NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

ERO Enterprise CMEP Practice Guide:

Information to be Considered by CMEP Staff Regarding Inverter-Based Resources
December 1, 2024

Background

In support of successful implementation and compliance with the North American Electric Reliability Corporation (NERC) Reliability Standards, the Electric Reliability Organization (ERO) Enterprise[1] adopted the Compliance Guidance Policy.[2] The Compliance Guidance Policy outlines the purpose, development, use, and maintenance of guidance for implementing Reliability Standards. According to the Compliance Guidance Policy, Compliance Guidance includes two types of guidance – Implementation Guidance and Compliance Monitoring and Enforcement Program (CMEP) Practice Guides.[3]

Purpose

Several events, as well as work done by the industry and the ERO Enterprise through various task forces such as the NERC/WECC task force and NERC Inverter-Based Resource Performance Subcommittee (IRPS), have highlighted the importance of inverter-based resources in supporting grid reliability.[4] The North American bulk power system (BPS) continues to undergo changes with the resource mix, including increasing amounts of installed wind and solar photovoltaic (PV) generation, and battery energy storage systems (BESS) resources. Renewable resources are often asynchronously connected to the grid, meaning they completely or partially interface with the BPS through power electronics (i.e., IBRs). While these resources have significant inherent differences to synchronous generation, substantial guidance is available to industry for reliable planning and operation of the BPS with an increasing number of inverter-based resources.

Industry Recommendations issued through the NERC Alert system have also raised awareness around the risks presented by IBRs. NERC has analyzed 10 large-scale disturbances on the BPS that involved the widespread and unexpected reduction in output of IBR since 2016. These 10 disturbances totaled nearly 15,000 MW of unexpected IBR output reduction with approximately 10,000 MW occurring between 2020 and 2024. The increase of IBR-related events coincides with an increase in IBR penetration across the BPS. Two contributing causes to these events are poor modeling and study practices to assess the performance of these resources. Accurate modeling of IBR facilities is critical in performing system studies to assess the reliable operation of the BPS.

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[1] The ERO Enterprise consists of NERC and the six Regional Entities.
[2] The ERO Enterprise Compliance Guidance Policy is located on the NERC website at: https://www.nerc.com/pa/comp/guidance/Documents/Compliance%20Guidance%20Policy.pdf
[3] **Implementation Guidance** provides a means for registered entities to develop examples or approaches to illustrate how registered entities could comply with a standard that are vetted by industry and endorsed by the ERO Enterprise. **CMEP Practice Guides** differ from Implementation Guidance in that they address how ERO Enterprise CMEP staff executes compliance monitoring and enforcement activities, rather than examples of how to implement the standard.
[4] Inverter-Based Resource Performance Subcommittee (IRPS) (nerc.com)

The purpose of this CMEP Practice Guide is to provide guidance to ERO Enterprise CMEP staff (CMEP staff) with respect to information that may be considered when assessing the planning and operations of a registered entity's IBRs in relation to certain Reliability Standards. In particular, the Practice Guide outlines aspects that may be considered by CMEP staff in understanding how the registered entities have mitigated reliability risk, including risks that may not be addressed in specific Requirements. This risk information can be used to inform CMEP staff's understanding of a registered entity (i.e., Compliance Oversight Plan, audit approach, etc.). Compliance determinations are to be made considering facts and circumstances of the individual registered entities and the language of the requirements.

Protective Functions: PRC-024-3

In PRC-024-3, 4.2 Facilities, it states that frequency, voltage, and volts per hertz protection may be provided by relaying or functions within associated control systems. As such, CMEP staff will review protective functions within control systems, including those within IBRs that respond to voltage or frequency inputs and trip the generator or provide tripping signals.

