



PJM EMT Model Development Guidelines for Inverter-Based Resources

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System Planning Division

PJM Interconnection

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Section 1. Revision History

Revision	Date	Description
0	03/05/2026	Initial version

Section 2. Introduction

2.1 Necessity of EMT Simulations

PJM is experiencing an increasing penetration of inverter-based resources (IBRs) on both the distribution and bulk power systems (BPS). High penetration level of IBRs has introduced undesirable dynamics, such as subcycle overvoltage and Sub-Synchronous Oscillations (SSO), with weak grid-associated stability challenges being the most significant challenges to higher IBR penetrations.¹

The underlying reason for this is that IBRs are asynchronously connected to the grid through a power electronics interface, and currently, most control systems for IBRs rely on a consistent terminal voltage magnitude and angle to maintain stable operation. However, in weak systems, the terminal voltage of IBRs becomes more sensitive to variations of current injections, which can potentially trigger adverse IBR controller reactions, thereby posing risks to system stability. Interactions with other IBRs in proximity may further impact stability. Thus, observability of the lightning-fast control actions, nonlinear behaviors, and high-frequency dynamics that govern IBR interactions with the grid are crucial for reliable planning and operation of the system. However, conventional positive-sequence phasor-domain (PSPD) dynamic models are not intended for studying phenomena outside of the typical range of frequencies of interest in power system stability studies (i.e., 0.1–10 Hz). Therefore, PSPD models are inadequate for studying phenomena such as switching transients, torsional interactions, harmonics and other electromagnetic transients.²

To cope with challenges arising from IBR integration, standards such as IEEE 2800-2022³ and IEEE 1547-2018⁴ require IBRs to demonstrate capabilities such as voltage and frequency ride-through, reactive current support, and fast control responses that only Electromagnetic Transient (EMT) simulations can accurately capture. The [NERC Reliability Guideline](#) (PDF) provides recommendations to Transmission Owners (TOs), Transmission Planners (TP) and Planning Coordinators (PC) for the development of EMT model requirements, model quality checks and verification practices specifically for EMT models used to represent BPS-connected IBRs. Also, the urgency for TOs, TPs, PCs and currently registered Generator Owners (GO) to take essential actions to enhance minimum technical requirements and study processes for IBR performance and modeling is underscored by the [NERC Level 3 Alert](#) (PDF) issued in May 2025. Further, MOD-26-2 requires each TP and its PC to jointly develop dynamic model requirements, for both PSPD and EMT models, for the purpose of evaluating submitted dynamic models and accompanying documentation of [Model Verification and Model Validation](#) (PDF).

To meet the needs for studies in power system planning as well as comply with NERC requirements, moving forward, both PSPD and EMT models are therefore necessary for screening any potential reliability risks for IBR interconnections. The PSPD model shall be submitted in the format of PSS/E per the requirements of the [PJM Dynamic Model Development Guidelines](#) (PDF). The EMT model and deliverables shall be developed in accordance with the requirements specified in this document. This document aims at significantly reducing

¹ [AEMO, "System Strength Workshop," Nov. 6, 2020 \(video\)](#)

² [WECC Modeling and Validation Subcommittee, "Inverter-Based Resources Power Plant Modeling and Validation Guideline," February 2026 \(PDF\).](#)

³ "IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems," in *IEEE Std 2800-2022*, vol., no., pp.1–180, 22 April 2022, doi: 10.1109/IEEEESTD.2022.9762253.

⁴ "IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces," in *IEEE Std 1547-2018 (Revision of IEEE Std 1547-2003)*, vol., no., pp.1–138, 6 April 2018, doi: 10.1109/IEEEESTD.2018.8332112.

deficiencies and conflicts between PSS/E and EMT models up front, before the data package is submitted and studies are conducted, minimizing study delays.

In the system planning horizon, EMT studies shall be performed for the following scenarios, based on [NERC Reliability Guideline recommendations](#) (PDF):

- 1 | Low system strength
- 2 | Poor stability performance in PSPD studies
- 3 | System topology or conditions with stability risks

For more detailed information on each scenario, users shall refer to the source [document](#).

2.2 EMT Software Requirements

To facilitate EMT model verification and studies, EMT models submitted to the PJM Planning Division shall be in a format compatible with the PSCAD™/EMTDC™ simulation tool (e.g., *.pswx, *.pscx and *.pslx). More comprehensive model requirements are outlined in **Section 7**.

2.3 General Submittal Requirements and Timeline

This document provides an overview of PJM requirements for IBR facilities, PSCAD modeling and deliverables submission. This document is applicable to all IBRs, including solar photovoltaic (PV) generation, battery energy storage systems (BESS), type III and IV wind plants, as well as co-located and hybrid power plants (e.g., PV plus BESS or wind plus BESS). The timeline of major submission requirements is shown in **Figure 1**, specifically:

- 1 | **For Transition Cycle 2**, during the start of Phase II, PJM will perform a screening to identify projects connecting in areas of low system strength, for which a PSCAD model will be required. A notification will be sent out to the identified Project Developers that a PSCAD model and associated documents must be submitted at Decision Point II. The submission shall include: the PSCAD model, Model Requirements Checklist, Model Quality Test and Benchmark Report per this guideline.
- 2 | **For Cycle 1 and beyond**, all BPS-connected projects shall submit a PSCAD model at Decision Point II, following the submission requirements of this guideline.
- 3 | **For Necessary Study, Surplus Study and any non-cycle requests***, all BPS-connected projects shall submit a PSCAD model following this guideline with the submission of the study request.
- 4 | **For As-Built verification requests***, the submission shall include a PSS/E User Defined Model (UDM), PSS/E library model, PSCAD model that accurately reflects the As-Built site parameters, PSCAD Model Quality Test and Benchmark Report, and Parameter Verification Report. It is worth noting, for the As-Built Model Test and Benchmark Report, more tests are required than earlier stages, which is further clarified in **Section 5**. The Parameter Verification Report shall demonstrate that the PSCAD model parameters accurately reflect the As-Built facility configuration. Any difference between the model used for study and the

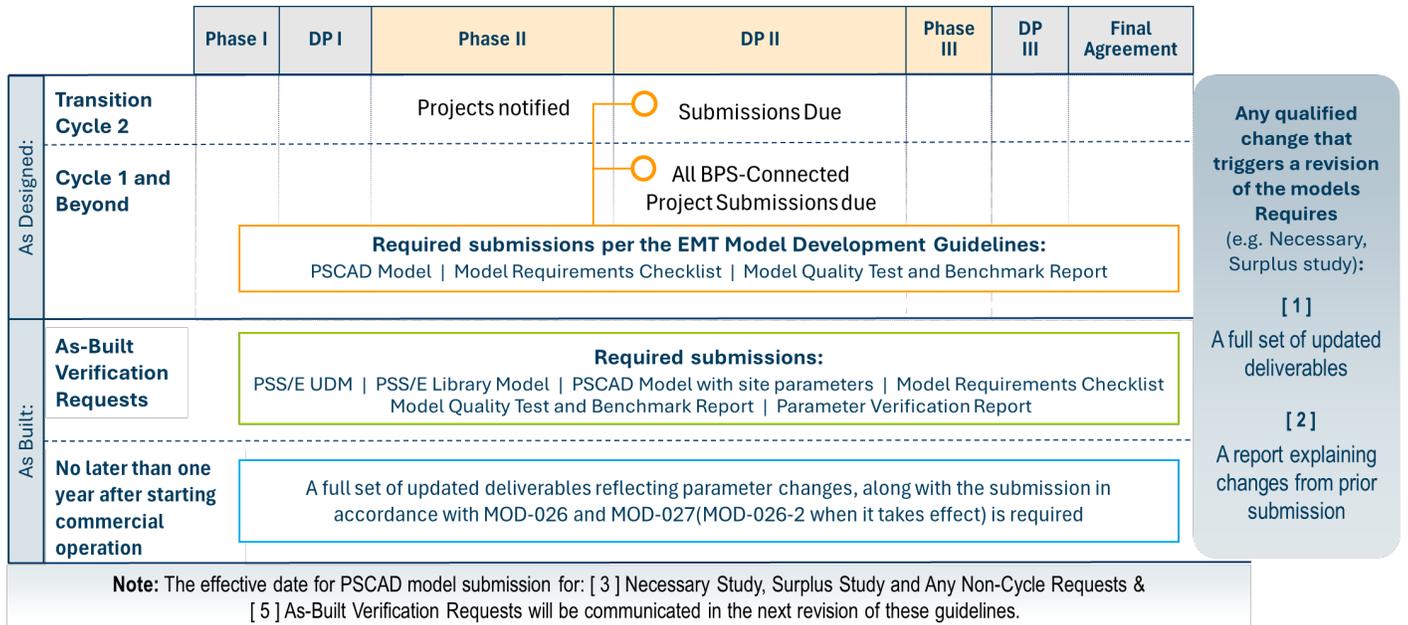
actual installed settings in the field should be deemed as a qualified change per FAC-002-4 or its successor and be reviewed prior to commercial operation to determine whether the existing studies are still valid.⁵

**The effective date for PSCAD model submission for Necessary Study, Surplus Study and Any Non-Cycle Requests & As-Built Verification Requests will be communicated in the next revision of these guidelines.*

5 | No later than one year after starting commercial operation, the Interconnection Customer shall provide a tuned set of models as part of the submission in accordance with NERC MOD-026 and MOD-027 (MOD-026-2 when it takes effect). In alignment with the field tests specified in the standards, the models shall be tuned to accurately reflect the dynamic response of the IBR.

6 | In addition, any qualified change to the project (that has already submitted a PSCAD model previously) that triggers a revision of models (e.g., Necessary Study, Surplus Study), such as device updating, the addition of energy storage to a wind or solar facility, or operation modes conversion, shall trigger a new submission. The new submission shall include a full set of revised deliverables based on the prior submission that reflects the latest construction and operating conditions as well as a report clarifying the changes.

