Access Standard Assessment Guide

January 2019

AEMO – Network Development

Important notice

PURPOSE

This publication has been prepared by AEMO to assist Connection Applicants and Generators and Network Service Providers in their development and assessment of proposed access standards.

DISCLAIMER

This document or the information in it may be subsequently updated or amended. This document does not constitute legal or business advice, and should not be relied on as a substitute for obtaining detailed advice about the National Electricity Law, the National Electricity Rules, or any other applicable laws, procedures or policies.

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VERSION CONTROL

Version	Release date	Changes
1.0	20/12/2011	First issue
2.0	31/01/2019	Revised and updated to account for: • National Electricity Amendment (Generator technical performance standards) Rule 2018 • National Electricity Amendment (Generating System Model Guidelines) Rule 2017 • National Electricity Amendment (Managing power system fault levels) Rule 2017 • National Electricity Amendment (Managing the rate of change of power system frequency) Rule 2017 and related methodologies, guidelines and requirements published by AEMO under those amendments.

About these Guidelines and AEMO functions

AEMO operates Australia's National Electricity Market (NEM) and interconnected power system in Australia's eastern and south-eastern seaboard. AEMO's NEM functions are prescribed by the National Electricity Law (NEL)[1] and the National Electricity Rules (NER)[2]. AEMO also carries out the *declared network functions* in Victoria[1] and advises the Essential Services Commission of South Australia on certain requirements for generation licences in South Australia.

One of AEMO's functions as system operator is to assess and advise Network Service Providers (NSPs) whether to accept or reject certain negotiated access standards proposed by Connection Applicants or Generators (Applicants)[3]. These standards relate to matters that could have power system security implications and are called *AEMO advisory matters*. Once accepted, performance standards are documented in the connection agreement and registered by AEMO, and the registered performance standards are enforceable under the NER.

AEMO provides a copy of the performance standards register to the AER by 1 July each year and on request.

AEMO assesses simulation models of generating plant and their control systems to confirm their expected performance and power system impact, and is involved in commissioning and post-commissioning activities, including information and validation requirements. Simulation models are subsequently used for assessment of power system performance/limits, and in real-time analysis tools.

These Guidelines explain AEMO's requirements for information from Applicants and NSPs to facilitate the assessment of:

- AEMO advisory matters[4] for:
  - New generation connections (NER clause 5.3.4A).
  - Alteration of existing generating systems (NER clause 5.3.9).
  - Assessments of compliance of generating systems with agreed performance standards, and proposed amendments to those standards.
- Negotiated access standards proposed by Applicants for new generation connections and alterations to existing generating systems connected to the Victorian declared transmission system, for which AEMO also acts as the NSP.

These Guidelines are not a substitute for the NER and AEMO's NER-mandated guidelines and procedures. The NER and other documents required by the NER will prevail to the extent of any inconsistency with

1 See https://www.legislation.sa.gov.au/LZ/C/A/NATIONAL ELECTRICITY (SOUTH AUSTRALIA) ACT 1996.aspx.

2 See https://www.aemc.gov.au/regulation/energy-rules/national-electricity-rules/current.

3 For convenience, both Connection Applicants wishing to connect new generation and Generators wishing to alter their GSs are referred to as Applicants in this document.

4 See section 1.3 "AEMO advisory matters"

these Guidelines. These guidelines provide useful information relating to the submission of proposed performance standards and assessment of those proposed performance standards by NSP’s and AEMO.

These Guidelines do not:

- Apply to the assessment of access standards for plant other than generation.
- Detail the scope of studies to be undertaken by the Connection Applicant, Generator or the NSP. These should be discussed and agreed with AEMO and the relevant NSP.
- List all studies required, or the breadth of transmission/distribution system and generating system operating conditions to be considered.
- Describe acceptable commissioning practices or ways in which Applicants can demonstrate compliance with their performance standards.
- Provide any statement or guarantee about the acceptability of proposed negotiated access standards.
- Cover system strength impact assessments, except to note where they may be relevant to the assessment of a proposed access standard (including any proposed remediation).

To provide feedback on these guidelines, please contact us at vic.connections@aemo.com. au

Contents

1. Rules framework

1.1 Relevant rules and other instruments

The requirements and process for proposing and agreeing access standards for generating systems (GSs) are primarily covered by NER clauses 5.3.4, 5.3.4A (for new connections), and 5.3.9 (for alterations to existing GSs)[5], and the access standards are detailed in Schedule 5.2. The resulting performance standards are registered by AEMO under rule 4.14.

In conjunction with changes to the NER made in 2017 and 2018, AEMO has undertaken technical investigations and published several documents under the NER to provide details on the technical and information requirements to be met by Applicants, including:

- *System Strength Impact Assessment Guidelines*[6].
- *Power System Model Guidelines*[7]
- *Power System Design Data Sheets and Power System Setting Data Sheets*[8]
- *System Strength Requirements Methodology, System Strength Requirements and Fault Level Shortfalls*[9].
- *Inertia Requirements Methodology and 2018 Inertia Requirements and Shortfalls*[10].

These documents also clarify the information and tools necessary for NSPs and AEMO to perform the extended analyses required to assess the power system security impacts of proposed access standards.

The *National Electricity Amendment (Generator technical performance standards) Rule* 2018 commenced on 5 October 2018. The Rule changed many of the technical requirements for connecting GSs. For convenience, the 2018 changes to NER Schedule 5.2 are summarised in Table 1.

Table 1 Summary of NER Schedule 5.2 changes from 5 October 2018

NER	Change from 5 Oct 2018
S5.2.5.1	Now an AEMO advisory matter.
S5.2.5.3	New rate of change of power system frequency (df/dt) requirements.
S5.2.5.4	New technical voltage envelope requirements.

[5] Although not an access standard, the impact of new/altered generation on system strength is also relevant to the assessment of access standards (see NER clause 5.3.4B).

[6] See http://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/System_Strength_Impact_Assessment_Guidelines_PUBLISHED.pdf.

[7] See http://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/Power_Systems_Model_Guidelines_PUBLISHED.pdf.

[8] See http://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/Power_System_Design_and_Setting_Data_Sheets_PUBLISHED.xlsx

[9] See http://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/System_Strength_Requirements_Methodology_PUBLISHED.pdf.

[10] See http://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/Inertia_Requirements_Methodology_PUBLISHED.pdf.

NER	Change from 5 Oct 2018
S5.2.5.5	New requirements for multiple disturbance ride-through, response thresholds for over- and under-voltage events, amended requirements for synchronous and asynchronous GSs, capacitive and reactive current injection requirements including rise and settling times.
S5.2.5.7	Amended requirements for asynchronous generation.
S5.2.5.8	Negotiated access standard deleted.
S5.2.5.9	Negotiated access standard deleted.
S5.2.5.10	Minimum access standard applies to GSs, not GUs.
S5.2.5.11	Amended automatic access standard requirement for delivery of all FCAS, droop functionality and provision of control capability in the minimum access standard.
S5.2.5.12	Minor changes.
S5.2.5.13	Amended capability to operate in any of the 3 modes (voltage control, reactive power or power factor), accuracy requirements for reactive power or power factor control. The automatic access standard requires the voltage setpoint to be controllable in the range of 95%-105% of the target voltage (unless reactive power exceeds the automatic access standard in clause S5.2.5.1).
S5.2.5.14	Mandates AGC capability for all scheduled and semi-scheduled generation, removal of 30MW capacity exclusion, capability to apply a dispatch cap to non-scheduled generation.
S5.2.6.1	Additional quantities required and inclusion of remote control capability (control mode, setpoint, ramp rates).
S5.2.6.2	Minor changes.

Other notable NER changes relate to the introduction of:

- Schedule 5.5.4 – short circuit ratio (SCR), which is to be recorded for new generation connections.
- Amended definitions of AEMO advisory matters and continuous uninterrupted operation (CUO).
- Definitions for rise time and settling time in Chapter 10.

1.2 Proposing access standards

There are three levels of technical performance, called access standards, from GSs referred to in NER Schedule 5.2:

- The highest technical level of performance is the automatic access standard.
- The minimum access standard is the minimum technical level of performance that can be accepted, depending on the location of the connection point.
- A negotiated access standard is a level of performance in between the automatic access standard and the minimum access standard applicable to a technical requirement. Negotiated access standards can be proposed by an Applicant under NER clause 5.3.4 and are to be assessed by the connecting NSP[11] and AEMO (for AEMO advisory matters) but the Applicant's proposal must comply with NER clause 5.3.4A(b1) and (b2). Importantly, the Applicant must demonstrate that the proposed negotiated access standard is as close as reasonably practicable to the automatic access standard, noting that *"if a connection applicant proposes a lower level of performance because it is not commercially feasible to meet the automatic access standard, AEMO and the NSP are not required to consider commercial feasibility in their assessment of the proposed negotiated access standard."*[12]

[11] The 'connecting NSP' for the declared shared network in Victoria is AEMO.

[12] National Electricity Amendment Rule 2018, Rule Determination, See https://www.aemc.gov.au/sites/default/files/2018-09/Final%20Determination_0.pdf

When the Applicant ultimately applies for registration, the success of its application depends, among other things, on satisfying AEMO that its GS is capable of meeting or exceeding the agreed performance standards.

