AEMO review of technical requirements for connection - National Electricity Rules Schedules 5.2, 5.3 and 5.3a

22 December 2023

Final Report

National Electricity Rules clause 5.2.6A

Important notice

Purpose

This document presents AEMO's final recommendations from its first periodic review of the technical requirements for connection in the National Electricity Market under clause 5.2.6A of the National Electricity Rules.

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Executive summary

This final report completes AEMO's first review of the technical requirements for connection to the National Electricity Market (NEM) power system, in Schedules 5.2, 5.3 and 5.3a of the National Electricity Rules (NER) (the Review). These schedules set out the access standards that may be agreed for the connection of generators and integrated resource providers[1], customers (loads) and market network service providers respectively, for the performance of their plant in relation to specified technical requirements. For most requirements, access may be negotiated between an automatic access standard (AAS) and a minimum access standard (MAS), with requirements applicable to a negotiated access standard (NAS). The agreed performance standards for plant should be consistent with achieving the network performance requirements of the relevant network service provider (NSP), and in turn the overall system standards for the NEM.

This report presents final recommendations for NER changes and further targeted review of some aspects of the requirements and related issues.

AEMO undertook the Review in accordance with NER 5.2.6A. This clause requires AEMO to conduct a review at least once every five years to assess whether the technical requirements for connection should be amended, having regard to the following criteria:

- the national electricity objective (NEO);
- the need to achieve and maintain power system security;
- changes in power system conditions; and
- changes in technology and capabilities of facilities and plant.

In making its final recommendations, AEMO has had regard to the NER review criteria and has sought to promote the achievement of nine related high-level objectives formulated for this Review, described in section 1.1.2.

This review commenced in October 2022 and incorporated extensive consultation through multiple technical industry workshops and meetings at each stage, the development of on an approach paper (October 2022) and two further stages of public reporting and written submissions: on draft recommendations (March and April 2023), and on updated draft recommendations (July 2023).

AEMO adopted a systematic and detailed approach to identify the issues that arise in respect of both individual technical requirements of the schedules and their broader application to the connection of existing and developing technologies in the NEM. This approach has led to a wide spectrum of recommended rule changes, as well as recommendations for further work in some areas. The recommended rule changes give effect to different aspects of the review criteria and high level objectives, depending on the issues encountered or anticipated for the relevant rule; for example to improve the resilience of the power system, streamline the connection process, align with best power system performance, or support the connection of technologies such as grid-forming inverters and synchronous condensers.

Schedules 5.2 and 5.3a recommendations

Table 1 and Table 2 below summarise out AEMO's final recommendations to address the reviewed issues relating to the technical requirements in Schedules 5.2 (generation and integrated resource systems [IRS]) and

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[1] From 3 June 2024

5.3a (market network services) respectively. The final recommendations incorporate some material changes from the updated draft recommendations in response to stakeholder feedback, including the following:

- AEMO is not proposing a change to introduce a size threshold of 30 MW on AEMO advisory matters at this stage. The issue requires further examination, to consider more broadly AEMO's role in efficiently supporting NSPs on power system security matters related to both individual and cumulative impacts of smaller plant on the operation of the power system.
- In NER S5.2.5.4, the recommendation on continuous uninterrupted operation (CUO) relating to voltages above 130% no longer references the IEC 70061-1 standard. The proposed wording has been revised to "at least 130% for at least 20 ms", with further clarification that voltages referred to in this clause are power frequency root mean square (RMS) voltages.
- In addition to the recommended requirement for an NSP to manage repeated switching surges from the network that affect a Schedule 5.2 Participant's plant, AEMO has recommended a reciprocal requirement on Schedule 5.2 Participants to manage repeated switching surges from their plant.
- In NER S5.2.5.5, AEMO has removed two previously recommended clauses that sought to limit and focus the studies undertaken for multiple fault ride through performance.
- AEMO has recommended that the application of the partial load rejection requirements in NER S5.2.5.7 is limited to synchronous generation.
- For the AAS in NER S5.2.5.8 only, AEMO has added a recommendation that voltage-related protections should not trip the schedule 5.2 plant in less than 20ms.
- For NER S5.2.5.13 AEMO has removed the proposed reference to apparent system impedance, and refined the risetime and settling time requirements and applicable compliance requirements, including the range of system impedance, holistically considering them across primary and secondary operating modes, automatic and minimum access standards for voltage, power factor and reactive power modes.

Detailed explanation of the basis for AEMO's Schedule 5.2 and 5.3a recommendations, including the changes since the update report, is provided in sections 2 and 3 and Appendix 2. All consultation material for the review can be found on AEMO's website at: https://aemo.com.au/en/consultations/current-and-closed-consultations/aemo-review-of-technical-requirements-for-connection.

Table 1 Schedule 5.2 Final recommendations summary

Issue	Schedule 5.2 final recommendation
NER S5.2.1 – Outline of requirements	
Application of Schedule 5.2 based on plant type instead of registration category and extension to synchronous condensers	Replace all the references to Generators or Integrated Service Providers in NER Schedule 5.2 with another defined term (e.g. 'Schedule 2 Participant'), to apply the schedule more generally to generation, bidirectional units and synchronous condensers ('schedule 5.2 plant)', with appropriate interpretation clauses to confirm the meaning of the terms in the context of the schedule. Corresponding changes are required elsewhere in Chapter 5 and some other parts of the NER, including definitions, where the access standards and associated performance standards are referenced. Amend NER S5.2.1 to extend the application of the schedule to synchronous condensers, with exceptions and modifications to be specified in the technical requirements as necessary.
NER S5.2.5.1 – Reactive power capability	
Voltage range for full reactive power requirement	Modify the AAS to include a voltage-dependent requirement for reactive power (with percentages based on nominal voltage): • Limit the requirement for full reactive power capability to a 10% voltage band around a centre point nominated by the NSP, where the centre point can be nominated in the range 95% to 105%

Issue	Schedule 5.2 final recommendation
	• For voltages within the 10% voltage band, require at least 0.395 x Pmax reactive injection and absorption. • For voltages below the 10% voltage band down to 90%, require at least 0.395 x Pmax reactive injection. • For voltage from the lower limit of the 10% voltage band to 90%, the requirement for reactive absorption decreases linearly with decrease in voltage from -0.395 x Pmax to 0 MVAr. • For voltages above the 10% voltage band up to 110%, the requirement for reactive injection reduces linearly from 0.395 x Pmax to 0 MVAr. • As bidirectional units can have different demand and active power capability, separate reactive power requirements can be established for injection and absorption of active power. • Use active power capability definition instead of rated active power. Additionally, specify that the maximum active power level and maximum demand are only to consider the in-service (operating) units for the purpose of assessing compliance with reactive power requirements. .
Treatment of reactive power capability considering temperature derating	Amend NER as follows: • Have no derating of active or reactive power at the AAS level below 50°C. • Require any derating of active and reactive power with temperature to be documented in the performance standard as part of a NAS. • Express that, unless otherwise agreed with the NSP and AEMO, the derating is to be based on a proportional derating of active power and reactive power at equipment level, projected to the connection point.
Compensation of reactive power when units are out of service	Amend NER as follows: When the schedule 5.2 plant is not in service, compared with fully disconnecting the plant: • In the AAS add a requirement that there is no impact on voltage. • In the MAS add a requirement to limit the impact on voltage to 1% or greater percentage agreed with the NSP. • The value to be expressed as an MVAr level in the performance standard. The voltage impact is to be assessed considering the system impedance value nominated by the NSP, based on the equivalent impedance for the minimum three phase fault level declared (under NER 5.20C.1(c)) at the electrically closest system strength node and the impedance between that point and the connection point. Additionally, require that for conditions where schedule 5.2 plant is not in service, (other than solely for the purpose of reactive compensation): • maximum active power consumption of a generating system or integrated resource system in respect of auxiliary load and the range of permitted reactive power at the connection point are to be specified as steady state values. For performance compliance purposes, units in service solely for the purpose of reactive compensation should meet protection requirements, requirements under S5.2.5.10, relevant steady state performance requirements (considering the number of units in service) which would include power quality requirements, and the relevant requirements of S5.2.5.13, as if for a secondary operating mode.
S5.2.5.7, S5.2.5.8, S5.2.5.13	
Simplifying standards for smaller connections	Amend NER as follows: • S5.2.5.7 AAS, MAS: Exempt production systems less than a contingent threshold. • S5.2.5.8 AAS, MAS: Apply consistent technology-neutral contingent threshold for the emergency over-frequency response requirements under this clause. • S5.2.5.13 Apply consistent reduced requirements for some elements of the MAS across all technologies, for systems less than a contingent threshold. The contingent threshold is given effect through the definition of a ‘relevant system’, where the threshold is set to the lesser of 30 MW (or MVA as relevant) and 5% of the largest credible contingency event defined in the Frequency Operating Standards. For Tasmania the largest credible contingency event has been defined as 144 MW, so the threshold is approximately 7 MW.
NER S5.2.5.2 – Quality of electricity generated	
Reference to plant standard	Remove reference to AS1359.101(1997) in respect of a synchronous generating unit as a plant standard for harmonic voltage distortion.
NER S5.2.5.4 – Generating system response to voltage disturbances	
Over-voltage requirements for medium voltage and lower connections	Amend NER as follows: • As a negotiated access standard, allow agreement by the NSP and AEMO to a point of application of over-voltage requirements at a location with nominal voltage higher than the connection point, where the plant is connected at nominal voltage less than 66 kV with no automatic tap-changing transformer between its production units and the connection point.

Issue	Schedule 5.2 final recommendation
	• Remove the limit on negotiation based on size of plant.
Requirements for over-voltages above 130%	Amend NER as follows: • Require the plant remain in CUO for voltages at least 130% for at least 20 ms in S5.2.5.4 AAS. • Apply an obligation on an NSP to design its network and insulation coordination so that switching of network elements does not expose a Network User's plant to repeated switching surges for voltages above those described in the system standards. • Amend NER 5.7.2 so that a Registered Participant whose plant is affected by repeated switching surges can request the NSP to undertake an assessment of the cause. • Add a requirement (in NER S5.2.3) on the Schedule 5.2 Participant not to cause repeated switching surges that would affect the NSP's equipment (complementary to the obligation on NSPs) • Clarify that the voltages in S5.2.5.4 refer to RMS power frequency quantities. • In S5.2.5.8 AAS, add a requirement for no voltage-related protection settings less than 20 ms.
Clarification of continuous uninterrupted operation in the range 90% to 110% of normal voltage	Amend NER as follows: • Specify that for the purposes of NER S5.2.5.4(a)(6) reactive capability must be maintained, and active power not reduced other than for transient response, losses, energy source availability and any other factors the NSP and AEMO consider are reasonable in the circumstances, for voltages in the range 90 to 110% of normal voltage, for voltage variations up to 10%. • Clarify that for voltage variations greater than 10% within the range 90% to 110% of nominal voltage, temporary active power output reduction and temporary reduction in reactive power capability, corrected by tap-changing transformer action are permitted. AEMO will review its proposed drafting for S5.2.5.4(e1)(2) and S5.2.5.13 (2B)(iv) to confirm it does not promote unnecessary limits on reactive power capability.
NER S5.2.5.5 – Generating system response to disturbances following contingency events	
Definition of end of a disturbance for multiple fault ride through	Specify that the end of a power system disturbance, for the purpose of multiple fault ride through (MFRT) assessment, is the time when, following fault clearance, the voltage recovers to and remains within the range 90 to 110% of normal voltage at the connection point for at least 20 ms.
Number of faults and time between them	Amend the NER as follows: • Retain for the MAS, up to six faults within 5 minutes but allow for technology-related specific limitations for example, impacting the spacing between faults, to be carved out of these requirements. • Require documentation of the specific limitations in the performance standard.
Reduction of fault level below minimum level for which the plant has been tuned	Amend NER as follows: • Carve out from the MFRT conditions for CUO, in both the AAS and MAS, conditions where fault levels fall below the lower bound of the fault level range for which the plant has been tuned. • Require that the range of fault levels for tuning be advised by the NSP and recorded, in the releasable user guide (RUG). Additionally, define the minimum fault level as the higher of the value equivalent to the SCR recorded in S5.2.5.15, and the level that would be achieved at the connection point, considering the minimum three phase fault level at the electrically nearest system strength node, in conjunction with the network outage that most reduces the fault level at the connection point.
Active power recovery after a fault	Amend NER as follows: • Amend the MAS to include reference to clause 4.4.2(c1) for primary frequency response (PFR) where S5.2.5.11 has been referenced in regard to a frequency disturbance, and include frequency response in the AAS. • Apply consistent conditions for synchronous machines. • Use the same definition of end of a disturbance as for MFRT. • Amend MAS to refer to inertial response and phase angle response as well. • Define "recovery" to be the "first instance after the end of the power system disturbance at which the active power reaches 95% of the pre-fault level".
Rise time, settling time and commencement time for reactive current injection	Amend as follows: • Omit the settling time requirement in the AAS. • Add commencement time of 10 ms to the AAS requirements and clarify, in both AAS and MAS that this is for response opposing the voltage deviation. • Use "adequately controlled" instead of "adequately damped" (consistent with the MAS) • Qualify that rise time is to be assessed for steplike voltages (this will affect MAS and AAS).

Issue	Schedule 5.2 final recommendation
	Add a definition for “adequately controlled”: the response of the schedule 5.2 plant to transient over-voltage or transient under-voltage achieves the agreed level of reactive current injection or absorption within the duration of the relevant disturbance, considering: (i) expected positive and negative sequence reactive current response; (ii) expected active current response; and (iii) stable control when operating at and transitioning into and out of limits, and does not cause or exacerbate: • over-voltages, beyond the more restrictive of the system standards and levels and durations agreed under S5.2.5.4, and • under-voltages, below levels and durations agreed under S5.2.5.4 and • Voltage transients or oscillations that could adversely affect the ability of other schedule 5.2 plant to remain in operation during the disturbance.
Commencement of reactive current injection **&** **Clarity on reactive current injection location**	Amend NER as follows: • Specify that reactive current response to an under-voltage event commence above 85% of nominal voltage at the connection point, and for an over-voltage event commence below 115% of nominal voltage at the connection point. • Clarify under NER S5.2.5.5(u)(2) that reactive current rise time and commencement time can be measured at a location other than the connection point. • Require under NER S5.2.5.5(o1) that all elements of reactive current response must be recorded, including: – the location for measurement of reactive current injection level as a function of voltage; – the location of measurement of commencement time and rise time; and – the response initiating condition, including the location at which it is measured, noting that rise time and commencement time might be measured at a different location.
Consideration of unbalanced voltages and clarity on reactive current injection volume	Amend NER as follows for asynchronous plant: • Retain in the AAS the requirement for the plant to have facilities for 4% and 6% levels for injection and absorption (applying to both balanced and unbalanced voltage disturbances). • Require the control strategy to minimise voltage deviation on each phase from pre-disturbance levels, for balanced and unbalanced faults. • Require in the AAS either inherent response or control response that opposes voltage unbalance during faults or temporary over-voltages. • Record in the performance standard (allowing that response may be different for different fault types): – response to balanced voltage disturbance: ▪ the positive sequence reactive current response as a function of positive sequence voltage deviation and – response to unbalanced voltage disturbance: ▪ the negative sequence reactive current response, as a function of negative sequence voltage or ▪ reactive current response on each phase, to phase unbalance, in % current per % voltage deviation; or ▪ another way of describing the negative phase sequence response agreed with AEMO and the NSP, and – control priority (active vs reactive current, and/or positive vs negative sequence).
Metallic conducting path	Remove NER S5.2.5.5(a).
Reclassified contingency events	Expand the credible contingency reference, for both the AAS and MAS, by reference to credible contingency events selected by the NSP for the purpose of NER S5.1.2.1 (credible contingency events) with additional commonly reclassified contingencies likely to affect the connection point.
NER S5.2.5.7 – Partial load rejection	
Application of minimum generation to energy storage systems	Apply S5.2.5.7 only to synchronous generation.
Clarification of meaning of continuous uninterrupted	Replace the term “be capable of” with “remain in”. Permit active power and reactive power changes within the concept of remaining in CUO to oppose a voltage variation or frequency variation.

