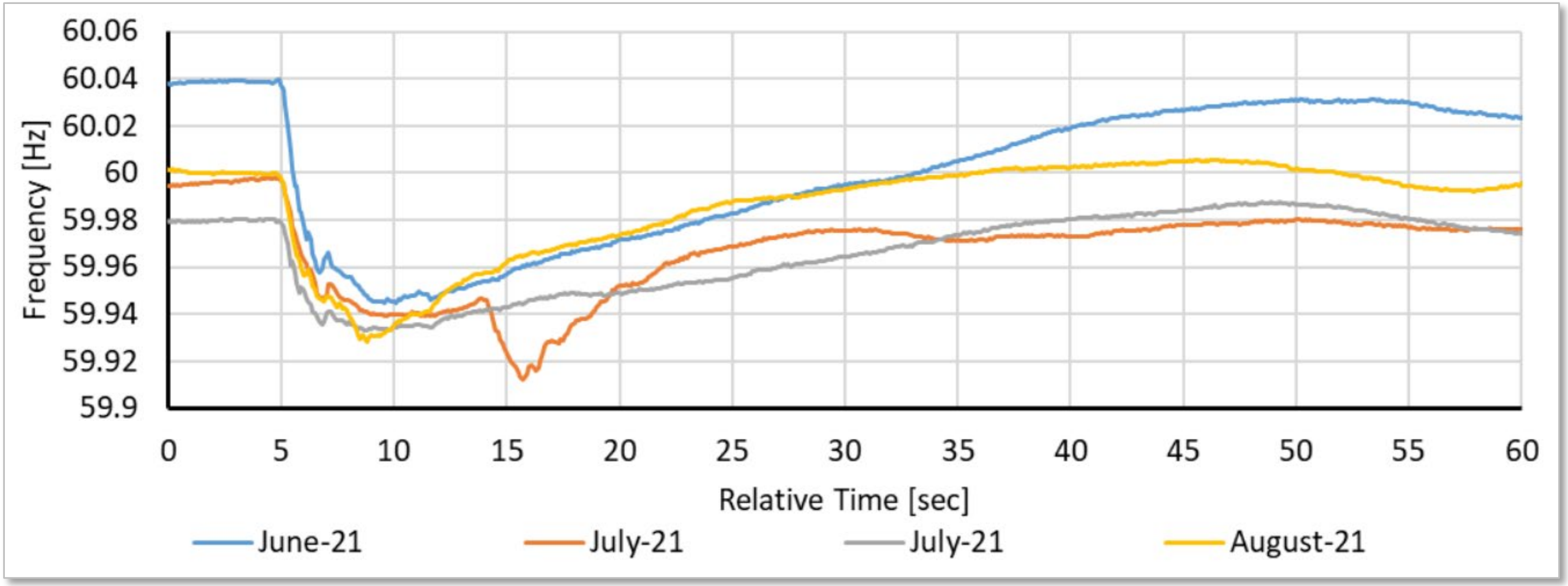


Table 1.1: CAISO Predisturbance Operating Conditions [Source: CAISO]								
Operating Condition	**June 24, 2021**		**July 4, 2021**		**July 28, 2021**		**Aug 25, 2021**	
	Value	**%**	**Value**	**%**	**Value**	**%**	**Value**	**%**
CAISO Internal Net Demand	30,513	N/A	28,185	N/A	33,003	N/A	32,523	N/A
Solar PV Output [MW]	11,373	37.3%	11,404	40.5%	10,892	33%	11,526	35.4%
Wind Output [MW]	2,268	7.4%	3,156	11.2%	172	0.5%	1,407	4.3%
BESS Output [MW]	-115	-0.4%	-249	-0.9%	-169	-0.5%	100	0.3%

CAISO Predisturbance Operating Conditions



CAISO Predisturbance Operating Conditions



Growing Solar PV Portfolio

California ISO

News Release

April 14, 2022 — **Media Email | ISOMedia@caiso.com**

California ISO hits all-time peak of more than 97% renewables

Electric grid breaks another record, giving glimpse of zero-carbon future

FOLSOM, Calif. – In another sign of progress toward a carbon-free power grid, the California Independent System Operator (ISO) set a new record on April 3, when 97.6 percent of electricity on the grid came from clean, renewable energy.

The peak, which occurred briefly at 3:39 p.m., broke the previous record of 96.4 percent set on March 27, 2022. Before that, the grid's record for clean power was 94.5 percent, set on April 21, 2021. The new milestone comes as the ISO integrates growing amounts of renewable energy onto the grid in support of the state's clean energy goals.

"This new record is testament to the hard work and collaboration of many people, from policymakers to system operators," said ISO President and CEO Elliot Mainzer. "While these all-time highs are for a brief time, they solidly demonstrate the advances being made to reliably achieve California's clean energy goals."

Ashutosh Bhagwat, chair of the ISO Board of Governors, said the new record is a tribute to California's ambitious policy goals on climate and clean energy.

"When we see renewable energy peaks like this, we are getting to re-imagine what the grid will look like for generations to come," he said. "These moments help crystallize the vision of the modern, efficient and sustainable grid of the future."

The grid also set a historical solar peak of 13,628 megawatts (MW) just after noon on April 8, and an all-time wind peak of 6,265 MW just before 3 p.m. on March 4.

Renewable peaks typically occur in the spring, due to mild temperatures and the sun angle allowing for an extended window of strong solar production. ISO analysis forecasts a potential for more renewable records in April.