Figure 1. PSCAD Model and Supplemental Model Submission Timeline



⁵ [NERC, “Reliability Guideline: Electromagnetic Transient Modeling for BPS-Connected Inverter-Based Resources-Recommended Model Requirements and Verification Practices,” March 2023 \(PDF\).](#)

Section 3. PSCAD Model Requirements

3.1 Aggregate Representation Requirements

The IBR project shall be modeled up to the Point of Interconnection (POI). Moreover, if a single plant is split into multiple generating resources requiring individual submissions, it is acceptable and desirable to submit the PSCAD model for the entire plant as part of each individual submission.

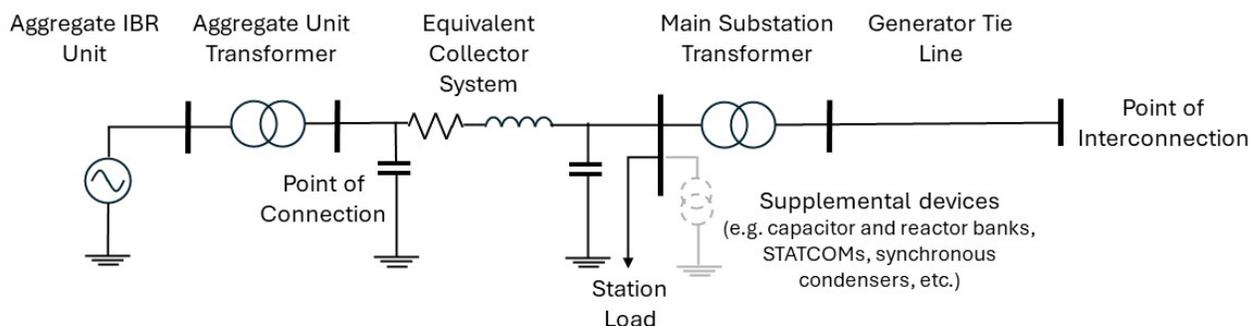
For most BPS reliability studies, the PSCAD model should be an aggregate, or a partially equivalent, representation of the IBR. **Figure 2** shows an example of an aggregated IBR plant when a single type of inverter is present. In an aggregate model, multiple inverters are represented as one larger unit with the collector system represented as an equivalent line or cable model.

If multiple inverter types or different designs are used in a plant, an aggregate representation for each individual type must be developed. For example, if a PV plant uses two different solar inverters, two distinct aggregated units representing each inverter type shall be used.

The IBR model shall include:

- Aggregated generation or energy storage model
- Aggregated generator transformer
- Equivalent collector branch
- Main step-up transformers
- Generator tie line
- Supplemental devices, as applicable (e.g., STATCOMs, synchronous condensers, capacitors and reactive banks, harmonic filter banks)
- Station service load

Figure 2. Representation of an Aggregated IBR Plant



The remaining system will be represented with AC source and Thevenin Impedance to represent the external system.

Based on the size of the project and its location in the electric system, PJM will determine if a study of interactions, such as control interactions with nearby equipment or an evaluation of equipment performance (e.g., low short-circuit conditions) is required as part of the Interconnection Study.

Appendix: Section 7 provides a model requirements [checklist](#) that must be completed by the supplier of the model and submitted with each PSCAD model. The model supplier must review every item in the checklist and indicate compliance with each item.

If the supplied model does not meet any given requirement, an explanation must be provided in the Check or Comments column.

The [checklist](#) includes sections covering:

- Model and project documentation
- Model accuracy features
- Model usability features
- Model efficiency features

In addition to **Appendix: Section 7**, this checklist is also available as a standalone document (DOC).

Section 4. PSCAD Model Quality Test Cases

PSCAD model quality tests are designed to ensure the PSCAD models meet minimum levels of functional capabilities and can be effectively used in studies. Some tests are required to be benchmarked with PSS/E study models depending on the model submission type, which is specified in **Section 5**. All test results will be reviewed by PJM upon receipt, at which point PJM may choose to rerun some tests for verification.

To support this verification, all cases and files used for testing must be included in the submission package.

4.1 General Instructions on Model Setup and Plotting

- 1 | Default value of SCR and X/R:** The PSCAD model shall be set up using a Thevenin equivalent impedance with a default SCR of 3 and X/R of 5, unless otherwise specified in a test case.
- 2 | Measured signals and plotting requirements:** For all test cases in **Section 4.2** and **4.3**, the Model Quality Test and Model Benchmark Report shall include plots of total active (P) and reactive power (Q), phase-to-ground voltages (RMS) of each phase (positive sequence for comparison with PSS/E model), and frequency at both the POI and Point-of-Connection (PoC). See **Section 8.1: Appendix** for more details on plotting requirements.

3 | BESS projects: Perform all tests at full charge (positive Pmax) and discharge (negative Pmax). For hybrid power plants (e.g., PV plus BESS or wind plus BESS), all operation modes shall be tested:

- a. Generation alone
- b. BESS alone charging
- c. BESS alone discharging
- d. Generation + BESS charging
- e. Generation + BESS discharging

If any operation mode(s) does not apply to the project, the Project Developer shall note this in the Model Quality Test and Benchmark Report with appropriate justification.

The PSCAD model quality test cases are shown in **Section 4.2** and **4.3**, with signal profile **Figure 4** through **Figure 15** for some of the tests in **Section 8.2: Appendix**.

4.2 Functional Tests

Test 1. Flat Start

Test Name: Flat Start		
<p>Objective: The model shall achieve steady state within the specified time and remain in steady state for the remainder of the simulation.</p>	<p>Operating Point at POI:</p> <ul style="list-style-type: none"> ▪ Active Power = Maximum Facility Output (MFO) ▪ Unity Power Factor (PF) ▪ Vpoi = 1.0 p.u. ▪ SCR = default 	<p>Simulation-Specific Setup: 15 second duration</p>
<p>Acceptance Criteria:</p> <ol style="list-style-type: none"> 1) Verify P, Q, V as measured at the POI reach steady state within 5 seconds and stay in steady state for the remainder of the simulation. 2) The variations of generator outputs are no greater than 0.1 MW or 0.1 MVAR. 		

Test 2. Active Power Reference Step-Down

Test Name: Active Power Reference Step Down		
<p>Objective: Test to verify the model can appropriately follow active power commands dynamically during the simulation and is configured with reasonable parameters.</p>	<p>Operating Point at POI:</p> <ul style="list-style-type: none"> ▪ Active Power = MFO ▪ Unity PF ▪ Vpoi = 1.0 p.u. ▪ SCR = default 	<p>Simulation-Specific Setup: Initialize the model into steady state. At t=10s, step down Pref of the PPC from 1 p.u. to 0.9 p.u. Run the simulation for at least an additional 10 seconds.</p>
<p>Acceptance Criteria:</p> <ol style="list-style-type: none"> 1) P follows Pref command, and response time is within reasonable range. 2) Q is maintained within the acceptable range. 		

Test 3. Frequency Step-Up

Test Name: Frequency Step-Up		
Objective: Verify the model is configured to provide adequate primary frequency response.	Operating Point at POI: <ul style="list-style-type: none"> ▪ Active Power = MFO ▪ Unity PF ▪ $V_{poi} = 1.0$ p.u. ▪ SCR = default 	Simulation-Specific Setup: <ul style="list-style-type: none"> ▪ Frequency step size = 0.3 Hz. ▪ Initialize the model into steady state. At $t=10s$, step up the frequency of the voltage source by the specified step size. Run the simulation for at least an additional 10 seconds.
Acceptance Criteria: <ol style="list-style-type: none"> 1) P response is in the appropriate direction, and response time is within acceptable range. 2) Q is maintained within the acceptable range. 		

Test 4. Frequency Step-Down, With Headroom

Test Name: Frequency Step-Down, With Headroom		
Objective: Verify the model is configured to provide adequate primary frequency response.	Operating Point at POI: <ul style="list-style-type: none"> ▪ Active Power = 80% of MFO ▪ Unity PF ▪ $V_{poi} = 1.0$ p.u. ▪ SCR = default 	Simulation-Specific Setup: <ul style="list-style-type: none"> ▪ Frequency step size = 0.3 Hz ▪ Initialize model into steady state, then at $t=10s$, step down the frequency of the voltage source by the specified step size, run simulation for at least an additional 10 seconds.
Acceptance Criteria: <ol style="list-style-type: none"> 1) P response is in the appropriate direction, and response time is within acceptable range. 2) Q is maintained within the acceptable range. 		

Test 5. Voltage Step-Up Test

Test Name: Voltage Step-Up Test		
Objective: Verify the model provides an appropriate reactive power response and is configured with reasonable parameters.	Operating Point at POI: <ul style="list-style-type: none"> ▪ Active Power = MFO ▪ Unity PF ▪ $V_{poi} = 1.0$ p.u. ▪ SCR = default 	Simulation-Specific Setup: <ul style="list-style-type: none"> ▪ Voltage step size = 0.03 p.u. ▪ Initialize the model into steady state. At $t=10s$, step up the voltage of the voltage source by the specified step size. Run the simulation for at least an additional 10 seconds.
Acceptance Criteria: <ol style="list-style-type: none"> 1) Q response is in the appropriate direction, and response time is within acceptable range. 2) P is maintained within the acceptable range. 		

Test 6. Voltage Step-Down Test

Test Name: Voltage Step-Down Test		
Objective: Verify the model provides an appropriate reactive power response and is configured with reasonable parameters.	Operating Point at POI: <ul style="list-style-type: none"> ▪ Active Power = MFO ▪ Unity PF ▪ $V_{poi} = 1.0$ p.u. ▪ SCR = default 	Simulation-Specific Setup: <ul style="list-style-type: none"> ▪ Voltage step size = 0.03 p.u. ▪ Initialize the model into steady state. At $t=10s$, step down the voltage of the voltage source by the specified step size. Run the simulation for at least an additional 10 seconds.
Acceptance Criteria: <ol style="list-style-type: none"> 1) Q response is in the appropriate direction, and response time is within acceptable range. 2) P is maintained within the acceptable range. 		

