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NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

San Fernando Disturbance Follow-Up

NERC Inverter-Based Resource Performance Working Group (IRPWG)
White Paper – June 2021

This brief white paper was developed by the NERC Inverter-Based Resource Performance Working Group (IRPWG) as a follow-up to the July 2020 San Fernando Disturbance Report published by NERC.[1] 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. Table 1 shows the key findings and recommendations from the NERC disturbance report on the left-hand column and the IRPWG follow-up and recommendations for each item in the right-hand column.

The following are the recommended actions from the IRPWG review:

1. FERC should integrate the recommendations from the San Fernando report and the IRPWG guidelines into the pro forma LGIA for all newly interconnecting inverter-based resources. The future PRC-002 Standard Drafting Team should consider P2800 Clause 11 efforts, and ensure that the modifications require disturbance monitoring equipment at inverter-based resource facilities.
2. IRPWG will continue summarizing lessons learned from the events with systematic causes of inverter tripping IRPWG in future publications (white papers, guidelines, SARs etc.). FERC and NERC, in coordination with industry, should develop a coordinated strategy to ensure the effective and widespread adoption of IEEE P2800 once it is approved.
3. IRPWG should draft a SAR to address the outstanding recommendation by NERC to address the issue identified in EOP-004-4 regarding the generation loss criteria so that it is applicable for inverter-based resources as well synchronous generation.
4. Modeling and study standards (e.g., MOD and TPL) should be reviewed by IRPWG to consider the inclusion of EMT models for study purposes by the TP and PC. Currently these studies that would be used to identify possible tripping or abnormal performance from inverter-based resources are not required and are performed only in certain occasions where the TP or PC has identified issues with other modeling tools. However, the issues identified in these disturbances have not been identified or highlighted by the TPs or PCs in their

[1] https://www.nerc.com/pa/rrm/ea/Pages/July_2020_San_Fernando_Disturbance_Report.aspx

respective area. IRPWG is working on an EMT modeling reliability guideline; however, this does not ensure any one entity actually executes EMT studies, when needed.

5. Future industry efforts may consider assessing the extent to which industry has adopted the recommendations in the NERC guidelines regarding interconnection requirements improvements. This would help understand the extent to which these risks are being addressed by industry.

Table 1: Review of Disturbance Report Findings and Recommendations

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	• **Poor Solar PV Data Resolution:** Almost all solar PV facilities involved in this disturbance were not able to provide adequate information to the analysis team to fully understand the causes of tripping and develop recommended mitigating actions. In many cases, the archived data had resolutions of one-minute or even five-minutes; this serves no useful purpose for post-mortem disturbance analysis. Data resolutions should be on the order of one-second, and other forms of high-speed data recording should be available from the individual inverters within the facility as well as at the plant-level controller. Point-on-wave digital fault recorder data is the most useful data for this type of analysis along with inverter fault codes and inverter oscillography data. ▪ **Recommendation (GO, Generator Operator (GOP)):** All GOs and GOPs should ensure adequate data monitoring within their facilities for inverter-based resources to determine root causes of abnormal performance to BPS disturbances. This includes having access to inverter and plant-level settings, fault codes, oscillography records, digital fault recorder data, and archived plant data (i.e., supervisory control and data acquisition (SCADA) data) with a resolution	IRPWG (formerly IRPTF) submitted a SAR on PRC-002-2 regarding its minimal applicability to inverter-based resources due to the size criteria for dynamic disturbance recording data and the fundamental way in which digital fault recorder data and sequence of events data are specified. Both requirements in PRC-002-2 preclude the selection of locations near or at inverter-based facilities on the bulk power system. IRPWG has published NERC Reliability Guideline: Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources, which strongly recommends all BPS-connected inverter-based resources to have sufficient monitoring capability to capture data for event analysis and real-time visibility. However, those recommendations are not mandatory nor appear to be adhered to by BPS-connected inverter-based resource owners since this disturbance further illustrated that nearly no usable data is available from a wide range of owner/operators of these facilities.

