# 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 |
| 1 | 10/12/2026 | 1. In Section 4, change “Vpoi = 1.0 p.u.” to “Vpoi = Vscheduled.”<br><br>2. Relax Unity Power Factor (PF) requirement. While unity PF is ideal at POI, near unity PF is acceptable to accommodate certain scenarios, such as BESS charging/discharging, where keeping the POI unity PF may be difficult.<br><br>3. In Section 4, acceptance criteria for tests are revised.<br><br>4. Delete Test 11. Overvoltage Ride-Through test.<br><br>5. Update LVRT, HVRT tests refer to NERC PRC-029-1. Also, corresponding signal profiles in Appendix 7.3.<br><br>6. Remove HFRT and LFRT tests. Instead, statements of the model frequency ride-through settings are required.<br><br>7. In Section 6, remove the submission requirement for output files from tests.<br><br>8. In 7.2, delete “Transient period zoom” plots submission requirement. |

# 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 sub-cycle 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 2800-2022[3] and IEEE 1547-2018[4] 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, also necessary for synchronous generation interconnection assessments as identified.[5] The PSPD model shall be submitted in the format of PSS/E per the requirements of the PJM Dynamic Model Development

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[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/IEEESTD.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/IEEESTD.2018.8332112

[5] Please refer to PJM EMT Model Development Guidelines for Synchronous Generators.

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 deficiencies and conflicts between PSS/E and EMT models up front, before the data package is submitted and studies are conducted, minimizing study delays. This document may not cover all possible scenarios, and it is the responsibility of the Project Developer to ensure that the PSCAD model submitted for their project is an accurate working model that meets all the criteria in this document at the MFO requested.

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 (PDF).*

## 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 **0**.

## 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 for 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 Tests 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

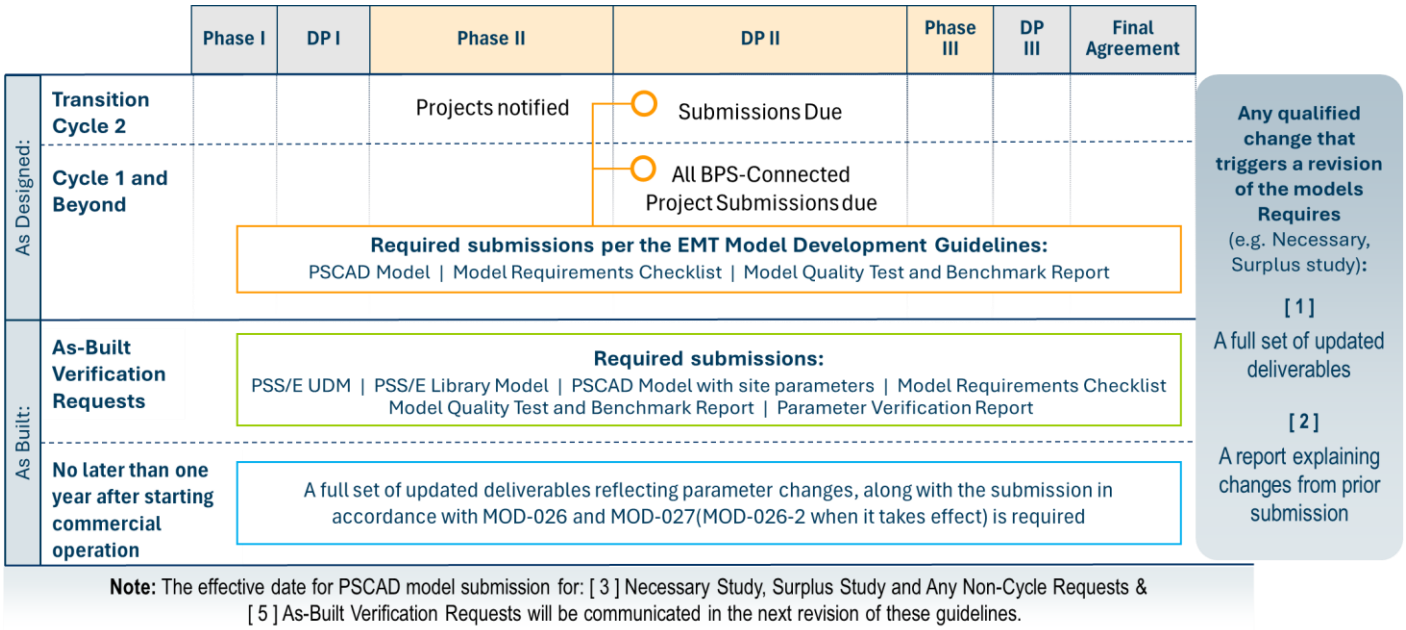
**Section 5**. The Parameter Verification Report shall demonstrate that the PSCAD model parameters accurately reflect the As-Built facility configuration. Any difference between the model used for study and the actual installed settings in the field should be deemed as a qualified change per FAC-002-4 or its successor and be reviewed prior to commercial operation to determine whether the existing studies are still valid.[6]

**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




[6] 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.

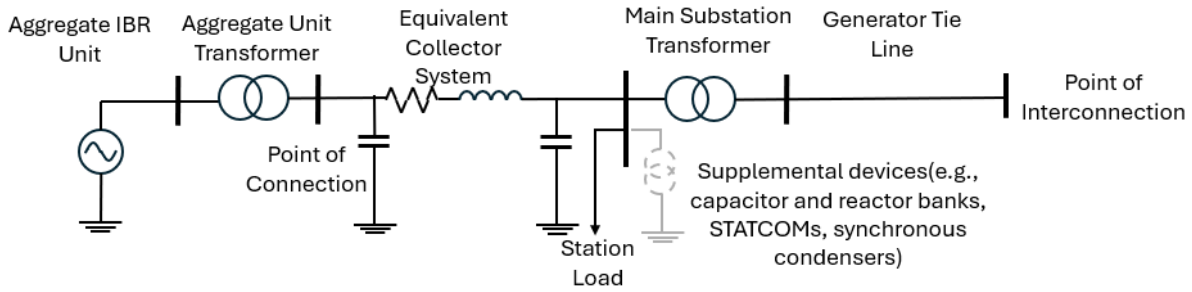
For most BPS reliability studies, the PSCAD model should be an aggregate, or a partially equivalent, representation of the IBR. **Figure 2** shows an example of an aggregated IBR plant when a single type of inverter is present. In an aggregate model, multiple inverters are represented as one larger unit 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:** Error! Reference source not found. provides information on the Model Requirements Checklist that must be completed and submitted with each PSCAD model.

