

ERO Enterprise CMEP Practice Guide:

Information to be Considered by CMEP Staff Regarding Inverter-Based Resources

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Background

In support of successful implementation and compliance with the North American Electric Reliability Corporation (NERC) Reliability Standards, the Electric Reliability Organization (ERO) Enterprise¹ 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 recent 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 Task Force (IRPTF), 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. Renewable resources are often asynchronously connected to the grid, meaning they completely or partially interface with the BPS through power electronics (i.e., “inverter-based resources”). While these resources have inherent differences to synchronous generation, substantial guidance is available to industry for reliable planning and operation of the BPS with an increasing amount of inverter-based resources.

The purpose of this CMEP Practice Guide is to provide guidance to ERO Enterprise CMEP staff (CMEP staff) with respect to information that should be considered when assessing the planning and operations of a registered entity’s inverter-based resources in relation to certain Reliability Standards. In particular, the Practice Guide outlines aspects that should 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

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:

http://www.nerc.com/pa/comp/Resources/ResourcesDL/Compliance_Guidance_Policy_FINAL_Board_Accepted_Nov_5_2015.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 [Industry Recommendation: Loss of Solar Resources during Transmission Disturbances due to Inverter Settings; June 2017; Industry Recommendation: Loss of Solar Resources during Transmission Disturbances due to Inverter Settings - II; May 2018; NERC Modeling Improvements Initiative Update; May 2018; Reliability Guideline: BPS-Connected Inverter-Based Resource Performance; September 2018.](#)

in light of facts and circumstances of the individual registered entities and the language of the requirements.

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Protective Functions: PRC-024-2

In PRC-024-2, footnote 1 states that voltage and frequency protective relaying includes, but is not limited to, frequency and voltage protective functions for discrete relays, volts per hertz relays evaluated at nominal frequency, multi-function protective devices, or protective functions within control systems that directly trip or provide tripping signals to the generator based on frequency or voltage inputs. As such, CMEP staff will review protective functions within control systems, including those within inverter-based resources that respond to voltage or frequency inputs and trip the generator or provide tripping signals.

The NERC IRPTF Reliability Guideline stresses the importance of inverter-based resources operating in a manner that supports BPS reliability, including maintaining current injection (maintaining real power production and providing reactive power for voltage control) within the “No Trip” zone as defined by PRC-024-2 Attachments 1 & 2.⁵ Recent events and work done by the ERO Enterprise and industry have highlighted the concept of momentary cessation during frequency and voltage excursions, which some BPS-connected inverter-based resources that are not involved in the fault and are located away from the event are exhibiting. Use of momentary cessation hinders the ability of inverter-based resources to provide BPS support during these excursions. Momentary cessation, as explained in the IRPTF Reliability Guideline, 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.⁶

The use of momentary cessation is considered tripping of a generating unit as it results in the output of the generator being instantaneously withdrawn from the BPS, effectively seen by the BPS as a trip of the generating unit and it’s no longer being connected, as described in the purpose of PRC-024-2. 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 inverter-based resources this can also be achieved using semiconductor switches within the inverter circuitry to block the output, or ‘break’ the circuit.

PRC-024-2 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 should understand the following related to inverter-based resources when reviewing PRC-024-2:⁷

⁵ [Reliability Guideline: BPS-Connected Inverter-Based Resource Performance; September 2018.](#)

⁶ Id.

⁷ This Practice Guide focuses on PRC-024-2. CMEP staff should also consider PRC-025-1 and PRC-026-1, which apply to inverter-based resource protection.

- 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 to provide real and reactive power within the “No Trip” zone defined in PRC-024-2? (PRC-024-2 R1, R2)
 - 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 of the ride-through curves.
- How has the GO determined the minimum and maximum voltage and frequency excursions it is able to ride-through? (PRC-024-2 R1, R2)
 - 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.
- What equipment limitations exist, if any, which prevent the GO’s inverter-based resources from remaining connected and injecting current to provide real and reactive power within the “No Trip” zone defined in PRC-024-2? (PRC-024-2 R3)
 - If any of the entity’s inverter-based resources cease to inject current to provide real and reactive power, either through frequency/voltage protective relay settings or through protective functions within control systems, within the “No Trip” zone, then 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.⁸
 - If the entity has identified and documented limitations, how are they communicated to their TP and PC?

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

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 Planning Coordinators (PC) and Transmission Planners (TP) develop and communicate model data specifications; 2) the Generator Owners (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 IRPTF Reliability Guideline highlights the need for inverter-based resources to be effectively modeled,⁹ especially where solar PV resources are using momentary

⁸ [Reliability Guideline: BPS-Connected Inverter-Based Resource Performance; September 2018 - pp. 1-3.](#)

