

Appendix C-2
Model Acceptance Tests for Inverter-Based Resources (IBR)
Revision 2.0

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Section 1

Introduction

The positive sequence and electromagnetic transient (EMT) model submittals in support of an Interconnection Request, or subsequent changes to the models, must be accompanied by model acceptance tests (MAT). This document outlines dynamic performance and benchmarking requirements, applicable tests, and the procedures for conducting these tests.

1.1 Scope of Model Acceptance Tests

To assess the consistency, accuracy, and dynamic performance of the models provided in support of an Interconnection Request (IR), a series of tests shall be conducted in a single machine infinite bus (SMIB) system bounded by low and relatively high short circuit ratio (SCR)¹ conditions. Additionally, the tests verify the IBR plant model's ability to demonstrate compliance with the IEEE 2800 sub-clauses adopted by PP5-6 Appendix F, and the performance requirements noted below reflect these sub-clauses. While the Appendix F requirements only apply to IBR plants starting with the first Cluster Study and subsequent Interconnection Studies, the tests provided in the Appendix will be performed for model reviews of IBR plants that interconnected prior to the first Cluster Study as well. In the case of the latter, for tests that specifically reference IEEE 2800, the performance requirements employed will be relaxed to reflect the applicable performance requirements for the interconnection study associated with the IBR plant. An overview of the tests is provided in Table 1 below.

Table 1 Model Acceptance Tests

Test No	Test Name
1	Flat Run
2	Steady-State Reactive Power Limit
3	Dynamic Reactive Power Limit
4	Voltage Reference Step Change
5	Active Power Reference Step Change
6	Grid Frequency Magnitude Change
7	Balanced Fault Ride-Through
8	Balanced Remote Fault Ride-Through
9	Unbalanced Fault Ride-Through

¹ SCR is a measure of the strength of the network to which the equipment is connected (or to be connected). Further details can be found in Annex C of IEEE Std. 2800-2022.

10	Voltage Protection Verification
11	NERC PRC-024 Voltage Ride-Through
12	Frequency Ride-Through
13	Rate of Change of Frequency (ROCOF) Ride-Through
14	Grid Voltage Phase Angle Change Ride-Through
15	Point of Interconnection SCR Change Ride-Through
16	Power Factor Verification Test
17	Consecutive Voltage Deviation Ride-through
18	Voltage Oscillation Ride-through

1.1.1 Battery Energy Storage System (BESS)

For battery energy storage system (BESS), all model acceptance tests must be performed in both discharging and charging mode.

1.1.2 Hybrid IBR Plant

Should a plant incorporate multiple IBR technologies, such as a combination of photovoltaic (PV) and BESS, model assessment tests must be applied to each technology type individually per its designated operational strategy. For instance, in a PV-BESS facility, should the BESS be designed to inject or absorb power from the transmission network, irrespective of the PV's operational status, the testing should encompass the stand-alone operation of the PV and BESS and their concurrent functioning.

1.1.3 SCR for Model Acceptance Tests

The model acceptance tests shown in Table 1 shall be conducted for the three SCRs listed below:

1. SCR = 2.5 and X/R = 10
2. SCR = 20 and X/R = 10
3. SCR = Infinite ²

The SCR and X/R shown above and IBR's rated aggregate MVA value shall determine the required grid impedance between the IBR plant's Point of Interconnection (POI) and the infinite bus representing the transmission grid. For a HVDC connected IBR plant, the MVA capability of the HVDC transmission facility shall be used.

For a hybrid IBR plant, the grid impedance calculated for model acceptance tests is guided by the plant's designated operational strategy. If each technology type (e.g., PV, BESS) in the plant is

² For any test that uses an infinite SCR, if reactive drift is observed during testing, this can be changed to a finite value that is still sufficiently high to where the generator will not influence the dynamics of the POI.

intended to operate in stand-alone mode only, the grid impedance will be determined using the aggregate rating of the specific IBR resource being evaluated. If not, the total aggregated rating of all IBR resources will be used.

1.1.4 Reference Point of Applicability for Dynamic Performance and Benchmarking Requirements

The reference point of applicability for the dynamic performance and benchmarking requirements is the Point of Measurement (POM)³. The applicable requirements are provided along with each model acceptance test.

1.1.5 Simulation Tools

The model acceptance tests shall be conducted using PSSE for positive sequence modeling and PSCAD for EMT modeling. The software version used shall be the ISO-NE version in effect.⁴

1.1.6 Benchmarking Report

A benchmarking report must be submitted to document the analysis results, as specified in section 5.

1.1.7 Results Evaluation

ISO-NE will use good engineering judgment and the requirements outlined herein to evaluate submitted model dynamic performance and benchmarking results for acceptability.

1.1.8 Interconnection Stage Applicability

The model acceptance tests in this Appendix correspond to, and leverage, the design-evaluation activities described in IEEE 2800.2-2026 Section 7.3, conducted in support of a Cluster Study.

³ Definitions adopted as used in IEEE Std. 2800-2022, and per PP5-6 Appendix F

⁴ The list of software and software versions used by ISO for interconnection studies is posted on its website at <https://askiso.iso-ne.com/s/article/Modeling-Data-Software-Compatibility>

Section 2

Test System

The model acceptance tests in Table 1 shall be conducted using an SMIB test system.

2.1 Single Machine Infinite Bus

A SMIB test system generally consists of an equivalent IBR plant connected to a bus representing the transmission grid (i.e., infinite bus). The transmission line between the IBR POI and the infinite bus represents the grid impedance. The following figure provides a representation of the appropriate equivalent to be used.

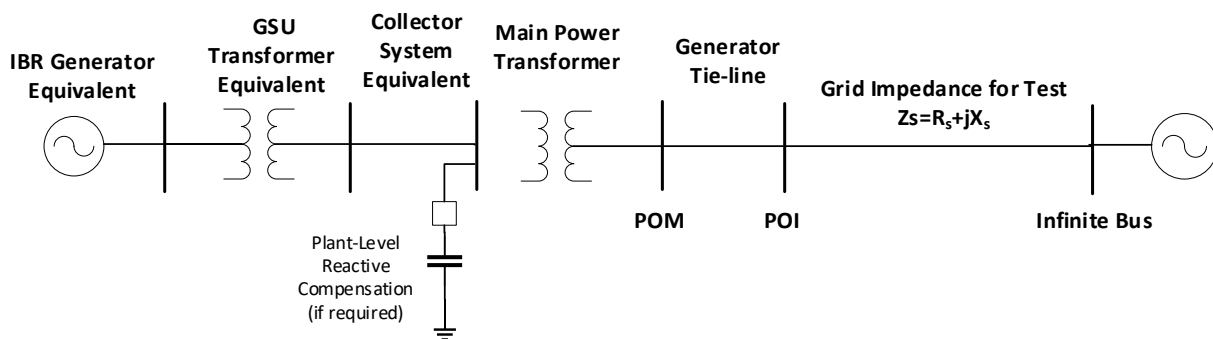


Figure 1 Single Machine Infinite Bus Test System

2.1.1 Equivalent IBR generator representation in PSSE and PSCAD

The equivalent IBR generator represents all the inverters' total generating capacity.

2.1.2 Equivalent Generator Step-up Transformer in PSSE and PSCAD

The equivalent generator step-up transformer represents the aggregate effect of all step-up transformers.

2.1.3 Equivalent Collector System in PSSE and PSCAD

The equivalent collector system branch represents the aggregate effect of the IBR plant collector system.

2.1.4 Main Power Transformer (MPT)⁵

Where applicable, the main power transformer shall be modeled as two-winding.

2.1.5 Voltage Control

2.1.5.1 Equivalent IBR generator

By default, the equivalent IBR generator shall be in voltage control mode. For the MAT's purposes, the voltage control target shall be set to regulate the POI according to the voltage schedule defined

⁵ The MPT is the power transformer that steps up voltage from the collection system voltage to the nominal transmission/interconnecting system voltage for dispersed power producing resources.

in Table 2. If an auxiliary device (e.g., STATCOM) is used to regulate the POI voltage, adequate technical rationale must be provided on the proposed coordination between the IBR and the auxiliary device.

