NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Industry Recommendation

Inverter-Based Resource Performance Issues

Initial Distribution: March 14, 2023

NERC analyzed multiple large-scale disturbances on the bulk power system (BPS) involving widespread loss of inverter-based resources (IBRs). In 2021 and 2022, two disturbances in Odessa, Texas, resulted in abnormal performance across several Bulk Electric System (BES) solar photovoltaic (PV) generating resources. These resources have exhibited systemic performance issues that could lead to unexpected losses of BPS-connected generation, with the potential to cause widespread outages. As the penetration of BPS-connected IBRs continues to rapidly increase, it is paramount that any performance deficiencies with existing (and future) generation resources be addressed in an effective and efficient manner.

While this Level 2 alert is being distributed to Generator Owners (GO) of BES solar PV resources, the recommendations should also be reviewed and implemented by owners of all BPS-connected[1] solar PV resources (See Background section for more information). The alert also seeks to gather data from solar PV asset owners to understand whether additional actions are necessary to mitigate possible BPS performance risks. Applicable GOs are strongly encouraged to consult their inverter- and plant-level controller manufacturers, review inverter settings and controls currently installed in the field, and implement the recommendations described herein, and review this information with the associated Generator Operators (GOPs) as applicable.

Note: This alert pertains specifically to solar PV resources, however, the recommendations may be applicable to BPS-connected battery energy storage systems (BESS). This alert does not pertain to wind resources as the observed performance issues are different.

For more information, see the NERC Major Event Analysis Reports webpage. All recipients are strongly encouraged to read the findings from these reports, particularly the 2021 Odessa Disturbance report and the 2022 Odessa Disturbance report.

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[1] GOs of all BPS-connected solar PV resources are strongly encouraged to adopt the recommendations provided in this Alert, including BES resources as well as non-BES resources connected to the BPS. This is to ensure uniformity of performance across all BPS-connected resources.

Status:	**Acknowledgement Required[2] by Midnight Eastern on March 21, 2023** **Reporting Required[2] by Midnight Eastern on June 30, 2023**
	**PUBLIC:** No Restrictions More on handling >>
Instructions:	This Level 2 Industry Recommendation provides specific actions that registered entities should consider for responding to a particular issue. Pursuant to Rule 810 of NERC's Rules of Procedure (ROP), NERC registered entities shall 1) acknowledge receipt of this Industry Recommendation within the NERC Alert System, and 2) report to NERC on the status of their activities in relation to this recommendation as provided below. For U.S. entities, NERC will compile the responses and report the results to the Federal Energy Regulatory Commission (FERC). Information supplied by Canadian registered entities will not be provided to FERC. This recommendation is not the same as a Reliability Standard and your organization will not be subject to penalties for a failure to implement. Issuance of this recommendation does not replace or modify the requirements of any approved Reliability Standard or excuse the prior failure to follow the practices discussed in the recommendation if such failure constitutes a violation of a Reliability Standard.
Distribution:	Generator Owner (GO) Who else will get this alert? >>
Primary Interest Groups:	Generation Engineering, Generation Operations
Recommendation:	GOs of all BPS-connected solar PV resources who are receiving this Industry Recommendation are strongly encouraged to adopt the following recommendations: **Recommendation 1:** Coordinate with inverter manufacturers to ensure that inverter protection settings are set using the following principles: a. Expand AC voltage protection settings as widely as possible within the inverter equipment capability. Eliminate or minimize the use of inverter instantaneous AC voltage tripping (e.g., zero or near-zero[3] time delay using instantaneous peak measurements).

[2] To the extent that Canadian jurisdictions have implemented laws or requirements that vary from Section 810 of the ROP, NERC requests entities in such jurisdictions voluntarily participate in response to this Alert.

