Model Quality Test Criteria

NSPI-TPR-014-2

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Transmission Planning

Nova Scotia Power Inc.

REVISION RECORD

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2023-06-30	0	Joy Brake	Initial document
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Table of Abbreviations

Term	Definition
BESS	Battery Energy Storage System
EMT	Electromagnetic Transient
FRT	Fault Ride Through
HVRT	High Voltage Ride Through
IBR	Inverter Based Resource
IC	Interconnection Customer
IR###	Interconnection Request No. ###
LVRT	Low Voltage Ride Through
MFRT	Multiple-Fault Ride Through
MSU	Mechanically Switched Unit
MQT	Model Quality Test
NERC	North American Electric Reliability Cooperation
NPCC	Northeast Power Coordinating Council
NSPI	Nova Scotia Power Inc.
OLTC	On Load Tap Changer
POI	Point of Interconnection to NSPI facilities
PPC	Power Plant Controller
PV	Photovoltaic
RMS	Root Mean Squared
SCMVA	Short Circuit Megavolt-Amperes
SCR	Short Circuit Ratio
SIS	System Impact Study
SMIB	Single Machine - Infinite Bus
TSIR	Transmission System Interconnection Requirements
WECS	Wind Energy Conversion System
WF	Wind Farm

1 Purpose

This guideline lists the minimum requirements that must be met by a proponent submitting simulation models of plants that are to be connected to the electric network operated by Nova Scotia Power Inc. (NSPI). The plant can include generation, load or other major equipment for which the connecting party is expected to provide simulation models in PSS®E and PSCAD™ format. The requirements listed in this document are in addition to the general model feature requirements listed in the 'PSSE and PSCAD Model Requirements' document published by NSPI.

This document outlines the model response tests to be performed, test procedure to be followed, and the test results that are to be submitted along with the software models for NSPI review and approval.

2 Background and Scope

NSPI is expecting a rapid transformation of its generation fleet to include up to 100% Inverter Based Resources (IBR) in some operating conditions. Rapid expansion and the expected addition of Wind Energy Conversion Systems (WECS), Battery Energy Storage Systems (BESS) and Solar Photovoltaic (PV) generation will present significant technical challenges that must be identified at planning and operational stages. To enable this analysis, it is critical that NSPI maintains an accurate network model of the power system.

In an IBR-heavy power system, the dynamic response characteristics of IBR plants will have a significant impact on overall stability and security of the power system. In addition, NSPI will confirm that the specific plant will operate stably, meeting dynamic response characteristics outlined by NSPI in the Transmission System Interconnection Requirements (TSIR) and other applicable documents. Thus, NSPI will be depending on the third-party proponents who are connecting plant and equipment to the NSPI network to provide accurate and robust simulation models that closely capture the response of the plant under a variety of potential operating conditions.

The main objective of the tests outlined in this document is to ensure that the models provided:

- Are robust and compliant with NSPI model requirements (as outlined in 'PSSE and PSCAD Model Requirements').
- Are accurate representations of the plant response under a range of operating conditions.
- Meet the minimum dynamic response requirements for plant design.
- Meet plant characteristics as outlined in the Grid Code and other applicable documents.
- Include model documentation, model structure, and model data that are in accordance with NSPI guidelines or established industry practice.
- Can be readily incorporated into the overall network model of the NSPI power system to perform power system planning, operation and connection studies.

This document covers the model acceptance tests for both Root Mean Square (RMS) and Electromagnetic Transient (EMT) type models that are to be provided to NSPI. The models should be provided in PSS®E (RMS) and PSCAD™ (EMT) software platforms. If the project proceeds to Operations, ASPEN OneLiner modelling data may be required at that time.

The model acceptance tests are performed with the plant model connected to a simplified representation of the rest of the system. Thus, it is important to note that the submission and subsequent acceptance of the Model Quality Test (MQT) Report by NSPI does not imply that:

- The plant design meets final compliance and acceptance.
- The models provided are fully compliant – all models are to be further updated as required by NSPI based on design modifications and test results during commissioning.

3 Related Policies and Procedures

The models provided should be an accurate representation of the physical plant. In addition to demonstrating the robustness and accuracy of the model through the tests outlined in this document, the model response should be aligned with the Grid code, interconnection agreements, as well as protection and measurement requirements.

NSPI will inform the proponent if the model and the test results are acceptable to NSPI.

NSPI will not disclose model test results nor specific proprietary details embedded in the model with third parties.

4 Acceptance Criteria

The Model Acceptance Tests are designed to ensure that the models provided are robust and compliant with NSPI model requirements (as outlined in Power System Model Guidelines) and that the models are an accurate representation of the plant response under a range of reasonable operating conditions.

The tests outlined below are designed to verify the following aspects of the model and the plant response that the model represents:

- Robustness of the model
- Steady state response
- Robustness of the control system and the overall plant design
- Dynamic response
- Response under large disturbances
- Multiple Fault Ride Through (MFRT)
- I_Q injection during Low Voltage Ride Through (LVRT) and High Voltage Ride Through (HVRT)
- Response to specific tests to verify specific compliance requirements

The tests that should be performed at minimum for NSPI approval are listed in the following sections. All tests will be performed with the plant model connected to a simplified representation of the external NSPI network. Unless otherwise directed by NSPI, all tests will be carried out on a Single Machine - Infinite Bus (SMIB) type test setup as shown in Figure 1.

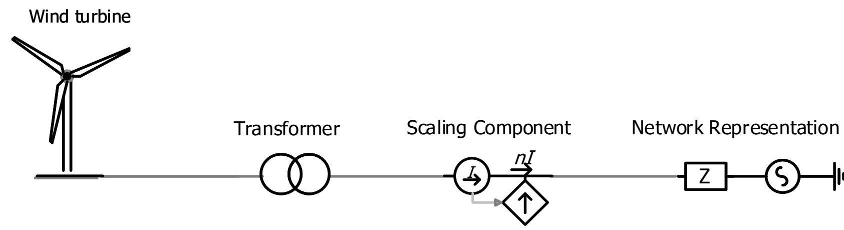

Figure 1: Overview of a SMIB Setup Used for IBR Generation Testing

5 Acceptance Tests

All tests will be performed on the version of the software specified by NSPI. NSPI will also specify the required Fortran compiler compatibility. The Point of Interconnection (POI) voltage should be set to 1.0 pu and the equivalent voltage source frequency set to 60 Hz.

Unless otherwise specified, all tests will be conducted with various Short Circuit Ratio (SCR) and X/R values, as well as different combinations of active and reactive power setpoints. Additionally, all tests will be executed in voltage droop control mode, except where otherwise specified.

Unless otherwise indicated, the tests described below are applicable for both PSS®E and PSCAD™.

5.1 Robustness of the Model

T01: The model should reach the expected steady state.

- The PSCAD™ simulation should reach the expected steady state in less than 3 s of simulation time. This test should be performed at 10 μs and at the largest time step recommended by the proponent.
- The PSS®E model should run stably in a 60 s no fault, 'flat start', simulation with no suspect initial conditions.

T02: The PSCAD™ model should be able to start from a saved 'snapshot' file (the PSCAD™ simulation under T01 will utilize a snapshot taken when the system has reached a steady state).

5.2 Steady State Response

The objective of the steady state tests is to verify that the plant can operate while meeting steady state operating criteria. The steady state tests should be run for a minimum of 5 s after the simulation has reached steady state.

T03: With the simulation in steady state (power output close to 100%), operate the plant at maximum expected lagging reactive power output. This test should be performed with the plant operating under voltage droop control mode or reactive power control mode.