# 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 short-circuit ratio (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 7.2: 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.

4 | **Multi-fuel-type generation interconnection:** The whole plant should be modeled and tested, rather than only the IBRs.

The PSCAD Model Quality Test cases are shown in **Section 4.2** and **4.3**, with signal profile shown in **Figure 4** through Error! Reference source not found. for some of the tests in **Section 7.3: Appendix**. For "Vscheduled" values at POI in the following tests, please refer to PJM Manual 3, Section 3.11 (PDF).

## 4.2 Functional Tests

**Test 1.** Flat Start

| **Test Name:** Flat Start | | |
|---|---|---|
| **Objective:**<br>The model shall achieve steady state within the specified time and remain in steady state for the remainder of the simulation. | **Operating Point at POI:**<br>▪ Active Power = Maximum Facility Output (MFO)<br>▪ Unity Power Factor (PF)[7]<br>▪ Vpoi = Vscheduled<br>▪ SCR = default | **Simulation-Specific Setup:**<br>15-second duration |
| **Acceptance Criteria:**<br>1) Verify P, Q, V as measured at the POI reach steady state within five seconds and stay in steady state for the remainder of the simulation.<br>2) The variations of generator outputs are no greater than 0.1 MW or 0.1 MVAR. | | |

[7] While unity PF is ideal at POI, near unity PF is acceptable to accommodate certain operating scenarios, such as BESS charging/discharging, that keeping the POI unity PF may be difficult. This applies to all of the following tests.

**Test 2.** Active Power Reference Step-Down

| **Test Name:** Active Power Reference Step-Down | | |
|---|---|---|
| **Objective:**<br>Test to verify the model can appropriately follow active power commands dynamically during the simulation and is configured with reasonable parameters. | **Operating Point at POI:**<br>▪ Active Power = MFO<br>▪ Unity PF<br>▪ Vpoi = Vscheduled<br>▪ SCR = default | **Simulation-Specific Setup:**<br>Initialize the model into steady state. At t=10s, step down active power reference (Pref) of the PPC from 1 p.u. to 0.9 p.u. Run the simulation for at least an additional 10 seconds. |
| **Acceptance Criteria:**<br>1) The active power output (P) shall track the applied Pref command.<br>2) Reactive power output (Q) shall remain within the acceptable range of reactive power control settings. | | |

**Test 3.** Frequency Step-Up

| **Test Name:** Frequency Step-Up | | |
|---|---|---|
| **Objective:**<br>Verify the model is configured to provide adequate primary frequency response. | **Operating Point at POI:**<br>▪ Active Power = MFO<br>▪ Unity PF<br>▪ Vpoi = Vscheduled<br>▪ SCR = default | **Simulation-Specific Setup:**<br>▪ Frequency step size = 0.3 Hz.<br>▪ 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:**<br>1) P shall decrease in response to the frequency step-up event, with parameters in line with values in Table 8 of IEEE 2800-2022.<br>2) Q shall remain within the acceptable range of reactive power control settings. | | |

**Test 4.** Frequency Step-Down, With Headroom

| **Test Name:** Frequency Step-Down, With Headroom | | |
|---|---|---|
| **Objective:**<br>Verify the model is configured to provide adequate primary frequency response. | **Operating Point at POI:**<br>▪ Active Power = 80% of MFO<br>▪ Unity PF<br>▪ Vpoi = Vscheduled<br>▪ SCR = default | **Simulation-Specific Setup:**<br>▪ Frequency step size = 0.3 Hz<br>▪ 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:**<br>1) P shall increase in response to the frequency step-down event, with parameters in line with values in Table 8 of IEEE 2800-2022.<br>2) Q shall remain within the acceptable range of reactive power control settings. | | |

**Test 5.** Voltage Step-Up Test

| **Test Name:** Voltage Step-Up Test | | |
|---|---|---|
| **Objective:**<br>Verify the model provides an appropriate reactive power response and is configured with reasonable parameters. | **Operating Point at POI:**<br>▪ Active Power = MFO<br>▪ Unity PF<br>▪ Vpoi = Vscheduled<br>▪ SCR = default | **Simulation-Specific Setup:**<br>▪ Voltage step size = 0.03 p.u.<br>▪ 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:**

1) The plant shall not trip and shall have a stable, well-damped response.
2) Q shall respond appropriately in accordance with the control settings.
3) P shall remain within the acceptable range based on control settings.
4) The plant shall not enter momentary cessation mode.

**Test 6.** Voltage Step-Down Test

| **Test Name:** Voltage Step-Down Test | | |
|---|---|---|
| **Objective:**<br>Verify the model provides an appropriate reactive power response and is configured with reasonable parameters. | **Operating Point at POI:**<br>▪ Active Power = MFO<br>▪ Unity PF<br>▪ Vpoi = Vscheduled<br>▪ SCR = default | **Simulation-Specific Setup:**<br>▪ Voltage step size = 0.03 p.u.<br>▪ 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:**

5) The plant shall not trip and shall have a stable, well-damped response.
6) Q shall respond appropriately in accordance with the control settings.
7) P shall remain within the acceptable range based on control settings.
8) The plant shall not enter momentary cessation mode.

