NATF Inverter-Based Resources Performance Monitoring and Operating Practices

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Approval

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Review: every 5 years
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Contents

1. Purpose

Inverter-Based Resources (IBR) present unique challenges for transmission system operators in the Real-time operation of the Bulk Electric System (BES) due to their fast and complex dynamic behavior, limited inertia contribution, and sensitivity to grid disturbances. These characteristics require enhanced monitoring, data visibility, and coordination to ensure reliable system performance under rapidly changing conditions.

The purpose of this document is to provide guidance for system operators on the reliable operation of the BES with IBR directly connected to the transmission system. It establishes practices for monitoring and controlling IBR in real time, leveraging IBR data to understand resource behavior, and supporting event analysis and planning activities. The document also outlines effective communication protocols with IBR personnel to ensure coordinated and reliable system operations.

This document does not create, replace, or change any requirements in the NERC Reliability Standards or other applicable criteria, nor does it create binding norms by which compliance with NERC Reliability Standards is monitored or enforced. Implementation of NATF practices does not ensure compliance with the NERC Reliability Standards. In addition, this document is not intended to take precedence over any company or regional procedure. It is recognized that individual companies may use alternative and/or more specific approaches that they deem more appropriate.

2. Scope

This document applies to transmission system operators engaged in Real-time operations of the BES with IBR connected at the transmission level and focuses on the parallel operation with the Bulk Power System (BPS) of the IBR interconnection lifecycle (Figure 1). It provides guidance on how operators can monitor and control these resources in Real-time, ensuring that their unique operating characteristics are fully integrated into reliable system operations. It also describes how Real-time IBR data can be obtained, interpreted, and applied to strengthen situational awareness, support operational decision-making, and contribute to effective event analysis and planning. In addition, the document emphasizes the importance of clear and consistent communication with IBR personnel, outlining practices that foster coordination and shared understanding.

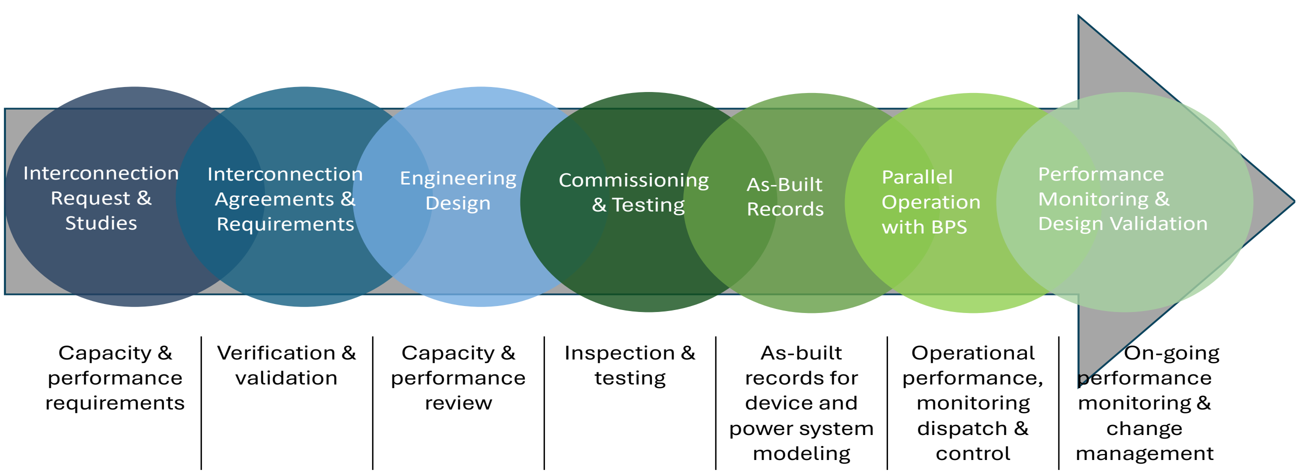

Figure 1. IBR Interconnection Lifecycle

3. Definitions

NATF Practice

A documented method for performing a process, under the same or similar circumstances, in a safe, effective manner where the requisite skills, diligence, prudence, and foresight are those that are reasonably expected from skilled and experienced industry organizations.

