Generator Testing Requirements

GL-EA-010

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Version	Date	Change
2.1	13/04/2022	Alignment to newly published Ancillary Services Procurement Plan
2.2	22/06/2022	Inverter testing and general update, draft for Asset Owner forum
3.0	31/3/2023	Document description changed from “Guidelines” to “Requirements”
3.1	30/5/2023	Updated 4.1, 8.4 and Appendix E.5 Instantaneous Reserves (generation reserves) for Code changes May 2022, for new category of reserve providers
4.0	18/8/2023	Updated to add testing and procurement basis for Instantaneous Reserve (FIR and SIR) from Inverter based resources, add Appendix E.6, E.7
5.0	30/1/2025	Cyclic Review: Minor change to align with GL-EA-404 Generation Commissioning Process.
6.0	7/7/2025	General overhaul and restructure of document to improve clarity; several IBR tests have been added; test results templates removed.
7.0	6 July 2026	Testing requirement guidance aligned with CACTIS; ancillary services tests and relevant signal curves moved to new GL-EA-1333 Ancillary Services Testing Requirements document.

	Name & Position	Date
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IMPORTANT

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Introduction

This document guides you, the asset owner, to understand what you must consider when testing a generating unit, including for the purpose of routine testing, commissioning, and to demonstrate capability after modifications such as component upgrades are implemented. These requirements will help you to demonstrate the performance and limitations of your asset, which in turn helps the System Operator to assess compliance, maintain power system tools, and operate the power system safely and efficiently.

If you are looking for tests to demonstrate ancillary services provision capability, refer to our *GL-EA-1333 Ancillary Services Testing Requirements* document and the *Ancillary Services Procurement Plan*. Those tests may be carried out in parallel to generation tests in this document. Ensure you discuss your intentions with your lead commissioning engineer as early as possible.

If you are undergoing a commissioning project, this guide forms part of a suite of documents that support you in that process. Refer to the document map on the next page for hyperlinks to the other documents and for an idea of when you should consult them. In particular, we expect you to read this document alongside the following:

- the *Electricity Industry Participation Code 2010* (the Code), especially Part 8, which includes the most up-to-date performance requirements
- the *Connected Asset Commissioning, Testing, and Information Standard* (CACTIS), especially Chapter 7
- *GL-EA-716* Modelling Requirements for Synchronous Assets and *GL-EA-1311* Modelling Requirements for Inverter-based Resources

Navigating the Document

The document begins by providing an overview of the testing process and our requirements, then explains standard test signals and the applicable signal measurement locations. The test descriptions and methodologies are separated into two sections: synchronous generating units and inverter-based resources.

We provide the test schedules in this document because they reliably produce results for asset owners that are required for model validation and compiling an accurate asset capability statement (ACS) during the closeout phase of commissioning. However, they are guidelines, not 'one-size-fits-all'. You may customise these tests to better fit the circumstances of your asset, but if you do, you must consult the System Operator if you intend to do this. You should also contact us if you intend to use factory testing, as this may be acceptable for compliance purposes in some circumstances.

> ***Note:*** *Model validation remains the responsibility of asset owners, as does compliance with all your obligations as stipulated in the Code (and any incorporated documents, such as the CACTIS). You therefore need to read, understand, and comply with asset owner obligations outlined within the Code. If there is a conflict between this document and the Code, the Code takes precedence. If you engage a consultant for testing and model validation purposes, it is your responsibility to ensure that they are aware of our requirements and expectations.*

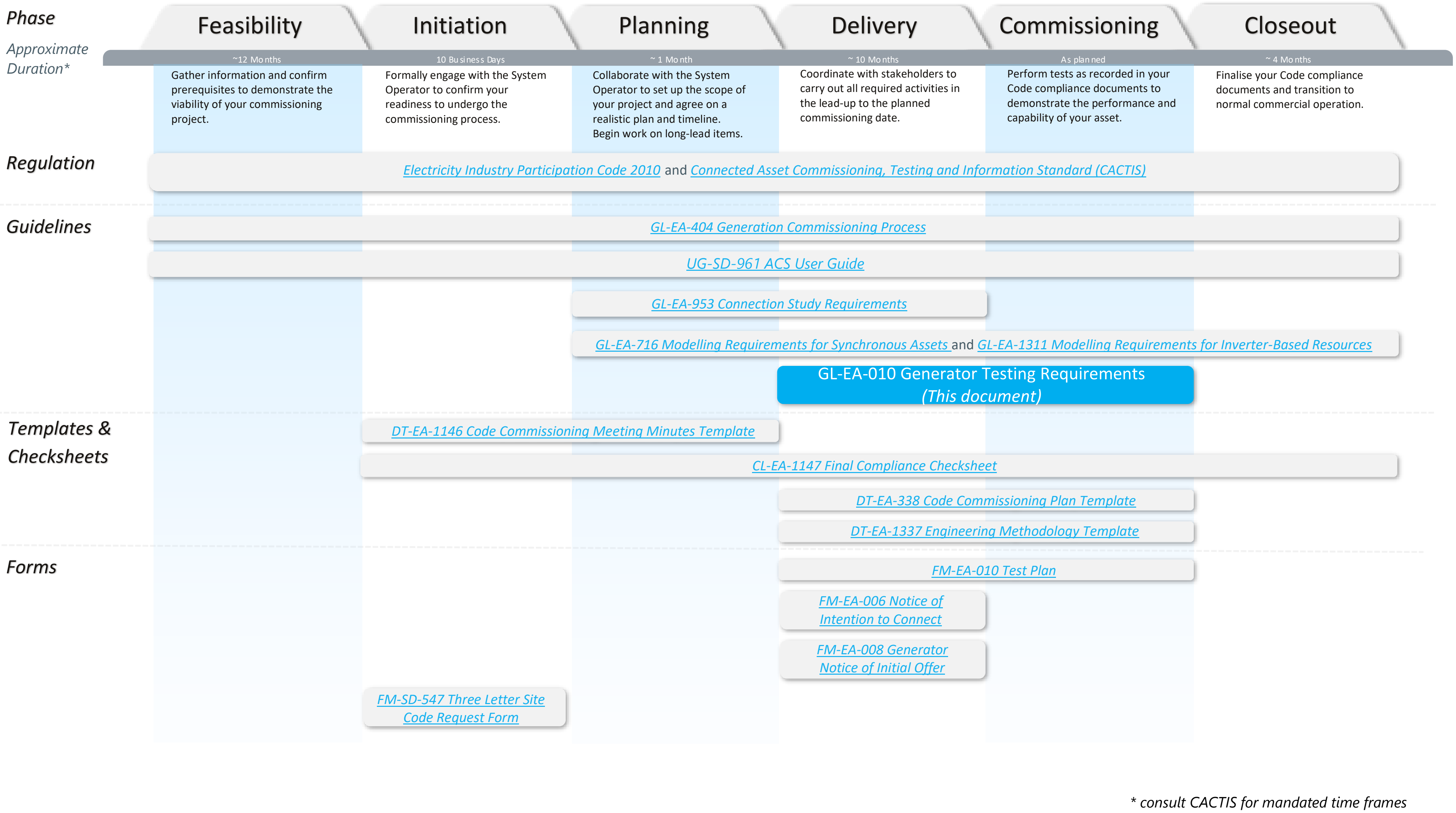


Figure 1 - Supporting Documentation Suite

1 Abbreviations and Terms

Abbreviation/Term	Expanded Form/Explanation
ACS	Asset Capability Statement
AOPO	Asset Owner Performance Obligation
AVR	Automatic Voltage Regulator
BESS	Battery Energy Storage System
The Code / EIPC	Electricity Industry Participation Code 2010
MCO	Maximum Continuous Output
NCC	National Co-ordination Centre
NSGR	Non-Specific Generation Reserve (includes BESS)
OEL	Over-excitation limiter
POC or PCC	Point of Connection
PLSR	Partially Loaded Spinning Reserve
PPC	Power Plant Controller
PPO	The System Operator's Principal Performance Obligations
PSS	Power System Stabiliser
SNL	Speed-no-load
TWD	Tail-water depressed
UEL	Under-excitation limiter

2 General Requirements for Testing

Testing assets while connecting to the power system is a controlled process. It has two objectives:

1. to meet the asset test objectives, and
2. to ensure minimal disturbance to the operation of the power system.

Testing requirements for assets are detailed in chapter 7 of the *CACTIS*. Ensure you familiarise yourself with the applicable obligations so that your testing can demonstrate compliance appropriately.

To assess the performance and risks associated with testing an asset to be commissioned, you must provide the System Operator with up-to-date information, including an up-to-date pre-commissioning asset capability statement, commissioning plan and engineering methodology according to the timings specified in chapter 1 of the *CACTIS*. If you are unable to produce these within the agreed timelines, testing will be delayed.

See our *Generation Commissioning Process* document The following sections provide further details on requirements before, during, and after testing.

If you need to test the performance of multiple pieces of equipment of the same design (i.e. a group of identical assets, built by the same manufacturer), you must:

- first complete a full set of tests on the asset that is to be representative of the group; then
- complete sufficient testing on the remainder of the assets to demonstrate the performance is fully consistent with the representative asset; and,
- certify to the System Operator the performance of assets is fully consistent with the representative asset as detailed in the Code.

2.1 Before Testing

2.1.1 Engineering Methodology

If you are commissioning (whether building a new asset or upgrading an existing asset), you must produce an engineering methodology to describe all your testing ahead of the planned test date (in addition to a commissioning plan). If you are undergoing routine testing, contact the System Operator for guidance on whether an engineering methodology will be necessary or not.

The rest of this document (GL-EA-010) will help you organise the contents of an engineering methodology, for which you should use our *DT-EA-1337 Engineering Methodology Template*. Submit your draft and final versions to *compliance@transpower.co.nz* (unless advised otherwise). The System Operator will review and provide feedback.

***Note:** If you deviate from any of the requirements in this testing document, ensure that you record this in your engineering methodology.*

2.1.2 Operational Test Plan

At least 15 business days before testing, you must submit an operational test plan to the System Operator, which must summarise the testing of each day. This will allow us to assess any potential risks related to:

- the asset owner's ability to meet their asset owner performance obligations (AOPOs); and,
- the System Pperator's ability to meet their principal performance obligations (PPOs).

After assessing your operational test plan, we may impose certain conditions. Testing can only go ahead if the asset owner agrees with those conditions. Further details and the *form* to use are available on our *Asset Testing webpage*. Send it to *operationaltestplans@transpower.co.nz*.

2.2 During Testing

The asset owner must follow all terms and conditions noted on the agreed operational test plan at all times.

2.3 After Testing

2.3.1 Results and Model Validation

You must submit hold point test results as specified in your Code commissioning plan. The final test results must be submitted to the System Operator at the end of testing, unless requested earlier. The mandated timings are listed in chapter 1 of *CACTIS*. The results should clearly identify the equipment and test they refer to.

Use your final test results to validate your model (including for routine testing) before submit it to the System Operator. Advise us if asset performance differs from your model. Refer to *GL-EA-716* (for synchronous assets) and *GL-EA-1311* (for inverter-based resources) for more information on modelling requirements.

2.3.2 Report

After tests are completed, you must submit a test report to the System Operator. It must contain the following:

- all recorded test results organised and identified as agreed with each test's methodology;
- a supporting summary set of test responses to complement the raw data files;
- a clear statement on whether testing met all the test objectives; and,
- any other supporting information that the System Operator would reasonably require to assess the test results such as:
  - asset capability information that is not in the asset capability statement (ACS) visible to the System Operator at the time of testing;
  - an explanation where any assumptions have been made (and why they have been made) particularly when manufacturer's data is not available;
  - an explanation of any deviations observed since the previous tests were carried out. You may refer to factory acceptance tests, type tests and previous test results as required;
  - an explanation of any discrepancies in plant performance or responses you observed during online and offline testing. You must also include these in the model validation report.

In *Appendix A*, we have provided a sample report structure as a suggestion for how you might organise your report.