## 4.3 Ride-Through Performance Tests

**Test 7.** Three-Phase-to-Ground Fault

| **Test Name:** Three-Phase-to-Ground Fault | | |
|---|---|---|
| **Objective:**<br>Verify the model can ride through a balanced fault, provide appropriate reactive power response and recover to pre-fault conditions. | **Operating Point at POI:**<br>▪ Active Power = MFO<br>▪ Unity PF<br>▪ Vpoi = Vscheduled<br>▪ SCR = default | **Simulation-Specific Setup:**<br>▪ Fault impedance: 0 Ohms<br>▪ Fault duration: 9 cycles<br>▪ 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:**

- The plant shall ride through and shall have a stable and well-damped response. An acceptable damping ratio is 3% or greater.
- After fault clearing and voltage recovery within the normal range, the active power recovers to the 95% pre-fault value within one second.
- If the plant enters momentary cessation (current blocking) mode, it shall resume current injection in less than five cycles following voltage recovery.
- If momentary cessation cannot be eliminated due to equipment limitations, notify PJM when submitting the Model Quality Test Report.

Single-Line-to-Ground Fault

| **Test Name:** Single-Line-to-Ground Fault | | |
|---|---|---|
| **Objective:**<br>Verify the model can ride through an unbalanced fault, provide appropriate reactive power response and recover to pre-fault conditions. | **Operating Point at POI:**<br>▪ Active Power = MFO<br>▪ Unity PF<br>▪ Vpoi = Vscheduled<br>▪ SCR = default | **Simulation-Specific Setup:**<br>▪ Fault impedance: 0 Ohms<br>▪ Fault duration: 9 cycles<br>▪ 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:**

- The plant shall ride through and shall have a stable and well-damped response. An acceptable damping ratio is 3% or greater.
- After fault clearing and voltage recovery within the normal range, the active power recovers to the 95% pre-fault value within one second.
- If the plant enters momentary cessation (current blocking) mode, it shall resume current injection in less than five cycles following voltage recovery.
- If momentary cessation cannot be eliminated due to equipment limitations, notify PJM when submitting the Model Quality Test Report.

**Test 8.** Line-to-Line Fault

| **Test Name:** Line-to-Line Fault | | |
|---|---|---|
| **Objective:**<br>Verify the model can ride through an unbalanced fault, provide appropriate reactive power response and recover to pre-fault conditions. | **Operating Point at POI:**<br>▪ Active Power = MFO<br>▪ Unity PF<br>▪ Vpoi = Vscheduled<br>▪ SCR = default | **Simulation-Specific Setup:**<br>▪ Fault impedance: 0 Ohms<br>▪ Fault duration: 9 cycles<br>▪ 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:**

- The plant shall ride through and shall have a stable and well-damped response. An acceptable damping ratio is 3% or greater.
- After fault clearing and voltage recovery within the normal range, the active power recovers to the 95% pre-fault value within one second.
- If the plant enters momentary cessation (current blocking) mode, it shall resume current injection in less than five cycles following voltage recovery.
- If momentary cessation cannot be eliminated due to equipment limitations, notify PJM when submitting the Model Quality Test Report.

**Test 9.** Low-Voltage Ride-Through (LVRT) Profile

| **Test Name:** Low-Voltage Ride-Through (LVRT) Profile | | |
|---|---|---|
| **Objective:**<br>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. | **Operating Point at POI:**<br>▪ Active Power = MFO<br>▪ Unity PF<br>▪ Vpoi = Vscheduled<br>▪ SCR = 50 | **Simulation-Specific Setup:**<br>▪ Voltage profile: NERC PRC-029-1 (PDF), Attachment 1, Voltage Ride-Through Criteria<br>▪ 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. |

**Acceptance Criteria:**

1) The plant rides through.
2) Units inject reactive current during the fault.
3) The active power recovers to pre-disturbance within one second following voltage recovery.
4) If the plant enters momentary cessation, it shall resume current injection in less than five cycles following voltage recovery.

***If momentary cessation cannot be eliminated*** due to equipment limitations, notify PJM when submitting the Model Quality Test Report.

**Test 10.** High-Voltage Ride-Through (HVRT) Profile

| **Test Name:** High-Voltage Ride-Through (HVRT) Profile | | |
|---|---|---|
| **Objective:**<br>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. | **Operating Point at POI:**<br>▪ Active Power = MFO<br>▪ Unity PF<br>▪ Vpoi = 1.0 p.u.<br>▪ SCR = 50 | **Simulation-Specific Setup:**<br>▪ Voltage profile: NERC PRC-029-1 (PDF), Attachment 1, High-Voltage Duration<br>▪ 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. |
| **Acceptance Criteria:**<br>1) The plant rides through.<br>2) Units absorb reactive current during the fault.<br>3) The active power recovers to pre-disturbance within one second following voltage recovery.<br>4) If the plant enters momentary cessation, it shall resume current injection in less than five cycles following voltage recovery. | | **If momentary cessation cannot be eliminated** due to equipment limitations, notify PJM when submitting the Model Quality Test Report. |

**Test 11.** System Strength Test

| **Test Name:** System Strength Test | |
|---|---|
| **Objective:**<br>Observe model performance under sequentially lower SCRs.<br><br>**Operating Point at POI:**<br>▪ Active Power = MFO<br>▪ Unity PF<br>▪ Vpoi = Vscheduled<br>▪ SCR = 5 | **Simulation-Specific Setup:**<br>▪ SCR sequence: 5, 3, 1.5, 1.2<br>▪ Interval between SCRs: 5s<br>▪ 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 three 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. |
| **Acceptance Criteria:**<br>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. An acceptable damping ratio is 3% or greater. | |

