# R2 TESTING GUIDELINE

PREPARED BY: Network Models – Systems Capability
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# Version Release History

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| 0.1 | June 2013 | BB | MS | |

This document has been created by the Network Models – Systems Capability and will be reviewed from time to time.

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## Important Notice

AEMO has prepared this Guideline to provide information to assist generators in the preparation of testing programs for 'R2' registered data to be provided to AEMO under Chapter 5 of the National Electricity Rules.

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# Contents

# Glossary

| | |
|---|---|
| AEMO | Australian energy market operator |
| BOP | Balance of plant |
| COMTRADE | Common format for Transient Data Exchange for power systems |
| CSV | Comma separated values |
| DFIG | Doubly fed induction generator |
| FRT | Fault ride through |
| GPS | Generator performance standard |
| HVDC | High voltage direct current |
| NSP | Network service provider |
| OLTC | On load tap changer |
| PCC | Point of common coupling |
| PV | Photovoltaic |
| STATCOM | Static compensator |

# 1 Purpose of Guideline

This R2[1] Testing Guideline has been developed to provide guidance for preparing testing programs intended to derive R2 models and data.

Model validation processes for wind and other variable generation technologies is a relatively new topic which merits clarification. This Guideline does not detail actual tests required for R2 validation, but outlines the types of tests that may be conducted. It is the generator's responsibility to ensure that their testing program is adequate to derive all the data appropriate for the generating, control and protection systems used in their installation.

Model validation for more conventional forms of generation such as steam, gas or hydro turbines has been performed for many years; the basis of models, parameter derivation and testing methodologies are all well understood. A range of relevant technical literature describes commonly used approaches adopted in industry; references are listed in Appendix A.

This document does not replace existing practices for R2 testing of synchronous machines, and all common practices will remain valid.

# 2 Legal and regulatory framework

The National Electricity Rules (the Rules) in clause S5.2.4(b) require that generators provide network service providers and AEMO with a range of data relating to their generating units, control systems and protection systems.

The Rules require AEMO to maintain a *Generating System Design Data Sheet*, a *Generating System Setting Data Sheet* (Data Sheets) and *Generating System Model Guidelines* (Model Guidelines). These documents provide detail about the information and data parameters required for each type of generation technology.

The data required is categorised by the installation development stage, denoted as standard planning data (S), detailed planning data (D), and registered data (R1 and R2). The data is used for modelling generation systems (including generating plant, control and protection systems) in network analysis software that is used to assess and plan the security and performance of the electricity system.

Clause S5.5.2 defines R1 and R2 data as follows:

**Registered data**

Registered data consists of data validated and agreed between the *Network Service Provider* and the *Registered Participant*, such data being:

(a) prior to actual *connection* and provision of access, data derived from manufacturers' data, detailed design calculations, works or site tests etc. (R1); and

(b) after connection, data derived from on-system testing (R2).

[1] R2 refers to data derived from on-system testing after system connection.

AEMO's Generating System Model Guidelines[2] require that:

Each model must be developed and tested to the extent reasonably necessary to establish that it will meet the accuracy requirements described for the relevant model type. To achieve this:

- During the generating system design and development stages, it is expected that the model will be rigorously derived from design information.
- Parameters and models that are designated as R2 in the Data Sheets must be derived from on-site tests.

Where parameters are not designated as R2 in the Data Sheets, the value of these parameters (in aggregate) must be validated through the overall performance validation of the system, device, unit or controller to which they pertain.

# 3 Relationship between commissioning and R2 testing

Plant testing is conducted for several reasons. AEMO's interests in generator testing include:

1. Commissioning tests: to establish that the installed plant performs as expected, and complies with the performance requirements set out in the Generator Performance Standard (GPS). Simulation models may be used for demonstration of some GPS clauses which cannot be practically demonstrated on-site. It is therefore expected that the simulation models are reasonably accurate while further fine tuning can be done at the R2 stage.
2. R2 (model verification) tests: to validate model data and ensure that the plant models are representative of the installed system. Accurate modelling is fundamental to ensuring that future power system studies adequately demonstrate network behaviour.

Despite the different objectives of the commissioning and R2 tests, it may be opportune to incorporate some R2 tests into the commissioning test program. Conducting the tests at the same time may enable generators to achieve the following:

- Gain advantage from potentially easier access to individual components within the generating system during the commissioning phases (e.g., single turbine in service enables component performance to be measured).
- Optimise the amount of time that is spent on testing.
- Benefit from the availability of skilled staff on-site.

For these reasons it is recommended that proponents consider their R2 testing needs and even prepare an R2 testing plan when preparing commissioning programs.

1. AEMO. Available at: www.aemo.com.au/registration/0110-0038.pdf. Viewed on 20/06/2013.

A complete re-assessment of the GPS and repeating the commissioning tests may be necessary when derived R2 models and data show materially different performance compared to the R1 data.

# 4 Related policies and procedures

This document is related to other policies, procedures and guidelines produced by AEMO and should be read in conjunction with these, as follows:

- Generating Systems Model Guidelines.
- Commissioning Requirements for Generating Systems.
- Data and model requirements for generating systems less than 30 MW.

# 5 Principles of R2 testing

In general, R2 testing entails deriving and validating generation system modelling data on-site, during and following commissioning. It includes a range of tests, measurements and simulations to demonstrate that the performance and behaviour of the installed generating system matches the modelled system.

R2 testing requires testing of plant and systems across a range of levels – from individual plant items up to integrated, farm-level systems. To demonstrate the validity of a model across the range of potential study conditions, it is expected that the behaviour of the actual generating system and its model will be assessed for both steady state and dynamic conditions.

## 5.1 Model and data requirements

The modelling requirements for generating systems are set out in AEMO's Generating System Model Guidelines. The data required in the Data Sheets relates to modelling of the generating system in power system simulation software. All power system studies, present and future, steady state and dynamic, rely on accurate and consistent models for plant and equipment connected to the system. It is important that both the physical properties and internal settings of each component are accurately modelled, together with any control or protection systems. The model must represent the system across the expected range of network, environmental (wind speed) and generating conditions.

