NERC

NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Summary of Activities

BPS-Connected Inverter-Based Resources and Distributed Energy Resources
September 2019

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"[1] are having a major impact on generation, transmission, and distribution systems. This document provides a landscape overview of this transformation with its specific changes. This document also provides some recommendations that industry, regulators, and other stakeholders may collaborate upon to ensure the continued reliability of the North American power grid.

Executive Summary

The North American Electric Reliability Corporation (NERC), as the Electric Reliability Organization (ERO), is actively supporting the reliable integration of inverter-based resources across North America by working collaboratively with key industry stakeholders. Some key takeaways from these activities include, but are not limited to, the following:

- At the distribution level, the Institute of Electronic and Electrical Engineering (IEEE) Standard (Std.) 1547-2018 is a significant advancement in ensuring improved capabilities from distributed energy resources (DERs). This standard specifies performance capabilities and addresses interconnection and interoperability. State regulators should encourage collaboration between utilities, regional reliability coordinators, industry stakeholders, and state commissions, and should support the adoption and implementation of IEEE Std. 1547-2018 to ensure consistent performance from DERs on a local, regional, and wide-area basis.
- For Bulk Electric System (BES) generation, the NERC Planning and Operating Committees and their technical working groups are actively developing consistent and clear performance requirements for all connected resources, including inverter-based resources and synchronous generation. While the intent and requirements of the standards are applicable to synchronous and inverter-based (nonsynchronous) resources, the terminology and language around these requirements need to clearly state, when applicable, the differing requirements for each technology.
- Many newly interconnecting inverter-based resources are not subject to NERC Reliability Standards nor relate to IEEE Std. 1547-2018 because these resources are connected to the Bulk Power System (BPS) but are not BES resources. In these cases, NERC is supporting Transmission Operators to

[1] In most cases, inverter-based generating resources refer to Type 3 and Type 4 wind power plants and solar photovoltaic 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 BPS level as well as at the distribution level, and they are differentiated accordingly throughout this paper.

improve their interconnection requirements that apply to all generation connected to their footprint.

- The IEEE P2800 project to develop a performance capability standard for newly interconnecting inverter-based resources connected to the BPS (i.e., transmission and subtransmission) will help bridge this gap in requirements applicability for smaller resources connected to the BPS. However, the development of this standard will take time and the improvements to local utility interconnection requirements for BPS-connected resources serve as a bridge solution in the interim time period.
- NERC is coordinating with Federal Energy Regulatory Commission (FERC) staff involved with the NERC Inverter-Based Resource Performance Task Force (IRPTF) to help facilitate changes to FERC's pro-forma large generator interconnection (LGIA) agreement and small generator interconnection agreement (SGIA). This will ensure that the issues and challenges common to non-BES resources will be addressed through the execution of those agreements.
- NERC, working collaboratively with its stakeholders and other key industry representatives, continues to lead the electric industry towards addressing emerging reliability issues related to inverter-based resources connected to the BPS. Future areas of focus include low short-circuit strength networks, control interactions between power electronic devices, sub- and super-synchronous oscillations, and the need for faster responding resources to grid disturbances.

Interconnecting Inverter-Based Resources: DERs and BES or BPS

Generation and transmission technologies are evolving at a rapid pace as is the composition of generation from centralized large power plants to smaller more distributed generating resources at both the distribution and transmission levels. The following is provided to establish some basic definitions to differentiate resources:

- **DERs:** The NERC Distributed Energy Resource Task Force defines a DER as "any resource on the distribution system that produces electricity and is not otherwise included in the formal NERC definition of the BES."[2] IEEE Std. 1547-2018 defines a DER as "a source of electric power that is not directly connected to a bulk power system. DER includes both generators and energy storage technologies capable of exporting active power to an electric power system."[3] Resources specifically located on the distribution system may include retail-scale DERs (e.g., rooftop solar photovoltaic (PV)) as well as utility-scale DERs (e.g., small combined heat and power and small solar PV power plants).
- **BES Resources:**[4] BES resources comprise active and reactive power resources connected at 100 kilovolts (kV) or higher with either a gross individual nameplate rating greater than 20 megavolt ampere (MVA) or gross plant/facility aggregate nameplate rating greater than 75 MVA. Generating resources that meet the BES definition are subject to certain NERC Reliability Standards, depending on the applicability of those individual standards.

[2] https://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/Distributed_Energy_Resources_Report.pdf.
[3] IEEE Std. 1547-2018 – IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces: https://standards.ieee.org/standard/1547-2018.html.
[4] https://www.nerc.com/files/glossary_of_terms.pdf

- **BPS Resources:**[4] The BPS includes facilities and control systems necessary for operating an interconnected electric energy transmission network or any portion thereof and the electric energy from generation facilities needed to maintain transmission system reliability. More broadly, BPS generating resources are those that are connected to subtransmission and transmission level voltages regardless of size. BES generating resources are a subset of the BPS generating resources.

