

Inverter-Based Resource Interconnection Lifecycle: Facility Engineering Design Review Practices



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Review and Update Requirements

- Review: every 5 years
- Update: as necessary

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1. Purpose

Interconnection engineering design has traditionally focused on high-capacity synchronous machines. The shift to inverter-based resources (IBR) requires further diligence, additional focus on the generating assets, and interoperability of IBRs with the rest of the bulk power system (BPS). An enhanced design review process that emphasizes collaboration with developers, generator design validation, compliance with IBR standards, current and accurate data, and additional modeling is vital to ensure the reliability of the network.

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 all functions that are involved in executing or supporting interconnection requests. These may include, but are not limited to, transmission planning, system protection, operations planning, transmission support, transmission engineering, and tariff administration.

This document focuses on the third step, facility engineering design review, of the IBR Interconnection Lifecycle Program (Figure 1). The NATF has created a series of documents to provide guidance for multiple phases of the process of connecting IBR to transmission systems. Other documents address interconnection requests and studies and interconnection agreements and requirements. This document addresses the responsibilities of the transmission organization for design review of the interconnecting facility.

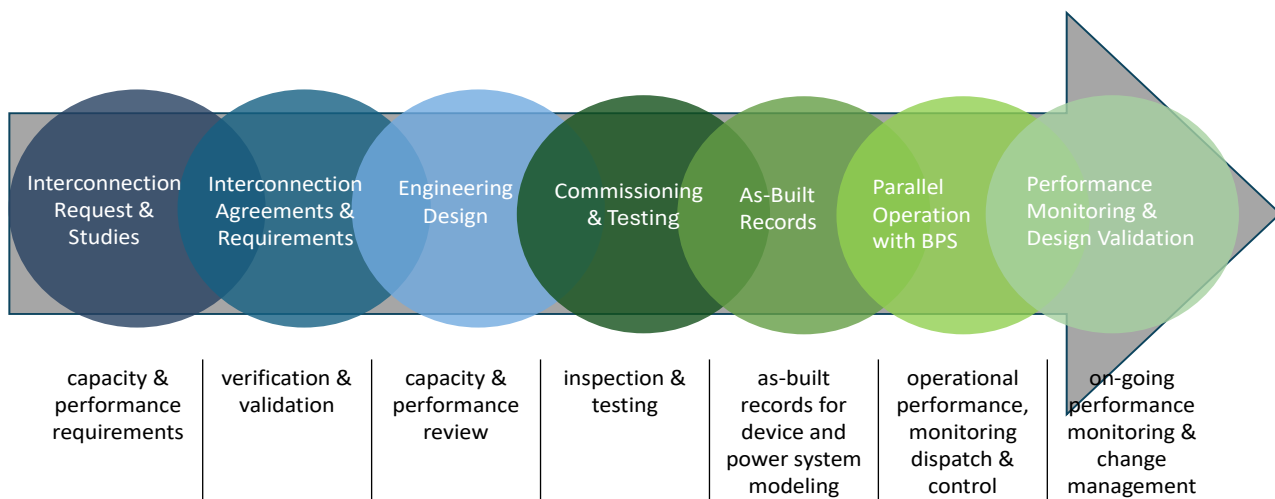


Figure 1. Inverter-based resource interconnection lifecycle

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.

Interconnection Facilities

Facilities and equipment between the generating facility and the POI, including any modifications, additions or upgrades that are necessary to physically and electrically interconnect the generating facility to the TP's transmission system. Interconnection Facilities are sole use facilities and shall not include distribution upgrades, stand alone network upgrades or Network Upgrades [1].

Network Upgrades

Additions, modifications, and upgrades to the TP's transmission system required at or beyond the point at which the Interconnection Facilities connect to the transmission system [1].

Reference Point of Applicability (RPA)

Location proximate to the IBR connection where the interconnection and interoperability performance requirements are specified [2].

Point of Measurement (POM)

A point between the high-side bus of the IBR and the interconnection system [2].

Point of Interconnection (POI)

A point where the interconnection system connects an IBR to the transmission system [2].

Inverter-Based Resource (IBR)

Generation resources that connect to the electric power system using power electronic devices to change direct current (DC) power produced by the resource to alternating current (AC) power compatible with distribution and transmission grids. IBR may refer to solar photovoltaic (PV), wind, fuel cell, battery storage and renewable resources [3].

Per Unit (p.u.)

Quantity expressed as a fraction of a defined base unit quantity.

Co-located Plant

Two or more generation or storage resources that are operated and controlled as separate entities yet connected behind a single point of interconnection [2].

Transmission Operator (TOP)

The entity responsible for the reliability of its “local” transmission system, and that operates or directs the operations of the transmission facilities [4].

Transmission Owner (TO)

The entity that owns and maintains transmission facilities [4].

Transmission Planner (TP)

The entity that develops a long-term (generally one year and beyond) plan for reliability (adequacy) of the interconnected bulk electric transmission system within its portion of the planning authority area [4].

Transmission Provider

The public utility (or its designated agent) that owns, controls, or operates transmission or distribution facilities used for the transmission of electricity in interstate commerce and provides transmission service under the tariff. The term Transmission Provider should be read to include the transmission owner when the transmission owner is separate from the Transmission Provider [1].

Transmission Service Provider (TSP)

The entity that administers the transmission tariff and provides transmission service to transmission customers under applicable transmission service agreements [4].

Interconnection Customer (IC)

Any entity, including the Transmission Owner or any of the affiliates or subsidiaries of either, that proposes to interconnect with the Transmission Owner’s transmission system [1].

4. Detailed Facility Engineering Design Review

The detailed facility engineering design review is a formal process, with documented milestones, in the interconnection lifecycle conducted prior to the commissioning and testing phase. It serves as the technical validation stage where the Transmission Owner (TO) and the associated independent system operator (ISO)/regional transmission organization (RTO), where applicable, confirm that the interconnection customer's (IC) IBR design, modeling data, and coordination of interconnection protection schemes satisfy all applicable interconnection requirements, planning criteria, and operational expectations. This review converts interconnection study assumptions into a verified, design-specific baseline.

