NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Quick Reference Guide: Inverter-Based Resource Activities

June 2022

INSIDE THIS QUICK REFERENCE GUIDE

The electric power grid in North America is undergoing a significant transformation in technology, design, control, planning, and operation, and these changes are occurring more rapidly than ever before. Particularly, technological advances in inverter-based resources are having a major impact on generation, transmission, and distribution systems.

In most cases, inverter-based generating resources refer to Type 3 and Type 4 wind power plants and solar photovoltaic (PV) resources. Battery energy storage is also considered an inverter-based resource. Many transmission-connected reactive devices, such as STATCOMs and SVCs, are also inverter-based. Similarly, HVDC circuits also interface with the ac network though converters. Inverter-based resources are being interconnected at the bulk power system (BPS) level as well as at the distribution level; however, this reference guide focuses specifically on BPS-connected inverter-based resource efforts.

This document acts as a quick reference guide for the work that the ERO Enterprise has done regarding inverter-based resource activities over the past seven years to ensure the continued reliability of the North American power grid.

Disturbance Reports			
Published	**Disturbance**	**Title**	**Summary**
April 2022	**2021 CAISO Disturbances**: Victorville 06/24/21 Tumbleweed 07/04/21 Windhub 07/28/21 Lytle Creek Fire 08/25/21	*Multiple Solar PV Disturbances in CAISO Disturbances between June and August 2021 Joint NERC and WECC Staff Report*	This report contains the ERO analysis of four BPS disturbances with widespread reductions of solar PV output that occurred in the California Independent System Operator (CAISO) footprint between June and August of 2021. Each disturbance was categorized as a Category 1i event per the NERC Event Analysis Process and involved widespread reductions of active power output from solar PV resources in the Southern California area (specifically in areas of high penetrations of solar PV and wind resources). Two of these events also involved tripping of synchronous generating resources, and three involved some degree of distributed energy resource (DER) tripping or reduction. All initiating faults were normally cleared with proper protection system operation. **Webinar:** Presentation | Streaming Webinar
September 2021	**Odessa**: 05/09/21 06/26/21	*Odessa Disturbance Texas Events: May 9, 2021 and June 26, 2021 Joint NERC and Texas RE Staff Report*	This report contains the ERO analysis of the BPS disturbance that occurred in Texas on May 9, 2021. While the ERO has analyzed multiple similar events in California, this is the first disturbance involving a widespread reduction of solar PV resource power output observed in the Texas Interconnection. The event involved solar PV facilities across a large geographic area of up to 200 miles away from the location of the initiating event. The Electric Reliability Council of Texas (ERCOT) provided Texas RE and NERC with a brief report as the disturbance was categorized as a Category 1i event. **Webinar:** Presentation | Streaming Webinar

November 2020	**San Fernando:** 07/07/20	*San Fernando Disturbance Southern California Event: July 7, 2020 Joint NERC and WECC Staff Report*	This report contains the ERO analysis of the BPS disturbance that occurred in Southern California on July 7, 2020, referred to herein as the "San Fernando Disturbance." This event involved a widespread reduction of active power output from solar PV facilities across a relatively large geographic area, initiating a more detailed ERO review. California Independent System Operator (CAISO) provided WECC and NERC with a brief report as the disturbance was categorized as a Category 1i event. Working with CAISO, it was determined that additional information beyond what was provided in the brief report was needed to determine the root cause of solar PV power reductions. Data requests were sent to the affected Generator Owners whose facilities were identified as experiencing a notable reduction in power during the event. In addition, NERC and WECC worked collaboratively with the impacted transmission service providers to gather additional information and corroborate incoming data with other sources. The purpose of the report is to document the analysis of this disturbance and provide key findings and recommendations for the industry.
January 2019	**Angeles Forest and Palmdale Roost:** 04/20/18 05/11/18	*April and May 2018 Fault Induced Solar Photovoltaic Resource Interruption Disturbances Report*	This report contains the ERO analysis of the BPS disturbances that occurred in the Southern California area on April 20, 2018, (Angeles Forest disturbance) and May 11, 2018, (Palmdale Roost disturbance). Both of these events consisted of a loss of solar PV facilities in response to transmission line faults. This report was prepared following data requests sent to Generator Owners subsequent to each event. The events were identified by NERC, WECC, California Independent System Operator (CAISO), and Southern California Edison (SCE). The purpose of the report is to document the analysis of these disturbance and provide key findings and recommendations for the industry.
February 2018	**Canyon 2 Fire:** 10/09/17	*900 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report*	The purpose of the report is to document the analysis, key findings, and recommendations from the Canyon 2 Fire disturbance. On October 9, 2017, the Canyon 2 Fire caused two transmission system faults near the Serrano substation east of Los Angeles. The first fault was a normally cleared phase-to-phase fault on a 220 kV transmission line that occurred at 12:12:16 Pacific time, and the second

