**Appendix C-2   
Model Acceptance Tests forInverter-Based Resources (IBR)**

**ISO-NE PUBLIC**

# Contents

[Contents ii](#_Toc169169843)

[Figures v](#_Toc169169844)

[Tables vi](#_Toc169169845)

[Section 1 Introduction 7](#_Toc169169846)

[1.1 Scope of Model Acceptance Tests 7](#_Toc169169847)

[1.1.1 Battery Energy Storage System (BESS) 8](#_Toc169169848)

[1.1.2 Hybrid IBR Plant 8](#_Toc169169849)

[1.1.3 Short Circuit Ratio (SCR) for Model Acceptance Tests 8](#_Toc169169850)

[1.1.4 Reference Point of Applicability for Dynamic Performance and Benchmarking Requirements 8](#_Toc169169851)

[1.1.5 Simulation Tools 9](#_Toc169169852)

[1.1.6 Benchmarking Report 9](#_Toc169169853)

[1.1.7 Results Evaluation 9](#_Toc169169854)

[Section 2 Test System 10](#_Toc169169855)

[2.1 Single Machine Infinite Bus 10](#_Toc169169856)

[2.1.1 Equivalent IBR generator representation in PSSE and PSCAD 10](#_Toc169169857)

[2.1.2 Equivalent Generator Step-up Transformer in PSSE and PSCAD 10](#_Toc169169858)

[2.1.3 Equivalent Collector System in PSSE and PSCAD 10](#_Toc169169859)

[2.1.4 Main Power Transformer (MPT) 10](#_Toc169169860)

[2.1.5 Voltage Control 10](#_Toc169169861)

[2.1.6 Infinite Bus Setup 11](#_Toc169169862)

[2.2 Grid Impedance Calculation 12](#_Toc169169863)

[Section 3 PSSE and PSCAD Simulation Setup 13](#_Toc169169864)

[3.1 Solution Parameters 13](#_Toc169169865)

[3.1.1 PSSE Dynamic Simulation Parameters 13](#_Toc169169866)

[3.1.2 PSSE and PSCAD Simulation Run Time 13](#_Toc169169867)

[3.1.3 PSCAD Simulation Parameters 13](#_Toc169169868)

[3.2 PSSE and PSCAD Simulation Plot 13](#_Toc169169869)

[3.2.1 Plot Time Step 14](#_Toc169169870)

[3.2.2 Plot Scale 14](#_Toc169169871)

[3.2.3 Benchmarking Analysis Plots 14](#_Toc169169872)

[3.3 Sample Plots 14](#_Toc169169873)

[3.3.1 Voltage Reference Step Test 15](#_Toc169169874)

[3.3.2 3-phase bolted fault 15](#_Toc169169875)

[3.3.3 Instantaneous Phase Voltage and Current 17](#_Toc169169876)

[Section 4 Model Acceptance Tests 18](#_Toc169169877)

[4.1 Test 1 – Flat Run 18](#_Toc169169878)

[4.1.1 Test Description 18](#_Toc169169879)

[4.2 Test 2 - Steady-state Reactive Power Limit 19](#_Toc169169880)

[4.2.1 Test Description 19](#_Toc169169881)

[4.3 Test 3 – Dynamic Reactive Power Limit 20](#_Toc169169882)

[4.3.1 Test Description 20](#_Toc169169883)

[4.4 Test 4 - Voltage Reference Step Change 21](#_Toc169169884)

[4.4.1 Test Description 21](#_Toc169169885)

[4.5 Test 5 - Active Power Reference Step Change 22](#_Toc169169886)

[4.5.1 Test Description 22](#_Toc169169887)

[4.6 Test 6 - Grid Frequency Magnitude Change 24](#_Toc169169888)

[4.6.1 Test Description 25](#_Toc169169889)

[4.7 Test 7 – Balanced Fault Ride-Through 25](#_Toc169169890)

[4.7.1 Test Description 25](#_Toc169169891)

[4.8 Test 8 – Balanced Remote Fault Ride-Through 27](#_Toc169169892)