4.3 Ride-Through Performance Tests

Test 7. Three-Phase-to-Ground Fault

Test Name: Three-Phase-to-Ground Fault		
Objective: Verify the model can ride through a balanced fault, provide appropriate reactive power response and recover to pre-fault conditions.	Operating Point at POI: <ul style="list-style-type: none"> ▪ Active Power = MFO ▪ Unity PF ▪ $V_{poi} = 1.0$ p.u. ▪ SCR = default 	Simulation-Specific Setup: <ul style="list-style-type: none"> ▪ Fault impedance: 0 Ohms ▪ Fault duration: 9 cycles ▪ Initialize the model into steady state. At $t=10s$, apply the specified fault at the POI bus and clear without the loss of any elements. Run the simulation for at least an additional 10 seconds.
Acceptance Criteria: <ul style="list-style-type: none"> ▪ The plant shall ride through and shall have a stable and well-damped response. An acceptable damping ratio is 0.3 or greater. * ▪ After fault clearing and voltage recovery within the normal range, the active power recovers to the pre-fault value within reasonable time. ▪ If the plant enters momentary cessation (current blocking) mode, it shall resume current injection in no fewer than 5 cycles following voltage recovery. ▪ If momentary cessation cannot be eliminated due to equipment limitations, notify PJM when submitting the model quality test report. 		
<p style="font-size: small; margin-top: 10px;">*See: "IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems," in IEEE Std 2800-2022, vol., no., pp.1–180, 22 April 2022, doi: 10.1109/IEEESTD.2022.9762253.</p>		

Test 8. Single Line-to-Ground Fault

Test Name: Single Line-to-Ground Fault		
Objective: Verify the model can ride through an unbalanced fault, provide appropriate reactive power response and recover to pre-fault conditions.	Operating Point at POI: <ul style="list-style-type: none"> ▪ Active Power = MFO ▪ Unity PF ▪ Vpoi = 1.0 p.u. ▪ SCR = default 	Simulation-Specific Setup: <ul style="list-style-type: none"> ▪ Fault impedance: 0 Ohms ▪ Fault duration: 9 cycles ▪ Initialize the model into steady state. At t=10s, apply the specified fault at the POI bus and clear without the loss of any elements. Run the simulation for at least an additional 10 seconds.
Acceptance Criteria: <ul style="list-style-type: none"> ▪ The plant shall ride through and shall have a stable and well-damped response. An acceptable damping ratio is 0.3 or greater. * ▪ After fault clearing and voltage recovery within the normal range, the active power recovers to the pre-fault value within reasonable time. ▪ If the plant enters momentary cessation (current blocking) mode, it shall resume current injection in no fewer than 5 cycles following voltage recovery. ▪ If momentary cessation cannot be eliminated due to equipment limitations, notify PJM when submitting the model quality test report. 		
*See: "IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems," in IEEE Std 2800-2022, vol., no., pp.1–180, 22 April 2022, doi: 10.1109/IEEESTD.2022.9762253.		

Test 9. Line-to-Line Fault

Test Name: Line-to-Line Fault		
Objective: Verify the model can ride through an unbalanced fault, provide appropriate reactive power response and recover to pre-fault conditions.	Operating Point at POI: <ul style="list-style-type: none"> ▪ Active Power = MFO ▪ Unity PF ▪ Vpoi = 1.0 p.u. ▪ SCR = default 	Simulation-Specific Setup: <ul style="list-style-type: none"> ▪ Fault impedance: 0 Ohms ▪ Fault duration: 9 cycles ▪ Initialize the model into steady state. At t=10s, apply the specified fault at the POI bus and clear without the loss of any elements. Run the simulation for at least an additional 10 seconds.
Acceptance Criteria: <ul style="list-style-type: none"> ▪ The plant shall ride through and shall have a stable and well-damped response. An acceptable damping ratio is 0.3 or greater. * ▪ After fault clearing and voltage recovery within the normal range, the active power recovers to the pre-fault value within reasonable time. ▪ If the plant enters momentary cessation (current blocking) mode, it shall resume current injection in no fewer than 5 cycles following voltage recovery. ▪ If momentary cessation cannot be eliminated due to equipment limitations, notify PJM when submitting the model quality test report. 		
*See: "IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems," in IEEE Std 2800-2022, vol., no., pp.1–180, 22 April 2022, doi: 10.1109/IEEESTD.2022.9762253.		

Test 10. Low-Voltage Ride-Through (LVRT) Profile

Test Name: Low-Voltage Ride-Through (LVRT) Profile		
<p>Objective: Screen that the model can ride through minimum LVRT requirements at the POI bus, provide appropriate reactive power response and recover to pre-fault conditions.</p>	<p>Operating Point at POI:</p> <ul style="list-style-type: none"> ▪ Active Power = MFO ▪ Unity PF ▪ $V_{poi} = 1.0$ p.u. ▪ SCR = 50 	<p>Simulation-Specific Setup:</p> <ul style="list-style-type: none"> ▪ Voltage profile: NERC PRC-024-3 Attachment 2, Low-Voltage Duration ▪ Initialize model into steady state, since $t=10s$, modulate the voltage of the voltage source following the specified profile, run simulation for at least an additional 10 seconds after voltage returns to continuous operating range.
<p>Acceptance Criteria:</p> <ol style="list-style-type: none"> 1) The plant rides through. 2) Units inject reactive current during the fault. 3) The plant transitions to normal active power injection and recovers to pre-fault conditions within the appropriate time. 4) Momentary cessation is not observed. 		<p><i>If momentary cessation cannot be eliminated</i> due to equipment limitations, notify PJM when submitting the model quality test report.</p>

Test 11. Overvoltage Ride-Through

Test Name: Overvoltage Ride-Through		
<p>Objective: Verify the model can ride through a high-voltage ride-through event, provide appropriate reactive power response and recover to pre-fault conditions.</p>	<p>Operating Point at POI:</p> <ul style="list-style-type: none"> ▪ Active Power = MFO ▪ Unity PF ▪ $V_{poi} = 1.0$ p.u. ▪ SCR = 50 	<p>Simulation-Specific Setup:</p> <ul style="list-style-type: none"> ▪ High-voltage magnitude: 1.2 p.u. ▪ Duration: 0.20 seconds ▪ Initialize the model into steady state. At $t=10s$, step voltage of the voltage source to the specified magnitude for the specified duration and then clear without the loss of any elements. Run the simulation for at least an additional 10 seconds.
<p>Acceptance Criteria:</p> <ol style="list-style-type: none"> 1) The plant rides through. 2) Units absorb reactive current during the fault. 3) The plant transitions to normal active power injection and recovers to pre-fault conditions within the appropriate time. 4) Momentary cessation is not observed. 5) Stable recovery occurs with the damping ratio within the acceptable range. An acceptable damping ratio is 0.3 or greater. * 		<p><i>If momentary cessation cannot be eliminated</i> due to equipment limitations, notify PJM when submitting the model quality test report.</p>
<p>*See: "IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems," in IEEE Std 2800-2022, vol., no., pp.1–180, 22 April 2022, doi: 10.1109/IEEESTD.2022.9762253.</p>		

Test 12. High-Voltage Ride-Through (HVRT) Profile

Test Name: High-Voltage Ride-Through (HVRT) Profile		
<p>Objective: Screen that the model can ride through minimum HVRT requirements at the POI bus, provide appropriate reactive power response and recover to pre-fault conditions.</p>	<p>Operating Point at POI:</p> <ul style="list-style-type: none"> ▪ Active Power = MFO ▪ Unity PF ▪ $V_{poi} = 1.0$ p.u. ▪ SCR = 50 	<p>Simulation-Specific Setup:</p> <ul style="list-style-type: none"> ▪ Voltage profile: NERC PRC-024-3 Attachment 2, High-Voltage Duration ▪ Initialize the model into steady state. At $t=10s$, modulate the voltage of the voltage source following the specified profile. Run the simulation for at least an additional 10 seconds after voltage returns to a continuous operating range.
<p>Acceptance Criteria:</p> <ol style="list-style-type: none"> 1) The plant rides through. 2) Units absorb reactive current during the fault. 3) The plant transitions to normal active power injection and recovers to pre-fault conditions within the appropriate time. 4) Momentary cessation is not observed. 		<p>If momentary cessation cannot be eliminated due to equipment limitations, notify PJM when submitting the model quality test report.</p>

Test 13. System Strength Test

Test Name: System Strength Test	
<p>Objective: Observe model performance under sequentially lower SCRs.</p>	<p>Simulation-Specific Setup:</p> <ul style="list-style-type: none"> ▪ SCR sequence: 5, 3, 1.5, 1.2 ▪ Interval between SCRs: 5s ▪ Initialize the model into steady state with the initial SCR. Test the model response to sequentially lower SCRs by first applying a bolted three-phase line-to-ground (3LG) fault at the POI bus for 3 cycles and changing the impedance of the Thevenin voltage source corresponding to the next specified SCR in the sequence, before the fault is cleared. Maintain the new SCR for the specified interval duration and repeat the process for each SCR in the sequence.
<p>Operating Point at POI:</p> <ul style="list-style-type: none"> ▪ Active Power = MFO ▪ Unity PF ▪ $V_{poi} = 1.0$ p.u. ▪ SCR = 5 	
<p>Acceptance Criteria: The plant shall have a positively damped response and shall return to steady state without tripping any unit for an SCR of 3 and higher.</p>	

Test 14. Phase Angle Change: +25deg

Test Name: Phase Angle Change: +25deg		
Objective: Verify the model can ride through an instantaneous voltage phase angle change and recover stably to pre-fault conditions.	Operating Point at POI: <ul style="list-style-type: none"> ▪ Active Power = MFO ▪ Unity PF ▪ Vpoi = 1.0 p.u. ▪ SCR = 50 	Simulation-Specific Set Up: <ul style="list-style-type: none"> ▪ Voltage phase angle change: +25 deg ▪ Initialize the model into steady state. Apply the specified instantaneous voltage phase angle change at t=10s without the loss of any elements. Run simulation for an additional 10 seconds.
Acceptance Criteria: <ol style="list-style-type: none"> 1) The plant rides through, and no unit trips. 2) The plant recovers to pre-fault conditions and stable recovery with the damping ratio within the acceptable range. An acceptable damping ratio is 0.3 or greater. * 3) Momentary cessation is not observed. 		
*See: "IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems," in IEEE Std 2800-2022, vol., no., pp.1–180, 22 April 2022, doi: 10.1109/IEEESTD.2022.9762253.		