1.3 AEMO advisory matters

An AEMO advisory matter is defined in the NER as:

> "A matter that relates to *AEMO's* functions under the *National Electricity Law* and a matter in which *AEMO* has a role under clause 5.3.4B or in schedules 5.1a, 5.1, 5.2, 5.3 and 5.3a. Advice on the acceptability of *negotiated access standards* under the following clauses are deemed to be *AEMO advisory matters*: S5.1.9, S5.2.5.1, S5.2.5.3 to S5.2.5.5, S5.2.5.7 to S5.2.5.14, S5.2.6.1, S5.2.6.2, S5.3a.4.1 and S5.3a.14."

2. Model requirements and model use

Applicants must submit GS models that meet the *Power System Model Guidelines*. The related data are specified in the *Power System Design Data Sheets* and *Power System Setting Data Sheets.* These enable NSPs and AEMO to comply with their obligations under the NER, especially those that relate to meeting AEMO's power system security responsibilities.

The NSPs and AEMO cannot assess an access standard until all required data and model information has been submitted and either a complete application to connect (clause 5.3.4) or an application to alter a GS (clause 5.3.9) has been received.

Consistent with the requirements of the *Power System Model Guidelines*, the following information must be provided as a minimum:

Table 2 Summary of Minimum Model Requirements

Model and Information	Inclusions
Site- specific root mean square (RMS) models	For all plant, protection and controls that comply with the *Power System Model Guidelines*, including: • model block diagrams; and • model source code; • RMS Model Acceptance Test Report consistent with the *Dynamic Model Acceptance Guideline*[13];
Site-specific EMT[14] models	For all plant, protection and controls that comply with the Power System Model Guidelines, including: • Complete parameter list consistent with NER 5.2.5, S5.2.4, Power System Design Data Sheets and Power System Setting Data Sheets, and, the Power System Model Guidelines
A Releasable User Guide (RUG)	For both RMS and EMT models in the form specified in the Releasable User Guide Template.
RMS/EMT[15] GS model benchmarking report	Generally based on a single machine infinite bus (SMIB) case setup taking into consideration the lowest applicable SCR condition

[13] Available at: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Network_Connections/Model_Acceptance_Testing.pdf

[14] Electro-magnetic transients, also used as EMT (used in the context of PSCAD™/EMTDC™ software models).

[15] At present AEMO primarily uses PSS®E and PSCAD™/EMTDC™, respectively, for RMS and EMT studies.

In addition to the above modelling requirements, the Applicant must provide a comprehensive design (connection study) report that demonstrates how the GS will meet the proposed access standards.

R2 data and model validation report must also be provided following commissioning of the GS. Following commissioning, the Applicant must also institute an ongoing compliance monitoring program.

AEMO has published a checklist[16] of information to be provided for the assessment of applications to connect and alterations to a GS that provide additional information on the study and model requirements to be met by Applicants when submitting their applications.

2.1 Importance of models and their use

AEMO uses a variety of software platforms when assessing proposed access standards, power system security and operational matters.

The provision of accurate models by Applicants is critical to AEMO and NSPs' ability to fulfil their roles and responsibilities under the NER. Equally, models are used for the validation and compliance/design assessment of proposed access standards.

As an Applicant, do I need to provide RMS PSS®E models?

Yes, PSS®E models are critical in the assessment of proposed access standards and must be provided to NSPs and AEMO in accordance with AEMO's modelling requirements[17] and *Power System Model Guidelines*. These models are used by NSPs and AEMO in setting applicable thermal/stability constraints across the NEM.

AEMO also provides PSS®E models through AEMO's Operations and Planning Data Management System (OPDMS) to enable other parties entitled to this information under the NER to assess the impact of their proposed plant, plant upgrade or plant setting change on the network.

Is PSS®E run in real-time by AEMO?

Yes, AEMO applies PSS®E in real-time, as well as other software platforms. Models are used by AEMO's Real Time Operations (with results, alarms and requirements for real-time action screened every few minutes). Some of the items captured include transient/dynamic stability, short circuit ratio studies, voltage stability and thermal assessments for which AEMO may need to invoke constraint equations to address operational circumstances at any time.

How accurate does a PSS®E model need to be?

It is expected that a PSS®E model will represent the plant as accurately as possible, in accordance with the *Power System Model Guideline* accuracy requirements. Accuracy (consistency) requirements must be met and models properly validated using post-connection (R2) data.

As an Applicant, do I need to provide PSCAD™/EMTDC™ models?

Yes, PSCAD™/EMTDC™ models are required from 1 July 2018 for existing and new plant as specified in the *Power System Model Guidelines*.

[16] Available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Network_Connections/Connection-Application-Checklist.pdf.

[17] See http://aemo.com.au/Electricity/National-Electricity-Market-NEM/Network-connections/Modelling-requirements.

As an Applicant, does the provision of PSCAD™/EMTDC™ models apply even if my proposed connection is to a "strong" network?

Yes, PSCAD™/EMTDC™ models are required even then.

Are PSCAD™/EMTDC™ models used in AEMO's operations?

NSPs and AEMO use PSCAD™/EMTDC™ models to assess system strength requirements and proposed access standards as well as to establish constraints and operational requirements for the secure operation of the power system.

The NER require NSPs to provide limit advice to AEMO, including limits based on EMT modelling. AEMO translates limit advice into constraint equations in accordance with the *Constraint Formulation Guidelines*[18] for implementation into NEMDE.

Use and application of PSCAD™/EMTDC™ models enables an accurate assessment of unbalanced/balanced events, power system security, weak system connections, and control and dynamic (stable/unstable) interactions (among other applications of PSCAD™/EMTDC™) between a GS and its surrounding network.

What could happen if PSS®E or PSCAD™/EMTDC™ models are inaccurate?

Inaccurate models will result in the application of inadequate constraint equations or operating requirements to maintain the power system within its technical envelope, jeopardise power system security, the future resilience of the power system, and could reduce power transfer capability for existing and future generation.

AEMO needs to be able to model power system behaviour continuously to ensure that it can operate the power system in accordance with the NER and, in particular, to allow for:

- NSP determination of network limits and implementation of constraint equations by AEMO.
- Predictive analysis of power system security using dynamic security assessment tools.
- Assessing the requirements for subsequent proposed connections and alterations.
- Assessing the impact of subsequent connections and alterations to existing network users.

To achieve these outcomes, AEMO needs up-to-date and complete RMS and EMT type models and related information about the behaviour of plant connected to the power system.

[18] http://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Congestion-Information/2016/Constraint_Formulation_Guidelines_v10_1.pdf.

3. Assessment approach

AEMO assesses proposed access standards against the technical requirements in NER Schedule 5.2. A key principle in assessing compliance with the technical requirements is that they must demonstrate that each proposed access standard will not adversely impact power system security (for AEMO advisory matters) and quality of supply to other network users.

The remainder of Section 3 details AEMO's approach to assessing each proposed access standard by reference to NER clauses S5.2.5, S5.2.6, S5.2.7 and S5.2.8.

3.1 [Clause 5.2.5.1] Reactive Power Capability

This requirement is concerned with the capability of a GS to deliver reactive power at its connection point, which assists in the maintenance of a suitable power system voltage profile.

A GS's reactive power capability is influenced by the voltage and reactive power control systems, including reactive plant design, tap changer range, system strength, reticulation and transformer losses, temperatures and derating factors/tolerance margins.

Aspects of this requirement overlap with NER clause S5.2.5.13.

To assess compliance, the following is required:

- Steady state load flow and dynamic studies be completed to validate the GS' reactive power capability at the connection point over a range of power system conditions.
- Details of GS limitations, especially those relating to the use and operation of transformer taps, equipment or control switching logic and temperature limitations.

Capability

The provision of reactive power depends on GU capability and the overall electrical balance of plant design.

Some GUs may need to maintain a certain voltage range at their terminals to ensure the full extent of reactive capability can be utilised. The control of GS (medium voltage) and GU voltage in these cases is governed by the capability of upstream transformers' tap capability and control. As the capability for resulting voltage step change depends on system strength and the design of transformer tap range, they must be taken into consideration when determining the ability to deliver proposed reactive power performance levels.

To determine the maximum and minimum capability levels, the Applicant must demonstrate to AEMO how these capability limits are to be achieved in the operational framework (including a description of the control mode and reference set points required), i.e. via dynamic studies, taking into account the plant's:

- Primary control and capability response.
- Secondary and tertiary (timeframe) control/equipment elements, such as OLTC and reactive plant switching.

For the modelling assessment, reduced (e.g. OLTC) time constants may be used and the actual OLTC's AVR time inverse curves must be provided to confirm the overall "real" time capability of the GS to meet maximum and minimum reactive power levels.

A timeframe from where a GS operates from its unity power factor (PF) (or expected operating range for normal voltage levels) to its maximum/minimum reactive power range must be included to provide transparency of operational limitations/plant abilities to deliver the proposed reactive power capability.

The voltage control strategy, provided in support of the proposed access standard under NER clause S5.2.5.13, must include reactive power capability curves and describe any switching and control logic steps required to achieve the capabilities required by the proposed access standard under clause S5.2.5.1.