NATF Superior Practice

A leading industry practice that can be consistently applied under a range of circumstances and that is a safe, effective, and efficient process or activity for achieving near-optimal industry results in terms of quality, reliability, and maintainability.

Battery Energy Storage System (BESS)

Technology that uses one or more batteries to store and distribute electricity.

Bulk Power System Connected Inverter-Based Resource (BPS-IBR)

An IBR connected directly to the Bulk Power System: wind, solar PV, battery energy storage systems, hybrid power plants, high voltage direct current networks, flexible ac transmission system devices, etc. [1].

Distributed Energy Resource (DER)

Any resource on the distribution system that produces electricity and is not otherwise included in the formal NERC definition of the BES [2].

Grid Services

The various services that DERs may provide to facilitate the reliable operation and planning of the bulk power system.

IBR-DER

An inverter-based resource connected to the distribution system [3].

IBR Personnel

Individuals who work at an IBR facility in any role. This includes anyone involved in operating, maintaining, supporting, or managing the facility regardless of their specific job title.

Point of Interconnection (POI)

The point where the interconnection system connects an IBR to the transmission system [4].

Power Plant Controller (PPC)

Advanced system designed to manage and optimize the performance of power plants, particularly those utilizing renewable energy sources.

Utility-Scale Distributed Energy Resources (utility-scale IBR-DER)

DER directly connected to the distribution bus or connected to the distribution bus through a dedicated, non-load serving feeder. These resources are specifically three-phase interconnections, and can range in capacity, for example, from 0.5 to 20 MW although facility ratings can differ [5].

4. Using Data Obtained from IBR

A broad range of data is available from both BPS-IBR and utility-scale IBR-DER facilities. There is data about each facility that is very useful to transmission operators for placing the IBR in proper context in the electrical network. Data from the IBR is also useful for understanding Real-time plant capability, behavior, and in some cases enabling control. Regardless of who owns the IBR or whether it is connected to the transmission or distribution system, data from the IBR is necessary for system operators to reliably operate the system. Both BPS-IBR and utility-scale IBR-DER should generate similar data. Appendix 1 is a table that categorizes, describes, and provides examples for different types of IBR data. The subsequent practices describe each data category or use case.

Plant Data

NATF Practices

4.1 System operations incorporate IBR facility data into systems and situational awareness displays.

- Geographic information system (GIS)
- Single line diagrams of the transmission network
- Capability and limitation information
- Operations procedures for the IBR facilities or procedures that may impact the IBR facilities
- Contact lists for each IBR facility, including facility name and any aliases

> Original facility owner names often remain in procedures, EMS, and facility diagrams due to the volume of name references that would need to be revised when facility ownership changes (e.g., models/diagrams, protection and control, wiring labels, etc.).

4.2 EMS displays can be easily navigated by system operators to obtain IBR facility data that describes the IBR facility's owner, location, nameplate information, etc. See the *NATF EMS Modeling of Inverter-Based Resources Practices* [6] for further detail.

4.3 GIS displays allow system operators to identify the location of the IBR facility and connections to the transmission network consistent with displays for all other generating facilities.

Control Data

NATF Practices

4.4 EMS displays are designed to allow system operators to easily distinguish between IBR facilities that are dispatchable and those that are not dispatchable.

4.5 EMS displays provide system operators with the ability to easily distinguish between IBR facilities that are owned by the utility and those that are owned by independent power producers.

4.6 EMS displays are designed to provide system operators the ability to easily locate concise information about a dispatchable IBR facility's current operational status, IBR facility capabilities, and operating limits to aid in Real-time control decisions.

4.7 EMS IBR facility displays are uniform in presenting control data for system operators and are consistent in the way the system operators interact with that data (e.g., inputting control set points).

