NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Inverter-Based Resource Strategy

Ensuring Reliability of the Bulk Power System with Increased Levels of BPS-Connected IBRs

Purpose and Background

The rapid interconnection of bulk power system (BPS)-connected inverter-based resources (IBR)[1] is the most significant driver of grid transformation and poses a high risk to BPS reliability.[2] The speed of this change continues to challenge grid planners, operators, protection engineers, and many other facets of the electricity sector. Implemented correctly, inverter technology can provide significant benefits for the BPS; however, the new technology can introduce significant risks if not integrated properly. Based on recent analysis, these are high impact and high likelihood events that require substantive action by the ERO as called out by the NERC *Framework to Address Known and Emerging Reliability and Security Risks* (*NERC Risk Framework*).[3] **Figure 1** shows reliability risk mitigation toolkit used by the ERO.

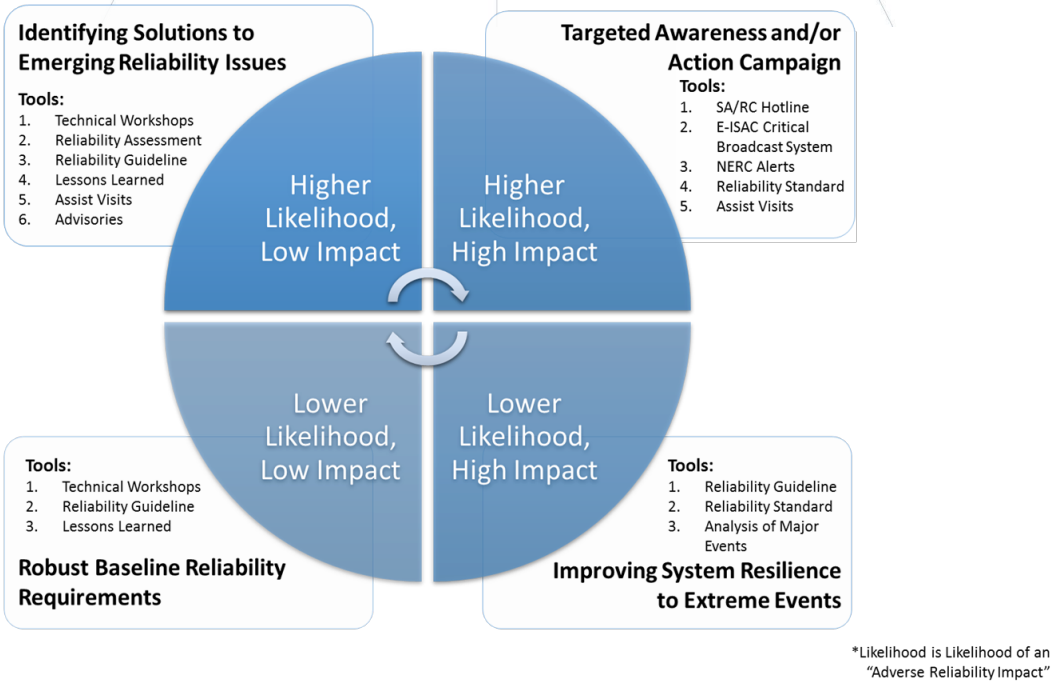


Figure 1: ERO Reliability Risk Mitigation Toolkit

[1] This strategy focuses specifically on BPS-connected IBRs: wind, solar PV, battery energy storage systems, hybrid power plants, high voltage direct current networks, flexible ac transmission system devices, etc.

[2] *2021 ERO Reliability Risk Priorities Report*: https://www.nerc.com/comm/RISC/Documents/RISC%20ERO%20Priorities%20Report_Final_RISC_Approved_July_8_2021_Board_Submitted_Copy.pdf

[3] https://www.nerc.com/comm/RISC/Related%20Files%20DL/Framework-Address%20Known-Emerging%20Reliabilit-Securit%20%20Risks_ERRATTA_V1.pdf

The *2021 NERC Long-Term Reliability Assessment*[4] projects a rapid growth of IBRs—mostly wind, solar photovoltaic (PV), battery energy storage systems, and hybrid plants—with projections of nameplate capacity for solar PV projects in all development stages exceeding 500 GW over the next 10 years. At the same time, wind projects are projected to total 360 GW of nameplate capacity. To maximize the amount of renewable resources, the inverter and plant controls and protection systems must support reliable operation of the BPS during system disturbances. Otherwise, these disturbances can become a limiting contingency, the correction of which may be to reduce the amount of renewable resource additions. This paper outlines NERC's strategy to ensure that the transformation will lead to a more reliable, resilient, and secure BPS.