Issue	Schedule 5.2 final recommendation
operation for NER S5.2.5.7	
NER S5.2.5.8 – Protection of generating systems from power system disturbances	
Emergency over-frequency response	Amend NER as follows: • Convert the MAS to a AAS and MAS, with the AAS reflecting frequency droop response, the MAS tripping and the NAS specifically including rapid reduction by 50% (by means other than tripping). Express the remainder of the rule as a general requirement. • Make the 50% reduction requirements subject to the plant remaining above a minimum generation level for continuous, stable operation, where applicable. • Change the reference from “upper limit of the extreme frequency excursion tolerance limits” to “0.5 Hz less than the upper limit of the extreme frequency excursion tolerance limits”. • Remove the reference from “not less than the upper limit of the operational frequency tolerance band”. • Allow for delays in achieving the required proportional response or fast ramp down which are longer than 3 seconds, or a relaxation of the 50% requirement, as part of a negotiated access standard, considering the capability and safe operation of the plant, but in any case, not unnecessarily delaying the commencement of the response. • Apply the same size threshold irrespective of nature of plant, being a threshold of 7 MW in Tasmania, and 30 MW on the mainland. (see ‘Simplifying standards for smaller connections’, above) • Remove the reference to transmission-connected, for the AAS and MAS.
Protection settings to maximise capability to ride through disturbances	Require the plant’s protection settings to be set to maximise the plant’s capability to remain in operation for abnormal power system conditions for which the plant is not required to disconnect under any performance standard, while maintaining safe and stable operation of the plant within safety margins consistent with good electricity industry practice.
NER S5.2.5.10 – Protection to trip plant for unstable operation	
Requirements for stability protection on asynchronous generating systems	For the AAS, amend the NER to specify that a generating system or IRS, for its asynchronous units: • Must have a system that can detect an instability in voltage, reactive power and active power. • Must have a facility capable of disconnecting the plant automatically for oscillatory behaviour. • On detection of oscillations, execute a hierarchy of actions based on configurable trigger conditions, thresholds and timeframes, agreed with the NSP and AEMO, having regard to the power system security impact of the oscillations or instability, where: – Any hierarchy of actions that includes a requirement to trip plant must take account of available automated information on the plant’s contribution to the oscillations or instability, and – Actions are taken automatically and promptly. For the AAS, synchronous and asynchronous production systems 100 MW or greater must have a phasor measurement unit (PMU) and capability to receive information about contribution to oscillations from an AEMO central system (in a form nominated by AEMO) For the MAS amend the NER as follows: • Where the plant, considering its reactive power range under S5.2.5.1, can change the voltage at the connection point, for system normal or planned outage conditions, by more than 1%, – The plant must have capability to detect an oscillation of voltage, reactive power and, where relevant, active power – For asynchronous production systems a process agreed with the NSP and AEMO to manage oscillations promptly – For synchronous production units and synchronous condensers a protection system to disconnect the plant for sustained pole slipping, if required by the NSP • If required by AEMO or the NSP production systems with active power capability 100 MW or greater (synchronous condensers 100 MVA) must have a PMU, and capability to receive data on contribution to an oscillation in a form nominated by AEMO.
NER S5.2.5.13 – Voltage and reactive power control	
Voltage control at unit level and slow setpoint change	Amend NER as follows: • Specifically allow rate-limited setpoint change of the generating system. Permit bypass of setpoint rate limiting during testing to assess stability of the controls. • Apply to voltage, reactive power and power factor modes. The changes would apply to both synchronous and asynchronous plant. The slow setpoint change amendment would apply to voltage, power factor and reactive power modes.
Optimise power system performance	For voltage control:

Issue	Schedule 5.2 final recommendation
over expected fault level (system impedance) range – Voltage control	In the AAS: • Require a 3 second rise time of reactive power system voltage change 2 to 5%, not into a limiter for the maximum system impedance and typical system impedance level nominated by the NSP. • Clarify the current requirement a 5 second settling time (step not into a limit) and 7.5 s settling time (step into a limit) for 2% to 5% step-like voltage change, and 5% voltage setpoint change, to specify that: – typical and maximum system impedance conditions apply, and – setpoint input ramp rate limit, if applicable, can be disabled for testing • Clarify the current requirement 5 second settling time (step not into a limit) and 7.5 s settling time (step into a limit) for a 2% to 5% step-like voltage change to specify: – Typical and Maximum system impedance conditions • Extend both the 7.5 s settling time requirements above to steps out of limits as well as into limits. In the MAS: • Allow a higher settling time longer than 7.5s to be agreed with the NSP for a voltage disturbance of 5%, not into a limit (for both synchronous and asynchronous plant) General Requirements • Define the maximum system impedance (for tuning and assessment) as the impedance value corresponding to the value at the connection point considering the minimum three phase fault level on the electrically nearest system strength node, in conjunction with the network outage that most reduces the fault level at the connection point. • apply the same range of impedances to synchronous machine settling time for voltage setpoint step and voltage disturbance into and not into limiters. The typical system impedance level should be reflective of typical unit commitment.
Materiality threshold on settling time error band	Amend the NER as follows, for active power settling time: • Apply a settling time error band that is the largest of: – ±0.5 MW – ±2% of the maximum active power (or maximum demand where relevant) agreed under a performance standard for clause S5.2.5.1, and – the value calculated under the settling time definition. Amend the NER as follows, for reactive power settling time: • Apply a settling time error band that is the largest of: – ±0.5 MVAr – ±2% of the maximum reactive power agreed under a performance standard for clause S5.2.5.1, and – the value calculated under the settling time definition. Amend the NER as follows for voltage settling time: • Apply a settling time error band that is the larger of: – ±0.5% of nominal voltage and – the value calculated under the settling time definition.
Clarification of when multiple modes of operation are required **&** **Treatment of voltage settling time for reactive power and power factor modes**	In the AAS: • Require two operating modes, a primary and secondary mode with the ability to switch between them • By default the primary mode is voltage control, but permit the NSP under the AAS to require a primary operating mode other than voltage control, with voltage as the secondary control mode • Where voltage is the secondary mode, omit the reactive rise time requirement. • For power factor and reactive power modes – Remove the requirement to assess voltage settling time – In primary operating mode, for a setpoint step, not into a limit, equivalent to at least half the range of reactive power agreed in S5.2.5.1 require a reactive power settling time of 5 seconds or less, if response overshoots or exhibits oscillatory behaviour. In the AAS and MAS: • Where power factor mode or reactive power mode is the primary operating mode, require settling time to be assessed for the typical to high system impedance conditions. • Otherwise for a secondary mode, require the voltage disturbance settling time to be assessed for typical impedance conditions. • A ramp-limit on a setpoint change may be applied, where agreed with the NSP and AEMO (apply this to all three modes).

Issue	Schedule 5.2 final recommendation
	The detail of how AEMO's proposal would apply for rise time and settling time requirements across voltage, power factor and reactive power control, AAS and MAS and primary and secondary modes, is provided in Appendix A4.
Impact of a generating system on power system oscillation modes	Amend NER as follows: • Where a Schedule 5.2 Participant has elected to pay the system strength charge (under NER 5.4.3B(b1)), require that assessments take into account the performance required to be provided by the SSSP at the relevant system strength node.
Definitions	
CUO - recognition of frequency response mode, inertial response and active power response to an angle jump	Modify the CUO definition or relevant clauses to: • Permit responses opposing voltage phase angle jumps and frequency changes, including inertial response during disturbances • Make the reference to contingency events more general.
Rise time – explicitly disregard longer-term dynamics and external influences	Modify the definition of rise time as follows: • In relation to a control system, the time taken for an output quantity to rise from 10% to 90% of the mean sustained change induced in that quantity by a step change of an input quantity, disregarding longer-term dynamics and influences external to the generating system following the step change.
Settling time – error band and materiality considerations	In conjunction with materiality thresholds described for P, Q and V in the context of settling time under S5.2.5.13, modify the settling time definition as follows: • In relation to a *control system*, the time measured from initiation of a step change in an input quantity to the time when the magnitude of error between the output quantity and its final settling value remains less than 10% of the sustained change induced in that output quantity.

Table 2 Schedule 5.3a Final recommendations summary

Issue	Schedule 5.3a final recommendations
NER S5.3a.1a Introduction to the schedule	
Alignment of schedule with plant-type rather than registration category	Amend NER as follows: • Define high voltage direct current (HVDC) systems (as 'schedule 5.3a plant) and apply the requirements of Schedule 5.3a to all to HVDC systems irrespective of registration classification. • Exclude HVDC systems from the requirements of NER S5.1 where they have performance standards documented under Schedule 5.3a. • Allow flexibility for application of the performance requirements to an offshore wind facility. Note: Current and committed HVDC projects will not be affected by the recommended changes to the HVDC access standards.
NER S5.3a.8 – Reactive power capability	
Reactive power	Align the reactive power capability requirements for HVDC systems with those for generators in NER S5.2.5.1, noting the proposed changes to NER S5.2.5.1 for generating systems.
NER S5.3a.13 – Market network service response to disturbances in the power system	
Voltage disturbances	Align the voltage disturbance power capability requirements for HVDC systems with those for generators in NER S5.2.5.4, considering the proposed changes to NER S5.2.5.4 for generating systems discussed in this report.
Frequency disturbances	Align frequency disturbance power capability requirements for HVDC systems with those for generators in NER S5.2.5.3, including the (Rate of change of frequency) RoCoF.
Fault ride through requirements	Amend NER as follows: • Align fault ride through and MFRT capability for HVDC systems with those for generators in NER S5.2.5.5, noting the proposed changes to NER S5.2.5.5 for generating systems discussed in this report require HVDC systems to inject or absorb reactive current during the fault.
NER S5.3a.4 – Monitoring and control requirements	
Remote monitoring and protection against instability	Align remote monitoring and protection against inverter instability requirements for HVDC systems to the equivalent requirements for generating systems in NER S5.2.5.10. Therefore, amend as follows:

Issue	Schedule 5.3a final recommendations
	AAS: • A requirement to install a PMU for each connection point • The capability to detect instabilities and execute hierarchy of automated actions agreed with the NSP and AEMO to supress instabilities; • The agreed hierarchy of automatic actions may include the protection system disconnecting the HVDC system if required by AEMO or NSP but it should only be triggered when all other measures have been taken and the HVDC system is contributing to the instability; • If required, the HVDC system must have the capability to send information from the detection system to AEMO and NSP. • If required, the HVDC system must have the capability to receive a remote tripping signal from NSP. • If required, the HVDC system must have the capability to receive information from AEMO about plant's contribution to instability. MAS: • A requirement to install a PMU, subject to request from NSP. • The capability to detect instabilities and execute hierarchy of actions to supress instability, and which is agreed with the NSP and AEMO. • If required, the capability to send information from the detection system to AEMO and the NSP. • If required, the capability to receive remote tripping signal.
New standards	
Voltage control	Align AC voltage control capability for HVDC systems with those for generators in NER S5.2.5.13, noting the proposed changes to NER S5.2.5.13 for generating systems discussed in this report.
Active power dispatch	Align active power control requirements for HVDC systems with those for generators in NER S5.2.5.14, including for dispatch and ramping.

Schedule 5.3 recommendations

In relation to NER Schedule 5.3 (conditions for connection of customers), the Review has identified many of the issues relevant to the access standards required for the future connection of large loads through extensive consultation with various stakeholders. To understand the need for more detailed technical requirements for load connections, such as ride through requirements, AEMO canvassed NSPs on the criticality and urgency of such measures. While responses varied, most respondents indicated moderate to high level criticality, with a preference for detailed requirements to be in effect in the NER within five years (four indicated within 24 months). NSPs also identified large data centres and hydrogen projects as being most likely to be covered by additional ride-through requirements.

At present there are several load projects at or nearing demonstration stage, with potential to scale up to several hundred MW within the next few years. AEMO understands that the ultimate size of some individual hydrogen loads may be in the order of 1000-5000 MW in some cases. In addition, AEMO's consultation so far has identified multiple potential new data centre loads more than 100 MW in size, and up to 600 MW. Several of these projects are at connection enquiry or pre-application phase and some projects propose to connect within the next two years.

However, given the nature of feedback received on fundamental aspects of AEMO's draft recommendations, further consultation and analysis is required before a rule change proposal for detailed technical standards can be submitted to the AEMC.

AEMO's final recommendations for Schedule 5.3 are in two categories:

- Initial rule changes to be proposed to the AEMC immediately following this Review:

  - A limited number of rule changes, to address issues raised by stakeholders where the solution is reasonably straightforward and non-contentious; or in one case, where there is an important issue requiring remedy in the near future. A key recommendation in this category is to introduce a limited set of highly flexible requirements, to allow the ride through capability of new load technologies to be captured in preparation for the negotiation of very large new load connections that may eventuate in the near term.
- Detailed technical requirements to be further developed outside of this Review:
  - AEMO intends to further consult with industry and develop more detailed technical requirements for ride through capability through a separate and subsequent review (Load Technical Requirements Review) using recommendations from this Review as a starting point; and propose additional rule changes to the AEMC based on the outcomes of that review.

AEMO adopted this approach because the Review has indicated that various technologies for very large load projects in hydrogen production, which are most likely to impact power system security, are experiencing a period of rapid development. This requires a more comprehensive understanding of their potential performance capabilities and impacts on power system operation, in close collaboration with the developers.

Nevertheless, the size and proposed timing of the projects envisaged means that their performance could materially impact the operation of the NEM within a few years, so it is critical that appropriate access standards are developed for those projects.

Table 3 summarises AEMO’s recommended initial rule changes for Schedule 5.3, and Table 4 sets out AEMO’s recommendations on detailed technical requirements, to form the starting point for the recommended Load Technical Requirements Review.

Table 3 Recommended initial rule changes for Schedule 5.3

Issue	Description of issue	Schedule 5.3 Recommendation
Recording ride through capability of new loads	The ride through capability of some loads is not well understood at this time and is likely to change as technologies mature. However, AEMO and the NSP‘s ability to efficiently manage system security require depends on them knowing the ride through capability of the large loads.	Provide NSPs the discretion, in consultation with AEMO, to require the ride through capability of a load intending to connect to its network to be established (under the existing NER connection process) and recorded in the performance standard, without any size threshold specified.
Short circuit ratio (SCR) requirement for loads	NER S5.3.11 requires that inverter-based load (IBL) be capable of operating at a short circuit ratio (SCR) of 3.0 or lower. AEMO understands that not all such loads may be able to achieve this without additional capital or operating expenditure.	Amend NER S5.3.11 to apply to IBLs that are also large inverter based resources, and make the minimum short circuit ratio (SCR) requirements more flexible.
Protection systems and settings	Some protection systems and settings may materially reduce the inherent ride through capability of the load, thus reducing the resilience of the power system.	Require protection settings with performance capability, considering reasonable safety margins.
Emergency under-frequency ramp down of large loads	Currently large loads must make 60% of their loads available to emergency under-frequency load shedding schemes. Some loads may be more flexible if they can ramp down their load in an emergency rather than shedding it in blocks.	In addition to the capability to shed load during an under frequency, permit fast ramp down of load where: • The load has the appropriate capability; and • AEMO and the NSP agree the scheme’s settings.
Stability of IBL – monitoring, protection and performance	Currently loads do not require stability monitoring and protection systems. However, modern IBLs may be susceptible to the same types of instability inverter-based generation and HVDC systems.	Require monitoring on IBL projects for control stability.

Table 4 Starting points for the recommended Load Technical Requirements Review

Issue	Description of issue	Schedule 5.3 Recommendation
Size threshold for new loads	Applying access standards for ride through capability to large loads has potential benefits to the operation of the power system but could add significant costs to the project, the NSP and AEMO.	Apply the access standards to single load facilities above a threshold size level, currently proposed to be set as a proportion of the smaller of the maximum load contingency size specified for the region, in the frequency operating standard, if any, and the maximum load contingency in the NEM.
Different load technologies	Applying different access standards to different technologies with different performance capabilities may or may not be efficient but may be complicated to specify and apply.	The same range of access standards, irrespective of the technology and whether the plant is an IBL.
CUO	The CUO requirements referred to in NER S5.2 for generating systems are arduous and may not be appropriate for load connections.	A light-handed definition of continuous uninterrupted operation to the access standards.
Size threshold for alterations to existing plant	AEMO is proposing that the access standards for large loads be applied for loads with a capacity greater than a size threshold. This approach requires clarification for alterations to part of load facility.	A size threshold for existing plant alterations based on the size of the alteration rather than the size of the whole facility unless AEMO and the NSP consider that power system security would be impacted by the performance of the whole plant.