Test 15. Phase Angle Change: -25deg

Test Name: Phase Angle Change: +25deg		
Objective: Verify the model can ride through an instantaneous voltage phase angle change and recover stably to pre-fault conditions.	Operating Point at POI: <ul style="list-style-type: none"> ▪ Active Power = MFO ▪ Unity PF ▪ Vpoi = 1.0 p.u. ▪ SCR = 50 	Simulation-Specific Set Up: <ul style="list-style-type: none"> ▪ Voltage phase angle change: -25 deg ▪ Initialize the model into steady state. At t=10s, apply the specified instantaneous voltage phase angle change without the loss of any elements. Run the simulation for an additional 10 seconds.
Acceptance Criteria: <ol style="list-style-type: none"> 1) The plant rides through, and no unit trips. 2) The plant recovers to pre-fault conditions and stable recovery with the damping ratio within the acceptable range. An acceptable damping ratio is 0.3 or greater. * 3) Momentary cessation is not observed. 		
*See: "IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems," in IEEE Std 2800-2022, vol., no., pp.1–180, 22 April 2022, doi: 10.1109/IEEESTD.2022.9762253.		

Test 16. High Rate of Change of Frequency (ROCOF)

Test Name: High Rate of Change of Frequency (ROCOF)		
Objective: Verify the model can ride through high rate of change of frequency sequence and recover stably to pre-fault conditions.	Operating Point at POI: <ul style="list-style-type: none"> ▪ Active Power = MFO ▪ Active Power = MFO ▪ Unity PF ▪ Vpoi = 1.0 p.u. ▪ SCR = 50 	Simulation-Specific Set Up: <ul style="list-style-type: none"> ▪ ROCOF sequence: <ul style="list-style-type: none"> · -5 Hz/s for 0.1s to 59.5 Hz, hold for interval · +5 Hz/s for 0.1s to 60 Hz, hold for interval · +5 Hz/s for 0.1s to 60.5 Hz, hold for interval · -5 Hz/s for 0.1s to 60 Hz ▪ Interval duration: 5 seconds ▪ Initialize the model to steady state. At t=10s, sequentially change the frequency of the Thevenin voltage source at the specified rate and sequence. Run the simulation for at least an additional 5 seconds after the frequency returns to nominal.
Acceptance Criteria: <ol style="list-style-type: none"> 1) Plant rides through, and no unit trips. 2) Recovers to pre-fault conditions and stable recovery with the damping ratio within the acceptable range. An acceptable damping ratio is 0.3 or greater. * 3) Momentary cessation is not observed. 		
*See: "IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems," in IEEE Std 2800-2022, vol., no., pp.1–180, 22 April 2022, doi: 10.1109/IEEESTD.2022.9762253.		

Test 17. High-Frequency Ride-Through (HFRT) Profile

Test Name: High-Frequency Ride-Through (HFRT) Profile		
Objective: Screen that the model can ride through minimum HFRT requirements at the POI bus and recover to pre-fault conditions.	Operating Point at POI: <ul style="list-style-type: none"> ▪ Active Power = MFO ▪ Unity PF ▪ Vpoi = 1.0 p.u. ▪ SCR = 50 	Simulation-Specific Set Up: <ul style="list-style-type: none"> ▪ Frequency profile: NERC PRC-024-3 Attachment 1, High-Frequency Duration ▪ Initialize the model into steady state. At t=10s, modulate the frequency of the voltage source following the specified profile. Run the simulation for 20 seconds from the start of the disturbance.
Acceptance Criteria: <ol style="list-style-type: none"> 1) The plant rides through and transitions to normal active power injection and recovers to pre-fault conditions within the appropriate time. 2) Momentary cessation not observed. 		If momentary cessation cannot be eliminated due to equipment limitations, notify PJM when submitting the model quality test report.

Test 18. Low-Frequency Ride-Through (LFRT) Profile

Test Name: Low-Frequency Ride-Through (LFRT) Profile		
<p>Objective: Screen that the model can ride through minimum LFRT requirements at the POI bus and recover to pre-fault conditions.</p>	<p>Operating Point at POI:</p> <ul style="list-style-type: none"> ▪ Active Power = MFO ▪ Unity PF ▪ Vpoi = 1.0 p.u. ▪ SCR = 50 	<p>Simulation-Specific Setup:</p> <ul style="list-style-type: none"> ▪ Frequency profile: NERC PRC-024-3 Attachment 1, Low-Frequency Duration ▪ Initialize model into steady state, at t=10s modulate the frequency of the voltage source following the specified profile, run the simulation for 20 seconds from the start of the disturbance.
<p>Acceptance Criteria:</p> <ol style="list-style-type: none"> 1) The plant rides through and transitions to normal active power injection and recovers to pre-fault conditions within the appropriate time. 2) Momentary cessation not observed. 		<p>If momentary cessation cannot be eliminated due to equipment limitations, notify PJM when submitting the model quality test report.</p>

Section 5. PSCAD and PSS/E Model Benchmark Requirements

5.1 As-Designed Model Benchmark Requirements

“As-Designed” refers to the process before “As-Built,” (e.g., the Cycle process, Necessary Study). To ensure the PSCAD model aligns with the latest submitted PSS/E model (either UDM or library model) for the same project, Model Quality Tests and PSCAD-PSS/E Model Benchmark Reports shall be provided with the PSCAD model submission. PSCAD and PSS/E signals must be overlaid and properly aligned with each other for each single signal plot of a test (e.g., active power, reactive power). The main objective is to ensure that the two models align with each other in the submission so that the PSCAD model can be used confidently to address complex issues from PSS/E study. All cases, files and plots used for the PSCAD-PSS/E Model Benchmark Report tests must be included in the submission package to PJM.

For the PSCAD-PSS/E Model Benchmark Report, the following tests shall be performed:

Table 1. PSCAD-PSS/E Model Benchmark Report – Required Tests

Required Tests	Table Reference
Functional Tests	Test 1–Test 6
3LG	Test 7
LVRT Profile	Test 10
HVRT Profile	Test 12

As noted in **Section 2.2**, for any qualifying changes to a project, including but not limited to device updating, addition of energy storage to a wind or solar facility, or operation modes conversion, a full set of deliverables shall be resubmitted with an accompanying report outlining what changes have been made since the last submission.

5.2 As-Built Model Benchmark Requirements

For As-Built PSCAD models, the Model Quality Tests along with benchmarked PSCAD simulation results overlaid with the latest PSS/E UDM and library model simulation results shall be provided. PSS/E UDM and PSS/E Library Model shall also be submitted as a part of model benchmark, if not submitted before.

The following test cases are **excluded** from this cross-platform benchmarking requirement:

Table 2. As-Built PSCAD-PSS/E Model Benchmark Requirements – Excluded Test Cases

Excluded Tests	Table Reference
Single Line-to-Ground Fault	Test 8
Line-to-Line Fault	Test 9
Phase Angle Change: +25deg	Test 14
Phase Angle Change: -25deg	Test 15

Parameter verification report shall compare As-Built site parameters (both PPC and IBR parameters) with PSCAD model parameters.

Section 6. Deliverables

To be considered a complete submission, deliverables shall include:

Deliverables	Required For:	References
1 PSCAD Model	<ul style="list-style-type: none"> ▪ As-Designed (e.g., the Cycle process, Necessary Study) ▪ As-Built and beyond – PSS/E UDM and PSS/E Library Model should also be submitted as a part of model benchmark, if not submitted before. 	
2 PSCAD Model Requirements Checklist	<ul style="list-style-type: none"> ▪ As-Designed ▪ As-Built and beyond 	Section 7
3 Model Quality Tests and PSCAD-PSS/E Model Benchmark Reports	<ul style="list-style-type: none"> ▪ As-Designed ▪ As-Built and beyond 	Section 4 Section 5
4 All cases and files for each Model Quality Test and Benchmark Report	<ul style="list-style-type: none"> ▪ As-Designed ▪ As-Built and beyond 	

Place all required files in a folder, zip and attach/upload in the Data Submission Platform under the **Generator Information Section > Stability Models** for Queue Point or **Project Capability Tab > Dynamic Files** for NextGen.

The file upload size limit is 250 MB. For file sizes greater than 250 MB, please contact your Project Manager about using Secure Share to submit.

Section 7. Appendix – PSCAD Model Requirements Checklist

Project Developer Name:

Project Identifier in PJM (e.g., Queue Number):

Date:

Signature of Authorized Representative:

Note: The requested information is subject to confidentiality provisions set forth in Tariff Part VII, Subpart E, section 327.

Item	Description	Check or Comments
	Model and Project Documentation	
1	<p>Identification Mechanism</p> <p>The model must have an identification mechanism for configuration. The model documentation should provide a clear way to identify the specific settings and equipment configuration that will be used in any study, such that during commissioning the settings used in the studies can be checked. This may include control revision codes, settings files or a combination of these, and other identification measures.</p> <p>The model documentation shall show the principle of user-defined model and block or module functions.</p>	
2	<p>Model Setup and Simulation</p> <p>The vendor’s name and the specific version of the model must be clearly observable in the .pscx PSCAD case. Documentation and supporting model file names must not conflict with model version shown in the .pscx case file. Setup and running instructions should accompany each model.</p>	
3	<p>Test-Case Models</p> <p>Include a sample implementation test case. Test-case models should be configured according to the site-specific real equipment configuration up to the Point of Interconnection. This includes but is not limited to the aggregated generation model, aggregated generator transformer, equivalent collector branch, main step-up transformers, generator tie line and any static/dynamic reactive resources.</p> <p>The test case should use a single-machine infinite bus representation of the system configured with an appropriate representative short-circuit ratio (SCR).</p>	
	Model Accuracy Features	
4	<p>Detailed Inner Control Loops</p> <p>Include the full detailed inner control loops of the power electronics. This representation should include all fast inner controls as implemented in the equipment installed. The approximate representation used in transient stability modeling is not sufficient. It is recommended to create models by embedding the actual hardware code into a PSCAD™ component, commonly referred to as “real code” models as defined in the NERC Reliability Guideline. If the model is assembled using standard blocks available in the PSCAD™ master library or manually translated from control block diagrams or product source code, a validation against actual hardware performance is required (i.e., validation using as-designed model in the Interconnection Study) and validation based on actual field measurement data in the As-Built model.</p>	