Risk Framework

The *NERC Risk Framework* guides the ERO in the prioritization of risks and provides guidance on the application of ERO policies, procedures, and programs to inform resource allocation and project prioritization in the mitigation of those risks. Additionally, the *NERC Risk Framework* accommodates measuring residual risk after mitigation is in place, enabling the ERO to evaluate the success of its efforts in mitigating risk, which provides a necessary feedback for future prioritization, mitigation efforts, and program improvements. The successful reduction of risk is a collaborative process between the ERO Enterprise, industry, and the technical committees including the Reliability and Security Technical Committee (RSTC) and Reliability Issues Steering Committee (RISC). The *NERC Risk Framework* provides a transparent process using industry experts in parallel with ERO Enterprise experts throughout the process from risk identification, to deployment of mitigation strategies, and to monitoring the success of these mitigations. Six specific steps have been identified that are consistent with risk management frameworks used by other organizations and industries:

1. Risk Identification and Validation
2. Risk Prioritization
3. Remediation & Mitigation Identification/Evaluation
4. Deploy Mitigation
5. Measure Success
6. Monitor Residual Risk

Each of these steps will require process development, including stakeholder engagement, validation/triage approaches, residual risk monitoring, ERO Enterprise's level of purview over a risk, etc. The graphical representation of the risk framework is shown in **Figure 2**.

[4] https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_LTRA_2021.pdf

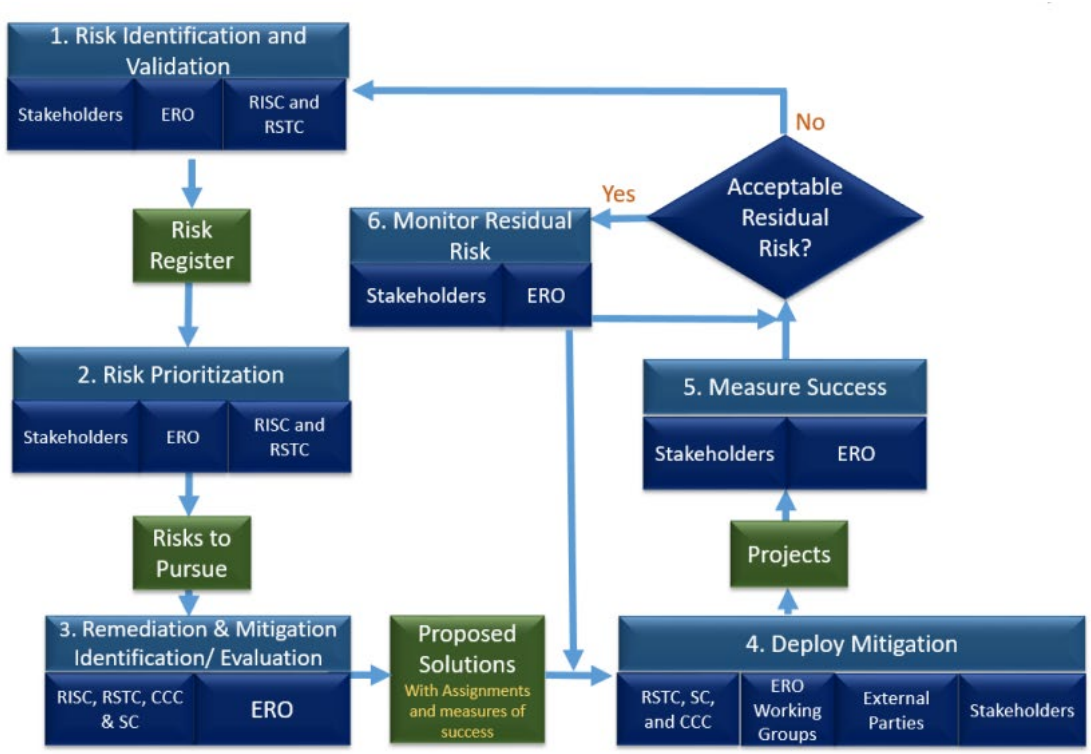


Figure 2: Risk Framework

Risk Identification and Analysis through Event Analysis Process and Disturbance Reports