California ISO | Monthly Renewables Performance Report

Mar. 2022 | Summary | Net Load | Pricing | VER Curtailment | Reliability Metrics

Summary

36.14% Mar Average Renewable Serving Load	31.28% Year to Date Average Renewable Serving Load	96.38% Max 5 min. Renewable Serving Load All-time	5.973TWh Mar Metered Renewable Generation
13456MW Mar Max Solar Production	13456MW Year to Date Max Solar Production	13456MW All-time Max Solar Production	436000MWh Mar Solar Energy Curtailed
6265MW Mar Max Wind Production	6265MW Year to Date Max Wind Production	6265MW All-time Max Wind Production	27310MWh Mar Wind Energy Curtailed
17813MW/3hr Mar Max 3 Hour Net Load Ramp	9.289% Percent of 5-min Intervals with Negative Prices	149.7% Mar Average Control Performance Standard (CPS1)	463310MWh Mar Wind and Solar Energy Curtailed

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Causes of Solar PV Reduction

Table 2.1: Causes of Reduction				
Cause of Reduction	**June 24 [MW]**	**July 4 [MW]**	**July 28 [MW]**	**August 25 [MW]**
Slow Active Power Recovery	111	193	184	91
Momentary Cessation	310	120	192	447
Cause Unknown	103	103	112	24
Inverter DC Voltage Unbalance	-	77	15	4
Inverter AC Overcurrent	49	74	17	13
Inverter DC Overcurrent	98	9	47	3
Inverter UPS Failure	-	4	-	-
Inverter Overfrequency	-	-	43	18
Inverter Underfrequency	14	-	-	-
Inverter AC Undervoltage	100	-	16	-
Total	**785**	**566**	**626**	**600**

Causes of Solar PV Reduction

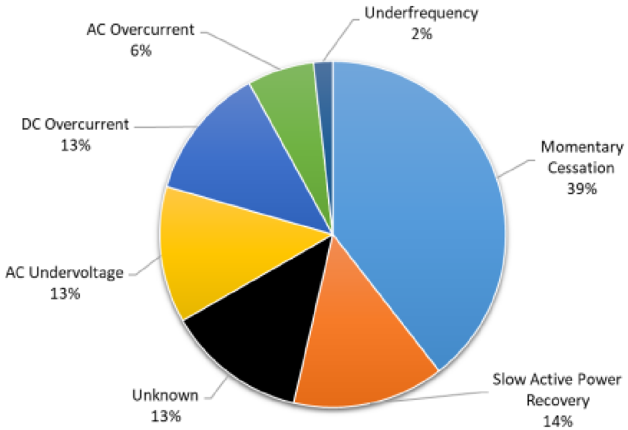


Figure 2.1: June 24 Disturbance Causes of Solar PV Reduction

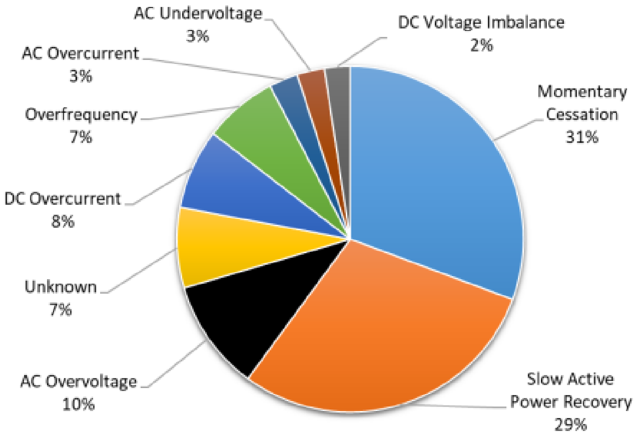


Figure 2.3: July 28 Disturbance Causes of Solar PV Reduction

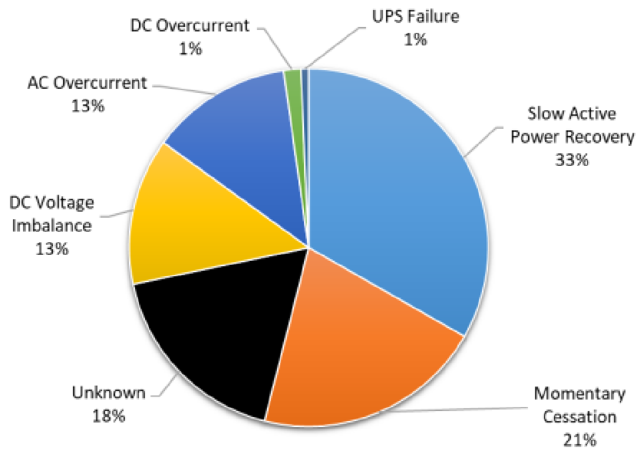


Figure 2.2: July 4 Disturbance Causes of Solar PV Reduction

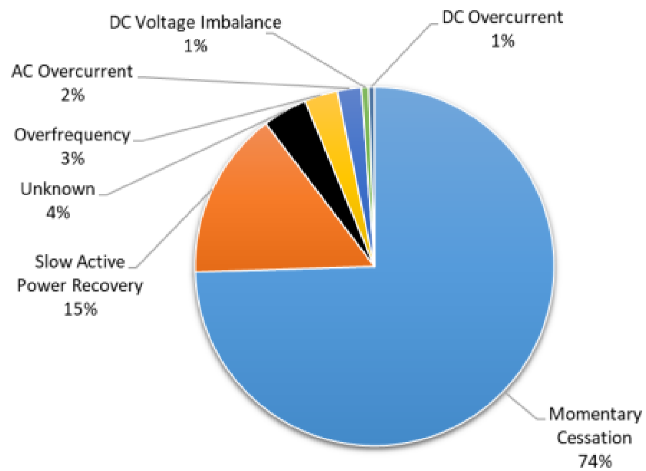
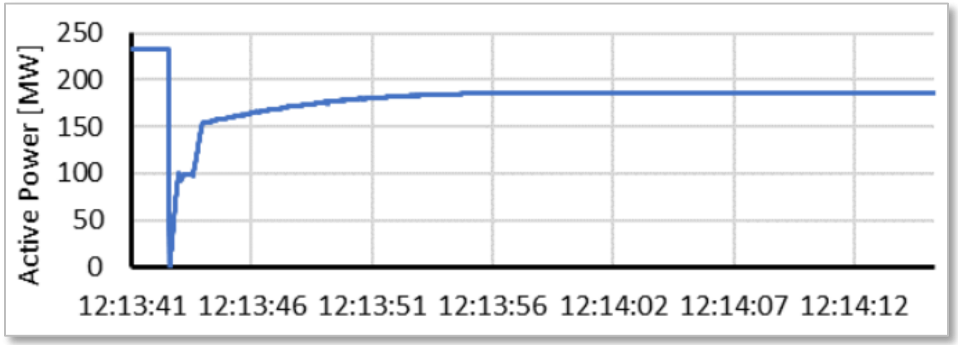