			fault was a normally cleared phase-to-phase fault on a 500 kV transmission line that occurred at 12:14:30 Pacific time. Both faults resulted in the reduction of solar PV generation across a wide region of the Southern California Edison (SCE) footprint. Approximately 900 MW of solar PV resources were lost as a result of these events, and six solar PV plants accounted for most of the reduction in generation. **Webinar:** Presentation | Streaming Webinar
June 2017	**Blue Cut Fire:** 08/16/16	*1,200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report*	This report contains the ERO analyses of the Blue Cut Fire, a system disturbance that occurred in the Southern California area on August 16, 2016. The Blue Cut Fire quickly moved toward an important transmission corridor that is comprised of three 500 kV lines owned by SCE and two 287 kV lines owned by Los Angeles Department of Water and Power (LADWP). The SCE transmission system experienced thirteen 500 kV line faults, and the LADWP system experienced two 287 kV faults as a result of the fire. Four of these fault events resulted in the loss of a significant amount of solar PV generation. The most significant event related to the solar PV generation loss occurred at 11:45 a.m. Pacific and resulted in the loss of nearly 1,200 MW. There were no solar PV facilities de-energized as a direct consequence of the fault event; rather, the facilities ceased output as a response to the fault on the system. **Webinar:** Presentation | Streaming Webinar

Alerts		
Initial Distribution	**Title**	**Summary**
May 2018	*Industry Recommendation: Loss of Solar Resources during Transmission Disturbances due to Inverter Settings - II*	NERC has identified adverse characteristics of inverter-based resource performance during grid faults that could present potential risks to reliability of the BPS. As the penetration of inverter-based resources (particularly solar PV resources) continues to increase in North America, these adverse characteristics need to be widely communicated. This Level 2 Industry Recommendation alerts industry to these adverse characteristics observed with BPS-connected solar PV resources, and provides recommended actions to address fault ride-through and timely restoration of current injection by all inverter-based resources connected to the BPS. Although this NERC Alert pertains specifically to Bulk Electric System (BES) solar PV resources, the same characteristics may exist for non-BES solar PV resources connected to the BPS regardless of installed generating capacity or interconnection voltage. Owners and operators of those facilities are encouraged to consult their inverter manufacturers, review inverter settings, and implement the recommendations described herein. While this NERC Alert focuses on solar PV, we encourage similar activities for other inverter-based resources such as, but not limited to, battery energy storage and wind resources. **Webinar:** Presentation | Streaming Webinar
June 2017	*Industry Recommendation: Loss of Solar Resources during Transmission Disturbances due to Inverter Settings*	NERC identified a potential characteristic exhibited by some inverter-based resources, particularly utility-scale solar PV generation, which reduces power output during fault conditions on the transmission system. An example of this behavior has been observed during recent BPS disturbances, highlighting potential risks to BPS reliability. With the recent and expected increases of utility-scale solar resources, the causes of this reduction in power output from utility-scale power inverters needs to be widely communicated and addressed by the industry. The industry should

		identify reliability preserving actions in the areas of power system planning and operations to reduce the system reliability impact in the event of widespread loss of solar resources during faults on the power system.

