North American Transmission Forum

NATF Inverter-Based Resource Interconnection Lifecycle: Interconnection Requests and Studies Practices

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Versioning

Version History

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01/10/2025	1.0	Initial version
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Review and Update Requirements

- Review: every 5 years
- Update: as necessary

Contents

1. Purpose

The electric utility industry is experiencing the highest volume of generator interconnections in history as a reaction to climate change and local, state, and federal initiatives. The North American Electric Reliability Corporation (NERC) has issued a recommendation to establish and improve clear and consistent interconnection requirements for bulk power system (BPS) connected inverter-based resources (IBR) [1]. Additionally, the Federal Energy Regulatory Commission (FERC) has issued Order No. 2023 regarding significant overhaul of the interconnection process, as well Order No. 901 regarding changes to NERC Reliability Standards [2] [3].

Generator interconnection requests and studies are the crux of an interconnection project. Study requirements and processes are continually evolving to accommodate IBR technologies. The quantity of interconnection applications, in addition to re-studies required as projects drop out of the process, further complicates the planner's ability to adequately evaluate the resource's impact to the transmission system. Studies are performed throughout the lifecycle of interconnections to identify needed system improvements, resource behavior and interactions, design validation, performance validation, etc. Thorough interconnection study processes must be developed and executed.

The pro forma Large Generator Interconnection Procedures (LGIP) and Large Generator Interconnection Agreement (LGIA) govern the relationship between the transmission service provider (TSP), Transmission Owner (TO), and the interconnection customer (i.e., the generation facility owner), in accordance with FERC rules. However, each TSP and TO have specific needs based on system topology and practices, therefore each TSP and/or TO may submit to FERC amendments and additions to the pro forma requirements. In addition, NERC standard FAC-001 requires that each TO establish and maintain facility interconnection requirements [4].

This document is designed to guide TSPs, Transmission Planners (TP) and TO through the interconnection request and study phase of an IBR interconnection.

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 are 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 planners, system protection, operations planning, transmission support, and tariff administration.

This document focuses on the first step, Interconnection Requests and Studies, of the IBR interconnection lifecycle (**Error! Reference source not found.**). The document describes a roadmap for accepting interconnection applications, administering the cluster process, change management for the cluster, cluster modeling techniques, cluster studies, and interactions with internal and external personnel during the process.

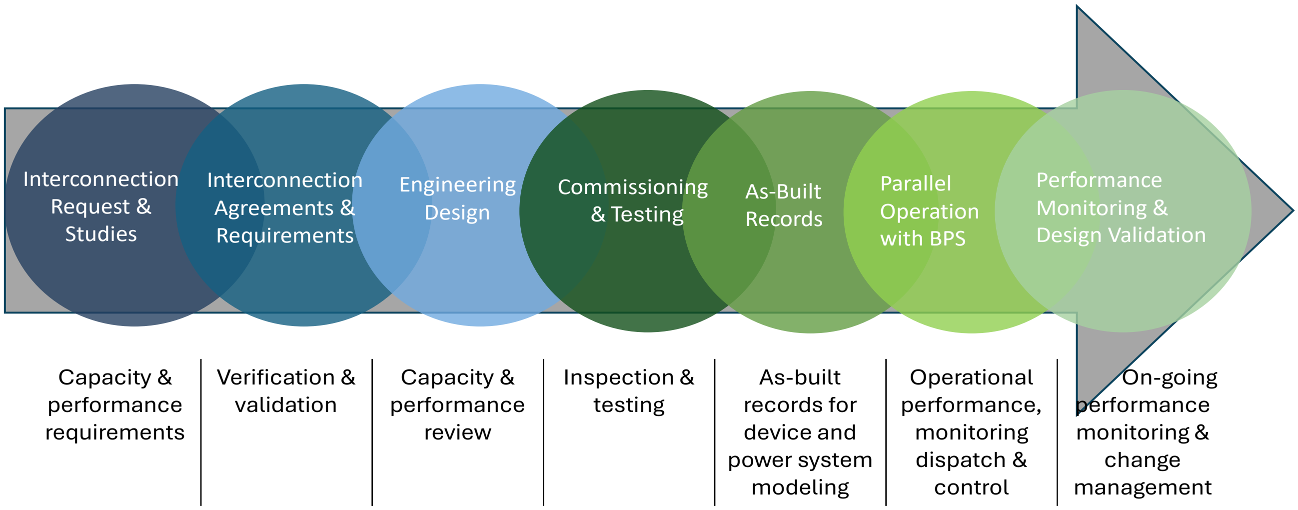

Figure 1. IBR Interconnection Lifecycle

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.

Reference Point of Applicability (RPA)

Location proximate to the IBR connection where the interconnection and interoperability performance requirements are specified [5].

Point of Measurement (POM)

A point between the high-side bus of the IBR and the interconnection system [5].

Point of Interconnection (POI)

A point where the interconnection system connects an IBR to the transmission system [5].

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 [6].

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 [5].

Hybrid Plant

A generating or storage facility that is comprised of multiple types of resources or energy storage systems controlled and operated as a single resource behind a single point of interconnection [5].

Facilities Study

An engineering study conducted by the TSP, based on and including interconnection facilities and network upgrades identified in the cluster study, that details modifications to the TSP's Transmission System required to provide the requested transmission service, including the cost and scheduled completion date for such modifications.

4. Interconnection Request

Navigating the interconnection process for IBR connecting to the BPS involves several crucial stages, each requiring careful consideration and adherence to specific requirements. From understanding interconnection requirements to navigating pre-application procedures, reviewing applications, and managing the interconnection queue, this process demands attention to detail and a comprehensive understanding of regulatory frameworks.

Interconnection Policies and Procedures

LGIP entails rigorous assessments, intricate studies, stringent technical requirements, and extensive coordination to ensure integration of high-capacity resources into the BPS. This process emphasizes reliability and system stability, due to the significant impact of these large resources on grid operations.

NATF Practices

4.1 Develop and maintain an Open Access Transmission Tarriff (OATT) regardless of jurisdiction.

> Jurisdictional utilities, regional transmission organizations (RTO), and independent system operators (ISO) are obligated to have and maintain an OATT in accordance with applicable regulations. Non-jurisdictional utilities, such as federal agencies, municipalities, and rural electric cooperatives should maintain an OATT which resembles that of jurisdictional utilities, with modifications to fit their business practices.

Applications

The application process involves several steps that assist the applicant in decision making and to ensure appropriate data is collected for interconnection studies.

NATF Practices

4.2 Require interconnection applicants to become familiar with state-specific interconnection procedures for state-jurisdictional projects.

4.3 Implement an electronically-accessible interconnection application process.

> This acts as a formal process for the interconnection customer to submit an interconnection application during the open enrollment window.

4.4 Require a fee for the interconnection application.

> The application fee should cover administrative costs to process the application, which includes the cost of all steps preceding the signed cluster study agreement.

4.5 Implement cluster study deposits using the following recommendations:

- Interconnections with a lower capacity (i.e., less than 80 MW) have a base deposit fee and a per MW adder

- Interconnections with a medium capacity (i.e., 80 MW – 200 MW) have a set deposit amount
- Interconnections with a higher capacity (i.e., greater than 200 MW) have a different set deposit amount

> Deposits are established by the individual TSP and should increase with the increase in interconnection request capacity. Deposits should reflect the cost to administer the cluster and perform the studies associated with the application.
>
> The Commission adopted a tiered study deposit framework, as illustrated, in FERC Order 2023 [2].

4.6 Implement cluster withdrawal penalties that progressively increase as a project advances through the cluster process. The withdrawal penalties [2] are the greater of the study deposit or:

- Withdrawal during cluster study or after cluster study report: two times study cost
- Withdrawal during restudy or after restudy report: 5% of network upgrade cost
- Withdrawal during facilities study or after facilities study report: 10% of network upgrade cost
- Withdrawal after executed LGIA or filing of an unexecuted LGIA: 20% of network upgrade cost

> Withdrawal penalties cannot exceed the dollar amount collected from the interconnection customer and withdrawal penalties will not be assessed if the withdrawal does not have a material impact on any interconnection request in the same cluster.