Several events and resulting work done by the ERO Enterprise and industry have highlighted the concept of momentary cessation during frequency and voltage excursions, including some BPS-connected IBRs that are not involved in the fault and are located away from the event. Use of momentary cessation hinders the ability of IBRs to provide BPS support during these excursions. Momentary cessation involves a "zero current injection" into the point of connection with the grid at the inverter terminals, where injecting current to provide both real and reactive power goes to zero output because the power electronic firing commands are blocked such that the inverter does not produce current.[5]

The use of momentary cessation is comparable with tripping of a generating unit as it results in the output of the generator being instantaneously withdrawn from the BPS. This is effectively seen by the BPS as a trip of the generating unit and it is no longer being connected, as described in the purpose of PRC-024-3. The term tripping, which is not defined in the NERC Glossary, is traditionally done by circuit breakers to instantaneously remove generation resources from the BPS. However, for IBRs this can also be achieved using semiconductor switches, or software-based protective functions within the inverter circuitry to block the output, or 'break' the circuit.

PRC-024-3 contemplates that tripping inside the no-trip zone may occur under several circumstances, including documented and communicated regulatory and equipment limitations. As such, CMEP staff may need to understand the following related to IBRs when reviewing PRC-024-3:

- How has the Generator Owner (GO) set its protective functions at both the plant controller and individual inverter level to remain connected and injecting current needed to provide real and reactive power within the "No Trip" zone defined in PRC-024-3?
    - For discrete frequency and voltage protective relays and protective functions within control systems, review both the entity's low/high voltage ride-through settings (LVRT/HVRT) and the low/high frequency ride-through settings (LFRT/HFRT) to verify whether the settings are outside

[5] This Practice Guide focuses on PRC-024-3. CMEP staff should also consider PRC-025-2 and PRC-026-1, which apply to IBR protection.

of the ride-through curves.

- How has the GO determined the minimum and maximum voltage and frequency excursions it is able to ride-through?
  - Current industry tools and best practices highlight the need for voltage and frequency stability analyses to be able to provide reasonable assurance of real-time system operations. Determine the extent of the entity's dynamic study capabilities.
    - It is best practice for this assurance to be in the form of a detailed study report including model parameters and plots showing the IBR representation riding through the PRC-024-3 event as it occurs at the point of interconnection (POI)
- What equipment limitations exist, if any, which prevent the GO's IBRs from remaining connected and injecting current to provide real and reactive power within the "No Trip" zone defined in PRC-024-3?
  - Staff should be aware if any of the entity's IBRs cease to inject current, either through frequency/voltage protective relay settings or through protective functions within software-based control systems, while the POI is within the "no-trip" zone. In such cases, staff should inquire as to the entity's rationale for what regulatory or equipment limitations are impacting each generating unit in addition to how these limitations were determined and documented.
  - What steps has the registered entity taken to understand and eliminate any equipment limitations?
    - Registered entities should be encouraged to eliminate the use of momentary cessation to the greatest extent possible, and it is preferable for these resources to inject current to provide real and reactive power.[6]
    - If the entity has identified and documented limitations, how are they communicated to their Transmission Planner (TP) and Planning Coordinator (PC)?

CMEP staff should also familiarize themselves with the recommendations within the 2023 NERC Alert which detailed IBR performance issues and understand what actions have been taken by entities to meet these recommendations.

Modeling: MOD-026-1, MOD-027-1, MOD-032-1, and MOD-033-2

Accurate power system modeling capability is important given the highly complex and interconnected nature of the grid. The NERC Reliability Standards related to modeling (the MOD family) collectively lay out the intended process for developing, verifying, and maintaining accurate models. Relating specifically to generating resources, these processes specify: 1) the PC and TP develop and communicate model data specifications; 2) the GO provide the requested data per the data specifications developed by the PC and TP; and 3) the PC, TP, and the GO verify the accuracy of their model data. The Reliability Guideline highlights the need for IBRs to be effectively modeled,[7] especially where solar PV resources are using momentary

[6] https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline_IBR_Interconnection_Requirements_Improvements.pdf
[7] https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline_IBR_Interconnection_Requirements_Improvements.pdf

cessation where they stop injecting current needed to provide real and reactive power. As such, CMEP staff may need to understand the following related to IBRs when reviewing the applicable MOD Standards for PCs, TPs, and GOs:

- What steps have the GOs taken to validate that their model data matches actual system behavior and accurately represents generator responses?
  - How does the GO ensure the physical properties and responses to staged tests or measured system responses are accurately represented in dynamic models?
  - Is GO verification testing consistent with established best practices as outlined in NERC Reliability Guidelines for synchronous machines and IBRs?[8]
  - Does the GO provide plant level trip protection settings such as current, voltage and frequency elements, with vendor specific protective functions for all equipment to the TP/PC for modeling?
  - Has the GO used models recommended by the OEM and approved by the TP/PC?
  - What communication efforts have occurred between GOs and OEMs regarding model changes for current and future IBRs?
- Have GOs with Type 1 and Type 2 wind turbines correctly modeled and performed appropriate verification testing for these types of generating Facilities?
  - For plants with Type 1 and Type 2 wind turbines that have no devices reacting within the dynamic timeframe, evidence could be satisfied with model data from the manufacturer as verification testing would require subjecting the plant to a large disturbance which is not intentionally applied. Provided OEM data should be a spec sheet or type (factory) test, etc. This would constitute evidence to demonstrate that these devices do not need to be modeled dynamically. (NOTE – Entity should have notified TP per MOD-027 regarding the Type 1 and Type 2 wind turbines.)
  - For plants with Type 1 or Type 2 wind turbines that do have reactive support, including plants installed with an SVC or STATCOM as well as plant level controllers that are controlling shunt capacitors:
    - The controllers (in conjunction with the reactive support devices) would need to be modeled dynamically since dynamic simulations run out to 30 seconds in some instances. It is expected that these plant level controllers would operate within this time period.
    - If the controller causes the plant to respond to system events within the dynamic timeframe (15 seconds to 30/60 seconds), then dynamic models must include them to be accurate.
    - MOD-026 includes voltage controllers as part of the modeling requirements and are thus subject to applicable Requirements of each Standard.
    - These plant controllers (in conjunction with the reactive support devices) should already be modeled in steady-state. The entities should also have a dynamic model that includes a

[8] https://www.nerc.com/comm/Pages/Reliability-and-Security-Guidelines.aspx

specification sheet, state diagrams, block diagrams, or other diagrams of the controls, as well as verification from a small disturbance test may also be available.

- What approaches does the PC/TP have for selecting system events to use for their model validation[9]
  - Does the TP/PC review perform a review of plant level trip protection settings such as current, voltage and frequency elements, with vendor specific protective functions modeled?
  - Does the TP/PC include a requirement to reverify that the generator performs as designed after commercial operation begins (e.g., verification of power flow to actual system behavior)?
  - Have the models been updated to account for new interconnection requirements for pro forma Large and Small Generator Interconnection Agreements (LGIA and SGIA, respectively) whereby "all newly interconnecting resources install, maintain, and operate a functioning governor or equivalent controls as a precondition of interconnection"?
  - Do the model data specifications account for the use of momentary cessation? Refer to NERC modeling recommendations and best practices for modeling momentary cessation.[10]
  - Do the model data specifications account for verifying or checking that the large disturbance behavior (i.e., during faults) is reasonably captured by the models supplied?
  - Is PC verification testing consistent with established best practices as outlined in NERC Reliability Guidelines for synchronous machines and IBRs?[11]
  - How are updates communicated with the GOs, and do they provide recommendations on how to correct what has been deemed an "unusable" model?
- What steps did the GO take to ensure its dynamic model data met PC/TP specifications and accurately represented the operation of its IBRs?
  - Does the data supplied by the inverter manufacturer show the specific parameters used for this make and model of the inverter?
  - Does commissioning data show the gains and time constants of the inverter-level and plant- level controls that are site-specific?
  - How does the GO determine the output of the actual inverter matches the output of the models from tests or actual events?
  - What controls do the test engineers have in place to ensure accurate measurements are obtained during testing and commissioning?
  - How do resources operating with momentary cessation meet the dynamic model specifications from the PC/TP?
- How have PCs reviewed and updated their model data specifications to ensure they are collecting the necessary data for accurate representation of IBR characteristics?

[9] NATF MOD-033-1 Methodology Reference Document; March 2017
[10] NERC Modeling Notification: Recommended Practices for Modeling Momentary Cessation Distribution; April 2018.
[11] https://www.nerc.com/comm/Pages/Reliability-and-Security-Guidelines.aspx

- Accurate modeling of the reactive power response of IBRs depends on the control mode in which the plant is operating. How does the PC maintain their models to ensure that the aggregated response of IBRs accurately represents how these resources respond during a fault or system disturbance?
- How are generators that have a functional active power/frequency response capability, yet operate at maximum available power output, modeled such that they do not respond to normal grid events in simulation (i.e., generators that will not respond to under-frequency events but will respond to over-frequency events due to normal operations at maximum output)?