For an asynchronous GS, the model must represent the reticulation system characteristics (equivalent aggregate(s)) that can influence its reactive power range at the connection point. Consideration also needs to be given to the typical operating voltage at the connection point and each GU's terminals, and the tapping range (properly designed) on any connection (asset) transformer. AEMO will consider an Applicant's validation and will require evidence to demonstrate that the GS can provide the stated reactive power range between 90-110% of normal voltage at the connection point. This should be in the form of a capability diagram showing reactive power capability from >0 to 100% power output over a GS connecting point voltage range of 90-110% of normal voltage. If hot or cold weather can reduce the plant's operational capability, de-rated capability curves must be provided, including the maximum operating temperature at which the GU/GS can operate to provide its proposed reactive power capability. Consideration must also be given to the reactive output during start-up and shut-down procedures, e.g. for photovoltaic systems and wind power systems, to enable smooth transition for active power changing from zero to maximum output and when returning to no active power generation at sunset or no wind conditions.

To assess compliance, the following is required:

- GS capability curves covering 90%-110% operating voltage range, as well as temperature derating curves.
- GS capability based on dynamic assessment for demonstration of GS ability to deliver its maximum and minimum reactive power levels, including operation of applicable primary response, secondary and tertiary elements, e.g. on load tap changers, reactive plant switching and so on. The assessment must consider the adequacy of the reactive power and the ability to continuously control voltage in the range of at least 95% to 105% of the target voltage (with reference to the clause S5.2.5.13 (technical requirements applicable to the automatic access standard)
- Models must comply with the *Power System Model Guidelines*.
- Control block diagrams, including a description of relevant gains, limiters, time delays, time constants and scaling factors.
- Protection settings report review and a review to ensure full extent of stated capability is not limited by other protective system design elements (e.g. reverse relays).
- For battery energy storage systems, assessment of four-quadrant reactive capability.

3.2 [Clause S5.2.5.2] Quality of electricity generated

These technical requirements consider the quality of the electricity generated by a GS at its connection point and whether it can have a detrimental effect on other network users. For Victorian transmission connections, AEMO will assign an automatic access standard for allowable levels of voltage fluctuation, harmonic voltage distortion and voltage unbalance at each connection point.

To assess compliance, assessment (design) reports are required to demonstrate how the GS will comply with the relevant emission levels. A range of harmonic (impedance) frequency sweep studies are undertaken considering GU emissions, reticulation system design, the presence of capacitors or reactors, transformers etc (harmonic/power quality models) for which power quality design is carried out.

Post-connection assessment requires the collection and evaluation of pre-connection and post-connection power quality emissions (based on maximum 3 phase values considering probability values and sampling intervals as required by AS/NZS61000.3.6 & AS/NZS61000.3.7).

To ascertain whether adequate levels of protection are provided for the design of filter components (e.g. capacitor cans, resistors or inductors forming the filter bank) or other plant susceptible to power quality emissions the NSP should provide harmonic load flow information and data to the Applicant.

Power quality assessments need to consider all operating GS levels and the likely levels of existing background emissions.

To assess compliance, the following is required:

- Background measurements prior to connection as per AS/NZS61000.3.6 & AS/NZS61000.3.7 at the proposed connection point (or other agreed location).
- GU power quality data sheets (including model/data where used, e.g. converter model for harmonic studies).
- Assessment of power quality emissions, taking into account power system conditions at the connection point for which series or parallel resonances may occur depending on network configuration.
- The Applicant's power quality assessment report, which must include details of data inputs, study methodology (taking into account system normal and N-1 conditions as a minimum).
- Post-connection measurements in accordance with Australian Standards requirements.

3.3 [Clause S5.2.5.3] Generating unit response to frequency disturbances

These technical requirements consider the response of the GS, and each of its GUs, to frequency disturbances at the connection point, and the conditions for which they must remain connected. As frequency disturbance is a possible outcome following a power system incident, some aspects of the requirements may overlap with other requirements, such as those under clauses S5.2.5.7, S5.2.5.8, S5.2.5.11 and S5.2.5.5 depending on the nature and location of a disturbance that is likely to impact voltage or frequency performance.

To assess compliance details of the frequency protection system and over-frequency (OF) and under-frequency (UF) protection element settings including df/dt (rate of change of frequency (ROCOF)) are required. The assessment must consider if any auxiliary plant needed to support the GS can withstand the frequency disturbance. For example, if a synchronous GU requires key auxiliary loads to maintain operation (such as pumps or fans), evidence that these loads can maintain operation during a frequency disturbance must be provided. Similarly, for an asynchronous GU (wind turbines/solar PV, batteries), attention must be paid to yaw motors and the auxiliary supply system for which frequency protective mechanisms or malfunctions may apply, to ensure no plant stoppage or trips.

For weak connections that may experience large phase shifts due to system disturbances (or line switching) and, in turn, large measured/estimated local frequency, it may be necessary for the Applicant to design the GS to cope with such phase angle changes and avoid trips due to locally measured frequency associated with system weakness and not system frequency.

Applicants must provide information to AEMO that captures:

- Details of how frequency is derived by protective relay devices or phase lock loops (PLL) used within the GS.
- Frequency measurement algorithms and inclusions of those in the required models.

The following must also be considered in the assessment of access standards and GS capability:

- That the frequency would be unlikely to fall below the lower bound of the operational frequency tolerance band as a result of OF tripping of the GUs.
- That there would be no material adverse impact on the quality of supply to other network users or to power system security.

To assess compliance, the following is required from the Applicant:

- Application of df/dt and applicable trip settings to assess the operating conditions for which a GS remains connected and for which it will trip. Examples relate to:
  - Model/data validation benchmarking report based on a SMIB case via injected frequency playback (including mapping of parameters between the control/protection systems for both PSS®E and PSCAD™/EMTDC™ models).
  - OPDMS PSS®E network case via application of appropriate load/generation contingency.
  - Protection settings report, including secondary injection – protection settings confirmation for ROCOF and OF/UF settings.
- Confirmation of settings in the GS relays or devices that trigger plant stoppages or trips.

For weak connections and where studies involve PSCAD™/EMTDC™, assessment on confirmation of the worst case observed phase angle/frequency estimation against protection settings and confirmation of generator ride-through of such events. Where a GU loses control due to its PLL inability to track phase angle reference resulting in inappropriate active and reactive current (references) injections, a GS has failed to maintain continuous uninterrupted operation and AEMO requires the Applicant to design its control system to prevent the loss of proper control due to lost tracking capability/limitations of GU technology alone. Tuning of the control system may also be required as well as additional equipment (for the GS) to enable the Applicant to demonstrate that the plant maintains stable and damped performance.

3.4 [Clause S5.2.5.4] Generating system response to voltage disturbances

These technical requirements consider the response of a GS, and each of its GUs, to voltage disturbances at the connection point, and the conditions for which they do (and do not) remain connected.

As voltage disturbance is a possible outcome of a power system contingency event, aspects of these requirements may overlap, and relate to, other requirements, for example:

- Response to contingency events and capability for reactive support and commencement of GS response to UV and OV events (e.g. high voltage ride-through (HVRT) or low voltage ride-through (LVRT) in case of asynchronous plant) (refer to clause S5.2.5.5).
- Settings of protection systems.
- Voltage and reactive power control capabilities and primary plant design within the GS.

CUO, including capability of current-limited plant to maintain active and reactive power while in the normal operating voltage range, and not to exacerbate disturbances (e.g. by current blocking).

To assess compliance, the following is required:

- Details of the voltage protection system, in particular, OV, UV and over-fluxing protection element settings, including protection grading.
- Description of HVRT and LVRT mechanisms, including activation and deactivation thresholds for the (modelled) response.
- A capability curve (for OV and UV) showing the range of voltages for which the GS can ride through aligned against the capabilities required by clauses S5.2.5.4 and S5.2.5.5.
- Time domain dynamic studies showing the GS’s ability to remain connected, These studies must include the following:
  - Consistency of plant behaviour using both RMS and EMT models (provided as part of benchmarking);

- SMIB system evaluation (including the influence of tap changers where required/used);
- AEMO OPDMS network case studies considering applicable voltage disturbance events, including application of faults and sudden operation of nearby elements, such as load switching, reactive plant switching, loss or opening of a circuit etc; and
- EMT – Single Pole Auto Reclose (SPAR) evaluation where so used/implemented in the power system in the electrical vicinity of the proposed connection;

- Equipment specifications for the GS, including auxiliaries that details the voltage operating capability.
- If plant control systems are used, the assessment must consider the effect of central plant controls on the overall GS performance.
- If plant has a switchable voltage control strategy active within the timeframe under consideration, details of any logic, modes and references that are actioned (including OLTC, reactive plant and voltage control mode logic).
- The assessment will consider if any ancillary plant (such as static synchronous compensator (STATCOM)) can also withstand a voltage disturbance.
- Model/data validation benchmarking for PSS®E and PSCAD™/EMTDC™ (including mapping of parameters between the control/protection systems and RMS-EMT models).

Operational arrangements to meet the proposed levels of performance must be described in the proposed access standard and included in the assessment.