**Test 12.** Phase Angle Change: +25deg

| **Test Name:** Phase Angle Change: +25deg | | |
|---|---|---|
| **Objective:**<br>Verify the model can ride through an instantaneous voltage phase angle change and recover stably to pre-fault conditions. | **Operating Point at POI:**<br>▪ Active Power = MFO<br>▪ Unity PF<br>▪ Vpoi = Vscheduled<br>▪ SCR = 50 | **Simulation-Specific Setup:**<br>▪ Voltage phase angle change: +25 deg<br>▪ 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** | | |
| 1. Plant rides through; no unit trips. | 2. Plant recovers to pre-fault conditions. | 3. Momentary cessation not observed. |

**Test 13.** Phase Angle Change: -25deg

| **Test Name:** Phase Angle Change: -25deg | | |
|---|---|---|
| **Objective:**<br>Verify the model can ride through an instantaneous voltage phase angle change and recover stably to pre-fault conditions. | **Operating Point at POI:**<br>▪ Active Power = MFO<br>▪ Unity PF<br>▪ Vpoi = Vscheduled<br>▪ SCR = 50 | **Simulation-Specific Setup:**<br>▪ Voltage phase angle change: -25 deg<br>▪ 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** | | |
| 1. Plant rides through; no unit trips. | 2. Plant recovers to pre-fault conditions. | 3. Momentary cessation not observed. |

**Test 14.** High Rate of Change of Frequency (ROCOF)

| **Test Name:** High Rate of Change of Frequency (ROCOF) | | |
|---|---|---|
| **Objective:**<br>Verify the model can ride through high rate of change of frequency sequence and recover stably to pre-fault conditions. | **Operating Point at POI:**<br>▪ Active Power = MFO<br>▪ Active Power = MFO<br>▪ Unity PF<br>▪ Vpoi = Vscheduled<br>▪ SCR = 50 | **Simulation-Specific Setup:**<br>▪ ROCOF sequence:<br>  ◦ -5 Hz/s for 0.1s to 59.5 Hz, hold for interval<br>  ◦ +5 Hz/s for 0.1s to 60 Hz, hold for interval<br>  ◦ +5 Hz/s for 0.1s to 60.5 Hz, hold for interval<br>  ◦ -5 Hz/s for 0.1s to 60 Hz<br>▪ Interval duration: five seconds<br>▪ 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 five seconds after the frequency returns to nominal. |
| **Acceptance Criteria** | | |
| 1. Plant rides through; no unit trips. | 2. Plant recovers to pre-fault conditions. | 3. Momentary cessation not observed. |

**Test 15.** Frequency Ride-Through (FRT)

To verify frequency ride-through capability, PSCAD simulation is not required. Instead, statements of the frequency ride-through (FRT) settings of the model should be provided in the Model Quality Test Report, overlaying the FRT plot with the frequency ride-through envelope of Figure 1 in PRC-029-1.

**Acceptance Criteria:**
Plant rides through in the must ride-through zone.

# Section 5. PSCAD and PSS/E Model Benchmark Requirements

Tests 1 through 16 shall be completed for all projects to verify PSCAD model quality. In addition, PSCAD and PSS/E models shall be properly benchmarked 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. Depending on the stage of interconnection application, either As-Designed or As-Built, different number of tests are required, as specified in this section. Tests 1 through 16, as well as benchmark tests shall be documented in the Model Quality Tests and PSCAD-PSS/E Model Benchmark Report.

## *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, tests listed in Table 1 shall be performed for As-Designed projects. PSCAD and PSS/E signals must be overlayed and properly aligned with each other for each single signal plot of a test (e.g., active power, reactive power). All cases, files and plots used for the PSCAD-PSS/E model benchmark 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 9** |
| **HVRT Profile** | **Test 10** |

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 overlayed 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. Test 1 through Test 16, except the tests listed in Table 2, shall be performed for As-Built model benchmark.

*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** | **0** |
| **Line-to-Line Fault** | **0** |
| **Phase Angle Change: +25deg** | **Test 12** |
| **Phase Angle Change: -25deg** | **Test 13** |

In addition, a Parameter Verification Report shall be provided, comparing 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** | ▪ As-Designed (e.g., the Cycle process, Necessary Study)<br>▪ 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 | **Model Requirements Checklist** | ▪ As-Designed<br>▪ As-Built and beyond<br>**Note:** Please provide as a separate file, not included in Model Quality Test Report. | Error! Reference source not found. |
| 3 | **Model Quality Tests and Benchmark Report** | ▪ As-Designed<br>▪ As-Built and beyond<br>**Note:** All Model Quality Tests (Section 4, Tests 1–16) **AND** benchmark tests (Section 5, Tests in Table 1 or Table 2, as applicable) shall be documented in one PDF report. | **Section 4**<br>**Section 5** |
| 4 | **All PSCAD Cases and Files for Each Model Quality Test and Benchmark Report** | ▪ As-Designed<br>▪ As-Built and beyond<br>**Notes:** Output files from the Model Quality Tests are not required. All the Model Quality Tests should be replicable with the case files submitted. | |
| 5 | **Parameter Verification Report** | ▪ 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

## 7.1 PSCAD Model Requirements Checklist

The PSCAD Model Requirements Checklist 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 as an attestation.