AEMO will also consider whether a voluntary technical specification for large load performance would be of value, as an interim step, considering the lead times associated with progressing the first and second stage rules changes under a standard rule change process.

Other NER changes

As explained in the update report, some of AEMO's recommendations will necessitate extensive structural changes to other parts of Chapter 5, glossary definitions and some other NER provisions to reflect the application of technical requirements based on plant characteristics, rather than participant registration category or status.

The update report and associated indicative NER drafting also identified a number of definition changes and other drafting amendments related to, or consequential on, AEMO's technical recommendations, as well as corrections and clarifications in NER Chapter 5. AEMO's final recommendations on these amendments are largely unchanged from the update report.

AEMO will also propose amendments to NER 5.2.6A to allow AEMO to extend the time to complete the review if 12 months is insufficient, with the reasons and notice requirements for time extensions aligned with those under the rules consultation procedures (NER 8.9.2).

Further reviews

AEMO has identified three areas for separate review in the near to medium term to develop detailed proposals, in consultation with stakeholders, for outstanding issues considered under this Review. Due to timing or information constraints, AEMO is not in a position to make detailed recommendations on these issues with a sufficient level of confidence at this stage. AEMO envisages that further work would involve collaboration with technical representatives, similar to the stakeholder engagement approach used to develop recommendations for the Review. The three separate review areas are:

1. **Load Technical Requirements Review** – as discussed above in relation to AEMO's Schedule 5.3 recommendations.
2. **Connection of grid-forming (GFM) technology** – AEMO has focussed its Review recommendations for GFM connections on amending relevant technical requirements to ensure they do not inadvertently hinder the

connection of GFM technology. AEMO acknowledges the importance of further work to develop core requirements to support the connection of GFM technology, however this requires a prudent level of validation and testing, which AEMO could not achieve during the Review timeframe. Further work will leverage the outcomes of lessons learnt and knowledge sharing material developed through the Australian Renewable Energy Agency (ARENA) funded grid forming initiative.

3. **AEMO’s role in smaller connections** – As noted above, AEMO is not presently recommending a size threshold on AEMO advisory matters, largely based on feedback opposing the change. However, AEMO considers there would be value in examining this question further, to consider more broadly AEMO’s role in efficiently supporting NSPs on power system security matters related to both individual and cumulative impacts of smaller plant on the operation of the power system.

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1 Introduction and overview

AEMO has completed its first five-yearly review of the technical requirements for National Electricity Market (NEM) connection, in NER Schedules 5.2 (generation and, from June 2024, integrated resource systems), 5.3 (loads) and 5.3a (market network service facilities) (Review).

These three NER schedules set out the access standards that may be agreed for the connection of relevant plant to NEM transmission and distribution networks by registered participants and some other parties, to establish required levels of plant capability or performance in relation to specified technical requirements. For most requirements, access may be negotiated between an automatic access standard (AAS) and a minimum access standard (MAS). A number of requirements also specify negotiating parameters and general conditions to be met in all cases. The agreed performance standards for plant should be consistent with achieving the network performance requirements of the relevant network service provider (NSP), described in NER Schedule 5.1, and in turn the overall system standards for the NEM in Schedule 5.1a.

AEMO conducted the Review under clause 5.2.6A of the National Electricity Rules (NER), to assess the need for amendment to the technical requirements. The review provisions were introduced into the NER in 2018[2].

This is AEMO's final report (Report) on the Review, published under NER 5.2.6A(e). It sets out AEMO's conclusions and recommendations for amendment of the technical requirements and related NER provisions, as well as a description of proposed further work to be undertaken in some areas, including the development of detailed technical requirements for the connection of large loads.

In finalising its recommendations, AEMO has had regard to the submissions and extensive feedback from a broad range of industry stakeholders participating in Australia's energy transition. Stakeholders have contributed to the Review through forums, workshops and meetings, as well as responses to AEMO's formal reports. AEMO thanks all contributors for their engagement and support for the Review, and looks forward to further constructive collaboration as we move towards implementing the changes needed to facilitate the energy transition efficiently, while maintaining a safe, secure and reliable power system.

1.1 Review criteria and objectives

1.1.1 NER review criteria

In conducting the Review, AEMO must have regard to four key considerations (review criteria) under NER 5.2.6A(a):

- the national electricity objective (NEO)[3];
- the need to achieve and maintain power system security;
- changes in power system conditions; and
- changes in technology and capabilities of facilities and plant.

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[2] National Electricity Amendment (Generator technical performance standards) Rule 2018 No. 10

[3] The NEO is in section 7 of the National Electricity Law - to promote efficient investment in, and efficient operation and use of, electricity services for the long term interests of consumers of electricity with respect to price, quality, safety, reliability and security of supply of electricity; the reliability, safety and security of the national electricity system; and (from November 2023) the achievement of targets set by a participating jurisdiction for reducing Australia's greenhouse gas emissions, or that are likely to contribute to reducing those emissions.

The following subsection sets out the high-level objectives of the Review and how these relate to the review criteria.

1.1.2 Review objectives

AEMO developed and refined a set of high-level objectives for the Review, aligned with the NER review criteria, with input from stakeholders. AEMO's final recommendations in this Report seek to achieve or support the achievement of those high-level objectives, which are as follows:

1. **Align with best power system performance:**
   - Most access standards are written with AAS and MAS levels. Plant that meets the AAS must be accepted for connection. It is therefore essential that the technical requirements, especially the AAS, align with achieving an appropriate level of power system performance to meet the network performance requirements and, in turn, the system standards for the benefit of all network users.
2. **Improve power system resilience:**
   - Orient the technical standards towards more resilient performance under abnormal power system conditions, or where system strength may be low. As the NEM generation mix changes, system strength is likely to reduce with the reduction in synchronous generation. This can have adverse consequences for power system stability, especially when the system is under stress during multiple contingency events. The technical standards can support resilient operation of the power system by focusing standards related to tuning of plant controls towards stable operation in low system strength conditions.
3. **Streamline the connection process:**
   - Streamline the technical requirements for generation and IRS, to manage the high volume of connections required for the energy transition without compromising power system security. This includes clarifications to remove ambiguity and thereby improve efficiency and reduce negotiation time; removing unnecessary technology-specific or out-dated wording; and removing or refocusing some low value requirements.
4. **Support efficient investment and operation:**
   - Promote more efficient investment and efficient operation in the NEM, consistent with the NEO. For some technical standards there is a trade-off between capital expenditure or operating expenditure and performance. In some situations, the required performance may be beyond that which is useful or usable, or could be provided more cost-effectively in another way. There are some opportunities to consider where more efficient investment in the NEM can be achieved by tailoring the technical requirements better to power system performance requirements.
5. **Remove impediments for connection of grid-forming (GFM) inverters:**
   - Support the integration of GFM inverters in the technical standards by amending or adapting relevant technical requirements to ensure they do not inadvertently hinder the connection of GFM technology and the beneficial capabilities it might provide.
6. **Broaden application of technical requirements to synchronous condenser connections:**
   - Capture in Schedule 5.2 generating systems, IRS and synchronous condensers as appropriate, irrespective of the registration category of the person connecting the plant, providing for more consistent treatment of performance requirements for plant that has analogous characteristics and impacts on the power system.

7. **Broaden the application of technical requirements to all HVDC system connections:**
   - The requirements of Schedule 5.3a should cover all HVDC systems, such as regulated interconnectors and connections of multiple offshore wind generating systems, thereby providing more consistent and better coordinated performance of HVDC systems and improving system security.
8. **Incorporate impact and capability of HVDC systems into technical requirements:**
   - Make the improved capability of modern HVDC systems available to the power system, thereby improving system security by increasing the resilience of HVDC systems at a minimal incremental cost.
9. **Incorporate impact and capability of large loads into technical requirements:**[4]
   - Accommodate the anticipated growth of large converter-based loads (for example, large hydrogen hubs), ensuring they have appropriate standards to support their operation as part of the energy transition.

The table below shows how the high-level objectives align with the four review criteria.

Table 5 Regard for review criteria in considering Review recommendations

Objectives	NEO	… power system security	Changes in power system conditions	Changes in technology and capabilities…
1. Align with best power system performance	Yes (security of system)	Yes	Yes	
2. Improve power system resilience	Yes (security of system)	Yes		
3. Streamline the connection process	Yes (price of supply)		Yes	Yes
4. Support efficient investment and operation	Yes (price of supply).		Yes	
5. Remove impediments for GFM inverters	Yes (security of system)	Yes	Yes	Yes
6. Broaden application of technical requirements to production units and synchronous condenser connections	Yes (security of system)	Yes	Yes	Yes
7. Broaden the application of technical requirements to all HVDC system connections	Yes (security of system)	Yes	Yes	Yes
8. Incorporate impact and capability of HVDC systems into technical requirements	Yes (security of system)	Yes	Yes	Yes
9. Incorporate impact and capability of large loads into technical requirements[5]	Yes (security of system)	Yes	Yes	Yes

1.1.3 Amendment of the national electricity objective

The NEO has changed since the Review commenced, to include an emissions reduction component. Although under the transitional arrangements AEMO was not required to have regard to the amended objective in relation to this Review, AEMO's approach has been to design outcomes that will clarify, simplify and add flexibility to the connection requirements of low and no emission generation and storage technologies in the NEM.

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[4] This objective relates to Schedule 5.3 recommendations which will be set out in the addendum to this draft report.

[5] Recommendations to be set out in addendum to this draft report.

The recommendations from this Review, if implemented, should provide more certainty for investors about the technical standards their equipment must meet for connection, to maintain the levels of assurance in the power system technology needed to maintain a safe, secure and reliable NEM power grid in a low emissions future. To facilitate efficient investment, flexibility is provided where feasible for network service providers (NSPs), applicants, and where necessary AEMO, to modify the requirements for local network conditions. AEMO considers that both the increased certainty and flexibility reflected in the recommended changes will help to reduce negotiation periods and complexity, allowing more connections to be processed.

1.2 Consultation process

1.2.1 NER consultation requirements

NER 5.2.6A requires AEMO to conduct the Review in consultation with affected stakeholders, including the Reliability Panel. The NER consultation provisions prescribe:

- Commencement of the Review with the publication of an approach paper describing the scope of the review, and the technical requirements to be consulted on.
- A draft report setting out AEMO's recommendations for any amendments to the technical requirements, with reasons, and inviting written submissions on those recommendations.
- Publication of a final report with AEMO's final recommendations for any amendments to the technical requirements, having regard to submissions received on the draft report.

1.2.2 Extended consultation

In view of the large number and complexity of issues and potential changes to the technical requirements that were anticipated for this first Review, AEMO’s consultation process has been considerably more extensive than the NER requires. This included publication of an additional formal paper (the update report) and detailed drafting for the NER changes proposed at that stage. AEMO has actively sought input from representatives of all parties with a direct interest or involvement in the NEM connection process, including original equipment manufacturers (OEMs), NSPs, developers (generators) and major users. The feedback received and recommendations made have also been reviewed by AEMO’s own subject matter experts in network connections and delivery, systems capability, operational analysis and real time operations.

AEMO has also presented to the Reliability Panel at its scheduled meetings throughout the Review period, to provide updates on its consultation, key issues, and the development of its recommendations.

Prior to this Report, AEMO published the following key documents in the Review:

- An approach paper that described the matters that AEMO proposed to review[6].
- A draft report setting out its draft recommendations for amendments to technical requirements of NER Schedules 5.2 and 5.3a, and the reasons for its recommendations[7].

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[6] AEMO Review of technical requirements for connection - Approach Paper, 12 October 2022, refer to: https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/aemo-review-of-technical-requirements-for-connection-ner-clause-526a/aemo-review-of-ner-technical-requirements-for-connection.pdf?la=en

[7] AEMO Review of technical requirements for connection - draft report, 3 March 2023, refer to: https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/aemo-review-of-technical-requirements-for-connection-ner-clause-526a/2023-03-03_technical-requirements-review_draft-report_final.pdf?la=en

- An addendum to the draft report setting out its draft recommendations for amendments to technical requirements of NER Schedule 5.3, and the reasons for its recommendations[8].
- An update report setting out revised recommendations for amendments to technical requirements of NER Schedules 5.2 and 5.3a, the reasons for its recommendations, and initial proposed drafting of NER amendments that could give effect to the revised recommendations[9].

AEMO received 18 written submissions on the draft report, 11 on the addendum and 23 on the update report. Each successive report, including this Report, describes the key issues raised in submissions in the previous stage of the process, and sets out AEMO's consideration of those issues.

In addition to written submission opportunities, AEMO has held technical workshops, industry briefings and follow-up meetings - on an industry-wide basis and with representatives from stakeholder groups. This informal consultation greatly assisted in clarifying concerns, and in identifying or eliminating options for resolution.

The table below summarises AEMO's consultation activities within each Review stage.

Table 6 Key consultation undertaken throughout the review

Objective	Stakeholders
Stakeholder inputs to Approach paper (September to October 2022)	
Issues scoping Scoping across multiple stakeholder groups to identify issues for consideration under the Review.	• Network service providers (NSPs). • Connections Reform Initiative workshop attendees. • Central West Orana REZ access standards stakeholders. • Individual stakeholders to AEMO.
Stakeholder inputs to Draft Report (October 2022 – January 2023)	
Key stakeholder group briefings Briefings on the on the proposed scope set out in the Approach Paper and invited feedback on the scope of the Review.	• Clean Energy Council, • Energy Users Association of Australia (EUAA), • Australian Energy Council, • Energy Networks Association • Reliability Panel
Prioritisation workshops Four prioritisation workshops for each of the four technical focus groups to understand views on the criticality of addressing each identified issue, and obtain feedback to refine or amend issue statements. Workshop discussions informed AEMO's determination of issues to pursue through this Review.	AEMO established four technical focus groups comprising representatives with technical expertise and direct experience with technical requirements from NSPs, market participants (generators and large loads), developers and OEMs. The four technical groups covered: • General standards • Grid-forming inverter standards • Large load standards • HVDC standards The AEMC also observed these workshops.
Options assessment workshops 13 options assessment workshops on 28 issues involving greater complexity or with lower levels of consensus around their impact, interpretation or potential resolution. These workshops explored the issues in more detail, with the objective of seeking validation or refinement of the issues, determining the principles that should underpin any solution; and identifying potential options to address the issues.	Representatives of each of the relevant technical focus groups (noted above) attended these workshops, with 100 individuals attending one or more workshops. The AEMC also observed these workshops.