4.7 Develop and maintain a publicly posted interactive database for available capacity (i.e., heatmap) considering the following:

- Distribution factor (i.e., DFAX)
- MW impact based on proposed project size and distribution factor
- Percentage impact on each transmission facility
- Percentage of power flow on each transmission facility before MW injection (i.e., base case)
- Percentage of power flow on each transmission facility post MW injection (i.e., study case)

Application Data

NATF Practices

4.8 Require the following data, at minimum, to be submitted with an Interconnection Request application.

- Net MW injection
- Simplified and/or detailed one-line diagram
- Interconnection tie line characteristics
- Main transformer characteristics
- Collector system equivalent model

- Step-up transformer characteristics
- Inverter data and performance characteristics
- Plant reactive power compensation
- Short circuit contributions

> This is not meant to be an exhaustive list. The interconnection customer should consult the local TSP for exact information and format of information to be provided. Reference [7] provides an example of an interconnection application data form.

4.9 Develop a documented screening process to review the data submitted in the application.

4.10 Develop a database of application information that can be leveraged throughout the interconnection process.

> Additional information on this practice is in Section 9 "Interactions."

Model Requirements

Modeling Package Submittal

The modeling package submitted at the time of interconnection request is intended to represent a planned facility, which should include validated models per FERC Order No. 2023 (see Figure 2).

NATF Practices

4.11 Specify the following model requirements for each interconnection request application:

- A validated power flow model
- A validated short-circuit model
- A validated user-defined RMS positive sequence dynamic model
- An appropriately parameterized generic library RMS positive sequence dynamic model
- Model block diagram of the inverter control system
- Model block diagram of the plant control system
- A validated EMT model

> Each interconnection application for a non-synchronous (i.e., IBR) generating facility should include, at a minimum, the specified models. Each generic model should correspond to a model listed in the most recent NERC table of acceptable models [8] or a model approved by WECC [9].

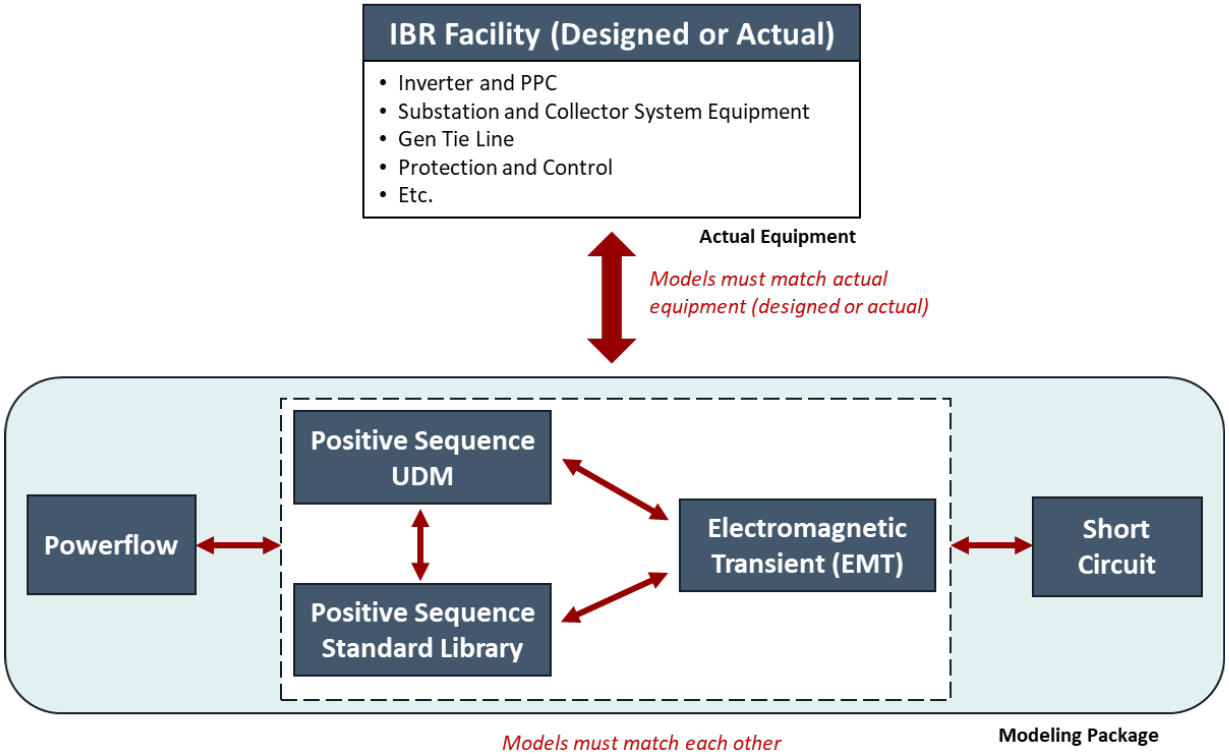

Figure 2 Relationship between the IBR Facility and Modeling Package

Data Collection

NATF Practices

4.12 Require that all data and models submitted with the interconnection application be validated and accompanied by documentation from the facility design work, original equipment manufacturer (OEM) attestations, specification sheets, factory testing or OEM benchmarking, and other data as specified by the TSP.

4.13 Require that all proposed facility changes or requests are accompanied by an updated modeling package.

> All models used to assess reliability should consistently represent the proposed facility throughout the process.

4.14 Ensure that modeling data matches the proposed equipment by using the following checks:

- Inverter

  The inverter specification sheet with configured control modes, settings, and parameters should be site-specific with OEM-supplied attestations. If product configuration, modes, settings, etc. are not finalized at the time of interconnection request, an initial estimate may be provided. However, both parties should understand that any changes made to the inverter that affect the electrical output during steady-state or dynamic events should be re-studied and may have implications for interconnection timeline, particularly as the system impact studies are completed and leading up to the signed interconnection agreement. The interconnection customer should also be required to provide hardware-in-the-loop (HIL) test results or factory test results that demonstrate that the inverter model matches the actual product. The inverter model may include the equivalent pad-mounted transformer model. Both these models can be scaled to represent an entire facility.

- Power plant controller (PPC)

  The PPC specification sheet, with configured control modes, settings, and parameters, should be supplied by the OEM or third-party consultant programming the logic controller. Again, any deviations from the initial interconnection request could require a re-study and affect interconnection timeline.

- Equivalent collector system

  Proposed electrical configuration, one-line diagrams, equivalence calculation, and other information must be provided to ensure that the equivalent feeder model represents the actual proposed facility. Changes to the electrical layout of the facility can affect impedances, losses, and electrical performance and should be evaluated by the TSP.

- Main power transformers

  A specification sheet, transformer test report, or nameplate pictures, of the transformers can be provided including the transformer type, ratings, impedances, tap position, etc. All are used to ensure the models match reality.

- Dynamic or static reactive compensation

  Any dynamic or static reactive devices should also have accompanied documentation to ensure accurate sizing/ratings. Any dynamic reactive devices should also include HIL tests, factory test reports, attestations, or other data from the OEM to confirm the model sufficiently matches the equipment.

- Substation equipment

  Substation equipment is sufficiently represented, including breaker configuration, ratings, etc. The main power transformers in the substation are explicitly modeled and accompanying documentation should include impedance values, winding configuration, tap positions, and other modeled values.

- Generator tie line

  The generator tie line(s) should be explicitly modeled, and sufficient documentation regarding conductor type, impedance, line configuration, and other information should be provided to avoid any incorrect line model values.

- Protection and controls

  All applicable protection and controls, including any communication delays between devices and controllers throughout the system, should be represented appropriately within the models or using supplemental models. The TP may want to explicitly specify the types of protection and controls to be modeled so that nothing is missing from the models supplied by the interconnection customer. The protection and controls may be in the inverter, PPC, supplemental reactive devices, feeder or substation equipment, etc.

The interconnection customer should gather documentation from the OEM(s) regarding internal protection and control settings so those can be passed to the TSP for verification purposes. This includes models such as positive sequence user defined model (UDM) or the EMT model. The TO or AGIR should specify this in their requirements, otherwise the interconnection customer will have difficulty gathering this information from the OEM, leaving all parties with insufficient understanding of the internal protection and control settings.

5. Interconnection Cluster

The interconnection queue is a critical component of the interconnection process by which new power generation projects (i.e., solar, storage, wind, synchronous machines, etc.) connect to the BPS. Projects in the interconnection queue have submitted an interconnection request application and associated data that meets the requirements set by the transmission owner to which they are connecting.