3.5 [Clause S5.2.5.5] Generating system response to disturbances following contingency events

3.5.1 General

A GS's ability to ride through disturbances and support power system disturbance recovery is critical in preserving power system security. The technical requirements specified in clause S5.2.5.5 require GS performance in response to disturbances, including network faults and contingency events. This includes a requirement that a GS remain in operation following the occurrence of both nearby faults and remote faults, or operational loss of power system elements, external to the GS.

Assessment of a proposed access standard requires time domain dynamic studies showing the GS's (and each of its GUs) ability to remain in CUO for the range of faults described in clause S5.2.5.5. Studies are expected to cover a range of operating conditions, including as a minimum:

- Maximum power generation of the GS in the over-excited and under-excited regions.
- Light, medium and high regional demand.
- High and low level of interconnector transfer conditions.
- Lowest system strength conditions (i.e. with the minimum in-service elements/generators providing system strength support).
- For battery energy storage systems, all the above when importing and exporting active power.

Fault simulation studies must demonstrate the following performance (for the automatic access standard):

- Supply of pre-disturbance reactive current during the fault or, if greater, reactive current equal to 4% of maximum continuous current for each 1% reduction in the connection point voltage.
- Absorption of pre-disturbance reactive current during a fault or OV, if greater, reactive current equal to 6% of maximum continuous current for each 1% increase in the connection point voltage.
- The achievement of 95% of the pre-fault active power output within 100ms of fault clearance.

Operational arrangements to meet the proposed level of performance, under both normal and abnormal network or GS conditions, must be described in the proposed access standard and included in the assessment. This includes, for example:

- Control settings for GU.
- Transformer tap changers.
- Reactive plant equipment.
- Central plant control system (including coordination with multiple generation types for hybrid installations).

Any settings required to meet the proposed access standard must be consistent with the requirements of all other access standards, particularly reactive capability under NER clauses S5.2.5.1 and S5.2.5.4. The dynamic models must have all applicable limitations for FRT assessment, including limits associated with reactive current injection or absorption capability and GU/GS protection mechanisms, and control system communication delays (such as between inverters and park controllers).

The assessment must also consider the expected range of power system operating conditions and the expected performance of:

- existing networks, existing GSs and relevant projects; and
- control systems and protection systems, including auxiliary systems and automatic reclose equipment (any required modifications to control systems or protection systems should form part of GS connection works).

The GS performance against the proposed access standard must demonstrate that the plant meets the CUO requirements – i.e. not exacerbate disturbances or cause other GSs or loads to trip as a result of an event for which they would not otherwise have tripped. This could be due to:

    - Current blocking or current reduction (active and reactive current) during the disturbance.
    - Active power absorption during and on clearance of faults.
    - Active power reduction not being in proportion to retained voltage.
    - Improper control of active current (power) recovery.
    - Improper control transitioning (e.g. without control reset) of the asynchronous plant from its LVRT or HVRT mode onto central control system and introduction of additional post fault reactive power, active power or voltage disturbance.
    - Loss of converter stability.
    - Multiple LVRT and HVRT activations due to power system weakness (collectively depending on the size of the GS with respect to available short circuit current capability at the connection point) and insufficient reactive power capability to maintain voltage at the connection point.
    - Intertrip schemes.

Lack of capability

Where GUs alone lack the capability to meet the appropriate level of performance, additional consideration in the design is required. This may include:

- Additional dynamic reactive power – voltage support and control capability.
- Additional control system development or tuning to meet contingency ride-through requirements.
- Use of grid forming capable technology that does not rely on system fundamental waveforms to be provided from synchronous generation.
- Additional equipment to address the GU's ability to withstand voltage-phase angle changes

- Additional equipment to ensure “no harm” and no adverse impact on the network and other network users.

System strength remediation

Applicants proposing system strength remediation schemes must satisfactorily demonstrate the impact of the proposed scheme and the performance of their GS under the circumstances for which those schemes are expected to apply.

3.5.2 Requirements for assessment purposes

The technical requirements under clause S5.2.5.5 may be grouped into the following main areas for assessment purposes:

- GS activation/deactivation of its response to OV and UV events.
- GS performance in the provision of required reactive current support.
- GS active power recovery.
- GS robustness to meet multiple voltage disturbance events.

Response activation thresholds and performance during disturbances

Synchronous GUs must contribute to reactive current responses that may be limited to 250% of the GS’s maximum continuous current, and asynchronous GSs may be limited to the maximum continuous current. Asynchronous plant must maintain its rated apparent power for OV exceeding 115% (or as agreed with AEMO and the NSP) and achieve current availability of maximum continuous current for voltages less than 85% (or as agreed with AEMO and the NSP).

In all assessments, the capabilities are to be specified at the connection point (unless otherwise agreed with AEMO), and assessments must include an analysis of GU and GS performance. With “hybrid” connections, e.g. batteries with solar PV or wind turbines, the capabilities of each GU are expected to be specified/ demonstrated at its terminals separately from the GS performance specified/demonstrated at the connection point taking into account plant losses and control performance impact of each type of technology. Unless otherwise agreed with AEMO, the reactive current contribution is based on RMS positive sequence voltage.

Table 3 Performance requirements during and following disturbances

Item	Automatic	Minimum	Comment
UV Activation Response	85-90%	80-90%	Threshold of normal voltage
UV Deactivation Response	90%	90%	Threshold of normal voltage
OV Activation Response	110-115%	110-120%	Threshold of normal voltage
OV Deactivation Response	110%	110%	Threshold of normal voltage
Reactive Current injection for UV Response	4%	2%	Per 1% voltage reduction
Reactive Current absorption for OV Response	6%	2%	Per 1% voltage rise
Rise time for Reactive Current Response	40ms	40ms	Where sustained response is ≤ 2sec, otherwise as practicable
Settling time for Reactive Current response	70ms	70ms	Where sustained response is ≤ 2sec, otherwise as practicable
Post-disturbance Active Power Recovery	100ms to 95%	As agreed	

Capability to sustain and respond to multiple disturbances

These requirements apply to both synchronous and asynchronous plant for which CUO assessments cover the items listed in Table 4.

Table 4 Performance requirements for multiple disturbances

Requirement	Automatic	Minimum
Number of recurring disturbances	15	6
Time	5 min	5 min
Sliding window time	Yes	NO sliding time window. Only 30 min grace period following a 5 min period of multiple disturbances
Cumulative time of voltages < 90% or sum of ΔV x Δt (pu.second)	1800ms or up to 1 pu.s	1000ms or up to 0.5 pu.s
# of disturbances where Volts at connection point < 50%	6	3
# 3 phase faults where ARC is applied (otherwise)	2 (1)	nil
# faults cleared by a CBF	1	nil
# of disturbances where voltage varies within ranges specified in clause S5.2.5.4(a)(7) and (8)	1	1
Recurring disturbance time	≥ 0ms	>200ms
Maximum # disturbances within 30 sec	Any, unless multiple disturbance requirements are exceeded	3
All other disturbances	Other than 3 phase faults	Other than 3 phase faults

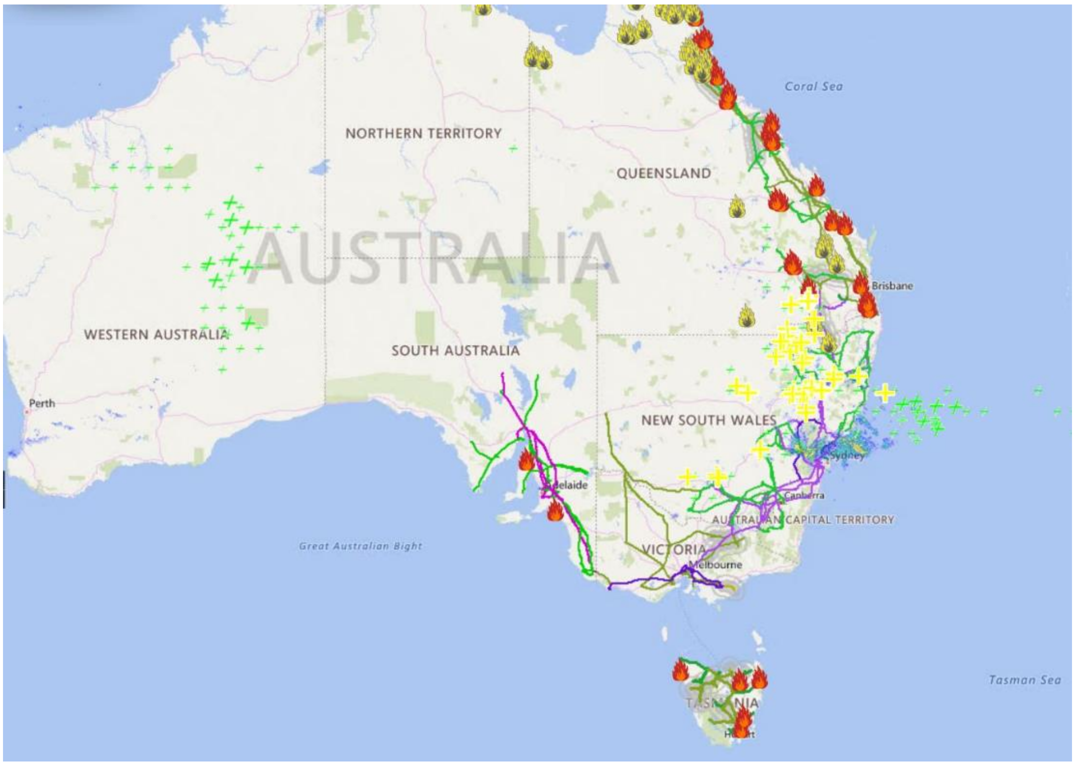
Practical approach

Multiple voltage disturbances could result from weather events that expose the operational integrity of one or more GSs and the networks in the NEM[19]. These events may be driven (for example) by storms (strong winds, lightning strikes) or bushfires that create successive disturbances across the power system or parts of the network.