T04: With the simulation in steady state, operate the plant at maximum expected leading reactive power output. This test should be performed with the plant operating under voltage droop control mode or reactive power control mode.

T05: Continuous operation under over voltage conditions – With the simulation in steady state, set the POI voltage to 1.10 pu.

T06: Continuous operation under low voltage conditions – With the simulation in steady state, set the POI voltage to 0.90 pu.

5.3 Robustness of the Control System and the Overall Plant Design

T07: Voltage Reference Change - With the simulation in steady state, implement step changes to the plant's voltage reference point as per Figure 2. The POI voltage should adjust to the requested voltage level and the overall responses (P, Q, and V_{RMS}) should be well damped.

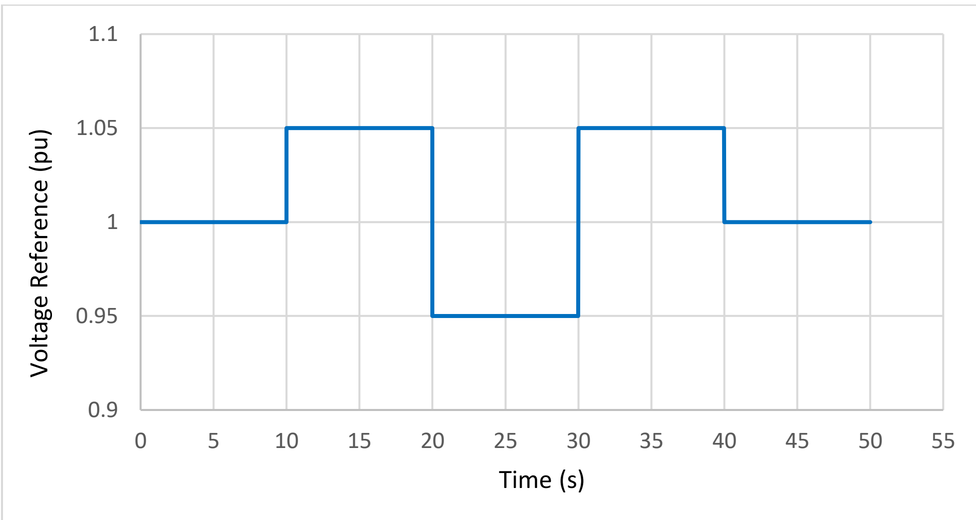

Figure 2: Voltage Reference Change

T08: Reactive Power Reference Change - With the simulation in steady state, implement step changes to the plant's reactive power reference point as per Figure 3. This test should be performed with the plant operating under reactive power control mode. The POI reactive power should adjust to the requested reactive power level and the overall responses (P, Q, and V_{RMS}) should be well damped.

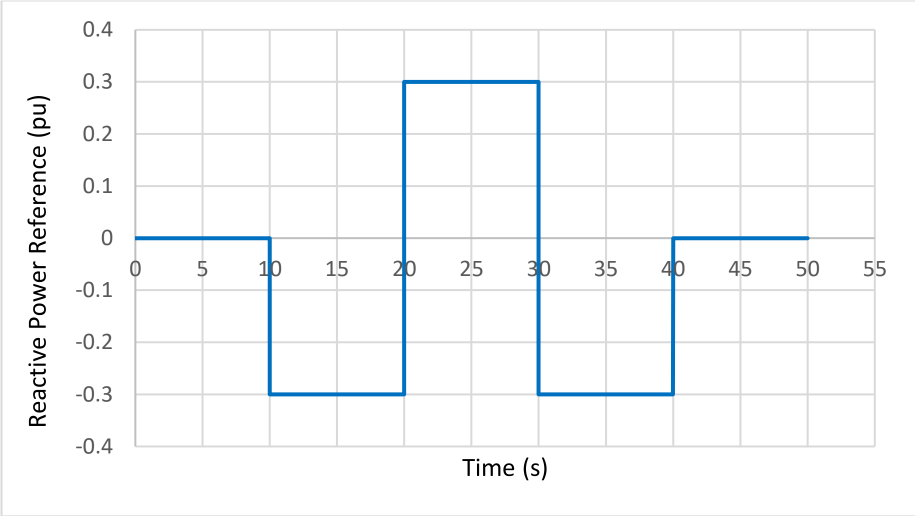

Figure 3: Reactive Power Reference Change

T09: Power Factor Reference Change - With the simulation in steady state, implement step changes to the plant's power factor reference point to achieve a reactive power output as shown in Figure 3. This test should be performed with the plant operating under power factor control mode. The POI reactive power should adjust to the requested reactive power level and the overall responses (P, Q, and V_{RMS}) should be well damped.

T10: Active Power Reference Change - With the simulation in steady state, implement step changes to the plant's active power reference point as per Figure 4 and Figure 5 (for BESS only). The POI active power should adjust to the requested active power level and the overall responses (P, Q, and V_{RMS}) should be well damped.

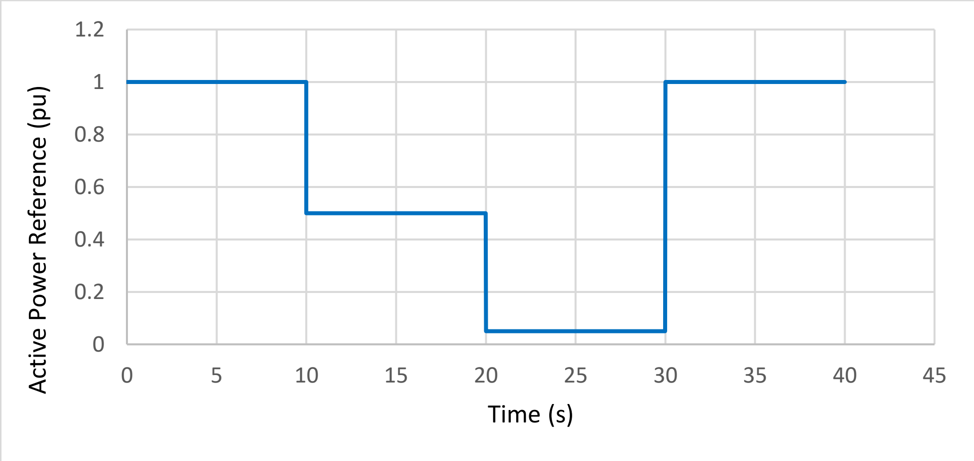

Figure 4: Active Power Reference Change

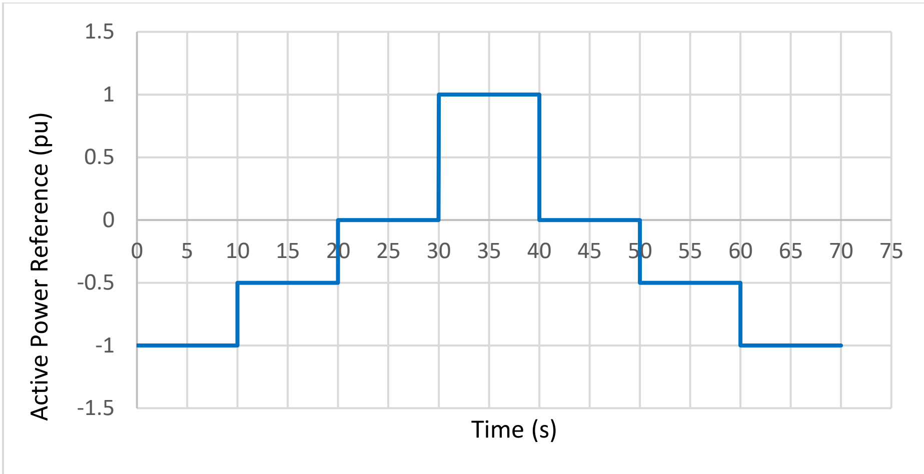

Figure 5: Active Power Reference Change for BESS

T11: Phase Angle Jump – With the simulation in steady state, implement a step change of +/- 50 deg to the POI bus voltage phase. This can be achieved by changing the phase angle of the equivalent voltage source. The plant should operate stably and continue to maintain pre-disturbance output conditions for P and Q.