FERC Order No. 2023 focused on reforming the interconnection process used by TSPs to study and connect generating facilities to the transmission system. These reforms included changes to the pro forma Generator Interconnection Agreements (GIA) and Procedures (GIP) [10] [11]. The order addressed a few broad categories of reform:

- Transitioning from a serial interconnection process to a “first-ready, first-served” cluster study approach, increasing financial readiness as well as demonstration of site control. Figure 3 illustrates the updated interconnection process, as reported by Berkeley Lab [12].
- Expediting the overall interconnection queue processing time by shortening study times and eliminating the “reasonable efforts” standard for TSPs to complete interconnection studies and replacing it with firm study deadlines and penalties for delays.
- Incorporating technological advancements that allow for the addition of co-located resources at a single point of interconnection, require the TSPs to assess alternative technologies to enable generation interconnection, and modeling and performance requirements for non-synchronous (IBR) generating facilities.

Generator Interconnection Minimum Cluster Process

NATF Practices

5.1 Establish an interconnection cluster queue that includes, at a minimum, the following processes

- Enrollment window (45 calendar days)
- Customer engagement window (60 calendar days)
- Cluster study (150 calendar days)
- Affected-systems study (150 calendar days, if required)

- Re-study (150 calendar days, if required)
- Facility study (90 calendar days [+/- 20% estimate] or 180 calendar days [+/- 10% estimate])[1]
- Interconnection agreements

FERC Order No. 2023 requires interconnection processes to adopt a "first-ready, first served" approach. Adoption of the cluster eliminates the "first-come, first-served" approach known as the serial cluster. Furthermore, FERC Order No. 2023 has set firm study deadlines as illustrated in Figure 3.

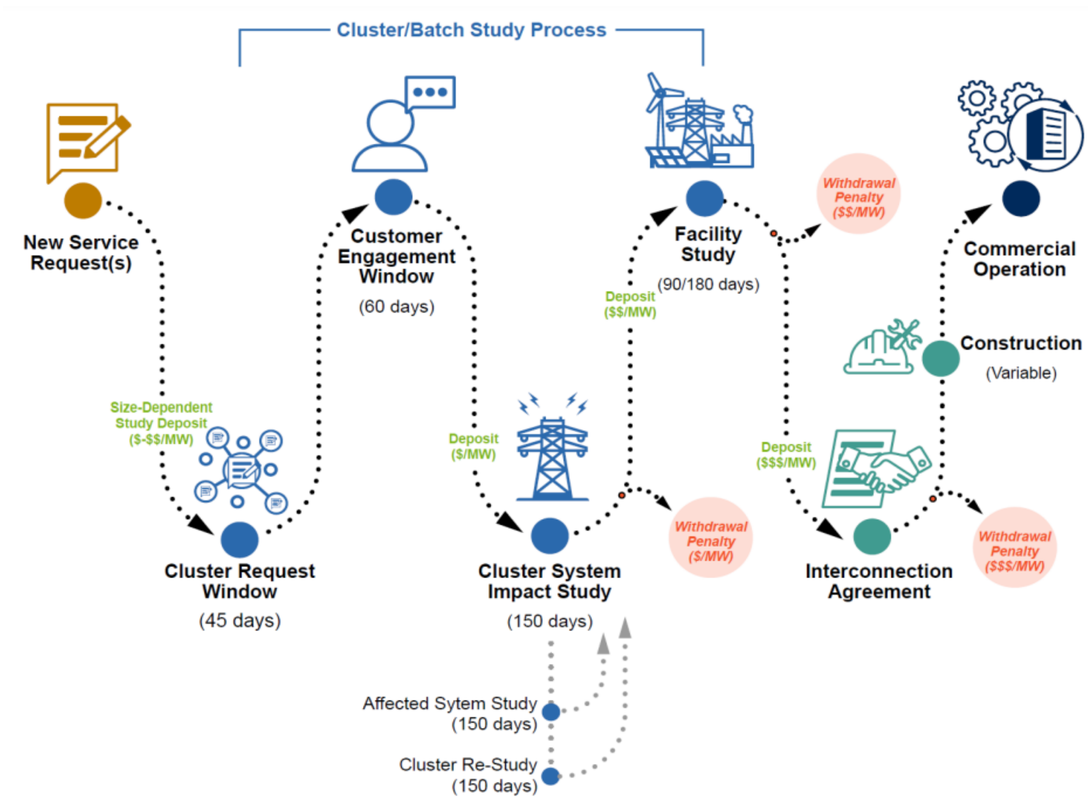

Figure 3. FERC Generator Interconnection Queue Process [12]

Generator Interconnection Enhanced Cluster Process

Many TSPs have developed interconnection cluster processes that have a multiphase structure. This structure is efficient and seen to be superior to the Pro-Forma structure outlined in FERC Order 2023. FERC Order 2023 [2] allows deviations from the Pro-Forma structure via paragraph 1764, which states the following:

"Consistent with Order Nos. 888, 890, 2003, 2006, and 845, we adopt the NOPR proposal to continue to apply the "consistent with or superior to" standard when considering proposals from non-RTO/ISO TSPs to deviate from the

[1] The interconnection customer can select from two facility study processes. A shortened facility study (i.e., 90 calendar days) will deliver a level of accuracy that assumes +/- 20% error in facilities and costs estimates. A full facility study (i.e., 180 calendar days) will deliver a level of accuracy that assumes +/- 10% error in facilities and costs estimates.

requirements of this final rule. Consistent with Order Nos. 2003, 2006, and 845, we adopt the NOPR proposal to continue to use the "independent entity variation" standard when considering such proposals from RTOs/ISOs. Consistent with Order Nos. 888, 890, 2003, 2006, and 845, we adopt the NOPR proposal to continue to allow non-RTO/ISO TSPs to use the regional differences rationale to seek variations made in response to established reliability requirements. In this final rule, we make no changes to the standards used to judge requested variations, as described in Order Nos. 888, 890, 2003, 2006, and 845."

NATF Practices

5.2 Enhance the interconnection queue process considering the following steps (Figure 4):

- Enrollment window (45 calendar days)

  A new cluster cycle kicks off each year where generators and resources enroll/request interconnection. Interconnection request applications can be taken any time during the enrollment window. The TSP acknowledges receipt of the application and provides any deficiency notice within five business days. The applicant must cure any deficiencies within 10 business days or the closing of the enrollment window, whichever comes first.

- Phase 1 - customer engagement window (60 calendar days)

  The phase 1 customer engagement window is designed to discuss project specifics with each applicant and ensure appropriate data is submitted to accompany the interconnection request.

- Phase 1 - studies (90 calendar days)

  Phase 1 studies include steady state power flow and voltage analysis. This phase may also include advanced analysis such as stability, short circuit, and EMT. However, depending on the volume of interconnection applications in the cluster, a phase 2 study approach may be included.

  > Phase 1 study results are presented to the interconnection customer before proceeding to phase 2 studies.

- Phase 2 - customer engagement window (30 calendar days)

  The phase 2 customer engagement window is designed to discuss project specifics with each applicant and ensure appropriate data is submitted to facilitate the phase 2 studies.

- Phase 2 - studies (150 calendar days)

  A phase 2 study approach includes more in-depth analysis such as stability, short circuit, and EMT when deemed applicable.

- Phase 3 customer engagement window (30 calendar days)

  The phase 3 customer engagement window is designed to discuss results from phase 2 studies, deliver facilities study agreements, and determine if any cluster positions drop out of the cluster.

- Phase 3 - re-study (150 calendar days)

  This phase is only required when a re-study of the cluster is identified. This process includes a re-study of phase 1 and phase 2 analysis where applicable.

- Phase 4 - individual facilities studies (90 calendar days [+/- 20% estimate] or 180 calendar days [+/- 10% estimate])

  The facilities study identifies individual project site requirements and network transmission requirements where applicable.

- Interconnection Agreement (IA)

  Interconnection Agreements are drafted and supplied to the interconnection party for review for both state and federal jurisdictional projects.

> The phases and duration may vary slightly based on the allocation of resources and responsibilities of the TSP, ISO, or RTO.