4.8 System operators are provided with the ability to view and/or control the charge/discharge schedule of battery energy storage system (BESS) IBR facilities. At a minimum, system operators have the ability to override BESS schedules to address Real-time reliability concerns.

4.9 Plant display alarms alert the system operators to abnormal operating conditions (e.g., facility offline, facility voltage excursion, etc.).

4.10 Link each IBR facility to the nearest Transmission Owner (TO)/Transmission Operator (TOP) owned interconnecting substation in EMS displays. For example, a system operator can easily navigate between an IBR facility display and the display that depicts the substation the IBR facility is most nearly connected to and vice versa.

4.11 EMS displays provide reliable contact information for both the IBR facility owner and the IBR facility operator.

4.12 Data from oscillation dampeners is presented to system operators in the form of alerts.

> IBR facility controllers and/or inverters are inherently likely to generate oscillations in the BES. Wide area or local oscillation dampeners are installed to detect oscillations and actuate counter control actions to reduce the intensity and impact of oscillations generated from IBR facilities.

Performance Data

NATF Practices

4.13 Develop a process to regularly evaluate IBR facility performance against defined metrics and priorities. Operation priorities could include capacity, energy yield, voltage support, frequency support, and regulation.

4.14 Develop a process to evaluate and trend actual IBR facility performance against contractual and market commitments.

4.15 Develop a process to use performance data and metrics to create meaningful performance-related alerts and/or alarms that inform system operators to abnormal IBR facility operations and provide the appropriate actions to take (e.g., the IBR plant is performing at a capacity that is lower than expected, etc.).

4.16 Develop a process to regularly evaluate and track IBR performance for IBR facilities connected to the transmission system to identify trends and how the performance relates to system events and overall grid activity.

4.17 Develop a process to regularly interface with IBR facility owners to review and discuss IBR facility performance.

Contract Data

NATF Practices

4.18 Develop a process to evaluate whether contractual data is being sent and received for operating within defined voltage schedules, providing voltage and frequency support, following power limits, and any other essential or secondary services according to interconnection agreement requirements as identified in the *NATF Inverter-Based Resource Interconnection Lifecycle: Interconnection Agreements and Requirements Practices* document [7]. The contract data collected includes:

- data that characterizes the capability of the IBR facility (e.g., d-curve, high speed cutout, operating temperature range, etc.);
- data or information about contractual or warranty restrictions to IBR facility operations (e.g., BESS cycle limitations or average state of charge).

4.19 EMS displays include contractual information that make system operators aware of any contractual restrictions that may affect the Real-time dispatch of facilities.

Standard Study Data

Standard study data includes any data required from the IBR facility to conduct outage studies, next-day studies (NDS), and long-range studies. IBR facilities that do not have telemetry will be obscured in studies as they serve to offset load. IBR facilities that do have telemetry are treated as generation or load. Wind and solar are strictly generation while BESS IBR facilities can be either a generation or a load.

NATF Practices

4.20 As much as possible, independently study IBR facilities that operate as load due to charging, IBR facilities that are being used for charging, and IBR facilities that are solely supplying energy, to aid in the accurate execution of Real-time studies and NDS.

4.21 Collect sufficient IBR modeling and Real-time data to enable accurate Real-time studies (RTS) that include an overlay of all generation and load.

4.22 Conduct NDS with conservative seasonal values for each IBR facility to ensure both low and peak demand cases are examined. Table 1: Seasonal NDS matrix is an example of a seasonal NDS matrix that identifies IBR output when low and high demand is expected for each season. Fall and spring weather can fluctuate dramatically, and IBR response can shift between the peak seasonal values.