T12: Step Change to Wind Speed / Solar Irradiation – With the simulation in steady state, apply a 25% step change to the wind speed or solar irradiation. If this test cannot be readily implemented due to model limitations, the proponent may request NSPI consent to omit this test.

5.4 Dynamic Response

T13: Grid Voltage Step Response - With the simulation in steady state, implement step changes to the grid voltage as per Figure 6. This may be achieved by changing the equivalent voltage source magnitude or by changing the transformer tap setting.

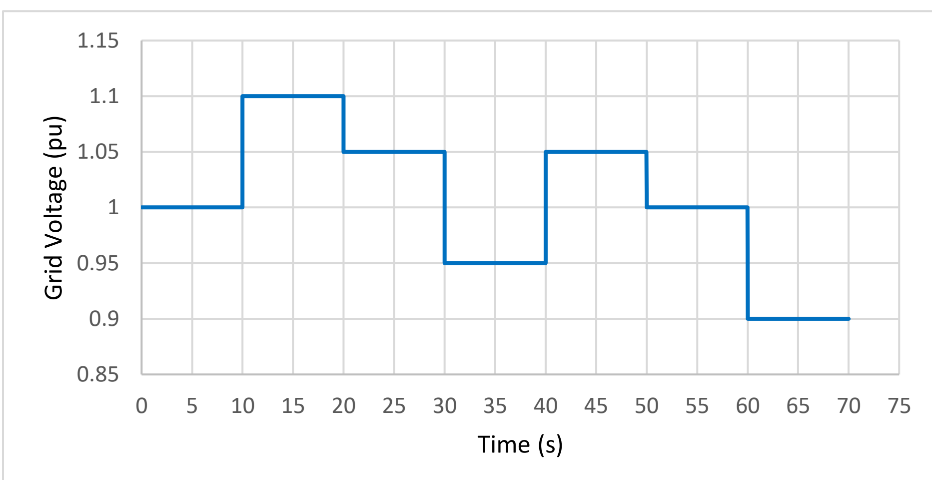

Figure 6: Grid Voltage Change

T14: Frequency Response (Over frequency) – With the simulation in steady state, apply a step change of 1.8 Hz to the equivalent voltage source frequency as shown in Figure 7, increasing it from 60.0 Hz to 61.8 Hz at a rate of 4.0 Hz/s. The power output should ramp down.

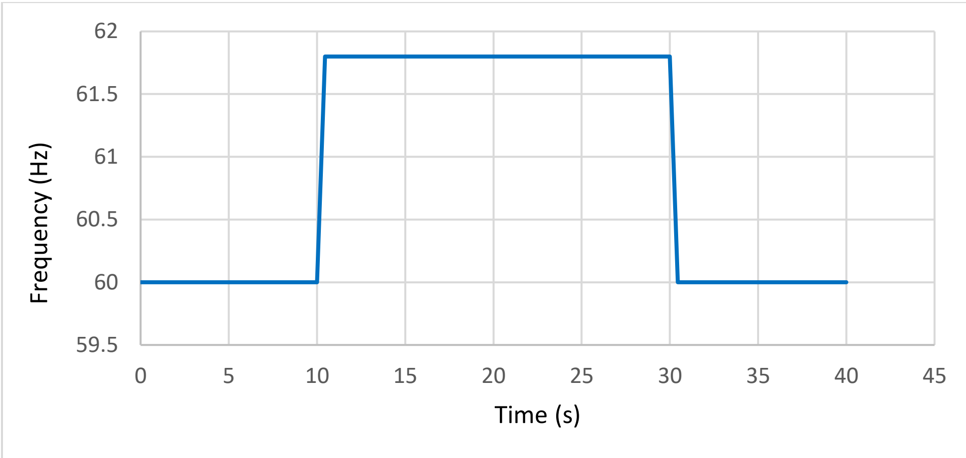

Figure 7: Grid Frequency Change - Over Frequency

T15: Frequency Response (Underfrequency) – With the simulation in steady state, apply a step change of 3.0 Hz to the equivalent voltage source frequency as shown in Figure 8, decreasing it from 60.0 Hz to 57.0 Hz at a rate of 4.0 Hz/s. The power output should ramp up.

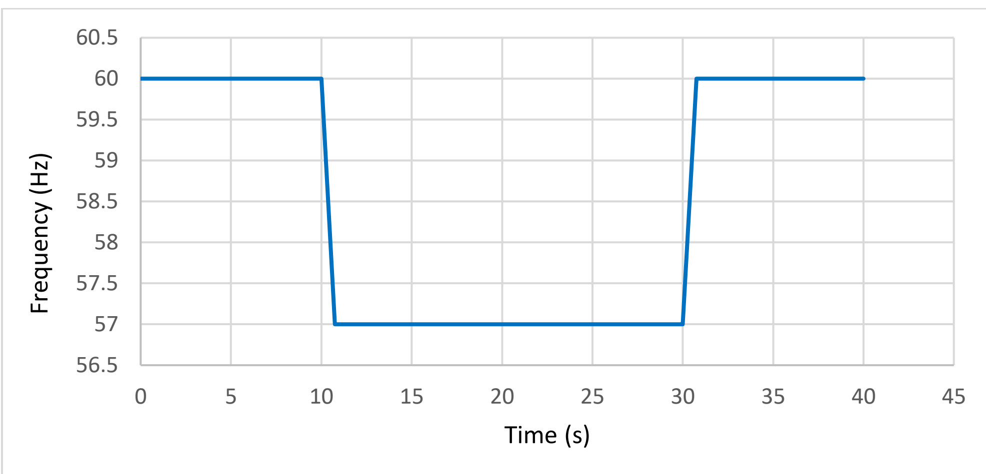

Figure 8: Grid Frequency Change - Underfrequency

T16: Frequency response (Underfrequency) – Repeat **T15** with the power output set to less than 100%. The power output should ramp up.

5.5 Response under Large Disturbances

The plant should recover from the fault and reach pre-fault operating conditions in less than 300 ms. If the plant reaches pre-fault operating conditions in less than 1 second, the performance will be reviewed considering the POI and potential impact on other Interconnection Customers.

T17: NERC Curve - Balanced 3-ph to ground fault applied for 0.15 s at the POI.

T18: NERC Curve - Balanced 3-ph to ground fault applied for 0.30 s at the POI. The residual voltage at the POI should be 0.45 pu. The fault impedance should be reactive.

T19: NERC Curve - Balanced 3-ph to ground fault applied for 2 s at the POI. The residual voltage at the POI should be 0.65 pu. The fault impedance should be reactive.

T20: NERC Curve - Balanced 3-ph to ground fault applied for 3 s at the POI. The residual voltage at the POI should be 0.75 pu. The fault impedance should be reactive.

T21: NERC Curve - Balanced 3-ph to ground fault applied for 10 s at the POI. The residual voltage at the POI should be 0.90 pu. The fault impedance should be reactive.

T22: NERC Curve - Balanced 3-ph disturbance applied for 0.20 s at the POI. The residual voltage at the POI should be 1.20 pu.

T23: NERC Curve - Balanced 3-ph disturbance applied for 0.50 s at the POI. The residual voltage at the POI should be 1.175 pu.