## 5.2 Measurement requirements

### 5.2.1 General

All relevant quantities necessary to confirm the R2 test results by simulation must be included. For example, for wind farms this includes measured wind speed; turbine terminal measurements (MW, MVAr, voltage); any relevant internal turbine or converter measurements; and other relevant test quantities (point of connection voltage, status of plant items such as reactive support plant, transformer tap position). Measurement equipment used should be independent of the plant under measurement.

The measurement data should:

- Be obtained digitally and provided in a readable format such as COMTRADE, CSV, Excel, etc to allow analysis.
- Be time synchronised, or at least using the same sampling time for all measurements.
- Have a measurement sampling rate and accuracy of measuring devices sufficient for deriving model parameters.

### 5.2.2 Additional requirements for variable generation technologies

For variable generation technologies such as wind and solar farms, demonstration of some aspects of performance standards, or derivation of some model parameters may not be practicable. Providing high-speed monitoring systems will be helpful in those circumstances.

For wind and solar farm connections, high-speed meters with a resolution corresponding to the numerical integration time step[3] used for the simulation model of the plant are needed at the following locations:

- Two wind turbine/solar panel generators, namely:
  - Any convenient wind turbine/solar panel that is electrically close to the collection grid.
  - The furthest wind turbine/solar panel from the collection grid.
- Medium voltage side of each network transformer.
- Point of common coupling.
- Central park level controller (if applicable).
- One meter for each reactive plant feeder.
- Additionally:
  - Where applicable and practicable from the communication bandwidth standpoint measurement devices should be installed at the following points inside the wind turbine nacelle:
    - Generating unit LV terminals (for all wind turbine and solar panel technologies).
    - Generator rotor terminals (for type 2 and 3 wind turbines only).[4]
    - Grid-side converter (for type 3 wind turbines only).
  - Subject to agreement by AEMO and relevant NSP the following measurement points may be necessary:
    - One meter for each particular type of the dynamic reactive support, i.e., STATCOM, synchronous condenser, etc.

[3] 1-2 ms in most applications.
[4] AEMO Wind Turbine Plant Capabilities Report. Available at: http://www.aemo.com.au/Electricity/Planning/Related-Information/2013-Wind-Integration-Studies. Viewed on 20/06/2013.

- At a specific wind turbine/solar panel generator feeder.

## 5.3 Timeframe for submission of R2 models and data

Generators are required to provide AEMO with information that updates the models and parameters provided under S5.2.4 of the Rules within three months of commissioning tests.

In general, it is expected that the R2 data validation activities are completed within three months of the commissioning test completion. However, AEMO acknowledges that not all components of R2 data are practical to test on-site. For parameters which cannot be derived on-site at the time of R2 testing, a combination of rigorous off-site and factory/type test results, and installation of the long-term monitoring equipment is necessary. This is explained in more details in Section x.

## 5.4 Fuel availability

AEMO recognises that testing will be affected by fuel variability, in particular for variable generation technologies such as wind and solar generation. The Generators should attempt to conduct tests under conditions where variability does not unduly impact the results.

For successful test completion, AEMO recommends that a number of online tests are carried out at an output power level of no less than 90% of the generating system's nominal output power. The required tests can vary depending on the project, and must be agreed by both AEMO and relevant NSPs.

For non-intermittent full sources, the tests need to be carried out at a higher output power level which needs to be agreed with AEMO and the relevant NSP during the commissioning.

## 5.5 Extent of coverage

The intention of R2 testing is to validate the plant models against the observed behaviour of the installed plant and systems. For this reason, it is important that R2 tests are performed on-site.

R2 testing needs to be undertaken at both component level and system level, to ensure that the integrated behaviour of various plant and control systems is understood and captured.

When derivation of model parameters would require sub-component level testing, such tests should be included in the test plan. As an example this applies to derivating model parameters for different constituting components of a wind turbine such as generator, pitch controller, etc. As discussed in Section 7 such sub-component level testing can be achieved through factory or type testing.

Testing across a broad range of conditions and near limits is required, particularly if there are non-linearities within the models or set points which affect system operation.

The R2 test plan should be devised to exercise each control system and plant characteristic within both the model and installed plant. R2 testing must capture the behaviour of all plant installed at site that forms the generating system. This includes the behaviour of dynamic reactive support plant such as STATCOMs and the way in which these devices interact with other power factor or voltage control systems installed at the site.

Accurate modelling of all plant connected to the power system ensures that the power system operator/s can understand and predict the operation of plant and interactions between various plant across the full range of system operating scenarios.

This enables operators to maintain power system security in real time, and allows planners to effectively guide the network development in the future. For this reason, if a generator model indicates capability well beyond its registered performance standards, the actual generator performance should be validated.

# 6 R2 model validation Process

## 6.1 Validation methodology

Where testing is conducted, extensive measurements of the generating unit behaviour as well as network and environmental conditions (e.g., wind speed) should be recorded. This data may then be used in simulations of the tested event to demonstrate alignment between the actual and simulated behaviour of the plant for those conditions.

For R2 tests, simulations should be performed for each test using the system conditions prevailing at the time measurements were taken. The simulations should be completed using the software simulation product nominated by AEMO. Suitable software packages are listed on AEMO's website at:

http://www.aemo.com.au/Electricity/Registration/Application-Forms/Generator/Generating-System-Data-and-Model-Guidelines.

Simulation results should be compared against the measured outcome to ensure that suitable accuracy is achieved. Where discrepancies between measured and simulated results are identified, the reason for the discrepancy should be identified, tested and validated in the simulation environment. It is not sufficient to suggest a theory for the discrepancy without demonstrating the validity of that theory.

## 6.2 Reporting requirements

The proposed test plan for on-site testing should include the following information:

- Test description
    - Objective of the test.
    - What is involved in the test?
    - What model or sections of models are being assessed?