Table 2 Voltage Schedule Assumption

Voltage Schedule Assumption for MAT	
Nominal Voltage (kV) at POI	Voltage Schedule (kV) at POI
345	355
230	234
115	118

2.1.5.2 GSU, MPT, and reactive compensation device

GSU, MPT taps, and any reactive compensation device within the plant should be configured such that the plant's reactive power capability is utilized to its fullest extent; this utilization of the plant's reactive power capability shall be evaluated at the maximum net active power injection and absorption at the POI⁶. In addition, this configuration should respect the inverter terminal's continuous operating voltage range. Transformer taps and switched shunt settings should not be adjusted between tests.

- If an On-Load Tap Changer (OLTC) transformer is used, the tap should adjust based on the load flow solution; it should not be set manually to a specific tap.

2.1.6 Infinite Bus Setup

The infinite bus, as shown in Figure 1, is connected to the IBR plant POI bus through a transmission line; the impedance of this transmission line is determined using the information provided in Section 1.1.3 and represents the grid impedance for model acceptance tests. The infinite bus must be numbered 101.

2.1.6.1 Infinite bus source load flow representation in PSSE

The source connected to the infinite bus is modeled as a generator with a machine base of 10,000 MVA with an impedance of $R = 0$ and $X = 0.01$ per unit. The infinite bus generator voltage set point is set to a default value of 1.0 p.u., and may be adjusted to achieve the required reactive power at the POI for the model acceptance tests.

2.1.6.2 Infinite bus source PSSE dynamic model

The infinite bus generator in PSSE will use two different dynamic models depending on the model acceptance test being simulated. The specific model to be used is provided with the test details.

1. GENCLS with parameters $H=D=0$

⁶ Refer to Appendix D of ISO-NE Planning Procedure for additional guidance.

2. PLBVF1 to play-in voltage and/or frequency signal

2.1.6.3 Infinite bus source representation in PSCAD

An equivalent generator model shall be used in PSCAD to represent the infinite bus.

2.2 Grid Impedance Calculation

The grid impedance to be used for model acceptance testing can be calculated using the method below.

Grid impedance as per Figure 1 is $Z_S = R_S + jX_S$ where Z_S is in per unit. The following steps can be used to determine R_S and X_S :

Step 1. Determine base impedance Z_B

i.
$$Z_B = \frac{V_B^2}{MVA_B}$$

where

V_B is the nominal line-line POI voltage in kV

MVA_B is the system base MVA. MVA_B is assumed to be 100 MVA for calculation.

Step 2. Determine X_Ω using formula below

$$X_\Omega = \frac{V_B^2}{\frac{SCR \times IBR_{MVA}}{\sqrt{1 + \frac{1}{\left(\frac{X}{R}\right)^2}}}}$$

where,

V_B is the nominal line-line POI voltage in kV

SCR is the SCR required for the specific model acceptance test

X/R is the value required for the specific model acceptance test

IBR_{MVA} is the aggregate MVA of the IBR (MVA capability of HVDC, where applicable)

Step 3. Determine R_Ω

Given:

$$\frac{X}{R} = k$$

where k is the $\frac{X}{R}$ ratio

$$R_\Omega = \frac{X_\Omega}{k}$$

Step 4. Using Z_B , X_Ω , and R_Ω calculated above

$$X_S = \frac{X_\Omega}{Z_B}$$

$$R_S = \frac{R_\Omega}{Z_B}$$

Section 3

PSSE and PSCAD Simulation Setup

This section provides details on the dynamic simulation setup required for the model acceptance tests outlined in Table 1 of Section 1.1.

3.1 Solution Parameters

3.1.1 PSSE Dynamic Simulation Parameters

The default dynamic simulation solution parameters are shown below.

Settings	Values
Network solution iterations	100
Acceleration	0.5
Tolerance	0.0001
Island frequency acceleration	1.0
Island frequency tolerance	0.0005
Time step	4.16 ms
Frequency filter	0.033
Delta threshold intermediate	0.05
Delta threshold island frequency	0.116667

The number of iterations and acceleration may be adjusted as needed, within reasonable values, to aid in network convergence. The same solution parameters must be utilized for all the simulations and documented in the benchmark report.

3.1.2 PSSE and PSCAD Simulation Run Time

Unless stated otherwise, all tests shall be run for at least 30 seconds from disturbance inception and show that the response has reached steady-state.

3.1.3 PSCAD Simulation Parameters

The simulation parameters, as provided by the OEM of the IBR inverter model, should be adhered to.

3.2 PSSE and PSCAD Simulation Plot

The simulation output signals to be plotted for all the model acceptance tests are shown in Table 3.

Table 3 PSSE and PSCAD Simulation Plots

Simulation Output Quantity	Measurement Point	Measurement Quantity
Active Power	IBR Terminal and POM	The simulation tool calculated Root Mean Square (RMS) quantity.
Reactive Power		
Voltage Magnitude		
Grid frequency (computed by Power Plant Controller (PPC), Phase-Locked Loop (PLL) output, etc.)	POM	
Instantaneous Phase Voltage	IBR Terminal	Instantaneous measured quantity in PSCAD.
Instantaneous Phase Current		

3.2.1 Plot Time Step

3.2.1.1 PSCAD

The plot time step must not exceed 500 μ s (microsecond). A plotting filter time constant of 0.02 seconds must be used.

3.2.1.2 PSSE

The plot time step must adequately capture the transient behavior due to the applied disturbance.

3.2.2 Plot Scale

Plot scales shall be set appropriately for the reviewers to discern the entirety of the plotted signals without clipping.

3.2.3 Benchmarking Analysis Plots

A trace-over-trace comparison plot of the simulation output quantity must be provided for the model acceptance tests that require benchmarking analyses.

3.3 Sample Plots

The sample plots provided in this section illustrate the expected format of plots included in the benchmarking report.