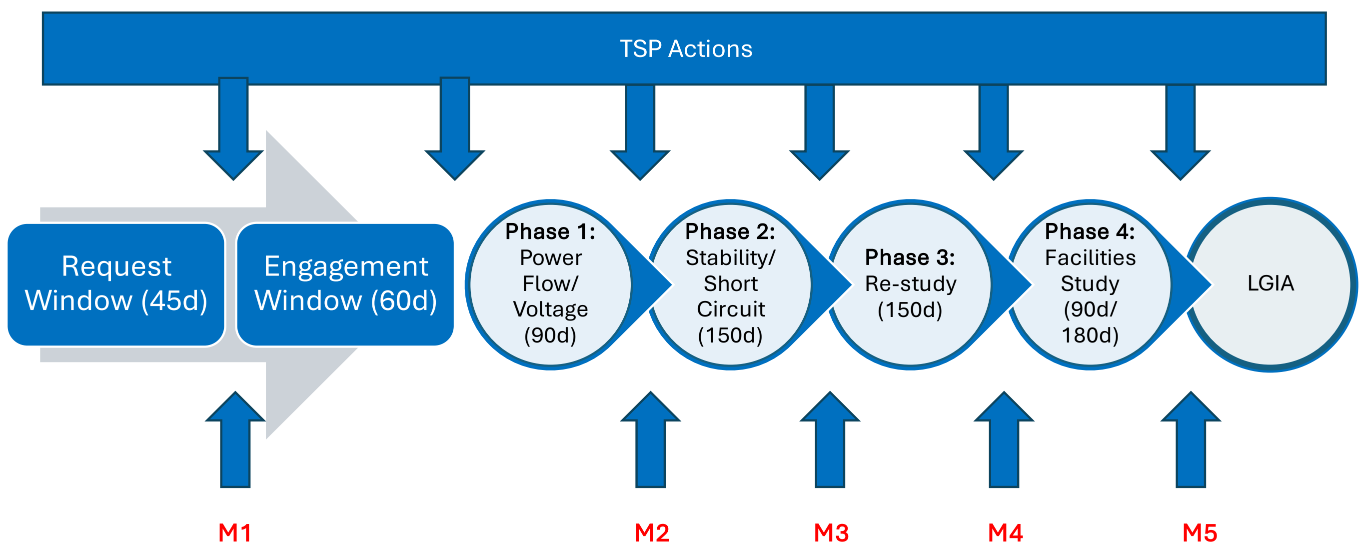

Figure 4. Enhanced cluster process

5.3 Institute measurable TSP actions between each phase of the interconnection process.

- TSP action 1

  When the interconnection request window closes, each application has been reviewed for completeness and correctness. Any applications that have not cured identified deficiencies or posted the application fee will be withdrawn by the developer or rejected by the TSP.

  The TSP prepares for the engagement window by providing the Interconnection Customer with a cluster study agreement and scheduling a cluster scoping meeting with Interconnection Customer. The cluster study agreement must be executed before the close of the engagement window.

The TSP can begin development of power flow cases and study files to facilitate the phase 1 thermal and voltage assessment.

- TSP action 2

  When the engagement window closes, any cluster study agreements that have not been executed and returned to the TSP shall be deemed withdrawn from the cluster.

  At this point, the study phases officially begin, and withdrawal penalties take effect.

- TSP action 3

  At the close of phase 1, thermal and voltage assessments of the cluster are complete. System constraints and associated system upgrades or reinforcements have been identified as well as non-binding cost estimates.

  The TSP holds a Phase 1 Customer Engagement window (e.g., 30 calendar days) and host an open meeting (i.e., Phase 1 Report Meeting) with Interconnection Customer within 10 business days of publishing the Phase 1 study results.

  The TSP moves forward with starting Phase 2 study development and execution. The Interconnection Customer has a grace period (e.g., 20 calendar days) after the open meeting to satisfy Milestone 2 requirements to proceed to Phase 2 of the cluster process.

  If Interconnection Customer withdrawals are significant enough to reassess the Phase 1 thermal and voltage assessment, the TSP should provision the Phase 2 process to include this reassessment.

Many of the network upgrades will be identified in the thermal and voltage assessments. Therefore, providing the Phase 1 study results earlier in the process gives Interconnection Customers an earlier opportunity to decide to continue or withdraw. This decision point benefits the customer by limiting the study costs, and if a choice is made to withdraw, it benefits the overall cluster by allowing the TSP to adjust study work earlier in the cluster process.

- TSP action 4

  At the close of phase 2, advanced (i.e., stability, short circuit, etc.) assessments of the cluster are complete. System constraints and associated system upgrades or reinforcements have been identified as well as non-binding cost estimates.

  The TSP holds a Phase 2 Customer Engagement window (e.g., 30 calendar days) and hosts an open meeting (i.e., Phase 2 Report Meeting) with Interconnection Customer within 10 business days of publishing the Phase 2 study results.

  If one or more Interconnection Customers withdraw from the cluster, the TSP shall determine if a phase 3 re-study is required.

If a phase 3 re-study is not deemed required, the TSP shall notify the Interconnection Customer that phase 3 is not required and provide a Facilities Study Agreement to the Interconnection Customer. At this point, the cluster process will advance to phase 4 Facilities Study.

If a phase 3 re-study is deed required, the TSP shall notify the Interconnection Customer that phase 3 is required. At this point, the cluster process will advance to phase 3 re-study.

> The primary objective of action 4 is to determine the need for phase 3. If phase 3 is required, the TSP has 150 calendar days to complete the analysis.

- TSP action 5

  If phase 3 is not required, no additional TSP actions are needed at this step.

  If phase 3 is required, the results of the phase 3 assessment shall identify the Interconnection Facilities and Network Upgrades expected to be required to reliably interconnect the Generating Facilities in that cluster and shall provide non-binding estimates for the required upgrades. The Phase 3 Report shall identify each Interconnection Request's estimated allocated costs for Interconnection Facilities and Network Upgrades.

  The TSP holds a Phase 3 Customer Engagement window (e.g., 30 calendar days) and hosts an open meeting (i.e., Phase 3 Report Meeting) with Interconnection Customer and identified Affected System Operators within 10 business days of publishing the cluster Phase 3 results.

  The TSP shall notify Interconnection Customer that no further re-studies are required and simultaneously provide a Facilities Study Agreement.

- TSP action 6

  At the close of phase 4, draft interconnection Facilities Study reports are delivered to Interconnection Customer. The TSP holds a grace period (i.e., 30 calendar days) for the Interconnection Customer to provide written comments on the study report. The TSP shall issue the final report within 15 business days of receiving Interconnection Customer comments or notice of no comments.

> The TSP actions between phases are there for the TSP to deliver a report for each phase, hold a results meeting, and give some time for Interconnection Customer to make decisions. The time allotted to results meetings and decision-making overlaps with the cluster study phase timelines and should be strictly adhered to.

5.4 Institute measurable milestones for Interconnection Customer between each phase of the interconnection process

- Milestone 1 (M1)

  At the close of the engagement window the following items must be fulfilled by the Interconnection Customer; any interconnection request not deemed sufficient shall not be included in the cluster:

  - Competed application and application fee

- Study deposit
- Demonstration of site control
- Generating facility capacity (MW)
- Requested interconnection service level (MW)
- Validated modeling package
- Operating assumptions and limitations
- Reference Point of Applicability (RPA)
- Service type (i.e., Network Resource Interconnection Service [NRIS] or Energy Resource Interconnection Service [ERIS])
- Signed system impact study agreement

> When the engagement window closes the study phases begin. The important step here is that this is the point where withdrawal penalties are applicable.
>
> 90% site control is required. A deposit in lieu of site control is allowed only when regulatory restriction prevents acquiring site control.

- Milestone 2 (M2)

  Interconnection Customer must supply 5% of identified network upgrade cost within 20 consecutive days of the Phase 1 report meeting to continue in the cluster.

- Milestone 3 (M3)

  Interconnection Customer must supply 10% of identified network upgrade cost within 20 consecutive days of the phase 2 report meeting to continue in the cluster

- Milestone 4 (M4)

  Interconnection Customer must supply 15% of identified network upgrade cost within 20 consecutive days and an executed facilities study agreement to continue in the cluster

- Milestone 5 (M5)

  Interconnection Customer must supply 20% of identified network upgrade cost within 20 consecutive days of the facilities study report to proceed to the interconnection agreement phase

  Interconnection Customer must demonstrate 100% site control to enter the interconnection agreement phase.