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	of one sample per second or faster. NERC Standards should be enhanced to ensure this data is available from all BPS generating facilities, as this continues to be a major issue limiting the ability to perform event analysis. ▪ **Recommendation (TO, FERC):** All TOs should establish or improve data recording requirements for all BPS-connected generating resources, including both synchronous and inverter-based resources, to ensure appropriate data is available for event analysis. FERC may consider adding this capability to the pro forma *Large Generator Interconnection Agreement*.[2] Detailed recommendations are documented in NERC *Reliability Guideline: Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources*.[3]	IRPWG is not aware of any activities within FERC to add the recommendations from this NERC guideline to the pro forma LGIA or SGIA; however, as the report highlights this action is recommended. The IEEE P2800 Clause 11 includes requirements for data monitoring, resolution, and retention that will bring future resources to current technology; however, this will only apply to new resources and is likely a few years away in terms of full adoption and effectiveness. **Recommended Action from IRPWG Follow-Up:** FERC should integrate the recommendations from the San Fernando report and the IRPWG guidelines into the pro forma LGIA for all newly interconnecting inverter-based resources. The future PRC-002 Standard Drafting Team should consider P2800 Clause 11 efforts, and ensure that the modifications require disturbance monitoring equipment at inverter-based resource facilities.
	• **Continued and Improved Analyses Needed:** This event, as with past events, involved a significant number of solar PV resources reducing power output (either due to momentary cessation or inverter tripping) as a result of normally-cleared BPS faults. The widespread nature of power reduction across many facilities poses risks to BPS performance and reliability. Many of the issues identified in this disturbance appear systemic and are not being widely addressed by the solar PV fleet.	The NERC Event Analysis Process now includes Category 1i to capture the "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." The ERO Enterprise will continue to analyze these types of disturbances to identify any possible systemic causes of inverter tripping. Entities are encouraged to do root cause analysis of smaller events that may occur, and GOs should ensure they have

[2] https://www.ferc.gov/industries-data/electric/electric-transmission/generator-interconnection/standard-interconnection
[3] https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Reliability_Guideline_IBR_Interconnection_Requirements_Improvements.pdf

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	▪ **Recommendation (RC, GO, GOP):** Analysis of inverter-based resource performance for system faults should be conducted on a regular basis to identify possible abnormal performance. Root cause analysis should be conducted for identified abnormal performance events to develop mitigating measures to improve fleet performance. RCs should be analyzing fleet performance after significant grid disturbances, identifying any abnormal performance, and ensuring affected entities are determining whether improvements to their facilities can be made to eliminate abnormal performance. It does not appear these activities are regularly taking place, and improvements to processes should be developed so that these activities occur more frequently by RCs and affected entities rather than primarily by the ERO Enterprise. Entities are strongly encouraged to share their lessons learned with NERC and its Inverter-Based Resource Performance Working Group (IRPWG) to help industry advance its capabilities moving forward. ▪ **Recommendation (NERC Inverter-Based Resource Performance Working Group (IRPWG), Industry):** NERC and its technical stakeholder groups (i.e., NERC IRPWG) should continue outreach and the development of recommended practices and reliability guidelines to help industry ensure BPS reliability as the penetration of BPS-connected inverter-based resources continues to increase. However, while outreach has been effective in supporting industry in these efforts, it is clear that outreach alone is not an effective	sufficient reporting capabilities to identify these events and determine root causes. NERC and the IRPWG continue to engage in many industry forums (e.g., IEEE, ESIG, CIGRE) and share the lessons learned and recommendations from the published reports, white papers, and guidelines. Further, many IRPWG members are also IEEE P2800 members. **Recommended Action from IRPWG Follow-Up:** NERC IRPWG will continue summarizing lessons learned from the events with systematic causes of inverter tripping IRPWG in future publications (white papers, guidelines, SARs etc.). FERC and NERC, in coordination with industry, should develop a coordinated strategy to ensure the effective and widespread adoption of IEEE P2800 once it is approved.