3.3.1 Voltage Reference Step Test

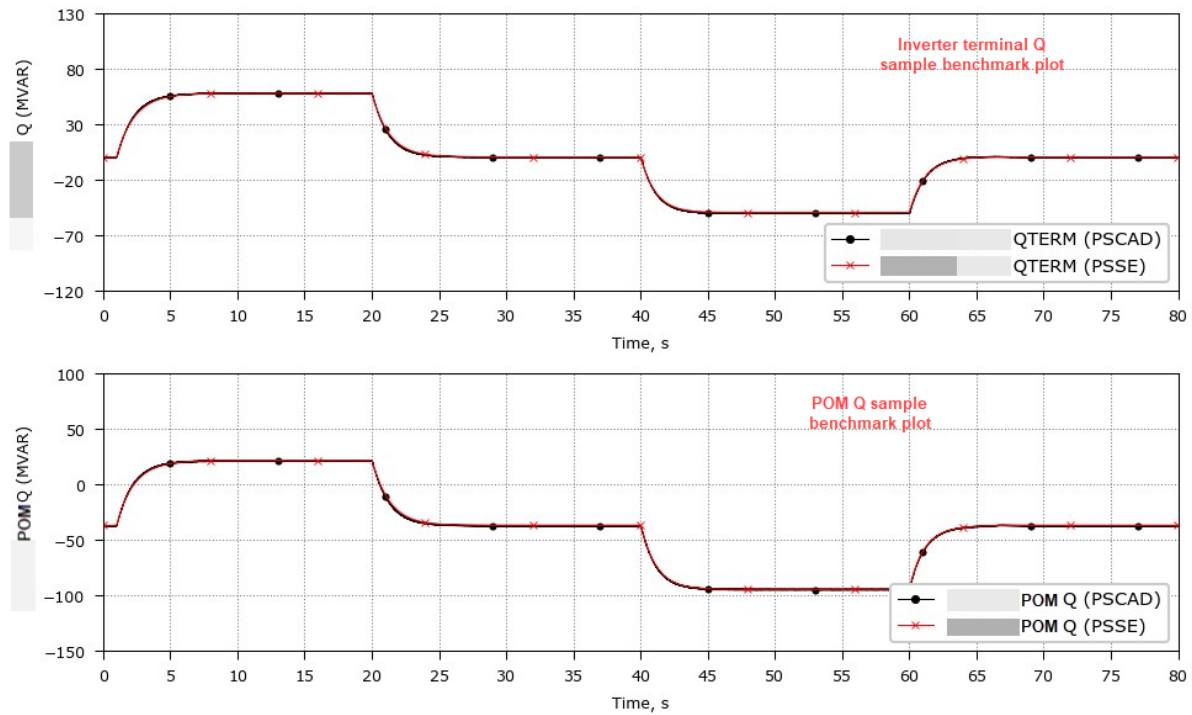
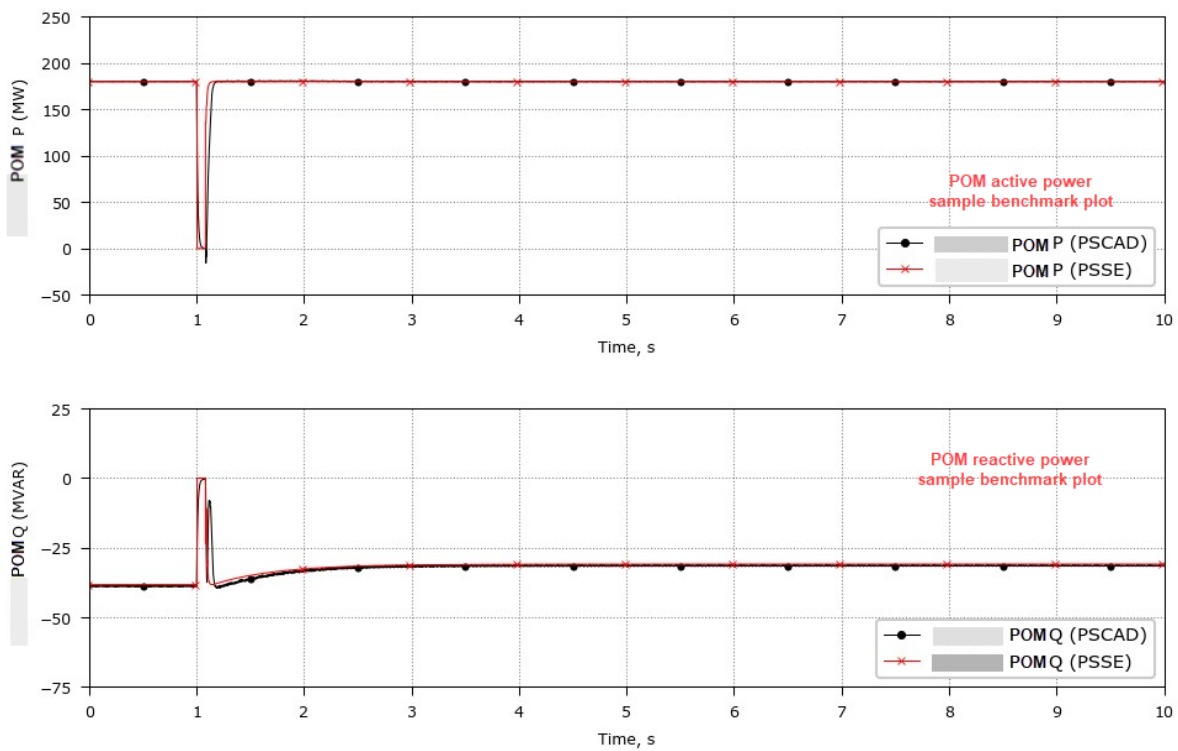