The process is structured as a guided, cross-functional review involving transmission planners, system protection, and system operations. The review systematically addresses capacity capability, reactive performance, ride-through compliance, protection coordination, inverter and plant power plant controller (PPC) behavior, and integration of power system models. Each discipline evaluates the submitted documentation and models within its area of responsibility while maintaining alignment across planning, protection, and operational impacts.

The TO, associated ISO/RTO (where applicable), and IC jointly examine coordination studies, inverter and PPC models, steady-state, dynamic, and electromagnetic transient (EMT) system models, protection designs, and operational control strategies. The objective is not only compliance verification, but confirmation that the facility, as designed, will perform reliably under normal and contingency conditions. Discrepancies that arise during the various engineering design and construction phases should be identified, documented, and resolved prior to advancement to pre-synchronization or commissioning.

Completion of the detailed facility engineering design review establishes a technically defensible baseline. The accepted and subsequently validated models, control parameters, protection settings, and performance expectations become the reference configuration for commissioning tests and field validation. This reduces commissioning risk, prevents late-stage redesign, and ensures that field testing confirms performance rather than discovering design deficiencies.

The facility engineering design review (i.e., CPR.2 and CPR.3) is part of a multiphase process referred to as a capability performance review (CPR). The CPR establishes validation checks throughout the interconnection process and follows the same structured cross-functional model described in this section.

See "Appendix 1: Data Assessed During Review" and "Appendix 2: Capacity Performance Review Timeline".

5. Developer Submittals and Validations

Complete and accurate data submittal from an IC is essential to the TO and Transmission Planner's (TP) ability to assess system reliability. All TP studies rely directly on IC-provided data to represent equipment ratings, controls, and protection behavior.

Incomplete or inaccurate data slows or potentially stalls the process. Accurate and traceable data promotes consistency across interconnection studies, facility design reviews, and enables compliance.

Data Submittal

The following practices highlight data and documentation that should be submitted to the TO during the facility engineering design phase. See “Appendix 3: Data Submittal Checklist” as a resource.

NATF Practices

- 5.1 The TO develops a facility engineering design review data submittal package for the IC to follow.
- 5.2 The IC provides a complete engineering design data submittal package to the TO six weeks prior to commissioning.
- 5.3 The IC provides a draft commissioning plan for the IBR facility to the TO once the facility design is completed.
- 5.4 Facility engineering design review data submittal is representative of actual equipment and includes the following:
 - Steady state modeling data for the generating facility in the format specified by the TO.
 - Dynamic modeling data for the generating facility in the format specified by the TO.
 - Electromagnetic transient models of the generating facility in the format specified by the TO.
 - Short circuit modeling data in the format specified by the TO.
 - Original equipment manufacturer (OEM) block diagrams, parameter sheets, and firmware version documentation for user-defined models (UDM).
 - Reactive capability curves that include P/Q settings and control mode
 - Voltage and frequency ride-through curves
 - Documentation of validated modeling data and evidence of model benchmarking for accuracy.
 - Single-line diagrams of the facility layout detailing equipment such as transformers, collector systems, inverters, inverter step-up transformers, and reactive power equipment.
 - Single-line diagrams that detail all protection and relay components.
 - Network diagrams, telemetry points, signal mapping, and supervisory control and data acquisition (SCADA) protocols.
 - Harmonic study report demonstrating the facilities adherence with IEEE 2800 [2] harmonic performance standards.
 - Certified test reports for the main transformer(s) at the point of interconnection (POI) or point of measurement (POM), each inverter step-up transformer, and any grounding transformers on the collector system.
 - Manufacturer specifications and inverter harmonic data sheets for all inverters installed.
 - Equipment nameplate data for main transformers, inverter step-up transformers, inverters, and plant controllers.
 - Geospatial data in the format specified by the TO.

Developer Validation

The developer should demonstrate adherence to utility interconnection and design requirements through submitting required documentation and evidence. This section defines practices derived from IEEE 2800 [2] and the *NATF IBR Interconnection Agreements and Requirements Practices* [5] document. See “Appendix 4: Validation Checklist” as a resource.

Frequency Response

The IBR demonstrates its design can provide active power and frequency control functions as specified in section 9 of *NATF IBR Interconnection Agreements and Requirements Practices* [5].

NATF Practices

- 5.5 Provide documentation confirming that the IBR frequency control system droop characteristic is set to 5%, within the acceptable range of 3% to 7%.
- 5.6 Submit test results and control logic demonstrating that the IBR regulates output as a function of system frequency and desired MW output to maintain the normal 60 Hz frequency.
- 5.7 Provide evidence of adherence to primary frequency response capability and performance requirements in Clause 6 of [2].
- 5.8 Submit documentation and test results verifying that the IBR can respond to under-frequency and over-frequency disturbances.
- 5.9 Provide a statement confirming that primary frequency response control functions are always enabled and cannot be blocked or disabled without Transmission Operator (TOP) approval.
- 5.10 Provide documentation verifying adherence to fast frequency response (FFR) capability and performance requirements in Clause 6.2 of [2].
- 5.11 Submit test data or control logic showing that the IBR can provide FFR proportional to frequency deviation as specified in Clause 6.2.2.1 of [2].

Reactive Power Capability

The IBR demonstrates its design has reactive power capability as specified in section 9 of *NATF IBR Interconnection Agreements and Requirements Practices* [5].

NATF Practices

- 5.12 Submit documentation demonstrating that all reactive power devices meet requirements specified in Clause 5.1 of [2].
- 5.13 Provide verification that the IBR has the required reactive power capability as per Clause 5.1 of [2], with Q_{min} set at 0.95 pf or as required by the TO.
- 5.14 Submit test data and documentation showing that leading and lagging minimum reactive power capability is deliverable to the POI across the full range of MW outputs.