5.5 Publicly-posted cluster queue should contain, at a minimum, the following:

- Requested capacity
- Location by county and state
- Location of interconnection by transmission station, line, and lines

- Projected in-service date
- Type of interconnection service requested
- Type of generating facility or facilities
- Type of fuel

> Publicly posted interconnection data should be anonymized so as not to disclose sensitive information related to the interconnection applicant. Data for the new cluster should be posted within the first 10 business days of the engagement window.

6. Cluster Process Change Management

It is important that the model used in studies accurately reflects the most up-to-date information about the facility seeking interconnection. Any updates to the facility information must be reflected in the modeling package so that new or updated evaluations can be conducted by the TSP.

NATF Practices

6.1 Modeling requirements, at a minimum, should address the following:

- Initial modeling package

  This defines what must be submitted as part of the interconnection request and is linked directly to the requirements established in FERC Order No. 2023. The TSP should specify the details of which model types are required, the level of detail, and how the package will be assessed by the TSP. As described in this section, this package should also include all associated documentation, a performance conformity test report, a model quality checklist, and a model benchmarking report.

- Modifications for permissible technological advancements

  These sections of the LGIP and associated business practice manuals should clearly and explicitly define the obligations and process for updating the modeling package for any changes made to the facility. Any change that affects the electrical behavior of the facility should require a resubmittal of the modeling package so that the new performance can be adequately evaluated. This could include change in MW capacity, change in equipment selection, change in electrical topology/configuration, change in inverters or turbines, change in control or protection settings, and other factors.

- Re-evaluation process

  For any modifications that require a resubmittal of the modeling package, the requirements should explicitly define how the changes will be evaluated by the TSP. This should include, at a minimum, some language giving the TSP the authority to re-evaluate (whether by study or engineering judgment) how the proposed changes will affect BPS reliability and whether that results in a material modification, the need for re-study, or a more simplified assessment by the TSP.

- Signed GIA locking down equipment selection

  The signing of the interconnection agreement defines the finalized agreement between entities regarding the requirements, obligations, and responsibilities on both sides. The modeling requirements can point to the GIA and highlight that the agreement, in essence, locks down the expected delivery of a product/capability which cannot be further modified without breaching the agreement. This gives the TSP some authority to baseline the expectation of models at this point in the process and hold the interconnection customer accountable for changes made thereafter that differ from what is studied.

> The interconnection request is governed by the modeling and study requirements established. Having accurate, clear, consistent, and comprehensive modeling requirements is a critical aspect of addressing the known systemic IBR risks.

Qualified Change

Interconnection Process

NATF Practices

6.2 Define a process to identify where qualified changes to the interconnection require further evaluation or constitute a re-study, using Table 1 as a guide.

Table 1 Re-Evaluation and Re-Study Considerations

Re-Evaluation (no Re-Study)	Re-Study
• Inverter or PPC software version update, with little/no impact on electrical controls • Minor[2] changes to collector system impedance • Minor ride-through settings changes (improvements) • Minor change in inverter control settings (e.g., droop setting, deadband, etc.)	• Change plant capacity, design, configuration, or type • Change plant RPA or connection design • Change inverter OEM or model number • Significant changes to inverter control mode or settings (e.g., voltage control gains, time constants, etc.) • Significant changes to inverter ride-through or protection settings • Significant changes to PPC control mode or settings • Add or remove dynamic reactive elements (e.g., D-STATCOM) • Significant changes to collector system, transformer, or generator tie line impedances

> Table 1 is meant to be used as a guide and is not an exhaustive list of considerations for re-evaluation or re-study. The TSP should develop and maintain their own list of change scenarios.

[2] The term “minor” in this column implies that the changes have very small (insignificant) or no impact on the electrical behavior of the IBR plant.

Existing Generation

NATF Practice

6.3 Define a process to identify qualified change to existing interconnections and generation, using table 2 [13] as a guide.

Table 2 Qualified Change for Generation

Category	Examples from NERC Implementation Guidance
Change in generator output	Change that affects the Seasonal Real Power or Reactive Power capability by more than 10 percent of the last reported and/or verified capability and change is expected to last more than six months. Change in power factor capability of the generator
Change of GSU	Change of GSU that results in any of the following differences: • Reduction in rating by more than 10% • Impedance change by more than 10% o Change in transformer losses o Change in transformer saturation differences
Change in generator characteristics	Change in the inertia of the generator by more than 10% (synchronous generators only) Change in steady state transient and sub-transient reactance of the generator or generator Interconnection Facilities by more than 10% (synchronous or induction generators only) Transmission Planner requested generator facility projects in MOD-027 or MOD-026 resulting in changes that alter the equipment response characteristic. Changes to a generator's electromagnetic transient models Change of 5% or more of the plant to an alternate production profile
Change in protection system of the generator facilities or generator interconnection facilities	Changes in relay settings where changes or limitation are required in PRC-024 R3 to be reported to TP and Planning Coordinator within 30 days. • include high and low frequency protection settings along with delay times if applicable • include high and low voltage protection settings along with delay times if applicable
IBR only: Change in inverter or inverter settings or change in the power plant controllers	Change of 10% or more of the IBR units at a facility that is not replacement in-kind Adding 5% or more battery energy capacity Changes to inverter settings are communicated to the TSP. The TSP reviews and determines if actions are needed to address the changes.

Category	Examples from NERC Implementation Guidance
	Change to any power plant controller setting or firmware resulting in a difference in: • frequency or voltage support of the IBR • a difference in when the IBR discontinues current injection BPS (i.e., blocking commands)

Table 2 is meant to be used as a guide and is not an exhaustive list of qualified change. The TO should develop and maintain their own list of qualified changes.

7. Interconnection Modeling

A critical component of establishing interconnection requirements is ensuring that comprehensive, clear, consistent, and applicable modeling and study requirements are also established. The interconnection studies serve a critical role in ensuring reliability of the BPS according to the reliability requirements of the TO, NERC, and associated regional reliability organizations, and define whether an interconnection customer is allowed to connect and the associated network upgrades required to enable that interconnection.

Model Quality Test

Once the models and accompanying documentation have been collected and verified, the models must undergo quality tests to ensure they adequately function in the simulation tools.

NATF Practices

7.1 Develop robust model quality requirements and checks.[3]

The following list of model quality checks should be incorporated into requirements:

- User-settable control modes and settings are accessible in the model and well-documented (e.g., protection settings, ramp rates, ride-through thresholds, dynamic active/reactive power controls, etc.).
- The model can meet minimum simulation time step requirements and operate across a range of time steps.
- Flags and setpoint signals are available to the user for debugging purposes.
- The inverter and PPC models interact with each other seamlessly and there are no interoperability issues. This is particularly important when supplied by different OEMs/parties.
- The models initialize properly.
- The model meets software version, dynamic link libraries (DLL), and/or complier requirements and compatibility.
- The model passes initialization checks and does not flag any built-in checks within the software platform.

[3] For example, Electranix [20] maintains a publicly-available and regularly updated PSCAD Model Requirements document:

Model Performance Conformity Test

The submittal of a modeling package should also include a test report that ensures that the plant, on its own, meets the performance requirements established. Those requirements will involve adoption of IEEE 2800 performance requirements and/or TSP specific requirements.

NATF Practices

7.2 Studies should be conducted by the Interconnection Customer prior to submitting the interconnection request.

The Interconnection Customer can conduct these studies with a single machine infinite bus (SMIB) test system using either:

- A specified Thevenin impedance
- Specified system strength and X/R ratio.

> The TSP can specify a range of system strengths (or one as the minimum) to be used for these studies; however, it is possible to consider a minimum short circuit ratio (SCR) and a much higher SCR value to be tested as bookends.

7.3 Performance conformity tests should be well-defined by the TSP to standardize how the interconnection customer is expected to demonstrate conformity with the requirements.

7.4 Performance conformity tests should satisfy the following:

- Does the IBR respond with appropriate fault current levels during fault conditions?
- Does the IBR dynamically respond with the active and reactive current priority and dynamic active and reactive power recovery times?
- Does the IBR appropriately ride through the voltage and frequency ride-through curves?
- Does the IBR appropriately ride through the maximum phase angle jump and rate-of-change-of-frequency (ROCOF) conditions?
- Does the IBR stably and reliably respond to large signal voltage and frequency disturbances with sufficient oscillation damping?
- Are there any undesirable controller interactions between the inverter and PPC?
- Is the transient response to unbalanced faults accurately represented in the EMT model?