[4.8.1 Test Description 27](#_Toc169169893)

[4.9 Test 9 – Unbalanced Fault Ride-Through 28](#_Toc169169894)

[4.9.1 Test Description 28](#_Toc169169895)

[4.10 Test 10 – Voltage Protection Verification 29](#_Toc169169896)

[4.10.1 Test Description 29](#_Toc169169897)

[4.11 Test 11 – NERC PRC-024 Voltage Ride-Through 31](#_Toc169169898)

[4.11.1 Test Description 31](#_Toc169169899)

[4.12 Test 12 – Frequency Ride-Through 32](#_Toc169169900)

[4.12.1 Test Description 32](#_Toc169169901)

[4.13 Test 13 - Rate of Change of Frequency (ROCOF) Ride-Through 34](#_Toc169169902)

[4.13.1 Test Description 34](#_Toc169169903)

[4.14 Test 14 - Grid Voltage Phase Angle Change Ride-Through 34](#_Toc169169904)

[4.14.1 Test Description 34](#_Toc169169905)

[4.15 Test 15 - Point of Interconnection SCR Transition Ride-Through 35](#_Toc169169906)

[4.15.1 Test Description 36](#_Toc169169907)

[Section 5 Benchmarking Report 38](#_Toc169169908)

[5.1 Introduction 38](#_Toc169169909)

[5.2 System Description 38](#_Toc169169910)

[5.3 Modeling Methodology 38](#_Toc169169911)

[5.4 Simulation Results 39](#_Toc169169912)

[5.5 PSCAD model instructions 39](#_Toc169169913)

[5.6 Plant-specific settings and description of the control scheme 39](#_Toc169169914)

[Section 6 Addendum 41](#_Toc169169915)

# Figures

[Figure 1 Single Machine Infinite Bus Test System 10](#_Toc169169916)

[Figure 2 Voltage Reference Step Test 15](#_Toc169169917)

[Figure 3 3-phase bolted fault – POM 16](#_Toc169169918)

[Figure 4 3-phase bolted fault - IBR Terminal 16](#_Toc169169919)

[Figure 5 Instantaneous Phase Voltage and Current – IBR Terminal 17](#_Toc169169920)

[Figure 6 Voltage Protection Test - Grid Overvoltage 30](#_Toc169169921)

[Figure 7 Voltage Protection Test - Grid Undervoltage 31](#_Toc169169922)

[Figure 8 POI SCR Transition 37](#_Toc169169923)

# Tables

[Table 1 Model Acceptance Tests 7](#_Toc169169924)

[Table 2 Voltage Schedule Assumption 11](#_Toc169169925)

[Table 3 PSSE and PSCAD Simulation Plots 14](#_Toc169169926)

[Table 4 Flat Run Test 18](#_Toc169169927)

[Table 5 Steady-state Reactive Power Limit Test 19](#_Toc169169928)

[Table 6 Dynamic Reactive Power Limit Test 20](#_Toc169169929)

[Table 7 Voltage Reference Step Change Test 21](#_Toc169169930)

[Table 8 Reactive Power- Voltage Performance for Voltage Reference Step 22](#_Toc169169931)

[Table 9 Active Power Reference Step Change Test 23](#_Toc169169932)

[Table 10 Active Power-Frequency Dynamic Performance 24](#_Toc169169933)

[Table 11 Grid Frequency Magnitude Change Test 25](#_Toc169169934)

[Table 12 Balanced Fault Ride-Through with Reclosing Test 26](#_Toc169169935)

[Table 13 Balanced Remote Fault Ride-Through Test 27](#_Toc169169936)

[Table 14 Unbalanced Fault Ride-Through Test 28](#_Toc169169937)

[Table 15 Voltage Protection Verification Test 29](#_Toc169169938)

[Table 16 NERC PRC-024 Voltage Ride-Through Test 32](#_Toc169169939)

[Table 17 Frequency Ride-Through Test 33](#_Toc169169940)

[Table 18 Low and High Frequency Test Threshold 33](#_Toc169169941)

[Table 19 Rate of Change of Frequency Ride-Through Test 34](#_Toc169169942)

[Table 20 Grid Voltage Phase Angle Change Test 35](#_Toc169169943)

[Table 21 Grid Voltage Phase Angle Change 35](#_Toc169169944)

[Table 22 POI SCR Transition Test 36](#_Toc169169945)

# Introduction

The positive sequence and electromagnetic transient (EMT) model submittals in support of an Interconnection Request 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.