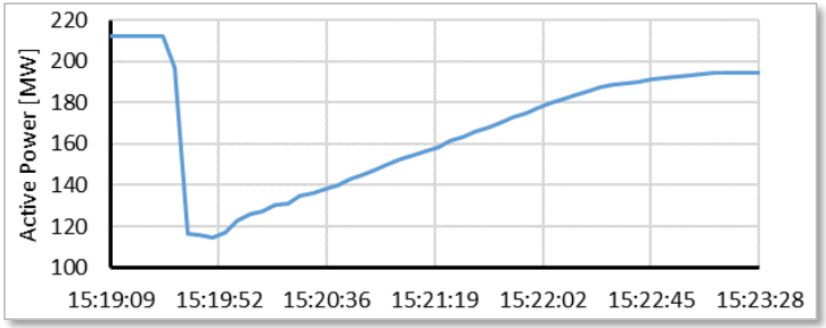
Figure 2.4: August 25 Disturbance Causes of Solar PV Reductions

Cause Unknown – Inability to Perform Root Cause Analysis

- Lacking necessary recording data
  - Poor resolution SCADA data, difficulties coordinating with plant personnel
  - No fault code data retrievable from inverters, inverter overwriting
  - No high-speed recording (e.g., DFR data) at plant POI
- Plant personnel unaware facility reduced output
- Plant personnel unable to access inverter information
  - Fault codes, inverter oscillography, inverter settings, etc.
- Inverters from manufacturers now out of business—no access to inverter information, no ability to make changes
- Difficulties for plant personnel working with manufacturers
  - Workload, prioritization, long lead times for support, etc.
- Plant change in ownership
- Non-BES facilities chose not to respond to RFIs nor participate in follow-up
- Challenges coordinating between inverter and plant-level controller manufacturers (and third-party consultants)

Momentary Cessation





- Plants with legacy inverters – no means of eliminating or modifying settings
  - Will continue adverse performance for lifetime of project
  - Momentary cessation applied when voltage falls below ~ 0.9 pu
  - Inverters should recover to predisturbance output relatively quickly when voltage recovers
- Some newer plants tripped but also stated they have momentary cessation
  - Appear to conflict with existing CAISO interconnection requirements
- Ongoing plant-level controller interactions – very slow active power recovery
  - Uncoordinated control of inverter and plant-level controllers
  - Inappropriate use of plant controller limits; negatively impacts grid stability
- Not meeting recommended performance in NERC reliability guidelines

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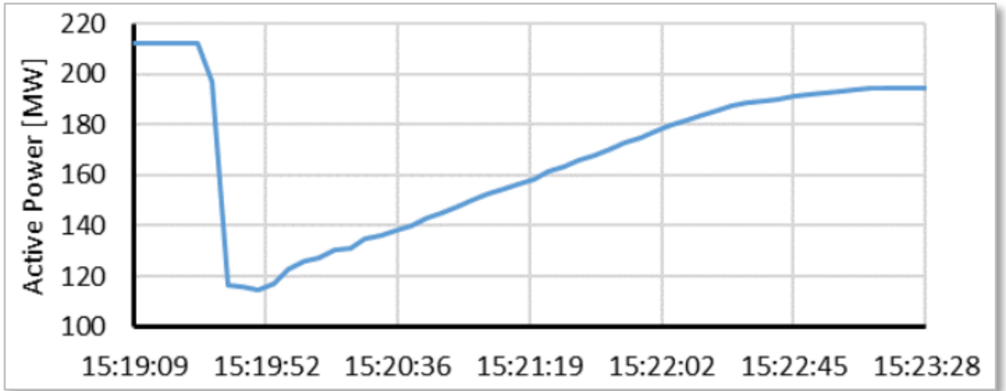
Plant Controller Interactions Persist



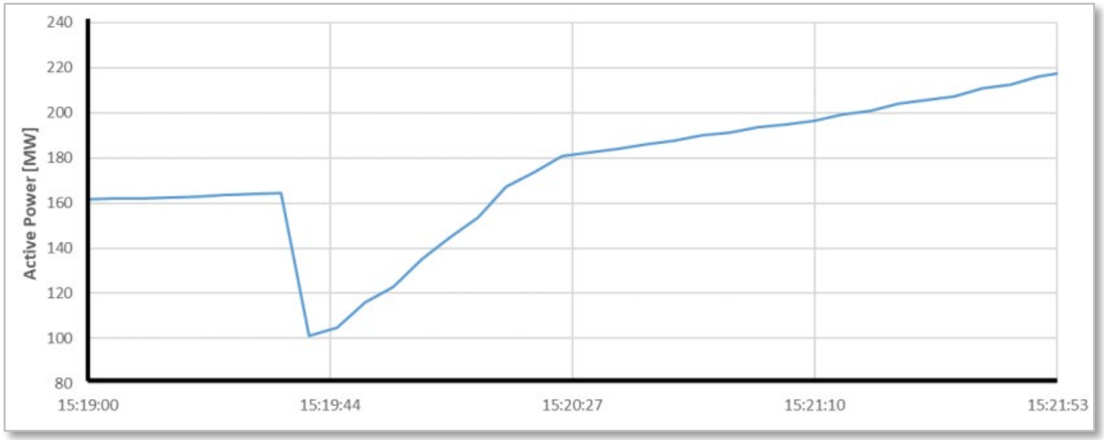
Example: Plant with Legacy Inverters

- Momentary cessation settings:
  - Voltage threshold: 0.875 pu
  - Delay to recover: 1.020 sec
  - Recovery ramp rate: 8.2%/sec
- Expect recovery to pre-disturbance in about 13-14 seconds
- Plant requires about 4 minutes to restore output