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	means of minimizing possible abnormal behavior from these resources and developing mitigating measures to eliminate these issues. Additional actions (e.g., standards enhancements, updates to interconnection requirements, engagement in IEEE P2800 activities) are needed by industry to ensure entities are taking appropriate steps to support reliable operation of the BPS.	
	• **Improvements to Identification of Disturbances and Event Reporting:** These events impact many resources across multiple BAs and Reliability Coordinator (RC) footprints. EOP-004-4[4] does not include events of this nature due to the large generation loss criteria contained within EOP-004-4. Therefore, no reporting on these types of events is required and has led to the identification of these events being on an ad hoc basis. CAISO provided a brief report for this event under the voluntary NERC EA Process; however, NERC and WECC needed to perform a more comprehensive analysis to determine any root causes since the brief report did not provide this level of detail or recommend any mitigating actions. ▪ **Recommendation (Industry, NERC, FERC):** Ad hoc reporting of events involving multiple generating resources and possible systemic performance issues should not be considered an acceptable level of reporting. NERC EOP-004-	There is no known action to develop a SAR to address the issues raised by NERC regarding EOP-004-4 and the generation loss requirement it includes. Without addressing this issue, these types of events will not be reported on any uniform basis and will continue to be ad hoc in terms of initiating an analysis. BA and RC reporting helps ensure that the ERO Enterprise is apprised of widespread events and coordinated analyses can occur to support industry address possible reliability risks. NERC Event Analysis Process now includes Category 1i to capture the "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." The ERO Enterprise will continue to analyze these types of disturbances to identify any possible systemic causes of inverter tripping.

[4] https://www.nerc.com/_layouts/15/PrintStandard.aspx?standardnumber=EOP-004-4&title=Event%20Reporting

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	4 should be reviewed in terms of the thresholds used for generator tripping events and should also consider the extent of resources involved in the disturbance. A reasonable threshold for reporting would be around 500 MW of reduction in output (partial or full tripping across all affected resources). Updates to reporting these types of events (not necessarily with quick turnaround times) will help industry improve their situational awareness of abnormal inverter-based resource performance and possible issues needing mitigating action by facility owners to improve their performance.	**Recommended Action from IRPWG Follow-Up:** IRPWG should draft a SAR to address the outstanding recommendation by NERC to address the issue identified in EOP-004-4 regarding the generation loss criteria so that it is applicable for inverter-based resources as well synchronous generation.

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	• **Inverter Tripping:** There were three causes of BPS-connected solar PV tripping during this disturbance—ac overcurrent protection, dc low voltage protection, and ac low voltage protection. The vast majority of inverters that tripped were from a single manufacturer that tripped on either ac overcurrent or dc low voltage protection. All inverter tripping was considered abnormal since the BPS fault events were normally-cleared and no resources were disconnected as a consequence of the faulted elements being removed. The primary form of tripping, ac overcurrent protection, is not considered in PRC-024 since it is not related to voltage or frequency protection within the facility. Similar to past disturbances involving tripping due to dc reverse current protection, phase jump protection, and phase lock loop loss of synchronism protection, none of these common trip mechanisms are captured in the latest version of PRC-024. ▪ **Recommendation (GO, GOP, TO, NERC, FERC):** Partial tripping of inverters within a facility is still considered tripping and has an adverse impact on BPS performance. Partial tripping of inverters during normally-cleared faults should not be considered an acceptable level of performance from inverter-based resources. Facility performance should be more closely reviewed for compliance with NERC Reliability Standards and other applicable interconnection requirements. GOs and GOPs should analyze partial tripping events and work with their	Some of the causes of tripping identified in the San Fernando disturbance (as well as the Canyon 2 Fire, Palmdale Roost, Angeles Forest disturbances) are not addressed in NERC Reliability Standards. In particular, NERC PRC-024 only focuses on voltage and frequency protective relaying or controls that could cause momentary cessation or tripping of a generating resource. However, dc reverse current, phase lock loop loss of synchronism, sub-cycle ac overvoltage, and ac overcurrent tripping all are generally not considered in any NERC standards/requirements. This requires TOs to implement and enforce their interconnection requirements for these resources. IEEE P2800 will be addressing these types of tripping or cessation for newly interconnecting inverter-based resources in the future (likely a couple years from widespread adoption); however, existing resources will continue to experience possible tripping and reduction of power output for these reasons. GOs are encouraged to put measures in place to identify partial tripping events and address possible tripping issues. TOPs and RCs should also analyze fault disturbance events and review the performance of inverter-based resources to identify possible partial tripping events and engage the respective GO to address the abnormal performance. These types of tripping are also not generally identifiable using positive sequence dynamic models and require EMT models;