## 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]](#footnote-1) conditions. 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 |
| **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 |

### Battery Energy Storage System (BESS)

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

### 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.

### Short Circuit Ratio (SCR) for Model Acceptance Tests

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

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

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 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.

### 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)[[2]](#footnote-2). The applicable requirements are provided along with each model acceptance test.

### 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, as posted on the Interconnection Process Guide website.[[3]](#footnote-3)

### Benchmarking Report

A benchmarking report must be submitted to document the analysis results.

### 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.

# Test System

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

## 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

### Equivalent IBR generator representation in PSSE and PSCAD

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

### Equivalent Generator Step-up Transformer in PSSE and PSCAD

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

### Equivalent Collector System in PSSE and PSCAD

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

### Main Power Transformer (MPT)[[4]](#footnote-4)

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

### Voltage Control

#### 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 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 |

#### 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 POI[[5]](#footnote-5). 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.

### 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.

#### 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.

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

#### Infinite bus source representation in PSCAD

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

## 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 where is in per unit. The following steps can used to determine and.

*Step 1*. Determine base impedance

1. where

is the nominal line-line POI voltage in kV

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

*Step 2*. Determine using formula below  
   
 where,   
 is the nominal line-line POI voltage in kV  
 SCR is the short circuit ratio required for the specific model acceptance test   
 X/R is the value required for the specific model acceptance test  
 is the aggregate MVA of the IBR (MVA capability of HVDC, where applicable)  
  
*Step 3*. Determine   
 Given:

where is the ratio

Step 4. Using ,, and calculated above

# PSSE and PSCAD Simulation Setup

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

## Solution Parameters

### 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.

### 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.

### PSCAD Simulation Parameters

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

## 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 |

### Plot Time Step

#### PSCAD

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

#### PSSE

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

### Plot Scale

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

### 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.

## Sample Plots

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

### Voltage Reference Step Test

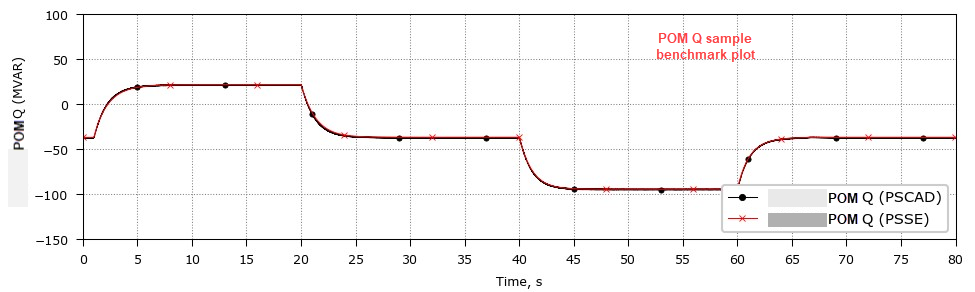
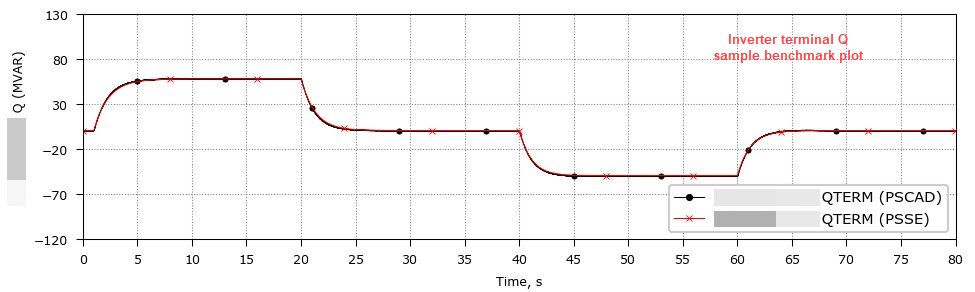
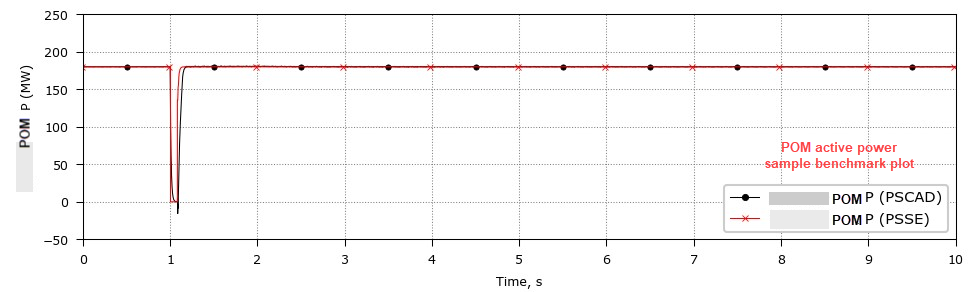
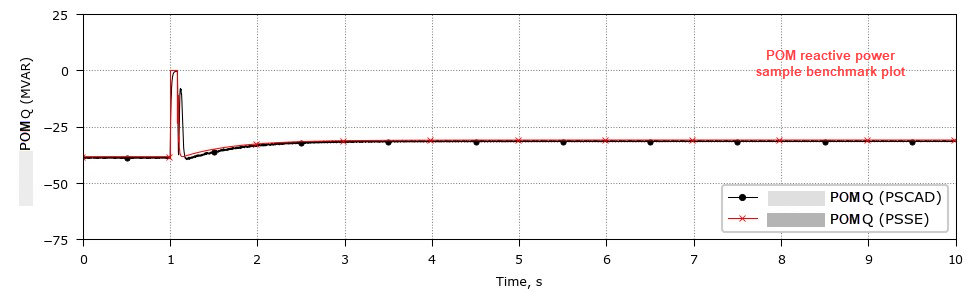