Fault Occurs
⇩
Voltage Drops
⇩
Inverters Enter Momentary Cessation
⇩
Plant Controller Pauses Control
⇩
Fault Clears
⇩
Voltage Recovers
⇩
Plant Controller Regains Control
⇩
Plant Controller Limits Inverter Recovery

- Systemic issue seen across many facilities – big and small, old and new

Plant Controller Interactions Persist ...Yet Can Be Fixed

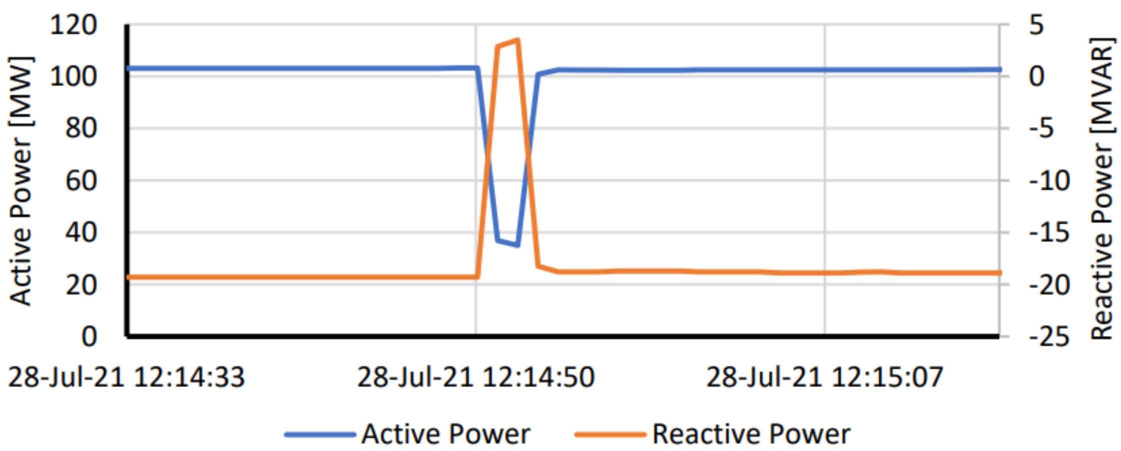


- NERC and WECC engaged affected entity to inform them of issues
- Plant owner worked with internal controls team and inverter manufacturer to develop mitigation

- Legacy plant-level controller from entity now out of business
  - Problem: Slower response time due to set point change that plant-level controller sends after faults, trigger "normal" plant-level ramp rate rather than the faster 8.2%/second ramp rate expected from the inverters after faults
  - Solution: Plant owner/operator added latch to plant-level controller that holds P and Q set points when voltage is outside of nominal (i.e., below 0.9 pu or above 1.1 pu) and for a specified time delay to allow inverters to fully recover
    - Allow inverters to respond as fast as possible to faults while maintaining ability to control plant voltage within schedule.
- NERC and WECC monitoring performance of plant for future events

Slow Dynamic Active Power Recovery

- Dynamic response to fault event
  - Inverters programmed with momentary cessation *disabled* – reactive current injection (e.g., K-factor control) enabled.
- Fault clears in ~50 ms, voltage recovers very quickly
- Active power recovery to predisturbance levels extended many seconds (or minutes)
  - Beyond the recommendations specified in NERC reliability guidelines



Overcurrent Protection

- DC Overcurrent
  - One large solar PV facility, legacy inverters; most inverters tripped
  - Inverters have parallel-connected IGBT bridges (dc in, 3-phase ac out)
    - All parallel bridges initiated a dc overcurrent trip
  - Issue identified in Blue Cut Fire, led inverter manufacturer to disable fast dc current protection for all newer inverters
    - Legacy inverters require fast dc overcurrent protection remain enabled
- AC Overcurrent
  - Multiple facilities and three inverter manufacturers
    - Pronounced issue for one inverter manufacturer specifically
  - Appears to be issue for older inverter models
  - Inverter protection typically set at 110–150% of rated ac current (instantaneous peak)

Inverter Frequency Tripping

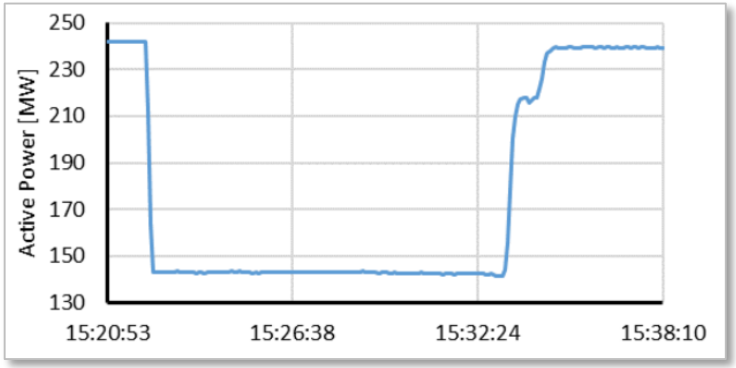
- Facility #1: Inverters trip on overfrequency (61.7 Hz for 1 ms)
- Facility #2: Inverters trip on underfrequency (59.3 Hz for 20 ms)
- Near-instantaneous trip timer, unnecessary tripping risk
  - Spikes in calculated frequency during voltage phase jumps during faults
  - Exact issue identified in Blue Cut Fire
  - Attempted to be corrected/clarified in PRC-024-3
  - Protection settings not based on equipment limitations
- Recommendation that inverter manufacturer proactively update settings at all existing facilities