Figure 1 illustrates an operational situation in the NEM on 10 October 2018 indicating cloudy/stormy or rainy conditions near Sydney (light blue), an electrical storm in northern NSW indicating lightning (yellow and green crosses) concurrent with bushfires (red/orange) in Queensland, Tasmania and South Australia, all at the same time and in the electrical vicinity of the HV transmission system (green and purple).

[19] Multiple disturbances could also occur during calm weather conditions due to multiple electrical failures (including as a result of aging infrastructure)

Figure 1 Record from AEMO Control Room on 10 October 2018



The purposes of multiple ride through voltage disturbance assessment are:

- To confirm the conditions under which a GS can sustain, support and is protected from.
- To achieve robust performance for power system security needs when multiple voltage disturbances occur.

Is the intention to achieve compliance resulting in N-6 or N-15 network configuration?

Generally not, however, power system conditions can exist for which N-1 conditions are exceeded. Examples include a disturbance affecting single tower/double circuit transmission elements or resulting network conditions following (prior) element outages.

In preparation for this assessment, it is expected that the NSP will provide the Applicant with auto-reclose relay settings (where present) for the MFRT assessment.

The existence of N-n conditions may apply:

- To the extent that the GS is not islanded.
- SCR available to the GS is not below the stated SCR withstand capability.
- Voltage and frequency at the GS connection point without the GS being connected are within an acceptable range.

What if the proposed connection is in a remote area or supplied mainly by a long radial network connection?

Unless the GS is islanded, the integrity of the GS ride through capability will mainly be influenced by remote events expected to result in shallower retained voltage profiles at the connection point. If the radial line connection includes a SPAR, a SPAR event must be considered as part of the assessment.

Is the Applicant still required to undertake single disturbance ride through type assessment?

Yes, even though automatic reclosing may be provided to support power system security and used for MFRT assessments, the power system must be planned for stability purposes without reclosure. Likewise, if as a result of a proposed generating facility, auto-reclose results in an unstable response, the dead-time for auto-reclose may need to be increased (changed) to maintain power system security. This, however, may be subject to protection scheme design with the involvement of the NSP and AEMO.

In some distribution systems a single fault could be at least 2 seconds and exceed the time integral of 1800ms or (1000ms for the minimum access standard, see Table 3). In these cases, the plant still needs to ride through a single long-duration fault.

Could UV relay settings be sufficient to demonstrate multiple UV ride through capability?

Only in part. The access standards do not specify the minimum time of recurring disturbances due to their inherent randomness (e.g. lightning strikes), however, they specify that recurring disturbances could be 0 ms apart.

Assessment must consider a range of disturbances, including recurring events with and without any delays, and the GS's own protective elements (including thermal and mechanical susceptibility to MFRT events), rather than just an assessment against UV relay settings. These protective elements may range from pole slip protection, thermal limits associated with heating/cooling of GU components, rotor-speed protection for wind turbines, level of energy dissipation in wind turbine chopper etc.

What if application of a disturbance or clearance of a disturbance results in OVs?

If there are OV limitations (or protection counts) associated with multiple OV disturbance occurrences, the Applicant must state those limits and provide information on the effect of OV ride through capability, to be covered in the assessment under clause S5.2.5.4.

The Applicant must provide a model that accounts for any such settings and limitations. The assessment that an Applicant carries out must account for all possible inter-relations and susceptibilities at the proposed connection point.

How could multi-disturbance ride through capability be summarised?

The following tables summarise GS/GU MFRT capability.

Table 4 could be used by the OEM or the Applicant to state plant capability based on the type, FAT or assessment of plant firmware, and considering the connection point characteristics.

Table 5 MFRT table based on fault durations and stated delays between successive disturbances (applicable to RMS / EMT studies assessment)

Capability: number of successive LVRT events							
Retained Voltage [pu]	Fault duration [ms] with (to be nominated) delay(s) between successive disturbances						
	80ms	100ms	120ms	175ms	220ms	430ms	other
0.8							
0.7							
0.6							
0.5							
0.4							
0.3							
0.2							
0.1							
0							

Table 5 can be used in consideration of the connection point and how MFRT applies in the surrounding circumstances. A list of faults, fault durations and delays between them must be provided to AEMO for review.

Table 6 MFRT table based on applicable OPDMS network data/locations and network faults taking into consideration cumulative and integral time limitations

Capability: number of successive LVRT events							
Retained Voltage [pu]	Fault Type [total of 15 / unless exceeding cumulative/integral times of 1800ms or 1pu.s]						
	1PHG	2PHG	2PH	3PHG	CBF	S5.2.5.4(a)(7) & (8)	Total #Faults
0.8							
0.7							
0.6							
0.5							
0.4							
0.3							
0.2							
0.1							
0							
Total							[15 max]

This table is to be applied in consideration of the actual connection point using AEMO's OPDMS data (applicable to RMS/EMT studies - assessment).

Importance of models

Models must be checked against the stated capability to ensure consistency for which the GS and GUs remain in operation and conditions for which they do not. Models must include protective elements (protection systems) to enable validation of stated performance. Models with separately stated performance (not included in the RMS/EMT software) are unlikely to comply with the *Power System Model Guidelines* and AEMO will not be able to assess the proposed access standard.

Some examples of protective mechanisms that AEMO expects to be included in the assessment include pole slip protection, rotor speed protection, UV, OV, UF and OF limitations, protection due to heating of resistive or inductive components, and any others where multi-disturbance limitations are driven by count mechanisms (as occurred across many GSs prior to the South Australian black system in September 2016). Provision of models representing only a current source platform, excluding its machine, DC link (for asynchronous plant), and necessary protective mechanism, which are critical for ensuring adequate assessment of MFRT capability, will not comply with the *Power System Model Guidelines* nor the assessment requirements for this access standard.

Suggested assessment pathway

1. Obtain Applicant (or OEM) information considering:
   - Statement and a test report from the OEM/ Applicant indicating equipment capability to sustain successive FRT events substantiated with the technical evidence, e.g. FAT or type test verification of FRT and MFRT (and their validation).
   - Description of protective elements, including settings that may trigger GU trip/stops for multi-disturbance events (examples include resistor/chopper heating, rotor speed acceleration/limits, auxiliary system).

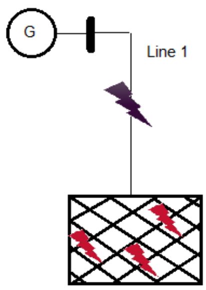
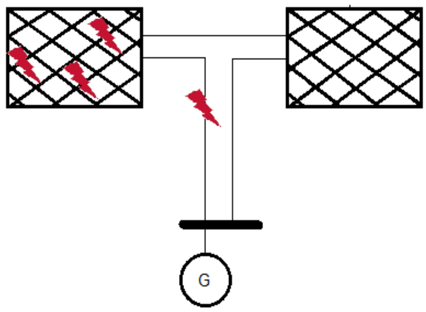
- Inclusion of limits or limiting functions in RMS/EMT models (including FAT or type test reports for validation)
- Confirmation that RMS and EMT models include reactive current limitations as per plant firmware for single and MFRT events.

2. On a SMIB case[20] taking into account the proposed GS layout and system strength at the connection point (RMS and EMT models):
   - Application of a voltage/disturbance or playback with different retained voltage levels (as a minimum, suggested levels are 80%, 50%, 25% and 0%):
   - Benchmarking of PSS®E and PSCAD™/EMTDC™ results for balanced disturbances.
   - Confirmation of FRT response activation and de-activation threshold if applicable (including settings).
   - Demonstration of reactive current injection capability.
   - Demonstration of rise and settling time on a SMIB case, excluding the influence of the NSP's network.
   - For OV events, demonstration of capability to maintain rated apparent power of the GS.
   - For UV events, demonstration of capability to make available maximum continuous current of the GS (these are expected to be demonstrated via $I_{total} = \sqrt[2]{I_{active}^2 + I_{reactive}^2}$ on a SMIB and on a network case (including results explicitly showing I_{total}, I_{active} and $I_{reactive}$ in addition to active power, reactive power and voltage) for each case).
   - Demonstration of active power recovery:
     - Demonstration of active power reduction in proportion to retained voltage.
     - Demonstration there are no adverse active power responses which exacerbate disturbances.
   - Validate RMS/EMT models against the stated MFRT capability to test for conditions for which it should and should not trip
3. Considering the proposed connection point and AEMO OPDMS data (Note: confirmation of SMIB observed capability is expected using OPDMS data taking into account connecting network characteristics for which RMS and EMT modelled assessments are carried out):
   - As a minimum the assessment must consider peak and light load conditions.
   - Obtain and confirm auto-reclose times and mechanisms for nearby circuits.
   - Obtain confirmation of any intertrips or other protection schemes that may need to be considered.
   - Set up a list of all faults and fault types taking into consideration the practicality of the assessment, e.g. see "Practical Approach" and Figure 1 example. The assessment must consider both close-up and remote events, each emulating as an example "electrical thunderstorm" sweeping through a region.
   - Set up a sequence of fault occurrences and time delays between faults used in the assumptions where some faults may occur immediately after each other, and others with a delay between each fault. The intention is not to create N-15 (or N-6) situation, however, part of the assessment may lead to an indication of when the GS is islanded or no longer able to support the power system. For these reasons, it is important to note auto-reclose characteristics of the NSP's network and use discretion in demonstrating the ride-though capability considering the possibility of a disturbance recurrence immediately or following a delay.