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	inverter manufacturers to mitigate inverter tripping to the extent possible. ▪ **Recommendation (GO, GOP, TO, FERC):** Inverters are commonly tripped for reasons other than voltage- or frequency-related tripping, and the PRC-024 curves are often set directly in the inverter solely for compliance with PRC-024 rather than to protect the inverter from physical damage. These other forms of tripping (e.g., ac overcurrent, phase lock loop loss of synchronism) lead to partial tripping of many different solar PV facilities and have an adverse impact on BPS performance. These types of tripping should not be considered acceptable for normally-cleared BPS fault events and enhancements to PRC-024 (or a possibly a new standard focused on ride-through capability) should be made to account for these other forms of tripping. ▪ **Recommendation (TO, Transmission Planner (TP), Planning Coordinator (PC), TOP, RC):** Interconnection requirements should ensure that the models provided during the interconnection study process are able to account for all forms of tripping by inverter-based resources so that sufficiently accurate studies can be conducted by the TP and PC. In most cases, this will require the collection of accurate, plant-specific electromagnetic transient (EMT) models. TPs and PCs should be conducting studies during the interconnection process to ensure adequate fault ride-through while considering all possible forms of inverter tripping. Phase lock loop issues, dc reverse current tripping,	yet EMT modeling is not a widely adopted and used practice for interconnection studies. Therefore, possible tripping will likely go unnoticed for inverter-based resources that are not studied adequately during the interconnection study process. **Recommended Action from IRPWG Follow-Up:** Modeling and study standards (e.g., MOD and TPL) should be reviewed by IRPWG to consider the inclusion of EMT models for study purposes by the TP and PC. Currently these studies that would be used to identify possible tripping or abnormal performance from inverter-based resources are not required and are performed only in certain occasions where the TP or PC has identified issues with other modeling tools. However, the issues identified in these disturbances have not been identified or highlighted by the TPs or PCs in their respective area. IRPWG is working on an EMT modeling reliability guideline; however, this does not ensure any one entity actually executes EMT studies, when needed.

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	ac overcurrent tripping, and any other form of tripping beyond simply PRC-024 protection requirements should be accurately modeled and tested by the TP and PC during their interconnection studies. Any unexpected or abnormal performance identified during interconnection studies should be addressed prior to allowing that facility to interconnect to the BPS (per the NERC FAC standards). Furthermore, all models should be updated after plant commissioning and checked to ensure that the model matches the as-built, plant-specific settings, controls, and behavior. Any modeling issues or performance issues identified by the TP and PC should be addressed as quickly as possible, reported to the TOP and RC, and corrective actions put in place in a timely manner.	

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	• **Dynamic Behavior of Solar PV during Faults:** Many facilities had a dynamic response to the fault events in this disturbance; however, multiple facilities exhibited dynamic behavior that does not meet the recommended performance specified in previously published NERC reliability guidelines.[5] Some solar PV facilities use legacy inverters that cannot make improvements to performance. Other facilities have relatively newer inverters where changes could be made but were not made prior to the faults, signifying a lack of action being taken by industry to incorporate the recommendations set forth. Some facilities with newer inverter technology were able to use current injection during the fault (eliminating momentary cessation) but required tens of seconds to return to predisturbance output; this is not a preferred behavior. Concerted focus should be made by NERC Compliance Monitoring and Enforcement Program (CMEP) to ensure all BES facilities are meeting the requirements set forth in NERC Reliability Standards including the latest version of PRC-024. ▪ **Recommendation (GO, GOP):** All existing solar PV facilities should review the recommendations in the NERC reliability guidelines and ensure that their equipment is configured to meet the recommendations set forth. Solar PV resources should eliminate the use of momentary cessation to the extent possible. If elimination is not possible, the	The recommendation made by NERC to focus CMEP activities on inverter tripping of BES resources will hopefully help improve the performance of existing resources not meeting the requirements of PRC-024. Further, the NERC reliability guidelines on recommended performance of BPS-connected inverter-based resources and improvements to interconnection requirements for these resources have been widely shared with industry. Hopefully industry is adopting the recommendations contained in these guidelines to address this issue for newly interconnecting resources. **Recommended Action from IRPWG Follow-Up:** No further action is needed by IRPWG; however, future efforts may consider assessing the extent to which industry has adopted the recommendations in the NERC guidelines regarding interconnection requirements improvements. This would help understand the extent to which these risks are being addressed by industry.