[3] For example, on the order of a few milliseconds.

b. Inverter frequency protection should be set based on equipment capability. Frequency protection should operate on a filtered frequency measurement over a time window.[4] Eliminate or minimize the use of inverter instantaneous frequency tripping.

c. Inverter instantaneous AC overcurrent protection should be set based on maximum inverter capability.

d. Inverter phase lock loop loss of synchronism and/or phase jump protection should be set as widely as possible (or eliminated, if possible) to maximize ride through capability while still preventing equipment damage or degradation.

e. Inverter dc bus protection should be configured to prevent equipment damage or degradation and to avoid any inadvertent tripping in response to BPS faults, particularly unbalanced faults.

f. Document all inverter AC and DC protections, including technical basis as well as the inverter capability curves (particularly for items a–e above).

g. Inverter reconnection settings (voltage and frequency levels and time delay) should be coordinated with inverter protection settings and the requirements established by the Balancing Authority (BA).

Recommendation 2: Ensure that all collector systems and substation protection settings at the facility are set using the following principles:

a. Protection settings should be based on equipment ratings of the equipment they are intended to protect.

    a. Eliminate or minimize the use of instantaneous voltage tripping (e.g., zero or near-zero[4] time delays).

    b. Eliminate or minimize the use of instantaneous frequency tripping. Frequency protection should operate on a frequency measurement over a time window.

b. Protection settings should be coordinated with inverter- and plant-level controller protection and controls.

c. Protection settings in the power plant controller should generally be disabled.

Recommendation 3: Coordinate with inverter manufacturers to document and mitigate known causes of inadvertent protection system operation during normally cleared BPS faults. Inverter hardware or firmware updates should be completed for all inverters supplied by manufacturers that have observed

[4] Sufficient measurement time windows should be selected by the inverter manufacturer, typically 6 cycles or more.

inadvertent operations of protection systems including, but not limited to, the following:

a. Instantaneous voltage protection settings
b. Instantaneous frequency protection settings
c. Instantaneous overcurrent protection settings
d. DC bus protection functions and settings
e. Phase lock loop protection settings

Potential hardware or firmware updates should be communicated to the Transmission Planner (TP) and Planning Coordinator (PC) for authorization prior to the changes being made in the field per NERC FAC-002. These changes should also be communicated to the Transmission Operator (TOP), Reliability Coordinator (RC), and BA.

Recommendation 4: Coordinate with inverter manufacturers and power plant controller manufacturers to ensure that facility control modes, fault ride through modes and parameters, and protections are set and coordinated according to the following principles:[5]

a. Inverter- and plant-level fault ride through controls should be set and coordinated to ensure maximum ride through capability and the provision of essential reliability services.[6]
b. Fault ride through parameters should be set to maximize active current delivery during the fault and post-fault periods unless otherwise limited by its current limit or reactive power priority mode. Reactive power priority modes should be set to minimize reductions in active current, while providing and prioritizing a strong and appropriate reactive current response.
c. All protection settings should be set to maximize ride through performance, while still preventing damage to or degradation of the equipment.
d. Facility output returns to pre-disturbance active power levels as soon as possible without any artificial ramp rate limit or delay imposed by the power plant controller.[7] Ramp rates established by the BA for dispatch should not impede plant recovery of active power post-fault.

[5] All BES generating resources should ensure they comply with any local interconnection or performance requirements.
[6] https://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/ERSTF%20Framework%20Report%20-%20Final.pdf
[7] Plants connected to low short circuit strength systems or other special circumstances may require a slower dynamic response to BPS faults and should be studied appropriately by the TP and PC during interconnection studies. In these circumstances, the plant performance necessary for BPS reliability takes precedence over these recommendations.

Recommendation 5: Coordinate with inverter manufacturers in instances where IBRs fail to ride through BPS faults to proactively determine and implement potential corrective actions.[8]

Recommendation 6: Coordinate with inverter manufacturers and power plant controller manufacturers to not artificially limit dynamic reactive power capability delivered to the point of interconnection during normal operations and BPS disturbances. Power plant controllers should not hinder the full utilization of available dynamic reactive capability during or following BPS faults.[9] For example, plant dynamic reactive power capability should not be artificially limited to ±0.95 power factor across the full range of active power capability (e.g., a triangular capability curve).