The ERO Enterprise has analyzed numerous widespread IBR loss events and identified many systemic performance issues with the inverter-based fleet over the past six years. Through the Event Analysis Process and the development of disturbance reports[5] and alerts,[6] NERC has shared key findings and recommendations with industry stakeholders. This has involved working with NERC registered entities as well as directly with inverter and plant controller manufacturers, developers, national laboratories, the U.S. Department of Energy, research institutes, and international colleagues in an effort to enhance the performance of IBRs for existing and newly interconnecting projects. NERC continues to leverage the Event Analysis Process and work collaboratively with stakeholders to gather information, analyze large-scale disturbances, assess new risks, and monitor residual risks. This process is integral to the effective root cause analysis and dissemination of important information to industry.

[5] https://www.nerc.com/pa/rrm/ea/Pages/Major-Event-Reports.aspx
[6] https://www.nerc.com/pa/rrm/bpsa/Pages/Alerts.aspx

Addressing Inverter-Based Resource Performance Issues

The disturbance reports, alerts, guidelines, and other deliverables developed by the ERO thus far have highlighted that abnormal IBR performance issues pose a significant risk to BPS reliability. Each event analyzed has identified new performance issues, such as momentary cessation, unwarranted inverter or plant-level tripping issues, controller interactions and instabilities, and other critical performance risks that must be mitigated.

Core Tenets of the IBR Risk Mitigation Strategy

The ERO Enterprise is dedicated to proactively identifying and addressing IBR integration challenges and continues to work with industry stakeholders to drive risk mitigation activities. **Figure 3** provides the core tenets of this risk mitigation strategy, balancing near- and long-term approaches to ensure reliable operation of the BPS. The tenets of the IBR Mitigation Strategy can be mapped to the NERC Risk Framework.