Item	Description	Check or Comments
5	<p>Full IGBT Representation</p> <p>A full IGBT representation or voltage source interface that mimics IGBT switching, such as a firing pulse-based model, should be used. A three-phase sinusoidal source representation is not acceptable.</p>	
6	<p>Control Features</p> <p>Represent all control features pertinent to the type of study being done. Examples of control features include but are not limited to external voltage controllers, plant-level controllers, customized phase locked loop (PLL) systems, ride-through controllers and sub-synchronous control interaction damping controllers. Actual hardware code is required for control and protection features. Operating modes that require system-specific adjustment should be user accessible.</p>	
7	<p>Power Plant Control</p> <p>Represent plant level in sufficient detail to accurately represent short-term performance, including specific measurement methods, communication time delays, transitions into and out of ride-through modes, settable control parameters and any other specific implementation details that may impact plant behavior. For example, plant-level voltage control should be represented along with adjustable droop characteristics.</p> <p>Generic PPC representations are not sufficient unless the final Power Plant Control (PPC) is designed to exactly match the generic PPC model. If multiple plants are controlled by a common controller, or if the plant includes multiple types of IBRs such as Hybrid BESS/PV, the functionality must be included in the plant control model. If external or multiple voltage control devices such as STATCOMs are included in the plant, these should be coordinated with the PPC.</p>	
8	<p>SSO Mitigation</p> <p>Represent the Sub-Synchronous Oscillation (SSO) mitigation and/or protection. The model should have the ability to enable and disable SSO mitigation/protection, if applicable.</p>	
9	<p>Machine Slip Type</p> <p>Represent machine slip of Type III (DFIG) wind generation as appropriate for the power dispatch.</p>	
10	<p>Transformer Magnetizing Curves</p> <p>Include the transformer magnetizing curves.</p>	
11	<p>Dynamic Reactive Devices</p> <p>Represent dynamic reactive devices including automatically controlled capacitor and reactor banks, if applicable.</p>	
12	<p>Electrical/Mechanical Features</p> <p>Represent all pertinent electrical and mechanical configurations, such as filters and specialized transformers. Mechanical features (e.g., gearboxes, pitch controllers) shall be included in the model if they impact electrical performance. Any control or dynamic features of the actual equipment that may influence simulation behavior but are not represented or are approximated should be clearly identified and documented.</p>	

Item	Description	Check or Comments
13	Protection Systems Represent all installed protection systems in detail for both balanced and unbalanced fault conditions. Typically, this includes various overvoltage and undervoltage protections (individual phase and RMS), frequency protections, DC bus voltage protections, converter overcurrent protections and often other inverter-specific protections. Any protections that can influence dynamic behavior or plant ride-through in the simulation period must be included. Actual hardware code is required for these protection features. Other protections that can influence dynamic behavior or plant ride-through in the simulation period should be included.	
14	Demonstrate Behavior Throughout Range Accurately reflect behavior throughout the MW and MVar output range from minimum power through maximum power.	
15	Filters Include a detailed representation of any hardware or software filters for the IBR controllers if necessary.	
16	Site-Specific Equipment Settings (for As-Built Submissions Only) The model should be configured to match expected site-specific equipment settings. Any user-tunable parameters or options should be set in the model to match the equipment at the specific site being evaluated, as far as they are known. Default parameters are not appropriate unless these match the configuration in the installed equipment.	
Model Usability Features		
17	Control/Hardware Options The model must have pertinent control or hardware options accessible to the user (e.g., adjustable protection thresholds, real power recovery ramp rates, frequency or voltage droop settings, voltage control response times, or Sub-Synchronous Control Interaction damping controllers). Diagnostic flags (e.g., flags to show control mode changes or which protection has been activated) should be accessible to facilitate analysis and should clearly identify why a model trips during simulations.	
18	Time Steps The model can be run at solution time steps in the range from 5 μ s to 20 μ s. The recommended timestep is 10 μ s. The model shall be capable of working across a range of time steps and does not require a specific time step.	
19	Self-Initialization The model must be capable of initializing itself. Once provided with initial condition variables, the model must initialize and ramp to the ordered output without external input from simulation engineers. Any slower control functions that are included (such as switched shunt controllers or power plant controllers) must also accept initial condition variables if required. Note that during the first few seconds of simulation (e.g., 0 to 2 seconds), the system voltage and corresponding terminal conditions may deviate from nominal values due to other system devices initializing, and the model must be able to tolerate these deviations or provide a variable initialization time.	

Item	Description	Check or Comments
20	<p>External Reference Variables</p> <p>The model must accept external reference values. This includes real power reference values (for active power control mode) or frequency reference values (for frequency control), as well as reactive power reference values (for Q control modes) or voltage reference values (for V control modes). The model should accept these reference variables for initialization and be capable of changing these reference variables mid-simulation (i.e., dynamic signal references).</p>	
21	<p>Disable Protection Functions</p> <p>Protection models must be allowed to be disabled. Many studies result in inadvertent tripping of converter equipment, and the ability to disable protection functions temporarily provides study engineers with valuable system diagnostic information.</p>	
22	<p>Scalable Active Power Capacity</p> <p>The active power capacity of the model must be allowed to be scaled if using the same inverter, collector and/or pad-mount transformer models. The active power capacity of the model should be scalable in some way, either internally or through an external component, such as a scaling transformer. This is distinct from a dispatchable power order described in item 23 and is used for modeling different plant capacities or breaking a lumped equivalent plant into smaller composite models.</p>	
23	<p>Dispatch Capability</p> <p>The model must have the ability to dispatch its output to values less than its nameplate values. This is distinct from scaling a plant from one to multiple units and is used for testing plant behavior at various operating points.</p>	
Model Efficiency Features		
24	<p>Intel Fortran Version 15 or Higher Preferred</p> <p>The model should not be dependent on a specific Fortran version to run. It is recommended that the model supports the new Intel OneAPI HPC free Fortran compiler.</p>	
25	<p>Compiled Using Microsoft Visual Studio 2015 or Higher</p> <p>The model should be compiled using Microsoft Visual Studio 2015 and higher.</p>	
26	<p>PSCAD Version 5.0.1 or Higher Used</p> <p>The model should not be dependent on a specific PSCAD version to run.</p>	
27	<p>Quick Initialization</p> <p>The model must reach its ordered initial conditions as quickly as possible (e.g., < 5 seconds) to user supplied terminal conditions.</p>	
28	<p>Multiple Instances Supported</p> <p>The model shall support multiple instances of its own definition in the same simulation case.</p>	
29	<p>“Timed Snapshot” Feature Supported</p> <p>The model shall support PSCAD’s “timed snapshot” feature.</p>	
30	<p>“Multiple Run” Feature Supported</p> <p>The model shall support PSCAD’s “multiple run” feature.</p>	

Item	Description	Check or Comments
31	Global Variables Not Used The model must not use or rely upon global variables in the PSCAD environment.	
32	Replication of PSCAD Cases Allowed Allow replication in different PSCAD cases or libraries through the “copy” or “copy transfer” features.	
33	File Formats Recognized by PSCAD The model must be in formats recognized and usable by PSCAD. This includes: *.pswx (project files), *.pscx (case files), *.pslx (library files) and user-defined models.	
34	Multiple Layers Not Used The model should not utilize multiple layers in the PSCAD environment, including “disabled” layers.	
35	Contact Information Provided Contact information for modeling support engineers must be provided.	

Section 8. Appendix

8.1 PSCAD Model Quality Test Plotting Requirements

To facilitate efficient and standardized evaluation of the PSCAD model quality test results and benchmark results, plotting of simulation results are specified as follows:

1 | Quantities for plotting

- RMS voltage in p.u.
- Active power in MW
- Reactive power in MVar
- Frequency in Hz

2 | Measurement Points

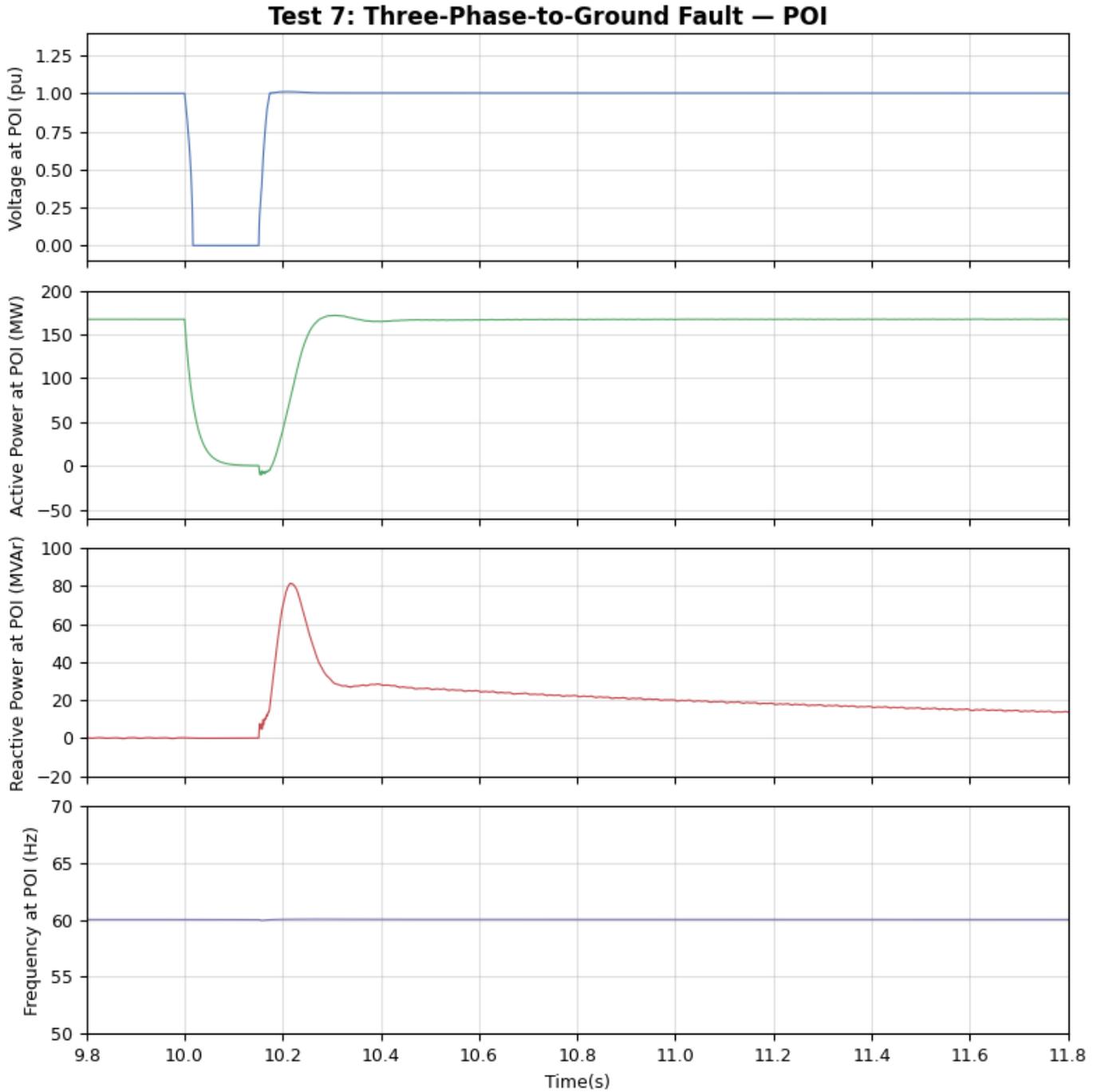
- Point of Connection (PoC) or inverter terminals, for all IBR models in the simulation
- Point of Interconnection (POI)