2.3.3 File Names

We have provided the file name format in Table 1 below to help you correctly associate test result files to specific tests. Your files names should follow this pattern:

AssetName_EquipmentID_TestID_TestNumber_DateTime

Table 1: Expected File Name Pattern Explanations

Part	Explanation
AssetName	The asset name under test; for example, the name of a station.
EquipmentID	The ID of the equipment under test; for example, G1 to represent the ID of generating unit 1.

Part	Explanation
TestID	The ID assigned to each test; for example GEN_FSP refers to Frequency Step Response test in *section 5.2.5*.
Test Number	The number to identify the test from another test of the same type; for example 01 represents the first test of that type.
DateTime	The timing formatted as follows: DDMMYYYYhhmmss

2.3.4 Time Stamping

You must GPS-time stamp all data to ensure that data obtained from different sources aligns accurately. If a GPS time stamp is not available, you must submit all test data in an Excel worksheet or datafile aligned to a common time stamp.

3 Standard Test Signals

This section describes some commonly injected signals used to characterise generating unit/plant responses.

3.1 Frequency Step

Purpose: Demonstrates how the equipment will respond to a grid frequency deviation.

- Offline testing can help determine parameter values when the characteristics of offline modes are the same as those used once the unit is synchronised to the power system.
- Figure 2 below illustrates a suitable signal with frequency steps of ±1%. Other step values may be required to determine particular parameters. This test can be used for both off- and on-line tests.

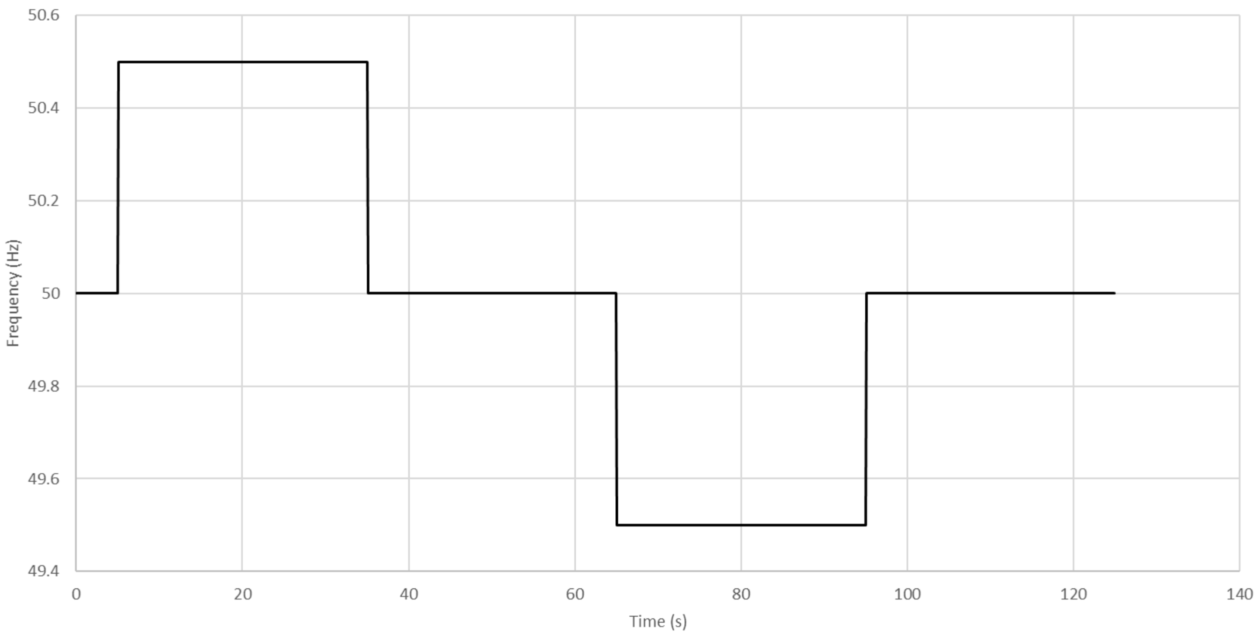


Figure 2: Frequency Step Injection

3.2 Governor Characterising Curve

Purpose: Helps to establish the performance of the governor in response to a grid frequency deviation.

- The frequency drop curve is defined by:

Equation 1 (blue curve)	$\boldsymbol{Freq(t) = 49.7 + (0.3 - 0.8t)e^{-0.95t}}$

- The frequency rise curve is defined by:

Equation 2 (red curve)	$\boldsymbol{Freq(t) = 50.3 - (0.3 - 0.8t)e^{-0.95t}}$

- Figure 3 shows curves used to demonstrate governor response to over- and under-frequencies.

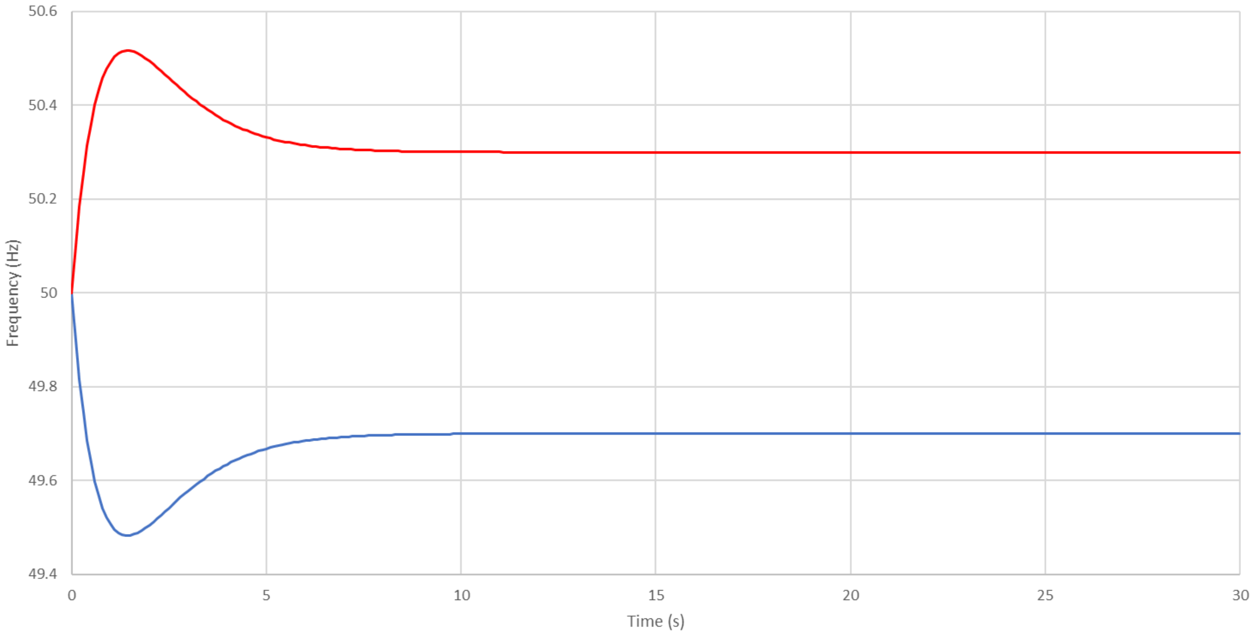


Figure 3: Commonly Injected Frequency Curves to Demonstrate Governor Performance

- For units offering generation reserves, you can replace the frequency drop curve with the standard under-frequency curve discussed in *section 3.3* to reduce the number of tests. If these curves don't fully demonstrate the control logic of a governor, you will need to conduct additional tests using a modified curve.

3.3 Frequency Response

Purpose: Helps to derive Nyquist and Bode stability plots to demonstrate acceptable governor operation.

- It requires a low frequency signal generator to inject control signals modulated with frequencies from 0.01-10 Hz, as shown in Figure 4 below.

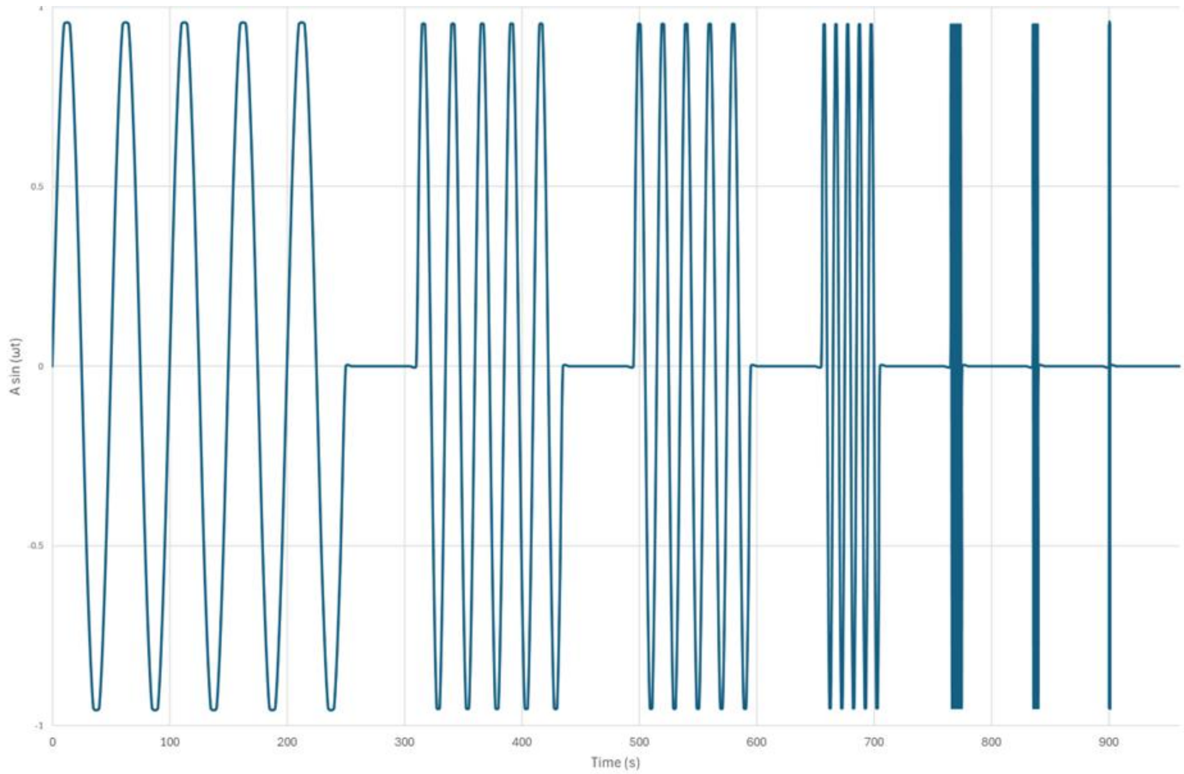


Figure 4: Frequency Sweep Test Signal

3.4 Voltage Step

Purpose: Demonstrates how the equipment will respond to a grid voltage deviation.

- Figure 5 shows a voltage step that would provide test data to validate AVR parameters, droop, line drop compensation, PSS or AVR dynamics.
- The step size used is usually small, typically around ±2% for online test. A bigger step size of ±5% can be used in an offline test to validate the ceiling parameters.