T24: NERC Curve - Balanced 3-ph disturbance applied for 1 s at the POI. The residual voltage at the POI should be 1.15 pu.

T25: NERC Curve - Balanced 3-ph disturbance applied for 10 s at the POI. The residual voltage at the POI should be 1.10 pu.

T26: LVRT Curve - Phase A to B fault applied for 0.15 s at the POI.

T27: LVRT Curve - Phase A to B fault applied for 0.30 s at the POI. The residual voltage per faulted phase at the POI should be 0.50 pu. The fault impedance should be reactive.

T28: LVRT Curve - Phase A to B fault applied for 0.30 s at the POI. The residual voltage per faulted phase at the POI should be 0.75 pu. The fault impedance should be reactive.

T29: LVRT Curve - Phase AB to ground fault applied for 0.15 s at the POI.

T30: LVRT Curve - Phase AB to ground fault applied for 0.30 s at the POI. The residual voltage per faulted phase at the POI should be 0.50 pu. The fault impedance should be reactive.

T31: LVRT Curve - Phase AB to ground fault applied for 0.30 s at the POI. The residual voltage per faulted phase at the POI should be 0.75 pu. The fault impedance should be reactive.

T32: LVRT Curve - Phase A to ground fault applied for 0.15 s at the POI.

T33: LVRT Curve - Phase A to ground fault applied for 0.30 s at the POI. The residual voltage per faulted phase at the POI should be 0.50 pu. The fault impedance should be reactive.

T34: LVRT Curve - Phase A to ground fault applied for 0.30 s at the POI. The residual voltage per faulted phase at the POI should be 0.75 pu. The fault impedance should be reactive.

T35: PQ Ride Through - With the simulation in steady state, apply a step change to the POI voltage from 1.0 pu to 0.95 pu and set the plant's active power to 1.0 pu and reactive power to 1.0 pu. Once the simulation reaches steady state, apply a 3-ph to ground fault for 0.30 s at the POI.

T36: PQ Ride Through - With the simulation in steady state, apply a step change to the POI voltage from 1.0 pu to 0.95 pu and set the plant's active power to 1.0 pu and reactive power to 0 pu. Once the simulation reaches steady state, apply a 3-ph to ground fault for 0.30 s at the POI.

T37: PQ Ride Through - With the simulation in steady state, apply a step change to the POI voltage from 1.0 pu to 0.99 pu and set the plant's active power to 1.0 pu and reactive power to -1.0 pu. Once the simulation reaches steady state, apply a 3-ph to ground fault for 0.30 s at the POI.

T38: PQ Ride Through (additional test for plants with STATCOM mode) - With the simulation in steady state, apply a step change to the POI voltage from 1.0 pu to 1.03 pu and set the plant's reactive power to 1.0 pu. Once the simulation reaches steady state, apply a 3-ph to ground fault for 0.30 s at the POI.

T39: PQ Ride Through (additional test for plants with STATCOM mode) - With the simulation in steady state, apply a step change to the POI voltage from 1.0 pu to 1.05 pu and set the plant's reactive power to -1.0 pu. Once the simulation reaches steady state, apply a 3-ph to ground fault for 0.30 s at the POI.

5.6 Multiple Fault Ride Through

Scenario A: Phase A to ground faults, each with a duration of 120ms, applied at time t and t+0.5 seconds.

Scenario B: 3-ph to ground faults, each with a duration of 120ms, applied at time t and t+2 seconds.

Scenario C: 3-ph to ground faults, each with a duration of 120ms, applied at time t, t+2, and t+9 seconds.

T40: With the simulation in steady state, apply the faults as described in Scenario A.

T41: With the simulation in steady state, apply the faults as described in Scenario B.

T42: With the simulation in steady state, apply the faults as described in Scenario C.

5.7 I_Q Current Injection/Absorption During LVRT and HVRT

These tests should be performed with an SCR of 3 only. The instantaneous reactive current at the inverter terminals and at the POI during the fault should be observed.

T43: Balanced 3-ph to ground fault applied for 0.12 s at the POI. The residual voltage at the POI should be 0.20 pu. The fault impedance should be reactive.

T44: Balanced 3-ph to ground fault applied for 0.12 s at the POI. The residual voltage at the POI should be 0.40 pu. The fault impedance should be reactive.

T45: Balanced 3-ph to ground fault applied for 0.12 s at the POI. The residual voltage at the POI should be 0.60 pu. The fault impedance should be reactive.

T46: Balanced 3-ph to ground fault applied for 0.12 s at the POI. The residual voltage at the POI should be 0.70 pu. The fault impedance should be reactive.

T47: Balanced 3-ph to ground fault applied for 0.12 s at the POI. The residual voltage at the POI should be 0.85 pu. The fault impedance should be reactive.

T48: Balanced 3-ph disturbance applied for 0.12 s at the POI. The residual voltage at the POI should be 1.12 pu.

T49: Balanced 3-ph disturbance applied for 0.12 s at the POI. The residual voltage at the POI should be 1.15 pu.

T50: Balanced 3-ph disturbance applied for 0.12 s at the POI. The residual voltage at the POI should be 1.20 pu.

5.8 PQ Capability Curve

These tests should be performed at the maximum and minimum expected site SCR and X/R. For each test below, record the P, Q, and V_{RMS} at the POI. Plot the collected set of P-Q points for each voltage level tested to create graphs similar to those shown in Figure 9. These tests should be performed with the plant operating under reactive power control mode.

T51: With the simulation in steady state, apply a step change to the POI voltage from 1.0 pu to 0.90 pu and set the plant's active power to 1.0 pu and reactive power to 1.0 pu.

T52: With the simulation in steady state, apply a step change to the POI voltage from 1.0 pu to 0.99 pu and set the plant's active power to 1.0 pu and reactive power to 1.0 pu.

T53: With the simulation in steady state, apply a step change to the POI voltage from 1.0 pu to 0.99 pu and set the plant's active power to 1.0 pu and reactive power to -1.0 pu.

T54: With the simulation in steady state, apply a step change to the POI voltage from 1.0 pu to 1.03 pu and set the plant's active power to 1.0 pu and reactive power to 1.0 pu.

T55: With the simulation in steady state, apply a step change to the POI voltage from 1.0 pu to 1.03 pu and set the plant's active power to 1.0 pu and reactive power to -1.0 pu.

T56: With the simulation in steady state, apply a step change to the POI voltage from 1.0 pu to 1.10 pu and set the plant's active power to 1.0 pu and reactive power to -1.0 pu.