Figure 1 shows an illustrative example of the three categorizations of resources based on their interconnection location (distribution versus transmission or subtransmission) and their capacity. Differentiating resources this way is useful and effective because different standards and requirements apply to each of these resources based on jurisdiction. DER resources are subject to meeting IEEE Std. 1547, but only if that standard has been locally adopted by the interconnection tariff or SGIA through state jurisdiction. BES resources are subject to NERC Reliability Standards. BPS-connected non-BES resources may be subject to neither IEEE nor NERC Reliability Standards but are subject to the FERC's LGIA or SGIA and local interconnecting utility interconnection requirements.

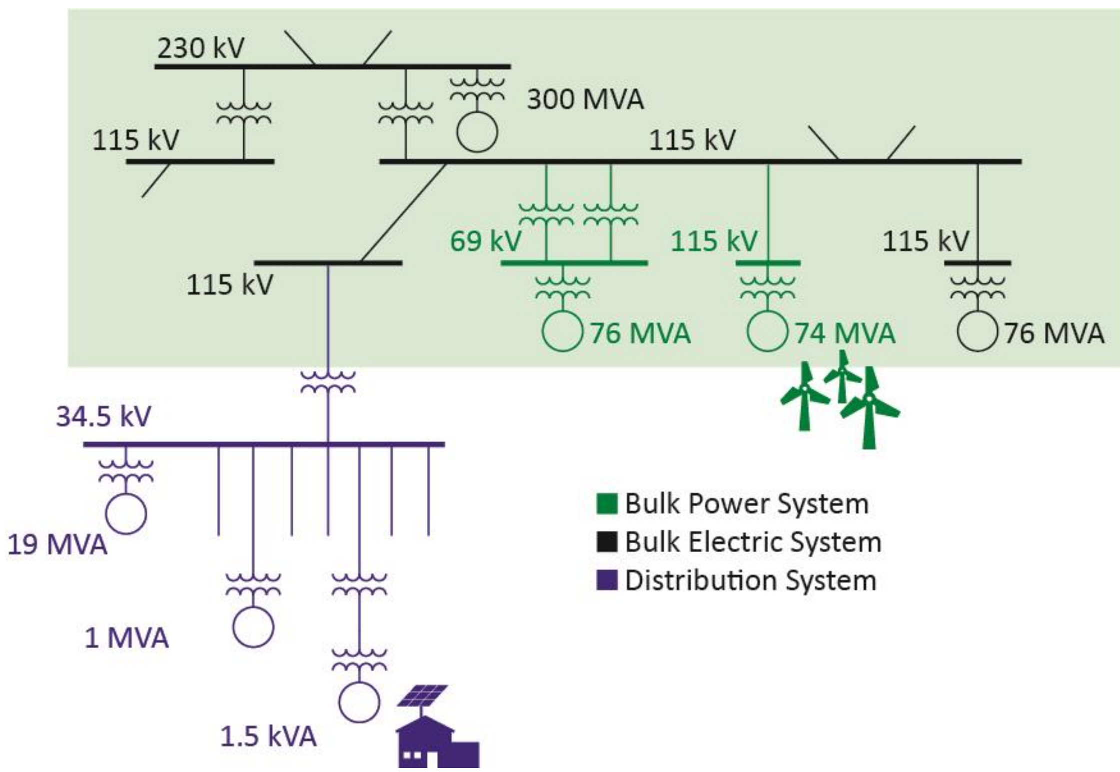

Figure 1: Designation of BPS, BES, and Distribution-Connected Resources

Figures 2 and 3 and Table 1 provide a cursory[5] review of the 2017 EIA-860[6] data for operable solar PV resources.[7] Figure 2 shows a scatter plot of the size in MW of resources relative to the interconnecting voltage level. From this figure, we can deduce the following:

- The majority of solar PV resources are connected at voltage levels less than 100 kV and are sized at less than 75 MW in capacity.[8]
- At transmission voltage levels, most resources are connected at 230 kV or less and are still less than 75 MW in capacity.

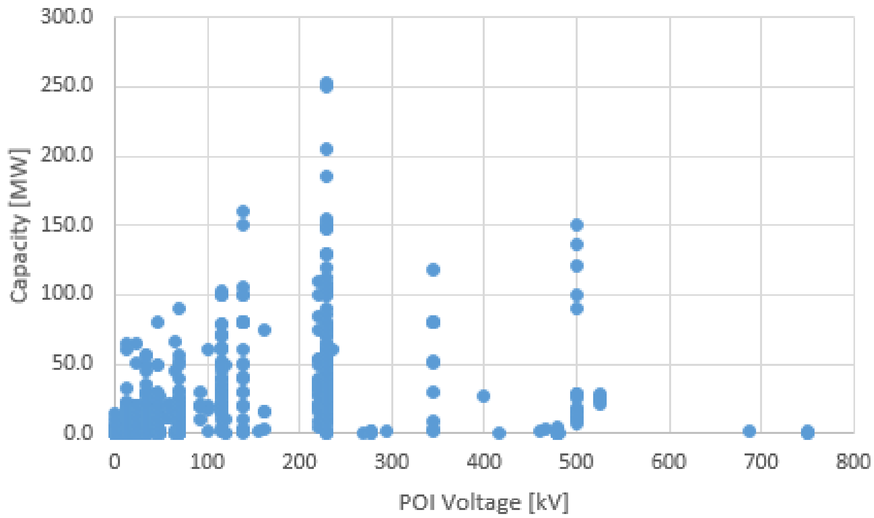

Figure 2: Resource Capacity versus Interconnecting Voltage

Figure 3 and Table 1 show a breakdown of the size and number of resources connected at a voltage level greater than 50 kV.[9] The illustrations attempt to separate out the distribution-level interconnections and focuses on the BPS-connected solar PV (transmission and subtransmission levels). The following observations are evident for resources connected at voltage levels greater than 50 kV, a part of the BPS:

- The majority of solar PV plants (i.e., more than 225 individual plants) are between 20 and 75 MW. This totals more than 8,000 MW of capacity.
- Around 6,300 MW of solar PV capacity comprise resources that are larger than 75 MW. Around 60 units constitute this total capacity.
- A relatively small amount of capacity exists for the units sized less than 20 MW although the number of units of this size more than doubles those of 75 MW or more.

In terms of quantity, the vast number of solar PV resources connected to the BPS are sized between 20 and 75 MW. In terms of capacity, about 8,000 MW are sized between 20 and 75 MW, and about 6,300 MW are

[5] The EIA-860 data has errors and data formatting issues this analysis avoided to some degree but not entirely. However, overall the key takeaways are the same.
[6] https://www.eia.gov/electricity/data/eia860/
[7] This data is not intended to capture small retail-scale DER installations (i.e., rooftop solar PV).
[8] Note that some units in the EIA-860 data separate out into many entries (reason unknown). Therefore, a large plant of 200+ MW may be represented by multiple 50 MW units in the data. Without a thorough review of the data, this data entry issue cannot be overcome.
[9] 50 kV was chosen as a reasonable nominal voltage level for differentiating between distribution-class voltages and subtransmission or transmission voltages on a broad level. It is acknowledged that there may be some areas with distribution voltages higher than 50 kV.

sized greater than 75 MW. Therefore, the vast majority[10] of solar PV plants connected to the BPS, totaling over half the capacity, are not considered BES and are therefore not subject to NERC Reliability Standards.

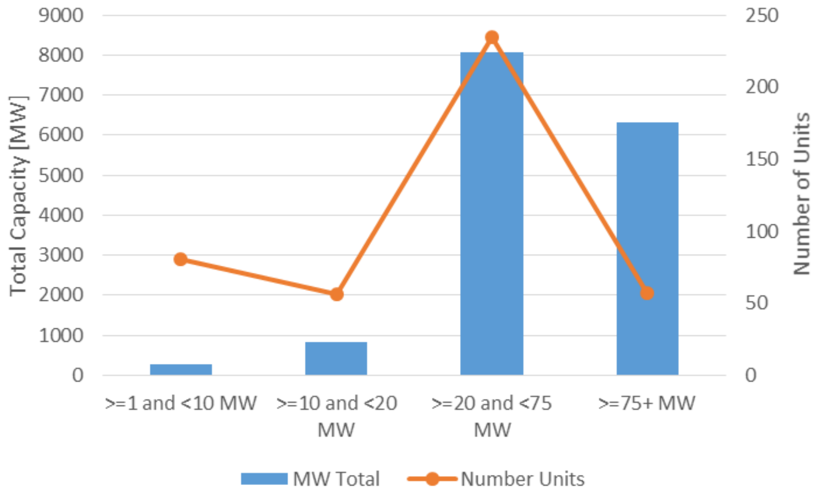

Figure 2: Categorization of Capacity and Number of Generating Resources

Table 1: Units Connected at Greater Than 50 kV		
Size	**MW Total**	**Number Units**
>= 1 and < 10 MW	269	81
>= 10 and < 20 MW	834	56
>= 20 and < 75 MW	8069	235
>= 75+ MW	6322	57

[10] In terms of number of individual facilities.

Performance Requirements for Distributed Energy Resources

IEEE Std. 1547-2018 significantly advanced the standardization of the interconnection and the interoperability of DERs connected to local distribution networks.[11] IEEE Std. 1547-2018 addresses the "performance, operation, testing, safety considerations, and maintenance of the interconnection." This includes general requirements, response to abnormal conditions, power quality, islanding, and other aspects. The requirements set forth in the standard "are universally needed for interconnection of DER, including synchronous machines, induction machines, or power inverters/converters." The IEEE P1547.1[12] project is also developing the testing and verification procedures for these requirements.