- 5.15 Provide transformer design data confirming that the transformers cover the entire range of possible transmission system voltages.
- 5.16 Provide tap changer details that confirm tap steps are $\leq 2.5\%$ between adjacent taps.
- 5.17 Submit reactive power capability data confirming that the plant can perform 0.98 pf injection and absorption (or as mandated by TO/TP reliability or regulatory requirements) across all operating transmission voltages and minimum reactive capability within acceptable ranges.

Enter and Return to Service

The IBR demonstrates its design adheres to enter and return to service criteria as specified in section 9 of *NATF IBR Interconnection Agreements and Requirements Practices* [5].

NATF Practices

- 5.18 Provide documentation confirming that the IBR does not energize the system until requirements of table 13 of [5] are met at the POI. Submit evidence of how this requirement is implemented in plant controls.
- 5.19 Submit test results or control logic confirming that once enter service criteria are met, the IBR waits five seconds before initiating the return to service process. Provide a list of enter, return, and restart timers with settings.
- 5.20 Provide ramp rate settings and documentation verifying that the IBR follows the required limits. Submit evidence that during restoration after an abnormal event active power recovery occurs as fast as possible.
- 5.21 Submit the maximum restoration ramp rate capability, actual restoration ramp rate setting, and a technical justification if the maximum restoration ramp rate is not used.

Harmonics

The IBR demonstrates its design adheres to harmonics criteria as specified in section 9 of *NATF IBR Interconnection Agreements and Requirements Practices* [5].

NATF Practices

- 5.22 Provide installation documentation and technical specifications for power quality metering in compliance with TO metering standards.
- 5.23 Provide documentation demonstrating compliance with current and voltage harmonic limits.
- 5.24 Provide a harmonic analysis report.
- 5.25 Provide documentation confirming that harmonic and interharmonic measurements follow the methodology in IEEE 519 [6]. Include measurement procedures and equipment specifications.
- 5.26 Provide measurement data demonstrating compliance with current harmonic distortion limits from tables 17 and 18 of [2].

- 5.27 Provide measurement data confirming compliance with harmonic voltage distortion limits in table 14 of [2].

Voltage and Reactive Power Control

The IBR demonstrates its design can perform voltage and reactive power control as specified in section 9 of *NATF IBR Interconnection Agreements and Requirements Practices* [5].

NATF Practices

- 5.28 Submit settings, control logic, and documentation demonstrating that the IBR operates in reactive current priority mode during both normal and abnormal operations, including high-voltage and low-voltage ride-through events.
- 5.29 Submit documentation that the IBR provides and makes available all standard reactive power control functions as defined in clause 5.2 of [2].
- 5.30 Provide documentation that the IBR meets clause 5.2 of [2], with the reference point of applicability (RPA) defined at the POI, and that the IBR operates in closed-loop automatic voltage control mode.
- 5.31 Submit implementation details of the voltage reference point, deadband, and droop. Include procedures showing how the POI voltage setpoints and ranges are applied and documentation of how setpoint changes are implemented via SCADA or manual methods.
- 5.32 Provide evidence that the IBR implements an alternate power factor control mode when voltage control is temporarily unavailable.
- 5.33 Submit documentation and test data confirming that the IBR meets voltage control and dynamic response requirements per subclause 5.2.2 and table 5 of [2].
- 5.34 Provide evidence that the IBR supports all reactive power control modes. This may include constant voltage, constant reactive power, and/or constant power factor.

Frequency Ride-Through Capability and Performance

The IBR demonstrates its design can meet frequency ride-through capability and performance as specified in section 9 of *NATF IBR Interconnection Agreements and Requirements Practices* [5].

NATF Practices

- 5.35 Provide documentation that the IBR plant adheres to the frequency ride-through capability and performance requirements of clause 7.3, table 15, and figure 12 of [2].
- 5.36 Submit a frequency ride-through capability chart for each inverter type and factory-set inverter frequency trip settings.
- 5.37 Provide numerical data defining all operating modes and factory-set inverter trip settings in a format consistent with table 15 of [2].
- 5.38 Provide documentation and test results or simulations confirming that the IBR performs according to clause 7.3.2.2 and 7.3.2.3 of [2].

- 5.39 Provide evidence, settings, and control logic demonstrating that the IBR meets the change in voltage phase angle ride-through requirements of clause 7.3.2.4 of [2].
- 5.40 Submit evidence that rate of change of frequency (ROCOF) protection is disabled unless approved by the TO.
- 5.41 Provide documentation, OEM data, or test validation verifying that the ROCOF protection does not block ride-through in accordance with clause 7.3 of [2].

Voltage Ride-Through Capability and Performance

The IBR demonstrates its design can meet voltage ride-through capability and performance as specified in section 9 of *NATF IBR Interconnection Agreements and Requirements Practices* [5].

NATF Practices

- 5.42 Provide documentation that the IBR adheres to the voltage ride-through capability and performance requirements in clause 7.2 of [2].
- 5.43 Submit a voltage ride-through capability chart for each inverter type, formatted per appendix D of [2].
- 5.44 Provide numerical data, formatted per table 11 and 12 of [2] defining all operating modes and factory set inverter trip settings.
- 5.45 Provide documentation confirming adherence to consecutive voltage deviation ride-through requirements of subclause 7.2.2.4 of [2].
- 5.46 Submit documentation showing compliance with transient overvoltage ride-through requirements in clause 7.2.3 of [2].
- 5.47 Provide documentation that the IBR supplies current injection for fault ride-through when voltage is outside the normal range.
- 5.48 Submit control settings that confirm the IBR operates in reactive current priority mode when in voltage ride-through mode.
- 5.49 Submit documentation showing that the IBR meets reactive current injection requirements per subclause 7.2.2.3.4 and 7.2.2.3.5 of [2].

6. Studies and Modeling Review

Confirm that the IBR design and associated models are complete, current, and consistent with prior interconnection analyses. As the IBR design evolves through the interconnection process, models submitted during earlier phases may no longer accurately reflect the facility design. This review validates that steady-state, dynamic, and EMT models align with the latest system impact and facilities studies, accurately represent installed equipment and control logic based on OEM documentation, and are consistent across modeling platforms.