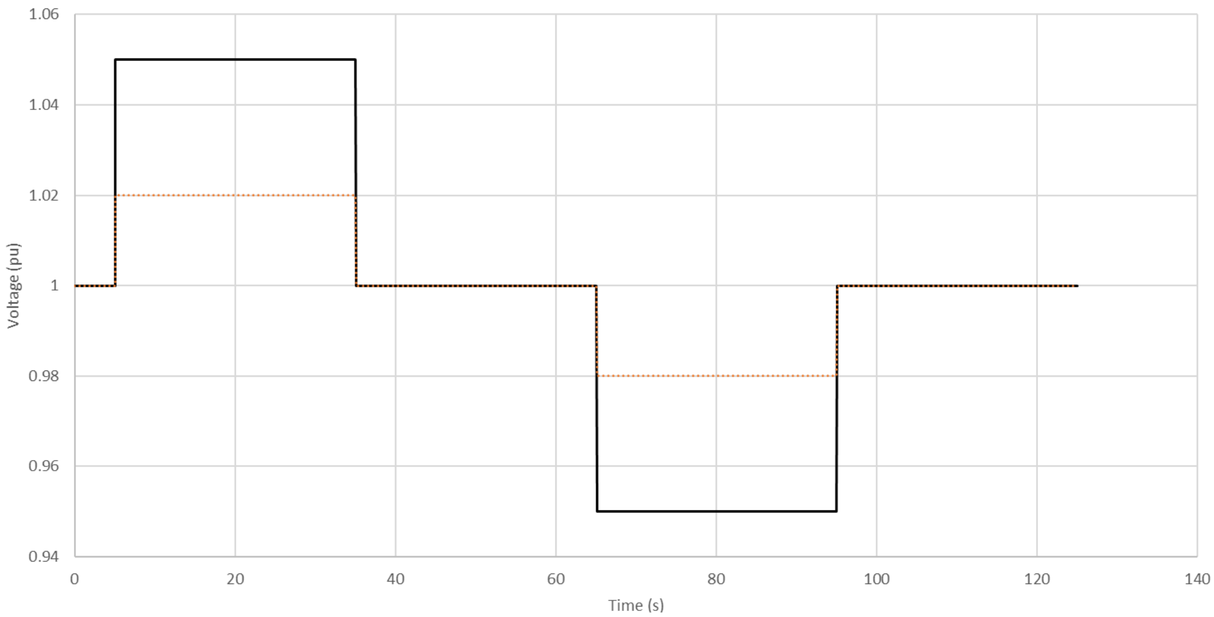


Figure 5: Voltage Step Injections

4 Signal Measurement Locations

You should measure signals according to the specifications below, depending on the type of asset.

4.1 Synchronous Generation

You must record signals:

- at the point of connection (POC/PCC);
- at the input and output of control components such as exciter; governor etc.; and
- at any physical points on the equipment where data is required for model validation.

The table below captures the signals the System Operator would typically expect.

Table 2: Synchronous generation signal ID, signal name and signal description (see Figure 6)

Signal ID	Signal Name	Signal Description
1	Ppcc, Qpcc, fpcc, Vpcc (HV)	PCC at HV of the generator unit transformer
2	Ppcc, Qpcc, fpcc, Vpcc (LV)	PCC at LV of the generator unit transformer
3	Vt, It, Pt, Qt, ft, SPt	Generator terminal parameters required if PCC is on LV only If SP_t cannot be obtained or is too noisy, this should be documented, and a clean frequency signal used
4	V_{fd},I_{fd}	Excitation system parameters For brushless excitation systems the field-voltage and field-current of the exciter should be recorded as the V_{fd} and I_{fd} will not be accessible
5	AVRcom	AVR output command
6	UELcom, OELcom	Limiters output command
7	PSScom	PSS output command
8	GOVcom, Pos	Governor output command, Gate/Valve position
9	fref, Pref	Frequency reference, Power reference
10	Vref, Qref	Voltage reference, Reactive power reference

Figure 6 below plots the measurement points on a typical synchonous asset's topology.

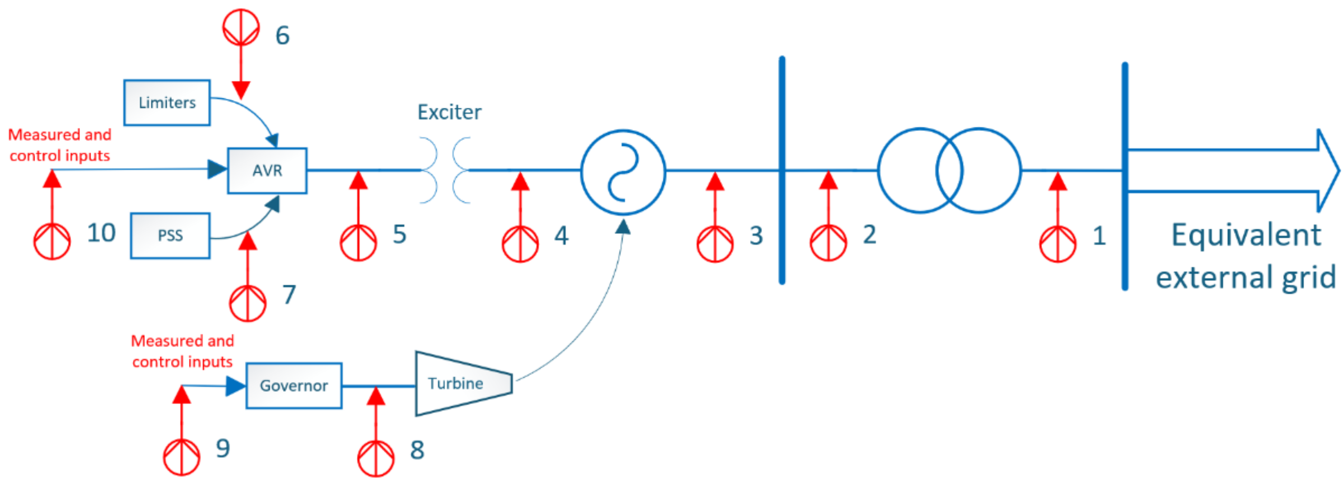


Figure 6: Typical Synchronous Generator Configuration and Measurement Points

4.2 Inverter-based Generation

You must record signals:

- at the individual Wind Turbine Generator level, solar inverter string or other Inverter connected module for both:
  - inputs and outputs for validating individual wind generator turbine model/inverter string model/module model; and
  - internal signals such as converter DC voltage and Phase-Locked Loop input and output if accessible; and
  -
- at the Power Plant Controller level:
  - inputs to the controller; and
  - active and reactive power at the point of connection (POC/PCC) (if applicable); and
  - outputs to wind turbine generator, inverter string or modules; and
  - outputs to reactive power compensation devices.

Note: If you are testing a battery energy storage system (BESS), ensure that you test all modes of operation: charging, standby, and discharging.

The table below captures the signals the System Operator would typically expect of this generator type.

Table 3: Inverter Generation Signal ID, Signal Name and Signal Description (see Figure 7)

Signal ID	Signal Name	Signal Description
1	P_{pcc}, Q_{pcc}, f_{pcc}, V_{pcc}	PCC at HV of the step-up transformer
2	P_{pcc}, Q_{pcc}, f_{pcc}, V_{pcc}	Required if PCC at LV of the generator unit transformer only
3	$Q_{STATCOM}$, Q_{MSR}, Q_{MSC}	Reactive power output – STATCOM, Shunt reactor & Shunt capacitor
4	$STATCOM_{COM}$, MSR_{COM}, MSC_{COM}	Plant controller request command to STATCOM, Shunt reactor & Shunt capacitor
5	P_{COM}, Q_{COM}, V_{COM}	Plant controller request command to inverter
6	INV_{COM}	Inverter command, signal type to be discussed with the System Operator
7	INV_{DC}	Inverter DC voltage
8	P_{INV}, Q_{INV}, V_{INV}	Inverter string parameters to be recorded for a few indicative inverters at each end of string for each type of device installed as agreed between the asset owner and System Operator

Figure 7 plots the measurement points on a typical inverter-based asset's topology.

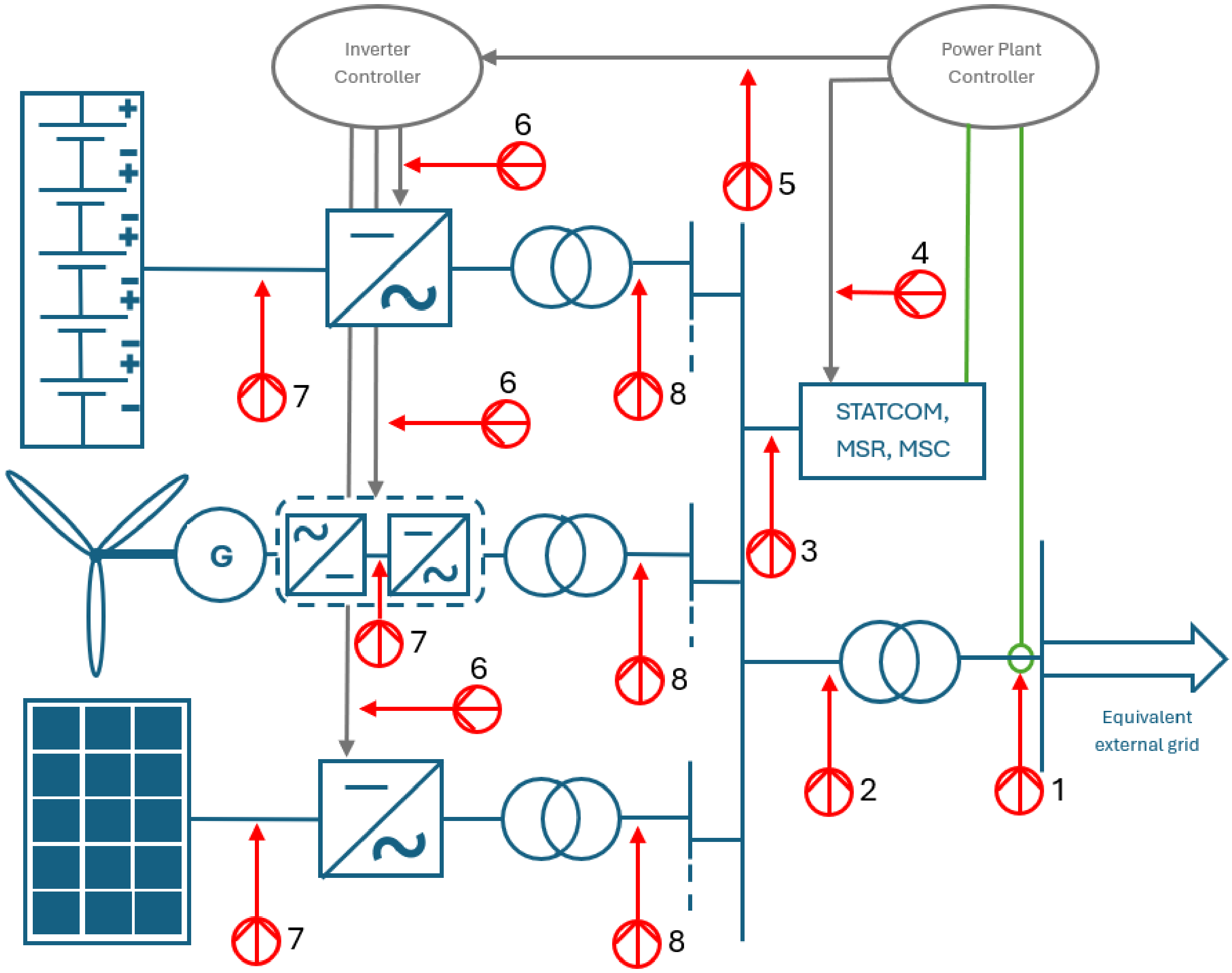


Figure 7: Typical Wind Farm or Solar Farm Inverter Configuration and Measurement points

5 Synchronous Generator Tests

5.1 Generating Unit Parameters

Application: determine parameters when manufacturer data is either missing or is no longer representative of the actual generating unit performance or at any other time where generator characteristics have changed.

Test Objectives: perform these tests to…	**Test Outcomes:** provide sufficient data to…
▪ determine generating unit parameters ▪ determine ACS parameters ▪ determine the reactive power capability over the full active power range ▪ validate of mathematical models against steady state and dynamic generator response.	▪ validate generator model parameters: ▪ generator impedances ▪ generator time constant ▪ saturation data ▪ determine the capability diagram ▪ draw the open-circuit curves ▪ determine the generating unit inertia.