Figure 2 Voltage Reference Step Test

### 3-phase bolted fault





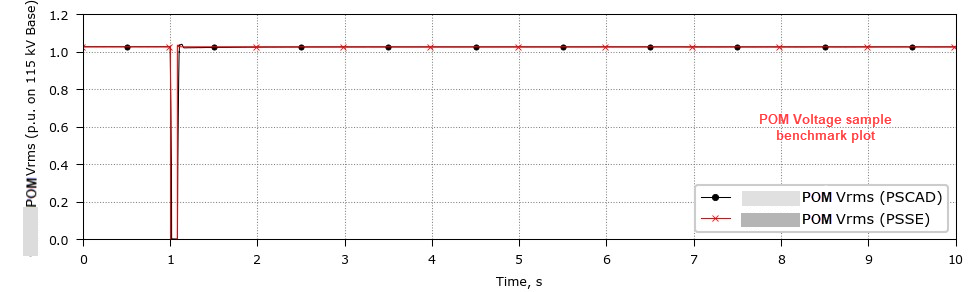


Figure 3 3-phase bolted fault – POM

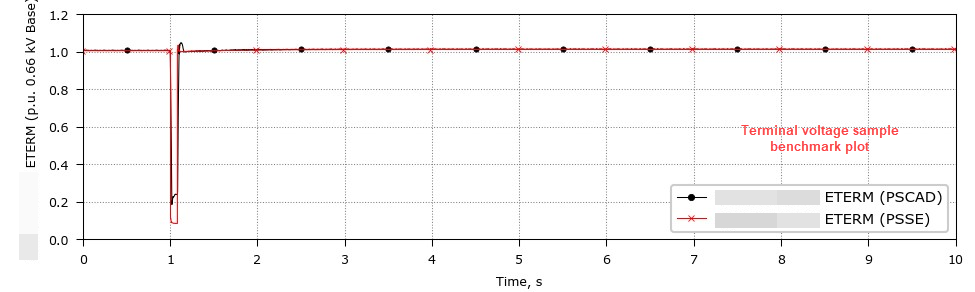
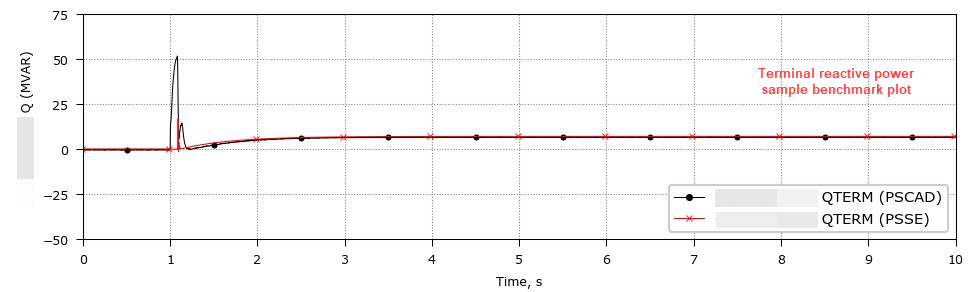
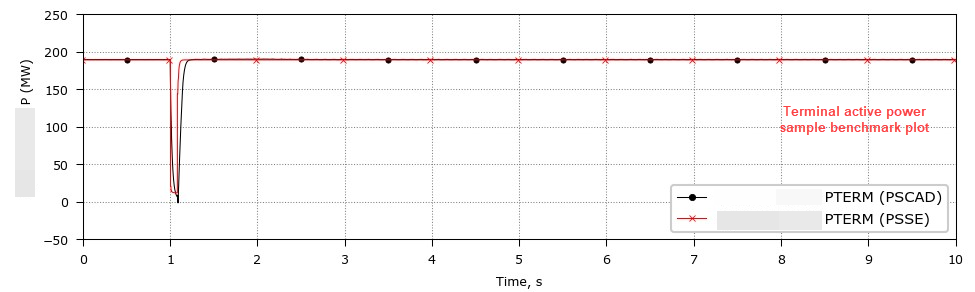


Figure 4 3-phase bolted fault - IBR Terminal

### Instantaneous Phase Voltage and Current

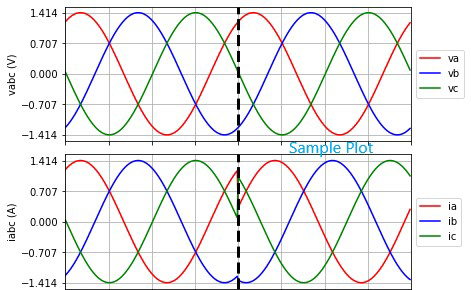


Figure 5 Instantaneous Phase Voltage and Current – IBR Terminal

# Model Acceptance Tests

The model acceptance tests specified in Table 1of 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.

## Test 1 – Flat Run

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

### 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[[6]](#footnote-6) | 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. 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. |
| **1b** | 30 | Infinite | 0.5 \* Pnet[[7]](#footnote-7) | ~0 | PSSE and PSCAD |

## 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.

### 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 | Infinite6 | Pnet | Qmax | PSSE and PSCAD | **Dynamic Performance**  The plant shall initialize at and maintain its stated steady state capacitive and inductive limit for the duration of the simulation.  The PSSE dynamic model should not result in 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. |
| **2b** | 30 | Infinite | Pnet | Qmin | PSSE and PSCAD |
| **2c** | 30 | Infinite | 0[[8]](#footnote-8) | Qmax | PSSE and PSCAD |
| **2d** | 30 | Infinite | 0 | Qmin | PSSE and PSCAD |

## Test 3 – Dynamic Reactive Power Limit

This evaluates the IBR plant’s ability to dynamically reach its capacitive and inductive limits.

### Test Description

A step increase and a step decrease in the grid 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.