Model and Study Validation

NATF Practices

- 6.1 Review the engineering design data submittal package to ensure all required information is available and complete.
- 6.2 Verify that models (i.e., steady-state, dynamic, EMT) are consistent with models used in system impact studies or the most recent assessment.
- 6.3 Verify that models are representative of actual equipment by benchmarking the models against OEM block diagrams and parameter sheets as well as the facility single-line diagram.
- 6.4 Benchmark positive sequence and time domain models (i.e., EMT) against each other to verify alignment and consistency.
- 6.5 Review system impact and facilities studies to ensure updated models are consistent and perform as previously identified.

Model Deviations

NATF Practices

- 6.6 The TO identifies model deviations and has them addressed prior to advancing the project to the commissioning phase.
- 6.7 Following initial energization and commissioning, the IC shall submit a post-commissioning model validation report comparing measured facility performance against the accepted steady state, dynamic, and EMT models.

If IBR design data is materially different than what was previously provided and studied, the TO evaluates the discrepancies on a case-by-case basis and determines the path forward.

7. Design Review and Validation

Diagrams

Diagrams serve as the technical representation that ties together planning assumptions, protection design, communication, and metering. Diagrams should be paired with a written narrative that explains the intent or philosophy of the design to assist the TO in understanding the IBR system behaviors. Diagrams are produced to represent portions of the electrical system as follows:

- Interconnection and substation one-line diagram establishes the electrical topology for steady state, short circuit, and dynamic studies.
- IBR collector system diagram provides impedances, grounding, and sectionalization that set the voltage seen by inverters, the amount of reactive and dynamic support to the transmission system, and the IBRs short-circuit behavior and protection coordination.
- Protection and controls three-line, AC/DC elementary, and logic diagrams provide the TO minimum visibility to review protection and control functions, verify tripping paths, redundancy, supervision, philosophy, and logic for interface with the transmission system.
- Metering one-line diagram provides current transformer (CT) and potential transformer (PT) locations, ratios, accuracy class, test switch blocks, and communication paths. It supports metering certification and validates the metering topology matches the interconnection topology.
- SCADA and telemetry diagram provides remote terminal unit (RTU) to plant controller interfaces, communications media and redundancy, demarcation, and time synchronization. It assists operations in confirming visibility and control requirements to ensure remote monitoring and control functions align with protection design and operating procedures.
- PPC block diagram provides set points, operating modes, limiters, voltage and reactive control, and ramp rates. It is the connection between the studies and actual IBR behavior in steady state and time domains.

NATF Practices

- 7.1 The IC provides interconnection and substation electrical one-line diagrams, collector system one-line diagrams, protection one-line diagrams, AC/DC elementary, logic diagrams, metering one-line diagrams, communications and SCADA architecture, and PPC block diagrams to the TO.
- 7.2 The IC maintains a change log for all topology changes from the initial interconnection study through commissioning.
- 7.3 The IC provides a narrative or explanation of the intended operation of the collector system, protection and controls philosophy, relay scheme operation descriptions, and PPC philosophy to the TO.
- 7.4 The TO publishes a diagram submittal standard that defines required diagram types, minimum content, naming conventions, symbols, file formats, version control, and acceptance criteria.

- 7.5 The TO reviews all IC provided diagrams and narratives to ensure they meet expectations and requirements.

Power Plant Controllers

The PPC serves as the primary interface for plant control, coordination, and response. The PPC is designed to reliably execute control commands, support operational flexibility, and maintain stable IBR operation under all applicable operating conditions. The following defines the minimum functional, control, and performance requirements for the IBR PCC.

NATF Practices

- 7.6 The PPC is capable of closed loop control for regulating active power, reactive power, voltage, and power factor at the POI consistent with specified operating modes.
- 7.7 The PPC is capable of local, remote, and automatic modes control with defined command authority and interlocks preventing conflicting setpoints from separate control modes.
- 7.8 The PPC meets specified command execution and mode transfer response times.
- 7.9 The PPC demonstrates repeatable, bounded latency from receipt of command to plant response at the POI.
- 7.10 The PPC provides adjustable ramp rates and smoothing functions for active and reactive power changes to prevent step changes at the POI.
- 7.11 The PPC implements plant and substation interlocking logic required to maintain safe switching.
- 7.12 The PPC control logic implemented in the field should be representative of planning models and provide version control, parameter traceability, and documented validation against measured or test-based evidence.
- 7.13 The PPC allows system operators to adjust parameters, setpoints, algorithms, limits, and threshold required to operate the IBR [7].
- 7.14 The PPC provides local monitoring, alarming, and control interface using human machine interface (HMI) that provides a local operator with all diagnostics of all IBR and transmission level components [7].
- 7.15 The PPC supports the SCADA protocols required by the TO.
- 7.16 The PPC provides event recordings and evidence by recording time-synchronized sequence of events, control mode transitions, command and setpoint changes, alarms, and disturbance records.
- 7.17 The PPC does not prohibit or prevent controls of IBR units and any supplemental IBR devices to meet ride-through performance requirements [2].
- 7.18 The PPC configuration is coordinated with plant protection to avoid unnecessary tripping during defined voltage or frequency excursions and preserve required ride-through behavior.

The PPC requirements are applicable to all IBR facilities, including co-location of different technology types and where multiple ICs are located behind one POI. All PPC requirements are to be met by the IC as defined by the TO to support a reliable and safe interconnection to the transmission system.

Transformer Configuration

NATF Practices

- 7.19 Each interconnection facility has one or more dedicated generator step-up (GSUs) to separate the IBR from the TO’s transmission system and provide an effectively grounded source for the collector system, TO’s transmission system, or both.
- 7.20 The TO identifies GSU configuration requirements in their interconnection technical requirements.
 - For smaller, radially-connected, and single breaker tap stations the GSU is delta-wye grounded, with the delta winding on the transmission side.