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[8] AEMO Review of technical requirements for connection – Addendum to draft report, 4 April 2023, refer to: https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/aemo-review-of-technical-requirements-for-connection-ner-clause-526a/2023-04-04_technical-requirements-review_draft-report_s53-addendum_final.pdf?la=en

[9] AEMO review of technical requirements for connection Draft Recommendations Update Report (Part 1) – Schedules 5.2 & 5.3a of the National Electricity Rules, 26 July 2023, refer to: draft-recommendations-update-reportpart-1-ner-schedules-52--53a.pdf (aemo.com.au)

Objective	Stakeholders
Stakeholder inputs to update report and draft NER amendments (April – July 2023)	
Draft Report Stakeholder Forum - AEMO review of technical requirements for connection This forum was facilitated to provide: • background, approach and current status of the Review • overview of recommendations made by the draft report and addendum • opportunity for stakeholders to raise questions or issues regarding the draft recommendations.	Over 100 interested parties attended the webinar (invitations to register were issued via the AEMO newsletter and website and communications targeted at technical focus groups).
Formal written submissions Submissions on draft report.	18 respondents made submissions in response to the draft report on recommendations for NER schedules 5.2 and 5.3a.
Ad hoc meetings Meetings to: • clarify understanding of issues raised and discuss proposed positions • discuss feedback with small number of HVDC link stakeholders • discuss draft recommendations with NSPs that had not made a formal written submission.	A range of stakeholders submitting formal feedback, as well as NSPs which had not been able to provide feedback.
Drafting discussion Discussion of key drafting and structural issues.	NSP legal and technical representatives
Stakeholder inputs to final report (August – November 2023)	
Update report stakeholder **forum - revised recommendations** The forum was facilitated to provide: • Current status of the Review and consultation • Overview of revised recommendations made by the update report • Opportunity for stakeholders to raise questions or issues regarding the revised recommendations.	130 interested parties attended the webinar – invitations to register were issued via the AEMO newsletter and website and communications targeted at technical focus groups.
Formal written submissions Submissions on addendum to draft report.	11 respondents made submissions in response to the draft report on recommendations for NER schedules 5.3 which were then addressed in final recommendations set out in this report (an update report was not issued in respect of loads).
EUAA workshops Follow-up workshops with the EUAA to discuss recommendations for load connections made in the draft report addendum, specifically to: • Discuss AEMO's recommendations and underlying rationale; • Understand EUAA member concerns as raised in its written submission • Discuss potential solutions and alternatives.	EUAA membership group.
Formal written submissions Submissions on update report and NER drafting.	23 respondents made submissions in response to the update report on recommendations for NER schedules 5.2 and 5.3a and the accompanying draft NER to give effect to those recommendations.
Large load connections fundamental concepts webinar The webinar was facilitated in response to stakeholder feedback that foundational detail would assist those stakeholders to better understand and discuss issues. The webinar provided: • an overview of fundamental technical, engineering and regulatory concepts underpinning AEMO's recommendations • opportunity for stakeholders to raise questions on, or clarify, fundamental concepts.	Approximately 60 attendees, largely representing large load connections, developers and OEMS – including hydrogen, BESS, manufacturing and mining industries.
Large load connections policy framework options assessment workshop The workshop sought to: • Share the project team's revised thinking on the policy framework that supports the application of technical requirements to large loads.	Approximately 70 attendees, largely representing large load connections, developers and OEMS, and NSPs.

Objective	Stakeholders
• invited stakeholder positions on the more substantial changes to the draft recommendations being proposed. • Identified whether there are solutions which result in broad consensus.	
One-on-one technical discussions Discussions to understand the technical capability and limitations of technology associated with hydrogen production facilities.	One-on-one discussions with hydrogen OEMs and potential developers.
Ad hoc meetings Meetings to clarify understanding of issues raised and discuss proposed positions.	Stakeholders which made submissions which sought further discussion with AEMO, or where further discussion was requested by AEMO.
Recommendations finalisation discussions Three separate discussions with NSP, OEM and developer representatives, respectively, to discuss proposed final positions, specifically to: • provide an update on key proposed final recommendations (issues of key interest and impact to specific groups). • Provide the opportunity to comment on proposed recommendations.	Approximately 100 individuals across NSP, OEM and developer stakeholder groups (invited from technical focus group member pool, stakeholders which made submissions and peak bodies).

Timing of subsequent reviews

NER 5.2.6A requires that AEMO must complete each technical requirements review within 12 months of publishing the approach paper. Notwithstanding AEMO's extensive consultation, on some significant matters AEMO has not been able to reach a final position with sufficient confidence to propose rule changes, necessitating further reviews on the topics discussed in section 1.3.2.

AEMO considers it likely that future NER 5.2.6A reviews will be complex given the pace of the transition to net zero and evolution of technologies and services, involving an increasingly diverse range of stakeholders. AEMO recognises the value of undertaking the Review in a timely manner, but also considers it important for the process of consultation and analysis to be sufficiently robust to deliver recommendations that give effect to the Review criteria.

AEMO will propose amendment to NER 5.2.6A to allow AEMO to extend the time to complete the review if 12 months is insufficient, proposing that reasons and notice requirements are aligned with those for time extensions under the rules consultation procedures (NER 8.9.2). AEMO does not consider that this additional time will slow the progress of required rule changes – comprehensive analysis and consultation is necessary for the development of fit-for-purpose rules.

1.3 Next steps

1.3.1 Rule change proposals

On publication of this report, AEMO will write to the AEMC to confirm that AEMO intends to submit rule change proposals.

Throughout the Review, AEMO has flagged that it will consider proposing NER amendments under the 'fast track' process in section 96A of the National Electricity Law (NEL) where appropriate, based on AEMO's consultation in the Review.

AEMO intends to ask the AEMC to consider the fast track process for the majority of its rule changes arising from the Schedule 5.2 and 5.3a recommendations. These concern amendments that, after detailed analysis and iterative consultation, AEMO considers are appropriate in accordance with the review criteria and meet the prior consultation condition of the NEL for fast track consideration. For most of these, stakeholder feedback has converged on a proposed solution. In some instances, AEMO has identified amendments that reconcile key points of difference between stakeholder views, where appropriate and consistent with the review criteria.

Fast tracking these rule changes is also considered appropriate to address technical requirements for generator connections that are presently creating uncertainty, delays, and unnecessary costs. Prompt rectification of these issues would give effect to the NEO.

AEMO intends to submit rule change proposals under the standard AEMC consultation process for:

- One schedule 5.2 and 5.3a issue where there may be further substantive questions to be resolved in consultation with affected parties. This relates to the consideration of reclassified contingency events under NER S5.2.5.5. .
- Initial light touch measures for large loads based on final recommendations. As these recommendations are materially different from the draft recommendations in the Review, the standard rule change process is appropriate.
- A proposed amendment to the timing requirement for AEMO reviews under NER 5.2.6A, which was not specifically consulted on during the Review.

AEMO will discuss its proposals further with the AEMC and consider any issues raised on the possible structure and grouping of rule change proposals, before finalisation and lodgement.

The final drafting of AEMO's proposed NER amendments is not provided with this Report. AEMO will amend the indicative drafting (previously provided with the update report) to reflect the final Review recommendations. AEMO is currently targeting submission of rule change proposals and amended drafting to the AEMC from Q1, 2024.

1.3.2 Further reviews

AEMO has identified three areas for separate further review in the near to medium term, in consultation with affected stakeholders. The purpose of these reviews will be to gather further information for analysis and development of detailed proposals to address outstanding issues considered under this Review. Due to timing or information constraints, AEMO is not able to make detailed recommendations on these issues with a sufficient level of confidence at this stage. AEMO envisages that any such work would involve collaboration with technical representatives, similar to the stakeholder engagement approach used to develop recommendations for the Review.

The three separate review areas are:

- Load technical requirements - The Review has indicated that the technologies for very large load projects in hydrogen production, which are most likely to impact power system security, are experiencing a period of rapid development. This therefore requires a more detailed understanding of their potential capabilities in close collaboration with the developers. AEMO intends to use the Schedule 5.3 recommendations from this Review as a starting point for the subsequent work, and develop more detailed technical requirements suitable for a rule change proposal or other solution in consultation with affected industry participants.
- Connection of grid-forming (GFM) technology – AEMO has focussed its Review recommendations for GFM connections on amending relevant technical requirements to ensure they do not inadvertently hinder the connection of GFM technology. AEMO acknowledges the importance of further work to develop core

requirements to support the connection of GFM technology, however this requires a prudent level of validation and testing, which AEMO could not achieve during the Review timeframe. Further work will leverage the outcomes of lessons learnt and knowledge sharing material developed through the ARENA funded grid forming initiative.[10]

- AEMO's role in smaller connections – AEMO is not presently recommending a size threshold on AEMO advisory matters, largely based on feedback opposing the change. However, AEMO considers there to be value in examining this question further, to consider more broadly AEMO's role in efficiently supporting NSPs on power system security matters related to both individual and cumulative impacts of smaller plant on the operation of the power system.

1.3.3 Possible interaction of Review recommendations with PFR rule change

The AEMC has made a draft determination on the "Clarifying mandatory primary frequency response obligations for bidirectional plant"[11] (PFR rule). The PFR rule deals with obligations on bi-directional units to provide mandatory primary frequency response. AEMO notes that there may be some interactions between, or flow-on requirements from, the PFR rule change and the Review recommendations, in relation to NER S5.2.5.8, S5.2.5.11 and possibly also S5.2.5.7. The AEMC may wish to consider these interactions prior to finalising the PFR rule.

1.4 Structure of this Report

The remaining sections of this Report are structured as follows:

- **Section 2** summarises the material issues considered in the Review in relation to NER Schedule 5.2, the high level review objective(s) to be met in addressing each issue, and AEMO's final recommendations. For comparative purposes, the draft recommendations previously made in the update report are also set out where they differ from the corresponding final recommendations. Section 2 should be read in conjunction with Appendix A2 which sets out a summary of stakeholder positions on the revised draft recommendations, AEMO's consideration of these views, and the adjustments made to those recommendations.
- **Section 3** summarises the material issues considered in the Review in relation to NER Schedule 5.3a, the high level review objective(s) to be met in addressing each issue, and AEMO's final recommendations. Section 3 should also be read in conjunction with the stakeholder feedback summary and responses in Appendix A2.
- **Section 4** summarises AEMO's final recommendations on initial rule changes to be proposed to the AEMC following this Review; and on the starting points for developing detailed technical requirements in the proposed Load Technical Requirements Review, and AEMO's reasons for adopting this approach. Section 4 should be read in conjunction with the stakeholder feedback summary on the draft report addendum and AEMO's responses in Appendix A5.
- **Section 5** summarises AEMO's final recommendations on material NER changes proposed either in addition to, or as a consequence of, the recommendations relating to Schedules 5.2, 5.3 and 5.3a.

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[10] Refer to ARENA website for further information on the initiative: arena.gov.au/news/arena-backs-eight-grid-scale-batteries-worth-2-7-billion/

[11] At https://www.aemc.gov.au/rule-changes/clarifying-mandatory-primary-frequency-response-obligations-bidirectional-plant.

2 Final recommendations – NER Schedule 5.2

This section summarises AEMO's final recommendations on the material issues considered in the Review in relation to NER Schedule 5.2, as informed by consultation on the update report. Where the final recommendation on an issue differs materially from the revised draft recommendation in the update report, that draft recommendation is also set out for comparative purposes. A summary of stakeholder positions on the revised draft recommendations, AEMO's consideration of these views, and the adjustments made (after further analysis and consultation where needed), is set out in Appendix A2 and this section should therefore be read in conjunction with the detail in that appendix.

The key material changes to AEMO's recommendations since the update report, after further consideration of stakeholder feedback and analysis of the merits of various options, include the following.

- AEMO is not proposing a change to introduce a size threshold of 30 MW/30MVA on AEMO advisory matters at this stage. The issue requires further examination, to consider more broadly AEMO's role in efficiently supporting NSPs on power system security matters related to both individual and cumulative impacts of smaller plant on the operation of the power system.
- In NER S5.2.5.4, the recommendation on continuous uninterrupted operation relating to voltages above 130% no longer references the IEC 70061-1 standard. The proposed wording has been revised to "at least 130% for at least 20 ms", with further clarification that voltages referred to in this clause are power frequency root mean square (RMS) voltages.
- In addition to the recommended requirement in NER S5.1.4 for an NSP to manage repeated switching surges from the network that affect a Schedule 5.2 Participant's plant, AEMO has recommended a reciprocal requirement on Schedule 5.2 Participants to manage repeated switching surges from their plant.
- In NER S5.2.5.5, AEMO has removed two previously recommended clauses that sought to limit and focus the studies undertaken for multiple fault ride through performance.
- AEMO has recommended that the application of the partial load rejection requirements in NER S5.2.5.7 is limited to synchronous generation.
- For the AAS in NER S5.2.5.8 only, AEMO has added a recommendation that timer-based protections should not trip the schedule 5.2 plant in less than 20 ms.
- AEMO has refined its recommendations for NER S5.2.5.13 to remove the reference to apparent system impedance, and adjust the settling time requirements and applicable compliance requirements, including the range of system impedance, considering primary and secondary operating modes, automatic and minimum access standards for voltage, power factor and reactive power modes.

2.1 NER S5.2.1 – Outline of requirements

2.1.1 Application of Schedule 5.2 based on plant type instead of registration category and extension to synchronous condensers

Description of issue

NER Schedule 5.2 sets out the details of additional requirements and conditions that Generators and IRPs (including bi-directional units) must satisfy as a condition of connecting to the NEM power system.

The obligations in Schedule 5.2 are expressed by reference to the 'normal' participant registration categories for those systems (Generators and IRPs). This means that synchronous condensers owned, operated or controlled by a person in a different registered participant category are not captured if they are not part of a generating system or IRS. In the NEM this includes synchronous condensers owned, operated and controlled by Network Service Providers (NSPs).

In future, it is likely that some existing generating systems will be converted to synchronous condenser operation and the plant would not be able to meet some of the requirements under NER Schedule 5.2 post-conversion (mainly relating to active power). In such a circumstance, the provisions of Schedule 5.2 should remain applicable.

Relevant Review objectives

Broaden application of technical requirements to synchronous condensers.

Support efficient investment and operation.

Update report recommendation

As final recommendation.

Final recommendation

Replace all references to Generators or Integrated Service Providers in NER Schedule 5.2 with another defined term (e.g. 'Schedule 2 Participant'), to apply the schedule more generally to generation, bidirectional units and synchronous condensers ('schedule 5.2 plant'), with appropriate interpretation clauses to confirm the meaning of the terms in the context of the schedule. Corresponding changes are required elsewhere in Chapter 5 and some other parts of the NER, including definitions, where the access standards and associated performance standards are referenced.

Amend NER S5.2.1 to extend the application of the schedule to synchronous condensers, with exceptions and modifications to be specified in the technical requirements as necessary.

2.2 NER S5.2.5.1 – Reactive power capability

2.2.1 Voltage range for full reactive power requirement

Description of issue

NER S5.2.5.1 currently specifies the AAS for reactive power capability as a function of the generating system's active power capability ('rated active power') and the requirement is constant over the voltage range 90% to 110% of normal voltage at the connection point.

Adding reactive power capability for injection at high voltages and absorption at low voltages is not desirable as:

- It causes high voltages to increase further, and low voltages to reduce further, putting unnecessary stress on the generating system.
- Can add capital costs to the generating system project and, if a lower access standard were to be negotiated, requires additional time and resource to negotiate.

Relevant Review objectives

Align with best power system performance.

Streamline the connection process.

Support efficient investment and operation.

Update report recommendation

Modify the AAS to include a voltage-dependent requirement for reactive power (with percentages based on nominal voltage):

- Limit the requirement for full reactive power capability to a 10% voltage band around a centre point nominated by the NSP, where the centre point can be nominated in the range 95% to 105%.
- For voltages within the 10% voltage band, require at least 0.395 x Pmax reactive injection and absorption.
- For voltages below the 10% voltage band down to 90%, require at least 0.395 x Pmax reactive injection.
- For voltage from the lower limit of the 10% voltage band to 90%, the requirement for reactive absorption decreases linearly with decrease in voltage from -0.395 x Pmax to 0 MVAr.
- For voltages above the 10% voltage band up to 110%, the requirement for reactive injection reduces linearly from 0.395 x Pmax to 0 MVAr.
- As bidirectional units can have different demand and active power capability, separate reactive power requirements can be established for injection and absorption of active power.
- Use active power capability definition instead of rated active power, as, because of the convention for nameplate rating of IBR, rated active power would represent MVA rating for IBR plant.

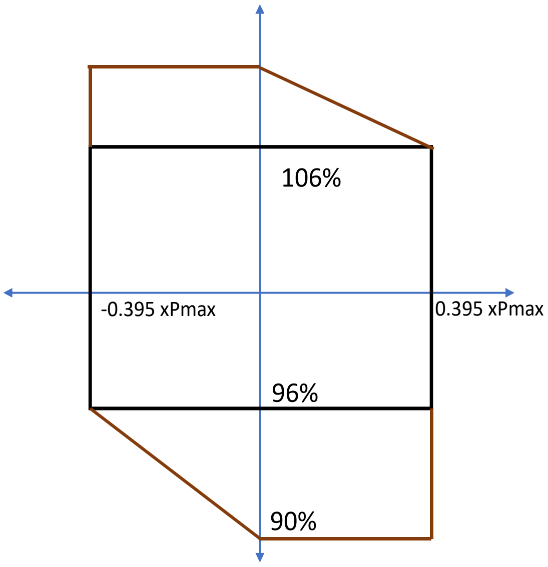
Final recommendation

Modify the AAS to include a voltage-dependent requirement for reactive power (with percentages based on nominal voltage):

- Limit the requirement for full reactive power capability to a 10% voltage band around a centre point nominated by the NSP, where the centre point can be nominated in the range 95% to 105%.
- For voltages within the 10% voltage band, require at least 0.395 x Pmax reactive injection and absorption.
- For voltages below the 10% voltage band down to 90%, require at least 0.395 x Pmax reactive injection.
- For voltages above the 10% voltage band up to 110% require at least 0.395 x Pmax reactive absorption.
- For voltage from the lower limit of the 10% voltage band to 90%, the requirement for reactive absorption decreases linearly with decrease in voltage from -0.395 x Pmax to 0 MVAr.
- For voltages above the 10% voltage band up to 110%, the requirement for reactive injection reduces linearly from 0.395 x Pmax to 0 MVAr.
- As bidirectional units can have different demand and active power capability, separate reactive power requirements can be established for injection and absorption of active power.
- Use active power capability definition instead of rated active power. Additionally, specify that the maximum active power level and maximum demand are only to consider the in-service (operating) units for the purpose of assessing compliance with reactive power requirements.