> The performance conformity tests should be demonstrated using both root mean squared (RMS) positive sequence stability model(s) and EMT model(s) to prove that the plant reliably operates and meets the performance requirements in both domains.

Dynamic Model Benchmarking

Different dynamic models (i.e., positive sequence standard library model, positive sequence UDM, and EMT model) should match,[4] this can be verified with dynamic model benchmarking. Simulation tool limitations need to be considered when demonstrating, reviewing, and approving model benchmarking reports.

NATF Practices

7.5 Perform a qualitative review of the dynamic response by applying disturbances[5] across models. Characteristics to check include:

- The models generally behave similarly when subjected to voltage, frequency, and phase angle jump tests
- Any protective functions operate similarly across models
- The dynamic active and reactive current (and power) responses follow the same general trend during and immediately following fault conditions
- Stability performance (damping, oscillatory behavior, etc.) generally matches and any anomalies are explained thoroughly
- Post-event steady-state conditions match
- The responses of the models overlay on top of one another with sufficient precision

> EMT models are expected to have a significant amount of additional modeling detail included (inner control loops, phase-based protection, etc.) which may not be represented in the positive sequence models. Additionally, the positive sequence models assume a balanced 3-phase system, so they cannot accurately represent unbalanced faults.

7.6 Document and explain all discrepancies or limitations between models.

> There may be discrepancies between models given the level of detail and capability of each model type; however, clear documentation should be kept so that the TSP is aware of these limitations when conducting reliability studies.

EMT Modeling and Screening

NERC has published guidance and is in the process of modifying standards related to EMT modeling for newly connecting IBRs. Accurate and validated EMT models should be required for all newly connecting IBRs as part of the interconnection study process [8] [14]. However, there is less clarity regarding situations where TSPs and Planning Coordinators should be conducting EMT studies and the timing of such EMT studies during the interconnection study process. The NERC EMT Task Force (EMTTF) is presently working on draft guidance in this area; however, it does not address the interconnection queue process directly [15].

[4] Different dynamic models should match to the extent feasible given software limitations and model fidelity.

[5] Disturbances as defined in practice 7.4 or as defined by the Transmission Provider

NATF Practices

7.7 Establish an EMT model screening criteria that considers, at a minimum, the following:

- Low short circuit strength
- Penetration level of IBRs within a localized area, zone, or region
- Proximity of series capacitors and potential for sub-synchronous control interactions
- Proximity of critical loads and other critical BPS connections, such as high voltage direct current (HVDC) converters

> If any of the criteria are met, then a detailed EMT study may be needed for the interconnecting IBR. For example, an IBR connecting to a weak grid or near a series capacitor should have an EMT study performed as part of the interconnection study process to ensure no reliability risks exist. Increasing levels of IBRs are putting a strain on conventional phasor domain positive sequence stability tools, and therefore EMT studies will likely be increasingly needed over time.

8. Interconnection Studies

The interconnection studies are governed by the timeline set forth in the cluster process. These studies are intended to identify system limitations and system improvements to uphold the integrity of the BPS.

Steady State Analysis

NATF Practices

8.1 Base cases should be developed to represent all planning projects over the specified time horizon (i.e., 10 years).

> Base cases are the starting point, representing the system as is, and are used to evaluate the interconnection request. These cases can start from regional development (i.e., Multiregional Modeling Working Group [MMWG]) and then be further enhanced with more detailed models for the local system being studied.

8.2 Perform steady state thermal and voltage assessments considering the following:

8.2.1 Selected contingencies

Studies are performed for normal and contingency conditions in accordance with NERC Reliability Standard TPL-001 [16] or more stringent criteria as set by the TSP’s local planning criteria. The thermal and voltage guidelines should not be violated for either normal operations or under the loss of:

- Single transmission circuit
- Single transformer
- Single generating unit

- Single reactive power source or sink
- Combination of a single generating unit and single transmission circuit, capacitor bank, or transformer
- Combination of two generating units
- Select P6 contingencies
- Select P7 events within region

> Abnormal single contingencies can exist and should be included as defined based on system topology and relaying designs.

8.2.2 Use the following guidelines to ensure acceptable thermal loading:

- Under normal conditions, no facility should exceed its continuous thermal loading capability
- With a transmission contingency having an expected duration of less than 12 hours (line outage or single-phase transformer outage where spare is available), no facility should exceed its 12-hour emergency loading capability.
- With a capacitor, transformer (three phase or single phase with no spare) or generator contingency having an expected duration of more than 12 hours, no facility should exceed its long-term emergency loading capability.

8.2.3 Use the following guidelines to ensure acceptable system voltage:

- Voltage limits defined by a minimum (e.g., 95%) and maximum (e.g., 105%) allowable voltage as percentage of the nominal voltage
- Voltage drop under contingency conditions has a maximum decrease (e.g., 5%) as percentage of the nominal voltage not to exceed the voltage limits
- Autotransformer voltage limits are based on the secondary tap setting. The minimum voltage is 95% of the tap voltage and the maximum voltage is 105% of the tap voltage under full load and 110% of the tap voltage under no load.

8.3 Perform power transfer assessments with a minimum import and export first contingency incremental transfer capability (FCITC) limit to be maintained in accordance with applicable reserve sharing requirements.

Dynamic Stability Analysis

The stability of the TSP's system and neighboring systems must be maintained for the contingencies specified in the applicable sections of NERC Reliability Standard TPL-001 or more stringent criteria as set by the TSP's local planning criteria.

NATF Practices

8.4 Update dynamic data files to include dynamic models provided by the interconnection customer(s).

8.5 Include dynamic models of all projects to be considered in the study, using the following as guide:

- Create dynamic stability contingencies for the BPS as required per NERC Reliability Standard TPL-001-5 or more stringent criteria.
- Perform dynamic stability analysis for each case.
- Analyze and compare the results to determine the impact of the interconnecting queue on the Transmission System.
- If necessary, perform additional analysis to ensure the interconnecting queue does not impact any existing RAS.

8.6 Perform dynamic stability assessments considering the following:

- All machines in the interconnected system shall remain in synchronism as demonstrated by their relative rotor angles.
- System stability is evaluated based on the damping of the relative rotor angles and the damping of the voltage magnitude swings.
- System damping is assessed visually with the aid of stability plots. All oscillations that do not show positive damping within 30 seconds after the start of the studied event are deemed unstable.
- Following fault clearing, the voltage shall recover to 80% of the pre-contingency voltage within 20 seconds of the initiating event for all TPL-001 P1 through P7 events, for each applicable BPS bus serving load.
- Following fault clearing and voltage recovery above 80%, the voltage at each applicable BPS bus serving load shall neither dip below 70% of pre-contingency voltage for more than 30 cycles nor remain below 80% of pre-contingency voltage for more than two seconds, for all TPL-001 P1 through P7 events.
- P6 transient stability runs will be performed by applying a one second delay between the first and second outages to allow the system an opportunity to adjust.
- If a result from the study case violates any of the criteria, the base case transient stability analysis is run for comparison to determine if the issue was pre-existing or caused by the interconnection of the project.

8.7 Perform additional transient stability analysis considering the following:

- Voltage criteria violations
- Load tripping by load shedding relays
- Generator tripping by generic generator protection
- Generator tripping by voltage and frequency protection
- Visual checks of transient simulation plots

NATF Superior Practices

8.8 Post-transient analysis can be performed to determine if adequate reactive power margins are retained post-project. The following criteria are used to evaluate post-transient stability performance:

- All P0 – P2 events (as well as selected P3 – P7 events) shall demonstrate a positive reactive power margin at a minimum of 105% of forecasted peak system load.
- If any P0-P2 result demonstrates a negative reactive power margin at the 105% load level, the pre-project post-transient stability analysis is run for comparison to determine if the issue was pre-existing or caused by the interconnection request.
- If any P3-P7 events demonstrate a negative reactive power margin at the 105% load level, the analysis is rerun at a 102.5% load level before running the analysis on the pre-project case.
- Steady-state voltages at all monitored buses shall stay within each of the following limits, or within limits determined by the TSP or TO local planning criteria:
    - 95% to 105% of nominal for 230 kV buses and 100% to 110% of nominal for 500 kV buses for P0 – P1 events.
    - 90% to 110% of nominal for 230 kV buses, 95% to 110% of nominal for 500 kV buses for P2 – P7 events.