- System requirements
    - Are there any special requirements to perform test, i.e., voltage levels, power flows?
    - Is measurement equipment from AEMO or the NSP required for the test?
    - Minimum generation levels required to achieve the test objectives.

- Measured quantities
    - What is being measured (what channels of data are critical to the test)?
    - Where is the measurement being taken?

   - What measuring device is capturing the data?
   - What is the format of the recorded data?
   - File naming convention.

- Prerequisites
   - What other tests need to be completed and signed off prior to starting this test (if any)?
   - Are there any special test setups, i.e., application of temporary settings?

- Pre-test system studies
   - Investigation of the anticipated impacts on connection point voltage and frequency during the test by performing pre-test simulation studies.
   - Identification of potential risks if the test was not to go as planned (risk of tripping?).

- Success criteria
   - What outcome is expected to allow the test to be completed and the next test commenced?

### 6.3 Presentation of R2 data

The primary outcome AEMO requires from the R2 testing process is a completed and validated set of model and data for the installed generation system, including all control, protection and auxiliary systems.

The validated model and data should adequately demonstrate the behaviour of individual plant items as well as the performance of the installed generating system as an integrated system. It should and demonstrate compliance with the agreed generator performance standards for the generating system.

AEMO requires that the parameters derived from R2 testing are presented in a format that enables efficient cross-checking between the data, the data requirements and the means by which the data was validated. This can be achieved by including a completed set of data sheets, with a reference in the comment field for each data item to the appropriate section of an R2 test report with each R2 testing report.

AEMO suggests that proponents requesting guidance from AEMO and NSPs in relation to a proposed R2 testing program also include a set of data sheets with a reference in each data field to the test proposed to validate that piece of data.

# 7 Typical approaches for R2 model validation

## 7.1 Factory tests

### 7.1.1 Objectives

Components of R2 data that may be impractical to test on site include generator electrical and mechanical parameters for generators that connect to the network via a converter interface, where there is limited or no access to measurement points.

To derive such parameters, results obtained from factory tests may be presented for consideration. Additionally, factory tests can be used to demonstrate correct operation of the turbine protective relays such as voltage, frequency, and speed relays.

### 7.1.2 Extent of coverage

Typically, factory tests would be acceptable only for individual items of plant, e.g., the mechanical drive train of a wind turbine.

Factory tests would normally only be acceptable with regard to physical plant properties. Control systems are very susceptible to hardware, version and setting changes and should always be tested on-site.

Factory tests alone are not sufficient for R2 testing. A proposal for factory testing must be supported by the generator installing suitable dynamic event recording equipment and establishing a monitoring plan to enable model validation to take place following the occurrence of an actual event at site.

### 7.1.3 Acceptance criteria

Generators wishing to present factory test results for consideration must submit a variation request to AEMO outlining the reason why on-site testing is not considered possible. The variation request should include detailed information regarding the methodology and equipment used for the factory test, together with any standards that apply to the test conducted. To be acceptable it must be demonstrated that factory tests were conducted on the actual plant installed on-site (e.g., a test certificate showing serial number/s).

## 7.2 Type tests

### 7.2.1 Objectives

For multi-unit generating systems comprising tens of identical units, on-site testing of each and every unit can be impractical. For these generating systems, proof of type test may be acceptable. This will serve to demonstrate that various generating units installed on-site are identical, and therefore conducting R2 test on one unit will be appropriate for deriving R2 model and data for all other identical units.

### 7.2.2 Extent of coverage

Type tests would only be acceptable for an integrated assembly of individual items. Similar to the factory tests, type tests can only apply to physical plant properties and not the control systems.

### 7.2.3 Acceptance criteria

Generators wishing to present type test results for consideration must submit a variation request to AEMO outlining the reason why on-site testing is not considered possible. The variation request should include detailed information regarding the methodology, together with any standards that apply to the test conducted. To be acceptable, it must be demonstrated that type tests were conducted on the same combination of components as installed on-site (e.g., same turbine designation/description, configuration, capacity, blade diameter).

## 7.3 Off-site testing

### 7.3.1 Objectives

AEMO acknowledges that not all components of R2 data are practical to test on-site (e.g., the control systems for fault ride-through (FRT) performance might only be exercised through application of a fault which would be difficult to achieve on-site).

### 7.3.2 Extent of coverage

Aside from demonstrating FRT performance, off-site tests could also be used to achieve model validation and model parameter derivation of other control systems (i.e., systems other than those strictly applicable to the FRT control systems), where the simulated model of the control system cannot be validated on-site due to the required size of the disturbance and its impact on system security.

### 7.3.3 Acceptance criteria

The data sheets[5] set out the acceptance criteria for provision of off-site test results associated with FRT performance of wind farms as follows:

The R2 data provision is not necessary, provided that R1 data is available that is derived from an off-site test that is the application of a fault, where:

- The fault applied is a 2 phase-ground or 3-phase fault equivalent to what might be experienced by the generating unit installed on-site.
- The post-fault fault level is reasonably representative of, or lower than, the post-fault fault level that the generating unit would experience on-site (assuming all generating units of the generating system operated the same way).
- The generating unit tested is identical to the ones being installed on-site.
- The generating unit tested has identical control system settings to the one being installed on-site, or the difference in settings can be translated into appropriate model parameter values applicable to the generating unit being installed on site.
- The test and associated documentation clearly demonstrate the features and settings of the fault-ride through control system.

Generators wishing to present off-site test results for consideration must submit a variation request to AEMO outlining the reason why on-site testing is not considered possible. The variation request should also include detailed information regarding the methodology and equipment used for the off-site test, together with any standards that apply to the test conducted. To be acceptable it must be demonstrated that off-site tests were conducted as follows:

- Using the same type of plant installed at site.
- For the same or more onerous system conditions than expected at site.
- For all relevant control systems.

[5] www.aemo.com.au/registration/0110-0039.pdf.

- Across a range of power output and wind-speed conditions (e.g., <50%, 50–75% and full load conditions).