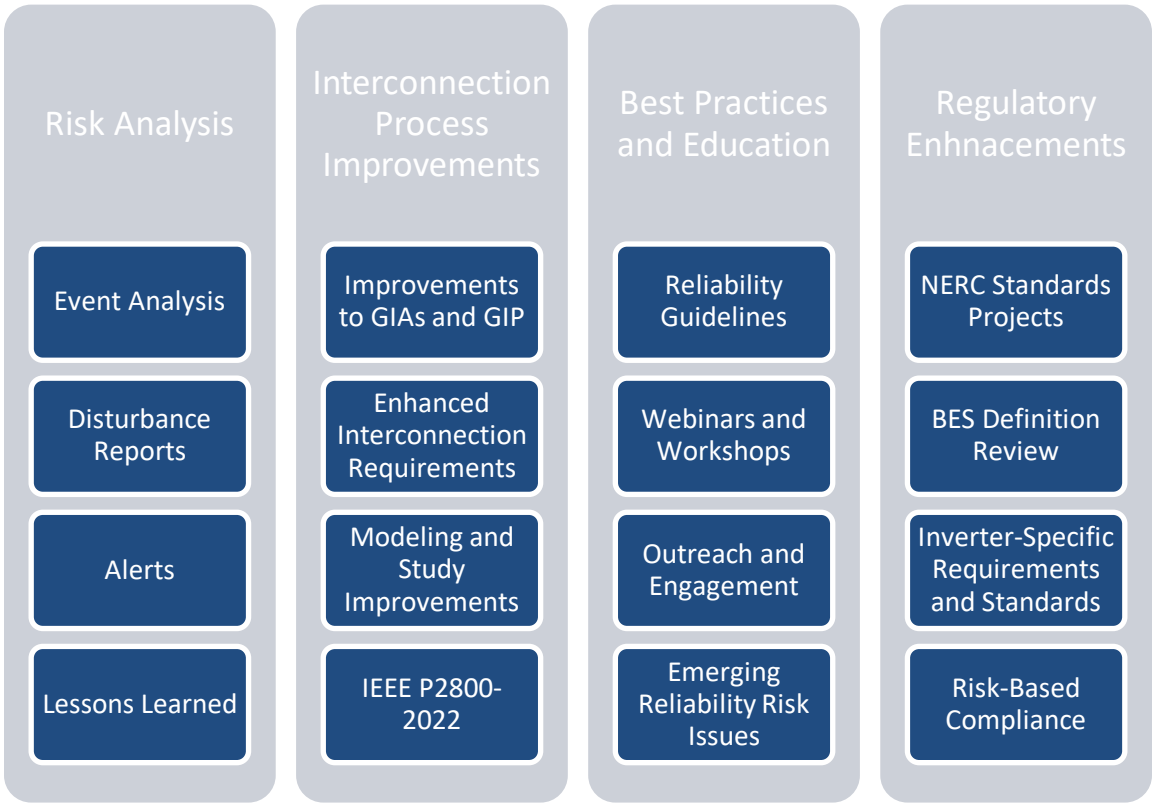


Figure 3: NERC IBR Risk Mitigation Strategy

The following sections briefly describe each tenet of the risk mitigation strategy.

Mitigating IBR Performance Issues

A number of mitigation steps (see the **Risk Framework**) have been developed and deployed; however, consistent mitigation of the risks has been uneven. Generation ride-through and provision of essential

reliability services is a core principle for reliable operation of the BPS. NERC continues to drive improved resource performance through NERC guidelines,[7] disturbance reports, and standards modifications. Most recently, this has included a NERC Standard Authorization Request (SAR) to overhaul PRC-024 to ensure generator ride-through performance, numerous NERC standards projects underway, and considerations for inverter-specific performance standards (and requirements). NERC has supported the development of IEEE 2800-2022[8] and continues to support the IEEE P2800.2 standards development efforts.

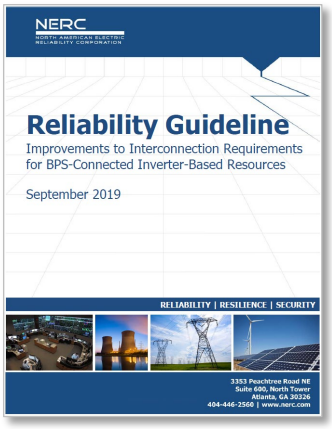
Additional ERO Enterprise mitigating efforts include the following:

1. **Supporting Modifications to the Generator Interconnection Procedures and Agreements**

   Many of the reliability risks associated with BPS-connected IBRs (e.g., model discrepancies, inaccurate reliability studies, poor ride-through performance) stem from challenges associated with the generator interconnection process. NERC recommended FERC overhaul and modernize the interconnection process to address these systemic issues. This includes significant revisions to the *pro forma* generator interconnection agreements and enhancements to the interconnection studies and commissioning process. FERC recently released a Notice of Proposed Rulemaking[9] regarding the interconnection process and the backlog of IBRs currently in the interconnection queues across North America. NERC continues to provide comments and technical basis for recommended modifications.

2. **Driving Improvements to Interconnection Requirements for Inverter-Based Technologies**

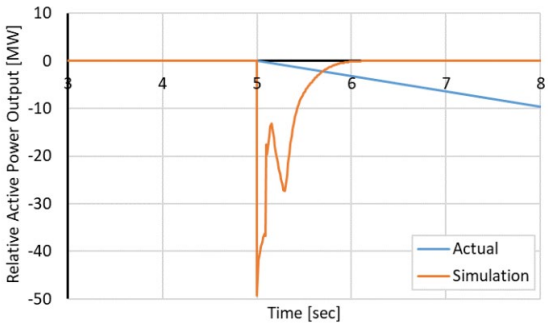
   In 2019, NERC published *Reliability Guideline: Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources*,[10] which strongly recommends significant enhancements to Transmission Owner interconnection requirements per NERC FAC-001 and modeling and study requirements per NERC FAC-002. This guideline has served as a pillar for IEEE 2800-2022 developments and NERC activities regarding effective IBR integration. However, NERC continues to observe and highlight that many applicable entities have not implemented the recommendations outlined in the guideline and continue to rely mostly on the *pro forma* GIAs with some modifications for specific topics (but not comprehensively).