An example of the proposed profile is shown below, with a midpoint at 101%.

Figure 1 Example re active power – voltage profile



2.2.2 Treatment of reactive power capability considering temperature derating

Description of issue

At present, NER S5.2.5.1 is silent on temperature derating, although it is common for the rating of some production units to be temperature dependent and common practice for the temperature derating to be documented.

If the apparent power is derated with temperature, it is unclear what value of active power should be recorded under NER S5.2.5.1(g) and hence be used to define the reactive power requirements as a function of temperature.

There are different ways to derate that can be suitable depending on technology and the power system operation around the connection point.

The best outcome for the power system is to have no derating, but if derating is necessary the NER should allow flexibility regarding how this is applied. The access standard should recognise that most plant will have a practical maximum temperature for operation. Even if the maximum operation is above the level specified in the standard, it should be reflected in the documented performance standard.

Relevant Review objective

Align with best power system performance.

Streamline the connection process.

Update report recommendation

Clarify that for the purpose of NER S5.2.5.1, the rated active power or rated maximum demand may take account of the temperature dependency of the rating, and that the required Qmax and Qmin are functions of Pmax as derated. That is, Qmax (T) = 0.395 Pmax (T), and Qmin (T) = -0.395 Pmax(T) for operating temperature T at the connection point, for reactive power absorption, where at least these levels of reactive power injection and absorption apply.

Where there is derating, require the performance standards to document:

- Active power derating of production units as a function of temperature, if any.
- Reactive power derating as a function of temperature of production units and any other reactive power facility, if any.
- Maximum operating temperature and minimum operating temperature of the generating system or IRS.
- Maximum operating temperature for which the plant is not derated.
- Reactive power performance requirement as a function of active power at the connection point at the maximum temperature for which the plant is not derated.
- Reactive power performance requirement as a function of active power at the connection point at the maximum operating temperature, where different.
- Reactive power performance requirement at the connection point as a function of temperature
- Any maximum operating temperature limit.

Note that there are three main variants for treatment of temperature derating. These are:

- Option 1: To require the same reactive power regardless of temperature derating
- Option 2: To require the same active power regardless of temperature derating
- Option 3: To require the reactive power proportional to active power accounting for any temperature derating.

For the common situation of temperature derating associated with a current limit, there is a trade-off between provision of active and reactive power. Option 1 prioritises provision of reactive power over active power, which is an advantage for power system voltage management. Option 2 prioritises provision of active power over reactive power, which is an advantage for maximising supply under high temperature conditions where a supply scarcity is more likely. The recommended Option 3 is a middle-ground where reactive power and active power both reduce proportionally when a temperature derating applies.

The NEO requires consideration of efficient investment in the NEM. There may be a high requirement for reactive power in some parts of the NEM during high temperature events, as demand is likely to be high, and some lines may be heavily loaded. Optimal location of reactive power may be at the generators' locations or at other locations distant from generators. Provision of reactive power for high demand periods would entail a cost to NSPs, which flows through to consumers. Provision of additional reactive power from generators involves additional capital expenditure and generator costs will also flow through to consumers. Active power supply requirements are also likely to be high during high temperature events, because of high demand. Reliability of supply must be considered under the NEO, and supply deficits lead to reliability impacts on consumers. The proposed Option 3 seeks to balance these considerations. AEMO welcomes further feedback on whether the proposed solution represents the most optimal solution considering the NEO.

Final recommendation

Amend NER as follows:

- Have no derating of active or reactive power at the AAS level below 50°C.
- Require any derating of active and reactive power with temperature to be documented in the performance standard as part of a NAS.
- Express that, unless otherwise agreed with the NSP and AEMO, the derating is to be based on a proportional derating of active power and reactive power at equipment level, projected to the connection point.

2.2.3 Compensation of reactive power when units are out of service

Description of issue

When a generating system's units are out of service there is typically some net load on the system. For different types of generation, the auxiliary load:

- May be insignificant compared to the rating of the generating system but may also have a leading power factor due to unloaded cables and lines, and from capacitors used for harmonic filters or reactive power contribution.
- May have a low lagging power factor, such as for thermal synchronous machines.

NER S5.2.5.1 specifies that the reactive power requirements of auxiliary loads for a generating system or IRS should be established under NER S5.3.5 as if the *Generator* or *IRP* was a *Market Customer*.

NER S5.3.5 specifies the reactive power requirements in terms of a minimum lagging power factor and excluding leading power factors. The MAS does permit a lower power factor where the NSP is advised by AEMO that this will not detrimentally affect power system security or reduce intra-regional or inter-regional power transfer capability.

The cost of correcting the power factor of the auxiliary loads when production units are out of service can include additional maintenance, additional reactive plant and operating restrictions. Whether there is net benefit to the power system in correcting the power factor of a generating system to meet the requirements of NER S5.3.5 will depend on the size and direction of the voltage impact, and the cost of providing this corrective response.

In addition, some NSPs require some production units to be kept in service to provide dynamic reactive power capability in voltage control mode. The access standards do not specifically address such a requirement, but also do not preclude it.

In the event that a small proportion of units is kept in service specifically for power factor correction, less arduous compliance requirements can be contemplated, considering that the impact on the power system will be small, to achieve efficient investment and operation of electricity services.

Relevant Review objective

Align with best power system performance.

Streamline the connection process.

Support efficient investment and operation

Update report recommendation

Amend as follows:

- Add a requirement to limit the impact on voltage to [0.5%] when the plant is not in service, compared with fully disconnecting the plant.
- Record in the performance standard how this requirement is to be met.
- Where the voltage impact at the connection point is limited by means of a subset of production units operating to compensate reactive power through the connection point, reduced compliance requirements apply, provided the operating mode is a primary or secondary mode under S5.2.5.13. Compliance with S5.2.5.2 applies. Compliance with other clauses is not required.
- Clarify that maximum active power consumption of a generating system or integrated resource system in respect of auxiliary load and the range of permitted reactive power at the connection point to be specified as steady state values.

AEMO requested specific feedback on the 0.5%. The threshold provides a balance between provision of reactive compensation centrally by an NSP and provision by multiple connecting parties individually. Either way there will be costs borne by the consumer that are reflected in the price of electricity. The challenge is to set a threshold that achieves the overall minimum cost to consumers consistent with the NEO.

Final recommendation

Amend NER as follows:

When the schedule 5.2 plant is not in service, compared with fully disconnecting the plant:

- In the AAS add a requirement that there is no impact on voltage.
- In the MAS add a requirement to limit the impact on voltage to 1% or greater percentage agreed with the NSP.

- The value to be expressed as an MVAr level in the performance standard.

The voltage impact is to be assessed considering the system impedance value nominated by the NSP, based on the equivalent impedance for the minimum three phase fault level declared (under NER 5.20C.1(c)) at the electrically closest system strength node and the impedance between that point and the connection point.

Additionally, require that for conditions where schedule 5.2 plant is not in service, (other than solely for the purpose of reactive compensation):

- maximum active power consumption of a generating system or integrated resource system in respect of auxiliary load and the range of permitted reactive power at the connection point are to be specified as steady state values.

For performance compliance purposes, units in service solely for the purpose of reactive compensation should meet protection requirements, requirements under S5.2.5.10, relevant steady state performance requirements (considering the number of units in service) which would include power quality requirements, and the relevant requirements of S5.2.5.13, as if for a secondary operating mode.

2.3 NER S5.2.5.7, S5.2.5.8, S5.2.5.13

2.3.1 Simplifying standards for smaller connections

Description of issue

Smaller plants have individually less impact on the power system than large ones, but the impact needs to be considered in the context of its connection location. In addition, there can be a cumulative effect, depending on:

- The number and size of plants connected in a local area, with similar (undesirable) response.
- Whether the disturbance is global or local in nature.
- The nature of the response, and how it affects other plants.
- Whether the performance impacts system security or power quality in the affected part of the network.

The technical standards are written with automatic and minimum standards, to take account of the differences from one connection to the next and to promote more efficient investment. However, differences relating to the size or impact of the plant on its connection point and the wider power system cannot always be accounted for.

AEMO has reviewed NER S5.2 to examine whether further opportunities exist to reduce any requirements that may be unnecessarily onerous for smaller plant.

As part of this review, AEMO identified that, because the Tasmanian network is small and connected by DC link to the rest of the NEM, the threshold for plant size to have a material impact on the power system is lower in that jurisdiction.

Relevant Review objective

Streamline the connection process.

Support efficient investment and operation

Update report recommendation

Amend as follows:

- S5.2.5.7 AAS, MAS: Exempt production systems less than a threshold of 30 MW on the mainland and (effectively) 7 MW in Tasmania from this clause in both automatic and minimum access standards.
- S5.2.5.8 MAS: Apply consistent technology-neutral thresholds for the emergency over-frequency response requirements under this clause: 30 MW on the mainland, and (effectively) 7 MW in Tasmania.
- S5.2.5.13 Apply consistent reduced requirements for some elements of the MAS across all technologies, with a 30 MW threshold on the mainland and (effectively) 7 MW in Tasmania.
- The lower thresholds proposed for Tasmania are achieved by definition of a 'relevant system', where the threshold is set to the lesser of 30 MW (or MVA as relevant) and 5% of the largest credible contingency event defined in the Frequency Operating Standards. For Tasmania the largest credible contingency event has been defined as 144 MW.

AEMO advisory matter threshold to all technical requirements

- In the definition of AEMO advisory matters, exclude connections less than 30 MW.

Final recommendation

Amend NER as follows:

- S5.2.5.7 AAS, MAS: Exempt production systems less than a contingent threshold.
- S5.2.5.8 AAS, MAS: Apply consistent technology-neutral contingent threshold for the emergency over-frequency response requirements under this clause.
- S5.2.5.13 Apply consistent reduced requirements for some elements of the MAS across all technologies, for systems less than a contingent threshold.
- The contingent threshold is given effect through the definition of a 'relevant system', where the threshold is set to the lesser of 30 MW (or MVA as relevant) and 5% of the largest credible contingency event defined in the Frequency Operating Standards. For Tasmania the largest credible contingency event has been defined as 144 MW, so the threshold is approximately 7 MW.

AEMO is not proposing a change to introduce a size threshold of 30 MW/30 MVA on AEMO advisory matters at this stage. The issue requires further examination, to consider more broadly AEMO's role in efficiently supporting NSPs on power system security matters related to both individual and cumulative impacts of smaller plant on the operation of the power system.

2.4 NER S5.2.5.2 – Quality of electricity generated

2.4.1 Reference to plant standard

Description of issue

AS 1359.101 (1997) and IEC 60034-1 are referenced as plant standards for synchronous generating units for harmonic voltages in NER S5.2.5.2. The former Australian Standard was superseded by AS1359.0-1998 (which has subsequently been withdrawn) and AS 60034.1-2009. IEC 60034-1 published by the International Electrotechnical Commission is the equivalent standard to AS 60034.1, but references the current version from 2022.

The IEC 60034-1 includes reference to total harmonic distortion measurement for synchronous machines.

Relevant Review objective

Streamline the connection process.

Update report recommendation

As final recommendation.

Final recommendation

Remove reference to AS1359.101(1997) in respect of a synchronous generating unit as a plant standard for harmonic voltage distortion.

2.5 NER S5.2.5.4 – Generating system response to voltage disturbances

2.5.1 Over-voltage requirements for medium voltage and lower connections

Description of issue

The durations for which generating systems are required to remain in continuous uninterrupted operation (CUO) for over-voltages is specified in NER S5.2.5.4.

The rationale for the current NER S5.2.5.4 focused on high voltage (HV) transmission level over-voltages, and long durations were justified based on the ENTSO-E requirement for plant connected to the 400 kV system[12]. The requirements can be met using a transformer tap changer. However, at lower voltages plant is often directly connected and, unlike the ENTSO-E requirements which are less arduous for lower voltage connections, the NER applies the same requirements regardless of the connection voltage. For plant directly connected to the connection point and not through a step-up transformer with tap changer, the automatic access standards may not be met at the connection point, but may be met at the HV side of the transformer that electrically connects the plant to the transmission system. The negotiation process currently does not allow flexibility to consider application of the over-voltages at another location.

Considering the renewable energy zones and designated network assets (DNAs) where a connection point for a large plant may be at the MV side of a step-up transformer, the issue can arise for any size connection, which is the reason for removing the restriction on negotiating a performance standard less than AAS level.

Relevant Review objective

Streamline the connection process.

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[12] At https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:JOL_2016_112_R_0001#d1e1043-1-1.

Update report recommendation

Amend as follows:

- Amend the AAS to make the point of application of over-voltages the nearest HV transmission location, for connections below 66 kV and not through a transformer with an automatic onload tap changer.
- Remove the limit on negotiation based on size of plant.

Final recommendation

Amend NER as follows:

- As a negotiated access standard, allow agreement by the NSP and AEMO to a point of application of over-voltage requirements at a location with nominal voltage higher than the connection point, where the plant is connected at nominal voltage less than 66 kV with no automatic tap-changing transformer between its production units and the connection point.
- Remove the limit on negotiation based on size of plant.

2.5.2 Requirements for over-voltages above 130%

Description of issue

The current drafting of NER S5.2.5.4 leaves the upper voltage for continuous uninterrupted operation for the first 20ms open-ended, requiring compliance for voltages above 130% for at least 20 ms. This represents an unbounded compliance risk for Schedule 5.2 participants.

The alternative “at least” formulation does not cause this issue.

In addition, the voltages in NER S5.2.5.4 are generally considered to be power frequency RMS values, to be consistent with the system standards in NER S5.1a.4. However, peak voltages of the order of 130% for the first 20 ms would typically be caused by either switching over-voltage or lightning strikes, where the voltage shape is not sinusoidal. Protection of plant for these extreme short duration events is typically by means of surge arresters, which have limited energy capacity and number of operations. Despite the extreme over-voltage phenomena mostly relating to surges or lightning, most stakeholders preferred the simplicity of referencing voltages within S5.2.5.4 in a consistent manner across the whole rule.

In reviewing the requirements around these extreme over-voltage conditions AEMO found that the NER does not currently provide a requirement for NSPs to manage network conditions that lead to repeated surges on connected plant, nor does it provide a requirement for schedule 5.2 plant not to cause repeated switching surges in the network.

Whereas nearby lightning strikes are rare and unpredictable, repeated switching surges:

- Will likely cause plant deterioration over time.
- May cause tripping and non-compliances.
- Can be mitigated by various means.

It is therefore reasonable to require management of repeated switching surges to improve plant and power system performance and be consistent with efficient investment in the NEM.

The requirement in the AAS was added in response to a stakeholder suggestion, as it contributes to the resilience of the power system. It is proposed for the AAS only (no MAS) because some plant may not be able to achieve this requirement, in which case a access standard can be negotiated reflecting the plant's actual capability. Without such a requirement there is a tendency for protection to be set to trip just beyond the CUO level.

Relevant Review objective

Align with best power system performance.

Streamline the connection process.