Short Circuit Analysis

NATF Practices

8.9 Perform short circuit assessments to ensure fault currents do not exceed a set percentage of the breaker's rating as defined by the TSP's local planning criteria. Consider the following conditions for each breaker evaluation:

- single phase-to-ground fault
- three phase-to-ground fault
- fault resistance assumed to be zero
- location of fault assumed to be at terminals of the breaker in question
- all elements in-service as planned
- all breakers at a bus in service
- breakers taken out, one at a time
- line mutual impedance included
- all generation online
- adjacent system fault contributions included
- linear network solution used to determine the pre-fault voltage

8.10 Determine the impact of an interconnection by comparing the short circuit fault currents between the post-project and pre-project cases. Use the following as a guide:

- buses with breaker duties exceeding 95% of the interrupting capabilities as a direct result of the project.
- buses with breaker duties increased by 2% of the interrupting capability as a direct result of the project.

Facilities Study

NATF Practices

8.11 Perform a facilities study or engineering assessment. This study quantifies the cost estimates, work scope, and tentative schedule associated with the design and installation of all required interconnection facilities and network upgrades. Consider the following:

- Interconnection facilities that are directly associated with the new generation. This includes cost estimates, work scope, and schedule. The work scope can be broken down into interconnection facilities that are required to support the interconnection (i.e., substation layout, relays, controls, communications, and relay house or enclosure).
- Network upgrades assigned[6] to the interconnection including cost estimates, work scope, and schedule.
- Network upgrades allocated to the interconnection including cost estimates, work scope, and schedule.
- Contingent facilities required to be completed before the interconnection can be placed in-service

> The facilities study report should also include connection requirements as defined by the TSP. An example facilities study report can be found in reference [17].

Power Factor Analysis

NATF Practices

8.12 Perform a power factor assessment to ensure the interconnection customer meets the minimum specified requirements [18]. The following method can be utilized for this assessment.

- Record the base case bus voltage.
- Model the generator with zero reactive capability at full output.
- Turn off shunt devices.
- Model two fictitious synchronous condensers with infinite reactive capability: one at the terminal bus of the unit regulating the bus voltage to 1.0 p.u. and one at the high side of the generation substation regulating the RPA to the base case voltage level.
- The amount of plant losses can be determined by adding the MVAr flow at the high side of the generation substation and the sum of the fictitious synchronous condenser output. Based on the maximum output of the plant, determine the minimum reactive capabilities required to meet the 0.95 leading and lagging power factor range. The sum of the two determines the maximum amount of reactive support the project must provide.

[6] Assigned network upgrades are network facilities required to enable the interconnection. These network facilities are only required for the specific project. Allocated network upgrades are network facilities that are also required to enable the interconnection, however allocated facilities are required by more than one interconnection project in the cluster and therefore the cost of the allocated network upgrades is shared among those interconnection projects.

Electromagnetic Transient (EMT) Analysis

NATF Practices

8.13 EMT analysis should only be performed once final equipment has been selected and the EMT models can be fully validated with attestations and supplemental materials supplied by the OEM.

> Selection of inverter make, model, and control decisions are very important for grid stability analysis under the conditions outlined in practice 7.7. Therefore, it is not appropriate to conduct EMT studies using "generic" information that does not reflect actual equipment. Any necessary EMT studies can be run in parallel with the conventional phasor domain positive sequence stability studies. However, the cluster study window is rather tough to adhere to for detailed EMT studies, particularly in areas involving multiple IBRs and complex grid stability issues. Therefore, processes may need to be adapted to allow for sufficiently detailed EMT studies to further inform potential network upgrades for some IBR projects.

Reliability Study Considerations

TSPs should proactively prepare for future challenges that may arise due to high IBR penetration. Industry can learn from the experience and expertise of systems with relatively high IBR conditions and adapt requirements, processes, tools, and technology proactively to avoid the same challenges.

NATF Practices

8.14 Energy Resource Interconnection Service (ERIS)

Energy Resource Interconnection Service allows the Interconnection Customer to connect to the BPS and be eligible to deliver energy using the existing firm or non-firm capacity of the Transmission System on an "as available" basis.

The assessment process for an interconnection customer requesting ERIS is consistent with the cluster studies outlined in section 8 to the extent the assessment will identify the following:

- Direct interconnection facilities
- Network upgrades necessary to address short circuit issues associated with the Interconnection Facilities.
- Necessary upgrades to allow full output of the proposed generator
- Maximum allowed output, at the time the study is performed, of the proposed generator without requiring additional network upgrades.

8.15 Network Resource Interconnection Service (NRIS)

Network Resource Interconnection Service allows the Interconnection Customer to connect to the BPS and deliver the full output of the proposed generator.

The assessment process for an Interconnection Customer requesting NRIS is consistent with the cluster studies outlined in section 8. Furthermore, the assessment shall be conducted in a manner comparable to that in which the TSP integrates its generating facilities to serve native load customers or in an ISO/RTO with market-based congestion management, in the same manner as network resources.

8.16 Evaluate potential ancillary services provided by the interconnection customer which may include but are not limited to the following:

- scheduling, system control and dispatch
- voltage support
- regulation and frequency response
- black start capability

> Ancillary services support the transmission of energy from resource to load while maintaining reliable operation of the BPS. For additional information see [19].

8.17 In all cases the point of interconnection limit shall not be exceeded during normal operations. Data shall be provided to the TSP that explicitly shows the power output from each resource. Energy storage resources that create bi-directional power flow require separate points of measurement behind the single point of interconnection.

9. Interactions

Effective communication and interactions with subject matter experts (SMEs) and stakeholders throughout the interconnection process is a key element of success. SMEs possess specialized knowledge that can enhance decision-making and project outcomes. Structured engagement and collaboration can ensure that technical and regulatory requirements are met while aligning with stakeholder expectations. Clear communication helps to identify potential challenges early, allows for proactive solutions, and minimizes delays.

Data Management System

The interconnection process requires many experts internal and external to the TSP and it is data and process intensive. TSPs are challenged with data visibility, data availability, managing communications, queue prioritization, and reporting throughout the interconnection process.

NATF Practices

9.1 Define, design, build, and implement a generator interconnection management system to facilitate transmission interconnections. Use the following as a guide:

- Organize all project-related documents logically within the system, serving as a central repository that allows stakeholders to easily access necessary information.
- Implement a queuing system that categorizes project information based on priority and relevance to enhance cross-departmental engagement and collaboration.
- Utilize automated dashboards to display key performance indicators (KPIs) and metrics, enabling stakeholders to make data-driven decisions efficiently.

- Customize dashboards to reflect the specific needs of different departments or roles within the organization, ensuring relevant data is highlighted for each user.
- Ensure that all data entries are timestamped to facilitate tracking of project milestones. This feature is for monitoring progress and accountability throughout project lifecycles.
- Maintain historical data records that can be analyzed to identify trends and inform future project planning.
- Revolve the data management system around a defined workflow that streamlines operations and reduces the complexity of task management.
- Automate routine tasks and notifications within the workflow to minimize manual intervention, thereby increasing efficiency and accuracy in data handling.
- Leverage the system to ensure that modeling data is submitted accurately and verified, which is essential for facilitating interconnection clusters and meeting targeted milestones.
- Integrate the tool seamlessly with existing systems to pull in necessary data without relying on disparate sources like emails or local spreadsheets.
- Replace reliance on personnel emails, shared drives, and local spreadsheets with a unified platform that consolidates all communications and documentation related to projects.
- Establish the tool as the single source of truth for all project-related information, reducing confusion and improving collaboration across teams.

> FERC standards of conduct must be upheld through any process. Data sharing and access must meet internal requirements and those set by regulators.

Communications between TO and ISO or RTO

Clear and effective communication between organizations is a key component to the interconnection process. These organizations must act as one and establish responsibilities throughout the process to ensure it is managed and executed effectively.

NATF Practices

9.2 Establish a document tracking system that is accessible to each party of the interconnection with appropriate permissions to share, view, or edit documents as defined by the ISO/RTO

9.3 The ISO/RTO acts as the communication link between the TO and the interconnection customer

9.4 The ISO/RTO should establish a point of contact for the TO to facilitate the following:

- Project updates and status changes
- Address issues during the process (i.e., data validation or clarification)
- Customer engagement window discussions and decisions points
- Constant communication during the study and study review process

Communications methods should be agreeable to both parties and have a means to document communications for future process improvements.