[7] https://www.nerc.com/comm/Pages/Reliability-and-Security-Guidelines.aspx
[8] https://standards.ieee.org/ieee/2800/10453/
[9] https://www.ferc.gov/news-events/news/ferc-proposes-interconnection-reforms-address-queue-backlogs
[10] https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline_IBR_Interconnection_Requirements_Improvements.pdf

3. Addressing Model Quality Issues and Inadequate Reliability Studies during the Interconnection Process and Long-term Planning Horizons

The aforementioned challenges regarding the interconnection process have led to significant modeling and study gaps when assessing BPS reliability for newly connecting IBRs. NERC continues to document systemic modeling errors in positive sequence dynamic models that are pervasive in the interconnection-wide planning cases. Disturbance analyses have also highlighted vast mismatches between modeled (expected) and actual performance. Modeling errors are due to changes made to equipment during the interconnection process and little to no updates to the models made along the way. Inadequate model quality checks throughout the process and a lack of modeling attention during plant commissioning are also contributors to these issues. As plants drop out of the queue, reliability studies must be re-executed, leading to delays in the process and gaps in sufficient studies being performance. Electromagnetic transient (EMT) models are not required to be collected and EMT studies are not required to be performed; however, as the penetration of IBRs grows, these studies will become increasingly necessary to ensure reliable operation of the BPS. The NERC *Odessa Disturbance* report[11] highlighted that essentially all EMT models collected by ERCOT had modeling limitations in them that resulted in those models being unable to recreate the abnormal performance across many different resources.



These issues stem from the interconnection study process but ultimately result in poor model quality issues in the interconnection-wide base cases that serve as the foundation for long-term planning studies. Model quality issues need to be addressed broadly across the industry to ensure that reliability studies are sufficiently accurate to make appropriate reliability decisions: corrective action plans, transmission reinforcements, operating limits, etc. NERC RSTC recently endorsed a SAR regarding model quality and EMT requirements for the FAC, MOD, and TPL standards; this SAR will be presented to the NERC Standards Committee in July 2022.

4. Focused Improvements to Commissioning Processes

A critical component of the interconnection process is the commissioning and trial operation period immediately prior to commercial operation. These activities ensure the plant has been modeled, studied, designed, constructed, and configured to match expectations and requirements of the local interconnecting utility (and per the interconnection procedures). Industry stakeholders from both generation and transmission have expressed concerns regarding the commission testing procedures, seeking clarity and consistency regarding what these processes entail. NERC IRPS is beginning the development of guidance materials in this area, and NERC is exploring the possible need for standards enhancements to ensure critical aspects of commissioning are conducted appropriately: model validation and quality checks, study result validation, plant configuration (operating modes, settings, controls, protections, etc.), and testing procedures.

[11] https://www.nerc.com/pa/rrm/ea/Documents/Odessa_Disturbance_Report.pdf

5. Post-Event Performance Validation and Addressing Abnormal Inverter Performance Issues

Through the NERC Event Analysis Process, NERC has identified that very few inverter-based Generator Owners are conducting performance validation activities (i.e., ensuring the facility responds to grid disturbances with a suitable and expected performance). Furthermore, NERC has also identified that Reliability Coordinators and Balancing Authorities are either not conducting this analysis and/or may not have suitable mechanisms to seek corrective actions if discrepancies are identified. Proactive mitigation of performance issues is critical to avoid large-scale outages and to address systemic performance issues. These issues need to be addressed through appropriate NERC standards enhancements in the near-term.

6. Analysis and Enhanced IBR Performance Issues

The NERC Inverter-Based Resource Performance Subcommittee (IRPS) is drafting a SAR focused on analysis and reporting of IBR performance issues. A SAR focused on mirroring PRC-004 in terms of defining the type of inverter-specific performance issues that are similar to a "misoperation" that should have analysis conducted by the Generation Owner or Generation Operator and reported to the Reliability Coordinators, Balancing Authorities, and Transmission Operator.