Recommendation 7: Provide the findings from this alert with respective TO, TP, PC, TOP, RC, and BA. These findings include the Data Submission Worksheet and any information regarding deficiencies in ride through performance. Any potential changes to equipment installed in the field should be coordinated with these entities, as required by NERC Reliability Standards.

Reporting Instructions:

Initial acknowledgement of receipt is required[2] by **March 21, 2023, Midnight Eastern** via the NERC Alert System. Responses to the questions below are required[2] to be submitted via the NERC Alert System by **June 30, 2023, Midnight Eastern**.

The questions below seek data pursuant to Section 800 of the ROP to support NERC's evaluation of actions taken in response to this alert and of risks to reliability presented by the identified issues.[10] Plant and inverter information, for example, will enable NERC to track responses, including actions taken in response to this NERC Alert, and to evaluate the extent of conditions associated with the identified issues. Confidential Information should be labeled appropriately per the dropdown option in the **Data Submission Worksheet**.[11] Confidential Information shall be protected in accordance with the provisions of Section 1500 of the ROP. As emphasized in Section 810, for example, NERC's report to FERC regarding actions taken in response to this

[8] Establishing a process to record, analyze, and mitigate any abnormal performance issues at IBR facilities is aligned with Project 2023-02 Performance of IBRs.
[9] Again, special circumstances such as low short circuit strength systems may require the TO, TP, or PC to impose operational requirements.
[10] *See*, Section 810 of the ROP stating, "Members of NERC and Bulk Power System owners, operators, and users shall provide NERC with detailed and timely operating experience information and data."; *see also*, Section 804 of the ROP stating, "To carry out the reviews and assessments of the overall reliability of the interconnected Bulk Power Systems, the Regional Entities and other entities shall provide sufficient data and other information requested by NERC in support of the annual long-term and seasonal assessments and any special reliability assessments."
[11] *See*, Section 810 of the ROP; *and* Section 804 of the ROP stating, "Some of the data provided for these reviews and assessment may be considered confidential from a competitive marketing perspective, a Critical Energy Infrastructure Information perspective, or for other purposes. Such data shall be treated in accordance with the provisions of Section 1500 – Confidential Information."

Alert will include "appropriate protection for Confidential Information or Critical Energy Infrastructure Information."[12]

A valid response in the NERC Alert System consists of the following three steps by the submitting entity:

1) Acknowledgement of Alert
2) Submission of Response
3) Approval of Response

The NERC Alert System contains menu options for each of the above commands that are available to authorized individuals upon login. **A response will not be considered valid until all three steps have been completed.**

All registered entities belonging to the GO functional group are required to acknowledge receipt of this alert and respond as applicable.

All GOs are required to respond to the following question:

For GOs: Do you own any BPS-connected solar PV generating facilities?[13] (Yes, No)

- **For GOs that answered "Yes" to the question above**, answer the following questions in the attached Data Submission Worksheet**.**
- **For GOs that answered "No" to the question above,** there is no requirement to complete the attached Data Submission Worksheet.

Use the "Add Additional Document" link on the NERC Alert System response web page to submit the completed worksheet(s). There should be one Data Submission Worksheet completed for each EIA-860 solar PV plant.

Additional Information:

NERC analyzed multiple large-scale disturbances on the BPS involving the widespread loss of IBRs. Through this analysis, it was observed that some BPS-connected IBRs, specifically solar PV resources, appear to have systemic fault ride through deficiencies that have resulted in their unexpected and abnormal performance during grid disturbances. The widespread loss of many resources due to systemic performance issues poses a significant risk to BPS reliability. Furthermore, NERC has observed that control settings installed in the field do not always match those that were studied during the interconnection process. This alert focuses specifically on addressing the observed performance issues. NERC plans to issue a subsequent alert in Q3 2023 regarding modeling issues.