[20] A SMIB case may be used in the initial assessment step which could help confirm capabilities without the influence and variations of the external network. With the use of AEMO's OPDMS data, the Applicant is then required to confirm these capabilities with the application of disturbances in the power system network itself.

- Results may cover a couple of assessment variants of close-up and remote faults surrounding the connection point. At least 5 sequences (of fault disturbance combinations) are suggested for consideration and provision to AEMO for review.
- It is also required to study a case where the GS should not ride through and does not ride through.

An illustrative example is provided below.

	
Fault application on Line 1 would cause Generator G islanding, however, this should not prevent MFRT assessment. In this instance, remote disturbances could be evaluated.	Application of faults in the network including a fault that directly disconnects Generator G to that part of the network. The sequence of fault application may result in: a. faults resulting in a mid-range retained voltage at connection point of Generator G, followed by shallow voltages at Generator G on the occurrence of a close-up fault resulting in faulted line disconnection; or b. close-up fault resulting in deep voltage disturbance at Generator G terminals, and following up on faulted line disconnection, the remaining regional faults may be perceived as shallower events until the faulted line recloses.

- For the applied voltage disturbances, records of applied voltage at the connection point may be collected (with the GS disconnected). The waveform could be used as a playback in EMT/RMS SMIB case to validate and add other aspects of disturbances, e.g. those referred to in clause S5.2.5.4(a)(7) and (8), different fault combinations etc, noting that such prolonged voltage sags may be difficult to create considering the connection point characteristics and architecture of the NSP's network. Whilst this approach may not take varying system strength into consideration, however, it might aid the Applicant/OEM in ensuring the equipment ratings or protective elements are designed and sized properly in consideration of "reasonable" voltage disturbance profiles applicable to the connection point.

4. The application of both RMS and EMT platforms is expected in the evaluation of this access standard regardless of system strength conditions. Taking into account that EMT network information might not be available to the Applicant, and network-based EMT modelling is required, the Applicant and the NSP (and AEMO) will need to agree on the process, assumptions and timeframe to assess the contingencies of concern.

Tables 3 and 4 should be used to aid in the presentation of the results/capability summary and included in the proposed access standards.

Post-connection: Review of Applicant's R2 data and model validation as part of the compliance plan (capturing system incidents when they occur to demonstrate compliance with the relevant performance standard and model accuracy).

3.6 [Clause S5.2.5.6] Quality of electricity generated and continuous uninterrupted operation

The NER specifies a minimum access standard only for this requirement.

The Applicant must confirm that the GS can remain in CUO for the assigned limits for voltage fluctuation, harmonic voltage distortion and voltage unbalance at the connection point. The Applicant must confirm its protection system settings, in particular, those that relate to current asymmetry or unbalance that can be tolerated by the GU and GU auxiliary systems, including pumps, cooling systems, and yaw gear motors that could suddenly stop the plant from operating.

Furthermore, the Applicant must confirm through adequate resonance studies that there are no adverse coupling effects or converter instability (for asynchronous generation) that may result in voltage fluctuations, distortion and unbalances above the levels specified in NER clauses S5.1.a.5, S5.1.a.6 and S5.1.a.7 resulting in unstable active power and reactive power of voltage at the connection point.

The Applicant must provide study reports or evidence on how the GS will remain in CUO for the assigned levels.

3.7 [Clause S5.2.5.7] Partial load rejection

These technical requirements consider the ability of a synchronous or asynchronous GS to remain connected during and following the loss of power system load. A load rejection event could be expected to result in an increase in power system frequency, so aspects of this requirement overlap with clause S5.2.5.3 (and clause S5.2.5.8), but this requirement is intended to ensure that GS controls do not move in the wrong direction in response to a sudden frequency change, which means that aspects of clause S5.2.5.11 must also be considered.

To assess compliance, the following is required:

- Time domain dynamic studies showing the GS's ability to remain connected for a load rejection event. These studies must include any active power control models. Modelling of the load rejection event must be appropriate to the GU technology. For example, the following methodologies may be applied:
  - OPDMS network case via application of appropriate load contingency.
  - A large synchronous GU could be modelled supplying load in isolation from the rest of the power system, with this load stepped or ramped to simulate the partial load rejection.
  - An asynchronous GS could be modelled connected to a controllable voltage source behind the power system impedance at the point of connection. The frequency of the controlled voltage source could then be ramped up to the maximum level for which the GS must remain connected under clause S5.2.5.3. This assessment is supplemented via EMT-SMIB playback of the recorded voltage and frequency signals from OPDMS network case. The reduction in MW output from the GS must be assessed against the requirements of clauses S5.2.5.8 and S5.2.5.11.
  - Commissioning procedure/tests, including demonstration of response to frequency injection at the plant level.

3.8 [Clause S5.2.5.8] Protection of generating systems from power system disturbances

These technical requirements consider the performance of protection systems that disconnect and prevent damage to a GS from a power system disturbance, including the frequency protective mechanisms through which the GS can reduce its power output following OF events in the power system. Parts of this access standard could overlap with those in clause S5.2.5.11 and S5.2.5.3.

To assess compliance, the following is required:

- Protection system settings design report, inclusive of:
  - One or more protection single line diagrams (SLDs) detailing all relevant protection circuits, circuit breaker tripping logic with relevant X and Y schemes implemented within the GS.
  - A protection design report that includes:
    - the derivation of individual protection element pickups and operating times; and
    - confirmation that fault clearance trips specified in NER Table S5.1a.2 can be achieved.
  - Assessment of the suitability of chosen protection current transformers (CTs).
  - Confirmation from the NSP (by letter) of a coordinated design for the interface between the GS and the NSP's network.
- Connection study report, which includes a demonstration of power reducing capability for OF events, for both RMS and EMT models. A study may be performed on a SMIB network representation.

Applicants with asynchronous plant must confirm whether there are any coded converter or controller implemented disturbance counts that may cause GS (and GU) stops as a result of power system disturbances, including the following:

- Description and mechanisms for UV and OV counts-programmed capabilities.
- "Error" lists for which the GU or GS stops operating to isolate itself from external network disturbances.

During the assessment, consideration must be given to whether there is a requirement for a local or remote control scheme to automatically disconnect the GS under an islanding condition.

The proposed access standard must describe all conditions for which the GS must, and must not, trip.

3.9 [Clause S5.2.5.9] Protection systems that impact on power system security

These technical requirements consider the performance of protection systems that influence GS performance, the ability of the GS to meet other access standards, and thereby the impact on power system security. Details of the protection system must be provided for assessment to support AEMO's review of the proposed access standards under clauses S5.2.5.8 and S5.2.5.9, including the design report, SLDs, and confirmation the design is coordinated with the NSP's protection systems.

3.10 [Clause S5.2.5.10] Protection to trip plant for unstable operation

These technical requirements consider the performance of protection systems that prevent an active power, reactive power, or voltage instability at the connection point, for example:

- A pole slip for a synchronous GU.
- Transformer (and Plant Control) Hunting.

- Unstable converter/controller resonance/undamped oscillations in power, reactive power or voltage and a loss of control in the case of an asynchronous GU or asynchronous GS.

Part of this assessment is expected where system strength remediation options include inter-trips to isolate an unstable GU from the network.

The Applicant must provide details of the protection system design, which may overlap with the information supplied for assessment of the proposed access standard under clause S5.2.5.8. For all network connections (including for prior planned and unplanned outages) the assessment must confirm adequate resonance studies demonstrating that there are no adverse coupling effects or converter instability (in case of asynchronous generation) that may result in unstable active power and reactive power of voltage at the connection point.

As a result of the assessment, the NSP or AEMO may require installation of a protection system to prevent consequential tripping or damage to other GUs, the network, or the facilities of other network users, or to prevent unstable operation with an adverse impact on power system security (e.g. sub-synchronous resonance relay). AEMO must be advised by the NSP/Applicant of results considering both N-1 and N-1-1 system conditions (i.e. network configuration considering prior outage). Where sub-synchronous resonances occur in the assessment of this proposed access standard, the Applicant/NSP must consider the following, at least:

- application of protective sub-synchronous resonance protection; and
- pre-contingent active power curtailment where sub-synchronous resonance studies yield unstable or undamped active power, reactive power or voltage at the connection point,

and provide results of these studies to AEMO for review.