⁹ [Reliability Guideline: Power Plant Model Verification for Inverter-Based Resources; September 2018.](#)

cessation where they stop injecting current to provide real and reactive power. As such, CMEP staff should understand the following related to inverter-based resources 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? (MOD-026-1 R2, MOD-027-1 R2)
 - 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 inverter-based resources?¹⁰
- Have GOs with Type 1 and Type 2 wind turbines correctly modeled and performed appropriate verification testing for these types of generating Facilities? (MOD-026-1 R2, MOD-027 R2)
 - For plants with type 1 and 2 wind turbines with 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.
 - For plants with type 1 or 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 and 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 and MOD-027 include voltage controllers as part of the modeling requirements and are thus subject to applicable requirements of each Standard.
 - These plant controllers with reactive support should already be modeled in steady-state, and the entities should have a dynamic model that includes a spec sheet or pictures or diagrams of the controls, as well as verification from a small disturbance test.
- What approaches does the PC/TP have for selecting system events to use for their model validation (MOD-033-1 R1)?¹¹
 - Have the models been updated to account for new interconnection requirements for pro forma Large and Small Generator Interconnection Agreements (LGIA and SGIA, respectively)

¹⁰ [Reliability Guideline: Power Plant Model Verification and Testing for Synchronous Machines; July 2018; Reliability Guideline: Power Plant Model Verification for Inverter-Based Resources; September 2018.](#)

¹¹ [NATF MOD-033-1 Methodology Reference Document; March 2017.](#)

- 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.¹²
 - 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 inverter-based resources?¹³
 - How are updates communicated with the GOs?
- What steps did the GO take to ensure its dynamic model data met PC/TP specifications and accurately represented the operation of its inverter-based resources? (MOD-032-1 R2)
 - 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?
 - Understand how 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 inverter-based resource characteristics? (MOD-032-1 R1)
 - Accurate modeling of the reactive power response of inverter-based resources 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 inverter-based resources 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 (e.g., generators that will not respond to under-frequency events but will respond to over-frequency events due to normal operations at maximum output)?

¹² [NERC Modeling Notification: Recommended Practices for Modeling Momentary Cessation Distribution; April 2018.](#)

¹³ [Reliability Guideline: Power Plant Model Verification and Testing for Synchronous Machines; July 2018; Reliability Guideline: Power Plant Model Verification for Inverter-Based Resources; September 2018.](#)

Interconnection Requirements: FAC-001-2

To avoid adverse impacts on the reliability of the Bulk Electric System, Transmission Owners and applicable Generator Owners document and make Facility interconnection requirements available so that entities seeking to interconnect will have the necessary information. CMEP staff should understand TO processes for reviewing current system needs, potential adverse impacts, and how interconnection requirements are impacted. (FAC-001-2 R1)

- How does the TO ensure minimum static and dynamic reactive power requirements are met by its interconnection requirements?
 - How does the TO periodically review its requirements to incorporate internal lessons learned and best practices as highlighted by the IRPTF, Reliability Guidelines, NERC Alerts, etc.?
 - Specifically for inverter-based resources, has the TO considered designed-vs-built inverter-based resource capabilities, voltage/frequency ride-through settings, and use of momentary cessation?

Interconnection Studies and Transmission Planning: FAC-002-2 and TPL-001-4

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 inverter-based resources become more prevalent. To address this risk, PCs and TPs should conduct various system studies using likely system conditions that reflect the integration of inverter-based resources. Likewise, CMEP staff should understand the following related to inverter-based resources when reviewing compliance with Standards related to performing system studies for PCs and TPs:

- How does each PC and TP study the reliability impacts of interconnecting new generation facilities? (FAC-002-2 R1)
 - Consider 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:
 - Inverter-based resources are accurately and sufficiently modeled in steady-state power flow base cases, and that limits and collector system equivalent impedances are within reasonable tolerances?
 - Inverter-based resources are accurately and sufficiently modeled with dynamics data, and that those models coordinate with the power flow data?
 - Inverter-based resources 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?
- Did the PC/TP include scenarios or cases that would evaluate the impact of inverter-based resources when performing its annual planning assessment? (TPL-001-4 R2)

- 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 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.¹⁴ 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).
- Does the entity consider studying stressed system conditions during off-peak hours¹⁵ while variable resource outputs are high to better understand system inertia and frequency responsiveness of operational reserves?

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

Generator Owners and Transmission Owners of generating unit Facilities or synchronous condensers must verify coordination of voltage regulating controls, limit functions, equipment capabilities, and Protection System settings. CMEP staff should understand of how an entity is coordinating regulating controls, equipment capabilities, and trip settings at both the individual inverters and at the plant's point of interconnection.¹⁶

- How do the GO and 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. (PRC-019-2 R1)
 - 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), both during steady-state conditions and during ride-through operations?
 - How has the GO implemented recommendations from the NERC Alert related to momentary cessation mitigation?¹⁷

¹⁴ [NERC 2016 Long-Term Reliability Assessment; December 2016.](#)

¹⁵ Note that off-peak hours can be seasonal low load periods where there are less resources and minimum reserves on-line.

¹⁶ [Reliability Guideline: BPS-Connected Inverter-Based Resource Performance; September 2018 - pp. 52-55.](#)

¹⁷ [NERC Alert: Loss of Solar Resources during Transmission Disturbances due to Inverter Settings – II; May 1, 2018](#) – See Recommendation 2.

Revision #	Revision Date	Revision Details
V1.1	3/12/19	Page 4: Changed text in 2nd main bullet to read "MOD-033-1 R1"
		Page 5: Changed text in 1st 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	06/01/20	Page 4: Added section on type 1 and type 2 wind turbines.