> *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

## 7.2 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**

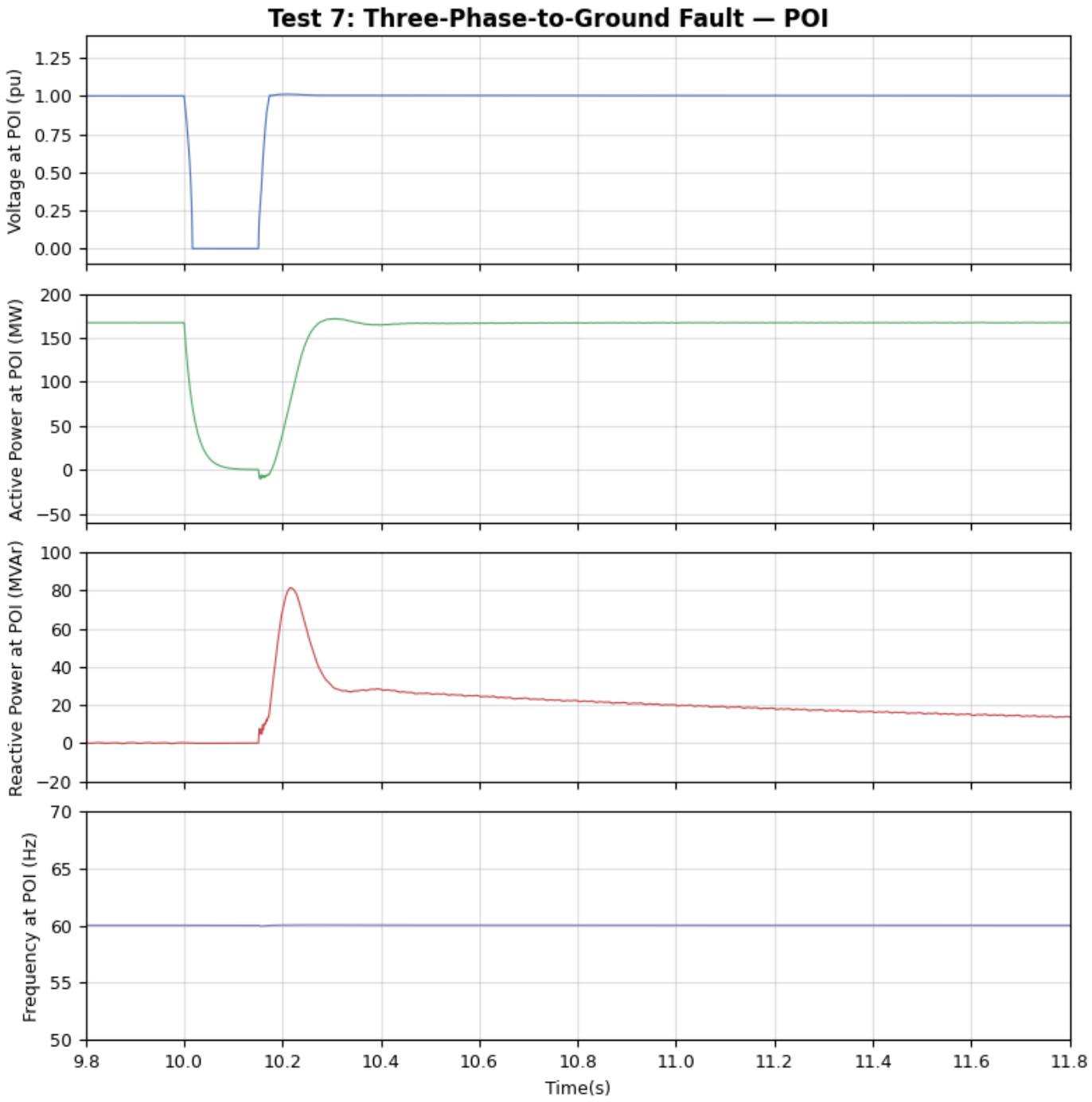
- Point of Connection (PoC) or inverter terminals, for all IBR models in the simulation
- Point of Interconnection (POI)

**3 | Plotting Zoom Level**

- Standard zoom: Figures include full simulation period.

*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



## *7.3 Signal Profiles for PSCAD Model Quality Test Cases*

(See **Section 4.2** and **Section 4.3**)