Specific Tests: perform these tests to achieve the required outcomes… (ctrl+click to go to each test)
5.1.1 Load Rejection Test (GEN_REJ)
5.1.2 Generator Capability (GEN_CAP)
5.1.3 Open-Circuit Saturation Curve (GEN_OCT)

References:

- IEC 60034-4: Rotating Electrical Machines: Methods for Determining Synchronous Machine Quantities from Tests
- IEEE Std 115-2009: IEEE Guide for Test Procedures for Synchronous Machines
- IEEE Std 492-1999: IEEE Guide for Operation and Maintenance of Hydro-Generators
- ANSI C50.12-1982 (Reaff 1989): Requirements for Salient Pole Synchronous Generators and Generator/Motors for Hydraulic Turbine Application

5.1.1 Load Rejection Test (GEN_REJ)

Purpose: This test aims to…

- determine the combined inertia (H) of the generator and the prime-mover
- determine synchronous generator parameters
- determine excitation system model parameters
- determine governor and turbine model parameters
- determine d-axis parameters.

Pre-testing:

- Generating unit is synchronised to the grid.

Monitoring Signals: Record the following:

- Electrical frequency – ft (Hz)
- Mechanical Speed – SPt (rpm)
- Generator terminal voltage – Vt (kV)
- Generator terminal active power – Pt (MW)
- Generator terminal reactive power – Qt (Mvar)
- Field voltage – Vfd (V)
- Field current – Ifd (A)

(see *section 4* for signal measurement locations)

Methodology:

Load rejection test

1. Hold generator active power between 5-20% of rated value.
2. Set AVR to voltage control mode.
3. Confirm active power and grid frequency are both stable.
4. Confirm data recorder is ready.
5. Open the generator circuit breaker.
6. Record monitoring signals listed above until the generator terminal voltage and speed is stabilised.

D-axis parameters verification test

1. Generator active power at 0 (or as close to this as possible) and under excited between -0.10 p.u. and -0.40 p.u.
2. Set the AVR to manual mode, maintain the excitation voltage.
3. Open the generator circuit breaker.
4. Record monitoring signals listed above until the generator terminal voltage and speed is stabilised.

Notes:

Data Requirements:

See *section 4*, and include any additional test details relevant to system operator assessment.

Acceptance Criteria: Generator remains stable pre- and post-test.

5.1.2 Generator Capability (GEN_CAP)

Purpose: This test aims to…

- determine reactive power capability and under- and over-excitation limits (UEL and OEL)
- measure generator auxiliary power consumption
- measure the power/gate curve (hydro generators only)
- confirm compliance with Code Clauses 8.22 and 8.23
- assess generator on-load saturation effects.

Pre-testing:

- Generating unit is synchronised to the grid. Note the active and reactive auxiliary power requirements while connected to the power system.
- Over-Excitation Limiter (GEN_OEL) and Under-Excitation Limiter (GEN_UEL) tests have been completed and enabled.
- All AVR parameter settings have been finalised.
- Agree with the system operator the operating mode and points for testing.

Monitoring Signals: Record the following:

- Generator terminal voltage – Vt (kV)
- Generator terminal active power – Pt (MW)
- Generator terminal reactive power – Qt (Mvar)
- Field voltage – Vfd (V)
- Field current – Ifd (A)
- AVR mode

Additional requirements for hydro generating units only:

- Gate/valve position – POS (%) (refer to power/gate test)
- Water flow
- Head and tail race water levels

(see *section 4* for signal measurement locations)

Methodology:	Notes:
1. Set generator online with terminal voltage as close to 1 p.u. as possible. 2. Adjust the generator active and reactive power output to the first operating point. The measurements here should be made monotonically to avoid magnetic hysterisis skewing the data when determining generator on-load saturation effects. For example, at each P (MW) level, start first at the lowest possible reactive power level (i.e. absorbing as much reactive power from the grid as practical under the given system conditions).	The capability recorded should be inclusive of all restrictions on the real and/or reactive power range such as under and over excitation limits, stability limits etc.
3. Maintain the voltage as close to the initial voltage level using other generation at the same site if available. 4. Stabilise generator under test then hold output for at least 5 minutes. 5. Record all signals before moving to the next point.	Generator terminal voltage should be maintained within +/- 0.5% from the initial voltage level during the test.
6. Gradually increase reactive power in steps in one direction until the highest reactive power level is achieved. 7. When the highest reactive power point is achieved stabilise the generator then hold the output for at least 5 minutes. Repeat steps 2-5 at 0 (or minimum active power output), 25, 50, 75 and 100% (or maximum allowable active power output).	*Data Requirements:* See *section 4*.

Acceptance Criteria: There is stable operation at each operating point.

5.1.3 Open-Circuit Saturation Curve (GEN_OCT)

Purpose: This test aims to…

- determine the generator's saturation curve when open-circuited
- determine the direct-axis unsaturated synchronous reactance.

Pre-testing:

- Generating unit is offline.
- Check generator operation voltage range to ensure the test is carried out within the terminal voltage range stated in the asset capability statement.
- AVR is in manual mode.

Monitoring Signals: Record the following:

- Mechanical Speed – SPt (rpm)
- Generator terminal voltage – Vt (kV)
- Field voltage – Vfd (V)
- Field current – Ifd (A)
- AVR mode

(see *section 4* for signal measurement locations)

Methodology:	Notes:
1. Run the generating unit offline at full speed no load.	If the allowable maximum voltage is less than 1.1 p.u., then extrapolation of the curve to 1.1 p.u. will be required.
2. Reduce the excitation to lower the generator terminal voltage to as low as 70% of the rated value. For some excitation systems, it may not be possible to reduce the field to this low value without significant changes in the controls. In this case it is sufficient to lower the terminal voltage into the linear range of the saturation curve which is typically between 80 to 90% of rated voltage.	Ensure generator speed is kept constant throughout the test.
3. Raise the excitation in 2 to 5% increments to increase the generator terminal voltage.	*Data Requirements:*
4. Wait until terminal voltage stabilises then record the Monitoring Signals.	See *section 4*.
5. Continue to increase the generator excitation until 110% of the rated value or the maximum allowable.	

Acceptance Criteria: An open-circuit saturation curve is produced with clear labels of generator field current at 1 p.u. voltage and 1.2 p.u. terminal voltage.

5.2 Governor Control System

Application: governors that have just been commissioned, had modifications carried out on their governor systems, or are due for routine testing.

Test Objectives: perform these tests to…	**Test Outcomes:** provide sufficient data to…
▪ determine under-/over-frequency response of the generating unit ▪ determine active power control mode if available ▪ determine frequency performance and any trip settings ▪ validate the governor and turbine models.	▪ estimate the gain and time constants in the governor control system ▪ estimate turbine parameter values ▪ validate limits in the governor and turbine systems ▪ validate governor and turbine models ▪ demonstrate ability to support system frequency.

Specific Tests: perform these tests to achieve the required outcomes… (ctrl+click to go to each test)

5.2.1 Governor Offline Response (GEN_ISO)

5.2.2 Valve/Gate Step Response (GEN_VGS)

5.2.3 Frequency Deadband (GEN_DBD)

5.2.4 Governor Droop (GEN_DRO)

5.2.5 Frequency Step Response (GEN_FSP)

5.2.6

Power Step Response (GEN_PSR)

5.2.7 Governor Frequency Response (GEN_GFR)

5.2.8 Under-Frequency Performance (GEN_UFP)

5.2.9 Over-Frequency Performance (GEN_OFP)

5.2.1 Governor Offline Response (GEN_ISO)

Purpose: This test aims to…

- validate governor speed control and model parameter settings.

Pre-testing:

- Generating unit is off-line at full speed no load.
- Generator excitation system is active.
- Governor is set in isochronous mode (i.e. droop response is disabled).
- Valve/gate positioning is enabled.

Monitoring Signals: Record the following:

- Electrical frequency – ft (Hz)
- Mechanical speed – SPt (rpm)
- Governor output command – GOVcom (p.u. or %)

Additional requirements for this test:

- Injected test signal
- Gate/valve controller input and output

(see *section 4* for signal measurement locations)

Methodology:	Notes:
1. Hold the pre-test condition stable. 2. Inject a ± 2 to 5% test signal to the speed reference 3. Record all data points. 4. Allow the generating unit to reach steady-state before injecting a new step. 5. Conduct minimum of three tests with different speed reference setpoint changes.	*Data Requirements:* See *section 4*.

Acceptance Criteria: Controlled speed changes are successful and response is adequately damped.

5.2.2 Valve/Gate Step Response (GEN_VGS)

Purpose: This test aims to…

- verify the relationship between the valve/gate position and unit output
- validate governor control and model parameter settings.

Pre-testing:

- Generating unit is online with valve/gate positioning enabled.

Monitoring Signals: Record the following:

- Electrical frequency – ft (Hz)
- Mechanical speed - SPt (rpm)
- Generator terminal active power – Pt (MW)
- Generator terminal reactive power – Qt (Mvar)
- Governor output command – GOVcom (p.u. or %)

Additional requirements for this test:

- Injected test signal
- Gate/valve controller input and output

(see *section 4* for signal measurement locations)

Methodology:	Notes:
1. Hold the pre-test condition stable. 2. Inject a ± 2 to 5% test signal to the valve/gate position reference controller. 3. Record all data points. 4. Allow the generating unit to reach steady-state before injecting a new step. 5. Conduct minimum of three tests at different valve/gate position to confirm the valve/gate response.	*Data Requirements:* See *section 4*.

Acceptance Criteria: Valve/gate responds to the MW output, and is adequately damped.

5.2.3 Frequency Deadband (GEN_DBD)

Purpose: This test aims to…

- measure and validate governor's frequency deadband.
- transition to new deadband requirement of +/- 0.1 Hz enacted on 1 July 2026.

Pre-testing:

- Generating unit is synchronised to the grid.
- Governor is in frequency control mode.

Monitoring Signals: Record the following:

- Electrical frequency – ft (Hz)
- Mechanical speed – SPt (rpm)
- Generator terminal active power – Pt (MW)
- Generator terminal reactive power – Qt (Mvar)
- Frequency reference – fref (p.u. or Hz)
- Governor output command – GOVcom (p.u. or %)
- Gate/valve position – POS (%)

Additional requirements for this test:

- Governor mode
- Deadband output

(see *section 4* for signal measurement locations)

Methodology:

Repeat tests below for each governor mode providing frequency regulation whilst connected to the power system:

Method 1 – ramp test

1. Set the generating unit to the frequency control mode to be used when synchronised to the power system.
2. Inject a frequency input into the governor to ramp the frequency from one side of the deadband through 50 Hz and to the other side; for example, starting from 49.75 to 50.25 Hz.

Method 2 – step response test

1. Inject frequency step input starting with a value 0.02 Hz below the deadband upper limit.
2. Maintain this signal for a period of 60 seconds, or until the unit response stabilises.
3. Repeat step 1 by an increment of 0.01 Hz until the edge of the deadband is determined.
4. Restore frequency to 50 Hz.
5. Repeat step 1-4 to determine the deadband lower limit.

Notes:

Data Requirements:

See *section 4*.

Acceptance Criteria: Demonstration of:

- deadband function complete with all 'break-points'
- smooth transition into, throughout, and out of the deadband range

5.2.4 Governor Droop (GEN_DRO)

Purpose: This test aims to…

- measure and validate the governor's droop.

Pre-testing:

- Generating unit is synchronised to the grid.
- Governor is in frequency control mode.
- GEN_DBD test (see *section 5.2.3*) has been completed.

Monitoring Signals: Record the following:

- Electrical frequency – ft (Hz)
- Mechanical speed – SPt (rpm)
- Generator terminal voltage – Vt (kV)
- Generator terminal active power – Pt (MW)
- Frequency reference – fref (p.u. or Hz)
- Governor output command – GOVcom (p.u. or %)
- Gate/valve position – POS (%)

Additional requirements for this test:

- Governor mode

(see *section 4* for signal measurement locations)

Methodology:

Repeat the tests below for each governor mode providing frequency regulation whilst connected to the power system:

Method 1 – steady state test

1. Set the generating unit to the frequency control mode to be used when synchronised to the power system.
2. Measure steady state speed, frequency reference, and active power over a wide operating range.
3. Plot speed reference – speed (%) Vs power (MW).

Method 2 – step response test

Perform this test for a minimum of 5 operating points by varying the active power output.

1. Set the generating unit to the frequency control mode.
2. Inject up to 0.5% frequency step input to start.
3. Maintain this signal for 60 seconds or until the unit response stabilises.
4. Restore to 50 Hz.
5. Repeat step 1-4 to demonstrate the droop at each active power operating point.