This practice also applies to vertically integrated organizations with a dedicated point of contact or project management office as the interface with the interconnection customer.

Cross Departmental Engagement and Collaboration

Multi-disciplinary, cross-departmental effort is needed to enhance the interconnection process and interconnection requirements.

NATF Practices

9.5 The following departments or functions should be included, at a minimum, for successful execution of the interconnection process:

- Transmission planning, modeling, and/or special studies
- Generation interconnection department (if dedicated department or group exists)
- Transmission lines department
- Transmission substation department
- Protection and control department
- Billing and accounting department
- Operations planning and energy management system (EMS) support
- System operations and operator training
- Legal and regulatory compliance
- Project management
- Transmission construction
- Asset management

Specific departments and business unit names may vary between organizations.

9.6 A dedicated project management office should become the primary point of contact between all internal and external project stakeholders.

9.7 Cross-departmental initiative requires executive sponsorship across all departments or divisions involved.

Executive sponsorship should be a steward throughout the process to enable effective collaboration across teams. This requires attention to resourcing, prioritization, and other factors at a strategic and managerial level.

10. Related Documents

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

- IEEE
    - Institute of Electrical and Electronics Engineers (IEEE). *1547-2018, Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power System Interfaces,* https://standards.ieee.org/ieee/1547/5915/
    - Institute of Electrical and Electronics Engineers (IEEE). *519-2022, Standard for Harmonic Control in Electric Power Systems*, https://standards.ieee.org/ieee/519/3710/
    - Institute of Electrical and Electronics Engineers (IEEE). *2800-2022, Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems,* https://standards.ieee.org/ieee/2800/10453/
- NERC
    - North American Electric Reliability Corporation (NERC). *Quick Reference Guide: IBR Registration Initiative, https://www.nerc.com/pa/Documents/IBR_Quick%20Reference%20Guide.pdf*
    - North American Electric Reliability Corporation (NERC). *Project 2022-02,* https://www.nerc.com/pa/Stand/Pages/Project2022-02ModificationstoTPL-001-5-1andMOD-032-1.aspx
    - North American Electric Reliability Corporation (NERC). *Project 2021-04,* https://www.nerc.com/pa/Stand/Pages/Project-2021-04-Modifications-to-PRC-002-2.aspx
    - North American Electric Reliability Corporation (NERC). *Reliability Guideline, Power Plant Model Verification for Inverter-Based Resources,* https://www.nerc.com/comm/RSTC_Reliability_Guidelines/PPMV_for_Inverter-Based_Resources.pdf
    - North American Electric Reliability Corporation (NERC). *2022 California Battery Energy Storage System Disturbances,* https://www.nerc.com/comm/RSTC/Documents/NERC_BESS_Disturbance_Report_2023.pdf
    - North American Electric Reliability Corporation (NERC). *Reliability Guideline, Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources,* https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline_IBR_Interconnection_Requirements_Improvements.pdf
    - North American Electric Reliability Corporation (NERC). *Reliability Guideline, BPS-Connected Inverter-Based Resource Performance,* https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Inverter-Based_Resource_Performance_Guideline.pdf
    - North American Electric Reliability Corporation (NERC). *Reliability Guideline, Performance, Modeling, and Simulations of BPS-Connected Battery Energy Storage Systems and Hybrid Power Plants,*

https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline_BESS_Hybrid_Performance_Modeling_Studies.pdf

- National Labs
  - National Renewable Energy Laboratory (NREL). *Introduction to Grid Forming Inverters,* https://www.nrel.gov/docs/fy24osti/90256.pdf
  - National Renewable Energy Laboratory (NREL). *Renewable Energy Integration,* https://www.nrel.gov/grid/renewable-energy-integration.html
- EPRI
  - Electric Power Research Institute (EPRI). *Transmission Harmonic and Power Quality Analysis for Changing Resource Mix,* https://www.epri.com/research/products/000000003002028366
  - Electric Power Research Institute (EPRI). *Assessing Risk of Sub-Synchronous Oscillations,* https://www.epri.com/research/products/000000003002028605
  - Electric Power Research Institute (EPRI). *Review of Grid Reliability Services from Inverter-Based Resources,* https://www.epri.com/research/products/000000003002029347
- FERC
  - Federal Energy Regulatory Commission (FERC). *Order 2003, Standardization of Generator Interconnection Agreements and Procedures,* https://www.ferc.gov/sites/default/files/2020-06/order-2003.pdf
  - Federal Energy Regulatory Commission (FERC). *Order 2006, Standardization of Small Generator Interconnection Agreements and Procedures,* https://www.ferc.gov/sites/default/files/2020-06/OrderNo.2006.pdf
  - Federal Energy Regulatory Commission (FERC). *Order 807, Open Access and Priority Rights on Interconnection Customer's Interconnection Facilities,* https://www.ferc.gov/sites/default/files/2020-04/E-1_58.pdf
  - Federal Energy Regulatory Commission (FERC). Order 842, *Essential Reliability Services and the Evolving Bulk-Power System—Primary Frequency Response,* https://www.ferc.gov/media/order-no-842
  - Federal Energy Regulatory Commission (FERC). *Order 845, Reform of Generator Interconnection Procedures and Agreements,* https://www.ferc.gov/sites/default/files/2020-06/Order-845.pdf
  - Federal Energy Regulatory Commission (FERC). *Order 872, Qualifying Facility Rates and Requirements,* https://www.ferc.gov/media/order-no-872
  - Federal Energy Regulatory Commission (FERC). *Order 2222*, *Facilitating Participation in Electricity Markets by Distributed Energy Resources,* https://www.ferc.gov/media/ferc-order-no-2222-explainer-facilitating-participation-electricity-markets-distributed
  - Federal Energy Regulatory Commission (FERC). *Order 1000, Transmission Planning and Cost Allocation*, https://www.ferc.gov/sites/default/files/2020-04/OrderNo.1000.pdf

- Federal Energy Regulatory Commission (FERC). *Order 2023, Improvements to Generator Interconnection Procedures and Agreements*, https://www.ferc.gov/media/e-1-order-2023-rm22-14-000
- Federal Energy Regulatory Commission (FERC). *Order 901, Reliability Standards to Address Inverter-Based Resources,* https://elibrary.ferc.gov/eLibrary/filelist?accession_number=20231019-3157&optimized=false

- ISO/RTO/Utilities
  - Electric Reliability Council of Texas (ERCOT). *Resource Interconnection Handbook,* https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.ercot.com%2Ffiles%2Fdocs%2F2021%2F01%2F07%2FResource_Interconnection_Handbook_v1.94_03012023.docx&wdOrigin=BROWSELINK
  - New York State Reliability Council (NYSRC). *Procedure for Application of IEEE 2800-2022 Standard for Large IBR Generating Facilities for the New York Control Area,* https://www.nysrc.org/wp-content/uploads/2024/02/RR-151-Procedure-Document-2-9-2024.pdf

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[1] North American Electric Reliability Corporation, "Reliability Guideline, Improvments to Interconnection Requirments for BPS-Connected Inverter-Based Resources," [Online]. Available: https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline_IBR_Interconnection_Requirements_Improvements.pdf.

[2] Federal Energy Regulatory Commission, "E-1, Order 2023, RM22-14-000," [Online]. Available: https://www.ferc.gov/media/e-1-order-2023-rm22-14-000.

[3] Federal Energy Regulatory Commission, "Reliability Standards to Address Inverter-Based Resources," [Online]. Available: https://www.federalregister.gov/documents/2023/10/30/2023-23581/reliability-standards-to-address-inverter-based-resources.

[4] North American Electric Reliability Corporation, "FAC-001-4 Facility Interconnection Requirements," [Online]. Available: https://www.nerc.com/pa/Stand/Reliability%20Standards/FAC-001-4.pdf.

[5] Institute of Electrical and Electronics Engineers, "IEEE 2800-2022, Interconnection and Interoperability of Inverter-Based Resources Interconnecting with Associated Transmission Electric Power Systems," [Online]. Available: https://standards.ieee.org/ieee/2800/10453/.

[6] Federal Energy Regulatory Commission, "Notice of Proposed Rulemaking: Reliability Standards to Address Inverter-Based Resources," 17 November 2022. [Online]. Available: https://www.ferc.gov/media/e-2-rm22-12-000.

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