Support efficient investment and operation

Update report recommendation

Amend as follows:

- Require CUO for peak voltages greater than 184% (with reference to IEC 60071.1 waveforms).
- Apply an obligation on NSPs under S5.1.4(a1) to design its network and insulation coordination so that switching of network elements does not expose a Network User's plant to switching surges for voltages above those described in the system standards.
- Amend NER 5.7.2 so that a Registered Participant whose plant is affected by switching surges can request the NSP to undertake an assessment of the cause.
- Permit the plant to block for transient over-voltages that exceed 184% peak voltage at the connection point for less than 10 ms.
- Clarify that for the voltages described in S5.2.5.4 (a) (2) to (8) and (b)(1) to (5) are power frequency root mean square voltages and the voltage described in S5.2.5.4(a)(1) refers to voltage waveforms described in IEC 60071.1.

Final recommendation

Amend NER as follows:

- Require the plant remain in CUO for voltages at least 130% for at least 20 ms in S5.2.5.4 AAS.
- Apply an obligation on an NSP to design its network and insulation coordination so that switching of network elements does not expose a Network User's plant to repeated switching surges for voltages above those described in the system standards.
- Amend NER 5.7.2 so that a Registered Participant whose plant is affected by repeated switching surges can request the NSP to undertake an assessment of the cause.
- Add a requirement (in NER S5.2.3) on the Schedule 5.2 Participant not to cause repeated switching surges that would affect the NSP's equipment (complementary to the obligation on NSPs).
- Clarify that the voltages in S5.2.5.4 refer to RMS power frequency quantities.
- In S5.2.5.8 AAS, require no voltage-related protection settings less than 20 ms.

2.5.3 Clarification of CUO in the range 90% to 110% of normal voltage

Description of issue

NER S5.2.5.4(a)(6) requires a generating system or IRS to be capable of continuous uninterrupted operation where a power system disturbance causes the voltage at the connection point to vary within 90%-110% of normal voltage. The application of CUO in this context has been interpreted differently across the NEM, potentially having a significant cost impact on connecting IBR plant. Interpretations include:

- AEMO published a clarificatory document in 2018 which requires the generating system to be capable of maintaining its active and reactive power when the voltage at the connection point drops to 90% of normal voltage. This is site specific and depends on the pre-disturbance voltage. For example, if the pre-disturbance voltage was 107% of nominal the plant would need to maintain its active and reactive power for a 17% step (down to 90%).
- Some TNSPs have adopted methodologies that require a generating system to maintain its active and reactive power for a voltage drop of 10%, including to 90% of normal operating voltage. This is consistent with TNSP planning obligations under NER S5.1.4 to keep variation in voltage magnitude to be no more than 10%, except as a consequence of a contingency event.
- The capability should be provided continuously, rather than relying on the time for tap changer operation to return the reactive capability to its maximum steady state level.

Relevant Review objectives

Streamline the connection process.

Support efficient investment and operation.

Update report recommendation

Amend as follows:

- Specify that for the purposes of NER S5.2.5.4(a)(6) reactive capability must be maintained, and active power not reduced other than for transient response, losses, energy source availability and any other factors the NSP and AEMO consider are reasonable in the circumstances, for voltages in the range 90 to 110% of normal voltage, for voltage variations up to 10%.
- Clarify that for voltage variations greater than 10% within the range 90% to 110% of nominal voltage, temporary active power output reduction and temporary reduction in reactive power capability, corrected by tap-changing transformer action are permitted.

Final recommendation

Amend NER as follows:

- Specify that for the purposes of NER S5.2.5.4(a)(6) reactive capability must be maintained, and active power not reduced other than for transient response, losses, energy source availability and any other factors the NSP and AEMO consider are reasonable in the circumstances, for voltages in the range 90 to 110% of normal voltage, for voltage variations up to 10%.

- Clarify that for voltage variations greater than 10% within the range 90% to 110% of nominal voltage, temporary active power output reduction and temporary reduction in reactive power capability, corrected by tap-changing transformer action are permitted.

AEMO will review its proposed drafting for S5.2.5.4(e1)(2) and S5.2.5.13 (2B)(iv) to confirm it does not promote unnecessary limits on reactive power capability.

2.6 NER S5.2.5.5 – Generating system response to disturbances following contingency events

2.6.1 Definition of end of a disturbance for multiple fault ride through

Description of issue

NER S5.2.5.5 describes requirements for generating system multiple fault ride through (MFRT). The AAS states that the minimum clearance from the end of one disturbance and the commencement of the next disturbance for the AAS may be 0 ms.

NER S5.2.5.5 does not define what constitutes the end of a disturbance. It is possible to interpret the AAS to require ride through of 15 faults consecutively with no voltage recovery between them. The probability of this occurring is very low and such an interpretation would be unreasonable and unnecessarily onerous.

Relevant Review objective

Streamline the connection process.

Update report recommendation

As final recommendation.

Final recommendation

Specify that the end of a power system disturbance, for the purpose of MFRT assessment, is the time when, following fault clearance, the voltage recovers to and remains within the range 90% to 110% of normal voltage at the connection point for at least 20 ms.

2.6.2 Form of multiple fault ride through clause

Description of issue

The nature of multiple contingency events is that it is possible only to identify non-compliance, but not to prove compliance as many combinations of event are possible. In order to provide most value at least cost from assessments on this clause, it is desirable to limit the studies, but target aspects of performance that are most relevant and important. A key change proposed for this clause is the declaration of specific limitations, as described in the next section. It benefits all parties when limitations are properly understood and described.

Currently NER S5.2.5.5 clause does not facilitate the necessary flow of information required for connections to meet required standards. Connection proponents may require information on contingency events to test for onerous conditions which might reveal limitations. NSPs may require further information on the limitations of plant operation so that these may be appropriately addressed.

Relevant Review objectives

Streamline the connection process.

Improve power system resilience.

Update report recommendation

Amend as follows:

- Require the NSP, where requested by the Schedule 5.2 Participant, to provide connection-specific advice to the Connection Applicant about combinations of contingency events that might be onerous for CUO of the plant.
- Provide the NSP the flexibility to require additional studies only where it has reasonable grounds to believe there is an inadequately disclosed limitation.
- Require documentation of the specific limitations in the performance standard.

Final recommendation

- Require documentation of the specific limitations in the performance standard. (See next section for the related change to the MAS).

2.6.3 Number of faults and time between them

Description of issue

The MAS for MFRT currently requires the plant to remain in CUO for up to 6 faults that are 200ms or more apart, within a 5-minute window, subject to a set of criteria about the fault combinations. Some plants may have difficulty demonstrating compliance because:

- some of the limitations that cause a plant to trip may not be modelled in power system modelling software.
- the limitation on the plant may relate to the time between consecutive faults.

Failure to ride through a particular combination of simulated fault conditions should not automatically be an impediment to connection of a plant, unless the risk associated with the failure is significant given the likelihood and impact on the power system.

Nevertheless, it is beneficial for the power system resilience for plant to be able to remain in continuous uninterrupted operation for a reasonable number of faults. This requirement was originally introduced to address circumstances relating to tripping of some South Australian wind farms in the September 2016 black system event, due to an undisclosed counter-based protection.

Disclosure of specific limitations will also allow them to be managed in the operation of the power system.

Relevant Review objectives

Streamline the connection process.

Align with best power system performance.

Improve power system resilience.

Support efficient investment and operation.

Update report recommendation

As final recommendation.

Final recommendation

Retain for the MAS, up to six faults within 5 minutes but allow for technology-related specific limitations for example, impacting the spacing between faults, to be carved out of these requirements.

2.6.4 Reduction of fault level below minimum level for which the plant has been tuned

Description of issue

Most technical standards are studied considering fault levels applying for system normal and single outage conditions, for a range of generation dispatch conditions. MFRT is different, in that it considers non-credible combinations of conditions. Currently, the MFRT rule excludes material reductions of power transfer capability from the conditions for which the plant must remain in CUO, but does not contemplate that multiple faults could reduce the fault level at the connection point below the level for which the plant was tuned.

Control system tuning affects the dynamic performance of the plant, including the damping of its controls during disturbances.

In addition, the NER does not specify the range of conditions for which the plant must remain in CUO.

Transparency on this will assist future assessment of whether tuning of plant is still adequate considering the changes in the power system over time (particularly the retirement of synchronous plant).

At present the fault levels for which the plant is tuned are not recorded, so this information is lost. Recording it in an accessible document will facilitate review, and if required retuning at some later time.

Linking the tuning level to the fault level considering the nearest system strength node and the network outage that most reduces the fault level at the connection point would provide an objective method of setting the tuning requirement. The level in S5.2.5.15 must also be considered, as this is a technical limit of the plant, but it cannot be used directly as a lower bound on tuning because the settings for S5.2.5.15 may not be the same as those used for normal operation.

Review objective

Streamline the connection process.

Update report recommendation

Amend as follows:

- Carve out from the MFRT conditions for CUO, in both the AAS and MAS, conditions where fault levels fall below the lower bound of the fault level range for which the plant has been tuned.

- Require that the range of fault levels for tuning be advised by the NSP and recorded, in the releasable user guide (RUG).

Final recommendation

Amend NER as follows:

- Carve out from the MFRT conditions for CUO, in both the AAS and MAS, conditions where fault levels fall below the lower bound of the fault level range for which the plant has been tuned.
- Require that the range of fault levels for tuning be advised by the NSP and recorded, in the RUG.
- Define the minimum fault level as the higher of the value equivalent to the SCR recorded in S5.2.5.15, and the level that would be achieved at the connection point, considering the minimum three phase fault level at the electrically nearest system strength node, in conjunction with the network outage that most reduces the fault level at the connection point.

2.6.5 Active power recovery after a fault

Description of issue

The AAS of S5.2.5.5 requires active power recovery from 100 ms after clearance of a fault to at least 95% of the level existing just prior to the fault.

The recent Efficient Reactive Current Injection rule change changed the MAS to refer to the recovery of positive sequence voltage at the connection point to remain between 90% and 110% of normal voltage.

For an inverter-based technology the plant's MVA is reduced in proportion to voltage. Below 90% of connection point voltage the plant is expected to inject additional reactive current to support voltage, and this is typically at the expense of active power.

In combination, these factors mean that recovery of active power post-fault is dependent on voltage recovery post-fault. The voltage at the connection point post-fault can be affected by external factors as well as by the behaviour of the plant itself.

Therefore, it is practical to apply a similar approach as employed by the AEMC in the recent MAS change to link the active power recovery to the voltage recovery.

The active power after a fault can also be influenced by the voltage angle change after a fault and the frequency change after the fault (if any).

The amendment aligns the definition of end of a disturbance in the MFRT clause with that for active power recovery. This makes the synchronous and asynchronous requirements equivalent.

Changing both the AAS and MAS would therefore better align the clause with best performance on the power system, as well as contributing to streamlining the connection process.

Review objective

Streamline the connection process.

Remove impediments for GFM inverters.

Update report recommendation

Amend as follows:

- Amend the MAS to include reference to clause 4.4.2(c1) for primary frequency response (PFR) where S5.2.5.11 has been referenced in regard to a frequency disturbance, and include frequency response in the AAS.
- Apply consistent conditions for synchronous machines.
- Use the same definition of end of a disturbance as for MFRT.
- Amend MAS to refer to inertial response and phase angle response as well.

Final recommendation

Amend NER as follows:

- Amend the MAS to include reference to clause 4.4.2(c1) for primary frequency response (PFR) where S5.2.5.11 has been referenced in regard to a frequency disturbance, and include frequency response in the AAS.
- Apply consistent conditions for synchronous machines.
- Use the same definition of end of a disturbance as for MFRT.
- Amend MAS to refer to inertial response and phase angle response as well.
- Define “recovery” to be the “first instance after the end of the power system disturbance at which the active power reaches 95% of the pre-fault level”.

2.6.6 Rise time, settling time and commencement time for reactive current injection

Description of issue

The rules around the minimum access standard for S5.2.5.5 were changed in the recent rule change for “Efficient reactive current access standards for inverter-based resources”.

In this rule change process, the problems associated with use of settling time were demonstrated with respect to a wind farm technology.

AEMO has also found that settling time can also cause similar issues for grid forming inverters.

Because of the issues found with this settling time requirement, AEMO proposes also to remove the requirement from the automatic access standard, as well.

‘Commencement time’ has been previously added to the MAS and, for consistency, should be added to the AAS with a higher requirement, with higher performance to reflect better power system performance.

The new rule included the term “adequately controlled”. In feedback during the consultation stakeholders sought a definition for this term.

Relevant Review objectives

Align with best power system performance.

Streamline the connection process.

Align with best power system performance.

Remove impediments for GFM inverters.

Update report recommendation

Amend as follows:

- Omit the settling time requirement in the AAS.
- Add commencement time of 10 ms to the AAS and clarify, in both AAS and MAS that this is for response opposing the voltage deviation.
- Use “adequately controlled” instead of “adequately damped”.
- Define “adequately controlled”.
- Qualify that rise time is to be assessed for steplike voltages (this will affect MAS and AAS).

Final recommendation

Amend as follows:

- Omit the settling time requirement in the AAS.
- Add commencement time of 10 ms to the AAS requirements and clarify, in both AAS and MAS that this is for response opposing the voltage deviation.
- Use “adequately controlled” instead of “adequately damped” (consistent with the MAS)
- Qualify that rise time is to be assessed for steplike voltages (this will affect MAS and AAS).

Add a definition for “adequately controlled”: the response of the schedule 5.2 plant to transient over-voltage or transient under-voltage achieves the agreed level of reactive current injection or absorption within the duration of the relevant disturbance, considering:

(i) expected positive and negative sequence reactive current response;

(ii) expected active current response; and

(iii) stable control when operating at and transitioning into and out of limits,

and does not cause or exacerbate:

- over-voltages, beyond the more restrictive of the system standards and levels and durations agreed under S5.2.5.4, and
- under-voltages, below levels and durations agreed under S5.2.5.4 and
- voltage transients or oscillations that could adversely affect the ability of other schedule 5.2 plant to remain in operation during the disturbance.

2.6.7 Commencement of reactive current injection and clarity on reactive current injection location

Description of issue

In the "Efficient reactive current access standards for inverter-based resources" rule change commencement time was added for the MAS. For consistency with the MAS, a shorter commencement time is proposed for the AAS. The proposed value is well within the capability of well-performing plant.

Also, in the rule change, the wording around commencement was changed from a range, to commencing above 90% and below 120% of normal voltage (noting references to normal voltage are proposed to be changed to nominal voltage). This was to accommodate grid forming inverters, and because there is no benefit in specifying an upper limit on the commencement of reactive injection.

A corresponding change has been proposed for the AAS here.

Relevant Review objectives

Align with best power system performance.

Streamline the connection process.

Remove impediments for GFM inverters.

Update report recommendation

Specify that reactive current response to an under-voltage event commence above 85% of normal voltage at the connection point, and for an over-voltage event commence below 115% of normal voltage at the connection point.

Final recommendation

Amend NER as follows:

- Specify that reactive current response to an under-voltage event commence above 85% of nominal voltage at the connection point, and for an over-voltage event commence below 115% of nominal voltage at the connection point.
- Clarify under NER S5.2.5.5(u)(2) that reactive current rise time and commencement time can be measured at a location other than the connection point.
- Require under NER S5.2.5.5(o1) that all elements of reactive current response must be recorded, including:
  - the location for measurement of reactive current injection level as a function of voltage;
  - the location of measurement of commencement time and rise time; and
  - the response initiating condition, including the location at which it is measured, noting that rise time and commencement time might be measured at a different location.

2.6.8 Consideration of unbalanced voltages and clarity on reactive current injection volume

Description of issue

The current rule requires facilities for schedule 5.2 plant to have facilities to provide reactive current injection of 4%/% voltage drop and 6%/% voltage rise but does not specify how the plant should be tuned and what performance is sought.

The 4%/% and 6%/% requirements do not necessarily lead to the best outcomes on the power system. They are also typically considered as positive sequence, whereas most faults on the system are unbalanced faults. There is a need therefore to reorient the AAS so that achievement of it will lead to the best outcomes for the power system.

To do this AEMO has proposed a control objective, which if met will lead to the optimal outcomes for the power system considering the capabilities of the plant.

AEMO has also proposed that for the automatic access standard, the plant provide for either inherent response or control response that opposes voltage unbalance. This means that the plant would either be able to respond to counter negative phase sequence or individual phase deviations.

This requirement, in conjunction with the tuning to meet the control objective should improve response to disturbances.