Notes:

If your generating unit is configured with multiple droop settings, each droop setting must be tested as each active power operating point.

Data Requirements:

See *section 4*.

Acceptance Criteria: Demonstration of the droop response

5.2.5 Frequency Step Response (GEN_FSP)

Purpose: This test aims to…

- demonstrate the correct operation of the governor
- demonstrate governor stability, valve/gate control behaviour, turbine characteristics, and governor droop characteristics
- determine governor and turbine parameters

Pre-testing:

- Refer to methodology below for how to approach test for different operational modes.
- Governor is in frequency control mode.

Monitoring Signals: Record the following:

- Electrical frequency – ft (Hz)
- Mechanical Speed – SPt (rpm)
- Generator terminal active power – Pt (MW)
- Frequency reference – fref (p.u. or Hz)
- Governor output command – GOVcom (p.u. or %)
-
- Gate/valve position – POS (%)

Additional requirements for this test:

- Governor mode

(see *section 4* for signal measurement locations)

Methodology:	Notes:
Offline Test 1. Run the generating unit offline at full speed no load. 2. Inject a positive step of 1% (refer to 3.1 Frequency Step) to the governor speed reference. 3. Record the monitoring signals. 4. Allow adequate settling time to reach new steady-state conditions. 5. Remove the step signal. 6. Wait until the response stabilises. 7. Inject a negative step of 1% (refer to 3.1 Frequency Step) to the governor speed reference. 8. Record monitoring signals. 9. Wait until the response stabilises. Repeat tests below for each governor mode providing frequency regulation whilst connected to the power system. *Online test at 50% (or at practical operating point) rated output* - Repeat step 2-9 of the offline test. *Online Test at 90% rated output* - Repeat step 2-9 of the offline test.	Offline test is used to check the correct operation of the governor control system before proceeding to the online test. The online tests must be carried out with grid frequency within ± 0.1 Hz of the nominal frequency. If grid frequency goes outside these limits, the test should be repeated. *Data Requirements:* See *section 4*.

Acceptance Criteria: Correct, predictable and stable governor response demonstrated.

5.2.6 Power Step Response (GEN_PSR)

Purpose: This test aims to…

- assess the generating unit's response to a change in power set-point.

Pre-testing:

- Generating unit is synchronised to the grid.
- Governor is in active power control mode.

Monitoring Signals: Record the following:

- Electrical frequency – ft (Hz)
- Mechanical speed – SPt (rpm)
- Generator terminal voltage – Vt (kV)
- Generator terminal active power – Pt (MW)
- Active power reference – Pref (p.u.)
- Governor output command – GOVcom (p.u. or %)
- Gate/valve position – POS (%)
- Additional requirements for this test:
- Governor mode

(see *section 4* for signal measurement locations)

Methodology:	Notes:
1. Run the generating unit online at minimum allowable active power output. 2. Record the monitored signals. 3. Step up power reference by 5% (maximum of 10 MW) to change the generating unit active power output. 4. Maintain that power reference for 5 minutes before setting a new set-point. 5. Perform 3 tests at three different MW outputs between 0 and 100% that the machine is likely to operate at. For example, excluding rough running ranges.	*Data Requirements:* See *section 4*.

Acceptance Criteria: Active power output quickly and stably reaches the new power reference.

5.2.7 Governor Frequency Response (GEN_GFR)

Purpose: This test aims to…

- measure a hydro governor's stability margins.

Pre-testing:

- Generating unit is synchronised to the grid.
- Governor is in frequency control mode.
- Governor speed feedback-signal is open looped.
- PSS is turned off.

Monitoring Signals: Record the following:

- Electrical frequency – ft (Hz)
- Mechanical speed – SPt (rpm)
- Generator terminal voltage – Vt (kV)
- Generator terminal active power – Pt (MW)
- Frequency reference – f_{ref} (p.u. or Hz)
- Governor output command – GOVcom (p.u. or %)
- Gate/valve position – POS (%)

Additional requirements for this test:

- Governor mode

(see section 4 for signal measurement locations)

Methodology:

Repeat the tests below for each governor mode providing frequency regulation whilst connected to the power system.

1. Load unit to 80% of rated active power.
2. Replace the governor speed feedback signal with a simulated signal.
3. Inject a sinusoidal frequency from 0.01 Hz to 10 Hz with an appropriate amplitude.
4. Record the response for at least five data points.
5. Step up the frequency of the injected signal, repeating for additional frequencies.
6. Calculate the gain and phase per frequency and plot the results.

Notes:

Test must be carried out with grid frequency at 50 ± 0.1 Hz. If grid frequency goes outside these limits, repeat the tests.

Unit output must follow closely to a sine wave. If the response is not a sine wave, then only the fundamental is to be considered in the analysis.

During stability testing, the wicket gate movement must not be limited in any way.

Data Requirements:

See section 4.

Acceptance Criteria: Demonstration of gain margin greater than 3 dB and phase margin greater than 25 degrees.

5.2.8 Under-Frequency Performance (GEN_UFP)

Purpose: This test aims to…

- verify under-frequency performance.

Pre-testing:

- Generating unit is synchronised to the grid.
- Governor is in frequency control mode.
- Governor tuning has been completed.

Monitoring Signals: Record the following:

- Electrical frequency – ft (Hz)
- Mechanical speed – SPt (rpm)
- Generator terminal voltage – Vt (kV)
- Generator terminal active power – Pt (MW)
- Frequency reference – f_{ref} (p.u. or Hz)
- Governor output command – GOVcom (p.u. or %)
- Gate/valve position – POS (%)

Additional requirements for this test:

- Governor mode

(see *section 4* for signal measurement locations)

Methodology:	Notes:
1. Run the generator at 80-90% of rated active power output. 2. Inject the under-frequency curve (refer to *section 3.2*) for 60 seconds. 3. Record the generating unit response for the duration of the test.	*Data Requirements:* See *section 4*.

Acceptance Criteria: Demonstration:

- of predictable and stable governor response
- that the governor makes the maximum possible injection to maintain frequency within, and to restore frequency to, the normal band.

5.2.9 Over-Frequency Performance (GEN_OFP)

Purpose: This test aims to…

- verify over-frequency performance.

Pre-testing:

- Generating unit is synchronised to the grid.
- Governor is in frequency control mode.
- Governor tuning has been completed.

Monitoring Signals: Record the following:

- Electrical frequency – ft (Hz)
- Mechanical speed – SPt (rpm)
- Generator terminal voltage – Vt (kV)
- Generator terminal active power – Pt (MW)
- Frequency reference – f_{ref} (p.u. or Hz)
- Governor output command – GOVcom (p.u. or %)
- Gate/valve position – POS (%)

Additional requirements for this test:

- Governor mode

(see *section 4* for signal measurement locations)

Methodology:

Repeat tests below for each governor mode providing frequency regulation whilst connected to the power system.

1. Run the generator at 80-90% of rated active power output.
2. Inject the over-frequency curve (refer to *section 3.2*) for 60 seconds.
3. Record the generating unit response for the duration of the injected frequency curve.

Notes:

Data Requirements:

See *section 4*, and include:

- any additional test details relevant to system operator assessment
- a results chart showing the response of the generating unit.

Acceptance Criteria: Demonstration of predictable and stable governor response.

5.3 Generating Unit Transformer Voltage Control

Application: transformers with on-load tap-changers that provide automatic voltage regulation.

Test Objectives: perform these tests to…	**Test Outcomes:** provide sufficient data to…
▪ demonstrate tap-changer capability and operating characteristics.	▪ validate the transformer model ▪ identify and demonstrate the basic controls for on-load tap-changers, particularly: ▪ number of taps ▪ step size ▪ delay (seconds) before first tap moves ▪ delay (seconds) for subsequent tap movements ▪ controlled voltage and the control range.

Specific Tests: refer to individual asset owner's standard equipment test procedures.

5.4 AVR and Excitation System

Application: excitation systems that have just been commissioned, or are due for routine testing, or whose voltage response control systems have undergone modifications that may change the response of the unit.

Test Objectives: perform these tests to…	**Test Outcomes:** provide sufficient data to…
▪ determine the operational characteristics and stability of the automatic voltage regulator and the excitation system ▪ determine the voltage performance, limiters, PSS actions and trip settings ▪ validate the AVR and excitation system's mathematical models	▪ estimate the gain and time constants of the AVR and excitation system ▪ demonstrate the control functions and limits in the AVR and excitation systems including (where implemented): ▪ over-excitation limit ▪ under-excitation limit ▪ power system stabiliser (PSS) ▪ any discontinuous control blocks (i.e. deadband) ▪ validate AVR, excitation system, PSS and limiters models. Limiters can be demonstrated at an intermediate value and then returned to final settings by prior agreement with the system operator. ▪ demonstrate the ability to support system voltage.

Specific Tests: perform these tests to achieve the required outcomes… (ctrl+click to go to each test)
5.4.1 Voltage Step Response and PSS (GEN_VSR)
5.4.2 Over-Excitation Limiter (GEN_OEL)
5.4.3 Under-Excitation Limiter (GEN_UEL)
5.4.4 Volt/Hertz Limiter (GEN_VHT)

References:

- IEEE Std 421.2-1990: Identification Testing and Evaluation of the Dynamic Performance of Excitation Systems

5.4.1 Voltage Step Response and PSS (GEN_VSR)

Purpose: This test aims to…

- demonstrate the correct operation of AVR and excitation system
- demonstrate the stability of the AVR controller
- determine the current compensation settings
- assess the performance of PSS
- validate model parameters of the generator, AVR and the excitation system.

Pre-testing:

- Refer to methodology below for how to approach test for different operational modes.
- AVR must be in voltage control mode.

Monitoring Signals: Record the following:

- Electrical frequency – ft (Hz)
- Mechanical Speed – SPt (rpm)
- Generator terminal voltage – Vt (kV)
- Generator terminal reactive power – Qt (Mvar)
- Voltage reference – V_{ref} (p.u.)
- Field voltage – Vfd (V)
- Field current – I_{fd} (A)

Additional requirements for this test:

- AVR Mode
- Status of PSS, UEL, OEL

(see *section 4* for signal measurement locations)

Methodology:	Notes:
Offline 1. Run the generator offline at 1 p.u. voltage. 2. Ensure PSS is off. 3. Inject a positive voltage step of 5% (refer to Frequency Response 3.3) to the voltage reference. 4. Allow the generating unit to reach steady-state. 5. Remove voltage step and return to pre-test voltage level. 6. Inject a negative voltage step of 5% (refer to Frequency Response 3.3) to the voltage reference . 7. Record the monitoring signals as indicated above. *Online at minimum active power and at rated active power* 1. Ensure PSS is off. 2. Run the generator online at the pre-agreed operating points. 3. Ensure generator terminal voltage and reactive power output at suitable range allows headroom for the step response test. 4. Inject a positive step of 2-5% to the voltage reference. 5. Allow the generating unit to reach steady-state. 6. Remove voltage step and return to pre-test voltage level. 7. Inject a negative voltage step of 2-5% to the voltage reference. 8. Record the signals as indicated above. 9. Repeat the step 2-8 with PSS on.	*Data Requirements:* See *section 4*, and include: - Pre-test status of PSS, OEL and UEL; and - AVR, PSS, OEL and UEL settings.

Acceptance Criteria: Demonstration that generator terminal voltage responded in a correct manner and within 0.5% of the target value, and that voltage response is stable and well damped.

5.4.2 Over-Excitation Limiter (GEN_OEL)

Purpose: This test aims to…

- demonstrate the operation of the OEL controller
- validate the OEL model.

Pre-testing:

- Generating unit is synchronised to the grid.
- AVR is in voltage control mode.
- AVR and PSS tuning has been completed.
- Confirm that PSS, OEL and UEL are enabled.
- Agree with the system operator 3-5 operating points close to the OEL limit.