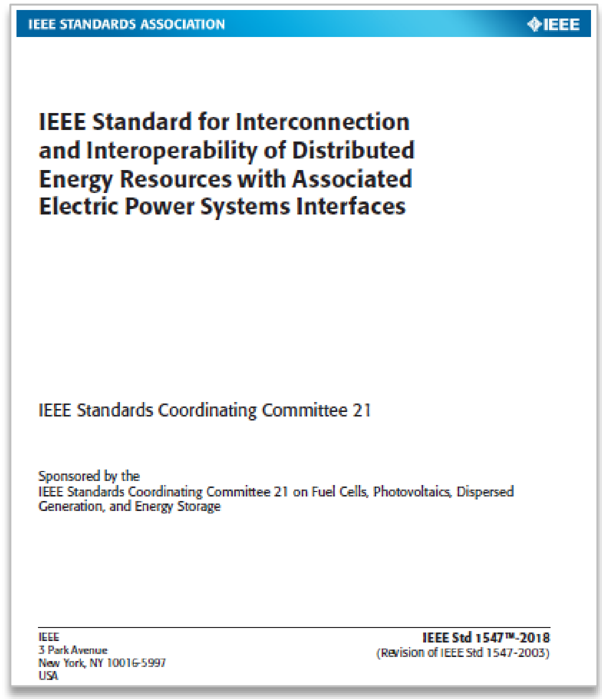

Figure 3: IEEE Std. 1547-2018

The specifications and capabilities established in IEEE Std. 1547-2018 are a major improvement to the previously developed standards of IEEE Std. 1547-2003[13] and IEEE Std. 1547a-2014.[14] Key specifications within the IEEE Std. 1547-2018 that are relevant and related to BPS reliability include, but are not limited to, the following:

- Entering service following disconnection due to widespread outage
- Voltage and frequency ride through and trip settings
- Dynamic performance during BPS disturbances (coordinated with distribution considerations)
- Response to grid disturbances and fault events
- Active power-frequency and reactive power-voltage performance

IEEE Std. 1547-2018 defines performance requirements and capabilities with default settings as well as ranges of adjustability. Utilities and state regulatory entities should evaluate and select appropriate performance categories and settings to suit their specific system characteristics. This involves coordination between these entities with Reliability Coordinators, Independent System Operators, Transmission Operators, Transmission Planners (TPs), and Planning Coordinators (PCs) on those issues described above pertaining to BPS reliability and performance. The requirements set forth in IEEE Std. 1547-2018 foster this

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[11] IEEE Std. 1547-2018 – IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces.: https://standards.ieee.org/standard/1547-2018.html.

[12] IEEE P1547.1 Draft Standard Conformance Test Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces: http://grouper.ieee.org/groups/scc21/1547.1_revision/1547.1_revision_index.html.

[13] IEEE Std. 1547-2003 – IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems: https://standards.ieee.org/standard/1547-2003.html.

[14] IEEE 1547a-2014 – IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems - Amendment 1: https://standards.ieee.org/standard/1547a-2014.html.

collaboration between the local utility and entities with a regional or wide-area view to ensure some uniformity in settings that impact the BPS.

Existing state rules, regulations, or utility interconnection requirements based on the IEEE Std. 1547-2003 should be updated to reflect the current requirements in IEEE Std. 1547-2018. These updates are effectively being rolled out through stakeholder processes in many states, supporting an efficient transition to the new framework and requirements of the new standard. It is recommended that all state jurisdictions review the implementation and require the adoption of IEEE Std. 1547-2018 so as to be equipped with the tools and capabilities the new standard provides to safely and reliably interconnect DERs. Organizations like the National Association of Regulatory Utility Commissioners (NARUC) are well-suited to coordinate the implementation of IEEE Std. 1547-2018 requirements. NARUC's members "have an obligation to ensure the establishment and maintenance of utility services" and "ensure that such services are provided at rates and conditions that are fair, reasonable and nondiscriminatory for all consumers."[15]

The adoption of IEEE Std. 1547-2018 with appropriate selection of DER settings, coordinated as necessary among all applicable stakeholders, should be a high priority for state regulatory and utility distribution entities. States that have not yet embarked on these activities should start the process of adoption soon.[16] Experiences around the world have proved that retroactive changes to installed resources can be extremely costly, complicated, and impact a wide range of stakeholders. Alternatively, clearly defining DER settings consistent with IEEE Std. 1547-2018 in state interconnection rules can improve efficiency, reduce costs, and ensure reliability of the local distribution systems and the BPS.

System Planning Impacts of Distributed Energy Resources

The NERC Planning Committee formed the NERC System Planning Impacts of Distributed Energy Resources Working Group (SPIDERWG),[17] focusing on the BPS impacts of DER from a transmission planning and system analysis perspective. NERC's SPIDERWG focuses on four key aspects of DER impacts to the BPS:

- **Modeling:** Representing aggregate DERs in BPS reliability studies, advancing industry capabilities and expertise with representing DERs in these reliability studies, developing robust and reasonable data sets for power flow and dynamic simulations
- **Verification:** Ensuring that the models used in studies provide a reasonable and suitable representation of the actual aggregate performance of these resources, benchmarking software platforms to ensure uniformity in tools, recommending analysis techniques for accounting for aggregate DERs during large BPS disturbances
- **Studies:** Improving study techniques and methods to ensure the most stressed operating conditions are chosen for BPS reliability studies, identifying key operating conditions and sensitivities to perform, improving software tools and study capabilities

[15] https://www.naruc.org/about-naruc/about-naruc/

[16] The IEEE 1547.2 *Application Guide for IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems* is being developed and should be completed within the next year or so. However, state regulatory entities and local utilities should not wait for the publication of this guide to start the process for stakeholder engagement and adoption of IEEE Std. 1547-2018: http://grouper.ieee.org/groups/scc21/1547.2/1547.2_index.html.