If grounding is required on both the collector and transmission sides, the design includes a three winding transformer with wye grounded for both the collector and utility windings with a delta tertiary. Alternatively, the design has two transformers consisting of a delta-wye main transformer and a grounding transformer with the delta connected to the collector side.

- For most applications the GSU is configured in either a wye grounded-delta with the wye grounded winding on the transmission side, or a wye grounded-wye grounded with a delta tertiary for a multi-breaker transmission station.

Wye grounded-wye grounded transformers without a delta winding (so called “phantom delta” transformers) may not be acceptable, as such transformers are weak sources of ground fault current.

8. Protection Schemes

This section defines the minimum protection expectations for an IBR facility interconnected to the transmission system. Protection schemes are designed to preserve transmission system reliability, isolate faults, and ensure IBR protections do not conflict with required ride-through performance.

Protection Equipment

The protection is designed with sufficient redundancy, speed, and reliability to isolate faults without degrading system performance or existing protection schemes.

NATF Practices

- 8.1 All protection designs impacting interconnection protection coordination are reviewed by the TO prior to finalization.
- 8.2 The IC installs and maintains all protection devices within the generating facility to accomplish the following:

- Prevent faults within the generating facility from adversely impacting TO equipment.
- Ensure coordination of fault clearing for faults on the TO's system in compliance with PRC-027 [8].
- Maintain compatibility with existing TO protection philosophies and relay schemes.

8.3 Protection equipment complies with the latest applicable versions of NERC PRC-019 [9] and PRC-029 [10] and should not reduce the dependability of the TO's protective systems.

8.4 The IC and TO mutually agree on redundancy levels, protection schemes, communications, and equipment types.

8.5 The IC provides the TO with a protection commissioning test report documenting all relay test results, trip test records and protection setting modifications prior to COD.

Basic Protection Design

Protection at the POI is selected based on configuration, fault contribution from the IBR, and physical separation between the IBR and the TO's system.

This list of protection schemes serves as a baseline to be applied where applicable.

- Line protection
- Bus differential protection
- Voltage and frequency protection
- Overcurrent protection
- Breaker failure protection
- Anti-islanding protection
- Direct transfer trip

NATF Practices

All protection schemes ensure the following:

8.6 Protection schemes do not limit ride-through capability

8.7 Protection schemes do not interfere with any under-voltage load shedding schemes.

8.8 Protection schemes do not interfere with any under-frequency load shedding schemes

8.9 Protection schemes do not limit transmission system and generator loadability in accordance with NERC Standards PRC-023 [11] and PRC-025 [12].

9. Regulatory and Utility Requirements

The IC and TO share the responsibility of the IBR design and operation to meet applicable standards and requirements with the intent to reduce non-compliance and ensure a safe and reliable interconnection.

The Federal Energy Regulatory Commission (FERC) serves as the ultimate authority over BPS reliability by reviewing, approving, and enforcing the mandatory reliability standards that NERC develops. When FERC issues a directive, NERC is obligated to act by creating or modifying standards, which then become enforceable for all registered entities.

The following FERC orders are the most significant for ensuring the reliable operation of IBRs connected to the BPS:

- FERC Order 901 [13] established the modern IBR regulatory framework, directing NERC to create new and revised standards covering disturbance monitoring, data sharing, model validation (including electromagnetic transient models), and planning/operational studies.
- FERC Order 909 [14] approved new IBR performance standards requiring resources to remain online and perform correctly during voltage and frequency disturbances.
- FERC Order 827 [15] requires all newly interconnecting non-synchronous generators (IBRs) to provide reactive power capability at the high-side of the generator substation.

While reliability and compliance are shared responsibilities across NERC functional entities, Transmission Operators are uniquely positioned to prevent non-compliance. Key NERC standards TOs must actively enforce include:

- PRC-027-1 [8] – Coordination of Protection Systems: Requires a process for coordination of protection systems to ensure they operate in the intended sequence during faults.
- PRC-028-1 [16] – Disturbance Monitoring for IBRs: Requires disturbance monitoring equipment and data capture to support post-event model validation.
- PRC-029-1 [10] – IBR Frequency & Voltage Ride-Through: Requires IBRs to remain connected and support the system during defined disturbances; TOs must obtain studies, settings, and controls demonstrating full conformance.
- PRC-030-1 [17] – Unexpected IBR Event Mitigation: Requires analysis and corrective action for unexpected inverter trips or current-cessation events.
- VAR-002-4.1 [18] – Automatic Voltage Regulation (AVR) Operation & Voltage Schedule Compliance: Requires generators to maintain AVR in service and follow TO-assigned voltage/reactive schedules, with mandatory notifications for deviations; TOs must verify proper AVR operation and adherence to schedules.
- MOD-026-2 [19] – Dynamic Model Verification: Consolidates MOD-026-1 and MOD-027-1 and explicitly includes IBRs, requiring both positive-sequence and EMT models to address modeling gaps that include capturing fast inverter controls, phasor-level behavior, and protection functions.
- MOD-033-3 [20] – Steady-State and Dynamic System Model Validation: Establishes a coordinated model validation process in accordance with the data required in MOD-032-2 [21].

Finally, IEEE 2800-2022 [2] defines the technical performance expectations for grid-connected IBRs and is frequently incorporated into utility interconnection requirements, with NERC often leveraging it as a reference.

Each TO clearly summarizes its interconnection requirements and publishes them on its open access information sharing site with direct links to governing documents. Even when requirements originate from NERC standards or FERC orders, TO-specific documentation is essential to ensure consistency, transparency, and enforceability for all ICs.