For acceptable validation, it is essential that the tested plant as closely as possible represents the plant installed at the site and is tested for conditions likely to occur at the installed location and for the installed configuration.

The same plant installed at site should be used for the tests. As an example, for wind turbines this would include items such as the turbine designation/description, configuration, capacity, blade diameter, control systems, FRT systems, reactive power support systems, and any converter systems.

Off-site tests alone are not sufficient for R2 testing, and a proposal for off-site testing must be supported by the generator installing suitable dynamic event recording equipment and establishing a long-term monitoring program, to enable further model validation following the occurrence of an actual event at site.

In presenting results of off-site testing in the context of model validation, a comparison should be made demonstrating the measured performance of the plant and control systems, the expected performance of the model representing the actual tested plant, and the model representing the actual installed plant (including settings applied) at the site.

## 7.4 On-site testing

### 7.4.1 Objectives

The intent of R2 testing is to validate models of the generating unit, balance of plant components, and generating system through on-site testing whenever possible. The general principle is that if a test can be carried out on-site, then it should.

### 7.4.2 Extent of coverage

In general on-site testing can be used for validation of the models with respect to:

- Active power/frequency control of the generating unit/generating system.
- Reactive power/voltage control of the generating unit/generating system.
- Reactive power capability of the generating unit/generating system.
- FRT tests may be performed on-site on the entire generating system. This, however, requires a thorough review of the protection settings to avoid power disruption in the system.

As an example, on-site tests typically carried out on wind and solar farms include:

- Wind turbine/solar panel and/or wind/solar farm reactive power capability.[6] Farm level tests will be performed with all dynamic reactive support equipment in service.

[6] Demonstration of the farm's reactive power capability may not be feasible for the full voltage range. This is because in some circumstances the network voltage limits may be reached before the reactive power limits are demonstrated. Additionally, increasing the voltage beyond a certain limit may have detrimental impact on the voltage security. For such conditions, accurate simulation models taking account of the power losses can be used to demonstrate the reactive power capability for those extreme operating points.

- Active and reactive power control loops of the generating unit.
- Reactive power control loop of any dynamic reactive support equipment.
- Coordinated control of voltage control scheme.
- Farm-level control systems that can adjust any of the active and/or reactive power output of farm – e.g., power-factor and slow-acting secondary voltage control systems. For wind farms where the central park level controller is operated as a slave, the tests should be carried out on both the park level controller and the master controller, which is commonly a dynamic reactive support equipment.

Wind farms based on type 1 and 2 wind turbines that are not equipped with such control systems are exempt from performing these tests.

### 7.4.3 Typical tests

In general, on-site testing should be exercised in the following sequence:

- Balance-of-plant components.
- Generating unit.
- Generating system.

As an example, the following sequence is normally applied to wind and solar farms:

- Balance of plant components including:
    - Dynamic reactive power support equipment such as STATCOMs and synchronous condensers.
    - Static reactive power support equipment such as transformers and shunt capacitor/reactor banks.
- Generating unit.
- Wind/solar farm comprising a few generating units, farm level controller (if applicable), and all BOP components.[7]
- Wind/solar farm comprising all generating units, farm level controller (if applicable), and all BOP components.

For DC-connected wind farms, the R2 testing should commence on the HVDC link, followed by the sequence highlighted above.

Note that with type 1 and type 2 wind turbines a shunt capacitor is included in the turbine nacelle. Such devices are considered as integral turbine components, and all tests conducted on the turbine should be performed with these devices in service.

One of the most commonly used forms of site testing is the step response test. This test can either be invoked by a step stimulus, or by component switching such as switching of the shunt capacitors/reactors or onload tap changers.

The latter would be more applicable to variable generation technologies as most conventional power plants do not use shunt capacitors/reactors. Network switching beyond the PCC may be exercised, but it needs a thorough review by AEMO and relevant NSPs to ensure that system security is not adversely affected.

[7] To ensure validity of the R2 model and data for a wide operating range, it is generally necessary to carry out wind farm level testing at several loading conditions, typically in the range of three to five.

For step stimulus tests, the testing should be carried out on all applicable set-points of the plant, e.g., power factor set-point, reactive power set-point, frequency set-point, voltage set-point.

Tests typically carried out for deriving R2 model and data for variable generation technologies are shown in Table 7-1.

TABLE 7-1 Tests typically carried out for derivation of R2 model and data for variable generation technologies

| PLANT | TYPICAL ON-SITE TESTS |
|---|---|
| Balance of plant | Synchronous dynamic reactive power support plant tests (if applicable) |
| | Tap changing transformer voltage step response test |
| | Tap changing transformer test via capacitor switching (if applicable) |
| | Non-synchronous dynamic reactive support plant tests (if applicable) |
| | Voltage set-point step response test with all reactive support plant in service (if applicable) |
| | Capacitor switching test with all reactive support plant in service (if applicable) |
| | Transformer tap changing test with all reactive support plant in service (if applicable) |
| Generating unit, e.g., wind turbine or solar panel | Steady-state measurements |
| | Reactive power capability test |
| | Voltage set-point step response |
| | Active power set-point step response |
| | Power factor set-point step response (if applicable) |
| Generating system | Voltage step-point step response |
| | Active power set-point step response |
| | Frequency set-point step response (full load) |
| | Frequency set-point step response (curtailed) |
| | Power factor step response (if applicable) |

| | |
|---|---|
| | Reactive power capability test |
| | Power run-back test (if applicable) |
| | Fault ride-through test (optional) |
| | Farm level capacitor switching test (if applicable) |
| | Farm level tap changing test |

### 7.4.4 Acceptance criteria

Responses obtained from the tests should be overlaid with the simulation results. The simulated results should be within ±10% of the measured results for time-domain response and within ± 5 degrees of the measured results for frequency-domain responses.

For more information refer to accuracy requirements in Generating System Model Guidelines. Any potential deviation from the accuracy requirements needs to be documented and approved by AEMO and relevant NSPs.