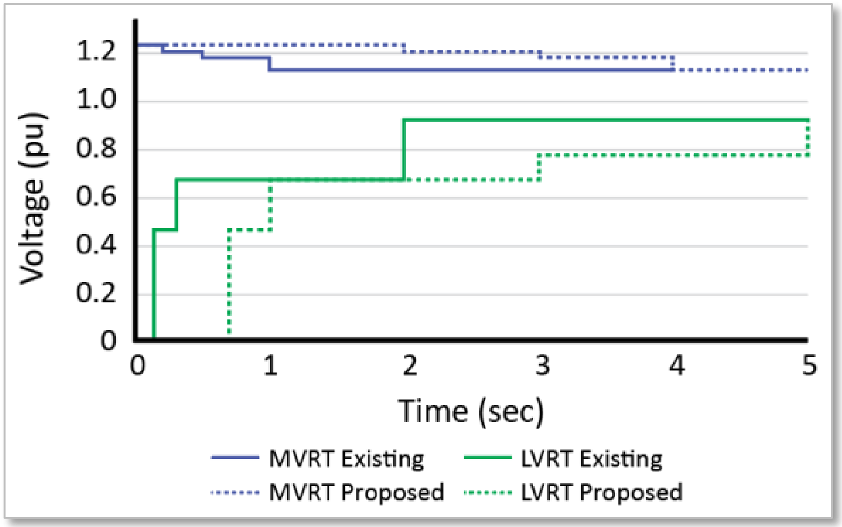
Table 2.2: Inverter Frequency Protection Settings

Setting	Threshold and Timer	Setting	Threshold and Timer
OF1	61.7 Hz for 0.001 seconds	UF1	57.0 Hz for 0.0 seconds
OF2	61.6 Hz for 30 seconds	UF2	57 Hz for 0.02 seconds
OF3	60.6 Hz for 180 seconds	UF3	59.3 Hz for 0.02 seconds

AC Undervoltage

- Two facilities involved
- One non-BES facility – ac undervoltage protection set within PRC-024-3 voltage boundaries
  - NERC recommended facility owner consider extending undervoltage trip settings, if possible, to help ensure resource ride-through for BPS faults
- Feedback from OEM enabled modified settings based on equipment capabilities





Other Causes of Inverter Tripping

- DC Voltage Imbalance
  - Inverters from one manufacturer
  - Unbalanced DC voltage conditions
    - DC positive and negative voltages relative to midpoint dc voltage exceeded a pre-defined threshold
  - May be unstable negative sequence voltage
- Uninterruptible Power Supply Failure
  - A few inverters tripped on uninterruptible power supply failure, remained off-line for rest of day
  - Plant owner manually restored inverters to service after inspection
  - No additional details were provided regarding the failure

Recovery Time for Minor Fault Events

- One plant owner planning changes to default return-to-service delay following "minor faults"
  - Minor faults: inverter initiates automatic restart (no manual intervention)
  - Inverters typically attempt automatic restart after restart timer (assuming healthy grid voltage and frequency)
- Most common timer is 300 seconds – artifact of IEEE 1547
  - **IEEE 1547 should not be used or applied to BPS-connected resources**
- Default restart time can be much faster – as low as 0 seconds
- Recommendations:
  - All plant owners/operators should seek input and feedback from their Balancing Authority and Reliability Coordinator on appropriate return-to-service settings
  - NERC guidelines recommend this be established clearly in interconnection requirements

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Distributed Energy Resource Tripping

- June 24 – 145 MW July 4 – 46 MW July 28 – 46 MW
  - Observed in past events – Angeles Forest, Palmdale Roost, San Fernando
- Challenging to quantify aggregate DER response during faults
  - Non-synchronized, area-wide load SCADA points may be calculated using summations pre- and post-fault
    - *Area Load = Intertie + Metered Generation*
  - Difficulty differentiating load response from DER response with lack of metering information available
  - Individual SCADA load points provides more reliable data of net load changes and possible DER tripping
    - Example: power flow across a 230/66 kV transformer bank
  - Process is more time consuming, and should be automated if possible