3 | Plotting Zoom Level

- Standard zoom: Figures include full simulation period.
- Transient period zoom: Figures focus on the 1 to 2 seconds around disturbance event.

*An example figure meeting these plotting requirements for a single measurement point and zoom level is shown in **Figure 3**.*

Figure 3. Example for the POI Measurement Point and Transient Period Zoom Level



8.2 Signal Profiles for PSCAD Model Quality Test Cases

(See Section 4.2 and Section 4.3)

Figure 4. Pref profile for Test 2

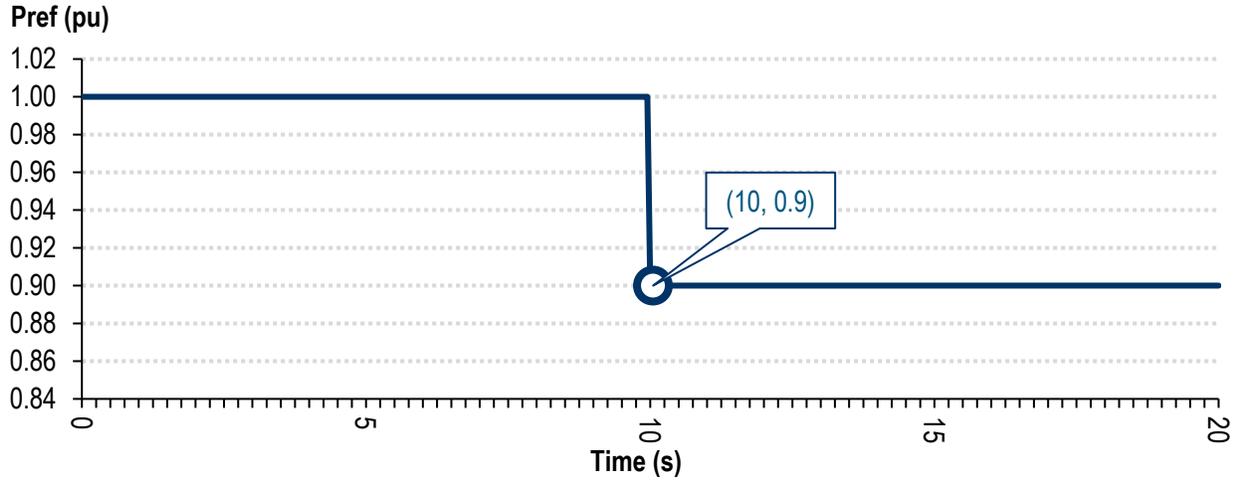


Figure 5. Frequency step up profile for Test 3

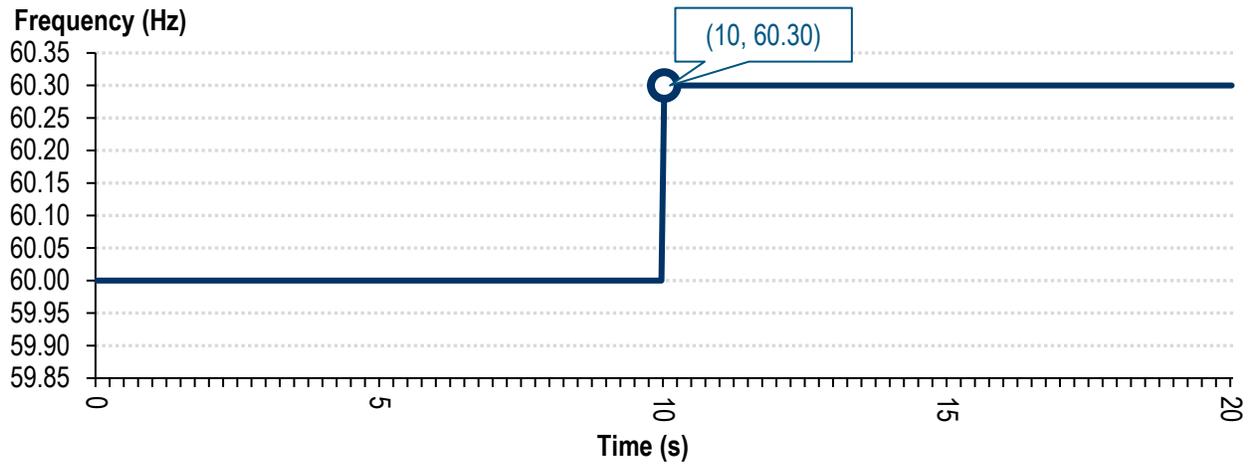