**Figure 4.** Pref Profile for **Test 2**

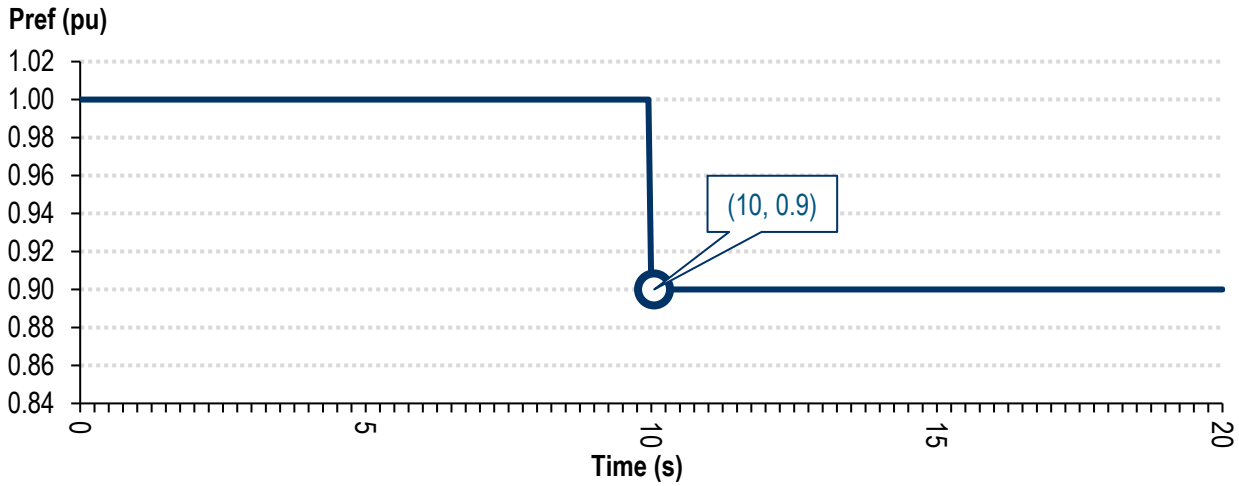



**Figure 5.** Frequency Step-Up Profile for **Test 3**

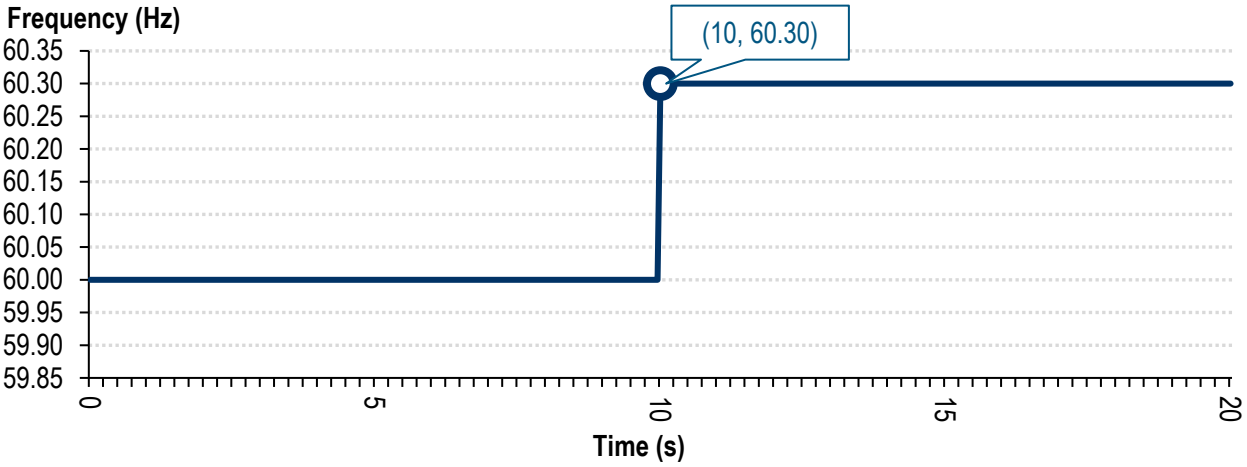


**Figure 6.** Frequency Step-Down Profile for **Test 4**

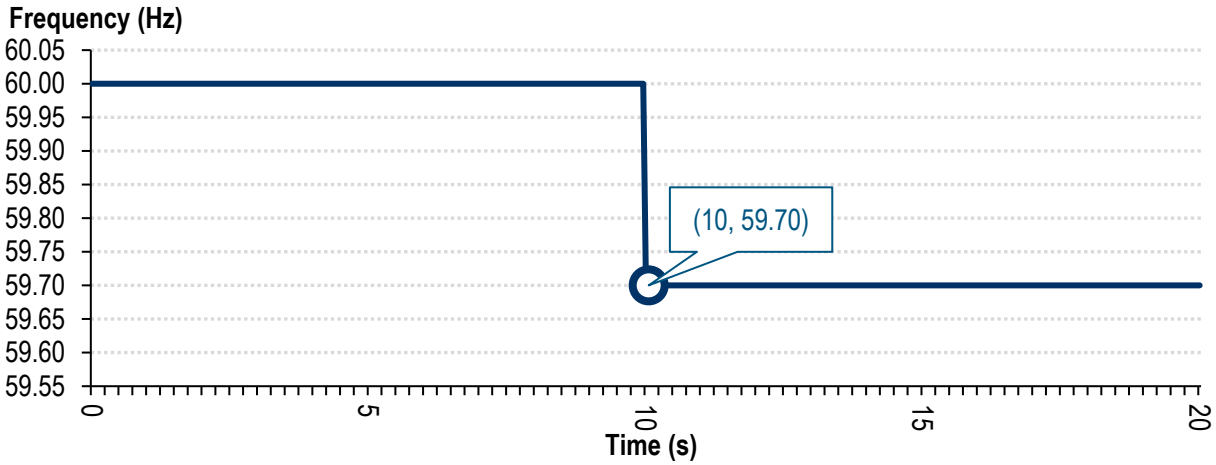



**Figure 7.** Voltage Step-Up Profile for **Test 5**

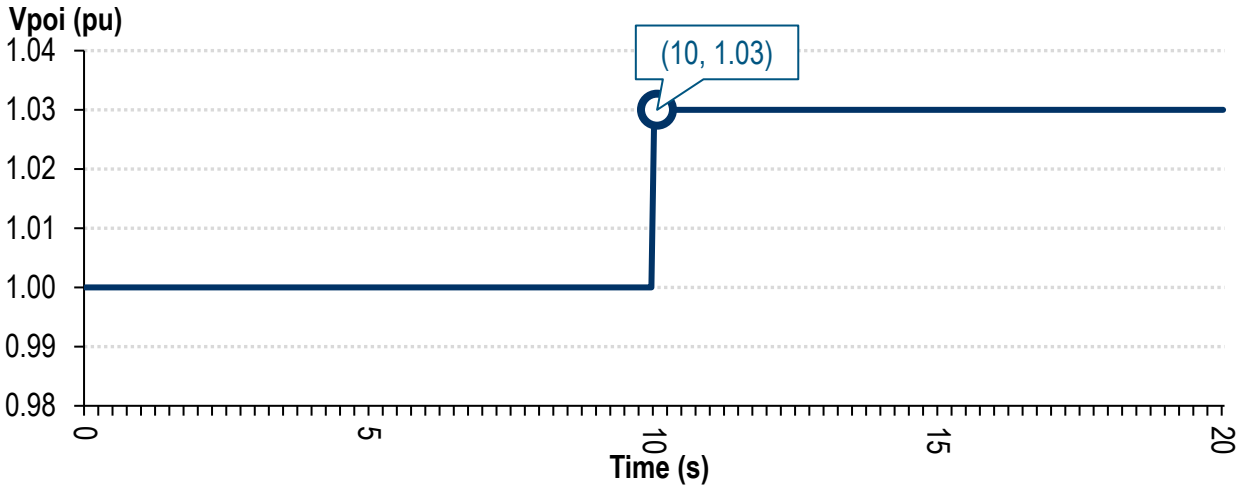