[5] https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Inverter-Based_Resource_Performance_Guideline.pdf
https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Reliability_Guideline_IBR_Interconnection_Requirements_Improvements.pdf

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	momentary cessation settings should be configured (if possible) to minimize its use (lower voltage threshold) and return to predisturbance output within one second. If elimination is possible, other forms of current injection during fault ride-through (e.g., reactive current injection or some form of active and reactive current injection) should be used. ▪ **Recommendation (GO, GOP):** All existing solar PV facilities should review the recommendations in the NERC reliability guidelines and ensure that their equipment is configured to meet the recommendations set forth. Solar PV resources that use current injection should ensure that the inverter controls and plant-level controls are configured to allow the resource to return to predisturbance output (assuming no current limits are reached) within one second. Resources should not have a prolonged recovery of active power following a dynamic response to a fault event on the BPS. Plant-level ramp rates or other BA-imposed balancing ramp rates should not interfere with the resource returning to predisturbance output levels in a quick and stable manner after a BPS fault event. ▪ **Recommendation (TO):** TOs should ensure their interconnection requirements are clear regarding the dynamic performance requirements and settings for inverter-based resources. TOs are strongly encouraged to ensure resources are complying with these requirements and developing mitigation plans for any requirements that	

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	are not being met. In particular, these requirements should ensure clarity and consistency for post-fault recovery of active power following fault events. Furthermore, rise times and settling times should also be specified as well as any reactive current injection (e.g., "K-factor") settings for large disturbance voltage support.	
	• **Settings Changes:** After coordinating with NERC and WECC on this disturbance analysis, a couple of solar PV facilities stated that they had made changes to equipment settings and performance to improve the dynamic response to fault events. This includes eliminating momentary cessation in favor of reactive current injection and some improvements to momentary cessation or active power recovery rates to be more aligned with the recommendations in the NERC reliability guidelines. ▪ **Recommendation (TO):** All GOs of solar PV facilities, and other BPS-connected inverter-based resources, should review these key findings and recommendations as well as those listed in **Chapter 2** [of disturbance report] and ensure their resources are configured to provide the best dynamic response to support BPS reliability. GOs should consult the NERC reliability guidelines as well as their BA, RC, TP, and PC if they have any questions regarding recommended performance.	**Recommended Action from IRPWG Follow-Up:** No further action is needed by IRPWG.

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	• **Dynamic Model Accuracy:** NERC and WECC have previously identified[6] modeling issues in the interconnection-wide planning base cases, and modeling challenges continue to be an issue with industry. Discussions with GOs of solar PV facilities during this analysis have highlighted that changes to equipment may take place, but there is little to no emphasis put on getting TP or PC approval of these changes (as a material modification to the facility) prior to making them, nor on ensuring that the TP and PC receive updated dynamic models following those changes. NERC IRPWG has submitted a standard authorization request to modify FAC-002-2 to clarify the use of "material modification" in that standard. ▪ **Recommendation (GO, GOP):** GOs and GOPs should ensure that any changes to plant-level settings, inverter settings, or facility topologies or ratings should be articulated to the TP, PC, BA, and RC. Any applicable interconnection requirements, per FAC-001-3 and FAC-002-2, must be met prior to these changes being made to the facility, including restudy of these changes by the TP and PC. GOs and GOPs should coordinate with their TP and PC to determine if any changes within the facility are considered "material" and require any additional restudy. ▪ **Recommendation (TO, TP, PC, Industry):** TOs should ensure that their interconnection requirements are clear and any	IRPWG submitted a SAR regarding the "material modification" issue identified in the San Fernando disturbance (and other disturbances). The changes to FAC-002 will hopefully address the issues of changes being made to equipment prior to studies being conducted to ensure reliability of the BPS for those changes made. IRPWG has also recommended that interconnection requirements be updated to capture these modeling issues more directly. **Recommended Action from IRPWG Follow-Up:** No further action is needed by IRPWG.

[6] https://www.nerc.com/comm/PC/InverterBased%20Resource%20Performance%20Task%20Force%20IRPT/NERC-WECC_2020_IBR_Modeling_Report.pdf

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	modifications to the facility that can or will change the electrical behavior of the facility (including any settings changes to inverters that affect its electrical output during steady-state or dynamic conditions) should be considered material and should be studied prior to those changes being made. TOs, TPs, and PCs should ensure that their processes for making these changes are timely and effective such that GOs are not discouraged from making these changes to support overall reliability of the BPS.	