[17] https://www.nerc.com/comm/PC/Pages/System-Planning-Impacts-from-Distributed-Energy-Resources-Subcommittee-(SPIDERWG).aspx.

- **Coordination:** Supporting coordination between transmission and distribution entities for improved data exchange and coordinating with IEEE leadership to support the application of IEEE Std. 1547-2018 across North America

The NERC SPIDERWG will develop recommended practices and guidelines around these topics to ensure registered entities have the tools and capabilities to advance transmission planning studies in light of rapidly growing penetrations of DERs. SPIDERWG also serves as an excellent forum for distribution and transmission entities to exchange ideas and sharing needs in terms of information for modeling and situational awareness. SPIDERWG also supports the review and applicability of NERC Reliability Standards and identifies whether these standards may need to be modified to ensure reliable operation of the BES in light of higher penetrations of DERs.

NERC Efforts to Address BPS-Connected Inverter-Based Resources

At the BPS level, there are a number of key activities that NERC is leading and supporting to ensure reliable operation of inverter-based resources connected to the BPS.

BPS Grid Disturbances Involving Solar PV Reduction

In August 2016, the Blue Cut Fire caused a fault on the BPS in Southern California. This normally cleared fault resulted in a significant number of solar PV resources erroneously tripping due to miscalculated frequency and many other resources operating in a previously unknown operating mode called "momentary cessation."[18] While the disturbance did not automatically qualify as part of the NERC Events Analysis program, it was clear that there may be systemic issues that needed to be addressed by industry. A coordinated event analysis was instigated by the ERO that worked closely with the California ISO and Southern California Edison. A disturbance report was published in June 2017 that outlined key findings and recommendations.[19] A Level 2 NERC Alert was issued to collect data to understand the extent of the condition and to provide recommended performance improvements for existing and newly interconnecting solar PV resources connected to the BPS.[20]

In October 2017, the Canyon 2 Fire disturbance again triggered the loss of solar PV resources caused by a normally cleared fault on the BPS. In this case, the predominant cause of tripping was attributed to subcycle transient over-voltages that resulted in inverter tripping at solar PV facilities. Momentary cessation was also identified as being a contributor to the reduction in solar PV output during the disturbance. The ERO, working with California ISO and Southern California Edison, published a disturbance report in February 2018 to outline key findings and recommendations.[21] Additionally, another Level 2 NERC Alert was issued to

[18] Momentary cessation is an operating mode when no current is injected into the grid by an inverter during low or high voltage conditions outside its continuous operating range.

[19] Blue Cut Fire Disturbance Report, June 2017: https://www.nerc.com/pa/rrm/ea/1200_MW_Fault_Induced_Solar_Photovoltaic_Resource_/1200_MW_Fault_Induced_Solar_Photovoltaic_Resource_Interruption_Final.pdf.

[20] Industry Recommendation: Loss of Solar Resources during Transmission Disturbances due to Inverter Settings: https://www.nerc.com/pa/rrm/bpsa/Alerts%20DL/NERC%20Alert%20Loss%20of%20Solar%20Resources%20during%20Transmission%20Disturbance.pdf.

[21] Canyon 2 Fire Disturbance Report, February 2018: https://www.nerc.com/pa/rrm/ea/October%209%202017%20Canyon%202%20Fire%20Disturbance%20Report/900%20MW%20Solar%20Photovoltaic%20Resource%20Interruption%20Disturbance%20Report.pdf.

provide recommended performance improvements and to initiate modifications to eliminate momentary cessation for existing resources to the greatest possible extent.[22]

As the NERC Alert for the Canyon 2 Fire disturbance was being rolled out, the Angeles Forest disturbance and Palmdale Roost disturbances occurred in April and May 2018, respectively. NERC issued a disturbance report to document the primary contributors to solar PV output reduction in the event. The causes of tripping and solar PV reduction were similar in nature to the Canyon 2 Fire disturbance.[23] A unique finding in these events was that some amount of DERs tripping was observed around the faulted region, causing a net load increase in the area.

Each disturbance analysis has led to new findings and recommendations regarding inverter-based resource performance. The causes of tripping and reduction of solar PV output have led to industry efforts to mitigate these issues. However, this requires the collaboration of multiple industry groups working together to understand the system needs and the capabilities of inverter-based resource technology.

Figure 4: NERC Disturbance Reports and Alerts related to Solar PV Disturbances

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[22] Industry Recommendation: Loss of Solar Resources during Transmission Disturbances due to Inverter Settings – II: https://www.nerc.com/pa/rrm/bpsa/Alerts%20DL/NERC_Alert_Loss_of_Solar_Resources_during_Transmission_Disturbance-II_2018.pdf.

[23] Angeles Forest and Palmdale Roost Disturbances Report, January 2019: https://www.nerc.com/pa/rrm/ea/April_May_2018_Fault_Induced_Solar_PV_Resource_Int/April_May_2018_Solar_PV_Disturbance_Report.pdf.