The design report must explain the derivation of settings that, in the case of instability at the connection point, may require time domain dynamic studies. For a GU with a pole slip protection relay, this would be an RX plot of the impedance seen by the pole slip protection relay during the fault/contingency conditions specified in clause S5.2.5.5, superimposed on the protection relay operating characteristic.

Where a proposed access standard is below the automatic access standard, agreement must be reached by all parties for the protection system to trip any other part of the GS to stop the instability. Proposals to trip the plant as a result of power system weakness and inadequate plant design (resulting in unstable voltage, reactive power or power control) to offset its dependence on the provision of system strength from external sources, might not be approved by AEMO as a system strength remediation scheme. For example, clause S5.2.5.10 does not circumvent the requirement to ride through disturbances.

3.11 [Clause S5.2.5.11] Frequency control

Frequency control capability is mandatory from 5 October 2018, and Applicants must provide evidence of frequency control capabilities for assessment.

These technical requirements consider the performance of the frequency control system and the ability of the GS to increase or decrease its active power output in response to a power system frequency event.

The NER require GSs to:

- deliver capability for all FCAS (automatic access standard); or
- have sufficient capability to operate in frequency (proportional) response mode with responses agreed with AEMO (minimum access standard).

To assess compliance, the following is required:

- Details of the control system, in particular, control block diagrams, operating modes topology, control system time constants, droop settings and operating deadbands (positive and negative).

- Time domain dynamic studies showing the active power response to changes in power system frequency for both RMS and EMT models.
- Commissioning procedure/tests, including demonstration of response to frequency injection at the plant level.
- Review of the Applicant's R2 data as part of the compliance plan-site tests (including capturing of measurements from system incidents (when they occur) to demonstrate compliance with the relevant access standard and model accuracy)
- RMS and EMT models and demonstration of performance on a SMIB case as well as with wider network representation, e.g. AEMO's OPDMS network information. Network studies are required to ensure to demonstrate the effect of GS droop settings, including demonstration that the response is adequately damped.

Consideration must be given to ensure any FCAS to be provided by the GS does not exceed those that would be consistent with the proposed access standard. Some aspects of this requirement overlap with clauses S5.2.5.7 and S5.2.5.8.

Where a proposed access standard is below the automatic access standard the Applicant must demonstrate that the increase or decrease in active power transfer is as close as practicable to the automatic access standard. It must also include the agreed values for maximum and minimum operating levels.

3.12 [Clause S5.2.5.12] Impact on network capability

These technical requirements consider the impact of the GS on inter-regional and intra-regional transfer capability.

With the operating reduction of GSs equipped with an excitation control system and power system stabilizers (PSS) found in synchronous generation, network capability is influenced by the emerging mix of asynchronous generation that broadly comprises converter interfaced technologies, such as full scale converter interfaced battery system, full scale converter interfaced wind turbines, doubly-fed wind turbine GUs (i.e. with a partial converter system) and full converter interfaced solar PV GSs.

Considering the provision of system strength on which some GSs may rely on, the proposed access standard must be supported by a demonstration of any system strength remediation scheme, inter-trip or runback schemes on inter-regional or intra-regional power transfer capability below the level that would apply as if the GS were not connected.

To assess compliance, the following is required:

- Steady state load flow and time domain dynamic studies showing the impact of the GS on key inter-regional and intra-regional transfer limits. TNSPs can advise on key limitations to be considered for a given inter-regional or intra-regional transfer, be it a voltage or transient stability limit, or a thermal limitation. As TNSPs are familiar with the modelling assumptions used to derive network operating limits, the assessment is often undertaken by the TNSP.
- Frequency domain (small-signal) studies showing the impact of the GS on key inter-area modes, as small-signal stability can restrict inter-regional transfer, and is of concern for AEMO, where some aspects of this requirement overlap with the requirements under clause S5.2.5.13.

Studies are expected to cover a range of operating conditions, including, as a minimum:

- maximum power generation in the over-excited and under-excited region;
- light, medium and high regional demand;
- high and low level of interconnector transfer conditions;
- minimum amount of synchronous generation;
- the performance of:

- existing networks, existing GSs and other relevant projects (as agreed with the NSP and AEMO to form part of the assessment, e.g. other committed or considered projects); and
- control systems and protection systems, including auxiliary systems and automatic reclose equipment;

- whether a control system could minimise any reduction in power transfer capability; and
- whether operational arrangements are necessary to ensure that the GS is operated to meet at least the minimum access standard under abnormal network and GS conditions, so that power system security can be maintained.

The assessment must be carried out using both RMS and EMT software to confirm there is no adverse power system operation associated with abnormal and unbalanced power system events, control interactions or control instabilities associated with converter equipped technologies that may influence inter-regional and intra-regional transfer capability.

Where a proposed access standard is below the automatic access standard and a control system to minimise a reduction in power transfer capability has been included, the agreed GS capabilities, control systems and operational arrangements to be maintained by the Applicant must be detailed in the performance standard.

3.13 [Clause S5.2.5.13] Voltage and reactive power control

These technical requirements consider the performance of the voltage, PF and reactive power control system, and the ability of the GS to increase or decrease its reactive power output in response to a power system incident and to support network voltage through changes in the control system reference points. This requirement overlaps with the requirements under clauses S5.2.5.1 and S5.2.5.12, and control mode settings may have an impact on the assessments associated with the proposed performance under clauses S5.2.5.4 and S5.2.5.5.

NSPs and AEMO require both RMS and EMT models to be provided and verified against this access standard, including the benchmarking of both platforms. An Applicant must provide a voltage control strategy for the GS, which includes:

- Connection controlled point (including a primary electrical SLD with a description of the location of GS CTs/capacitor voltage transformers (CVTs) used for the plant controller).
- Operating principles of park controller, as well as primary and secondary response controls (e.g. OLTC systems, reactive plant).
- Control Block Diagram of all operating voltage control modes clearly indicating input time delays, filtering, control gains, limiters, resets and computed output signal dispatched to all GUs (including ancillary plant)
- For hybrid systems, this must include details of each control system, overarching park controllers, operating modes and communication delays.
- Details of control system redundancy (if used) and any control system switchovers in topologies.
- Explanation and modelling studies showing how the GS reaches its maximum and minimum PF operating levels (as required by clause S5.2.5.1) and demonstration that reactive power levels are sufficient to allow the voltage setpoint to be continuously controllable in the range of at least 95% to 105% of the target voltage (automatic access standard).
- SCADA signal list (relevant to voltage and reactive power-PF control) that the NSP and AEMO can use to instigate remote control change in setpoints.

Assessment requires details of the voltage, PF and reactive control system, time domain dynamic studies in RMS and EMT software that demonstrate the adequacy of the voltage, PF and reactive control systems and is consistent with typical commissioning tests, and frequency domain (small-signal) studies.

For a synchronous GU, details of the voltage (PF and reactive control system) must be in the form of an excitation system design report that includes a block diagram and the derivation of key control system parameters. The coordination of excitation limiters with protection can be covered in the excitation system design report, or in the protection design report required for assessing the proposed access standard under clause S5.2.5.8. Where a PSS is to be installed, details on how the design parameters were determined is also required.

For an asynchronous GS, details of the voltage, PF and reactive power control system must include a block diagram and the derivation of key control system parameters for individual component voltage, PF and reactive power control and, where installed, the overall coordinated park voltage, PF and reactive power control scheme.

The time domain dynamic studies must demonstrate the adequacy of the voltage and reactive control systems. For a synchronous GU, this would include, though not be limited to, step and voltage disturbance response studies with the following:

- The GU unsynchronised, demonstrating adequate damping.
- The GU synchronised, demonstrating adequate damping with steps proving the performance of both over-excitation and under-excitation limiters.
- Excitation/voltage control sensitivity, rise time and ceiling voltage (field voltage and field current).
- Demonstrating operation of the GS does not cause instability that would adversely impact other Registered Participants.

For an asynchronous GS this would include, though not be limited to, step response and voltage disturbance studies with the following:

- Voltage setpoint reference steps into the GS voltage control scheme.
- PF setpoint reference steps into the GS PF control scheme.
- Reactive power setpoint reference steps into the GS reactive power control scheme.
- Induced voltage disturbance at the connection point, assessing the response of each control scheme.
- Validation of plant control transfer function (for RMS and EMT models) taking into account input references and output (dispatch) points.
- Demonstrating operation of the GS does not cause instability that would adversely impact other Registered Participants.

The frequency domain (small-signal) studies must show:

- Inter-area and local modes of oscillation are adequately damped.
- Operation of the GS does not degrade the damping of inter-area and local modes of oscillation.
- The damping performance of the PSS (if installed).
- No adverse impact on the stability of other network users' plant.

System strength remediation or control interaction

To assess whether the GS could cause another GS to become unstable, details of system strength remediation are required (if applicable).