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. |

## Test 4 - Voltage Reference Step Change

This test evaluates the IBR plant’s dynamic performance to a step change in the plant controller’s[[9]](#footnote-9) voltage reference.

### Test Description

A positive and a negative step change between 1% and 3% is applied such that the inverter and PPC[[10]](#footnote-10) 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.

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=3, 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=10, X/R=10 | Pnet | ~0 | PSSE and PSCAD |

Table 8 Reactive Power- Voltage Performance[[11]](#footnote-11) for Voltage Reference Step

| **Parameter**2 | **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 plantand the given grid to which the IBR plantis 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[[12]](#footnote-12) | Damping Ratio of 0.3 or higher |  |

## 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.

### 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.

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=3, 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 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=10, X/R=10 | ~0.5 \*Pnet | ~0 | PSSE and PSCAD |

Table 10 Active Power-Frequency Dynamic Performance11

| **Parameter**2 | **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]](#footnote-13)) | 1 | 5 |
| Note 1 – The reactiontimestarts when the fundamental-frequency component of the voltagemeasured at the POM has deviated outside of the applicable deadband[[14]](#footnote-14). 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 plantand the given grid to which the IBR plantis 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. | | | | |

## Test 6 - Grid Frequency Magnitude Change

This test evaluates the IBR plant’s dynamic performance to a step change in the grid frequency magnitude.

### Test Description

A grid frequency magnitude step change of + 0.3 Hz and -0.3 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= 3, 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 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=10, X/R=10 | 0.5 \*Pnet | ~0 | PSSE and PSCAD |

## Test 7 – Balanced Fault Ride-Through

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.  
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.

### 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 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=3, X/R=10 | Pnet | ~0 | PSSE and PSCAD | **Dynamic Performance**   1. The IBR plant successfully rides through. 2. In fault ride-through (FRT) mode, the inverter provides necessary support to help maintain system voltage. 3. After the fault is cleared, the IBR restores pre-disturbance active and reactive power injection as fast as possible while remaining stable and damped. 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. |
| **7b** | 30 | SCR=10, X/R=10 | Pnet | ~0 | PSSE and PSCAD |
| **7c** | 30 | SCR=3, X/R=10 | 0.5\*Pnet | ~0 | PSSE and PSCAD |
| **7d** | 30 | SCR=10, X/R=10 | 0.5\*Pnet | ~0 | PSSE and PSCAD |
| Additional Test for HVDC connected IBR plant | | | | | | |
| **7e** | 30 | SCR=10, 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. |

## 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.

### 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 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=3, X/R=10 | Pnet | ~0 | PSSE and PSCAD | **Dynamic Performance**   1. The IBR plant successfully rides through. 2. In fault ride-through (FRT) mode, the inverter provides necessary support to help maintain system voltage. 3. After the fault is cleared, the IBR restores pre-disturbance active and reactive power injection as fast as possible while remaining stable and damped. 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. |
| **8b** | 30 | SCR=10, X/R=10 | Pnet | ~0 | PSSE and PSCAD |

## Test 9 – Unbalanced Fault Ride-Through

This test evaluates the IBR plant’s ability to ride-through an unbalanced fault applied at the POI.

### Test Description

A single line-to-ground (1LG) fault is applied at the POI and cleared in 15 cycles without tripping any transmission elements. The fault impedance applied in PSSE should result in a similar voltage dip at the POI observed in PSCAD. The GENCLS model should be used in PSSE for the infinite bus dynamic model, and an equivalent model should be used in PSCAD.