10. Related Documents

The following documents influence or relate to this document in some manner:

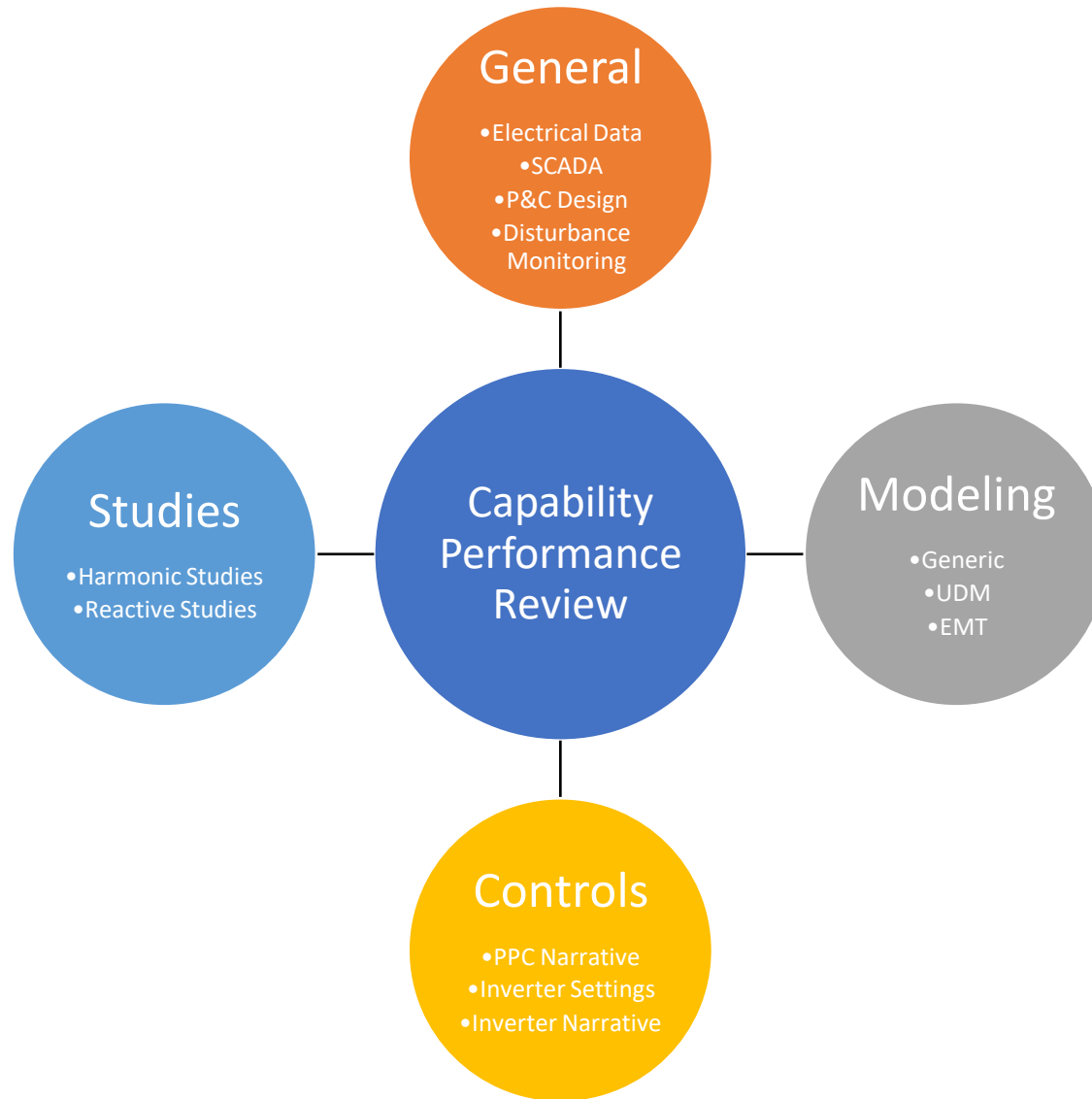
- NATF Interconnection Requests and Studies
- NATF Interconnection Agreements and Requirements
- NATF Transmission-to-Generation Protection System Coordination Guidance
- NATF Inverter-Based Resource Interface Reference

11. References

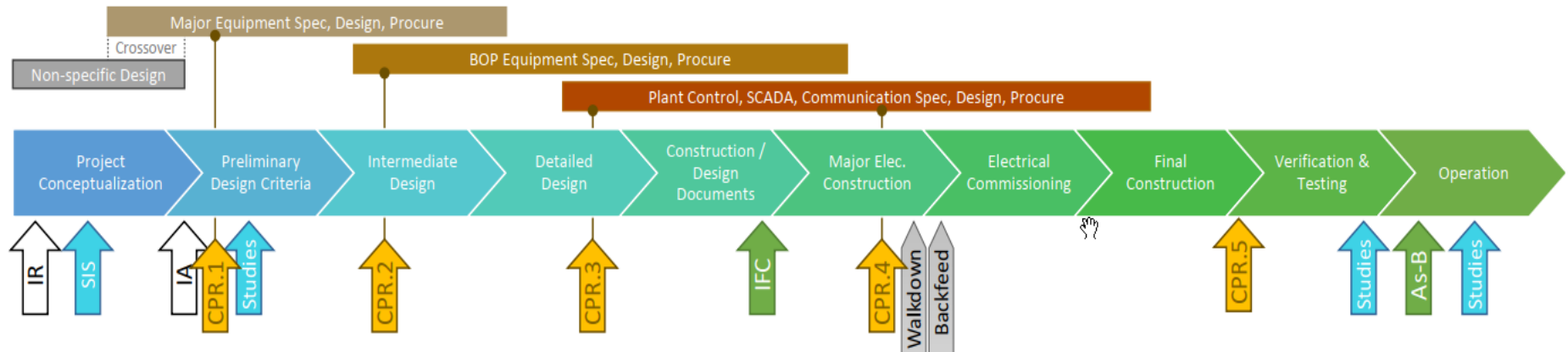
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Appendix 1: Data Assessed During Review



Appendix 2: Capability Performance Review Timeline



CPR.1

- Substitution Notifications
- All general documents
- Plant onelines
- Equipment specifications, capability, and datasheets
- Outlines for narrative content
- Vendor specific power system models
- Harmonic & Reactive studies

CPR.2

- Updated CPR.1 documents
- Preliminary PPC narrative
- Proposed Inverter settings
- Preliminary inverter narrative
- Protection schemes and settings