Figure 2 Voltage Reference Step Test

3.3.2 3-phase bolted fault



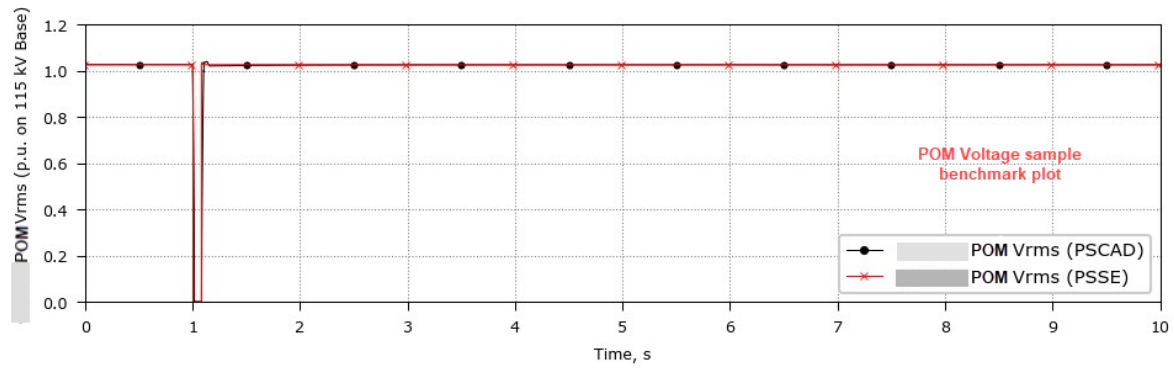


Figure 3 3-phase bolted fault – POM

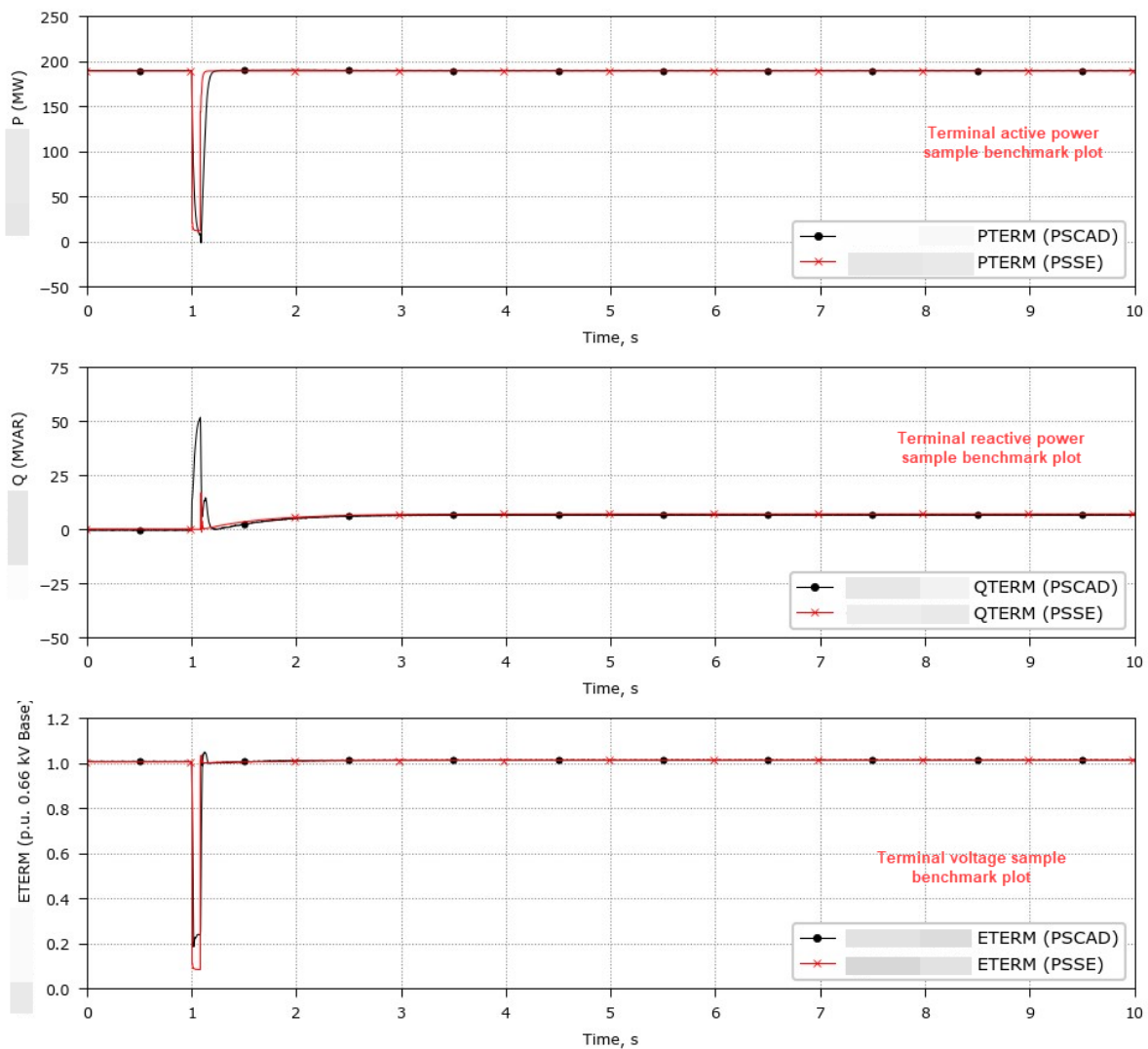


Figure 4 3-phase bolted fault - IBR Terminal

3.3.3 Instantaneous Phase Voltage and Current

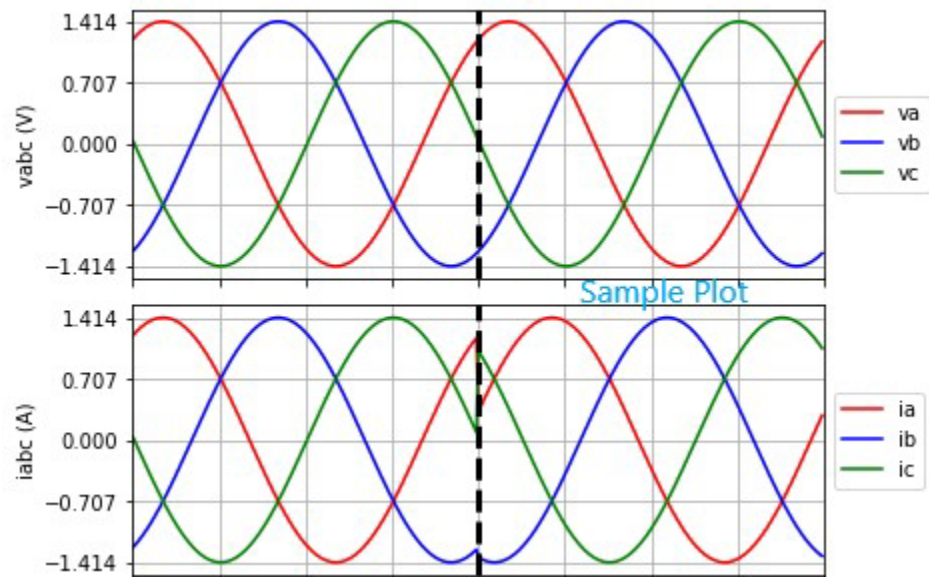


Figure 5 Instantaneous Phase Voltage and Current – IBR Terminal

Section 4

Model Acceptance Tests

The model acceptance tests specified in Table 1 of Section 1.1 are required to evaluate the provided models' consistency, accuracy, and dynamic performance. This section provides detailed guidance on simulating these tests and the dynamic performance and benchmarking requirements associated with each test.

The term Pnet used for all the tests refers to the net active power injection at the POI stated in the Interconnection Request. In model acceptance tests involving a BESS, Pnet refers to net injection (i.e., discharging) and absorption (i.e., charging) at the POI.

4.1 Test 1 – Flat Run

This test evaluates the model's ability to initialize accurately for given inputs and reach a steady-state output.

4.1.1 Test Description

The plant is initialized at the initial active and reactive power at POI values shown in Table 4. The GENCLS model should be used in PSSE for the infinite bus dynamic model, and an equivalent model should be used in PSCAD.

Table 4 Flat Run Test

Test No	Simulation Time (s)	SCR	Initial Active Power at POI (MW)	Initial Reactive Power at POI (MVAR)	Simulation Tool	Acceptance Criteria
1a	30	Infinite ⁷	Pnet	~0	PSSE and PSCAD	Dynamic Performance PSCAD model: The output reaches steady-state within 5 seconds PSSE model: Generator MW and MVAR will not change by 0.1 or more.
1b	30	Infinite	0.5 * Pnet ⁸	~0	PSSE and PSCAD	

⁷ Represented by a zero impedance line.

⁸ If the plant requires a minimum physical output, then test at the minimum value. Documentation must be provided to support the physical minimum value.

						Line Flow MW and MVAR will not change by 0.3 or more. Bus voltage will not change by 0.0001pu or more. Angle will not change by .1 or more The model shall not cause any DSTATE error. Benchmarking Performance The dynamic performance between PSSE and PSCAD must align to the fullest extent possible, particularly for active and reactive power at the POM.
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4.2 Test 2 - Steady-State Reactive Power Limit

This test evaluates the model's ability to initialize at its steady-steady capacitive and inductive reactive power limits, demonstrating the IEEE 2800 clause 5.1 Reactive power capability envelope at the POM

4.2.1 Test Description

The plant is initialized at its capacitive and inductive limits (Qmax and Qmin). The grid voltage can be adjusted such that the inverter (or HVDC, where applicable) can inject or absorb maximum (Qmax)/minimum (Qmin) reactive power at the terminals. The GENCLS model should be used in PSSE for the infinite bus dynamic model, and an equivalent model should be used in PSCAD.

Table 5 Steady-State Reactive Power Limit Test

Test No	Minimum Simulation Time (s)	SCR	Initial Active Power at POI (MW)	Initial Reactive Power at Inverter Terminal (MVAR)	Simulation Tool	Acceptance Criteria
2a	30	Infinite ⁷	Pnet	Qmax	PSSE and PSCAD	Dynamic Performance

2b	30	Infinite	Pnet	Qmin	PSSE and PSCAD	The plant shall initialize at and maintain its stated steady-state capacitive and inductive limit for the duration of the simulation.
2c	30	Infinite	0 ⁹	Qmax	PSSE and PSCAD	PSSE model: Generator MW and MVAR will not change by 0.1 or more. Line Flow MW and MVAR will not change by 0.3 or more.
2d	30	Infinite	0	Qmin	PSSE and PSCAD	Bus voltage will not change by 0.0001pu or more. Angle will not change by .1 or more The model shall not cause any DSTATE error. Benchmarking Performance The dynamic performance between PSSE and PSCAD must align to the fullest extent possible, particularly for active and reactive power at the POM.

4.3 Test 3 – Dynamic Reactive Power Limit

This evaluates the IBR plant's ability to dynamically reach its capacitive and inductive limits in conformity with IEEE 2800 clause 5.1 reactive power capability.

4.3.1 Test Description

A step increase and a step decrease in the POI voltage are applied such that the plant reaches inductive and capacitive limits, respectively. The step size applied should be such that the IBR does not transition to fault ride-through (FRT) mode. The simulation time should be sufficiently long that a steady-state condition is achieved before performing the next step event if multiple steps are performed in a single simulation. The PLBVF1 model should be used in PSSE for the infinite bus dynamic model, and an equivalent model should be used in PSCAD.

⁹ The real power output at the terminal is zero MW unless there is a physical minimum required output. Documentation must be provided to support the physical minimum value.

NOTE: Transformer taps or capacitors shall remain locked for this test.

Table 6 Dynamic Reactive Power Limit Test

Test No	Minimum Simulation Time (s)	SCR	Initial Active Power at POI (MW)	Initial Reactive Power at POI (MVAR)	Simulation Tool	Acceptance Criteria
3	30	Infinite	Pnet	~0	PSSE and PSCAD	Dynamic Performance For the step increase and decrease in the grid voltage, respectively, the plant shall reach its inductive and capacitive MVAR limit. Benchmarking Performance The dynamic performance between PSSE and PSCAD must align to the fullest extent possible, particularly for active and reactive power at the POM.