Interconnection Requirements: FAC-001-4

To avoid adverse impacts on the reliability of the BES, Transmission Owners (TOs) and applicable GOs document and make Facility interconnection requirements available so that entities seeking to interconnect will have the necessary information. CMEP staff should review evidence of Facility interconnection activities including how entities ensure accurate models, approve models, provide accurate data, address protection attributes, and maintain cyber security environments. The Facility interconnection process requires significant internal controls to be effective. The Facility interconnection requirements documentation is required per Reliability Standards and will have a significant role in ensuring reliable operations. CMEP staff should review how the Facility interconnection requirement documentation is developed, implemented, and updated. Adherence to the Facility interconnection requirements should be mandated and treated as a necessary milestone before synchronization. Model response and data submittals should be included as checkpoints after synchronization.

CMEP staff may need to consider, but are not limited to considering, the following:

- Documented Facility interconnection requirements
  - How does the TO ensure minimum static and dynamic reactive power requirements are met by its interconnection requirements?
  - What model submission requirements are in place and are they publicly posted?
  - What model quality requirements are in place and are they publicly posted? If they are not publicly posted, are they available upon request?
  - What processes does the TO have to verify model quality?
  - What process is in place for establishing and updating Facility interconnection requirements?
  - What is the level of validation within the approval process that ensures recommendations derived from event reports, NERC Alerts, and Reliability Guidelines are reflected in the Facility interconnection requirements?
  - What is the overall process to interconnect, from project conception to commissioning to post commercial operation date (COD)?
  - What is the process to manage Facility interconnection requests?

    - Does the entity have an internal control to train its internal staff on the entity's Facility interconnection process? What training is provided to internal staff? What training/orientation/support is provided to an entity seeking to interconnect?
    - If interconnection requirements are not met, what is the resolution process?
    - Is momentary cessation addressed in the Facility interconnection requirements?
    - When the definition of qualified change is updated, what impacts to the Facility interconnection requirements are considered? What impact to recent Facility interconnection requests occurs if the definition of qualified change occurs?
    - What power quality requirements are in the Facility Interconnection requirements?
    - Are there requirements to hold entities responsible for updating any parameters (e.g., control settings in an inverter) that are causes for events?
    - Does the TO incorporate post-commission review responsibilities and requirements specifically geared towards designed-vs-built IBR capabilities, relay setting, models, and other attributes necessary for reliable operations?
    - Does the TO require Electromagnetic Transient (EMT) Models to verify the resource capabilities and performance during disturbance Ride-through?
    - Does the TO allow the submission of equipment-specific models (i.e., user-defined; user-written) and if not, what is their justification?
    - Does the TO include a requirement to reverify that the generator meets all interconnection and reliability standards after entering commercial operation?
    - Are there requirements for staff of all parties to read, understand, and implement recommendations from event reports?
    - For a BESS, are the states and expected durations of the states (e.g., discharge and charging capabilities) of the BESS reflected in the Facility interconnection requirements for use in studies?
    - Describe your cybersecurity program as it relates to new Facility interconnections.
    - How does the Facility interconnection requirements describe expectations related to managing off premise/vendor/out of country monitoring and control of Facilities?
- Updating Facility interconnection requirements
    - Are there periodic reviews of Facility interconnection requirements?
    - What triggers are in place (e.g., significant system events (internally or externally), lessons learned, best practices publications, NERC Alerts, Reliability Guidelines, etc.) that require a review to determine updates to the Interconnection requirements?
    - How far back in the Facility interconnection queue does the entity go (e.g., is there a risk assessment that dictates what actions are needed) if an event indicates a recommendation needs to be included in Facility interconnection requirements?