Interface with the connecting NSP

Confirmation from the NSP is required of a coordinated design between the GS and any existing NSP voltage control schemes and dynamic plant in the surrounding network.

3.14 [Clause S5.2.5.14] Active power control

These technical requirements consider the ability of a GS to increase or decrease its active power transfer in response to a dispatch instruction from AEMO. AGC capability is mandatory for all scheduled and semi-scheduled plant.

Details of the active power control system must be supplied, including:

- ramp up and ramp down capability [e.g. expressed in MW/min] including maximum and minimum possible achievable ramp rates;
- a control block diagram of the overall active power control scheme (including PI control parameters where used); and
- a qualitative description of the active power control system and its dispatch logic with sufficient detail to allow AEMO to understand how the GS will respond to dispatch.

For hybrid connections involving any combination of wind turbine technology, battery and solar PV, a control logic (and a block diagram including its settings) for each local controller is required in addition to the overall control scheme. The Applicant must provide a description of active power control automation and the GS's dispatch logic considering each of the GUs/loads.

Demonstration of performance against this access standard requires a SCADA signal list inclusive of GS ramp rates (as required by clause S5.2.6.1) and the test of signals (send-acknowledge-receive, also known as end-to-end signal test) pre-energisation and immediately post energisation.

3.15 [Clause S5.2.6.1] Remote monitoring

These technical requirements consider the level of remote monitoring equipment and remote control equipment required for AEMO to discharge its market and power system security responsibilities.

To assess compliance, the following is required:

- A review of the SCADA points list to be supplied to AEMO by the Applicant (sufficient for forecasting, EMS SCADA system modelling, dispatch and VAR dispatch scheduling systems);
- Confirmation that the Applicant's communications facilities meet AEMO's *Standard for Power System Data Communications*[21]; and
- Testing (following physical implementation) to ensure that the information is being transmitted and received correctly. Tests are expected both pre- and post-energisation.

3.16 [Clause S5.2.6.2] Communications equipment

These technical requirements consider the telecommunications between the control centres of each of the Applicant and AEMO for the purposes of operational communications, and the electrical supply to the installed remote monitoring and control equipment.

To assess compliance, the following is required:

- Design details of the communication facilities to be installed. This may include schematic diagrams and a qualitative description of the communication facilities with sufficient detail to allow AEMO to understand the nature of communication facilities being installed.
- Design details on the effect of back-up supplies considering the loss of supply from the connection point, which may include, for example, Amp-hours rating (hours) for the substation battery bank supplying essential/non-essential load, diesel generator, details of uninterrupted power supply (UPS) in GUs.

[21] Available at: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Network_Connections/Transmission-and-Distribution/AEMO-Standard-for-Power-System-Data-Communications.pdf

3.17 [Clause S5.2.7] Power station auxiliary supplies

These technical requirements consider how a GS obtains auxiliary power.

The Applicant must advise AEMO on how power is supplied to the auxiliary load of its GS. Where active power is supplied from an alternative connection point to that through which a GS's active power is transferred, an additional performance standard must be established under clause S5.3.5.

The Applicant must provide a primary SLD showing the connection arrangements, auxiliary loads and how the auxiliary power is supplied. For hybrid connections (any combination of battery (charging and discharging), wind and solar PV technology), a SLD together with a description (GS operating protocol) of any switching or operational arrangement must also be provided describing the plant operation.

3.18 [Clause S5.2.8] Fault Current

These technical requirements consider the fault current contribution of a GS to the connecting network, and the fault current withstand of the GS and those circuit breakers used to isolate it from the network.

To assess compliance, the following is required:

- Maximum and minimum fault levels at the point of connection.
- Maximum and minimum fault levels in the wider network.
- GS equipment specifications for required fault withstand capability.

The Applicant/NSP also must ensure that:

- Protection setting details provided for assessment of the proposed access standards under clauses S5.2.5.8 and S5.2.5.9 are appropriate for the equipment ratings.
- The agreed fault contribution from the GS will not result in the fault withstand capability of the surrounding network to be exceeded.

In determining the design adequacy of GS equipment, it is expected that the Applicant and NSP would exchange information concerning the effect of supplying grid contribution, or ultimate fault levels for equipment, and reticulation system – cable design.

AEMO requires that modelling (RMS and EMT- SMIB) will confirm the expected current contribution and that the Applicant provides the following information for completeness:

- GU short circuit current limitations/capability.
- Description of GS for short circuit representation including its sequence components.
- Results of the EMT and RMS models against the stated short circuit contribution (balanced and unbalanced faults), taking into account transformer vector groups within the GS.

3.19 Additional information regarding Schedule 5.5.4

NER Schedule 5.5.4 includes a requirement to specify the SCR for which the GS and its control systems are designed and will be commissioned to maintain stable operation, and the Applicant must confirm it has the design capability to maintain stable operation.

To support this requirement, AEMO requires an OEM statement of the GS's equipment capability for operation in low SCR conditions for which the chosen technology and control systems can:

- Export power to its rated output.
- Satisfy requirements of grid FRT (consistent with changes that may result from application of a fault – e.g. see clause S5.2.5.5).

- Respond to jumps or fast changes in voltage and frequency, consistent with the requirements under clause S5.2.5.3, S5.2.5.4 or S5.2.5.13 in achieving stable CUO, not losing control or resulting in undamped responses.

Taking into account the declared SCR capability, if there are circumstances that may impact AEMO's ability to meet its power system security responsibilities, AEMO may constrain the generation by reason of the GS's dependency on system strength from third parties when this system strength is not available at the GS's connection point (including constraining on the basis of pre-contingent assessments).

These assessments take into account whether the Applicant has trip schemes, runback schemes or protection systems to disconnect it for unstable behaviour (e.g. loss of control stability resulting in sub-synchronous oscillations) and the impact the GS may have under those circumstances.

4. Post connection R2 model validation

Applicants must undertake R2 model validation tests and have a commissioning and compliance plan that captures system incidents when they occur (and are difficult to test, e.g. actual response to system faults) to demonstrate compliance with the performance standards (including model accuracy). Moreover, if either of the two circumstances contemplated by NER clause 5.7.7 occur, AEMO may request a test under clause 5.7.7 to verify plant performance and model validation.

All applicable and reasonable commissioning tests to verify plant configuration, protection, control settings, SCADA and market communications/control system interfaces and performances must be consistent with the performance standards (as recorded in the connection agreement and registered by AEMO).

These tests must be done upon energisation and staged through a number of commissioning points consistent with GS construction and mechanical and electrical completion of GS components. Depending on the nature of issues that occur and require rectification during commissioning, these commissioning points may be amended to verify GS performance considering any observed non-conformance. To support this process, Applicants must carry out FATs for equipment prior to energisation and undertake site acceptance tests (e.g. SCADA and grid control system, signals for AEMO's Energy Conversion Model) to verify that its own balance of plant design conforms to primary and secondary design specifications and will not cause adverse impact on other network users, adversely impact the operational integrity of the GS, or jeopardise its compliance with its performance standards.

See also AEMO's test plan templates for synchronous and asynchronous plant.[22]

[22] Available at: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Network_Connections/Transmission-and-Distribution/Generating-System-Test-Plan-Template-for-Conventional-Synchronous-Machines.pdf (for synchronous GS) and https://www.aemo.com.au/-/media/Files/Electricity/NEM/Network_Connections/Transmission-and-Distribution/Generating-System-Test-Template-for-Non-Synchronous-Generation.pdf (for asynchronous GS).

List of abbreviations

This document uses many terms that have meanings defined in the National Electricity Rules (NER) or are commonly used in the electrical engineering community. Some abbreviations may be specific to this document only.

Term	Definition
AGC	Automatic Governor Control (referred to in the NER as the automatic generation control system)
CBF	Circuit breaker fail
CT	Current transformer
CUO	Continuous uninterrupted operation
CVT	Capacitor voltage transformer
EMT	Electro-magnetic transients
FAT	Factory acceptance test
FCAS	Frequency control ancillary service
FRT	Fault ride-through
GS	Generating system
GU	Generating unit
HV	High Voltage
HVRT	High voltage ride-through
LVRT	Low voltage ride-through
MFRT	Multiple FRT, used in the content of multiple voltage disturbance (ride-through)
NEMDE	National Electricity Market Dispatch Engine
NSP	The connecting Network Service Provider
OEM	Original Equipment Manufacturer
OF	Over-Frequency
OLTC	On-load tap changer
OPDMS	Operations and planning data management system
OV	Over-Voltage
PF	Power factor

Term	Definition
PI	Proportional – integral controller
PLL	Phase lock loop
PSS	Power system stabilizer
QBASE	The reactive power base for the GS and the central plant (voltage) controller.
R1	Pre-connection data
R2	Post-connection data
RMS	Root mean square (used in the context of PSS®E software models)
ROCOF	Rate of change of frequency
RUG	Releasable user guide
SCR	Short circuit ratio
SLD	Single line diagram
SMIB	Single machine infinite bus
SPAR	Single pole auto re-close
STATCOM	Static synchronous condenser
THD	Total Harmonic Distortion
TNSP	Transmission Network Service Provider
UF	Under-frequency
UPS	Uninterrupted power supply
UV	Under-voltage

END of DOCUMENT