7. Other Topics Identified Through Stakeholder Activities and Lessons Learned

NERC and the IRPS continue to identify additional areas for improvement and are driving NERC standards enhancements in various areas. This includes improved monitoring capabilities for IBRs,[12] addressing confusion with "material modifications" during the interconnection study process,[13] clarifications in the long-term planning studies for IBRs,[14] and other topics. NERC is working with industry stakeholders through the IRPS to proactively identify challenges with existing standards or the potential standards enhancements to address the changing resource mix.

8. Industry Engagement, Outreach, Education, and Collaboration

NERC is committed to ensuring that industry stakeholders are aware of efforts underway in the area of IBR integration. All NERC activities directly related to the "IBR initiative" are now located under the Initiatives tab on the main NERC webpage.[15] Reliability guidelines related to IBRs are the most commonly downloaded documents on the NERC website. Disturbance report webinars and related joint industry webinars on inverter-related topics are heavily advertised and often have over 1,000 participants dialing in. NERC IRPS meetings often have over 150 dial-in participants each month. NERC is leveraging industry partnerships with other organizations, such as the Electric Power Research Institute, the North American Transmission Forum, the North American Generation Forum, the Energy Systems Integration Group, the IEEE 2800 leadership team, and many others to ensure coordinated efforts across the industry on many of the topics described in this strategy.

[12] https://www.nerc.com/pa/Stand/Pages/Project-2021-04-Modifications-to-PRC-002-2.aspx
[13] https://www.nerc.com/pa/Stand/Pages/Project-2020-05-Modifications-to-FAC-001-and-FAC-002.aspx
[14] https://www.nerc.com/pa/Stand/Pages/Project2022-02ModificationstoTPL-001-5-1andMOD-032-1.aspx
[15] https://www.nerc.com/pa/Documents/IBR_Quick%20Reference%20Guide.pdf

Monitoring Success of Mitigation Activities

Per the *NERC Risk Framework*, an important aspect of mitigation is measuring the effectiveness of mitigation activities. A portion is accomplished through ERO Enterprise event and disturbance analysis contributions. However, a more consistent/ensured notification approach is needed as data critically necessary to understanding an IBR-involved event can be omitted and/or overlooked due to lethargy in notification and/or misunderstanding of notification expectations. For this reason, the IRPS is working on an EOP-004 SAR, requiring ERO notification by Balancing Authorities and/or Reliability Coordinators of widespread inverter-related performance issues across the grid. This will ensure IBR-involved events of interest (based on notification criteria) are captured immediately resulting in improved quality and timeliness of analysis. This will enable the ERO to swiftly obtain event data, identify the causes of IBR loss, and measure the success of industry actions to mitigate the risks from poor performing IBRs.

Additional Activities

Additional activities will support the strategy now and into the future. Some of these are as follows:

1. **Risk-Based Compliance Activities**
   The ERO Enterprise risk-based Compliance Monitoring and Enforcement Program (CMEP) focuses on identifying, prioritizing, and addressing risks to the BPS and enables each Regional Entity to direct resources where most needed. CMEP activities are tailored based on BPS risk of registered entities, collectively and individually, to determine appropriate CMEP tools to use when monitoring an entity's compliance with NERC Reliability Standards. Reliable integration of BPS-connected IBRs is a high-risk topic across multiple Regional Entities, and the ERO Enterprise CMEP activities reflect this concern. Reliability Standards to consider in these activities include FAC-002, MOD-033, and IRO-008.[16]

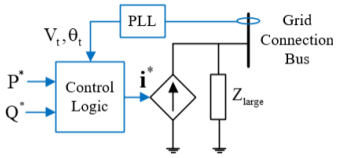
2. **NERC Alert Level 3**
   As the risks of abnormal IBR performance and challenges with modeling and studies are systemic in nature and are moving quickly, NERC is considering issuing a Level 3 alert in this area. This would enable industry action while Reliability Standards are being developed. Working with industry, NERC should develop an agreed upon process to develop and deploy Level 3 alerts.