Figure 6. Frequency step down profile for **Test 4**

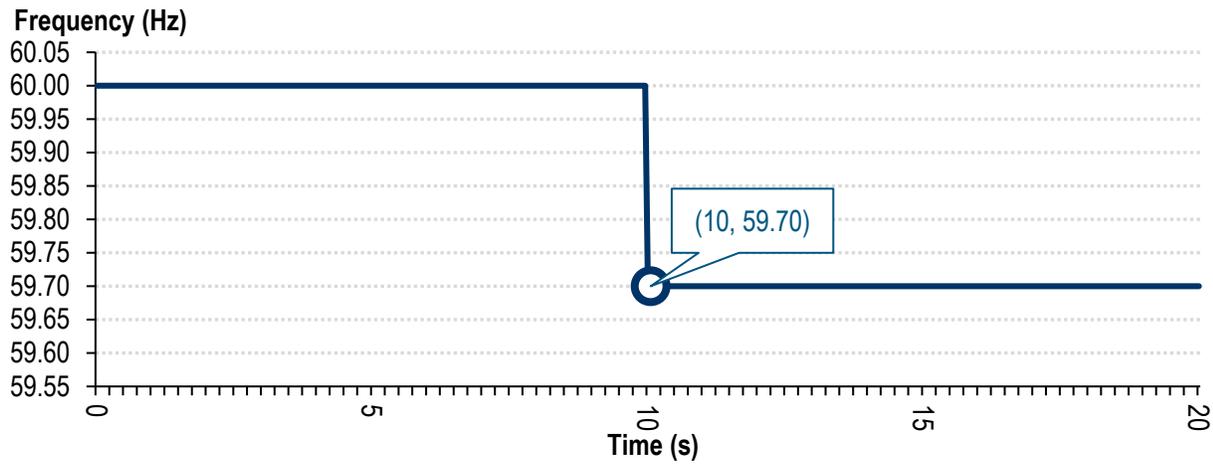


Figure 7. Voltage step up profile for **Test 5**

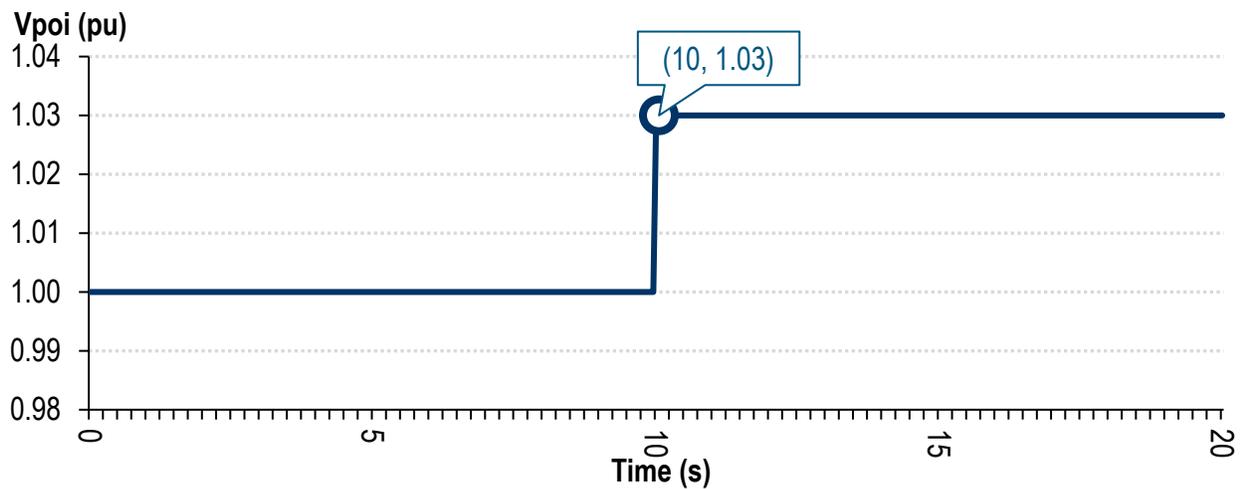


Figure 8. Voltage step down profile for **Test 6**

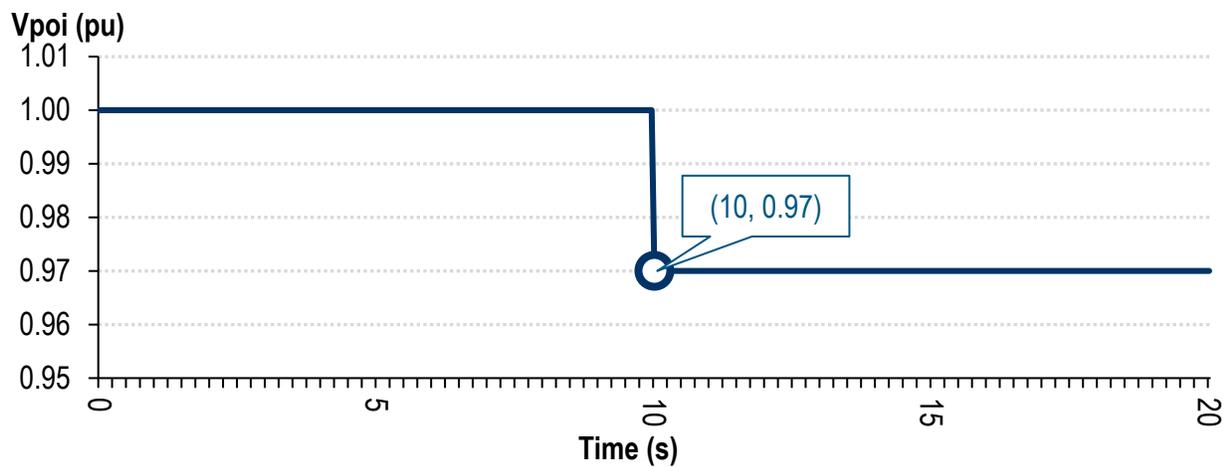


Figure 9. Low-voltage ride-through (LVRT) profile for **Test 10**

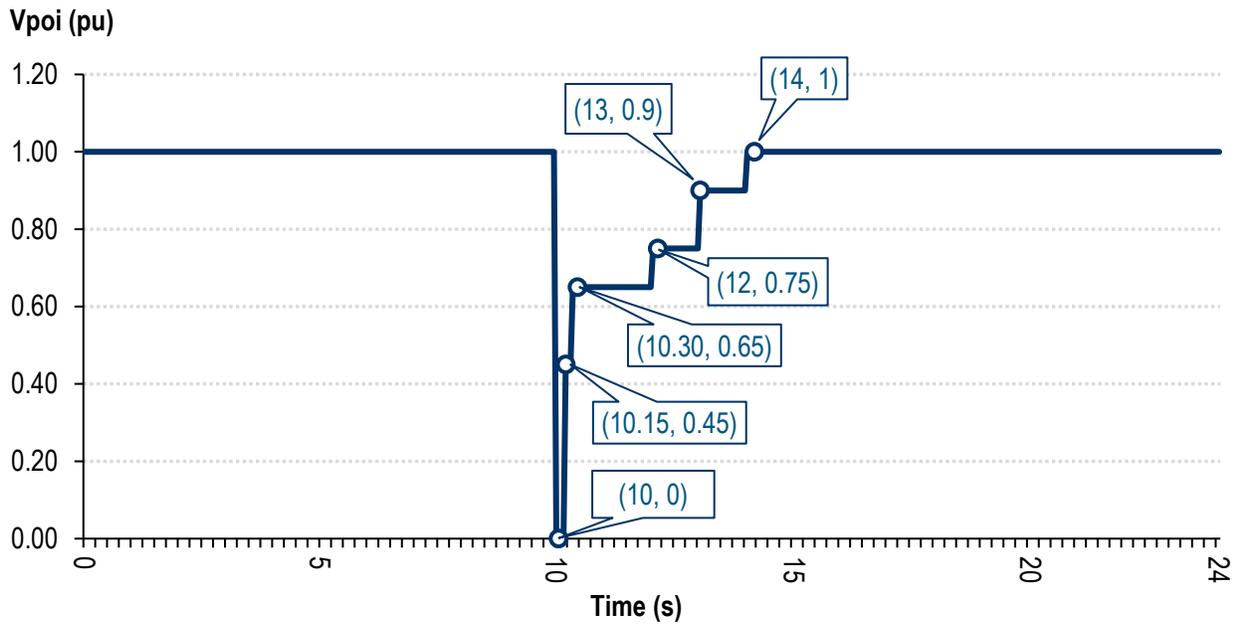


Figure 10. Over voltage ride-through profile for **Test 11**

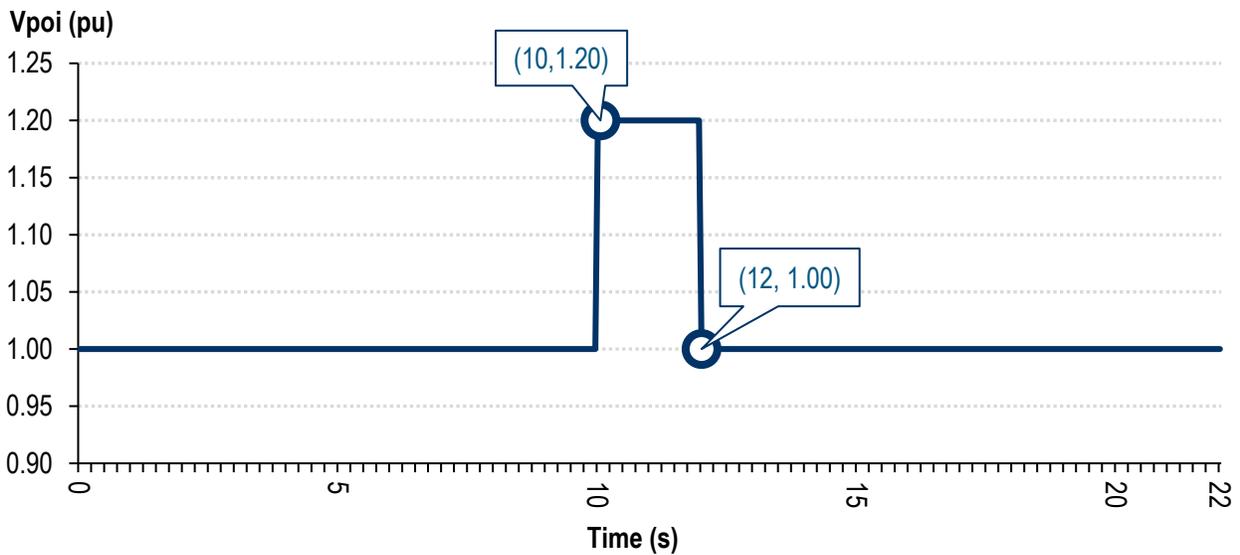


Figure 11. High-voltage ride-through (HVRT) profile for Test 12

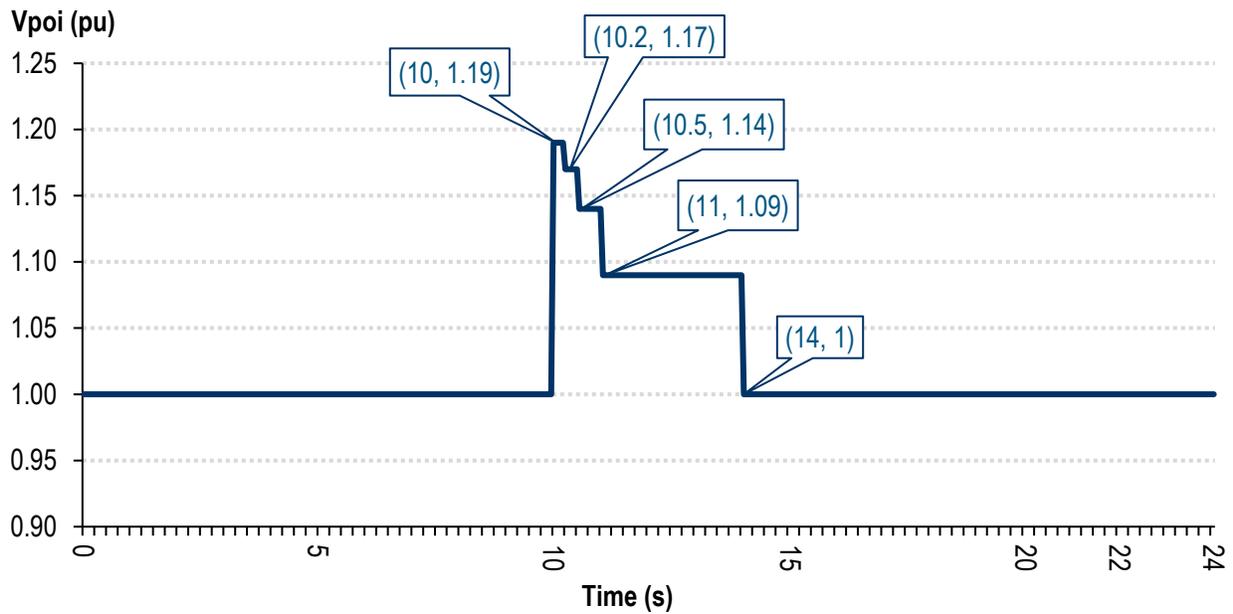
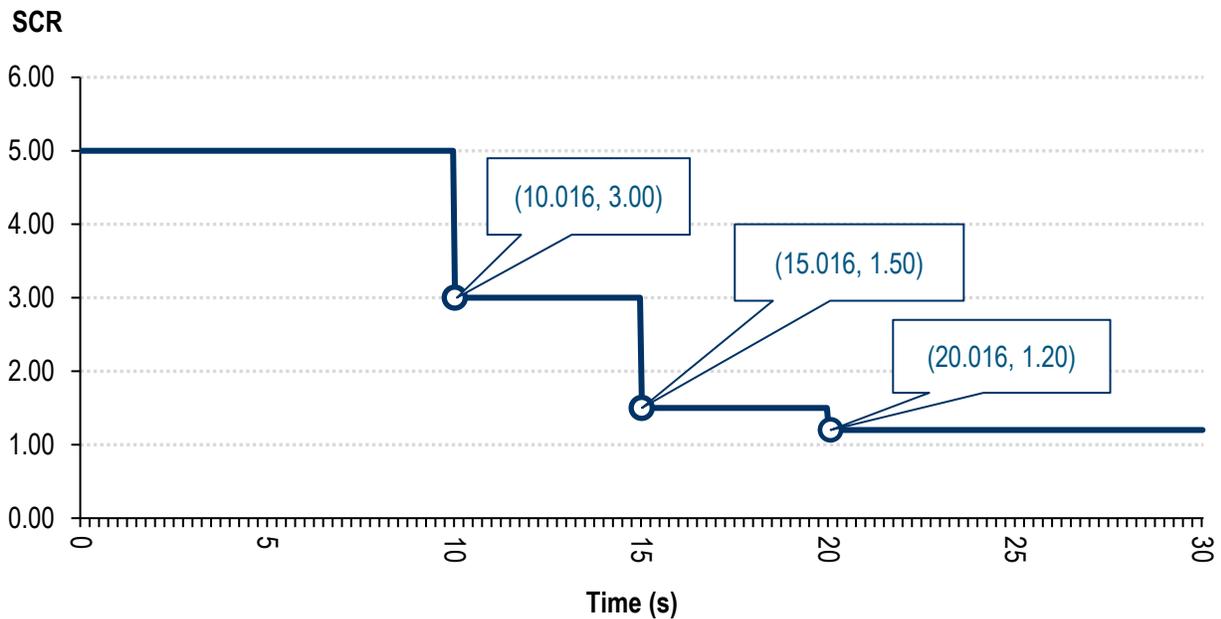