**Figure 8.** Voltage Step-Down Profile for **Test 6**

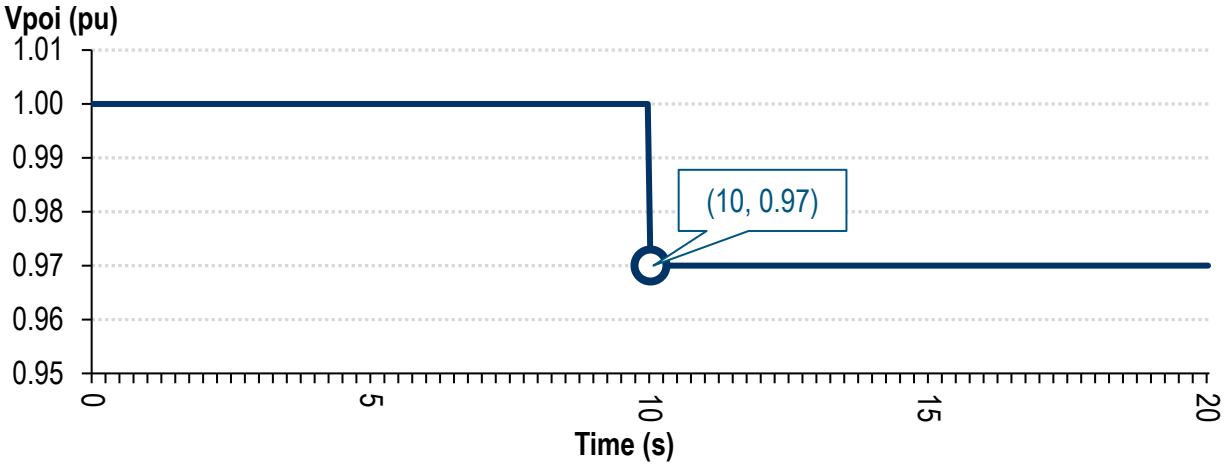


**Figure 9.** Low-Voltage Ride-Through (LVRT) Profile for **Test 9**

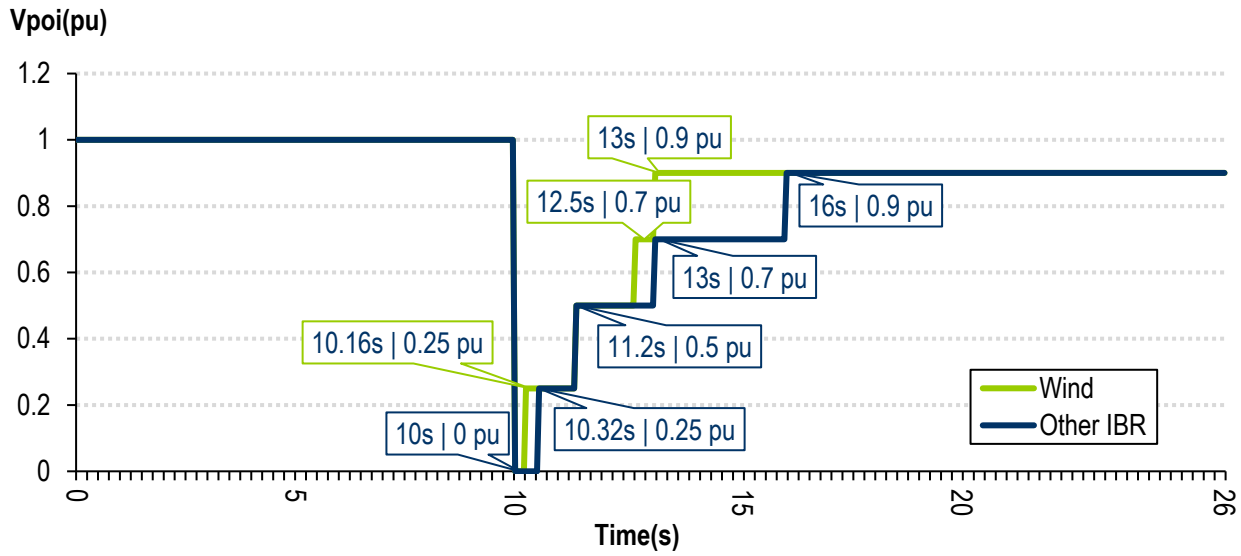



**Figure 10.** High-Voltage Ride-Through (HVRT) Profile for **Test 10**

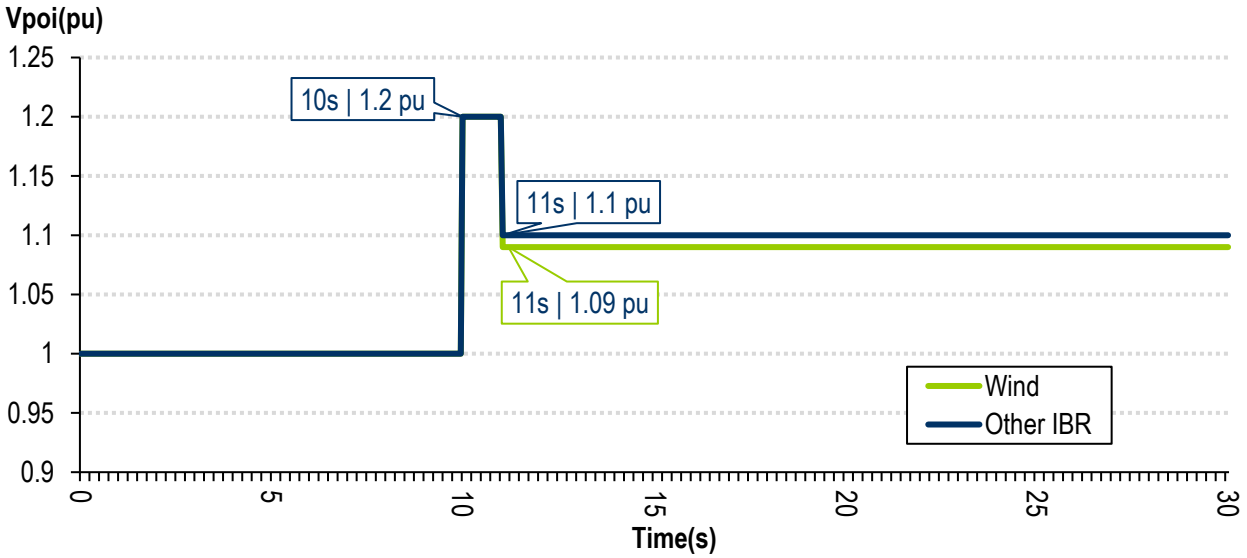
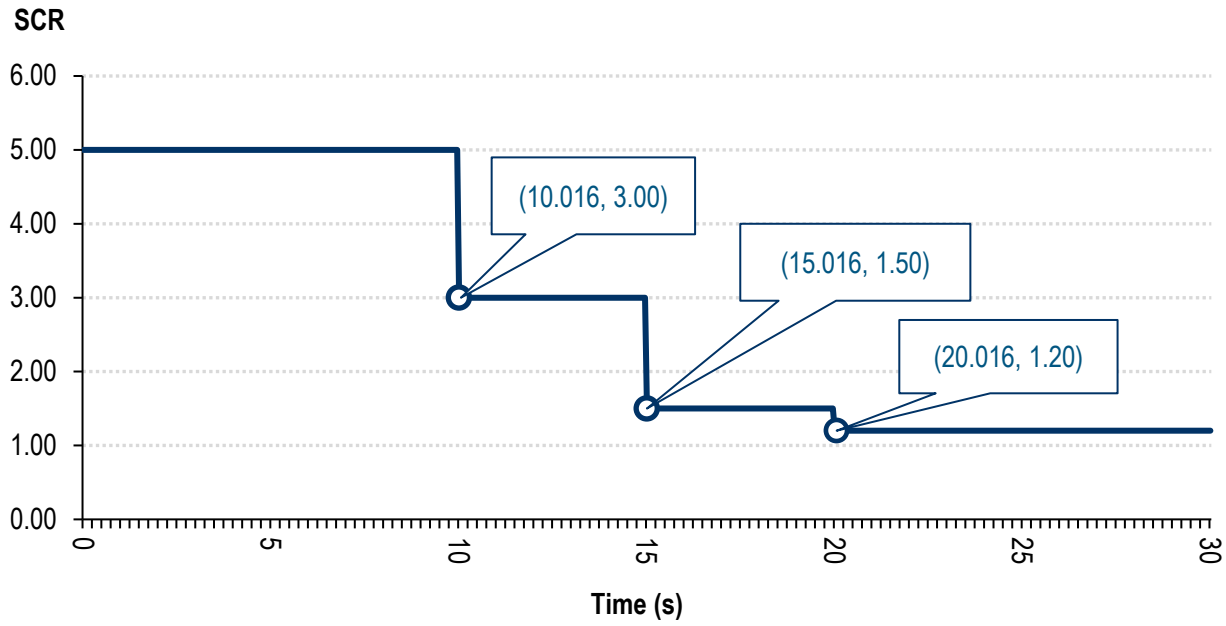
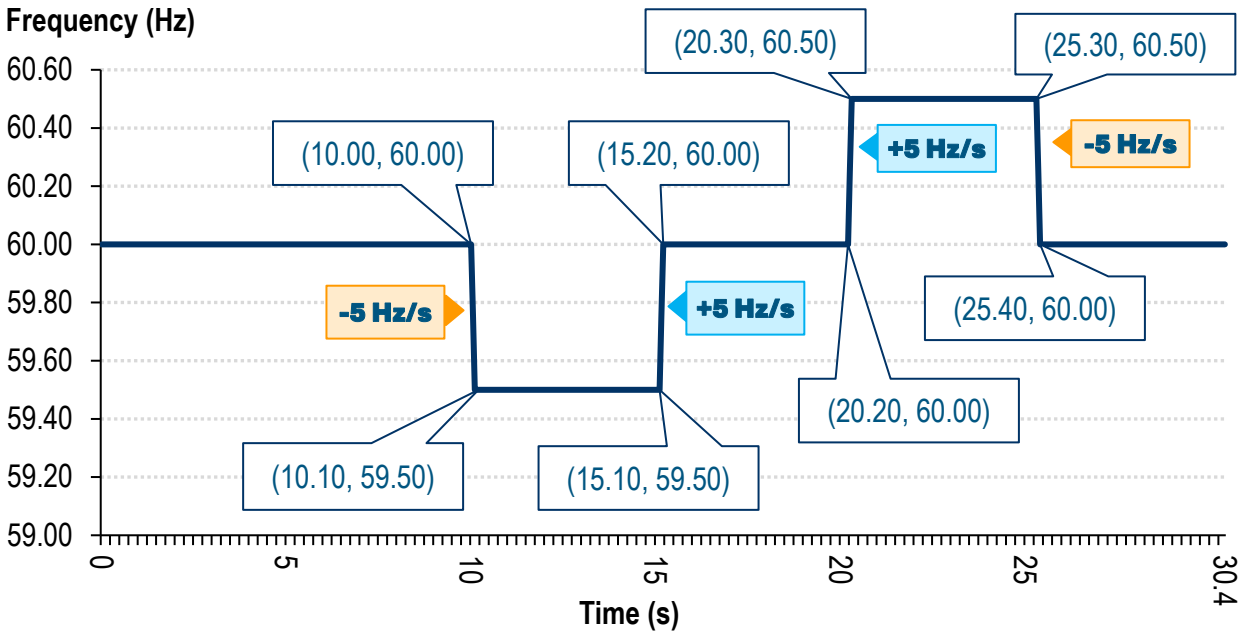


**Figure 11.** SCR Profile for **Test 11**




*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 three cycles.*

**Figure 12.** Frequency Profile for **Test 14**



## 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-024-4 Frequency and Voltage Protection Settings for Synchronous Generators, Type1 and Type 2 Wind Resources, and Synchronous Condensers (PDF)