Table 1: Seasonal NDS matrix

Solar Generation	Summer	Fall/Spring (Transitional)	Winter
Low BES Demand	6/7 am and solar gen is near minimum output	⟷	2 pm and solar gen is near max output
High BES Demand	6pm and solar gen is near min output	⟷	6/7 am and solar gen is near minimum output
Wind Generation	**Summer**	**Fall/Spring (Transitional)**	**Winter**
Low BES Demand	6/7 am and wind gen is dependent on wind forecast	⟷	2 pm and wind gen is dependent on wind forecast
High BES Demand	6pm and wind gen is dependent on wind forecast	⟷	6/7 am and wind gen is dependent on wind forecast
Battery Charge/Discharge	**Summer**	**Fall/Spring (Transitional)**	**Winter**
Low BES Demand	6/7 am and battery would be charging to increase load	⟷	2pm and battery would be charging to increase load
High BES Demand	6pm and battery is discharging	⟷	6/7 am and battery is discharging

4.23 Use NDS power flow and contingency studies that include hourly forecasted generation and load data. Results of the NDS indicate whether any system operating limits are exceeded in any hour.

4.24 Availability-adjusted forecasts that incorporate the current Real-time online IBR to the total available IBR are used to inform the NDS.

Exceptional Study Data

Exceptional studies are IBR grid event response studies that use detailed modeling tools other than EMS or state estimation, such as dynamic models in dynamic power flow analysis. Refer to the *NATF EMS Modeling of Inverter Based Resources* [6] and *NATF Inverter-Based Resources Interconnection Lifecycle: Interconnection Requests and Studies Practices* [8] documents for additional information to understand practices related to collecting data for exceptional studies.

NATF Practices

4.25 As-built IBR dynamic models are used to compare actual IBR performance to the interconnection studies.

4.26 Inverter settings are regularly scanned and evaluated to ensure they are within the applicable interconnection study's parameters.

4.27 Processes are in place to collect and maintain high resolution data from digital fault recorders (DFR), phasor measurement units (PMU), and inverters to accurately perform exceptional studies.

4.28 There are procedures to compare actual IBR facility performance during a grid disturbance against the expected modeled behavior using the IBR facility's dynamic model, similar to how testing is conducted for any BES generator in accordance with NERC MOD standards [9].

4.29 Support staff are trained on the procedures and modeling tools to evaluate actual IBR plant performance against the expected modeled behavior.

4.30 Exceptional study findings are reported on and shared with the plant owner. A corrective action plan is created to address any deficiencies that are discovered in IBR facility's performance.

4.31 Maintain the IBR dynamic models and implement a change management process to ensure any updates to the IBR power plant controller (PPC) program/code, inverter parameters, or inverter firmware that may affect the IBR dynamic models are captured.

4.32 Wide area oscillation monitoring of IBR output, typically performed with PMUs, is used to notify the responsible IBR operators to address high and low-level BES impact oscillations before the oscillations grow in intensity.

> Time constants for sending commands from PPCs to inverters may need to be investigated for possible interaction with Inter-area oscillation modes. For example, if the time constant for sending commands to inverters is 4 seconds and oscillations occur at that time constant (equal to 0.25Hz), that time constant should be changed to proactively mitigate IBR oscillations from aggravating inter-area oscillation modes.

5. Monitoring and Control of IBR

Proper monitoring and control of IBR is critical since these facilities interact with the grid in fundamentally different ways than traditional synchronous generators. Without accurate, Real-time visibility into IBR performance and the ability to adjust their output or settings, system operators may face challenges maintaining frequency stability, voltage control, and system reliability, especially during disturbances. Effective oversight ensures that IBR operate within agreed upon parameters and respond predictably to dynamic conditions.

IBR Operation

NATF Practices

5.1 Processes and procedures are in place to assist system operators in the operation of IBR, such as:

- Manual control of IBR import/export to maintain reserve capacity for congestion and reliability and address system constraints.
- Adjust IBR voltage schedules as needed for grid reliability.
- Notification and guidance on actions to take when IBR facilities are operating outside of contractual parameters.
- Notification of proper entities when IBR do not remain online or exhibit unexpected changes in import/export during voltage/frequency excursions or transient faults.