The third part of the proposed change is to document the settings for unbalanced faults, in a clearer manner than currently described in the rules, but still allowing for differences in implementations from different OEMs and technologies.

Relevant Review objectives

Align with best power system performance.

Streamline the connection process.

Align with best power system performance.

Update report recommendation

Amend as follows for asynchronous plant:

- Retain in the AAS 4% and 6% levels for injection and absorption but with clarification that these levels apply for balanced voltage disturbances.
- Require the control strategy to minimise voltage deviation on each phase from pre-disturbance levels, for unbalanced faults.
- Require for unbalanced faults and over-voltages positive and negative sequence current to meet the control objective.
- For unbalanced faults record in the performance standard:
  - The positive sequence reactive current response as a function of positive sequence voltage deviation and
    - ○ The negative sequence reactive current response as a function of negative sequence voltage, which may be different for different fault types; or

    - The reactive current response on each phase, to phase unbalance, in % current per % voltage deviation, which may be different for different fault types; or
    - another way of describing the negative phase sequence response agreed with AEMO and the NSP.
  - Priority (active current vs reactive, and/or positive vs negative sequence).

Final recommendation

Amend NER as follows for asynchronous plant:

- Retain in the AAS the requirement for the plant to have facilities for 4%/% and 6%/% levels for injection and absorption (applying to both balanced and unbalanced voltage disturbances).
- Require the control strategy to minimise voltage deviation on each phase from pre-disturbance levels, for balanced and unbalanced faults.
- Require in the AAS either inherent response or control response that opposes voltage unbalance during faults or temporary over-voltages.
- In the previously proposed NER drafting, NER S5.2.5.5(o)(1)(ii) correct 115% to 120%[13].
- Record in the performance standard (allowing that response may be different for different fault types):
  - the positive sequence reactive current response as a function of positive sequence voltage deviation; and
  - the negative sequence reactive current response, as a function of negative sequence voltage; or
  - reactive current response on each phase, to phase unbalance, in % current per % voltage deviation; or
  - another way of describing the negative phase sequence response agreed with AEMO and the NSP.
- Record the controller function priorities (active current vs reactive, and/or positive vs negative sequence).

2.6.9 Metallic conducting path

Description of issue

S5.2.5.5(a) states that “In this clause S5.2.5.5 a fault includes a fault of the relevant type having a metallic conducting path.” The statement does not appear to add clarity to the description of faults in the clause. Power system faults can generally have paths that are combinations of metallic and non-metallic conducting paths (for example an arcing fault through air). It could be argued that it potentially reduces clarity in some circumstances.

Relevant Review objective

Streamline the connection process.

Update report recommendation

As final recommendation.

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[13] Drafting error only in draft rule published with Update Report

Final recommendation

Remove NER S5.2.5.5(a).

2.6.10 Reclassified contingency events

Description of issue

NER S5.2.5.5(c)(1) requires generating systems and IRS to remain in CUO for credible contingency events, but for the purposes of establishing a standard, the defined term ‘credible contingency event’, by itself, does not set or limit the size of any resulting disturbance that the system must ride through. This is because what constitutes a credible contingency at any point in time can change, including under NER 4.2.3A if AEMO reclassifies a non-credible contingency event as credible where it is considered reasonably possible because of abnormal conditions.

The proposed change would limit the reclassified events considered for connection to commonly reclassified contingencies likely to affect the connection point.

Relevant Review objective

Align with best power system performance.

Streamline the connection process.

Update report recommendation

As final recommendation.

Final recommendation

Expand the credible contingency reference, for both the AAS and MAS, by reference to credible contingency events selected by the NSP for the purpose of NER S5.1.2.1 (credible contingency events) with additional commonly reclassified contingencies likely to affect the connection point.

2.7 NER S5.2.5.7 – Partial load rejection

2.7.1 Application of minimum generation to energy storage systems

Description of issue

The requirement to remain in CUO following a load reduction event is currently expressed to be subject to the loading level remaining above the minimum generation required for continuous stable operation. NER S5.2.5.7 applies to all generating systems, and (following the IESS rule commencement), to integrated resource systems. However, bi-directional units are not likely to have minimum generation for continuous stable operation. In the draft and update reports, AEMO recommended excluding the minimum generation condition for energy storage, and also extended the requirement to synchronous condensers (without the minimum generation condition).

In feedback on this issue, a stakeholder queried why this clause was applied to synchronous condensers at all, noting they are already required to ride through all relevant disturbances (frequency, RoCoF and voltage) under other standards.

After further examination, AEMO agrees that this requirement is unnecessary for synchronous condensers, but also observes that it adds little or no value for any plant other than synchronous generating systems, as the technical parameters involved are adequately covered by other Schedule 5.2 standards. In its original form, this clause applied only to synchronous generation, to deal with the stability of the prime-mover for rapid-deloading conditions.

AEMO therefore proposes that NER S5.2.5.7 should only apply to synchronous generating systems.

Relevant Review objective

Streamline the connection process.

Update report recommendation

Amend the clause to refer [only] to generating units for the carve out about operating above minimum generation.

Final recommendation

Apply S5.2.5.7 only to synchronous generation.

2.7.2 Clarification of meaning of CUO for NER S5.2.5.7

Description of issue

The AAS requires that a generating system or IRS must be capable of continuous uninterrupted operation during and following a power system load reduction of 30% from its pre-disturbance level or equivalent impact from separation of part of the power system in less than 10 seconds.

Two issues with this clause as currently drafted are:

- The ambiguity with “capable of” and whether that means such capability must be enabled at all times.
- The definition of CUO only allows for substantial reductions in output after fault clearance when allowed by specified performance standards and NER S5.2.5.7 is otherwise silent on the reduction in active power which would occur as a result of the frequency and inertial response to the loss of load.

AEMO considers that the capability must be enabled at all times, because an event that causes a power system load reduction cannot be anticipated in advance.

The second point relates to the way that the CUO definition interacts with this clause. It reflects what is expected behaviour of the plant for a major load change.

Relevant Review objective

Align with best power system performance.

Streamline the connection process.

Remove impediments for GFM inverters.

Update report recommendation

As final recommendation.

Final recommendation

Replace the term “be capable of” with “remain in”.

Permit active power and reactive power changes within the concept of remaining in CUO to oppose a voltage variation or frequency variation.

2.8 NER S5.2.5.8 – Protection of generating systems from power system disturbances

2.8.1 Emergency over-frequency response

Description of issue

NER S5.2.5.8(a)(2) describes three options for a generating system of 30 MW or more and an IRS (to the extent it comprises bidirectional units) of 5 MW or more to reduce their active power rapidly, in the event of an over-frequency event. The issues associated with this clause:

- NER S5.2.5.8(a)(2)(ii) requires the reduction in output to be completed within 3 seconds of the frequency reaching the upper limit of the extreme frequency excursion tolerance limits, but at this level generating systems and IRS are permitted to trip (considering NER S5.2.5.3 and S5.2.5.8(a)(1)), so the response might be too late to be useful.
- NER S5.2.5.8(a)(2)(i)(B) requires a response that reduces the plant’s output by at least half, within 3 seconds, but there are some plant (for example, some hydro generating units) that are physically unable to achieve a reduction output at the required rate safely. The same limitation might also arise with NER S5.2.5.8(a)(2)(ii). The third option, to trip the plant is not desirable as it could reduce the inertia of the power system, which would increase rate of change of frequency.
- The rule applies different requirements for different size systems based on whether they are bidirectional or not, but there is no sound technical reason for this distinction on size and technology.
- NER S5.2.5.8(a)(2) existed before the PFR requirements were introduced in NER chapter 4. A generating system meeting the PFR requirements may not meet this requirement, depending on the lag in its frequency response.

Relevant review objectives

Align with best power system performance.

Streamline the connection process.

Align with best power system performance.

Update report recommendation

Amend as follows:

- Convert the MAS to a AAS and MAS, with the AAS reflecting a proportional response, the MAS tripping and the NAS specifically including rapid reduction by 50% by means other than tripping. Express the remainder of the rule as a general requirement.
- Change the reference from “upper limit of the extreme frequency excursion tolerance limits” to “0.5 Hz less than the upper limit of the extreme frequency excursion tolerance limits”.
- Remove the reference from “not less than the upper limit of the operational frequency tolerance band”.
- Allow for lags in a proportional response or fast ramp down which are longer than 3 seconds, as part of a negotiated access standard, considering the capability of the plant.
- Apply the same size threshold irrespective of nature of plant, being a threshold of 7 MW in Tasmania, and 30 MW on the mainland.
- Remove the reference to transmission-connected, for the AAS and MAS.

Final recommendation

Amend NER as follows:

- Convert the MAS to a AAS and MAS, with the AAS reflecting frequency droop response, the MAS tripping and the NAS specifically including rapid reduction by 50% (by means other than tripping). Express the remainder of the rule as a general requirement.
- Make the 50% reduction requirements subject to the plant remaining above a minimum generation level for continuous, stable operation, where applicable.
- Change the reference from “upper limit of the extreme frequency excursion tolerance limits” to “0.5 Hz less than the upper limit of the extreme frequency excursion tolerance limits”.
- Remove the reference from “not less than the upper limit of the operational frequency tolerance band”.
- Allow for delays in achieving the required proportional response or fast ramp down which are longer than 3 seconds, or a relaxation of the 50% requirement, as part of a negotiated access standard, considering the capability and safe operation of the plant, but in any case, not unnecessarily delaying the commencement of the response.
- Apply the same size threshold irrespective of nature of plant, being the contingent threshold in Tasmania, and 30 MW on the mainland.
- Remove the reference to transmission-connected, for the AAS and MAS.
- Remove the italics from “disconnect” or otherwise modify the definition to allow for disconnection somewhere other than the connection point.

2.8.2 Protection settings to maximise capability to ride through disturbances

Description of issue

There is often a tendency for plant protection settings to be set just outside the required conditions for CUO for frequency, RoCoF and voltage, even though the plant may be capable of wider operating ranges.

Setting the protection to allow operation based on the capability of the plant (with safety margins consistent with good industry practice) would improve power system resilience at no cost to the plant.

Review objective

Improve power system resilience.

Update report recommendation

As final recommendation.

Final recommendation

Require the plant's protection settings to be set to maximise the plant's capability to remain in operation for abnormal power system conditions for which the plant is not required to disconnect under any performance standard, while maintaining safe and stable operation of the plant within safety margins consistent with good electricity industry practice.

2.9 NER S5.2.5.10 – Protection to trip plant for unstable operation

2.9.1 Requirements for stability protection on asynchronous generating systems

Description of issue

The AAS for NER S5.2.5.10 requires generating systems and IRS to have a protection system that trips the plant when it is operating unstably. This is intended to protect the network from active power, reactive power and voltage instabilities caused or amplified by a generating system or IRS.

In recent years, there has been uncertainty in the interpretation and application of the AAS and MAS. This caused delays and potentially suboptimal outcomes in multiple connection projects for asynchronous generating systems. For example, there are concerns over:

- whether asynchronous generating systems should be disconnected without considering their contribution to the instability,
- whether a prompt disconnection is the best solution for a modern grid with high renewable generation penetration, and
- what types of instabilities should be covered under NER S5.2.5.10.

Also, there have recently been several oscillatory events in multiple NEM states with different levels of oscillation severity. These events needed to be individually investigated by NSPs and AEMO to identify which generating systems and IRS were contributing to the instability. Some events required manual disconnection of the plant contributing to the instability because there was no protection system meeting the AAS requirements for NER S5.2.5.10.

This is not sustainable for a power system with a large and steadily increasing number of asynchronous generating systems and IRS.

Relevant review objectives

Align with best power system performance.

Improve power system resilience.

Streamline the connection process.

Support efficient investment and operation.

Update report recommendation

In the AAS, specify that a generating system or IRS, for its asynchronous units:

- Must have system that can detect an instability in voltage, reactive power and active power.
- Must have a protection system capable of disconnecting for oscillatory behaviour.
- On detection of oscillations, execute a hierarchy of actions based on configurable trigger conditions, thresholds and timeframes, agreed with the NSP and AEMO, where:
  - Any action to disconnect is based on contribution to the oscillations
  - Actions are automatically and promptly actioned.
- For synchronous and asynchronous production systems 100 MW or greater, must have a PMU and capability to receive information about contribution to oscillations from an AEMO central system (in a form nominated by AEMO).

The MAS requires:

- Where the plant, considering its reactive power range under S5.2.5.1, can change the voltage at the connection point, for system normal or planned outage conditions, by more than 1%,
  - The plant must have capability to detect an oscillation of voltage, reactive power and, where relevant, active power.
  - For asynchronous production systems a process agreed with the NSP and AEMO to manage oscillations promptly.
  - For synchronous production units and synchronous condensers a protection system to disconnect the plant for sustained pole slipping, if required by the NSP.
- If required by AEMO or the NSP, for production systems with active power capability 100 MW or greater and synchronous condensers 100 MVA a PMU, and capability to receive data on contribution to an oscillation in a form nominated by AEMO.

Final recommendation

For the AAS, amend the NER to specify that a generating system or IRS, for its asynchronous units:

- Must have a system that can detect an instability in voltage, reactive power and active power.
- Must have a facility capable of disconnecting the plant automatically for oscillatory behaviour.

- On detection of oscillations, must execute a hierarchy of actions based on configurable trigger conditions, thresholds and timeframes, agreed with the NSP and AEMO, having regard to the power system security impact of the oscillations or instability, where:
  - Any hierarchy of actions that includes a requirement to trip plant must take account of available automated information on the plant's contribution to the oscillations or instability.
  - Actions are taken automatically and promptly.

For the AAS, synchronous and asynchronous production systems 100 MW or greater must have a PMU and capability to receive information about contribution to oscillations from an AEMO central system (in a form nominated by AEMO).

For the MAS, amend the NER as follows:

- Where the plant, considering its reactive power range under S5.2.5.1, can change the voltage at the connection point, for system normal or planned outage conditions, by more than 1%:
  - The plant must have capability to detect an oscillation of voltage, reactive power and, where relevant, active power.
  - For asynchronous production systems a process must be agreed with the NSP and AEMO to manage oscillations promptly.
  - Synchronous production units and synchronous condensers must have a protection system to disconnect the plant for sustained pole slipping, if required by the NSP.
- If required by AEMO or the NSP, production systems with active power capability 100 MW or greater (synchronous condensers 100 MVA) must have a PMU, and capability to receive data on contribution to an oscillation in a form nominated by AEMO.

2.10 NER S5.2.5.13 – Voltage and reactive power control

2.10.1 Voltage control at unit level and slow setpoint change

Description of issue

Voltage control of asynchronous plant is typically implemented through a power plant controller (PPC). The PPC controls the voltage by sending the units active and reactive commands.

Issues with this approach include:

- This can be less stable than unit control of the voltage when the system strength is low due to the cycle time of the PPC and the variable communication delays to the individual production units.
- Is inherently less resilient to communication failures between the PPC and the production units and can result in undamped responses.
- Unit level voltage control will be beneficial for grid-forming inverters.
- Unit level voltage control responds better during fault conditions and eliminates the potentially unstable transfer between unit control to PPC control.

AEMO considers that the NER should avoid impediments to voltage control at the unit level for all production units. The current drafting of NER S5.2.5.13 confuses the requirements for unit control and PPC control.

Relevant Review objectives

Align with best power system performance.

Remove impediments for GFM inverters.

Align with best power system performance.

Update report recommendation

As final recommendation.

Final recommendation

Amend the NER as follows:

- Specifically allow rate-limited setpoint change of the generating system. Permit bypass of setpoint rate limiting during testing to assess stability of the controls.
- Apply to voltage, reactive power and power factor modes.

The changes would apply to both synchronous and asynchronous plant.

The slow setpoint change amendment would apply to voltage, power factor and reactive power modes.

2.10.2 Optimise power system performance over expected fault level (system impedance) range – Voltage control

Description of issue

The AAS and MAS for NER S5.2.5.13 both measure the performance for voltage control in terms of the rise time and settling time, with the AAS requiring a faster response.

- Settling time is used as a measure of stability in this clause, but a long settling time can also arise from an over-damped response, which would also be associated with a long rise time.