Reliability Guidelines		
Published	**Title**	**Summary**
March 2021	*Performance, Modeling, and Simulations of BPS-Connected Battery Energy Storage Systems and Hybrid Power Plants*	This guideline contains detailed recommendations regarding BESS and hybrid power plant performance, modeling, and studies.
September 2019	*Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources*	This guideline serves as a resource for utilities to develop interconnection requirements. Chapter 1 provides a summarization of recommended improvements to interconnection requirements for TOs to consider as they continually develop and enhance interconnection requirements per FAC-001-3 and interconnection study requirements per FAC-002-2.11 Chapter 2 covers the performance aspects while Chapter 3 cover modeling considerations (both key components to the interconnection process). **Webinar:** Presentation | Streaming Webinar
September 2018	*BPS-Connected Inverter-Based Resource Performance*	This guideline provides recommended steady-state and dynamic performance characteristics for inverter-based resources and also covers a wide range of related aspects from protective functions to monitoring capability.
December 2017	*Integrating Inverter-Based Resources into Low Short Circuit Strength Systems*	This guideline provides the electric utility industry with background and useful reference information pertaining to the topics of identifying weak grid conditions and potential issues that may arise from weak grids when connecting or operating inverter-based resources. The goal of this guideline is to proactively provide the industry with information to consider as these types of issues emerge for increased penetrations of inverter-based resources.

White Papers		
Published	**Title**	**Summary**
December 2021	*IRPWG Grid Forming Technology*	This white paper compares grid-forming (GFM) and grid-following (GFL) inverter-based resource capability and their major performance characteristics and advantages. Currently, the most commonly used GFM control strategies of droop-based GFM control, virtual synchronous machine control, and virtual oscillator control are briefly summarized. This white paper also provides recommendations for entities across North America to consider studying and deploying GFM technology to support BPS reliability and resilience with increasing inverter-based resource penetration levels.
October 2021	*IRPWG Odessa Follow-Up*	This brief white paper was developed by the NERC Inverter-Based Resource Performance Working Group (IRPWG) as a follow-up to the *Odessa Disturbance Report* published by NERC in October 2021. That report contained a set of key findings and recommendations. The IRPWG discussed each of the key findings and recommendations in detail and is providing a brief technical discussion and technical basis for each recommendation. Where appropriate, follow-up action items are identified.
September 2021	*IRPWG Utilizing the Excess Capability of BPS-Connected Inverter-Based Resources for Frequency Support*	The Federal Energy Regulatory Commission (FERC) issued Order No. 842 in 2018, amending the pro forma Large Generator Interconnection Agreement (LGIA) and Small Generator Interconnection Agreement (SGIA) to require all "newly interconnecting large and small generating facilities, both synchronous and non-synchronous, to install, maintain, and operate equipment capable of providing primary frequency response (PFR) as a condition of interconnection." This work extends on the FERC Order NO. 842 and the March 2020 NERC white paper and recommends leveraging primary frequency response (PFR) and fast frequency response (FFR). PFR and FFR capabilities from inverter-based resources to the extent possible to support BPS frequency as an essential reliability service.
June 2021	*IRPWG San Fernando Follow-Up*	This brief white paper was developed by the NERC IRPWG as a follow-up to the July 2020 San Fernando Disturbance Report published by NERC. That report contained a set of key findings and recommendations. The IRPWG discussed each of the key findings and recommendations in detail,

		provides a brief technical discussion and basis for each item, and where appropriate recommends follow-up action items.
March 2020	*IRPTF Fast Frequency Response Concepts and Bulk Power System Reliability Needs*	This white paper describes the interrelationships between primary frequency response (PFR) and fast frequency response (FFR). **Webinar:** Presentation | Streaming Webinar

Technical Reports		
Published	**Title**	**Summary**
August 2020	*NERC-WECC Report on WECC Base Case Review for Inverter-Based Resources*	This report documents the review of the WECC 2020 HS3 base with the latest available WECC MDF dynamics models. Data is being updated and provided to WECC constantly, so it is likely that updates to models have been made even in the time duration between analysis and publication of this report. The goal of this report is to further document some of the issues identified during the cursory review of base case quality, highlight how this analysis was performed, and provide key findings and recommendations for industry next steps to address the modeling issues.
May 2020	*BPS-Connected Inverter-Based Resource Modeling and Studies*	The NERC Inverter-Based Resource Performance Task Force (IRPTF) and the industry have been working diligently on modeling and simulation activities to accurately represent inverter-based resources in dynamic stability analyses and explore the impacts of inverter-based resources on BPS reliability. This report outlines the activities of the IRPTF related to inverter-based resource modeling and studies. **Webinar:** Presentation | Streaming Webinar