## 7.5 Long-term monitoring programs

### 7.5.1 Objectives

Some aspects of the R2 data validation process may require particular system conditions or specific events and may not be able to be tested by schedule. This includes system faults and operation of the system near limits. In this case, supporting R2 testing via an extended monitoring/testing program may be appropriate.

In general, long-term monitoring can be used for validation of steady-state and dynamic performance of the models for new connections projects. A monitoring program by itself is not sufficient for R2 testing, it should only be proposed in support of a testing program.

### 7.5.2 Acceptance criteria

Where a monitoring program is proposed within an R2 test program, the monitoring and assessment process should be defined within the test program and results submitted immediately following an appropriate event.

To ensure that R2 testing remains active and is completed as soon as practicable, a test plan that proposes long-term monitoring should include the following:

- A regular event checking and reporting schedule.
- Definition of the type of event/s to be observed.
- The manner in which the required event/s would be identified.
- The event recorders to be used.
- The parameters to be measured.

- Measurement accuracy.
- Consideration of the recorders' data storage capability (to ensure that adequate data relating to any actual events is captured and stored).
- Other measurement requirements as highlighted in Section 5.

Generator proposing a long-term monitoring program must undertake to review the responses of the generating system and unit(s) to system disturbances, compare those to the model responses, and provide the results to AEMO and relevant NSPs.

Conducting reviews and providing results and data to AEMO/NSPs must be completed in a timely manner following the occurrence of a relevant event.

# A. References for Synchronous Generator Model Validation Testing


1. IEEE Std 115-2009 IEEE Guide: Test Procedures for Synchronous Machine
2. IEEE 421.2-1990 Guide for Identification, Testing and Evaluation of the Dynamic Performance of Excitation Control Systems – testing
3. IEEE Task Force on Generator Model Validation Testing of the Power System Stability Subcommittee, " Guidelines for Generator Stability Model Validation Testing," in Proc. 2007 IEEE Power and Energy Society General Meeting
4. F.P. de Mello and J.R. Ribeiro, “Derivation of synchronous machine parameters from tests,” IEEE Trans. Power App. Syst., vol. PAS-96, no. 4, pp. 1211-1218, Jul./Aug. 1977.
5. F.P. de Mello and L.N. Hannett, “Determination of synchronous machine electrical characteristics by tests,” IEEE Trans. Power App. Syst., vol., PAS-102, no. 12, pp. 3810-3815, Dec. 1983.
6. J.W. Feltes, S. Orero, B. Fardanesh, E. Uzunovic, S. Zelingher, N. Abi-Samra, “Deriving Model Parameters from Field Test Measurements”, IEEE Computer Applications in Power Magazine, vol. 15, no. 4, pp.30-36, 2002.

# B. R2 data sheet requirements

The notes in this section are intended to provide general guidance to generators as to how they might develop an R2 testing program to validate the model data for their installation.

This information is general in nature and not specific to any particular application. As there are various manufacturers and technologies, and network conditions vary from site to site, a specific program must be developed for each generating system and connection point.

It should be noted that even for generators with similar systems across numerous connection points, the specific installation might vary from site to site (either in installed equipment, control system software versions, settings or network conditions). It is expected that generators will consider their particular requirements in detail and tailor tests to suit the site and the equipment that has been installed.

The tests outlined below cover both generating units and generating systems. It is important to note that this is not a complete list of tests.

Note: The numbering below corresponds to the Model Guidelines and Data Sheets. Appropriate sections for each type of generation technology are highlighted in Table B-1.

TABLE B-1 Summary table highlighting appropriate sections of the datasheets to each generation technology

## B.1 Specific data requirements

### 6. Generating system (power station)

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| Model documentation | Updated model and Releasable User Guide<br><br>This should include the overall integrated model and documentation for the generating system, including storage devices, grid interfaces, reactive compensation plant and schemes, control schemes and protection schemes. |
| Fault current contribution | Contribution of the generating system to balanced and unbalanced faults needs to be calculated by using an appropriate simulation program. Respective fault currents and impedances are entered in the relevant cells. |

### 7. Individual generating unit data

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| Number of units | A statement, supported by site inspection record. |
| Type of units | A statement, supported by site inspection record. |

| | |
|---|---|
| Auxiliary load at maximum output | Measure the power consumption with and without the generating unit. |
| Minimum load | Use a power set-point signal, identify the set point and measure the response. |
| Capability chart (reactive) | This will demonstrate the overall reactive power capability of the generating unit including the contribution of all applicable reactive power generating equipment such as electrical machine, power electronic converters, and any potential static or dynamic reactive support equipment.<br><br>Normally conducted as part of the commissioning tests.<br><br>Depending on the intended operating philosophy of the unit either of the two modes of operation will be considered: Power factor control mode, or voltage control mode. For either mode P, Q, V at the LV side of unit transformer are measured.<br><br>The tests are conducted with a combination of steady-state measurements and step response tests. The steps are applied at various power factor/voltage settings, near unity as well as near limits. There may be limitations imposed by system conditions, but may be ameliorated by tap positioning. The test is normally conducted over a sufficiently long period to expose the system to a range of network conditions. Tests should be carried at several wind speed conditions. |

# 8. Grid interfaces

## 8.1. Transformer

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| Step up transformer (number of units connecting, number of units installed) | A statement, supported by site inspection record. |
| Manufacturer name, product type | A statement, supported by site inspection record. |
| OLTC details – diagram | A statement, supported by site inspection record noting serial numbers and verifying nameplate data, compare test certificates against recorded and nameplate data. |
| Vref max | |
| Vref min | |
| Tap change voltage setting range | A combination of the following:<br>• Voltage step response test<br>• Capacitor switching test (if applicable) |
| Deadband | |
| High and low voltage - tap changing interlocks | |
| Tap change cycle time | |