CPR.3

- Any previous document updates
- Final PPC & inverter narrative
- Final Inverter settings
- Pre-commissioning plant models & parameterization
- SCADA details & specs
- Disturbance monitoring specs

CPR.4

- Any previous document updates
- Remaining CPR documents
- CPR Completion

CPR.5

- Update any CPR documents modified after Backfeed

Appendix 3: Data Submittal Checklist

Assessment / Evaluation (How to demonstrate compliance with capability and performance requirements)	CPR.1 – Initial Design	CPR.2 – Intermediate Design	CPR.3 – Final Design / Integration	CPR.4 – Pre-Commissioning & Pre-Verification	Design Documents
Plant Electrical					
Specify all use cases and operational modes for the plant (e.g., for solar: nighttime voltage regulation, etc.; battery: arbitrage, frequency regulation, smoothing, etc.)	X				X
Specify all non-normal plant operational configurations (alternate electrical configurations, including those with partial equipment in service)	X				
Identify the location of each of these interconnection points as defined in the TIR: POI, PCO, POM, POC	X				X
Update the IBR Data Request Form with the latest data for the equipment to be installed	X				X
Provide a list of all Equipment Substitution Notices (Identify all plant or equipment changes after the interconnection study)	X				X
AC one line diagram (a <u>complete</u> oneline: from the PCO to the POC)	X				X
DC one line diagram (for significant DC systems)	X				X
AC three-line diagram (focus on metering and protection information related to grid reliability functions)		X			X
Collector system equivalence model (per the NREL method or equal)	X				X
Major equipment datasheets: Main tx, Inverter tx, Inverter, Battery, Panels, Capacitor, STATCOM, etc.	X				X
Main / Generator step-up transformer test report	X				
Major equipment nameplates: MSU, ISU, inverter, capacitor, filters, SVC, etc.			X		X
All plant transformer tap positions (MSU, ISU, Aux)		X			X

Assessment / Evaluation (How to demonstrate compliance with capability and performance requirements)	CPR.1 – Initial Design	CPR.2 – Intermediate Design	CPR.3 – Final Design / Integration	CPR.4 – Pre-Commissioning & Pre-Verification	Design Documents
Power flow / Reactive power study that verifies active and reactive capacity at POM (include planning volt range, pf range, inverter and plant voltage limits, inverter H/LVRT setpoint coordination, enter service, plant protection settings)		X			X
Calculation that defines plant operation and limits when supplemental reactive power source(s) are unavailable (capacitor, SVC, STATCOM, etc.)		X			
Reactive capability data for any supplemental reactive power sources (capacitor, SVC, STATCOM, etc.)	X				X
Power Quality					
Power Quality / harmonic studies		X			
Power Plant Controller (PPC) Configuration and Functionality					
Power Plant Controller (PPC) installation and operations manual		X			X
PPC functional description / narrative		X			
All PPC settings (application specific notes / design bases to be included in inverter narrative / coordination document)			X		X
Voltage Ride-through Capability and Performance					
Inverter voltage ride-through capability (equipment capability, NOT the protection setting ranges)	X				
Auxiliary Equipment voltage ride-through capability	X				
Frequency Ride-through Capability and Performance					
Inverter frequency ride-through capability (equipment capability, NOT the protection setting ranges)	X				
Provide ROCOF equipment limits (inverter, aux loads, other)	X				
Inverter Data					
Reactive Capability Curve at the regional temperature requirement, 1 pu voltage. (i.e., P-Q graph, D-curve)	X				X

Assessment / Evaluation (How to demonstrate compliance with capability and performance requirements)	CPR.1 – Initial Design	CPR.2 – Intermediate Design	CPR.3 – Final Design / Integration	CPR.4 – Pre-Commissioning & Pre-Verification	Design Documents
Inverter temperature derate curve, temperature operational range	X				X
Short Circuit current capabilities and limits	X				X
Inverter Harmonic Current Injection Magnitudes	X				X
Inverter installation and operation manual(s)	X				X
Inverter User Manual (Function Descriptions)	X				X
All inverter settings (application specific notes / design bases to be included in inverter narrative / coordination document)		X			X
Measurement Data and Performance Monitoring					
Provide equipment datasheets that meet specifications in FCR, TIR, IA, etc.			X		
Plant SCADA / Telecom					
Control Network Diagram / SCADA Data Flow Diagram (including interface with the TO, PPC with inverters, POM meter, PPC/major plant equipment, etc.)		X			
Plant Protection					
Provide coordination charts of plant-level and inverter-level grid reliability protection settings: voltage, frequency, overcurrent			X		
Describe transfer trips (plant to utility, utility to plant)			X		
Describe trip functions for plant main breaker; separate automatic return and lockout			X		
Storage					
Battery controls / management system manual(s)		X			X
Plant Power System Models: PPC					
Initial Generic Dynamic Model (actual PPC model w/initial settings; PSSE)	X				X
Initial UDM Dynamic Model (actual PPC model w/initial settings; PSSE)	X				X

Assessment / Evaluation (How to demonstrate compliance with capability and performance requirements)	CPR.1 – Initial Design	CPR.2 – Intermediate Design	CPR.3 – Final Design / Integration	CPR.4 – Pre-Commissioning & Pre-Verification	Design Documents
Initial UDM EMT Models (actual PPC model w/initial settings; PSCAD)	X				X
Updated Generic Dynamic Model (actual PPC w/proposed settings; PSSE)			X		X
Updated UDM Dynamic Model (actual PPC w/proposed settings; PSSE)			X		X
Updated UDM EMT Model (actual PPC w/proposed settings; PSCAD)			X		X
As-built Generic Dynamic Model (actual PPC w/as-built settings; PSSE)				X	X
As-built UDM Dynamic Model (actual PPC w/as-built settings; PSSE)				X	X
As-built UDM EMT Model (actual PPC w/as-built settings; PSCAD)				X	X
Validated Generic Dynamic Model (match as-built model to test performance)				X	X
Validated UDM Dynamic Model (match as-built model to test performance)				X	X
Validated UDM EMT Model (match as-built model to test performance)				X	X
Plant Power System Models: Inverter					
Initial Generic Dynamic Model (actual inverter model w/initial settings; PSSE)	X				X
Initial UDM Dynamic Model (actual inverter model w/initial settings; PSSE)	X				X
Initial UDM EMT Models (actual inverter model w/initial settings; PSCAD)	X				X