  - If updated interconnection requirements are not met, what is the resolution process?
  - What operational limitations/restrictions/obligations are included in the Facility interconnection requirements if an entity fails to update parameters shown to be a cause in an event (e.g., not allowed to generate)?
  - Who is responsible for validating model data – before and after commissioning/COD?
- Making Facility interconnection requirements available
  - Does the TO entity have an internal control to train its staff on the interconnection of IBRs and potentially the unique risks they may bring?
  - What processes are in place to ensure interconnection requirements are available?
  - Does the entity have an approval process that ensures the integrity of the interconnection requirements (i.e., the "master" file is approved and available)?
  - Does the entity have a notification process that alerts entities seeking to interconnect changes to the Facility interconnection requirements?
  - How does the TO maintain an updated contact list of entities that are requesting an interconnection or already are interconnected?

Interconnection Studies and Transmission Planning: FAC-002-4 and TPL-001-5.1

Accurate models are the foundation needed for the PC and TP to evaluate system performance. Insufficient interconnection and planning assessments can lead to increased risks to reliability, especially as the resource mix continues to change and IBRs become more prevalent. To address this risk, PCs and TPs should conduct various system studies using likely system conditions that reflect the integration of IBRs. Applicable GOs, TOs, and Distribution Providers must coordinate and collaborate with their PC and TPs for new Facilities and for qualified changes to their Facilities to assure adequate studies of reliability impacts of new interconnections and changes to existing interconnections. CMEP staff may need to understand the following related to IBRs for PCs and TPs when reviewing compliance with Standards related to performing system studies for PCs, TPs:

- How does each PC and TP study the reliability impacts of interconnecting new Facilities?
- How does each PC and TP ensure the accuracy of the models submitted?
  - Which processes are in place to ensure all control functions that can affect the performance of the IBR are sufficiently modeled?
  - Which processes are in place to verify that the parameters used in the model can be accurately implemented at the actual site?
  - Which processes are in place to ensure that any modifications to parameters made through the study process are communicated with the GO and implemented in the field?
  - What processes are in place for the PC/TP to coordinate with a TO in cases where the TO interconnecting to the GO/DP is a different entity than the PC/TP?

- What expectations are provided by the TP/PC for entities where ownership of assets being interconnected are different (from the TP/PC or differences within equipment ownership used to interconnect)?
- What expectations are provided for ownership changes (during the interconnect process or after the process has been completed)?

- What processes are in place to ensure adherence to applicable NERC Reliability Standards, regional and TO planning criteria, and Facility interconnection requirements?
- What communication protocols are in place between the TO and the entity seeking to interconnect if issues are seen in the reliability impact study? How are issues resolved?
  - Regarding the steady state, short-circuit, and dynamic studies used to evaluate system performance during normal and contingency conditions, how does the PC and TP ensure that:
    - IBRs are accurately and sufficiently modeled in steady-state power flow base cases, and that limits and collector system equivalent impedances are within reasonable tolerances? Are standard library models or equipment-specific models used?
    - IBRs are accurately and sufficiently modeled with dynamics data, and that those models coordinate with the power flow data?
    - IBRs are accurately and sufficiently modeled with short-circuit data, and that correct assumptions on inverter performance during faults are included?
    - Any use of momentary cessation is correctly represented in the short-circuit data submitted by the GO?
  - As the industry continues to expand its modeling and study capabilities, some TPs and PCs have established adopted model requirements for newly interconnecting IBRs: If so, CMEP staff may consider the following questions.
    - Are PC/TPs requesting models as part of the interconnection study process?
    - If yes, do the modeling requirements establish a model documentation and verification process?
    - What verification is performed between the model and proposed generation to ensure that plant controller, inverters, generator step-up transformer (GSU), main power transformers, collector buses, and generators are modeled accurately.
    - What processes are used to verify software and hardware performance?
    - Does the TP/PC/GO/TO/DP have processes to determine if proposed equipment was a cause factor in any past BES performance events?
- Did the PC/TP include scenarios or cases that would evaluate the impact of IBRs when performing its annual planning assessment?