Monitoring Signals: Record the following:

- Generator terminal voltage – Vt (kV)
- Generator terminal reactive power – Qt (Mvar)
- Voltage reference – Vref (p.u.)
- Field voltage – Vfd (V)
- Field current – I_{fd} (A)
- OEL output command – OELcom (p.u.)
- PSS output command – PSS_{com} (p.u.)

Additional requirements for this test:

- AVR mode
- Status of PSS, UEL, OEL

(see section 4 for signal measurement locations)

Methodology:	Notes:
1. Run the generating unit online to the first agreed operating point. 2. Start recording the monitoring signals above. 3. Inject a +2% (or bigger) voltage step into the voltage reference to move the operating point marginally beyond the OEL limit. 4. Only remove the test signal after steady-state condition has been reached. 5. Repeat the test for a minimum of 3 operating points.	*Data Requirements:* See section 4, and include a comparison between the simulated and actual response.

Acceptance Criteria: Demonstration of:

- predictable and stable OEL response
- reactive power output being limited by the OEL setting
- no significant interaction with V/Hz limiter or PSS
- no activation of any other protections or reactive power limits.

5.4.3 Under-Excitation Limiter (GEN_UEL)

Purpose: This test aims to…

- demonstrate the operation of the UEL controller
- validate the UEL model.

Pre-testing:

- Generating unit is synchronised to the grid.
- AVR is in voltage control mode.
- AVR and PSS tuning has been completed.
- Confirm that PSS, OEL and UEL are enabled.
- Agree with the System Operator 3-5 operating points close to the UEL limit.

Monitoring Signals: Record the following:

- Generator terminal voltage – Vt (kV)
- Generator terminal reactive power – Qt (Mvar)
- Voltage reference – Vref (p.u.)
- Field voltage – Vfd (V)
- Field current – I_{fd} (A)
- UEL output command – UELcom (p.u.)
- PSS output command – PSS_{com} (p.u.)

Additional requirements for this test:

- AVR mode
- Status of PSS, UEL, OEL

(see *section 4* for signal measurement locations)

Methodology:	Notes:
1. Run the generating unit online to the first agreed operating point. 2. Start the recording system. 3. Inject a -2% (or bigger) voltage step into the voltage reference to move the operating point marginally beyond the UEL limit. 4. Repeat the test at a minimum of 3 operating points.	*Data Requirements:* See *section 4*, and include a comparison between the simulated and actual response.

Acceptance Criteria: Demonstration of:

- predictable and stable AVR response
- reactive power being limited by the UEL limit
- no significant interaction with other limiters
- no activation of any other protections or reactive power limits.

5.4.4 Volt/Hertz Limiter (GEN_VHT)

Purpose: This test aims to…

- demonstrate the operation of the volt/hertz controller
- validate the volt/hertz model.

Pre-testing:

- Generating unit is offline at speed no load (SNL).
- AVR is in voltage control mode.
- AVR and PSS tuning has been completed.
- Confirm that volt/hertz limiter is enabled.

Monitoring Signals: Record the following:

- Generator terminal voltage – Vt (kV)
- Generator terminal reactive power – Qt (Mvar)
- Voltage reference – Vref (p.u.)
- Field voltage – Vfd (V)
- Field current – I_{fd} (A)
- UEL output command – UELcom (p.u.)
- PSS output command – PSS_{com} (p.u.)

Additional requirements for this test:

- AVR mode
- Status of PSS, UEL, OEL
- V/Hz limiter status

(see *section 4* for signal measurement locations)

Methodology:	Notes:
1. Run the generating unit offline at SNL and 1 p.u. terminal voltage. 2. Either: a. gradually increase the terminal voltage and/or reduce the generating unit speed until the V/Hz limiter is triggered, or b. inject a step change to demonstrate the performance of the V/Hz limiter.	*Data Requirements:* See *section 4*.

Acceptance Criteria: Demonstration that:

- V/Hz limiter responds correctly
- V/Hz limiter responds stably and is adequately damped
- Other generator limiters or protections are not activated.

6 Inverter-Based Generator Tests

6.1 Voltage Response

Application: generating assets that are being commissioned, or to be tested, or whose voltage response control systems have undergone modifications that may change the asset's response.

Consideration should be given to generation connected to buses where voltage regulation cannot be achieved due to (but not limited to) off-load tap changer transformers. In these cases, ensure appropriate mitigation measures to avoid voltage exceedances are incorporated into the test methodology.

Test Objectives: perform these tests to…	**Test Outcomes:** provide sufficient data to…
▪ determine the operational characteristics and stability of the PPC's voltage controller ▪ determine the reactive power capability over the full active power range ▪ determine the voltage performance, limiters' actions and any trip settings ▪ validate the reactive power/voltage controller model.	▪ demonstrate the stability of the reactive power/voltage control system ▪ demonstrate the reactive power capability ▪ demonstrate the voltage/reactive power control strategy ▪ estimate gains, time constant, limits and other parameters in the voltage/reactive power controller ▪ validate the controller model ▪ demonstrate the ability to support system voltage/reactive power.

Specific Tests: perform these tests to achieve the required outcomes… (ctrl+click to go to each test)
6.1.1 Voltage Step Response (ING_VSR)
6.1.2 Reactive Power Step Response (ING_RST)
6.1.3
Reactive Power Coordination (ING_RCT)
6.1.4
Reactive Power Capability (ING_RPC)
6.1.5 Loss of Plant Controller Communication (ING_LOC)

6.1.1 Voltage Step Response (ING_VSR)

Purpose: This test aims to…

- demonstrate the correct operation of the voltage controller
- demonstrate a stable response of the voltage controller
- validate the plant voltage controller model.

Pre-testing:

- Generation is connected to the grid.
- All dynamic reactive power devices are in-service.
- Voltage controller is operating in voltage control mode.

Monitoring Signals: Record the following:

- PCC Electrical frequency – fpcc (Hz)
- PCC voltage – Vpcc (kV or p.u.)
- PCC active power – Ppcc (MW)
- PCC reactive power – Qpcc (MVAr)
- Shunt capacitor bank reactive power output – Qmsc (Mvar)
- Shunt reactor reactive power output – Qmsr (Mvar)
- STATCOM reactive power output – Qstatcom (Mvar)
- PPC request command to STATcom,
- PPC request command to MSRcom, MSCcom
- Inverter command – INVcom
- Inverter DC voltage – INVdc
- Wind turbine or solar inverter string reactive power output – Qinv (Mvar)
- Wind turbine or solar inverter string voltage – Vinv (kV or p.u.)

Additional requirements for this test:

- Injected signal
- Voltage controller operation mode
- Dynamic reactive support devices reactive power output and status
- Upstream on-load-tap changer position

(see *section 4* for signal measurement locations)

Methodology:	**Notes:**
1. Ensure that the generating asset is running with at least 80-90% of the individual inverter-based units online and able to provide reactive response. Record the number of individual inverter-based units online during the test. 2. Check measurement system is ready. 3. Inject a -2% voltage step command to the controller voltage reference. 4. Wait for 30 seconds or until the response has stabilises. 5. Inject a +2% voltage step command to voltage reference. 6. Wait for 30 seconds or until the response stabilises. 7. Issue another +2% voltage step command to voltage reference. 8. Wait for 30 seconds or until the response stabilises. 9. Issue a –2% voltage step command to voltage reference to return the voltage reference to pre-test value. 10. Wait for 30 seconds or until the response stabilises. 11. Retrieve the signals. 12. If the 2% voltage reference steps push the plant from either direction into its Qmax or Qmin limit, then repeat the test with a small step size. 13. Repeat the test with plant active power level at 50% and 80% rated capacity.	Where dynamic reactive support devices have their own reactive power controllers that operate independantly from the centralised controller, you should carry out testing with and without the controllers in service. If a STATCOM has its own independent automatic voltage control loop that has been coordinated with appropriate reactive droop compensation with the rest of the plant, then perform the ±2% tests in the methodology on the STATCOM's voltage reference input, ensuring the power plant controller is either placed in constant-Q control mode or the wind/PV generation is off-line. If there are mechanically-switched shunt capacitors and/or reactors that are controlled by a relatively slow controller – operating in the order of tens of seconds to minutes time frame – disable these during the tests to avoid interacting with the voltage reference step tests.

	Upstream on-load tap-changers (OLTC) may operate to change taps during voltage reference step tests. These should be monitored, or you should disable the OLTC temporarily during testing. *Data Requirements:* See *section 4*.

Acceptance Criteria: Voltage at PCC responds predictably to the voltage reference command, and in a stable and adequately damped manner.

6.1.2 Reactive Power Step Response (ING_RST)

Purpose: This test aims to…

- demonstrate that the reactive power controller:
- operates correctly,
- responds stably, and
- produces results to allow validation of its model.

Pre-testing:

- Generation is connected to the grid.
- All dynamic reactive power devices are in-service.
- Generation is operating in reactive power control mode.

Monitoring Signals: Record the following:

- PCC Electrical frequency – fpcc (Hz)
- PCC voltage – Vpcc (kV or p.u.)
- PCC active power – Ppcc (MW)
- PCC reactive power – Qpcc (Mvar)
- Shunt Capacitor Bank reactive power output – Qmsc (Mvar)
- Shunt Reactor reactive power output – Qmsr (Mvar)
- STATCOM reactive power output – Qstatcom (Mvar)
- Wind turbine or solar inverter string reactive power output – Qinv (Mvar)
- Wind turbine or solar inverter string voltage – Vinv (kV or p.u.)

Additional requirements for this test:

- Injected signal
- Voltage controller operation mode
- Dynamic reactive support devices reactive power output and status
- The number of individual inverter-based units on-line

(see *section 4* for signal measurement locations)

Methodology:

1. Ensure that the generating asset is running with at least 80-90% of the individual inverter-based units online and able to provide reactive response.
2. Check measurement system is ready.
3. Issue a -5 Mvar (or agreed) step command to Q reference.
4. Wait for 30 seconds or until the response stabilises.
5. Issue a +5 Mvar (or agreed) step command to Q reference.
6. Wait for 30 seconds or until the response stabilises.
7. Issue another +5 Mvar (or agreed) step command to Q reference.
8. Wait for 30 seconds or until the response stabilises.
9. Issue a –5 Mvar (or agreed) step command to Q reference to bring the voltage reference to pre-test value.
10. Wait for 30 seconds or until the response stabilises.
11. Retrieve the signals.
12. Repeat the test with plant active power level at 50% and 80% rated capacity.

Notes:

This test must be repeated for every dynamic reactive power support controller.

If there are mechanically-switched shunt capacitors and/or reactors that are controlled by a relatively slow controller – operating in the order of tens of seconds to minutes time frame – disable these during the tests to avoid interacting with the voltage reference step tests.

Upstream on-load tap-changers (OLTC) may operate to change taps during voltage reference step tests. These should be monitored, or you should disable the OLTC temporarily during testing.

Data Requirements:

See *section 4*.

Acceptance Criteria: Reactive power output at PCC responds predictably to the Q reference command, and in a stable and adequately damped manner.

6.1.3 Reactive Power Coordination (ING_RCT)

Purpose: This test aims to…

- assess the voltage/reactive power coordination strategy
- validate the voltage/reactive power controller model
- assess control actions between the controller and any wind turbine or solar panel level controls.

Pre-testing:

- Generation is connected to the grid.
- All dynamic reactive power devices are in-service.
- Generation is operating in voltage control mode.
- ING_VSR (see *section 6.1.1*) and ING_RST (see *section 6.1.2*) tests have been completed.

Monitoring Signals: Record the following:

- PCC electrical frequency – fpcc (Hz)
- PCC voltage – Vpcc (kV or p.u.)
- PCC active power – Ppcc (MW)
- PCC reactive power – Qpcc (Mvar)
- Shunt capacitor bank reactive power output – Qmsc (Mvar)
- Shunt Reactor reactive power output – Qmsr (Mvar)
- STATCOM reactive power output – Qstatcom (Mvar)
- STATCOM reactive power output – Qstatcom (Mvar)
- PPC request command to STATcom
- PPC request command to MSRcom, MSRcom
- Inverter command – INVcom
- Inverter DC voltage – INVdc
- Wind turbine or solar inverter string reactive power output – Qinv (Mvar)
- Wind turbine or solar inverter string voltage – Vinv (kV or p.u.)