### 8.2. Converters - may be full converter interface or converter connected to DFIG rotor (grid side converter)

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |
| Manufacturer name, product type | A statement, supported by site inspection record. |
| Converter type | A statement, supported by site inspection record.<br><br>The software version installed may need to be recorded. It may be worthwhile reviewing procedures for potential software upgrades to ensure any upgrades are reported (and potentially tested) as appropriate. |
| Capability chart | Will not be required if the corresponding test in item seven includes the contribution of converters. |
| Functional block diagrams | Consistent with the model. |

## 9. Electrical generator

### 9.1. Synchronous machine (including synchronous compensator)

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |
| Manufacturer name, product type | A statement, supported by site inspection record. |
| Maximum lagging reactive power at $P_{max}$ | For direct connected synchronous generators, and synchronous compensators this is performed as part of commissioning.<br><br>For full converter interface this test is not required as the corresponding test in item seven includes the contribution of converters. |
| Maximum lagging reactive power at $P_{min}$ | |
| Maximum leading reactive power at $P_{max}$ | |
| Maximum leading reactive power at $P_{min}$ | |
| Synchronous machine inertia constant (excluding prime mover inertia) | For direct connected synchronous generators most these parameters can be derived on-site using methodologies described in the references cited in Appendix A. Provision of factory tests may be acceptable for those |

| | |
|---|---|
| Rated rotor current at rated MVA and power factor, rated terminal voltage and rated speed | parameters which cannot be derived practically on-site.<br><br>For generating units interfaced through full converter schemes these parameters may not be represented in the model, and can therefore be neglected for R2 model validation. |
| Rotor voltage at which rated rotor current is achieved | |
| DC field voltage at VTgen and rated speed with unit unsynchronised | |
| DC field current at VTgen and rated speed with unit unsynchronised | |
| Stator resistance | |
| Rotor resistance | |
| Stator leakage reactance | |
| Direct axis unsaturated synchronous reactance | |
| Direct axis unsaturated transient reactance | |
| Direct axis unsaturated sub-transient reactance | |
| Quadrature axis unsaturated synchronous reactance | |
| Quadrature axis unsaturated transient reactance | |
| Quadrature axis unsaturated sub-transient reactance | |
| Direct axis open circuit transient time constant | |
| Direct axis open circuit sub-transient time constant | |
| Direct axis damper leakage time constant | |
| Quadrature axis open circuit transient time constant | |

| | |
|---|---|
| Quadrature axis open circuit sub-transient time constant | |

### 9.2. Asynchronous machine (cage rotor)

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |
| Manufacturer name, product type | A statement, supported by site inspection record. |
| Reactive power consumption over range of asynchronous machine output (0 to $P_{max}$) at VTgen | Will not be required if the corresponding test in item seven includes the contribution of asynchronous machine. |
| Asynchronous machine and gearbox inertia constant (excluding prime mover inertia) | Provision of factory test results is often acceptable. A verification process comparing test sheets against installed components would be appropriate.<br><br>For generating units interfaced through full converter schemes these parameters may not be represented in the model, and can therefore be neglected for R2 model validation. |
| Stator resistance | |
| Rotor resistance | |
| Stator leakage reactance – unsaturated and at VTgen | |
| Iron loss resistance, referred to the stator | |
| Magnetising reactance (referred to the stator) – unsaturated and at VTgen | |
| Rotor resistance as rated slip, referred to the stator | |
| Rotor leakage reactance, referred to the stator – unsaturated and at VTgen | |
| Zero sequence resistance | |
| Zero sequence reactance | |

### 9.3. Asynchronous machine (variable resistance rotor)

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |
| Manufacturer name, product type | A statement, supported by site inspection record. |
| Reactive power consumption over range of asynchronous machine output (0 to $P_{max}$) at VTgen | Will not be required if the corresponding test in item seven includes the contribution of asynchronous machine. |
| Asynchronous machine and gearbox inertia constant (excluding prime mover inertia) | Provision of factory test results is often acceptable. A verification process comparing test sheets against installed components would be appropriate. |
| Stator resistance | |
| Rotor resistance | |
| Stator leakage reactance – unsaturated and at VTgen | |
| Iron loss resistance, referred to the stator | |
| Magnetising reactance (referred to the stator) – unsaturated and at VTgen | |
| Rotor resistance as rated slip, referred to the stator | |
| Rotor leakage reactance, referred to the stator – unsaturated and at VTgen | |

## 9.4. Asynchronous machine (doubly fed)

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |
| Manufacturer name, product type | A statement, supported by site inspection record. |
| Generator capability chart | Will not be required if the corresponding test in item seven includes the contribution of asynchronous machine. |
| Maximum lagging reactive power | |

| | |
|---|---|
| at $P_{max}$ | |
| Maximum lagging reactive power at $P_{min}$ | |
| Maximum leading reactive power at $P_{max}$ | |
| Maximum leading reactive power at $P_{min}$ | |
| Asynchronous machine and gearbox inertia constant (excluding prime mover inertia) | Provision of factory test results is often acceptable. A verification process comparing test sheets against installed components would be appropriate. |
| Slip at $P_{max}$ | |
| Stator resistance | |
| Rotor resistance | |
| Stator leakage reactance – unsaturated and at VTgen | |
| Iron loss resistance, referred to the stator | |
| Magnetising reactance (referred to the stator) – unsaturated and at VTgen | |
| Rotor resistance as rated slip, referred to the stator | |
| Rotor leakage reactance, referred to the stator – unsaturated and at VTgen | |
| Zero sequence resistance | |
| Zero sequence reactance | |

### 9.5. PV cell array

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |

| | |
|---|---|
| Manufacturer name, product type | A statement, supported by site inspection record. |
| All functional block diagram parameters | Measurement and simulation of performance for normal conditions. Support with longer term monitoring for system events and severe generating conditions (e.g., a windy, scattered cloud day that causes substantial and regular output fluctuations).<br><br>The software version installed may need to be recorded. It may be worthwhile reviewing procedures for potential software upgrades to ensure any upgrades are reported (and potentially tested) as appropriate. |