- Who is responsible for validating model data before and after commissioning/COD to ensure the transmission studies were performed with correct data? What coordination occurs or is expected to occur in terms of validation efforts for modeling data?
- Is there an approved list of models? What does the approval process look like?
  - Are equipment specific models included in the approved model list? If not, what evidence is there to show that models on the approved list are sufficiently accurate when compared to the equipment specific models?
- What controls are in place to ensure the model is accurate and reflects the known conditions?
- What notification process regarding cooperation efforts (e.g., not receiving appropriate cooperation or model data updates), including escalation efforts, is implemented and who has the responsibility to ensure notification occurs (i.e., notification for reliability responsibility, approvals, rejections, and changes for internal and external parties)?
- What notification process regarding cooperation efforts (e.g., not receiving appropriate cooperation or model data updates), including escalation efforts, is implemented and who has the responsibility to ensure notification occurs (i.e., notification for reliability responsibility/approvals/rejections/changes for internal and external parties)?
- Planning assessments include the study of a loss of a single or multiple facilities during peak and off-peak hours for near and long-term planning horizons. The 2016 Long Term Reliability Assessment (LTRA) highlighted how additional installations of solar PV resources actually began shifting traditional peak load hours into later in the evening, thereby potentially changing established system characteristics and assessment criteria.[12] The planning assessments also include performing studies on sensitivity cases, and the PC/TP may include cases with modified dispatch scenarios within the assessment (other options are varying planning models based on credible conditions – e.g., reactive capability, active and reactive load forecast alterations).
- How do the collaborating entities consider studying stressed system conditions during off-peak hours[13] while variable resource outputs are high to better understand system inertia and frequency responsiveness of operational reserves?
- Does the collaborating entity (GO/TO/DP) have the PC's criteria for qualified changes requiring coordination when addressing interconnection of Facilities?
- How does collaborating entity (GO/TO/DP) know it has satisfied TP/PC's needs for information?
- Are obligations/expectation clear to ensure complete coordination, cooperation, and support the TP/PC's obligations to study reliability impacts?
- What controls does GO/TO/DP have in place to assure it has satisfied all TP/PC obligations? Are there checklists for each project? Is feedback provided from or to the TP/PC?

[12] NERC 2016 Long-Term Reliability Assessment; December 2016
[13] Note that off-peak hours can be seasonal low load periods where there are less resources and minimum reserves on-line.

Coordination of Voltage Regulating Controls and Protection Settings: PRC-019-2

GOs and TOs with applicable synchronous condensers must verify coordination of voltage regulating controls, limit functions, equipment capabilities, and Protection System settings. CMEP staff should understand how an entity is coordinating voltage regulating controls, equipment capabilities, and trip settings at both the individual inverters and at the plant's point of interconnection.[14]

- How do the GO and applicable TO coordinate voltage regulating controls with the applicable equipment capabilities and settings of the applicable Protection System devices and functions? This includes in-service limiters and protection functions.
  - What does the entity consider that could trip the individual inverters? How are those trip settings coordinated with the individual inverter capability and limiters?
  - If the generation is a current-limited device, then how are the current limits coordinated with protection (for each type of protection) to maintain power production and voltage control (via reactive power production)?
  - What limiters and protection exist at the power plant level (e.g., at the plant controller or POI), and how are those settings coordinated to prevent individual inverters from tripping unnecessarily?
  - How does the entity ensure that its individual turbine-level controls are functioning properly and coordinated with its plant level controller (e.g., configured with appropriate dead bands and frequency droop), during steady-state conditions and Ride-through (dynamic based) operations?
  - How has the GO implemented recommendations from the NERC Alert related to IBR performance issues (e.g., momentary cessation mitigation, inverter settings, model deficiencies)?[15]

[14] https://www.nerc.com/comm/Pages/Reliability-and-Security-Guidelines.aspx
[15] https://www.nerc.com/pa/rrm/bpsa/Pages/Alerts.aspx

Revision History

Revision #	Revision Date	Revision Details
V1.1	3/12/2019	Page 4: Changed text in second main bullet to read "MOD-033-1 R1"
		Page 5: Changed text in first main bullet to read "MOD-032-1 R1"
		Page 5: Changed example text to read "(e.g., generators that will not respond to under- frequency events but will respond to over- frequency events…)"
V1.2	06/01/2020	Page 4: Added section on type 1 and type 2 wind turbines.
V2	2024	Major revisions