NERC Inverter-Based Resource Performance Task Force

In response to the findings and recommendations of the Blue Cut Fire disturbance, NERC formed the NERC IRPTF,[24] which jointly reports to the NERC Planning and Operating Committees, to support the reliable integration of inverter-based resources to the BPS. While the NERC IRPTF started as a small group of industry experts that helped in the analysis and understanding of this grid disturbance, it has grown to well over 200 members and has wide-reaching industry support and participation. The NERC IRPTF involves the major inverter manufacturers in North America; generation entities; transmission planning and operations entities; national labs and research institutes; modeling and simulations experts; renewable energy integration experts; and other subject matter experts in the area of inverter-based resource performance, control, and protection.

Figure 5: NERC IRPTF Visit to Solar Site

The NERC IRPTF serves as a key stakeholder group in North America for addressing emerging reliability risks related to inverter-based resources, and it also brings together the original equipment manufacturers, transmission and generation entities, and reliability and regulatory entities to address these issues effectively and efficiently. A number of the accomplishments and ongoing activities of the NERC IRPTF are discussed below.

[24] https://www.nerc.com/comm/PC/Pages/Inverter-Based-Resource-Performance-Task-Force.aspx.

NERC Reliability Guideline: BPS-Connected Inverter-Based Resource Performance

The response of inverter-based resources to grid disturbances, unlike synchronous generation, is predominantly driven by the controls and logic programmed into the inverters that interface these resources with the grid. The current FERC Generator Interconnection Agreements and NERC Reliability Standards do not prescribe the exact behavior of generating resources. However, it was acknowledged by industry (including the inverter manufacturers) that recommended performance specifications would help support consistent response from resources connected to the BPS. For that reason, the NERC IRPTF developed the NERC *Reliability Guideline: BPS-Connected Inverter-Based Resource Performance*,[25] which provides recommended performance specifications. This guideline has been adopted in many ways by the inverter manufacturers that work with Generator Owners and project developers as a cornerstone document regarding the expected behavior of inverter-based resources connected to the BPS. While NERC has jurisdiction over BES resources, the guideline explicitly states that the recommendations provided are applicable to all resources connected to the BPS (not just BES resources). Refer to this guideline for detailed information regarding expected and recommended performance of inverter-based resources connected to the BPS.

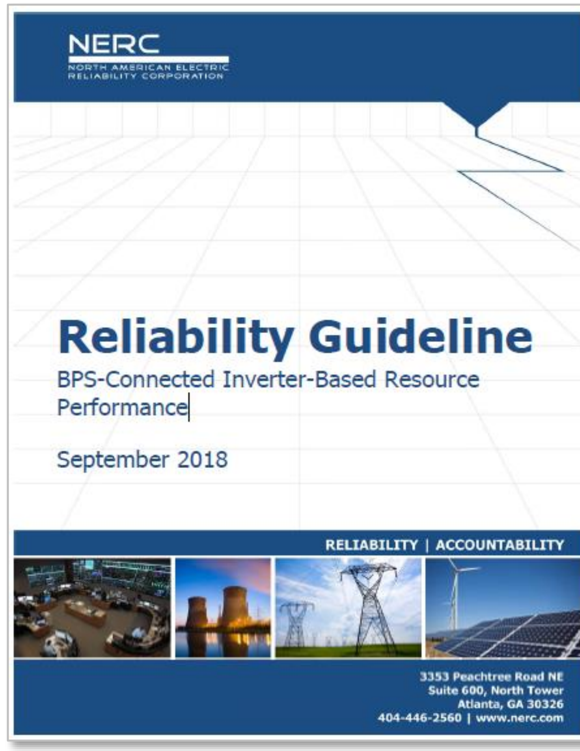

Figure 6: NERC IRPTF Reliability Guideline

IEEE P2800 Standard for Inverter-Based Resources Connecting to the BPS

The IEEE P2800 effort is developing a *Standard for Interconnection and Interoperability of Inverter-Based Resources Interconnecting with Associated Transmission Electric Power Systems*. This standard "establishes the recommended interconnection capability and performance criteria" for resources that interconnect at both the transmission and subtransmission system. The standard, similar to IEEE Std. 1547-2018, will provide "recommendations on performance for reliable integration of inverter-based resources into the BPS, 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." The IEEE P2800 team has an aggressive schedule to complete this standard due to the gravity of its importance for North America, and it is striving for approval and adoption by end of 2021. In the meantime, utilities should make sure that their interconnection requirements are sufficiently clear to ensure reliable operation and performance of inverter-based resources connecting the BPS.

[25] Reliability Guideline: BPS-Connected Inverter-Based Resource Performance, September 2018. Available: https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Inverter-Based_Resource_Performance_Guideline.pdf.