4.4 Test 4 - Voltage Reference Step Change

This test evaluates the IBR plant's dynamic performance to a step change in the plant controller's¹⁰ voltage reference in conformity with IEEE 2800 clause 5.2.

4.4.1 Test Description

A positive and a negative step change between 1% and 3% is applied such that the inverter and PPC¹¹ do not reach a reactive power or voltage limit. If the plant operates with a voltage droop, the droop value (percentage) is assumed larger than the applied voltage reference change; otherwise, a smaller step change may need to be used. The GENCLS model should be used in PSSE for the infinite bus dynamic model, and an equivalent model should be used in PSCAD.

¹⁰ The device regulating the active or reactive power at the POI, which can be the PPC, a supplementary dynamic reactive device, or a HVDC converter.

¹¹ A PPC regulates and controls the networked inverters, devices, and equipment at an IBR plant to meet specified set points and change grid parameters at the POI.

Table 7 Voltage Reference Step Change Test

Test No	Minimum Simulation Time (s)	SCR and X/R	Initial Active Power at POI (MW)	Initial Reactive Power at POI (MVAR)	Simulation Tool	Acceptance Criteria
4a	30	SCR=2.5, X/R=10	Pnet	~0	PSSE and PSCAD	Dynamic Performance The dynamic performance required in response to a change in voltage control reference is provided in Table 8. Any deviation from the performance target must be accompanied by adequate technical rationale. Benchmarking Performance The dynamic performance between PSSE and PSCAD must align to the fullest extent possible, particularly for active and reactive power at the POM.
4b	30	SCR=20, X/R=10	Pnet	~0	PSSE and PSCAD	

Table 8 Reactive Power- Voltage Performance¹² for Voltage Reference Step

Parameter ³	Performance Target	Notes
Reaction Time	< 200 ms	
Maximum step response time	< 10 seconds	The response time can be adjusted to allow for a stable and damped response. That is, if it is shown that for the applicable IBR plant and the given grid to which the IBR plant is connected, a stable response requires a response time that marginally exceeds the recommended response time, then this is preferred to provide a stable and damped response.
Damping	Damping Ratio of 0.3 or higher	

4.5 Test 5 - Active Power Reference Step Change

This test evaluates the IBR plant's dynamic performance to a step change in the plant controller's active power reference in conformity with IEEE 2800 Clause 6 active power dynamic performance requirements.

4.5.1 Test Description

A positive and a negative step change is simulated in the PPC's active power reference. The reference step size should be approximately 10% of the plant's net output; it should be such as to prevent the inverter from reaching a real power limit or transitioning into a charging mode of operation in the case of a BESS. The GENCLS model should be used in PSSE for the infinite bus dynamic model, and an equivalent model should be used in PSCAD.

¹² Reprinted with permission from IEEE. Copyright IEEE 2022. All rights reserved.

Table 9 Active Power Reference Step Change Test

Test No	Minimum Simulation Time (s)	SCR and X/R	Initial Active Power at POI (MW)	Initial Reactive Power at POI (MVAR)	Simulation Tool	Acceptance Criteria
5a	30	SCR=2.5, X/R=10	~0.5 *Pnet	~0	PSSE and PSCAD	Dynamic Performance The dynamic performance required in response to a change in active power control reference is provided in Table 10. Any deviation from the default value must be within the range of available values of Table 10 and must be accompanied by adequate technical rationale. Benchmarking Performance The dynamic performance between PSSE and PSCAD must align to the fullest extent possible, particularly for active and reactive power at the POM.
5b	30	SCR=20, X/R=10	~0.5 *Pnet	~0	PSSE and PSCAD	

Table 10 Active Power-Frequency Dynamic Performance¹²

Parameter ³	Units	Default Value	Range of available values	
			Minimum	Maximum
Reaction Time	Seconds	0.5	0.2 (0.5 for WTG)	1
Rise Time	Seconds	4.0	2.0 (4.0 for WTG)	20
Settling Time	Seconds	10.0	10	30
Damping Ratio	Unitless	0.3 or higher	0.2	1.0
Settling Band	% of change	Max (2.5 % of change or 0.5 % of ICR ¹³)	1	5
Note 1 – The reaction time starts when the fundamental-frequency component of the voltage measured at the POM has deviated outside of the applicable deadband¹⁴. Note 2 - The response time can be adjusted to allow for a stable and damped response. That is, if it is shown that for the applicable IBR plant and the given grid to which the IBR plant is connected, stable response requires a rise time or settling time that is marginally closer to the upper limit defined in Table 10, then this is preferred to provide stable and damped response.				

4.6 Test 6 - Grid Frequency Magnitude Change

This test evaluates the IBR plant's dynamic performance to a step change in the grid frequency magnitude in conformity with IEEE 2800 clause 6.1 primary frequency response requirements

¹³ ICR is defined as the Rated Active Power Output (or Rated Active Power Absorption, where applicable) at the POI.

¹⁴ https://www.iso-ne.com/static-assets/documents/rules_proceeds/operating/isone/op14/op14_rto_final.pdf

4.6.1 Test Description

A grid frequency magnitude step change of + 0.5 Hz and -0.5 Hz, relative to nominal grid frequency magnitude, is applied. The step size applied should be such as to prevent the inverter from reaching a real power limit or transitioning into a charging mode of operation in the case of a BESS. The PLBVF1 model should be used in PSSE for the infinite bus dynamic model, and an equivalent model should be used in PSCAD.

Table 11 Grid Frequency Magnitude Change Test

Test No	Minimum Simulation Time (s)	SCR and X/R	Initial Active Power at POI (MW)	Initial Reactive Power at POI (MVAR)	Simulation Tool	Acceptance Criteria
6a	30	SCR= 2.5, X/R=10	0.5 *Pnet	~0	PSSE and PSCAD	Dynamic Performance The dynamic performance required in response to a change in the grid frequency is provided in Table 10. Any deviation from the default value must be within the range of available values of Table 10 and must be accompanied by adequate technical rationale. Benchmarking Performance The dynamic performance between PSSE and PSCAD must align to the fullest extent possible, particularly for active and reactive power at the POM.
6b	30	SCR=20, X/R=10	0.5 *Pnet	~0	PSSE and PSCAD	

4.7 Test 7 – Balanced Fault Ride-Through Performance

This test evaluates the IBR plant's ability to ride-through a 3-phase bolted fault applied at the POI followed by an unsuccessful reclosing event in conformity with IEEE 2800 clause 7.2.2

For a HVDC connected IBR plant, an additional test evaluates the IBR's impact on the HVDC for a 3-phase bolted fault applied at the IBR collector system bus.

4.7.1 Test Description

A 3-phase bolted fault is applied at the POI and is cleared in 6 cycles without tripping any transmission element. A second 3-phase bolted fault is applied 5 seconds post first fault clearing and is cleared in 6 cycles without tripping any transmission element.

For a HVDC connected IBR plant, a 3-phase bolted fault is applied at the IBR collector system and cleared in 5 cycles. This fault is not simulated at the same time as the POI fault. The GENCLS model should be used in PSSE for the infinite bus dynamic model, and an equivalent model should be used in PSCAD.