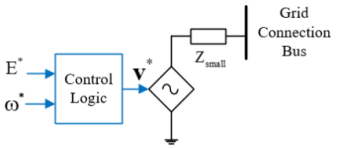
3. **BES Definition and Registration**
   The Bulk Electric System (BES) encompasses all elements and facilities necessary for reliable operation and planning of the BPS. A revised version of the BES definition was approved by FERC in 2014 that includes bright-line criteria with various inclusions and exclusions. The current BES definition generally includes individual generating units larger than 20 MVA and aggregate resources larger than 75 MVA that are connected to the BPS at a nominal voltage of 100 kV or above. The vast majority of newly connecting generators are dispersed power producing resources that do not have individual generating units larger than 20 MVA; hence, only the aggregate 75 MVA threshold would be applicable. However, a significant portion of the generation base does not meet this 75 MVA threshold and therefore does not meet the BES definition and are therefore not subject to any NERC

[16] https://www.nerc.com/pa/Stand/Reliability%20Standards%20Complete%20Set/RSCompleteSet.pdf

Reliability Standards. NERC is analyzing the breakdown of resource size, location, type, and applicability with the BES definition to make a determination of whether the current BES threshold should be updated to reflect the changing resource mix.

4. **Proactively Preparing for Future Reliability Challenges with Growing IBRs**





The BPS is undergoing a rapid transition and will need to adopt new technologies to ensure reliability in the future. Proactively integrating these new technologies may be drastically more cost effective than the possible reliability risks posed if no action is taken. For example, in very high IBR penetration levels, grid-forming technology may be necessary (in conjunction with synchronous condensers and other technologies). The incremental cost of adding grid-forming controls to battery energy storage systems is very low; however, newly interconnecting projects are not being installed with this technology enabled. NERC is working with industry stakeholders to identify future BPS reliability risks and develop strategies for more proactive solutions to mitigate future risks rather than waiting until those risks manifest.

Milestone Plan

The following deliverables are planned to be presented to the NERC Reliability and Security Technical Committee:

- **Disturbance Report Follow-Up Analysis:** Ongoing assessments after NERC disturbance reports are published reviewing key findings and recommendations and determining if any additional IRPS actions are needed. *(Ongoing)*
- **SAR – EOP-004:** SAR to ensure that reporting of widespread inverter-based disturbances are reported to the ERO Enterprise in a timely manner to enhance the analysis of these types of events. *(Q3 2022)*
- **SAR – PRC-004:** SAR to ensure that facility owners with resources operating (based on protection or controls) in an unreliable and unexpected manner identify these events, analyze them, and determine if corrective actions are necessary. *(Q3 2022)*
- **Reliability Guideline – EMT Modeling and Studies:** Industry guidance to prepare for the growing need for EMT studies to fully understand any possible reliability risks of IBRs. *(Q4 2022)*
- **Reliability Guideline – Recommended Approaches to Interconnection Studies for BPS-Connected IBRs:** Industry guidance on considerations during the interconnection study process to help expedite the processing and studies of newly interconnecting IBRs with sufficient due diligence. *(Q4 2022)*
- **SAR – Revisions to FAC-001 and FAC-002:** SAR to ensure that the standards provide sufficient strength such that any performance issues identified by Transmission Operators, Reliability Coordinators, or Balancing Authorities that do not meeting the established interconnection requirements are addressed with corrective actions. *(Q1 2023)*

- **White Paper – Grid Forming Roadmap:** Input and guidance around future grid reliability needs with increasing levels of IBRs and draft specifications for the possibility of needing grid forming technology. *(Q1 2023)*
- **White Paper – Gap Analysis of Any IBR Related Issues Not Addressed by Existing NERC Standards:** Comprehensive gap analysis of all known IBR issues, industry actions in these areas, and possible IRPS actions to address any existing gaps, including the need for more guidance or any possible future NERC standards revisions. *(Q1 2023)*
- **White Paper – BPS-Connected IBR Commissioning Best Practices:** Guidance and recommended practices related to commissioning IBRs, focused on ensuring plant operating modes, settings, controls, and protection are set appropriately and that models and studies were conducted accurately to match installed equipment. *(Q2 2023)*