Note: *For BESS and other energy storage systems, rerun tests **T51** to **T56** with the plant's active power set to -1.0 pu.*

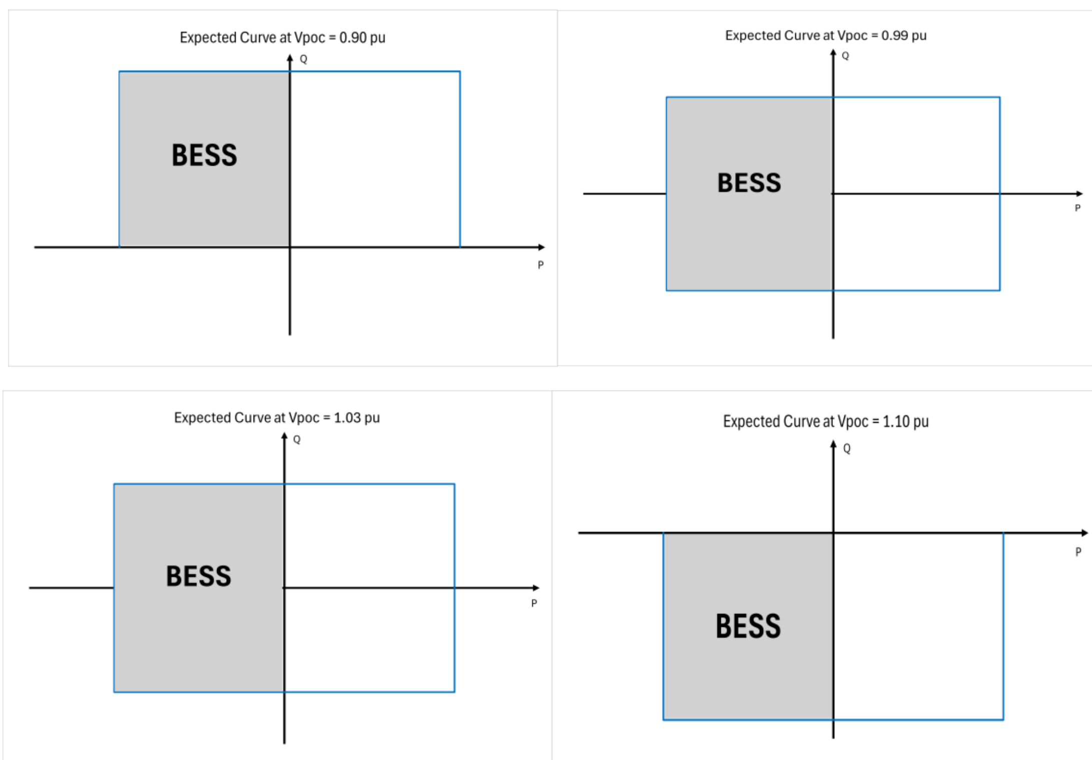

Figure 9: PQ Capability Curves at Different Voltages

5.9 Test for Harmonic Distortion Requirements

T57: Harmonic headroom calculation using IEC method (IEC 61000-3-6).
The equation to estimate 'Harmonic Headroom' is,

$$V_{hr}^{h} = \sqrt[\alpha]{(V_{pl}^{h})^{\alpha} - (V_{bg}^{h})^{\alpha}}$$

Coefficient α is defined for different harmonics:

Harmonic Order (h)	α
h<5	1
5<h<100	1.4
h>10	2

T58: Harmonic emission allocation calculation using IEC method.
Maximum allowed contribution of new user for each harmonic order h:

$$V_{hr-user}^{h} = V_{hr}^{h} \times k$$

"K - Coefficient which may vary from 0.25-0.75 depends on number of users connecting the electrical vicinity of point of connection. To be on the safe side, initial requirements should be set to 0.25"
As per the above note, it is NSPI's discretion to decide on a number for k, based on details of the specific connection and expected future connection in the local area.

5.10 Specific Tests for Special Projects

Project specific tests may be required for grid projects that have design requirements with more stringent or additional performance characteristics than those tested in the above protocol.

6 Model Benchmark Tests

NSPI will use the PSS®E model for a wide range of planning and operational studies. Thus, the PSS®E model should be an accurate representation of the plant response for the purpose of such studies. The PSS®E model should be benchmarked against the validated PSCAD™ model.

At a minimum, the response of the active power, reactive power, and voltage will be compared between PSS®E and PSCAD™ at the inverter terminal and POI level. The comparison should be acceptable to NSPI and should lie within a 10% tolerance band. The model should comply with NSPI requirements, and any noticeable deviations should be documented to the satisfaction of NSPI.

At a minimum, the following test results of PSS®E and PSCAD™ are to be benchmarked in the same plot for comparison:

- Voltage reference change test (**T07**)
- Active power reference change test (**T10**)
- Over voltage step response test (**T05**)
- Under voltage step response test (**T06**)
- Balanced fault tests
  - 3-ph to ground fault at POI (**T17**)
  - 3-ph to ground fault at POI with residual voltage (**T18**)
- Unbalanced fault tests
  - Phase AB to ground fault (**T29**)
  - Phase A to ground fault (**T32**)

7 Test Result Documentation

The documentation shall be in report form and include:

- The project name, location, and the associated Generator Interconnection Procedures (GIP) Interconnection Request number.
- The model and test case configuration, complete with graphics and descriptions as necessary to recreate the test scenario.
- A concise listing of each test performed or listed as not applicable.
- Test results, including any necessary data files, to facilitate a comprehensive review of compliance with requirements.

8 Commissioning Model Benchmark Tests

NSPI will use the PSS®E and PSCAD™ models for a wide range of planning and operational studies. Thus, the benchmarked models from the Planning stage, as documented in the Model Quality Testing, will be benchmarked against commissioning results. Where the field data results do not align with the simulated results, updated models that provide an accurate representation of the plant performance are required. The Model Quality Tests will be performed with the updated models and any deficiencies in plant performance are to be addressed before the plant can proceed into Commercial Operation.

Appendix A – Sample Test Scenarios

The tables below provide detailed combinations of SCR, X/R, active power setpoints, and reactive power setpoints for each test described in Section 5.

Note: *Tests with the active power set to -1.0 pu are specific to BESS and other energy storage systems. These tests should be performed in addition to all other tests when assessing BESS or other energy system plant models.*

Table 1: Robustness of the Model

Test Number	Event
1	Flat run test
2	Snapshot test

Table 2: Steady State Response

Test Number	Event	SCR	X/R	Active Power (pu)	Reactive Power (pu)
3.01	Maximum expected lagging reactive power	10	10	1	-1
3.02	Maximum expected lagging reactive power	3	3	1	-1
4.01	Maximum expected leading reactive power	10	10	1	1
4.02	Maximum expected leading reactive power	3	3	1	1
5.01	Continuous operation under over voltage conditions	10	10	1	0
5.02	Continuous operation under over voltage conditions	3	3	1	0
6.01	Continuous operation under low voltage conditions	10	10	1	0
6.02	Continuous operation under low voltage conditions	3	3	1	0

Table 3: Robustness of the Control System and Overall Plant Design

Test Number	Event	SCR	X/R	Active Power (pu)	Reactive Power (pu)
7.01	Voltage reference change per Figure 2	10	10	1	0
7.02	Voltage reference change per Figure 2	10	10	0	0
7.03	Voltage reference change per Figure 2	10	10	-1	0

Table 3: Robustness of the Control System and Overall Plant Design

Test Number	Event	SCR	X/R	Active Power (pu)	Reactive Power (pu)
7.04	Voltage reference change per Figure 2	3	3	1	0
7.05	Voltage reference change per Figure 2	3	3	0	0
7.06	Voltage reference change per Figure 2	3	3	-1	0
8.01	Reactive power reference change per Figure 3	10	10	1	0
8.02	Reactive power reference change per Figure 3	10	10	0	0
8.03	Reactive power reference change per Figure 3	10	10	-1	0
8.04	Reactive power reference change per Figure 3	3	3	1	0
8.05	Reactive power reference change per Figure 3	3	3	0	0
8.06	Reactive power reference change per Figure 3	3	3	-1	0
9.01	Power factor reference change per Figure 3	10	10	1	0
9.02	Power factor reference change per Figure 3	10	10	0	0
9.03	Power factor reference change per Figure 3	10	10	-1	0
9.04	Power factor reference change per Figure 3	3	3	1	0
9.05	Power factor reference change per Figure 3	3	3	0	0
9.06	Power factor reference change per Figure 3	3	3	-1	0
10.01	Active power reference change per Figure 4	10	10	1	0
10.02	Active power reference change per Figure 5	10	10	-1	0
10.03	Active power reference change per Figure 4	3	3	1	0
10.04	Active power reference change per Figure 5	3	3	-1	0
11.01	Phase angle jump (+50°)	10	10	1	0
11.02	Phase angle jump (+50°)	3	3	1	0
11.03	Phase angle jump (-50°)	10	10	1	0
11.04	Phase angle jump (-50°)	3	3	1	0
12.01	Wind speed change	10	10	1	0