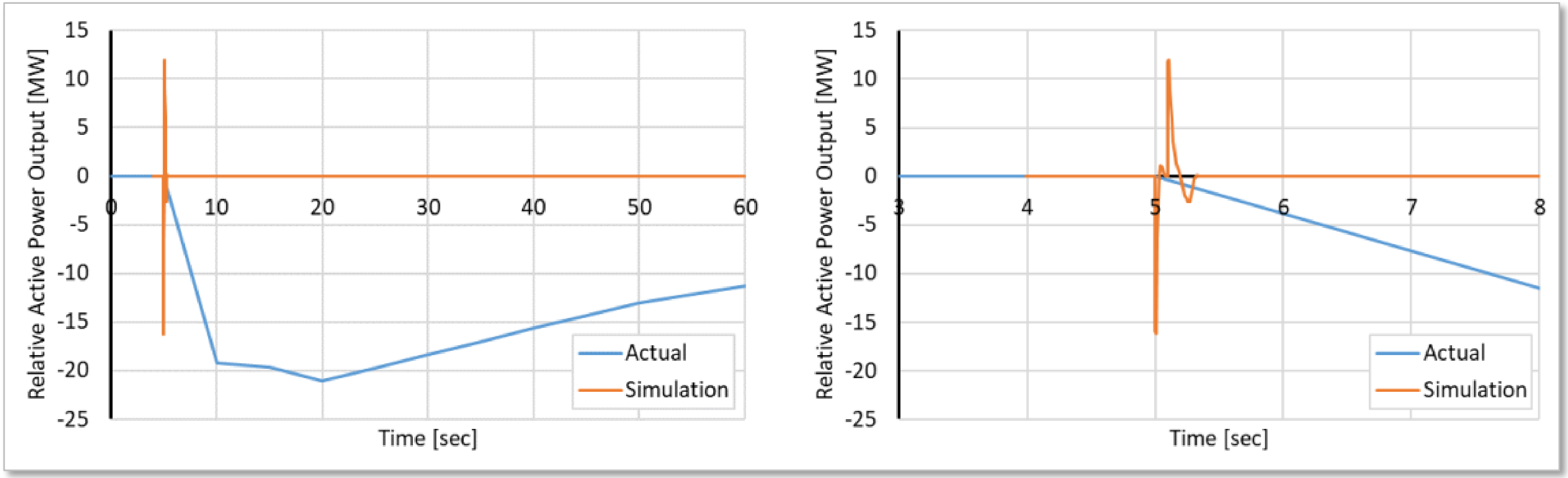
Synchronous Generator Reductions

- July 4
  - Combustion turbine at a combined cycle plant (125 MW)
  - Tripped due to two unhealthy sensors – power transducer and one dead fuel humidity sensor
    - Turbine controls operated incorrectly during fault
- August 25
  - Unexpected/unplanned RAS operation
    - Natural gas turbine tripped (212 MW) when 220 kV line exceeded RAS trip level
    - RAS initiated generator trip during power swing after fault
  - Combustion turbine tripping
    - Natural gas turbine tripped (91 MW) – excitation system diode failures
    - Redundant diodes – requires manual inspection to identify failure – undetected prior to event
      - Response of unit to fault likely led to failure of second diode and unit tripping
    - The plant has increased their inspection rate to avoid this issue in the future

Discussion on Modeling and Studies
The Real Root Cause of These Events

Model Validation Exercise

- Accurate modeling critical to BPS reliability
  - Inaccurate models → inaccurate studies → inaccurate reliability decisions
- Systemic modeling risks for solar PV fleet today



Example: Model recovers in 0.25 seconds. Actual recovers in 90+ seconds.

Model Limitations

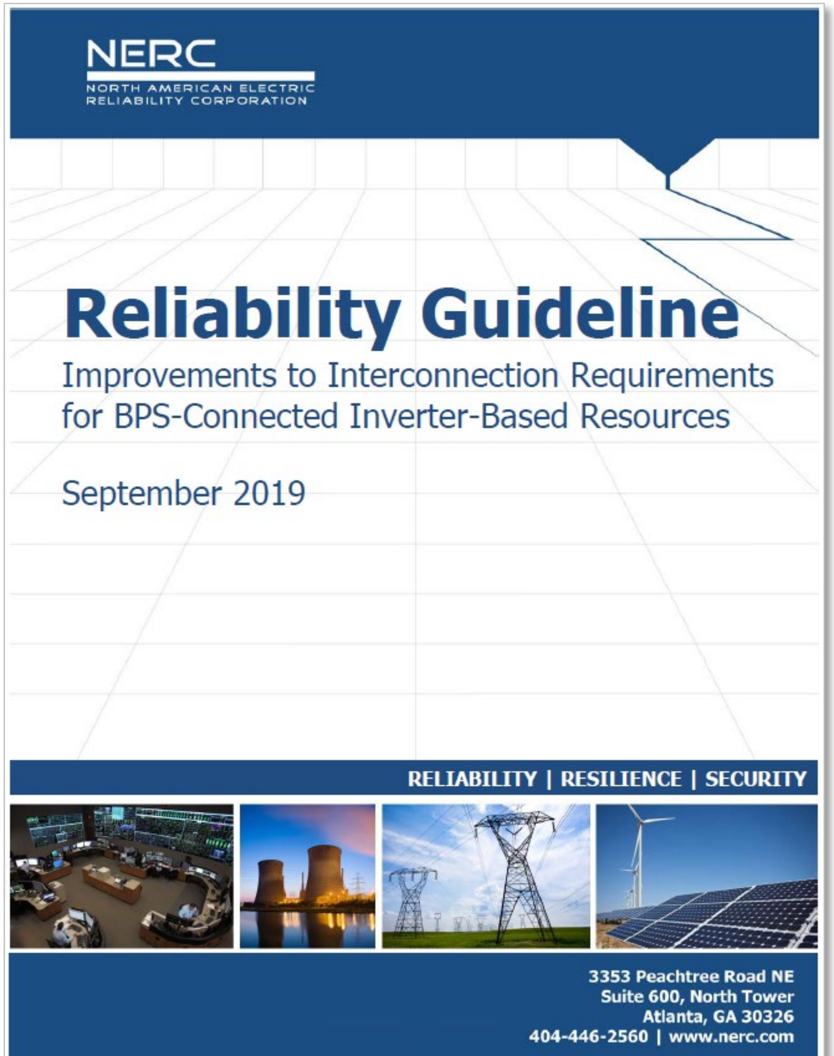
- All the disclaimers in the positive sequence column lead to modeling errors
- EMT models have much better capability – require expertise to create, parameterize, validate, and use

Table: Modeling Capabilities and Challenges

Name	Positive Sequence RMS	Electromagnetic Transient
AC Overcurrent	No	Yes
DC Overcurrent	No	Yes
AC Overvoltage	No, Sub-Cycle	Maybe
AC Undervoltage	Yes, If Modeled	Yes
Underfrequency	Yes, If Modeled	Yes
Overfrequency	Yes, If Modeled	Yes
Momentary Cessation	Yes	Yes
Plant Controller Interactions	Maybe*	Maybe*
Slow Active Power Recovery	Poor Parameterization	Yes
DC Voltage Imbalance	No	Maybe
UPS Failure	Not Modeled	Not Modeled

* Unlikely to be identified during interconnection studies

Modeling Requirements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Reliability Guideline

Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources

September 2019

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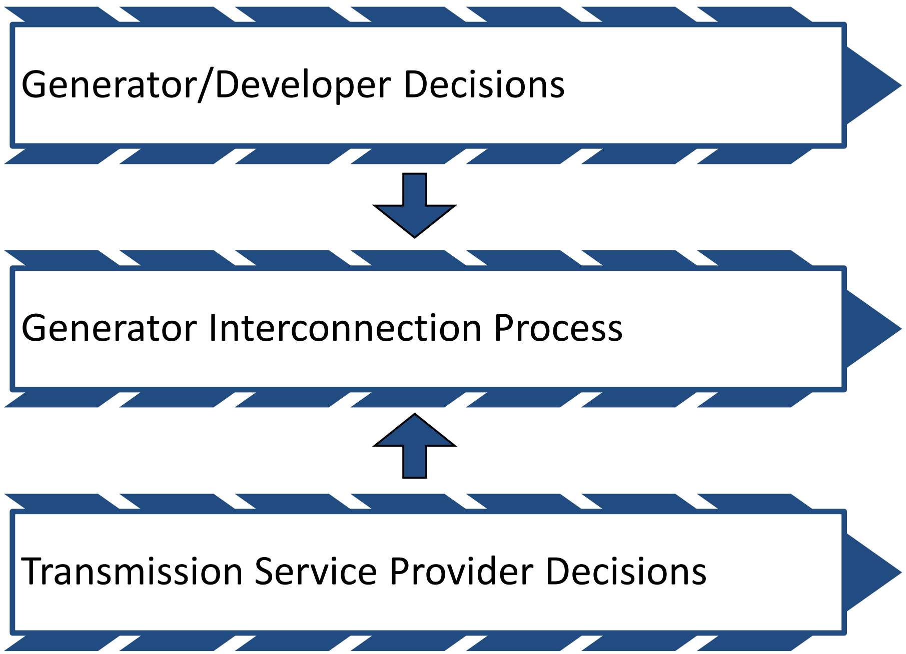
- Recommendation:
  - Establish clear, detailed, and necessary modeling requirements per FAC-001 and FAC-002 standards
  - Ensure sufficient model quality checks are in place
  - Enforce model quality reviews and checks throughout interconnection study process, planning studies, and operational planning assessments
  - Recognize that bad models lead to unnecessary or inaccurate studies, which lead to re-work and possible reliability risks

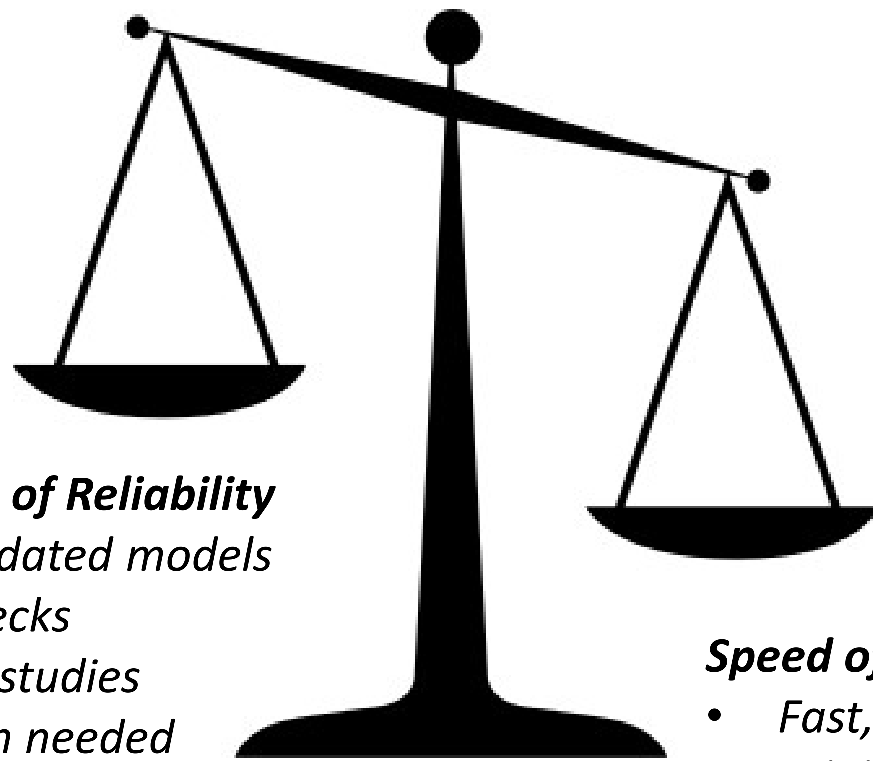
Complex Generator Interconnection Study Process



- Complex process
- Inconsistent modeling and study requirements
- Lack of clarity at time of request
- Changes in equipment and settings throughout process
- Short timeline to run detailed studies, if needed
- Lack of transparency and “sign-offs” on critical decisions
- Lack of mutual agreement and understanding about equipment settings/models
- Little to no model “true-up” at time of commissioning
- Process improvements needed
  - Difficult for both generation and transmission sides

Balancing Act

Under Conditions of High Penetrations of Inverter-Based Resources…



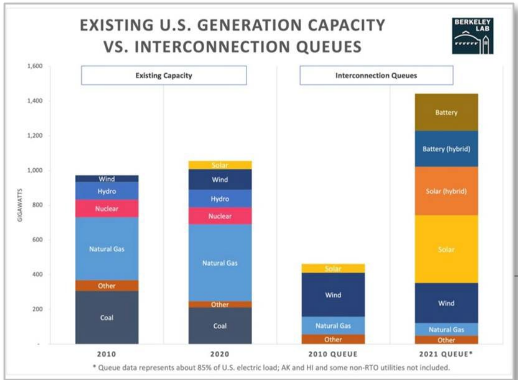
Adequate Assurance of Reliability

- *Accurate and validated models*
- *Model quality checks*
- *Detailed stability studies*
- *EMT studies when needed*

Speed of Interconnection

- *Fast, effective, streamlined*
- *Minimal re-work*
- *Clear modeling requirements*
- *Quick studies*