Table 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=3, X/R=10 | Pnet | ~0 | PSSE and PSCAD | **Dynamic Performance**   1. The IBR plant successfully rides through. 2. In fault ride-through (FRT) mode, the inverter provides necessary support to help maintain system voltage. 3. After the fault is cleared, the IBR restores pre-disturbance active and reactive power injection as fast as possible while remaining stable and damped. 4. IBR reactive current response shall not exacerbate transient overvoltage conditions on the transmission system.   **Benchmark Performance**  Not applicable. |
| **9b** | 30 | SCR=10, X/R=10 | Pnet | ~0 | PSSE and PSCAD |

## Test 10 – Voltage Protection Verification

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

### 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. |

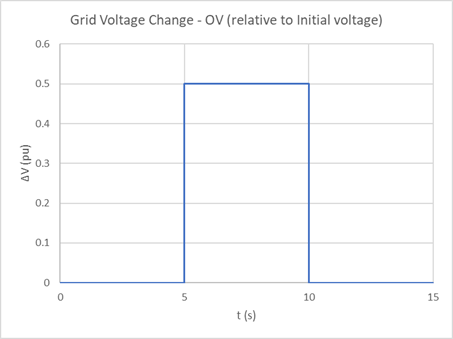


Figure 6 Voltage Protection Test - Grid Overvoltage

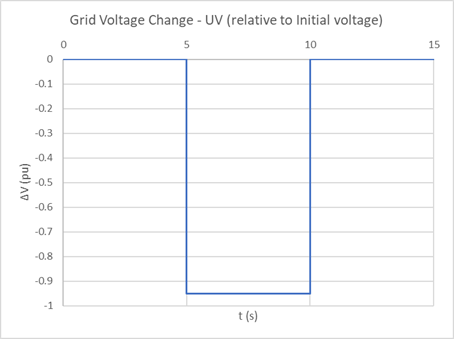


Figure 7 Voltage Protection Test - Grid Undervoltage

## Test 11 – NERC PRC-024 Voltage Ride-Through

This test evaluates the IBR plant’s ability to meet the NERC PRC-024 Voltage Ride-through requirement.[[15]](#footnote-15)

### Test Description

The NERC PRC-024 voltage ride-through curve is simulated at the IBR POI. 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 NERC PRC-024 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. |

## Test 12 – Frequency Ride-Through

This test evaluates the IBR plant’s ability to meet the NERC PRC-024 Frequency Ride-through and PRC-006-NPCC[[16]](#footnote-16) low frequency ride-through requirement14. The low and high frequency thresholds to be evaluated are shown in Table 18.

### 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)**1516 |
| **Low Frequency (Hz)** | |
| 57 | As required in NERC PRC-006-NPCC |
| 58 | As required in NERC PRC-024 |
| 59 | As required in NERC PRC-024 |
| **High Frequency** | |
| 61.8 | As required in NERC PRC-024 |
| 61.7 | As required in NERC PRC-024 |
| 60.5 | As required in NERC PRC-024 |

## 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.

### 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=3, 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=10, X/R=10 | 0.5 \*Pnet | ~0 | PSCAD |

## 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°.

### 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=3, 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=10, 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° |

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

This test evaluates the IBR plant’s ability to ride-through successive changes in short circuit ratio (SCR) at the POI.

### 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[[17]](#footnote-17) | As per Figure 8, X/R= 10 | Pnet | ~0 | PSSE and PSCAD | **Dynamic Performance**  The plant successfully rides through the minimum SCR capability[[18]](#footnote-18) as stated by inverter OEM. The response is expected to be stable and damped at up to SCR of 2.  **Benchmark Performance**  Not applicable. |

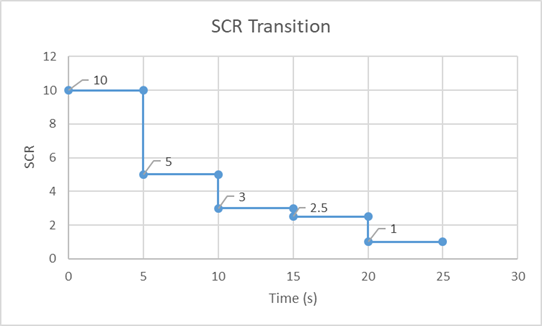


Figure 8 POI SCR Transition

# 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.

## Introduction

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

## System Description

This section should include the following.