5.2 Tools, such as symbols and displays, are used to help system operators differentiate between IBR type (i.e., wind, solar, battery), capability (i.e., charge or discharge), and characteristics (i.e., grid-following versus grid-forming).

5.3 Procedures are in place that guide operators on how to provide grid-following IBR with a voltage and frequency reference to follow. This is important when bringing grid-following IBR online and to ensure grid-following IBR remains online when needed (i.e., high demand, emergency scenarios, etc.).

5.4 Procedures are in place that guide system operators on how to use grid-forming IBR as the primary source to regulate voltage/frequency or as a source during blackstart restoration.

5.5 Training is provided to system operators on IBR processes and procedures to ensure adequate understanding of the capabilities, characteristics, and elements they can and cannot control.

5.6 System operators are trained on the alarms and expected response for IBR anti-islanding detection and protection schemes, such as direct transfer trip (DTT), for larger IBR sites.

5.7 There are operational curtailments, such as Remedial Action Schemes (RAS), that are based on pre-defined scenarios to minimize operator intervention.

5.8 Processes and tools are readily available to identify stability issues, such as frequency and voltage oscillations, that can occur in high IBR penetration situations.

5.9 There is a process to identify dispatchable IBR units to support grid services, curtailment, and/or black start, including:

- voltage regulation,
- frequency regulation and balancing,
- inclusion in blackstart plan to provide voltage control/frequency response during restoration,
- and confirmation of site status during blackstart restoration.

Battery Storage IBR

NATF Practices

5.10 Processes and tools are in place to easily identify BESS charge and discharge curves/schedules to make operational decisions based upon availability.

5.11 Situational awareness tools, such as displays and alarms, are in place to inform system operators of BESS export/input behavior when approaching a zero/full state of charge.

5.12 Procedures are in place that provide system operators with operational authority to direct a state change of a BESS facility for reliability reasons (e.g., a voltage emergency requires the BESS to change state from discharge to static, or charge mode of operation).

5.13 Processes and tools in place that identify how much energy is available from each BESS facility at set output levels to aid in capacity emergencies and outages.

Event Analysis

NATF Practices

5.14 IBR-related event identification and reporting processes are in place that include the types of reportable events, reporting responsibilities, reporting timelines, and the entities that receive notification.

5.15 Standard templates are in place for system operators to collect the required information for each reportable IBR event that compares actual performance to contractual performance that includes:

- real and reactive power output,
- frequency and voltage ride-thru performance,
- voltage schedule adherence,
- and auxiliary equipment behavior.

5.16 Oscillation events are studied to develop IBR damping control strategies where needed. Engage planning group to study potential oscillation issues and develop IBR damping control strategies if applicable.

5.17 Internal controls are included in a formal review and reporting process to ensure the correct data is collected within required timeframes.

5.18 Automated tools, that include fault recording, sequence of events recording, and/or PMU recordings, are used to retrieve event data for post event analyses and assessments.

6. Communication with IBR Operators

Ensuring effective communication between system operators and personnel managing IBR is critical for grid reliability. Miscommunication between system operators and IBR personnel often arises because these two groups come from different operational cultures, use different terminology, and have different visibility into the grid. Below are some examples that affect effective communication.

Differing Operational Perspectives

System operators focus on reliability, contingencies, and balancing generation/load, while IBR operators focus on the performance of facilities.

Terminology Differences

System operators may use terms familiar to traditional generation resources, like spinning reserve or governor response, while IBR operators may use terms like grid-following versus grid-forming or ride-through, for example.

Organizational and Cultural Barriers

System operators are accustomed to being a part of a regulated utility or ISO/RTO, with structured procedures and compliance requirements that focus on overall grid reliability, while IBR personnel may have different incentives such as plant performance, equipment warranty, or contractual obligations.

IBR personnel may have limited knowledge of how and where IBR facilities fall under their purview interconnect to the grid, while system operators can better see the interconnectivity of loads and resources over their portion of the transmission system.