Additional requirements for this test:

- Voltage controller operation mode
- Dynamic reactive support devices reactive power output and status
- The number of individual inverter-based units on-line during the test

(see *section 4* for signal measurement locations)

Methodology:	**Notes:**
1. Ensure that the plant is running with at least 80- 90% of the individual inverter-based units online and able to provide reactive response. Moreover, the plant must be above 50% total nameplate MW output to ensure that swtiching of a shunt device will not lead to excessive voltages on the collector system medium and low voltage circuits. 2. Check measurement system is ready. 3. Switch in a static reactive power device such as a capacitor bank. 4. Record for 60 seconds or until the response stablises. 5. Switch out the static reactive power device. 6. Record for 60 seconds or until the response stablises.	This test is not necessary if the plant does not have any mechancially-switched shunt reactive support devices. Under light load conditions, it may not be advisable to switch in a shunt capacitor due to potential high voltages on the plant's collector system medium and low voltage circuits. If the asset owner and system operator agree upon light load conditions when it is *safe* to switch in and out a shunt capacitor or reactor (if available), then the test should be repeated when the plant is at or near 10% of the nameplate rating. *Data Requirements:* See *section 4*.

Acceptance Criteria: Reactive power output at PCC responds correctly to the disturbance, and in a stable and adequately damped manner.

6.1.4 Reactive Power Capability (ING_RPC)

Purpose: This test aims to…

- determine the reactive power capability at the PCC.

Pre-testing:

- Generation is connected to the grid.
- All dynamic reactive power devices are in-service.
- Generation is operating in reactive power control mode.
- All voltage control system parameter settings have been finalised.
- Agree with the System Operator the operating points for testing.

Monitoring Signals: Record the following:

- PCC voltage – Vpcc (kV or p.u.)
- PCC active power – Ppcc (MW)
- PCC reactive power – Qpcc (Mvar)
- At the end of each string:
- Wind turbine or solar inverter string active power output – Pinv (MW)
- Wind turbine or solar inverter string reactive power output – Qinv (Mvar)
- Wind turbine or solar inverter string voltage – Vinv (kV or p.u.)

(see *section 4* for signal measurement locations)

Methodology:

1. Start testing at Qref = 0 Mvar.
2. Confirm measurement system is ready.
3. Ensure that the generating asset is running at the correct active and reactive power output to the agreed operating point.
4. Wait until the reactive power out has stabilised and hold for at least 5 minutes before proceeding to the next operating point (as agreed with the system operator).
5. Record monitoring signals.
6. Move to the next operating point.
7. Repeat the test with active power level at 25%, 50%, 75%, and 80% rated capacity (or maximum allowable active power output).

Notes:

The test must be carried out at constant active power output of at least 90% rated capacity unless agreed otherwise prior to the test.

Data Requirements:

See *section 4*.

Acceptance Criteria: Reactive power output at PCC responds correctly, and its capability agrees with the submitted ACS.

6.1.5 Loss of Plant Controller Communication (ING_LOC)

Purpose: This test aims to…

- validate the behaviour of the inverter when communication is lost between the electrical controller and plant controller.

Pre-testing:

- Generation is connected to the grid.
- Frequency and voltage contollers are tuned and operating in "as left" or final operating mode.
- ING_VSR (see section 6.1.1) and ING_RST (see section 6.1.2) tests have been completed.

Monitoring Signals: Record the following:

- PCC active power – Ppcc (MW)
- PCC reactive power – Qpcc (Mvar)
- Shunt Capacitor Bank reactive power output – Qmsc (Mvar)
- Shunt Reactor reactive power output – Qmsr (Mvar)
- STATCOM reactive power output – Qstatcom (Mvar)
- Wind turbine or solar inverter string active power output – Pinv (MW)
- Wind turbine or solar inverter string reactive power output – Qinv (Mvar)

Additional requirements for this test:

- Injected signal
- Voltage controller operation mode
- Frequency controller operation mode

(see *section 4* for signal measurement locations)

Methodology:	Notes:
1. Ensure that the generating asset is running with sufficient number of individual inverter-based units for the frequency and voltage controllers to operate. 2. Check measurement system is ready. 3. Initiate loss of communication between the plant controller and electrical controller (inverter). 4. Wait for 30 seconds or until output of the station reduces to 0 MWs.	*Data Requirements:* See *section 4*.

Acceptance Criteria: The output of the inverter(s).

6.2 Active Power and Frequency Control

Application: generating assets being commissioned or to be tested, or whose active power response control systems have undergone modifications that may change the response of the generating asset.

Test Objectives: perform these tests to…	**Test Outcomes:** provide sufficient data to…
▪ determine the operation characteristics and stability of the power/frequency controller ▪ validate active power/frequency control models.	▪ demonstrate the stability of the active power/frequency control system ▪ demonstrate the active power capability ▪ demonstrate the frequency/active power control strategy ▪ estimate gains, time constant, limits and other parameters in the frequency/active power controller ▪ validate the active power/frequency controller model ▪ demonstrate of the ability to support system active power/frequency and to validate models.

Specific Tests: perform these tests to achieve the required outcomes… (ctrl+click to go to each test)
6.2.1 Active Power Step Response (ING_PST)
6.2.2 Frequency Deadband (ING_DBD)
6.2.3 Inverter Droop (ING_DRO)
6.2.4 Frequency Step Response (ING_FSP)
6.2.5
Under-Frequency Response (ING_UFR)
6.2.6 Over-Frequency Response (ING_OFP)
6.2.7 Frequency Controller Priority (ING_FCP)

6.2.1 Active Power Step Response (ING_PST)

Purpose: This test aims to…

- demonstrate that the active power controller operates correctly, responds stably, and produces results to allow validation of its model
- demonstrate the ramp rate when following dispatch instructions.

Pre-testing:

- Generation is connected to the grid.
- All dynamic reactive power devices are in-service.
- Generation is operating in active power control mode.

Monitoring Signals: Record the following:

- PCC Electrical frequency – fpcc (Hz)
- PCC voltage – Vpcc (kV or p.u.)
- PCC active power – Ppcc (MW)
- PCC reactive power – Qpcc (Mvar)
- PPC request command to STATcom,
- PPC request command to MSRcom, MSCcom
- Inverter command – INVcom
- Inverter DC voltage – INVdc
- Wind turbine or solar inverter string active power output – Pinv (MW)
- Wind turbine or solar inverter string reactive power output – Qinv (Mvar)
- Wind turbine or solar inverter string voltage – Vinv (kV or p.u.)

Additional requirements for this test:

- Injected signal
- Controller operation mode

(see *section 4* for signal measurement locations)

Methodology:	Notes:
1. Check generating asset's active power output does not vary more than 5% in the 5 minutes before testing. 2. Start recording. 3. Inject an active power signal of -20% of rated capacity. 4. Record monitored signals for 120 seconds or until the active power stabilises. 5. Inject an active power signal of +20% of rated capacity. 6. Record for 120 seconds or until the active power stabilises.	This test must be carried out at constant active power output of at least 70% rated capacity, unless otherwise agreed with the system operator prior to the test. There will be natural variations in a wind or PV power plant output due to fluctuations in the wind/solar irradiance. To observe the effect of the controls, this test should be done when such variations are, as much as possible, less than the steps being imposed in active power. Check that the primary energy supply is adequate to reach the target active power reference. If necessary, adjust the step size between 10-20% to avoid shutting down large numbers of individual wind turbines or PV inverters within the collector system. Record the actual step size used. *Data Requirements:* See *section 4*.

Acceptance Criteria: Active power output at PCC responds predictably to the P reference command, and in a stable and adequately damped manner.

6.2.2 Frequency Deadband (ING_DBD)

Purpose: This test aims to…

- measure and validate the frequency controller deadband.
- transition to new deadband requirement of +/- 0.1 Hz enacted on 1 July 2026.

Pre-testing:

- Generating unit is synchronised to the grid.
- Generation is operating in frequency control mode.

Monitoring Signals: Record the following:

- PCC Electrical frequency – fpcc (Hz)
- PCC voltage – Vpcc (kV or p.u.)
- PCC active power – Ppcc (MW)
- Inverter command – INVcom
- Inverter DC voltage – INVdc
- Wind turbine or solar inverter string active power output – Pinv (MW)

Additional requirements for this test:

- Injected signal
- Controller operation mode

(see *section 4* for signal measurement locations)

Methodology:	Notes:
Method 1 – ramp test 1. Set the generating unit to the frequency control mode to be used when synchronised to the power system. 2. Inject a frequency input into the PPC to ramp the frequency from one side of the deadband through 50 Hz and to the other side; for example, starting from 49.75 to 50.25 Hz. *Method 2 – step response test* 3. Inject frequency step input starting with a value 0.02Hz below the deadband upper limit. 4. Maintain this signal for a period of 60 seconds, or until the unit response stabilises. 5. Repeat step 1 by an increment of 0.01 Hz until the edge of the deadband is determined. 6. Restore frequency to 50 Hz. 7. Repeat the same to determine the deadband lower limit.	*Data Requirements:* See *section 4*.

Acceptance Criteria: Demonstration of:

- deadband function complete with all 'break-points'
- smooth transition into, throughout, and out of the deadband range

6.2.3 Inverter Droop (ING_DRO)

Purpose: This test aims to…

- measure and validate the frequency control system droop.

Pre-testing:

- Generation is connected to the grid.
- Frequency control mode is selected.
- ING_DBD test (see *section 6.2.2*) has been completed.

Monitoring Signals: Record the following:

- PCC Electrical frequency – fpcc (Hz)
- PCC voltage – Vpcc (kV or p.u.)
- PCC active power – Ppcc (MW)
- Inverter command – INVcom
- Inverter DC voltage – INVdc
- Wind turbine or solar inverter string active power output – Pinv (MW)

Additional requirements for this test:

- Injected signal
- Controller operation mode

(see *section 4* for signal measurement locations)

Methodology:	Notes:
Perform this test for a minimum of three operating points by varying the active power output. 1. Inject a positive 0.5% frequency step input to start. 2. Maintain this signal for 60 seconds or until the unit response stabilises. 3. Restore to 50 Hz. 4. Inject a negative 0.5% frequency step input to start. 5. Maintain this signal for 60 seconds or until the unit response stabilises. 6. Restore to 50 Hz. 7. Repeat steps 1-7 to demonstrate the droop at each active power operating point. 8. If generating unit is configured with ,multiple droop settings, each droop setting must be tested as each active power operating point.	This test could run concurrently with ING_FSP if the same input power levels are chosen. *Data Requirements:* See *section 4*.

Acceptance Criteria: Demonstration of the droop response.

6.2.4 Frequency Step Response (ING_FSP)

Purpose: This test aims to…

- demonstrate correct operation of the PPC's frequency controller
- demonstrate that the PPC responds in a stable manner to frequency step commands.

Pre-testing:

- Generation is connected to the grid.
- All dynamic reactive power devices are in-service.
- Frequency control mode is selected.
- ING_PST test (see *section 6.2.1*) has been completed.

Monitoring Signals: Record the following:

- PCC Electrical frequency – fpcc (Hz)
- PCC voltage – Vpcc (kV or p.u.)
- PCC active power – Ppcc (MW)
- PCC reactive power – Qpcc (MVAr)
- Inverter command – INVcom
- Inverter DC voltage – INVdc
- Wind turbine or solar inverter string active power output – Pinv (MW)
- Wind turbine or solar inverter string reactive power output – Qinv (Mvar)
- Wind turbine or solar inverter string voltage – Vinv (kV or p.u.)