[12] Section 810(5) of the ROP.
[13] GOs of BES solar PV generating facilities are required to complete the Data Submission Worksheet; owners of non-BES solar PV facilities are requested to complete and submit the Data Submission Worksheet as well. This also applies to hybrid plants with solar PV components.

Although this alert and NERC observations pertain specifically to BES-connected solar PV resources, the same deficiencies may also exist for non-BES solar PV resources that are connected to the BPS as well as some BESS. For more information, see the NERC Major Event Analysis Reports webpage. All recipients are strongly encouraged to read the findings from these disturbance reports, particularly the 2021 Odessa Disturbance report and the 2022 Odessa Disturbance report.

Analyses of widespread solar PV loss events revealed systemic deficiencies in the ride through performance of IBRs. This is primarily driven by industry practices related to setting inverter- or plant-level protection systems (e.g., thresholds and time delays) as well as the parameterization of control modes and ride through settings. In addition, some causes of tripping are attributed to inverter controls that are not accessible to the owner/operator of the facility and require the equipment manufacturer to correct through firmware upgrades or parameter changes.

Primary concerns include the following:

- Inverter- and plant-level protection set with trip settings directly on, or very near to, the NERC PRC-024 curve and do not appear to be based on established equipment capabilities or ratings. Ride through performance of generating facilities can be optimized through setting protection system thresholds based on the capabilities of the resource. Furthermore, protection settings set on the PRC-024 curve demonstrate a lack of coordination between inverter and point of interconnection voltage levels that are expected during faults on the BPS.

- Inverter, collector system feeder, and substation protection systems using instantaneous measurements (i.e., no time delay) for both voltage and frequency protection. Instantaneous protection settings increase the likelihood of unexpected trips due to unfiltered measurements during sub-cycle excursions that the inverter would otherwise be able to ride through. Instantaneous protection should be based on the maximum capability of the inverter or other plant equipment ratings, and only operate when equipment damage or degradation would occur otherwise.

- Inverter phase lock loop or loss of synchronism protection has regularly tripped inverters across multiple sites and in different interconnections. Some inverter manufacturers have determined that these protection functions can either be disabled or modified to significantly enhance ride through performance.

- Inverter protection and controls not available to the owner or operator of the facility have caused numerous solar PV plant trips that should otherwise be addressed with hardware or firmware upgrades performed by the equipment manufacturer. These include control updates that can remediate inverter ac overcurrent and dc bus protection issue. Increased dialogue between GOs and equipment manufacturers should reduce the possibility of repeated performance issues; firmware updates for known performance issues should be conducted for all operational resources using a particular manufacturer's product, rather than only at facilities involved in any particular disturbance.

- Some inverter tripping has been attributed to the control modes and settings configured in inverter ride through settings. Inverter- or plant-level controls have been set in a manner that drives the facility past its established protection settings. Detailed discussions and coordination is needed between the GO and equipment manufacturer to ensure controls and protection are coordinated to ensure ride through and to provide essential reliability services.

- IBR plant reactive capability may be artificially limited by the power plant controller, underutilizing the full extent of available dynamic reactive capability at the facility. This can hinder the ability of the facility to support BPS voltage control during normal operating conditions.

Contact:	For clarification or content-related questions, contact: Alex Shattuck Alex.Shattuck@nerc.net For login/account/registration issues, contact: Bulk Power System Awareness Group North American Electric Reliability Corporation 3353 Peachtree Road NE Suite 600 – North Tower Atlanta, GA 30326 nerc.alert@nerc.net
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North American Electric Reliability Corporation
3353 Peachtree Road NE
Suite 600 – North Tower
Atlanta, GA 30326
www.nerc.com