Standards Authorization Request Activities

Standards are one piece of the complex, dynamic endeavor of providing a comprehensive approach to reliability. NERC has various other tools to fulfill this mission, including guidelines, training, assessments, and alerts. This multi-pronged approach has resulted in a secure and reliable bulk power system for North America. New Reliability Standards begin with a Standards Authorization Request (SAR), which may be submitted by anyone but must have technical justification. SARs occasionally arise from other projects like informal development projects, periodic reviews, other standard projects, or if a reliability threat that may be mitigated by a standard arises.

- IRPTF Review of NERC Reliability Standards (2020): The electric industry is still experiencing unprecedented growth in the use of inverters as part of the bulk power system and growth is possibly creating new circumstances where current standards may not be sufficiently addressing those needs. As a result, the NERC Planning Committee (PC) and Operating Committee (OC) assigned the task of evaluating today's current standards and requirements to the IRPTF. This white paper details the findings of the IRPTF as a result of this activity and makes recommendations on actions that should be taken to address the issues identified.
- IRPTF PRC-024-2 Gaps Whitepaper (2019): The IRPTF scope document includes a deliverable on "recommendations on inverter-based resource performance and any modifications to NERC Reliability Standards related to the control and dynamic performance of these resources during abnormal grid conditions." The white paper presented here details the findings of the IRPTF as a result of investigations related to this deliverable. Specifically, the white paper details potential gaps and needed clarifications in PRC-024-2: Generator Frequency and Voltage Protective Relay Settings. There is some overlap between the findings of this white paper and the Integration of Variable Generation Task Force (IVGTF) Summary and Recommendations of 12 Tasks, which was published in 2015.
- NERC Standards Projects related to Inverter-based Resources:
  - Project 2018-04 – Modifications to PRC-024-2
  - Project 2020-05 – Modifications to FAC-001 and FAC-002
  - Project 2020-06 – Verifications of Models and Data for Generators
  - Project 2021-01 – Modifications to MOD-025 and PRC-019
  - Project 2021-02 – Modifications to VAR-002
  - Project 2021-04 – Modifications to PRC-002
  - Project 2022-02 – Modifications to TPL-001-5.1 and MOD-032-1

Other Activities

- Inverter Manufacturer and Relay Manufacturer Coordination Meeting (2019): NERC facilitated an in-depth technical discussion between inverter manufacturers, protective relay manufacturers, and industry experts related to current injection of BPS-connected inverters during fault conditions and potential impacts and solutions for BPS protection schemes. This document contains the key takeaways, recommendations, and next steps that were an outcome of this discussion.
- IEEE/NERC Impact of Inverter-Based Generation on Bulk Power System Dynamics and Short-Circuit Performance (2018): This report covers the various aspects of low fault current conditions and how to accommodate a changing resource mix.
- IEEE 2800-2022: Uniform technical minimum requirements for the interconnection, capability, and lifetime performance of inverter-based resources interconnecting with transmission and sub-transmission systems are established in this standard. Included in this standard are performance requirements for reliable integration of inverter-based resources into the bulk power system, including, but not limited to, voltage and frequency ride-through, active power control, reactive power control, dynamic active power support under abnormal frequency conditions, dynamic voltage support under abnormal voltage conditions, power quality, negative sequence current injection, and system protection. This standard also applies to isolated inverter-based resources that are interconnected to an ac transmission system via dedicated voltage source converter high-voltage direct current (VSC-HVDC) transmission facilities; in these cases, the standard applies to the combination of the isolated inverter-based resources and the VSC-HVDC facility, and not to an isolated inverter-based resource on its own.