NERC Reliability Guideline: Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources

The NERC *Reliability Guideline: BPS-Connected Inverter-Based Resource Performance,* published in September 2018, provided recommended performance specifications and a repository of technical reference material regarding inverter-based resource behavior during normal grid operation and disturbances. While these recommendations are applicable to all inverter-based resources connected to the BPS (including BES and non-BES resources), many of the recommended specifications are not mandatory nor enforceable. Further, the majority of resources connected to the BPS are not subject to NERC Reliability Standards since they have a capacity of less than 75 MVA. Therefore, Transmission Owners and Transmission Service Providers requested that guidance be developed to strengthen and clarify their interconnection requirements, interconnection agreements, grid code requirements, and other operating guides. The NERC IRPTF published a *Reliability Guideline: Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources*[26] that builds off of the previous guideline, and seeks provide guidance for developing clearer and more consistent interconnection requirements for newly interconnecting BPS-connected inverter-based resources. It is particularly important that the local interconnection requirements, per NERC FAC-001-3,[27] and interconnection studies, per NERC FAC-002-2,[28] evolve with evolving technologies and the capabilities of inverter-based resources.

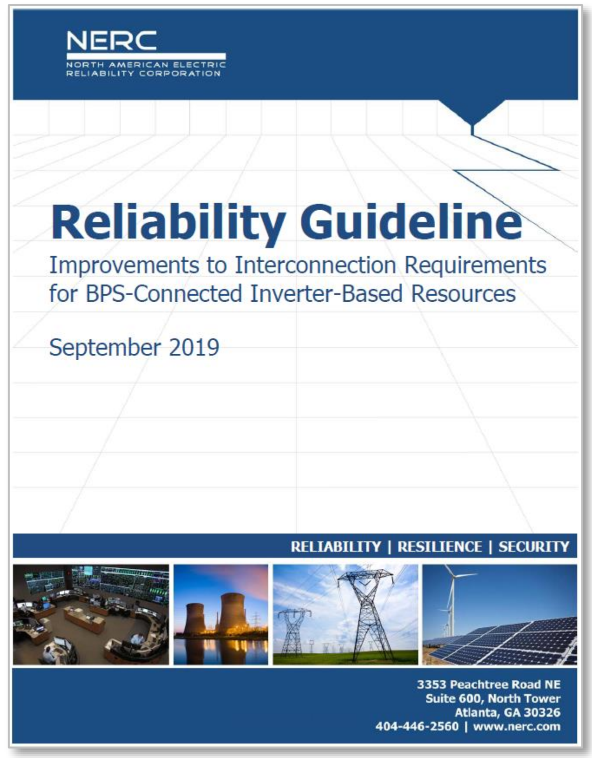

Figure 7: NERC IRPTF Reliability Guideline

[26] https://www.nerc.com/comm/OC_Reliability_Guidelines_DL/Reliability_Guideline_IBR_Interconnection_Requirements_Improvements.pdf
[27] https://www.nerc.com/pa/Stand/Reliability%20Standards/FAC-001-3.pdf
[28] https://www.nerc.com/pa/Stand/Reliability%20Standards/FAC-002-2.pdf

NERC Reliability Standards Improvements for BES Resources

The NERC IRPTF and a number of other NERC stakeholder groups that report to the NERC Planning and Operating Committees are exploring improvements to NERC Reliability Standards related to inverter-based resources. Many of these modifications to NERC standards help bring additional clarity and consistency to existing standard requirements. In many cases, these standards were written with some consideration for inverter-based resources, but the penetration of such resources at the time of development of those standards was substantially lower. In addition, technologies have evolved, and the standards under development are building off lessons learned that integrate these resources to ensure effective standards improvements.[29]

In particular, a number of the NERC PRC (protection and control) Reliability Standards are being closely reviewed to ensure they are applicable and clear for inverter-based resources. Some NERC MOD (modeling) Reliability Standards are also being reviewed for applicability and effectiveness. The IRPTF is also doing a more comprehensive review of the NERC Reliability Standards to identify potential areas for improvement or any gaps that should be addressed.

NERC-Driven Industry Efforts on Short Circuit Impacts from Inverter-Based Resources

Inverter-based resources, unlike synchronous generation, are limited on the amount of fault current they can provide due to their power electronic components. In addition, synchronous generators are “voltage sources behind an impedance,” meaning these generators produce a voltage and have a set impedance and therefore deliver necessary current under changing grid conditions. While an inverter does have a dc source, its output is driven by a tightly controlled current control. Therefore, from the grid side, an inverter is referred to as a current source. An inverter-based resource does not follow the conventions of a synchronous machine regarding current injection during fault events on the grid in terms of both magnitude as well as the phase relationship between voltage and current. Some grid codes have developed requirements around current injection during fault events, and NERC technical staff works with experts around the world to better understand the drivers and justification for these requirements.[30]