IBR facilities are typically not operated locally, with most being controlled remotely from a centralized location.

Ensuring Proper Communication

NATF Practices

6.1 Use standardized language consisting of technical terms to avoid misinterpretation (e.g., ride-through, curtailment, frequency response). See Appendix 2 for an example of a communication matrix.

6.2 Define roles and responsibilities that clarify who makes decisions, who executes them, and who monitors performance.

6.3 Processes and tools are provided for IBR personnel to communicate Real-time data for voltage, frequency, real and reactive power, and status.

6.4 Recurring meetings are scheduled with IBR personnel to review IBR operational performance, contractual performance, and discuss planned outages.

6.5 Event analysis meetings are scheduled to jointly perform post-incident reviews that analyze performance and identify areas for improvement.

6.6 Facilitate joint training and simulations to build trust and communication.

6.7 Perform drills or simulations to practice coordinated response to faults, islanding, and/or blackstart conditions.

7. References

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Appendix 1: IBR Data Use Case Matrix

The table below categorizes and defines the type of data that is collected, provides examples for how the data is used, and identifies the primary users of the data.

Table 2: IBR data use matrix

	Plant Data	**Control Data**	**Performance Data**	**Contract Data**	**Standard Study Data**	**Exceptional Study Data**
Data Definition	Data describing the IBR and its operational capabilities	Real-time data from the IBR that describes the current Real-time control setpoints and operating status	Real-time and historical IBR data to monitor and characterize performance against expected performance.	Contractual IBR data that describes operational parameters, service obligations, and how the IBR will interact with the grid.	IBR Real-time, historical, and model data used to predict how the IBR will serve a defined operating area.	IBR dynamic model data and historical high-resolution data recorded by digital fault recorders (DFR) and or power management units (PMU).
Data Examples	- Plant Type (Wind, Solar, Storage, etc.) - Plant Real Power Capacity (Battery; P out or P in) - Plant Reactive Power Capacity - Gross Inverter Nameplate Capacity - Cold Weather Operating Capability - Inverter Settings (as commissioned) - Inverter Count - Inverter Make/Model - Racking (Solar; fixed or tracking)	- Control Mode - Control Set Points (P, Q, kV, PF) - Control Set Points Feedback - Control Settings (droop, deadband) - Plant Level Telemetry (P, Q, kV, PF) Plant Alerts, Warnings, Alarms - Online Inverter Count - Transformer OLTC Tap Position - Breaker/Switch Status	- Plant Level Telemetry (P, Q, kV, PF) - Individual Inverter Telemetry (P, Q, V, I, Temp) - Meteorological Data (GHI, POA, Amb Temp, RH, Wind Speed) - Solar Panel Temperature - Battery Enclosure Temperature - Battery Cell (V, Temp) - Current Transducer Data (string current)	- Plant Capacity Limit - Plant PF Limit - Plant Voltage Schedule - Plant Cycle Limit (Battery) - Expected Essential Plant Services - Expected Ancillary Plant Services - Data Available to Transmission Operator (TOP) - IBR Dynamic Model Data	- Plant Real Power Capacity (Battery; P out or P in) - Plant Reactive Power Capacity - Interconnecting Substation - Historic Plant Performance trend (P, Q) - Plant Performance forecast (P) - Modeling parameters (as required by each EMS)	- High Resolution Measured Phasor Data (V, I, phase angle) - IBR Dynamic Model Data Inverter Settings (as commissioned)

	Plant Data	Control Data	Performance Data	Contract Data	Standard Study Data	Exceptional Study Data
	- Energy Storage (Battery; Wh) Location (Lat, Long) - Interconnecting Substation	- Cap Bank Status - Solar Plant Tracker Stow Control - *Expected P Output - *Forecasted P Output	- Solar Plant Tracker Position			
End Users	- Utility Personnel – not confined solely to System Operations	- System Operators Operations Support Staff	- Operations Support Staff - Power Supply Marketing Energy Services	- Operations Support Staff - Energy Services	- Operations Support Staff	- Operations Support Staff

Appendix 2: System Operator IBR Communication Matrix

This matrix is an example system operator-to-IBR personnel translation guide to share with IBR personnel. It helps ensure proper communication for day-to-day monitoring and control functions by expressing terms used by transmission system operators in language that is familiar to IBR personnel.