### 9.6. Fuel cell

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |
| Manufacturer name, product type | A statement, supported by site inspection record. |
| All functional block diagram parameters | Measurement and simulation of performance for normal conditions. Support with longer term monitoring for system events.<br><br>The software version installed may need to be recorded. It may be worthwhile reviewing procedures for potential software upgrades to ensure any upgrades are reported (and potentially tested) as appropriate. |

## 10. Primary electrical control systems

### 10.1. Synchronous machine excitation system

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |
| Manufacturer name, product type | A statement, supported by site inspection record. |
| Functional block diagrams for:<br>▪ Voltage control systems (AVR)<br>▪ Power system stabiliser<br>▪ Exciter<br>▪ Reactive current or reactive power compensation | This can be achieved with a combination of some or all of the following methods:<br>• Off-line frequency response<br>• Off-line time-domain step response<br>• Standstill frequency response<br>• On-line steady-state measurements<br>• On-line frequency response |

| | |
|---|---|
| ▪ OEL<br>▪ UEL<br>▪ Stator current limiter<br>▪ Flux limiter<br>▪ Any other limiters that may restrict excitation control system operation | • On-line time-domain step response<br>• Playback method[8]<br><br>As a minimum off-line and on-line step response tests are required. The response of each installed system to various step changes in input and/or reference signals is measured and compared against simulated response.<br><br>These tests can be invoked by a combination of step stimulus and component switching such as switching of the mechanically switched capacitors or onload tap changers.<br><br>Performance of the system needs to be measured over a sufficient time duration to ensure that time constants and long term performance of control systems are adequately modelled. |

### 10.2. Asynchronous machine P-Q (or P-V) control systems

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |
| Manufacturer name, product type | A statement, supported by site inspection record.<br><br>The control system software version installed may need to be recorded. It may be worthwhile reviewing procedures for potential software upgrades to ensure any upgrades are reported (and potentially tested) as appropriate. |
| Capability chart (as applied by P-V or P-Q control system) | Will not be required if the corresponding test in item 7 includes the contribution of asynchronous machine. |
| All functional block diagram parameters | Consistent with the model. |

## 11. Secondary Electrical Control Systems

### 11.1. Fault ride-through control systems

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |
| Manufacturer name, product type | A statement, supported by site inspection record. |
| All functional block diagram | The options available include: |

[8] A method where the measured signals are injected into the simulated model, and the model parameters are tuned (often automatically) such that deviation between the measured and simulated responses is maintained within a certain threshold.

| | |
|---|---|
| parameters | • Use of R1 data derived from off-site test results<br>• Application of fault ride-through test on-site<br><br>Either option should be supplemented by the use of long-term monitoring program. |

### 11.2. Other generating unit control systems

This includes any other generating unit control system that may affect its performance on the power system (in terms of its active power, reactive power or voltage). Included in this category are the control system for the following:

- High-voltage ride-through capability.
- Fast acting turbine-level voltage control.
- Synthetic inertia.

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |
| Manufacturer name, product type | A statement, supported by site inspection record. |
| All functional block diagram parameters | It can be partially or fully validated through time domain step response tests. As with previous control system tests, this test can be invoked by a combination of step stimulus and component switching such as switching shunt capacitors or onload tap changers.<br><br>The control system software version installed may need to be recorded. It may be worthwhile reviewing procedures for potential software upgrades to ensure any upgrades are reported (and potentially tested) as appropriate. |

### 11.3. Generating system control systems (co-ordinated control of generating system plant)

This includes any coordinated control of generating units or other plant within a generating system, for example:

- Active power scheduling.
- Reactive power scheduling.
- Voltage control.
- Reactive power support plant switching.
- Automatic switching of circuit breakers or tripping of plant.

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which | A statement, supported by site inspection record. |

| | |
|---|---|
| this applies | |
| Manufacturer name, product type | A statement, supported by site inspection record. |
| All functional block diagram parameters | It can be fully validated through time domain step response tests. As with previous control system tests, this test can be invoked by a combination of step stimulus and component switching such as switching shunt capacitors or onload tap changers.<br><br>The control system software version installed may need to be recorded. It may be worthwhile reviewing procedures for potential software upgrades to ensure any upgrades are reported (and potentially tested) as appropriate. |

## 12. Prime mover and primary mechanical control systems

### 12.1. Wind turbine aerodynamic model and blade pitch controller model

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |
| Manufacturer name, product type | A statement, supported by site inspection record.<br><br>The control system software version installed may need to be recorded. It may be worthwhile reviewing procedures for potential software upgrades to ensure any upgrades are reported (and potentially tested) as appropriate. |
| Cut-in wind speed | This test may require monitoring devices to be installed, measure wind speed and power output. Lowest speed at which active power is above zero. |
| Winds speed at which full power is attained | This test may require monitoring devices to be installed, measure wind speed and power output. Lowest speed at which power equals $P_{max.}$ |
| Power curve (diagram) | This test may require monitoring devices to be installed, measure wind speed and power output. Use scatter plot of recorded data. |
| Turbine and blade inertia (excluding electrical generator), as measured on the generator shaft | Provision of factory test results is often acceptable. A verification process comparing test sheets against installed components would be appropriate.<br><br>For generating units interfaced through full converter schemes these parameters may not be represented in the model, and can therefore be neglected for R2 model validation. |

## 13. Secondary mechanical control systems

Secondary mechanical control systems include those control systems that are not normally active, and take part in a corrective action to protect the plant. This may include, for example:

- Turbine over speed controllers.
- Power run-back.