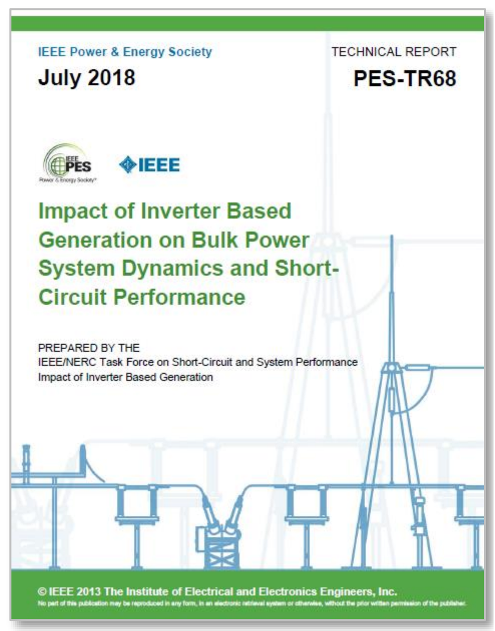

Figure 8: IEEE Report on Short Circuit Performance

NERC, in coordination with industry, posed the question as to what impacts a high penetration of inverter-based resources could have on existing transmission system protection. A joint IEEE/NERC task force was formed to explore these impacts and outline a path forward. This task force delivered a quick turnaround report titled, *Impacts of Inverter Based Generation on Bulk Power System Dynamics and Short-Circuit Performance*.[31] The report provided an overview of the impacts and helped set the stage for further analysis. NERC is hosting a

[29] For example, the NERC IRPTF identified issues related to transient overvoltage tripping of inverters during BPS fault events. That information is used as a useful reference for the PRC-024-2 standard drafting team.

[30] For example, the German VDE grid code requirements specify type of current injection during fault conditions: https://www.vde-verlag.de/normen/0100494/vde-ar-n-4130-anwendungsregel-2018-11.html.

[31] http://resourcecenter.ieee-pes.org/pes/product/technical-publications/PES_TR_7-18_0068

collaborative meeting between relay manufacturers, inverter manufacturers, and key industry experts to help address this issue effectively.

NERC also initiated a Department of Energy-funded activity to address this problem, working with inverter and protective relay manufacturers as well as modeling and simulation experts. This group, titled the "I2 Project," is using detailed electromagnetic transient simulation tools to understand the type of current injected by inverters during grid faults and the impacts this may have on protective relaying under high penetration conditions. This DOE project, being coordinated by Sandia National Labs and advised by NERC, will deliver a technical report that will help provide key findings and recommendations on necessary inverter behavior to ensure reliability.

NERC IRPTF Modeling and Studies Technical Report

A critical finding from the disturbance analyses and NERC Alert analyses described above was that the dynamic models used to represent existing inverter-based resources in reliability studies, particularly solar PV, do not accurately capture some aspects of the large disturbance behavior of these resources. While the models themselves are adequate to capture these aspects, the incorrect selection of parameters and use of these models has led to inaccurate models being submitted by GOs as part of the FAC-002-2 study process[32] as well as the MOD-032-1 annual case creation processes.[33] Therefore, the models used in studies by TPs and PCs were not accurately representing the actual behavior of these resources. Until the ERO analysis and NERC Alerts, this incorrect use of these models was not widely known or understood by most of industry, and these models were not able to recreate the previous disturbances via simulation.

As part of the NERC Alert following the Canyon 2 Fire disturbance, each GO was requested to provide an updated model of existing equipment (if identified as incorrect) and a proposed model based on the performance improvements outlined in the Alert. The TPs and PCs were to gather these models, study the existing models to identify any potential reliability issues, and ensure that the proposed performance changes (submitted via the updated proposed models) were suitable. NERC performed a follow-up request that was coordinated through the Regions, asking each TP and PC to report on their findings from these studies. A cursory review of the responses from these reports show the following:

- TPs and PCs received very few useable and accurate models of existing equipment, leading to the conclusion that a system modeling issue exists that needs to be addressed by the industry.
- Some TPs and PCs proactively updated the models themselves based on the NERC Alert data collected (not the models provided) to ensure that studies could be performed to identify any reliability issues.
- Studies did not identify any significant risks of instability, uncontrolled separation, or cascading; however, some performance aspects were degraded by the relatively widespread use of momentary cessation.
- Since the GOs did not provide the updated models, the TPs and PCs are not able to include the updates in the MOD-032-1 interconnection-wide base case process (since those models need to come from the equipment owners (i.e., the GOs)). Therefore, the interconnection-wide cases are

32 https://www.nerc.com/_layouts/15/PrintStandard.aspx?standardnumber=FAC-002-2&title=Facility%20Interconnection%20Studies&jurisdiction=United States
33 https://www.nerc.com/_layouts/15/PrintStandard.aspx?standardnumber=MOD-032-1&title=Data%20for%20Power%20System%20Modeling%20and%20Analysis&jurisdiction=United%20States

not being updated as quickly as possible (or as necessary) to incorporate the data gathered by the NERC Alert and provided to the TPs and PCs. Some TPs and PCs are coordinating follow-up data requests and are using requirements in the MOD standards to invoke change. However, this takes time.

- Very few models of proposed changes were provided by the GOs to the TPs and PCs. Based solely on this information, it is not expected that GOs are actively making the changes recommended in the NERC Alert following the Canyon 2 Fire disturbance. Follow up work is needed to understand the extent to which changes have been made. If changes have been made, they have not been coordinated with their TPs and PCs in many cases.

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