Real-time Dispatch & Control	
System Operator Term / Directive	**What It Means for IBR Personnel**
Real Power Setpoint	IBR Plant operates at its maximum forecasted output.
Reactive Power (MVAR) Target	IBR Plant operates at reactive power setpoint based on the real power output level.
Ramp Rate Limit	IBR plant is limited on how fast the MW injection can increase based on other generation profile with the Balancing Authority.
Curtailment	Directive to reduce output or limit battery charging for reliability or stability.
Voltage Setpoint at POI	POI voltage schedules are provided by the Transmission Owner (TO) to help maintain the reliability of transmission system voltages
Frequency Response	TO will require IBR plant to curtail generation for any over frequency event.
Capability & Ride-Through	
System Operator Term / Directive	**What It Means for IBR Personnel**
P–Q Capability Curve	IBR plant P-Q capability is roughly determined by interconnection agreement. The IBR plant may have additional capability however individual inverter P-Q capability is not indicative of the total IBR plant capability. The aggregate P-Q capability of individual inverters does not necessarily reflect the total IBR plant P-Q capability.
Voltage Ride-Through	IBR plant maintains voltage within its operating region during a disturbance, to maintain stability at the reference point of applicability as determined by interconnecting utility. Based on NERC and IEEE standards.
Frequency Ride-Through	IBR plant maintains frequency within its operating region during a disturbance, to maintain stability at the reference point of applicability as determined by interconnecting utility.
Momentary Cessation	Momentary cessation occurs when inverters cease to inject current per programmed voltage and/or frequency threshold settings. Individual inverters are programmed such that momentary cessation settings are disabled.
Telemetry & Data	
System Operator Term / Directive	**What It Means for IBR Personnel**
SCADA Telemetry	Representation of any Real-time analog or binary data that is being presented to an operator by the IBR plant SCADA system or data sent by utility devices.
Event Recorder / Disturbance Data	High resolution (sub second) phase voltage and phase current data recorded by digital fault recorder or PMU or protective relay. This data

	should be captured during a grid disturbance as required by NERC standard PRC-028 [10].
Alarm Reporting	Those alarms associated with the grid interaction (grid voltage, current, frequency) as recorded at the POI or IBR substation by the IBR facility SCADA system may be common or similar to those alarms recorded by the transmission operator. IBR and transmission operators should be able to validate alarms with one another.
Communication & Procedures	
System Operator Term / Directive	**What It Means for IBR Personnel**
Operating Instruction	A command to change or preserve the state, status, output, or input of an element of the BES. Example: We are required as the transmission operator in this area to [insert instruction]. For this reason, we need you to [*insert instruction*].
Outage Coordination	The outage coordination process between a Transmission Operator (TOP) and the Balancing Authority (BA) or Reliability Coordinator (RC) may be unfamiliar to IBR operators. The Transmission Operator should communicate to the IBR operator the number of days needed to plan for a generator to be taken offline for the purpose of studying the impact the generator outage might have on grid reliability.
Remedial Action Scheme (RAS) Enabling	A scheme to automatically take action based on predetermined system conditions such as tripping or adjusting generation output. IBR operators should know which of their plants are associated with a RAS and also understand the effects a RAS has on their associated IBR plants.
Emergency Directive	Because of current grid conditions, immediate manual action is required by the IBR operator to prevent or limit the failure of transmission facilities or generation supply and to preserve grid reliability. Like Operating Instruction, this directive will come to an IBR operator through the TOP from the BA or RC.