Table 12 Balanced Fault Ride-Through with Reclosing Test

Test No	Minimum Simulation Time (s)	SCR and X/R	Initial Active Power at POI (MW)	Initial Reactive Power at POI (MVAR)	Simulation Tool	Acceptance Criteria
7a	30	SCR=2.5, X/R=10	Pnet	~0	PSSE and PSCAD	Dynamic Performance 1. The IBR plant does not trip. If the IBR plant enters current blocking mode when the retained voltage at the POM is less than 10%, the IBR plant starts injecting current in 5 cycles or less once the applicable voltage at POM enters the continuous or mandatory operation region. 2. In fault ride-through (FRT) mode, the inverter injects current in accordance with clause 7.2.2.3.4 of IEEE 2800-2022, provides necessary reactive current support to help maintain system voltage and reactive power priority is maintained. 3. After the fault is cleared, the IBR restores pre-disturbance active power injection in accordance with clause 7.2.2.6 of IEEE 2800-2022 while remaining stable and damped (damping ratio > or = to 0.3
7b	30	SCR=20, X/R=10	Pnet	~0	PSSE and PSCAD	
7c	30	SCR=2.5, X/R=10	0.5*Pnet	~0	PSSE and PSCAD	
7d	30	SCR=20, X/R=10	0.5*Pnet	~0	PSSE and PSCAD	

						4. IBR reactive current response shall not exacerbate transient overvoltage conditions on the transmission system. Benchmark Performance The dynamic performance between PSSE and PSCAD must align to the fullest extent possible, particularly for active and reactive power at the POM.
Additional Test for HVDC connected IBR plant						
7e	30	SCR=20, X/R=10	Pnet	~0	PSSE and PSCAD	Dynamic Performance The IBR plant is expected to ride-through. Benchmark Performance The dynamic performance between PSSE and PSCAD must align to the fullest extent possible, particularly for active and reactive power measured at the IBR collector bus.

4.8 Test 8 – Balanced Remote Fault Ride-Through

This test evaluates the IBR plant's ability to ride-through due to a balanced fault remote from the POI in conformity with IEEE 2800 clause 7.2.2

4.8.1 Test Description

A 3-phase fault is applied with a fault impedance at the POI such that the POI voltage reaches approximately 66%. The fault is cleared in 6 cycles without tripping any transmission elements. The GENCLS model should be used in PSSE for the infinite bus dynamic model, and an equivalent model should be used in PSCAD.

Table 13 Balanced Remote Fault Ride-Through Test

Test No	Minimum Simulation Time (s)	SCR and X/R	Initial Active Power at POI (MW)	Initial Reactive Power at POI (MVAR)	Simulation Tool	Acceptance Criteria
8a	30	SCR=2.5, X/R=10	Pnet	~0	PSSE and PSCAD	Dynamic Performance 1. The IBR plant does not trip. If the IBR plant enters current blocking mode when the retained voltage at the POM is less than 10%, the IBR plant starts injecting current in 5 cycles or less once the applicable voltage at POM enters the continuous or mandatory operation region. 2. In fault ride-through (FRT) mode, the inverter injects current in accordance with clause 7.2.2.3.4 of IEEE 2800-2022, provides necessary reactive current support to help maintain system voltage and reactive power priority is maintained. 3. After the fault is cleared, the IBR restores pre-disturbance active power and reactive power injection in accordance with clause 7.2.2.6 of IEEE 2800-2022 while remaining stable and damped (damping ratio > or = to 0.3 4. IBR reactive current response shall not exacerbate transient overvoltage conditions on the transmission system. Benchmark Performance
8b	30	SCR=20, X/R=10	Pnet	~0	PSSE and PSCAD	

						The dynamic performance between PSSE and PSCAD must align to the fullest extent possible, particularly for active and reactive power at the POM.
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4.9 Test 9 – Unbalanced Fault Ride-Through

This test evaluates the IBR plant's ability to ride-through an unbalanced fault applied at the POI in conformity with IEEE 2800 clause 7.2.2

4.9.1 Test Description

A single line-to-ground, double line-to-ground, and line-to-line (1LG, 2LG, LL) fault is applied at the POI and cleared in 15 cycles without tripping any transmission elements.

Table 14 Unbalanced Fault Ride-Through Test

Test No	Minimum Simulation Time (s)	SCR and X/R	Initial Active Power at POI (MW)	Initial Reactive Power at POI (MVAR)	Simulation Tool	Acceptance Criteria
9a	30	SCR=2.5, X/R=10	Pnet	~0	PSCAD	Dynamic Performance 1. The IBR plant does not trip. If the IBR plant enters current blocking mode when the retained voltage at the POM is less than 10%, the IBR plant starts injecting current in 5 cycles or less once the applicable voltage at POM enters the continuous or mandatory operation region. 2. In fault ride-through (FRT) mode, the inverter injects current in accordance with clause 7.2.2.3.4 of IEEE 2800-2022, provides necessary reactive current support to help maintain system voltage and reactive power priority is maintained.
9b	30	SCR=20, X/R=10	Pnet	~0	PSCAD	

						3. After the fault is cleared, the IBR restores pre-disturbance active power injection in accordance with clause 7.2.2.6 of IEEE 2800-2022 while remaining stable and damped (damping ratio ≥ 0.3) 4. IBR reactive current response shall not exacerbate transient overvoltage conditions on the transmission system. Benchmark Performance Not applicable.
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4.10 Test 10 – Voltage Protection Verification

This test aims to verify that respective high and low voltage protection exists and operates as intended.

4.10.1 Test Description

A grid voltage step relative to the initial voltage is applied, as shown in Figure 6 and Figure 7. If needed, a larger grid voltage step can be applied to cause the inverters to trip. The PLBVF1 model should be used in PSSE for the infinite bus dynamic model, and an equivalent model should be used in PSCAD.

Table 15 Voltage Protection Verification Test

Test No	Minimum Simulation Time (s)	SCR	Initial Active Power at POI (MW)	Initial Reactive Power at POI (MVAR)	Simulation Tool	Acceptance Criteria
10	30	Infinite	Pnet	~ 0	PSSE and PSCAD	Dynamic Performance The inverter trips due to the applied voltage. Benchmark Performance

						Not applicable.
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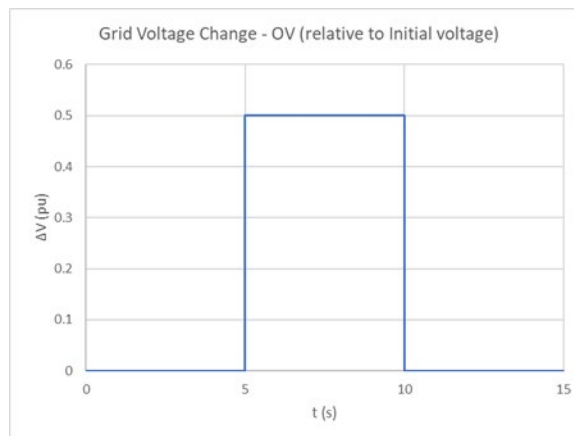


Figure 6 Voltage Protection Test - Grid Overvoltage

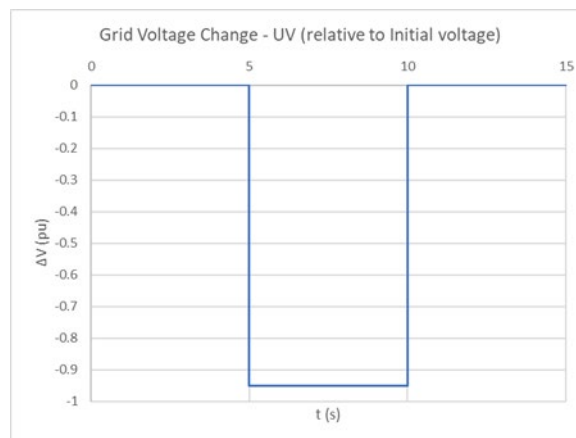


Figure 7 Voltage Protection Test - Grid Undervoltage

4.11 Test 11 –Voltage Ride-Through

This test evaluates the IBR plant's ability to meet the IEEE 2800 clause 7.2.2 Table 12 ¹⁵ Voltage Ride-through requirement.¹⁶¹⁷

4.11.1 Test Description

The IEEE 2800 voltage ride-through curve is simulated at the IBR POM. The entire curve should be played back at one time and not each section individually. The PLBVF1 model should be used in PSSE for the infinite bus dynamic model, and an equivalent model should be used in PSCAD.