Rapidly Increasing Levels of Inverter-Based Resources



Source: LBNL

Use Cases for EMT Studies for IBRs

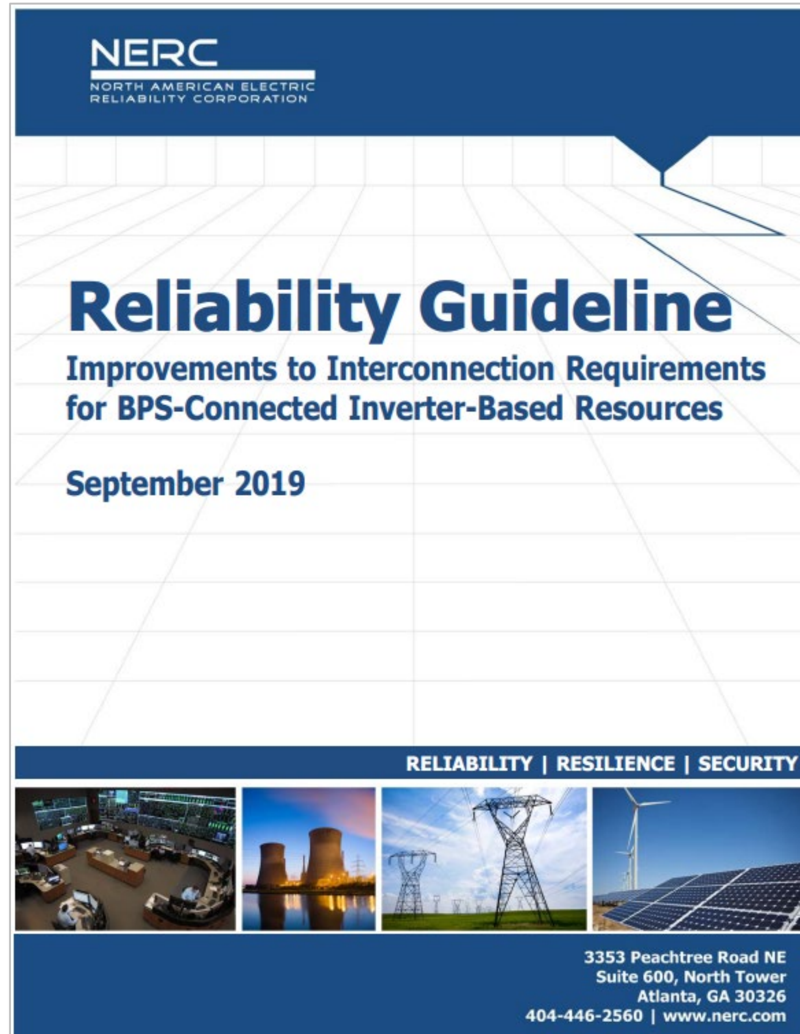
- Very high IBR penetrations and islanded networks
- Sub-synchronous controls interactions
- Unbalanced power flow studies
- High DER penetrations
- Power quality studies
- Benchmarking positive sequence models
- Controls interactions (plant-to-plant and within the plant)
- Ride-through capability and performance analysis
- Potential protection system operation
- Short-circuit current analysis
- Low short circuit strength networks
- Controls instability

Key Findings and Recommendations

Reiterating the Odessa Report Recommendations

Recommendation #1: Adopt the Reliability Guidelines

- IRPS guidelines widely known and referenced across industry
- However, industry not *comprehensively* adopting recommendations – leaves gaps
- All GOs, GOPs, developers, and equipment manufacturers should adopt the performance recommendations
- All TOs should establish or improve clear and consistent interconnection requirements for BPS-connected inverter-based resources
  - NERC FAC-001 and FAC-002



Recommendation #2: Improve the FERC GIP/GIA

- Inverter-based resources currently being inter-connected in an unreliable manner
- Significant improvements needed to FERC Generator Interconnection Process and Generator Interconnection Agreement
- Need comprehensive requirements that must be met during interconnection process
  - Should ensure reliable operation of resources ***prior to*** commercial operation
  - Poor models, inadequate studies, gaps in performance requirements
- Needs to be addressed in GIP and GIA; should not be left up to individual interconnecting TOs using only NERC FAC-001-3

Recommendation #3: Improve NERC Reliability Standards

- Significant enhancements needed to NERC Reliability Standards to address gaps in modeling, studies, and performance of BES inverter-based resources
  - Strong technical justification based on multiple disturbance reports
- NERC strongly recommends the RSTC to ensure development of SARS to address the following performance issues:
  - Performance Validation Standard Needed
  - Ride-Through Standard to Replace PRC-024-3
  - Analysis and Reporting for Abnormal Inverter Operations
  - Monitoring Data Improvements
  - Inverter-Specific Performance Requirements

Recommendation #3: Improve NERC Reliability Standards

- NERC strongly recommends the RSTC to ensure development of SARS to address the following modeling/studies issues:
  - Requirements for Accurate EMT Models at Time of Interconnection – Update FAC-001 and FAC-002
  - Update NERC MOD-032 to Include EMT Modeling
  - Updates to Ensure Model Quality Checks and Model Improvements

Recommendation #4: CAISO-Specific Recommendations

- Adopting the Recommendations in NERC Guidelines
  - Improvements to Interconnection Requirements
- Performance Validation and Follow-Up with Affected Facilities
- Event Analysis Improvements
  - Understanding momentary cessation versus tripping
  - Analyzing smaller events
  - Proactively engaging plant owners
  - Clarifying plant naming conventions
- Detailed Model Quality Review

WECC Follow-Up Plans

- Tailored recommendations to affected plant owners
- Quarterly follow-up until recommendations completed
  - Understanding of limitations or inability to mitigate issues
- Better tracking and documenting "legacy" facilities
- Concerted modeling improvement efforts

NERC Technical Follow-Up

- Better outreach to development community
  - Project developers
  - Engineering, procurement, and construction (EPC) entities
  - Protection and control contractors
  - Consultants
  - Etc.
- Ongoing engagement and outreach to manufacturers
  - Plant controller manufacturers
  - Inverter manufacturers
- Coordination with industry groups
  - SEIA, ESIG, NATF, NAGF, etc.

NERC Inverter-Based Resource Performance Subcommittee Activities

Questions and Answers

If interested in participating in the NERC Inverter-Based Resource Performance Subcommittee (IRPS), please reach out to Ryan Quint (ryan.quint@nerc.net).