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |
| Manufacturer name, product type | A statement, supported by site inspection record. |
| All functional block diagram parameters | Such control systems are only enabled during abnormal operating conditions. From GPS compliance standpoint such aspects can be included in the commissioning program, but there may not be any specific associated model or data that needs to be validated. It may not be always possible to test such control systems on-site. For those conditions it would be appropriate to rely on long-term monitoring program to capture such actions.<br><br>Record software version. Establish procedures for potential software upgrades to ensure any upgrades are reported (and tested) as appropriate. |

## 14. Prime mover mechanical coupling /sub-synchronous resonance

### 14.1. Shaft model/sub-synchronous resonance frequencies

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |

## 15. Auxiliary Compensation Equipment

### 15.1. Mechanically or electronically switched capacitor, reactor or resistor

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |
| Manufacturer name, product type | A statement, supported by site inspection record. |
| Number of steps normally on at $P_{Max}$ and $P_{Min}$ | A statement, supported by measured evidence and simulated results. |
| All functional block diagram | Demonstration of capacitor bank switching/status across the range of output |

| | |
|---|---|
| parameters | for generating unit/generating system and various network conditions (high load and low voltages, low load & high voltages).<br><br>Record control system software version. Establish procedures for potential software upgrades to ensure any upgrades are reported (and tested) as appropriate. |

## 15.2. SVC, thyristor controlled SVC

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |
| Manufacturer name, product type | A statement, supported by site inspection record. |
| All functional block diagram parameters | Performance assessment should form part of commissioning tests.<br><br>It can be fully or partially validated through time domain step response tests. As with previous control system tests, this test can be invoked by a combination of step stimulus and component switching such as switching shunt capacitors or on load tap changers.<br><br>Where practicable frequency response tests are also recommended.<br><br>Record control system software version. Establish procedures for potential software upgrades to ensure any upgrades are reported (and tested) as appropriate. |
| OLTC details – diagram | A statement, supported by site inspection record noting serial numbers and verifying nameplates data/test certificates. |
| Verve max | |
| Verve min | |
| Tap change voltage setting range | It can be done with a combination of the following:<br><br>• Voltage step response test.<br>• Capacitor switching test (if applicable). |
| Dead band | |
| High and low voltage - tap changing interlocks | |
| Tap change cycle time | |

## 15.3. Voltage source converter or current source converter, self-commutated or similar (VSC, CSC, Statcon or Statcom)

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|

| | |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |
| Manufacturer name, product type | A statement, supported by site inspection record. |
| Details of the control system described in block diagram form. If the device has an overload rating, include the control system characteristics to control this functionality. | Performance assessment should form part of commissioning tests.<br><br>It can be fully or partially validated through time domain step response tests. As with previous control system tests, this test can be invoked by a combination of step stimulus and component switching such as switching shunt capacitors or onload tap changers.<br><br>Record control system software version. Establish procedures for potential software upgrades to ensure any upgrades are reported (and tested) as appropriate. |
| All functional block diagram parameters | See above, demonstrate alignment between measured and simulated results. |
| OLTC details – diagram | A statement, supported by site inspection record noting serial numbers and verifying nameplates data/test certificates. |
| Vref max | |
| Vref min | |
| Tap change voltage setting range | It can be done with a combination of the following:<br><br>• Voltage step response test.<br>• Capacitor switching test (if applicable). |
| Deadband | |
| High and low voltage - tap changing interlocks | |
| Tap change cycle time | |

## 15.4. Flywheel

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |
| Manufacturer name, product type | A statement, supported by site inspection record. |
| All functional block diagram parameters | Measurement and simulation of performance for normal conditions. Support with longer term monitoring for system events and severe generating conditions (e.g. an event that triggers heavy use of the device due to substantial and regular output fluctuations).<br><br>Record software version. Establish procedures for potential software |

| | |
|---|---|
| | upgrades to ensure any upgrades are reported (and tested) as appropriate. |

### 15.5. Storage battery

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |
| Manufacturer name, product type | A statement, supported by site inspection record. |
| Nominal Capacity | A statement, supported by site inspection record.<br><br>Otherwise, fully charge, turn off generator/s and fully discharge while measuring output. |
| All functional block diagram parameters | Measurement and simulation of performance across a single day. Support with longer term monitoring for system events and severe generating conditions (e.g., an event that triggers heavy use of the device due to substantial and regular output fluctuations).<br><br>Record software version. Establish procedures for potential software upgrades to ensure any upgrades are reported (and tested) as appropriate. |

## 16. Protection systems

### 16.1. Synchronous machine protection systems (back-ups for excitation limiters)

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |
| Manufacturer name, product type | A statement, supported by site inspection record.<br><br>Record protection settings. Establish procedures for potential setting changes, to ensure any upgrades are reported (and tested) as appropriate. |

### 16.2. Asynchronous machine protection systems (for generating unit instability)

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |

| | |
|---|---|
| Manufacturer name, product type | A statement, supported by site inspection record. |
| All functional block diagram parameters | Testing may be performed by secondary signal injection or setting changes. A long term monitoring program may be appropriate for this functionality.<br><br>Measured responses should be compared against simulation results for the same system conditions.<br><br>Record protection settings. Establish procedures for potential setting changes, to ensure any upgrades are reported (and tested) as appropriate. |

### 16.3. Crowbar protection systems

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |
| Manufacturer name, product type | A statement, supported by site inspection record. |
| All functional block diagram parameters | Off-site testing and/or a long term monitoring program may be appropriate.<br><br>Application of fault ride-through test on-site provides some opportunity for validating some of model parameters on-site.<br><br>Record software version. Establish procedures for potential software upgrades to ensure any upgrades are reported (and tested) as appropriate. |

### 16.4. Other protection systems

This consists of protection systems that result in a protection trip of the generating unit or generating system, for example, due to:

- Over-speed or high or low frequencies
- High frequency rates of change
- High or low voltages
- Excessive negative phase sequence current
- Differential
- Over-current.
- Anti-islanding

| DATA ITEM | POSSIBLE METHOD FOR VALIDATION |
|---|---|
| List of generating units to which this applies | A statement, supported by site inspection record. |
| Manufacturer name, product type | A statement, supported by site inspection record. |
| All functional block diagram | Most these tests can be performed by secondary signal injection or by |

| | |
|---|---|
| parameters | applying settings outside normal operating ranges.<br><br>Testing of anti-islanding scheme can be carried out on-site.<br><br>The software version and/or protection settings should be recorded. Establish procedures for potential software upgrades or setting changes, to ensure any upgrades are reported (and tested) as appropriate. |