Table 16 Voltage Ride-Through Test

Test No	Minimum Simulation Time (s)	SCR	Initial Active Power at POI (MW)	Initial Reactive Power at POI (MVAR)	Simulation Tool	Acceptance Criteria
11	30	Infinite	Pnet	~0	PSSE and PSCAD	Dynamic Performance The plant successfully rides through with a stable and damped response. Benchmark Performance Not applicable.

4.12 Test 12 – Frequency Ride-Through

This test evaluates the IBR plant's ability to meet the IEEE 2800 clause 7.3.2 Frequency Ride-through and PRC-006-NPCC¹⁸ low frequency ride-through requirement¹⁶. The low and high frequency thresholds to be evaluated are shown in Table 18.

¹⁵ If applicable PRC-029 requirements exceed IEEE 2800 clause 7.2.2, then PRC-029 will be used.

¹⁷ If auxiliary devices restrict ride through capabilities, table 11 values may be used for those specific points that fail.

¹⁸ As stated in Requirement 10 (<https://www.nerc.com/pa/Stand/Reliability%20Standards/PRC-006-NPCC-2.pdf>)

4.12.1 Test Description

The low frequency and high frequency ride-through threshold to be evaluated are simulated at the IBR POI. The test can be simulated as individual tests for each frequency threshold to be evaluated; it can also be simulated as two separate composite tests – one for low frequency and one for high frequency. If tested as a composite, sufficient time should be provided between frequency transitions to allow the IBR to settle at a steady-state output. The PLBVF1 model should be used in PSSE for the infinite bus dynamic model, and an equivalent model should be used in PSCAD.

Table 17 Frequency Ride-Through Test

Test No	Minimum Simulation Time (s)	SCR	Initial Active Power at POI (MW)	Initial Reactive Power at POI (MVAR)	Simulation Tool	Acceptance Criteria
12	30	Infinite	0.5 *Pnet	~0	PSSE and PSCAD	Dynamic Performance The plant successfully rides through with a stable and damped response. Benchmark Performance Not applicable.

Table 18 Low and High Frequency Test Threshold

Frequency	Minimum Ride Through Time (s) ¹⁶¹⁸
Low Frequency (Hz)	
57	As required in IEEE 2800 Table 15
High Frequency	

61.8	As required by IEEE 2800 Table 15
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4.13 Test 13 - Rate of Change of Frequency (ROCOF) Ride-Through

This test evaluates the plant's ability to ride-through frequency excursions with a rate of change of frequency (ROCOF) magnitude equal to 5.0 Hz/s in conformity with IEEE 2800 7.3.2.3.5.

4.13.1 Test Description

A ROCOF event is simulated by ramping the grid frequency at a rate of 5.0 Hz/s from 60 Hz to 59 Hz. This test should be simulated in PSCAD only.

Table 19 Rate of Change of Frequency Ride-Through Test

Test No	Minimum Simulation Time (s)	SCR and X/R	Active Power at POI (MW)	Initial Reactive Power at POI (MVAR)	Simulation Tool	Acceptance Criteria
13a	30	SCR=2.5, X/R=10	0.5 *Pnet	~0	PSCAD	Dynamic Performance The plant successfully rides through with a stable and damped response. Benchmark Performance Not applicable.
13b	30	SCR=20, X/R=10	0.5 *Pnet	~0	PSCAD	

4.14 Test 14 - Grid Voltage Phase Angle Change Ride-Through

This test evaluates the plant's ability to ride-through a balanced system voltage phase angle change of +/- 25° in conformity with IEEE 2800 clause 7.3.2.4.

4.14.1 Test Description

A balanced system voltage phase angle jump is simulated as per Table 21. This test should be simulated in PSCAD only.

Table 20 Grid Voltage Phase Angle Change Test

Test No	Minimum Simulation Time (s)	SCR and X/R	Initial Active Power at POI (MW)	Initial Reactive Power at POI (MVAR)	Simulation Tool	Acceptance Criteria
14a	30	SCR=2.5, X/R=10	Pnet	~0	PSCAD	Dynamic Performance - The plant successfully rides through with a stable and damped response. - Current blocking is not allowed in the post-disturbance period. Benchmark Performance Not applicable.
14b	30	SCR=20, X/R=10	Pnet	~0	PSCAD	

Table 21 Grid Voltage Phase Angle Change

Test Sequence	Phase A	Phase B	Phase C
Balanced system phase angle change			
Base	0°	-120°	120°
Base + 25°	+25°	-95°	145°
Base - 25°	-25°	-145°	95°

4.15 Test 15 - Point of Interconnection SCR Transition Ride-Through

This test evaluates the IBR plant's ability to ride-through successive changes in SCR at the POI.

4.15.1 Test Description

The SCR at the POI is changed as per Figure 8. A 3-phase grounded fault is applied at each SCR transition. The time between each transition may be adjusted to allow the plant to stabilize. Prior to each transition, the reactive power at the POI should be adjusted such that the IBR is not at its capacitive or inductive limit. The GENCLS model should be used in PSSE for the infinite bus dynamic model, and an equivalent model should be used in PSCAD.

Table 22 POI SCR Transition Test

Test No	Minimum Simulation Time (s)	SCR and X/R	Initial Active Power at POI (MW)	Initial Reactive Power at POI (MVAR)	Simulation Tool	Acceptance Criteria
15	30 ¹⁹	As per Figure 8, X/R= 10	Pnet	~0	PSSE and PSCAD	Dynamic Performance The plant successfully rides through the minimum SCR capability²⁰ as stated by inverter OEM. The response is expected to be stable and damped at up to SCR of 2. Benchmark Performance Not applicable.

¹⁹ The simulation time can be extended to allow for testing all SCR transitions.

²⁰ At the POI or as interpreted at the inverter terminal.

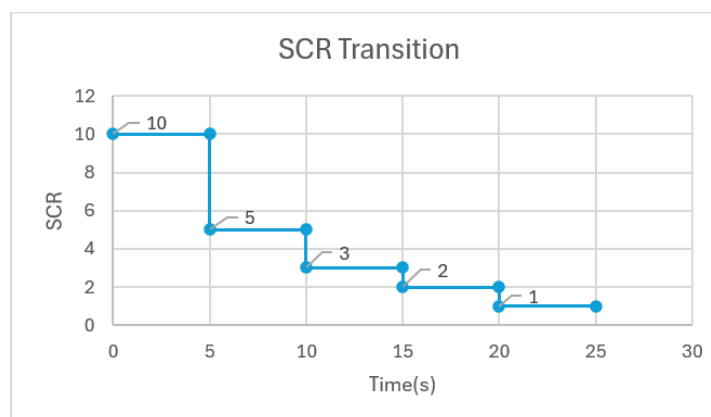


Figure 8 POI SCR Transition

4.16 Test 16 – Power Factor Verification

This tests verifies conformance with IEEE 2800 clause 5.1 minimum reactive power capability requirements

4.16.1 Test Description

The IBR plant is initialized at the specified active power level and commanded to deliver the specified reactive power at the POM. The voltage at the POM is set to the applicable corner-point voltage within .0001pu by adjusting the infinite bus voltage source and the IBR plant voltage reference. The plant must achieve and maintain the commanded operating point for the duration of the simulation without exceeding inverter terminal continuous operating voltage limits, without entering fault ride-through mode, and without protection trip or controller saturation.

NOTE: Any taps or capacitor switching used to help meet dynamic requirements shall remain locked for this test.