Table 3: Robustness of the Control System and Overall Plant Design					
Test Number	**Event**	**SCR**	**X/R**	**Active Power (pu)**	**Reactive Power (pu)**
12.02	Wind speed change	3	3	1	0

Table 4: Dynamic Response					
Test Number	**Event**	**SCR**	**X/R**	**Active Power (pu)**	**Reactive Power (pu)**
13.01	Grid voltage change per Figure 6	10	10	1	0
13.02	Grid voltage change per Figure 6	10	10	0	0
13.03	Grid voltage change per Figure 6	10	10	-1	0
13.04	Grid voltage change per Figure 6	3	3	1	0
13.05	Grid voltage change per Figure 6	3	3	0	0
13.06	Grid voltage change per Figure 6	3	3	-1	0
14.01	Grid frequency change per Figure 7	10	10	1	0
14.02	Grid frequency change per Figure 7	10	10	0	0
14.03	Grid frequency change per Figure 7	10	10	-1	0
14.04	Grid frequency change per Figure 7	3	3	1	0
14.05	Grid frequency change per Figure 7	3	3	0	0
14.06	Grid frequency change per Figure 7	3	3	-1	0
15.01	Grid frequency change per Figure 8	10	10	1	0
15.02	Grid frequency change per Figure 8	10	10	0	0
15.03	Grid frequency change per Figure 8	10	10	-1	0
15.04	Grid frequency change per Figure 8	3	3	1	0
15.05	Grid frequency change per Figure 8	3	3	0	0
15.06	Grid frequency change per Figure 8	3	3	-1	0
16.01	Grid frequency change per Figure 8	10	10	0.8	0
16.02	Grid frequency change per Figure 8	10	10	-0.8	0
16.03	Grid frequency change per Figure 8	3	3	0.8	0
16.04	Grid frequency change per Figure 8	3	3	-0.8	0

Table 5: Response Under Large Disturbances

Test Number	Fault Type	Fault Duration (s)	Residual Voltage (pu)	SCR	X/R	Active Power (pu)	Reactive Power (pu)
17.01	3PHG	0.15	0	10	10	1	1
17.02	3PHG	0.15	0	10	10	1	-1
17.03	3PHG	0.15	0	10	10	0	1
17.04	3PHG	0.15	0	10	10	0	-1
17.05	3PHG	0.15	0	10	10	-1	1
17.06	3PHG	0.15	0	10	10	-1	-1
17.07	3PHG	0.15	0	3	3	1	1
17.08	3PHG	0.15	0	3	3	1	-1
17.09	3PHG	0.15	0	3	3	0	1
17.10	3PHG	0.15	0	3	3	0	-1
17.11	3PHG	0.15	0	3	3	-1	1
17.12	3PHG	0.15	0	3	3	-1	-1
18.01	3PHG	0.3	0.45	10	10	1	1
18.02	3PHG	0.3	0.45	10	10	1	-1
18.03	3PHG	0.3	0.45	10	10	0	1
18.04	3PHG	0.3	0.45	10	10	0	-1
18.05	3PHG	0.3	0.45	10	10	-1	1
18.06	3PHG	0.3	0.45	10	10	-1	-1
18.07	3PHG	0.3	0.45	3	3	1	1
18.08	3PHG	0.3	0.45	3	3	1	-1
18.09	3PHG	0.3	0.45	3	3	0	1
18.10	3PHG	0.3	0.45	3	3	0	-1
18.11	3PHG	0.3	0.45	3	3	-1	1
18.12	3PHG	0.3	0.45	3	3	-1	-1
19.01	3PHG	2	0.65	10	10	1	1
19.02	3PHG	2	0.65	10	10	1	-1
19.03	3PHG	2	0.65	10	10	0	1
19.04	3PHG	2	0.65	10	10	0	-1

Table 5: Response Under Large Disturbances

Test Number	Fault Type	Fault Duration (s)	Residual Voltage (pu)	SCR	X/R	Active Power (pu)	Reactive Power (pu)
19.05	3PHG	2	0.65	10	10	-1	1
19.06	3PHG	2	0.65	10	10	-1	-1
19.07	3PHG	2	0.65	3	3	1	1
19.08	3PHG	2	0.65	3	3	1	-1
19.09	3PHG	2	0.65	3	3	0	1
19.10	3PHG	2	0.65	3	3	0	-1
19.11	3PHG	2	0.65	3	3	-1	1
19.12	3PHG	2	0.65	3	3	-1	-1
20.01	3PHG	3	0.75	10	10	1	1
20.02	3PHG	3	0.75	10	10	1	-1
20.03	3PHG	3	0.75	10	10	0	1
20.04	3PHG	3	0.75	10	10	0	-1
20.05	3PHG	3	0.75	10	10	-1	1
20.06	3PHG	3	0.75	10	10	-1	-1
20.07	3PHG	3	0.75	3	3	1	1
20.08	3PHG	3	0.75	3	3	1	-1
20.09	3PHG	3	0.75	3	3	0	1
20.10	3PHG	3	0.75	3	3	0	-1
20.11	3PHG	3	0.75	3	3	-1	1
20.12	3PHG	3	0.75	3	3	-1	-1
21.01	3PHG	10	0.9	10	10	1	1
21.02	3PHG	10	0.9	10	10	1	-1
21.03	3PHG	10	0.9	10	10	0	1
21.04	3PHG	10	0.9	10	10	0	-1
21.05	3PHG	10	0.9	10	10	-1	1
21.06	3PHG	10	0.9	10	10	-1	-1
21.07	3PHG	10	0.9	3	3	1	1
21.08	3PHG	10	0.9	3	3	1	-1

Table 5: Response Under Large Disturbances							
Test Number	**Fault Type**	**Fault Duration (s)**	**Residual Voltage (pu)**	**SCR**	**X/R**	**Active Power (pu)**	**Reactive Power (pu)**
21.09	3PHG	10	0.9	3	3	0	1
21.10	3PHG	10	0.9	3	3	0	-1
21.11	3PHG	10	0.9	3	3	-1	1
21.12	3PHG	10	0.9	3	3	-1	-1
22.01	3PHG	0.2	1.2	10	10	1	1
22.02	3PHG	0.2	1.2	10	10	1	-1
22.03	3PHG	0.2	1.2	10	10	0	1
22.04	3PHG	0.2	1.2	10	10	0	-1
22.05	3PHG	0.2	1.2	10	10	-1	1
22.06	3PHG	0.2	1.2	10	10	-1	-1
22.07	3PHG	0.2	1.2	3	3	1	1
22.08	3PHG	0.2	1.2	3	3	1	-1
22.09	3PHG	0.2	1.2	3	3	0	1
22.10	3PHG	0.2	1.2	3	3	0	-1
22.11	3PHG	0.2	1.2	3	3	-1	1
22.12	3PHG	0.2	1.2	3	3	-1	-1
23.01	3PHG	0.5	1.175	10	10	1	1
23.02	3PHG	0.5	1.175	10	10	1	-1
23.03	3PHG	0.5	1.175	10	10	0	1
23.04	3PHG	0.5	1.175	10	10	0	-1
23.05	3PHG	0.5	1.175	10	10	-1	1
23.06	3PHG	0.5	1.175	10	10	-1	-1
23.07	3PHG	0.5	1.175	3	3	1	1
23.08	3PHG	0.5	1.175	3	3	1	-1
23.09	3PHG	0.5	1.175	3	3	0	1
23.10	3PHG	0.5	1.175	3	3	0	-1
23.11	3PHG	0.5	1.175	3	3	-1	1
23.12	3PHG	0.5	1.175	3	3	-1	-1