Figure 12. SCR profile for Test 13



Note: 3LG fault should be applied at 10s, 15s, 20s with 5s interval, SCR is recommended to change while the 3LG fault is applied, roughly one cycle(16ms) after the 3LG fault is applied, before a 3LG fault is cleared. Each 3LG fault is recommended to last for 3 cycles.

Figure 13. Frequency profile for Test 16

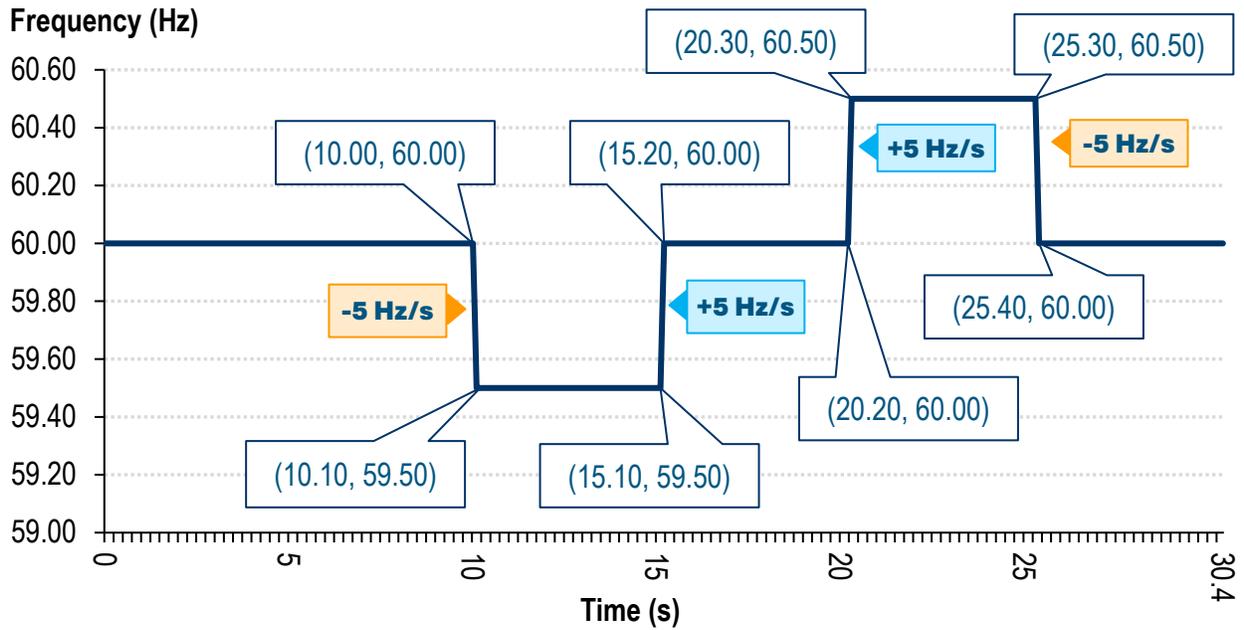
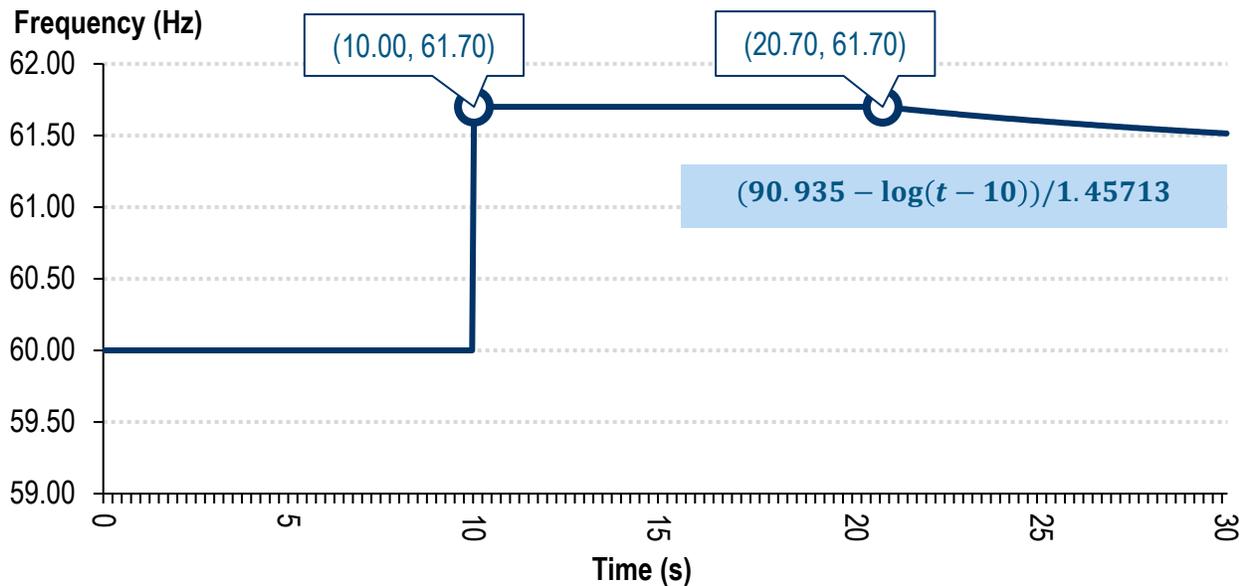
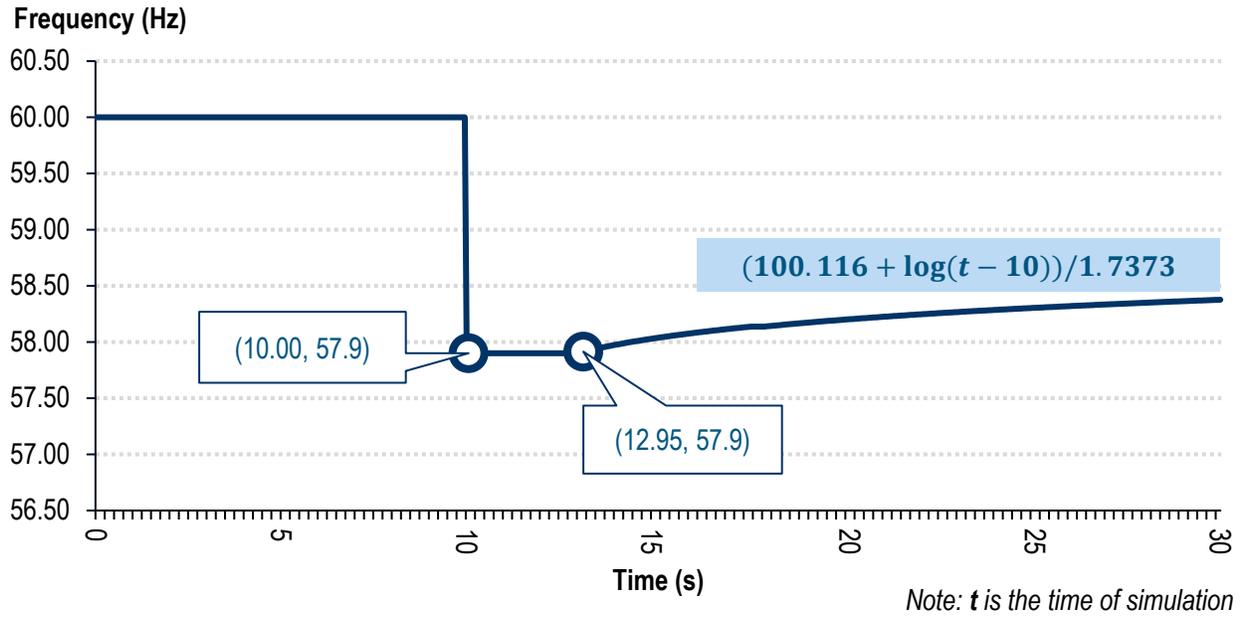


Figure 14. High frequency ride-through profile for Test 17



Note: t is the time of simulation

Figure 15. Low frequency ride-through profile for Test 18



Section 9. References

[NERC Reliability Guideline Template](#) (PDF)

[NERC, "Essential Actions to Industry: Inverter-Based Resource Performance and Modeling," May 20, 2025](#) (PDF)

[PJM Dynamic Model Development Guidelines](#) (PDF)

[NERC, "PRC-024-3 Frequency and Voltage Protection Settings for Generating Resources," October 2022](#)