Additional requirements for this test:

- Injected signal
- Controller operation mode

(see *section 4* for signal measurement locations)

Methodology:	Notes:
Perform this test for a minimum of 3 operating points by varying the active power output. 1. Set the generating unit to the frequency control mode. 2. Inject a positive 0.3-0.6% frequency step input to start. 3. Maintain this signal for 60 seconds or until the unit response stabilises. 4. Inject a positive 0.6-1% frequency step input to start. 5. Maintain this signal for 60 seconds or until the unit response stabilises. 6. Remove the step signal. 7. Wait until the response stabilises. 8. Inject a negative 0.3-0.6% frequency step input to start. 9. Maintain this signal for 60 seconds or until the unit response stabilises. 10. Inject a negative 0.6-1% frequency step input to start. 11. Maintain this signal for 60 seconds or until the unit response stabilises. 12. Remove the step signal. 13. Repeat step 1-12 at each active power operating point as agreed.	This test could run concurrently with ING_DRO if the same input power levels are chosen. *Data Requirements:* See *section 4*.

Acceptance Criteria: Demonstration that frequency control response is droop-based, stable, and predictable.

6.2.5 Under-Frequency Response (ING_UFR)

Purpose: This test aims to…

- demonstrate the under-frequency response of the generating asset.

Pre-testing:

- Generation is connected to the grid.
- All dynamic reactive power devices are in-service.
- Frequency control mode is selected.
- ING_PST test (see *section 6.2.1*) has been completed.

Monitoring Signals: Record the following:

- PCC Electrical frequency – fpcc (Hz)
- PCC voltage – Vpcc (kV or p.u.)
- PCC active power – Ppcc (MW)
- PCC reactive power – Qpcc (MVAr)
- Inverter command – INVcom
- Inverter DC voltage – INVdc
- Wind turbine or solar inverter string active power output – Pinv (MW)
- Wind turbine or solar inverter string reactive power output – Qinv (Mvar)
- Wind turbine or solar inverter string voltage – Vinv (kV or p.u.)

Additional requirements for this test:

- Injected signal
- Controller operation mode

(see *section 4* for signal measurement locations)

Methodology:	Notes:
1. Run the generating unit at 30% of rated active power output. 2. Inject the standard under-frequency curve. 3. Record for 120 seconds or until output is stable. 4. Repeat the test at 50% and 80% rated capacity and agreed hold points.	In the case intermittent generation, this test should be carried out at an operating point where there is enough generation to demonstrate the expected response. Care should be taken to avoid shutdown of a significant number of individual inverters. This test will also confirm the deadband settings. *Data Requirements:* See *section 4*.

Acceptance Criteria: Active power output at PCC responds predictably to the frequency reference, and in a stable and adequately damped manner.

6.2.6 Over-Frequency Response (ING_OFP)

Purpose: This test aims to…

- demonstrate the over-frequency response of the generating asset.

Pre-testing:

- Generation is connected to the grid.
- All dynamic reactive power devices are in-service.
- Frequency control mode is selected.
- ING_PST test (see *section 6.2.1*) has been completed.

Monitoring Signals: Record the following:

- PCC Electrical frequency – fpcc (Hz)
- PCC voltage – Vpcc (kV or p.u.)
- PCC active power – Ppcc (MW)
- PCC reactive power – Qpcc (MVAr)
- Inverter command – INVcom
- Inverter DC voltage – INVdc
- Wind turbine or solar inverter string active power output – Pinv (MW)
- Wind turbine or solar inverter string reactive power output – Qinv (Mvar)
- Wind turbine or solar inverter string voltage – Vinv (kV or p.u.)

Additional requirements for this test:

- Injected signal
- Controller operation mode

(see *section 4* for signal measurement locations)

Methodology:

1. Run at the highest available output.
2. Inject the standard over-frequency curve.
3. Record for 120 seconds or until output is stable.
4. Repeat the test at 30% and 70% rated capacity and at agreed hold points.

Notes:

In the case of intermittent generation, this test should be carried out at an operating point where there is enough generation to demonstrate the expected response. Care should be taken to avoid shutdown of a significant number of individual inverters.

This test will also confirm the deadband settings.

Data Requirements:

See *section 4*.

Acceptance Criteria: Active power output at PCC responds predictably to the frequency reference, and in a stable and adequately damped manner.

6.2.7 Frequency Controller Priority (ING_FCP)

Purpose: This test aims to…

- demonstrate that the generating plant frequency control system is correctly tuned and that frequency control action takes precedence over dispatch commands during system frequency disturbances.

Pre-testing:

- Generation is connected to the grid.
- All dynamic reactive power devices are in-service.
- Frequency control mode is selected.
- ING_FSP test (see section 6.2.4) has been completed.

Monitoring Signals: Record the following:

- PCC Electrical frequency – fpcc (Hz)
- PCC voltage – Vpcc (kV or p.u.)
- PCC active power – Ppcc (MW)
- PCC reactive power – Qpcc (MVAr)
- Inverter command – INVcom
- Inverter DC voltage – INVdc
- Wind turbine or solar inverter string active power output – Pinv (MW)
- Wind turbine or solar inverter string reactive power output – Qinv (Mvar)
- Wind turbine or solar inverter string voltage – Vinv (kV or p.u.)

Additional requirements for this test:

- Controller operation mode
- Injected signal
- Active Power setpoint - MW

(see *section 4* for signal measurement locations)

Methodology:

Part A : **Under frequency step during set point change**

- Run the generating station at 20% of rated active power output.
- Change the active power setpoint of the generator to 100% using the dispatch ramp rate.
- During the dispatch ramp, at around 40% active power output apply an under-frequency step of 0.5 Hz.
- Record the monitoring signals until the generating station has reached steady state conditions (active power setpoint).
- Repeat the test while generating station is ramping down from 100% to 20% active power set point.

Part B : **Over frequency step during set point change**

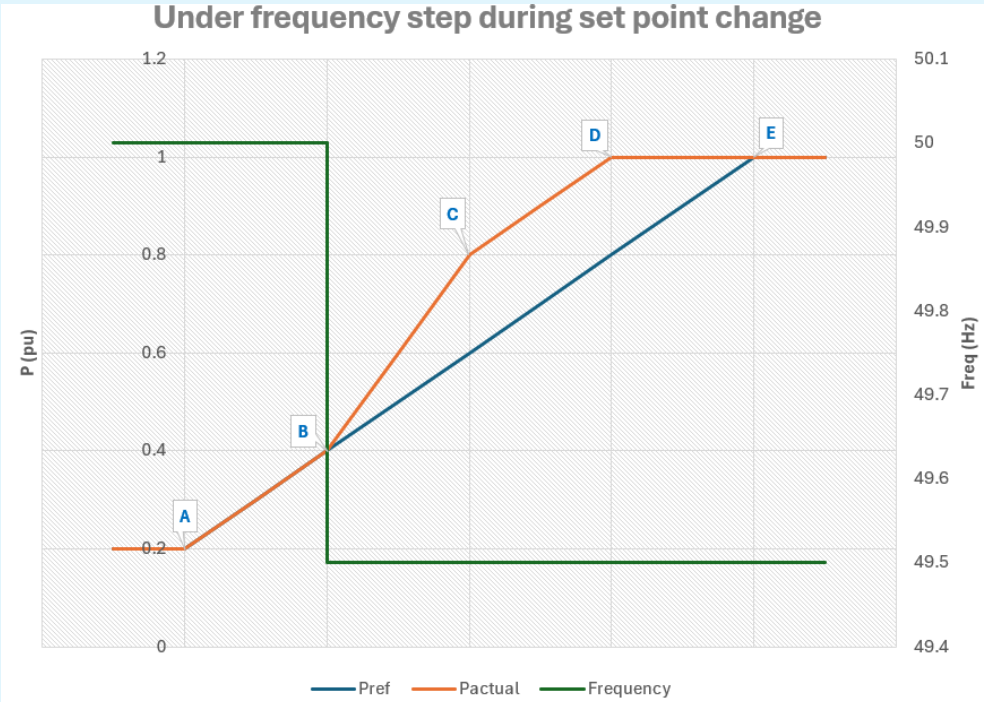
- Run the generating station at 100% of rated active power output.
- Change the active power setpoint of the generator to 20% using the dispatch ramp rate.
- During the dispatch, at around 80% active power output ramp apply an over-frequency step of 0.5 Hz.
- Record the monitoring signals until the generating station has reached steady state conditions (active power setpoint).
- Repeat the test while generating station is ramping up from 20% to 100% active power set point.

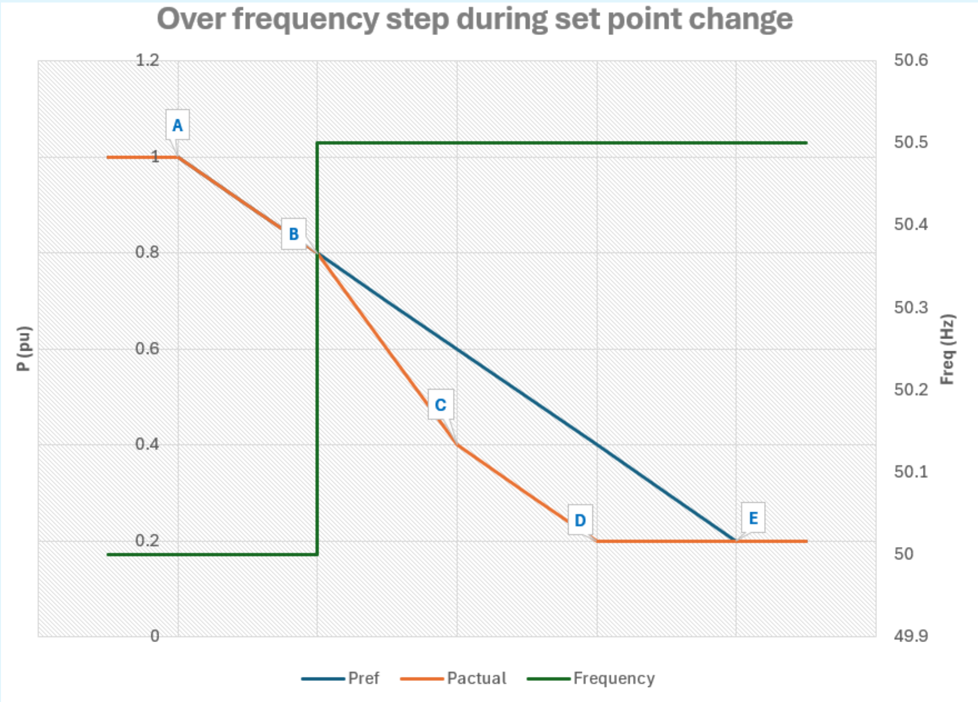
Notes:

Data Requirements:

See *section 4*.

Acceptance Criteria: Demonstration of the response rate requirements as stipulated below:





Pref: Active power reference from PPC to inverter **Pactual:** Measured inverter active power output

Expected response:

Pref trajectory

- A–B–E: Active power setpoint follows the dispatch ramp rate

Pactual trajectory

- A–B: Active power follows dispatch ramp rate under normal operation
- B–C: Active power follows frequency response ramp rate and the settling point (point C) shall be as per combined effect of:
  - ongoing dispatch ramp, and
  - droop-based frequency response
- C–D: Once the droop response is fully delivered, active power continues at dispatch ramp rate.

Appendix A. Sample Test Report Structure

Asset owners should submit test reports electronically in Adobe Portable Document format (PDF) or Word Document format (DOCX).

We suggest you organise the information in the sections below, based on the specific testing you have undergone:

Section	Contents
Document Control	▪ A cover page ▪ A table of contents ▪ Version and revision history
Key Asset Information	▪ Electrical details: ▪ rated MW and MVA, and ▪ rated terminal voltage ▪ Plant overall single-line diagram showing electrical connectivity between the generator, transformer, substation layout, switch-gear, grid interface circuit breaker, and/or electrical equipment interfacing the asset with the grid, unit and station auxiliary loads, excitation source ▪ Any other asset information relevant to the specific testing performed
Test Specifications	▪ Test ID ▪ Test objectives and methodology (only if different from what has been included in the descriptions in earlier parts of GL-EA-010) ▪ Test signal descriptions ▪ Test results organised and clearly labelled ▪ Any other information that demonstrates the performance of the equipment you have tested
Validation of Test Results	▪ Discussion of assumptions, deviations, and/or discrepancies ▪ Analysis, observations and recommendations