Table 23 Power Factor Verification Test

Test No	Minimum Simulation Time (s)	SCR	POM Voltage (p.u.) (within 0.001 p.u.)	Initial Active Power at POI (MW)	Minimum Initial Reactive Power at RPA (MVAR)	Simulation Tool	Acceptance Criteria

16a ²¹²²	30	SCR=20 X/R=10	0.90	Pnet	0.3287 × Pnet injecting	PSSE and PSCAD	Dynamic Performance The plant shall initialize at and maintain the minimum capacitive and inductive reactive power at the POM for the duration of the simulation. No protection trips, reduction in output, LVRT/HVRT Mode entry, PPC saturation, or any other change in electrical response is permitted. PSSE model: Generator MW and MVAR will not change by 0.1 or more. Line Flow MW and MVAR will not change by 0.3 or more. Bus voltage will not change by 0.0001pu or more. Angle will not change by .1 or more The model shall not cause any DSTATE error. Benchmarking Performance The dynamic performance between PSSE and PSCAD must align to the fullest extent possible, particularly for active and reactive power at the POM.
16b	30	SCR=20 X/R=10	0.95	Pnet	0.3287 × Pnet injecting	PSSE and PSCAD	
16c	30	SCR=20 X/R=10	POI <200kV: 0.99 ≥200kV: 1.00	Pnet	0.3287 × Pnet absorbing	PSSE and PSCAD	
16d	30	SCR=20 X/R=10	POI <200kV: 1.03 ≥200kV: 1.04	Pnet	0.3287 × Pnet injecting	PSSE and PSCAD	
16e	30	SCR=20 X/R=10	1.10	Pnet	0.3287 × Pnet absorbing	PSSE and PSCAD	
16f	30	SCR=20 X/R=10	POI <200kV: 0.99 ≥200kV: 1.00	0 MW ²³	0.3287 × Pnet absorbing	PSSE and PSCAD	

²¹ This test may not be applicable for IBR plants consisting of Type III WTGs (per IEEE P2800.2 Table 39 footnote a). For Type III WTG plants, the OEM-stated reduced capability curve below 0.95 p.u. shall be documented in lieu of the 0.7 × ICR factor, and the corresponding reduced reactive power capability applies as the acceptance criterion. Reduced capability shall be supported by OEM type-test or equipment-level model evidence and noted in the benchmarking report.

²² If tests fails at 0.3287 × Pnet, test will be re-run at 0.3287 × 0.7 × Pnet instead.

²³ The real power output at the terminal is zero MW unless there is a physical minimum required output. Documentation must be provided to support the physical minimum value.

4.17 Test 17 – Consecutive Voltage Deviation

This test aims to verify the IBR plants ability to ride through consecutive voltage deviations in conformity with IEEE 2800 clause 7.2.2.4

4.17.1 Test Description

A 3ph fault is first applied at the POI with impedance such that the voltage at the RPA is between 0 and .1 pu, after .32s, the fault is cleared. The simulation is then run for another 20 cycles, before applying another 3ph fault with impedance such that the RPA voltage is between .2 and .5PU, clear it after .88s

In a separate EMT simulation, the same test procedure is repeated using a 2ph fault instead.

Table 24 Consecutive Voltage Deviation

Test No	Minimum Simulation Time (s)	SCR	Initial Active Power at POI (MW)	Initial Reactive Power at POI (MVAR)	Simulation Tool	Acceptance Criteria
17a	30	SCR=2.5, X/R=10	Pnet	~0-+/- 10%	PSSE (3PH Only) and PSCAD (Both 3PH & 2PH)	Dynamic Performance 1. The IBR plant does not trip. If the IBR plant enters current blocking mode when the retained voltage at the POM is less than 10%, the IBR plant starts injecting current in 5 cycles or less once the applicable voltage at POM enters the continuous or mandatory operation region. 2. In fault ride-through (FRT) mode, the inverter injects current in accordance with clause 7.2.2.3.4 of IEEE 2800-2022, provides necessary reactive current support to help maintain system voltage and reactive power priority is maintained. 3. After the fault is cleared, the IBR restores pre-disturbance active power injection in accordance with
17b	30	SCR=20, X/R=10	Pnet	~0-+/- 10%	PSSE (3PH Only) and PSCAD (Both 3PH & 2PH)	

						clause 7.2.2.6 of IEEE 2800-2022 while remaining stable and damped (damping ratio $\geq$ 0.3) 4. IBR reactive current response shall not exacerbate transient overvoltage conditions on the transmission system. Benchmark Performance Not applicable.
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4.18 Test 18 – Voltage Oscillation Ride through

This test aims to verify the IBR plants ability to ride through post-fault dynamic voltage oscillations in conformance with IEEE 2800 clause 7.2.2.4

4.18.1 Test Description

A damped voltage oscillation of .25hz, .5hz, 1hz, and 2hz are each individually applied in separate simulations. The envelope of the oscillation has an upper limit of 1.15 PU and a lower limit of .8PU and a damping of 3%

Table 25 Voltage Oscillation Ride Through

Test No	Minimum Simulation Time (s)	SCR	Initial Active Power at POI (MW)	Initial Reactive Power at POI (MVAR)	Simulation Tool	Acceptance Criteria
18	30	SCR=2.5, X/R=10	Pnet	~0	PSCAD	Dynamic Performance 1. The IBR plant successfully rides through(no trip, no momentary cessation, no blocking outside permitted permissive operation regions).

						Benchmark Performance Not applicable.
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Section 5

Benchmarking Report

A benchmarking report must be submitted to document the analysis results. The report must include the following sections, at a minimum, and adhere to the order specified below.

5.1 Introduction

This section includes a brief description of the project, including Interconnection Request ID, proposed POI, and in-service date.

5.2 System Description

This section should include the following.

- a. A one-line diagram of the project up to the POI
- b. Component manufacturers (inverter, power-plant controller, auxiliary dynamic reactive device, etc.)
- c. As-modeled data, in PSSE and PSCAD, for the following in a tabular format including MVA base used for 'per unit' quantities
 - i. Individual and aggregated inverter ratings
 - ii. Inverter terminal continuous operating voltage range
 - iii. Individual and aggregated generator step-up (GSU) impedance and winding configuration
 - iv. Equivalent collector system impedance
 - v. Main power transformer (MPT) impedance and winding configuration
 - vi. Gen-tie impedance
 - vii. Static and dynamic reactive device

5.3 Modeling Methodology

This section should include the following.

- a. PSSE and PSCAD software versions used for the assessment (include minor release version number for e.g. PSSE 35.6.4²⁴ and PSCAD 5.1²⁴)
- b. PSSE and PSCAD model data revision used for the assessment
- c. PSSE and PSCAD simulation parameters which should include
 - i. Simulation time step
 - ii. Plotting time step
 - iii. Any other significant assumptions such as acceleration factor, tolerance
- d. Voltage droop, frequency droop, and applicable deadband
- e. GSU and MPT tap

5.4 Simulation Results

This section should include the following.

²⁴ Example only and may not be the version in use by ISO-NE.

- a. Test order number as per Table 1 in Section 1
- b. Mode of operation if BESS (i.e., discharging or charging)
- c. Any specific assumptions for the test
- d. Technical rationale if requirements not met
- e. Trace-over-trace PSSE and PSCAD plots for simulation output quantities as per Table 5 and include the following. Sample plots are provided in Section 3.
 - i. One set of plot at the POM
 - ii. One set of plot at the inverter terminal

5.5 PSCAD model instructions

This section should include the following.

- a. Directions for compiling and initializing the model
- b. Instructions on directory path settings if applicable, including a list of libraries, object files, or other files that may be required to run the model.

5.6 Plant-specific settings and description of the control scheme

In this section, any control parameters specific to an individual plant must be stated. Where applicable, these parameters shall align with the PSSE dynamic model. These parameters shall include (among others):

- a. Ride-through activation and deactivation thresholds and parameters
- b. Voltage and frequency ride-through settings
- c. Active power ramp rates following faults
- d. Plant-level voltage controller gains and time constants
- e. Interface parameters with auxiliary devices such as STATCOMs, if applicable
- f. Description of the planned (or installed) control schemes (such as voltage, frequency, reactive power and/or power factor, runback, etc.). The description should include:
 - i. The target of the control scheme
 - ii. Overview of how it achieves its intended result
 - iii. Parameters that directly affect the performance, trigger levels, deadband, etc.
 - iv. Limitations of the control scheme