Assessment / Evaluation (How to demonstrate compliance with capability and performance requirements)	CPR.1 – Initial Design	CPR.2 – Intermediate Design	CPR.3 – Final Design / Integration	CPR.4 – Pre-Commissioning & Pre-Verification	Design Documents
Updated Generic Dynamic Model (actual inverter model w/proposed settings; PSSE)			X		X
Updated UDM Dynamic Model (actual inverter model w/proposed settings; PSSE)			X		X
Updated UDM EMT Model (actual inverter model w/proposed settings; PSCAD)			X		X
As-built Generic Dynamic Model (actual inverter w/as-built settings; PSSE)				X	X
As-built UDM Dynamic Model (actual inverter w/as-built settings; PSSE)				X	X
As-built UDM EMT Model (actual inverter w/as-built settings; PSCAD)				X	X
Validated Generic Dynamic Model (match as-built model to test performance)				X	X
Validated UDM Dynamic Model (match as-built model to test performance)				X	X
Validated UDM EMT Model (match as-built model to test performance)				X	X

Appendix 4: Validation Checklist

Frequency Response and Regulation

Item No.	Description	Submitted	Reviewed	Notes
5.5	Provide documentation confirming droop characteristic set to 5% (range 3–7%).			
5.6	Submit test results/control logic showing frequency regulation to maintain 60 Hz.			
5.7	Provide evidence of adherence to primary frequency response (Clause 6 of [2]).			
5.8	Submit documentation/test results verifying under- and over-frequency response.			
5.9	Confirm primary frequency response functions always enabled (TOP approval required to disable).			
5.10	Provide documentation verifying FFR capability compliance (Clause 6.2 of [2]).			
5.11	Submit test data/control logic showing FFR proportional to frequency deviation (Clause 6.2.2.1 of [2]).			

Reactive Power Capability

Item No.	Description	Submitted	Reviewed	Notes
5.12	Demonstrate all reactive power devices meet Clause 5.1 of [2].			
5.13	Verify required reactive power capability (Qmin at 0.95 pf, Clause 5.1 of [2]).			
5.14	Submit data showing reactive power deliverable to POI across full MW range.			
5.15	Provide transformer design data covering full voltage range.			
5.16	Provide tap changer details ($\leq 2.5\%$ between steps).			
5.17	Confirm 0.98 pf injection/absorption across operating voltages with minimum reactive capability.			

Enter and Return to Service

Item No.	Description	Submitted	Reviewed	Notes
5.18	Confirm IBR does not energize until Table 13 [5] conditions are met at POI.			
5.19	Submit test results confirming 5-second wait before return to service, plus list of timers.			
5.20	Provide ramp rate settings; confirm recovery after an abnormal event is as fast as possible.			
5.21	Submit maximum restoration ramp rate, actual setting, and justification if not maximum.			

Harmonics

Item No.	Description	Submitted	Reviewed	Notes
5.22	Provide power quality meter documentation/specs per TO standards.			
5.23	Confirm compliance with current/voltage harmonic limits.			
5.24	Submit harmonic analysis report.			
5.25	Confirm harmonic/interharmonic measurements follow IEEE 519 [6].			
5.26	Provide measurement data for current harmonic distortion limits (Tables 17/18 of [2]).			
5.27	Provide measurement data for voltage distortion limits (Table 14 of [2]).			

Voltage and Reactive Power Control

Item No.	Description	Submitted	Reviewed	Notes
5.28	Submit documentation that IBR operates in reactive current priority mode (normal/abnormal ops).			
5.29	Confirm IBR provides standard reactive power control functions.			
5.30	Provide documentation of Clause 5.2 compliance; closed-loop AVC at POI.			
5.31	Submit implementation details of voltage reference point, deadband, and droop with setpoint procedures.			
5.32	Confirm alternate power factor control mode implemented when AVC unavailable.			
5.33	Submit test data confirming voltage control/dynamic response per Subclause 5.2.2 and Table 5 of [2].			
5.34	Confirm support of all reactive power control modes.			

Frequency Ride-Through Capability

Item No.	Description	Submitted	Reviewed	Notes
5.35	Confirm compliance with frequency ride-through (Clause 7.3, Table 15, Figure 12 of [2]).			
5.36	Submit frequency ride-through chart for each inverter type (include factory-set trips).			
5.37	Provide numerical data defining modes/trip settings (Table 15 of [2]).			
5.38	Submit documentation/simulations confirming IBR performance (Clauses 7.3.2.2 and 7.3.2.3 of [2]).			
5.39	Confirm compliance with phase angle ride-through (Clause 7.3.2.4 of [2]).			

Item No.	Description	Submitted	Reviewed	Notes
5.40	Confirm ROCOF protection is disabled unless approved.			
5.41	Verify ROCOF does not block ride-through (Clause 7.3 of [2]).			

Voltage Ride-Through Capability

Item No.	Description	Submitted	Reviewed	Notes
5.42	Confirm compliance with voltage ride-through (Clause 7.2 of [2]).			
5.43	Submit voltage ride-through chart for each inverter type (Appendix D of [2]).			
5.44	Provide numerical data per Tables 11/12 of [2] defining modes/trip settings.			
5.45	Confirm adherence to consecutive voltage deviation ride-through (Subclause 7.2.2.4 of [2]).			
5.46	Submit compliance documentation for transient overvoltage ride-through (Clause 7.2.3 of [2]).			
5.47	Confirm IBR supplies current injection for fault ride-through outside normal range.			
5.48	Submit control settings confirming reactive current priority during voltage ride-through.			
5.49	Confirm compliance with reactive current injection requirements (Subclauses 7.2.2.3.4 and 7.2.2.3.5 of [2]).			