* 1. A one-line diagram of the project up to the POI
  2. Component manufacturers (inverter, power-plant controller, auxiliary dynamic reactive device, etc.)
  3. As-modeled data, in PSSE and PSCAD, for the following in a tabular format including MVA base used for ‘per unit’ quantities
     1. Individual and aggregated inverter ratings
     2. Inverter terminal continuous operating voltage range
     3. Individual and aggregated generator step-up (GSU) impedance and winding configuration
     4. Equivalent collector system impedance
     5. Main power transformer (MPT) impedance and winding configuration
     6. Gen-tie impedance
     7. Static and dynamic reactive device

## Modeling Methodology

This section should include the following.

1. PSSE and PSCAD software versions used for the assessment (include minor release version number for e.g. PSSE 34.9.6[[19]](#footnote-19) and PSCAD 5.0.119)
2. PSSE and PSCAD model data revision used for the assessment
3. PSSE and PSCAD simulation parameters which should include
4. Simulation time step
5. Plotting time step
6. Any other significant assumptions such as acceleration factor, tolerance
7. Voltage droop, frequency droop, and applicable deadband
8. GSU and MPT tap

## Simulation Results

This section should include the following.

1. Test order number as per Table 1 in Section 1
2. Mode of operation if BESS (i.e., discharging or charging)
3. Any specific assumptions for the test
4. Technical rationale if requirements not met
5. 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.
6. One set of plot at the POM
7. One set of plot at the inverter terminal

## PSCAD model instructions

This section should include the following.

1. Directions for compiling and initializing the model
2. 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.

## 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):

1. Ride-through activation and deactivation thresholds and parameters
2. Voltage and frequency ride-through settings
3. Active power ramp rates following faults
4. Plant-level voltage controller gains and time constants
5. Interface parameters with auxiliary devices such as STATCOMs, if applicable
6. Description of the planned (or installed) control schemes (such as voltage, frequency, reactive power and/or power factor, runback, etc.). The description should include:
7. The target of the control scheme
8. Overview of how it achieves its intended result
9. Parameters that directly affect the performance, trigger levels, deadband, etc.
10. Limitations of the control scheme

# Addendum

The damping ratio, as described in Annex L of IEEE Std. 2800-2022, is attached here for reference10.



IEEE Std. 2800-2022 Annex L

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 at <https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/Short_Circuit_whitepaper_Final_1_26_18.pdf> [↑](#footnote-ref-1)
2. Definitions adopted as used in IEEE Std. 2800-2022 [↑](#footnote-ref-2)
3. https://www.iso-ne.com/participate/applications-status-changes/interconnection-process-guide [↑](#footnote-ref-3)
4. 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. [↑](#footnote-ref-4)
5. Refer to Appendix D of ISO-NE Planning Procedure for additional guidance [↑](#footnote-ref-5)
6. Represented by a zero impedance line [↑](#footnote-ref-6)
7. If the plant requires a minimum physical output, then test at the minimum value. Documentation must be provided to support the physical minimum value. [↑](#footnote-ref-7)
8. 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. [↑](#footnote-ref-8)
9. 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. [↑](#footnote-ref-9)
10. 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. [↑](#footnote-ref-10)
11. Reprinted with permission from IEEE. Copyright IEEE 2022. All rights reserved. [↑](#footnote-ref-11)
12. Refer to Section 6 of this document. [↑](#footnote-ref-12)
13. ICR is defined as the Rated Active Power Output (or Rated Active Power Absorption, where applicable) at the POI [↑](#footnote-ref-13)
14. https://www.iso-ne.com/static-assets/documents/rules\_proceds/operating/isone/op14/op14\_rto\_final.pdf [↑](#footnote-ref-14)
15. Refer to the NERC PRC-024 Standard version in effect [↑](#footnote-ref-15)
16. As stated in Requirement 10 (https://www.nerc.com/pa/Stand/Reliability%20Standards/PRC-006-NPCC-2.pdf) [↑](#footnote-ref-16)
17. The simulation time can be extended to allow for testing all SCR transitions [↑](#footnote-ref-17)
18. At the POI or as interpreted at the inverter terminal [↑](#footnote-ref-18)
19. Example only and may not be the version in use by ISO-NE [↑](#footnote-ref-19)