Table 5: Response Under Large Disturbances

Test Number	Fault Type	Fault Duration (s)	Residual Voltage (pu)	SCR	X/R	Active Power (pu)	Reactive Power (pu)
24.01	3PHG	1	1.15	10	10	1	1
24.02	3PHG	1	1.15	10	10	1	-1
24.03	3PHG	1	1.15	10	10	0	1
24.04	3PHG	1	1.15	10	10	0	-1
24.05	3PHG	1	1.15	10	10	-1	1
24.06	3PHG	1	1.15	10	10	-1	-1
24.07	3PHG	1	1.15	3	3	1	1
24.08	3PHG	1	1.15	3	3	1	-1
24.09	3PHG	1	1.15	3	3	0	1
24.10	3PHG	1	1.15	3	3	0	-1
24.11	3PHG	1	1.15	3	3	-1	1
24.12	3PHG	1	1.15	3	3	-1	-1
25.01	3PHG	10	1.1	10	10	1	1
25.02	3PHG	10	1.1	10	10	1	-1
25.03	3PHG	10	1.1	10	10	0	1
25.04	3PHG	10	1.1	10	10	0	-1
25.05	3PHG	10	1.1	10	10	-1	1
25.06	3PHG	10	1.1	10	10	-1	-1
25.07	3PHG	10	1.1	3	3	1	1
25.08	3PHG	10	1.1	3	3	1	-1
25.09	3PHG	10	1.1	3	3	0	1
25.10	3PHG	10	1.1	3	3	0	-1
25.11	3PHG	10	1.1	3	3	-1	1
25.12	3PHG	10	1.1	3	3	-1	-1
26.01	L-L	0.15	0	10	10	1	1
26.02	L-L	0.15	0	10	10	1	-1
26.03	L-L	0.15	0	10	10	0	1
26.04	L-L	0.15	0	10	10	0	-1

Table 5: Response Under Large Disturbances

Test Number	Fault Type	Fault Duration (s)	Residual Voltage (pu)	SCR	X/R	Active Power (pu)	Reactive Power (pu)
26.05	L-L	0.15	0	10	10	-1	1
26.06	L-L	0.15	0	10	10	-1	-1
26.07	L-L	0.15	0	3	3	1	1
26.08	L-L	0.15	0	3	3	1	-1
26.09	L-L	0.15	0	3	3	0	1
26.10	L-L	0.15	0	3	3	0	-1
26.11	L-L	0.15	0	3	3	-1	1
26.12	L-L	0.15	0	3	3	-1	-1
27.01	L-L	0.3	0.5	10	10	1	1
27.02	L-L	0.3	0.5	10	10	1	-1
27.03	L-L	0.3	0.5	10	10	0	1
27.04	L-L	0.3	0.5	10	10	0	-1
27.05	L-L	0.3	0.5	10	10	-1	1
27.06	L-L	0.3	0.5	10	10	-1	-1
27.07	L-L	0.3	0.5	3	3	1	1
27.08	L-L	0.3	0.5	3	3	1	-1
27.09	L-L	0.3	0.5	3	3	0	1
27.10	L-L	0.3	0.5	3	3	0	-1
27.11	L-L	0.3	0.5	3	3	-1	1
27.12	L-L	0.3	0.5	3	3	-1	-1
28.01	L-L	0.3	0.75	10	10	1	1
28.02	L-L	0.3	0.75	10	10	1	-1
28.03	L-L	0.3	0.75	10	10	0	1
28.04	L-L	0.3	0.75	10	10	0	-1
28.05	L-L	0.3	0.75	10	10	-1	1
28.06	L-L	0.3	0.75	10	10	-1	-1
28.07	L-L	0.3	0.75	3	3	1	1
28.08	L-L	0.3	0.75	3	3	1	-1

Table 5: Response Under Large Disturbances							
Test Number	Fault Type	Fault Duration (s)	Residual Voltage (pu)	SCR	X/R	Active Power (pu)	Reactive Power (pu)
28.09	L-L	0.3	0.75	3	3	0	1
28.10	L-L	0.3	0.75	3	3	0	-1
28.11	L-L	0.3	0.75	3	3	-1	1
28.12	L-L	0.3	0.75	3	3	-1	-1
29.01	2PHG	0.15	0	10	10	1	1
29.02	2PHG	0.15	0	10	10	1	-1
29.03	2PHG	0.15	0	10	10	0	1
29.04	2PHG	0.15	0	10	10	0	-1
29.05	2PHG	0.15	0	10	10	-1	1
29.06	2PHG	0.15	0	10	10	-1	-1
29.07	2PHG	0.15	0	3	3	1	1
29.08	2PHG	0.15	0	3	3	1	-1
29.09	2PHG	0.15	0	3	3	0	1
29.10	2PHG	0.15	0	3	3	0	-1
29.11	2PHG	0.15	0	3	3	-1	1
29.12	2PHG	0.15	0	3	3	-1	-1
30.01	2PHG	0.3	0.5	10	10	1	1
30.02	2PHG	0.3	0.5	10	10	1	-1
30.03	2PHG	0.3	0.5	10	10	0	1
30.04	2PHG	0.3	0.5	10	10	0	-1
30.05	2PHG	0.3	0.5	10	10	-1	1
30.06	2PHG	0.3	0.5	10	10	-1	-1
30.07	2PHG	0.3	0.5	3	3	1	1
30.08	2PHG	0.3	0.5	3	3	1	-1
30.09	2PHG	0.3	0.5	3	3	0	1
30.10	2PHG	0.3	0.5	3	3	0	-1
30.11	2PHG	0.3	0.5	3	3	-1	1
30.12	2PHG	0.3	0.5	3	3	-1	-1

Table 5: Response Under Large Disturbances

Test Number	Fault Type	Fault Duration (s)	Residual Voltage (pu)	SCR	X/R	Active Power (pu)	Reactive Power (pu)
31.01	2PHG	0.3	0.75	10	10	1	1
31.02	2PHG	0.3	0.75	10	10	1	-1
31.03	2PHG	0.3	0.75	10	10	0	1
31.04	2PHG	0.3	0.75	10	10	0	-1
31.05	2PHG	0.3	0.75	10	10	-1	1
31.06	2PHG	0.3	0.75	10	10	-1	-1
31.07	2PHG	0.3	0.75	3	3	1	1
31.08	2PHG	0.3	0.75	3	3	1	-1
31.09	2PHG	0.3	0.75	3	3	0	1
31.10	2PHG	0.3	0.75	3	3	0	-1
31.11	2PHG	0.3	0.75	3	3	-1	1
31.12	2PHG	0.3	0.75	3	3	-1	-1
32.01	1PHG	0.15	0	10	10	1	1
32.02	1PHG	0.15	0	10	10	1	-1
32.03	1PHG	0.15	0	10	10	0	1
32.04	1PHG	0.15	0	10	10	0	-1
32.05	1PHG	0.15	0	10	10	-1	1
32.06	1PHG	0.15	0	10	10	-1	-1
32.07	1PHG	0.15	0	3	3	1	1
32.08	1PHG	0.15	0	3	3	1	-1
32.09	1PHG	0.15	0	3	3	0	1
32.10	1PHG	0.15	0	3	3	0	-1
32.11	1PHG	0.15	0	3	3	-1	1
32.12	1PHG	0.15	0	3	3	-1	-1
33.01	1PHG	0.3	0.5	10	10	1	1
33.02	1PHG	0.3	0.5	10	10	1	-1
33.03	1PHG	0.3	0.5	10	10	0	1
33.04	1PHG	0.3	0.5	10	10	0	-1

Table 5: Response Under Large Disturbances

Test Number	Fault Type	Fault Duration (s)	Residual Voltage (pu)	SCR	X/R	Active Power (pu)	Reactive Power (pu)
33.05	1PHG	0.3	0.5	10	10	-1	1
33.06	1PHG	0.3	0.5	10	10	-1	-1
33.07	1PHG	0.3	0.5	3	3	1	1
33.08	1PHG	0.3	0.5	3	3	1	-1
33.09	1PHG	0.3	0.5	3	3	0	1
33.10	1PHG	0.3	0.5	3	3	0	-1
33.11	1PHG	0.3	0.5	3	3	-1	1
33.12	1PHG	0.3	0.5	3	3	-1	-1
34.01	1PHG	0.3	0.75	10	10	1	1
34.02	1PHG	0.3	0.75	10	10	1	-1
34.03	1PHG	0.3	0.75	10	10	0	1
34.04	1PHG	0.3	0.75	10	10	0	-1
34.05	1PHG	0.3	0.75	10	10	-1	1
34.06	1PHG	0.3	0.75	10	10	-1	-1
34.07	1PHG	0.3	0.75	3	3	1	1
34.08	1PHG	0.3	0.75	3	3	1	-1
34.09	1PHG	0.3	0.75	3	3	0	1
34.10	1PHG	0.3	0.75	3	3	0	-1
34.11	1PHG	0.3	0.75	3	3	-1	1
34.12	1PHG	0.3	0.75	3	3	-1	-1
35.01	3PHG	0.3	0.95	10	10	1	1
35.02	3PHG	0.3	0.95	3	3	1	1
36.01	3PHG	0.3	0.95	10	10	1	0
36.02	3PHG	0.3	0.95	3	3	1	0
37.01	3PHG	0.3	0.99	10	10	1	-1
37.02	3PHG	0.3	0.99	3	3	1	-1
38.01	3PHG	0.3	1.03	10	10	0	1
38.02	3PHG	0.3	1.03	3	3	0	1

Table 5: Response Under Large Disturbances							
Test Number	**Fault Type**	**Fault Duration (s)**	**Residual Voltage (pu)**	**SCR**	**X/R**	**Active Power (pu)**	**Reactive Power (pu)**
39.01	3PHG	0.3	0.95	10	10	0	-1
39.02	3PHG	0.3	0.95	3	3	0	-1

Table 6: Multiple Fault Ride Through					
Test Number	**Event**	**SCR**	**X/R**	**Active Power (pu)**	**Reactive Power (pu)**
40.01	Scenario A	10	10	1	1
40.02	Scenario A	10	10	1	-1
40.03	Scenario A	10	10	0	1
40.04	Scenario A	10	10	0	-1
40.05	Scenario A	10	10	-1	1
40.06	Scenario A	10	10	-1	-1
40.07	Scenario A	3	3	1	1
40.08	Scenario A	3	3	1	-1
40.09	Scenario A	3	3	0	1
40.10	Scenario A	3	3	0	-1
40.11	Scenario A	3	3	-1	1
40.12	Scenario A	3	3	-1	-1
41.01	Scenario B	10	10	1	1
41.02	Scenario B	10	10	1	-1
41.03	Scenario B	10	10	0	1
41.04	Scenario B	10	10	0	-1
41.05	Scenario B	10	10	-1	1
41.06	Scenario B	10	10	-1	-1
41.07	Scenario B	3	3	1	1
41.08	Scenario B	3	3	1	-1
41.09	Scenario B	3	3	0	1
41.10	Scenario B	3	3	0	-1

Table 6: Multiple Fault Ride Through					
Test Number	Event	SCR	X/R	Active Power (pu)	Reactive Power (pu)
41.11	Scenario B	3	3	-1	1
41.12	Scenario B	3	3	-1	-1
42.01	Scenario C	10	10	1	1
42.02	Scenario C	10	10	1	-1
42.03	Scenario C	10	10	0	1
42.04	Scenario C	10	10	0	-1
42.05	Scenario C	10	10	-1	1
42.06	Scenario C	10	10	-1	-1
42.07	Scenario C	3	3	1	1
42.08	Scenario C	3	3	1	-1
42.09	Scenario C	3	3	0	1
42.10	Scenario C	3	3	0	-1
42.11	Scenario C	3	3	-1	1
42.12	Scenario C	3	3	-1	-1

Table 7: I_Q Current Injection/Absorption During LVRT and HVRT							
Test Number	Fault Type	Fault Duration (s)	Residual Voltage (pu)	SCR	X/R	Active Power (pu)	Reactive Power (pu)
43.01	3PHG	0.12	0.2	3	3	1	0
43.02	3PHG	0.12	0.2	3	3	0	0
43.03	3PHG	0.12	0.2	3	3	-1	0
44.01	3PHG	0.12	0.4	3	3	1	0
44.02	3PHG	0.12	0.4	3	3	0	0
44.03	3PHG	0.12	0.4	3	3	-1	0
45.01	3PHG	0.12	0.6	3	3	1	0
45.02	3PHG	0.12	0.6	3	3	0	0
45.03	3PHG	0.12	0.6	3	3	-1	0
46.01	3PHG	0.12	0.7	3	3	1	0

Table 7: I_Q Current Injection/Absorption During LVRT and HVRT							
Test Number	**Fault Type**	**Fault Duration (s)**	**Residual Voltage (pu)**	**SCR**	**X/R**	**Active Power (pu)**	**Reactive Power (pu)**
46.02	3PHG	0.12	0.7	3	3	0	0
46.03	3PHG	0.12	0.7	3	3	-1	0
47.01	3PHG	0.12	0.85	3	3	1	0
47.02	3PHG	0.12	0.85	3	3	0	0
47.03	3PHG	0.12	0.85	3	3	-1	0
48.01	3PHG	0.12	1.12	3	3	1	0
48.02	3PHG	0.12	1.12	3	3	0	0
48.03	3PHG	0.12	1.12	3	3	-1	0
49.01	3PHG	0.12	1.15	3	3	1	0
49.02	3PHG	0.12	1.15	3	3	0	0
49.03	3PHG	0.12	1.15	3	3	-1	0
50.01	3PHG	0.12	1.2	3	3	1	0
50.02	3PHG	0.12	1.2	3	3	0	0
50.03	3PHG	0.12	1.2	3	3	-1	0

Table 8: PQ Capability Curve					
Test Number	**Residual Voltage (pu)**	**SCR**	**X/R**	**Active Power (pu)**	**Reactive Power (pu)**
51.01	0.9	10	10	1	1
51.02	0.9	3	3	1	1
52.01	0.99	10	10	1	1
52.02	0.99	3	3	1	1
53.01	0.99	10	10	1	-1
53.02	0.99	3	3	1	-1
54.01	1.03	10	10	1	1
54.02	1.03	3	3	1	1
55.01	1.03	10	10	1	-1
55.02	1.03	3	3	1	-1

Table 8: PQ Capability Curve

Test Number	Residual Voltage (pu)	SCR	X/R	Active Power (pu)	Reactive Power (pu)
56.01	1.1	10	10	1	-1
56.02	1.1	3	3	1	-1