These requirements were implemented when new generation was predominately synchronous and hence system strength was rising. In recent years the retirement of synchronous generation and the increase in grid-following inverters has resulted in a trend towards lower system strength. Experience has shown that:

- Grid following inverters have tended to be less stable at low system strength.
- Changing generation dispatch patterns have meant that there is generally a larger range of system strength conditions experienced in the network.
- At higher system strength responses are slower, but stable (longer rise time and settling time, if over-damped).
- At lower system strength responses are faster, but less stable (shorter rise time and settling time, unless highly under-damped).

If the controls are set to meet the AAS for rise time and settling time for low system impedance conditions, then the response may be unnecessarily oscillatory for high system impedance conditions and more likely to be unstable for multiple contingency events.

AEMO proposes that the power system is best served if generators prioritise stability over speed of response. For the AAS this can be achieved if the tuning prioritises the rise time and settling time for the range of highest to typical system impedance conditions (in preference to highest to lowest impedance).

Speed of response is important only for voltage disturbances and not for setpoint changes. Setpoint changes are, however, used for testing purposes as a convenient way to apply a step change, and check plant response for stability and alignment to a model. AEMO proposes to apply the rise time requirement to a voltage disturbance, and to require only setpoint change to measure settling time.

In the Update Report AEMO sought feedback on use of apparent system impedance in the description of the range of impedance conditions. AEMO subsequently undertook some studies to investigate the value of using apparent system impedance (refer to Appendix A3). The studies indicated insufficient benefit to justify using this more complex methodology, as the dynamics of nearby plant were found to have significantly greater impact. Considering this finding and stakeholder feedback, AEMO does not intend to progress this change.

Other issues AEMO proposes to address are:

- Cases have been observed where a plant controller may wind-up when either there is a setpoint change or a voltage disturbance that causes a limiter to operate. When the change is reversed there can be a delay in response that may lead to over-voltages or under-voltages being unnecessarily prolonged. Applying a settling time requirement on response that causes operation out of a limit would provide an incentive for a more appropriate response.
- Stable response to power system disturbances is the single most important performance requirement. In Schedule 5.2 this is captured by settling time. However, to measure settling time, a step is required in the input quantity (in this case voltage), or the settling time cannot be properly calculated. To address this AEMO proposes to clarify the disturbance using the term “step-like” as a term which should be understood in the given context.
- Similarly, in the context of setpoint change, the recommended rule allows for any setpoint ramp rate input limit to be disabled (so that the input setpoint change is step-like) to assess the settling time.
- Transgrid requested flexibility in the MAS for settling time greater than 7.5 s to be permitted, at the discretion of the NSP. In some unusual cases, interaction with the controls of other plants can lead to longer settling times (with no stability issues). AEMO has also observed this phenomenon.

Relevant review objective

Align with best system performance.

Improve power system resilience.

Update report recommendation

For voltage control:

In the AAS:

- Require a 2 second rise time of reactive power system voltage change up to 5% for the highest system impedance and typical system impedance level nominated by the NSP.
- Retain a 5 second settling time (5% step not into a limit) and 7.5 s settling time (5% step into a limit).

In the negotiated access requirements:

- Require that controls must be tuned to achieve the lowest reasonably achievable settling time for the highest apparent system impedance level, prioritising the primary operating mode.
- If a settling time of 5 seconds cannot be met for the full range of apparent system impedances, then target achieving it for the range highest to typical apparent system impedance.

In the MAS:

- Allow a higher settling time longer than 7.5s to be agreed with the NSP for a voltage disturbance up to 5% (for both synchronous and asynchronous plant).

General requirements

- In the general requirements, explain the concept of **apparent system impedance** (see note below) and require that the minimum, maximum and typical values be recorded in the RUG.
- The typical system impedance level should be reflective of typical unit commitment.

Final recommendation

For voltage control:

In the AAS:

- Require a 3 second rise time of reactive power system voltage change 2% to 5%, not into a limiter for the maximum system impedance and typical system impedance level nominated by the NSP.
- Clarify the current requirement a 5 second settling time (step not into a limit) and 7.5 s settling time (step into a limit) for 2% to 5% step-like voltage change, and 5% voltage setpoint change, to specify that:
  - typical and maximum system impedance conditions apply, and
  - setpoint input ramp rate limit, if applicable, can be temporarily disabled for testing.
- Clarify the current requirement 5 second settling time (step not into a limit) and 7.5 s settling time (step into a limit) for a 2% to 5% step-like voltage change to specify:
  - typical and maximum system impedance conditions.
- Extend both the 7.5 s settling time requirements above to steps out of limits as well as into limits.

In the MAS:

- Allow a higher settling time longer than 7.5 s to be agreed with the NSP for a voltage disturbance of 5%, not into a limit (for both synchronous and asynchronous plant).

General requirements:

- Define the maximum system impedance (for tuning and assessment) as the impedance value corresponding to the value at the connection point considering the minimum three phase fault level on the electrically nearest system strength node, in conjunction with the network outage that most reduces the fault level at the connection point.

- Apply the same range of impedances to synchronous machine settling time for voltage setpoint step and voltage disturbance into and not into limiters.
- The typical system impedance level should be reflective of typical unit commitment.

2.10.3 Materiality threshold on settling time error band

Description of issue

NER S5.2.5.13 requires calculation of settling time for each of voltage, reactive power and active power for steps of voltage, reactive power and power factors for operation in those modes.

The issues with this are:

- The calculation of the settling time, as defined in the NER, depends on the response staying within a 10% error band). This becomes meaningless for a small transient plant where the error band becomes very small and a materiality threshold should be considered.
  - Active power excursions, especially, tend to be quite small for step changes.
  - For voltage and reactive power, similar compliance issues may arise related to measurement error and background noise, when the error bands for calculating settling time are too small.

Relevant Review objective

Streamline the connection process.

Update report recommendation

Apply a materiality threshold of 3MW, below which the calculation of settling time for active power excursions is not required, and

Apply a settling time error band that is the larger of:

- ±0.5 MW, and
- the value calculated under the settling time definition, for voltage steps in any mode or setpoint change in voltage control.

Final recommendation

Amend the NER as follows, for active power settling time:

- Apply a settling time error band that is the largest of:
  - ±0.5 MW, and
  - ±2% of the maximum active power (or maximum demand, where relevant) agreed under a performance standard for clause S5.2.5.1, and
  - the value calculated under the settling time definition.

Amend the NER as follows, for reactive power settling time:

- Apply a settling time error band that is the largest of:
  - ±0.5 MVAr, and
  - ±2% of the maximum reactive power agreed under a performance standard for clause S5.2.5.1, and
  - the value calculated under the settling time definition.

Amend the NER as follows for voltage settling time:

- Apply a settling time error band that is the larger of:
  - ±0.5% of nominal voltage, and
  - the value calculated under the settling time definition.

2.10.4 Clarification of when multiple modes of operation are required & treatment of voltage settling time for reactive power and power factor modes

Description of issue

NER S5.2.5.13 has an AAS requirement for generating systems and IRS to:

- operate in multiple modes (voltage control, reactive and power factor);
- switch between modes; and
- be able to do so through remote control in response to a command from AEMO.

In practice, most plant will operate in one mode over its life, although there are some exceptions.

Requiring operation in three modes requires all the activities of connection and compliance to be repeated for multiple modes. This is a non-trivial cost over the life of the plant if only one mode is ever likely to be used.

There is potential to streamline the connection process by defining one primary mode (which is used most of the time) and a secondary mode (for testing and other abnormal conditions).

As the secondary mode is used infrequently the compliance obligations can be light-handed for this mode, as the risk level associated with it is lower.

The following other issues have also been addressed:

- In some cases the settling time requirements are applied to quantities that are not controlled by the mode:
  - In reactive power and power factor modes voltage is not controlled, so it is not appropriate to assess compliance against voltage settling time.
- The current rules require a 5 second settling time for setpoint changes for power factor and reactive power modes. This implies a fast response, which is not desirable, and a well-damped response, which is desirable. It is possible to separate these two components by specifying that the settling time requirement for a setpoint change only applies where the response overshoots or is oscillatory (i.e. underdamped).
- If a ramp-rate limit on setpoint is applied, it should be not so long that it interferes with steady-state accuracy requirements. Rather than specifying a time, the setting can be agreed with the NSP and AEMO.

Relevant review objective

Align with best power system performance.

Streamline the connection process.

Support efficient investment and operation.

Update report recommendation

Require two modes in the AAS (primary and secondary):

- With the ability to switch between them.
- Where primary mode is voltage control.
- Where secondary mode either power factor or reactive power.
- With reduced assessment requirements for secondary mode:
  - Remove the requirement for settling time compliance assessment for power factor and reactive power setpoint changes.
  - Retain the requirement for settling time assessment for voltage disturbances for reactive power and (for power factor mode) active power.
  - Remove the requirement to assess voltage settling time for reactive power and power factor modes.

Final recommendation

In the AAS:

- Require two operating modes, a primary and secondary mode with the ability to switch between them.
- By default the primary mode is voltage control, but permit the NSP under the AAS to require a primary operating mode other than voltage control, with voltage as the secondary control mode.
- Where voltage is the secondary mode, omit the (AAS) reactive rise time requirement.
- For power factor and reactive power modes:
  - Remove the requirement to assess voltage settling time
  - In primary operating mode, for a setpoint step, not into a limit, equivalent to at least half the range of reactive power agreed in S5.2.5.1 require a reactive power settling time of 5 seconds or less, if response overshoots or exhibits oscillatory behaviour.

In the AAS and MAS:

- Where power factor mode or reactive power mode is the primary operating mode, require settling time to be assessed for the typical to high system impedance conditions.
- Otherwise for a secondary mode, require the voltage disturbance settling time to be assessed for typical impedance conditions.
- A ramp-limit on a setpoint change may be applied, where agreed with the NSP and AEMO (in all three modes).

Full detail of how AEMO's proposal would apply for rise time and settling time requirements across voltage, power factor and reactive power control, AAS and MAS and primary and secondary modes, is provided in Appendix A4.

2.10.5 Impact of a generating system on power system oscillation modes

Description of issue

A plant that has an adverse impact on system strength may elect to pay a system strength service provider (SSSP) to provide these services, which would potentially improve the damping performance of the plant. This should be considered in the assessment of S5.2.5.13.

Relevant review objective

Align with best system performance.

Streamline the connection process.

Update report recommendation

Amend as follows:

- Modify the MAS to require the plant not to reduce the damping of any oscillation that is not adequately damped.
- Where a Schedule 5.2 Participant has elected to pay the system strength charge (under NER 5.4.3B(b1)), require that assessments take into account the performance required to be provided by the SSSP at the relevant system strength node.

Final recommendation

Amend NER as follows:

- Where a Schedule 5.2 Participant has elected to pay the system strength charge (under NER 5.4.3B(b1)), require that assessments take into account the performance required to be provided by the SSSP at the relevant system strength node.

2.11 Definitions

2.11.1 CUO - recognition of frequency response mode, inertial response and active power response to an angle jump

Description of issue

The definition of CUO does not currently anticipate inertial response, active power response opposing phase angle jumps and primary frequency response.

The absence of such consideration can be seen as providing a disincentive to such behaviour, even though it is beneficial to the operation of the power system.

Explicitly allowing for them in the definition avoids any potential impediment or additional time required to negotiate about these behaviours, particularly for grid forming inverters, for which these behaviours can be suppressed by changes to tuning.

Nevertheless, where the response is programmed, their settings should reflect good electricity practice.

Other changes have been proposed to make the definition more general for all types of disturbances, rather than focusing mainly on faults.

Relevant Review objective

Align with best system performance.

Streamline the connection process.

Remove impediments for GFM inverters.

Update report recommendation

Modify the CUO definition or relevant clauses to:

- Carve out inherent or programmed responses opposing rate of change of frequency (inertial response) and opposing phase angle jumps, and operation in accordance with PFR requirements.

Final recommendation

Modify the CUO definition or relevant clauses to:

- Permit responses opposing voltage phase angle jumps and frequency changes, including inertial response during disturbances, and
- Make the reference to contingency events more general.

2.11.2 Rise time – explicitly disregards longer-term dynamics and external influences

Description of issue

The NER currently has an unusual definition of rise time, which it defines as: *in relation to a control system, the time taken for an output quantity to rise from 10% to 90% of the maximum change induced in that quantity by a step change of an input quantity*.[14] It is more usual to describe the rise time in terms of 10% - 90% of the sustained change.

The definition is used in S5.2.5.5 and S5.2.5.13, but in the former the reactive current injection, especially for longer faults, may be affected by longer term dynamics of other controls or external influences, which can interfere with the calculation of these quantities.

Relevant review objectives

Align with best power system performance.

Improve power system resilience.

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[14] National Electricity Rules, Version 203, Chapter 10 p. 1423.

Streamline the connection process.

Update report recommendation

Change the definition to make it more standard, and work more effectively for grid forming inverters (especially in S5.2.5.5).

Final recommendation

Modify the definition of rise time as follows:

- In relation to a control system, the time taken for an output quantity to rise from 10% to 90% of the mean sustained change induced in that quantity by a step change of an input quantity, disregarding longer-term dynamics and influences external to the generating system, following the step change.

2.11.3 Settling time – error band and materiality considerations

Description of issue

The NER currently has a non-standard definition of settling time, with two parts based on the ratio of the maximum deviation to the sustained change:

In relation to a control system, the time measured from initiation of a step change in an input quantity to the time when the magnitude of error between the output quantity and its final settling value remains less than 10% of:

> *(a) if the sustained change in the quantity is less than half of the maximum change in that output quantity, the maximum change induced in that output quantity; or*
>
> *(b) the sustained change induced in that output quantity.*[15]

The purpose of this is to allow for the settling time to be calculated when the sustained change is very small, as well as when it is large. Effectively it is dealing with error band size, but the calculation still leads to unworkably small error bands when the maximum and sustained changes are small. AEMO proposes to deal with this by explicitly managing the error bands for small changes in S5.2.5.13 (described in Table 1). In conjunction with the proposed changes the settling time definition can be reduced to the standard form.

Note that AEMO proposes that settling time for reactive current injection be removed from S5.2.5.5.

Relevant Review objectives

Align with best power system performance.

Streamline the connection process.

Update report recommendation

Change to make the error bands for settling time consistent as the ratio of sustained change to maximum induced change increases.

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[15] National Electricity Rules, Version 203, Chapter 10 p. 1429.

Final recommendation

In conjunction with materiality thresholds described for P, Q and V in the context of settling time under S5.2.5.13, modify the settling time definition as follows:

In relation to a *control system*, the time measured from initiation of a step change in an input quantity to the time when the magnitude of error between the output quantity and its final settling value remains less than 10% of the sustained change induced in that output quantity.

3 Final recommendations – NER Schedule 5.3a

This section summarises AEMO's final recommendations on the material issues considered in the Review in relation to NER Schedule 5.3a, as informed by consultation on the update report. Submissions supported AEMO's amendments relating to Schedule 5.3a, with Marinus Link and TasNetworks providing most feedback. A summary of stakeholder positions on the revised draft recommendations, AEMO's consideration of these views, and its proposed amendments based on careful consideration of issues raised is set out in Appendix A2. This section should be read in conjunction with the details provided in Appendix A2. Given the general support for proposed amendments to the technical requirements, the final recommendations remain unchanged from the update report recommendations, although they will capture changes made to the Schedule 5.2 recommendations where these are adopted for application to HVDC links.

3.1 NER S5.3a.1a Introduction to the schedule

3.1.1 Alignment of schedule with plant-type rather than registration category

Description of issue

At present, Schedule 5.3a only applies to MNSPs. However, not all HVDC systems in the NEM are registered as MNSPs. Currently the HVDC systems owned and operated by TNSPs are required to meet the requirements in NER S5.1. However, S5.1 does not specifically apply to HVDC systems. In addition, future HVDC systems may be owned and operated by other parties. Currently the NER is silent on the technical standards that should apply in this case.

As HVDC system behaviour can impact power system security, it is appropriate for the technical requirements of these types of plant to be defined in Chapter 5 of the NER and registered with AEMO.

Relevant review objectives

Broaden the application of technical requirements to all HVDC systems.

Incorporate impact and capability of HVDC systems into technical requirements.

Update report recommendation

As final recommendation.

Final recommendation

Amend NER as follows:

- Define HVDC systems (as 'schedule 5.3a plant) and apply the requirements of Schedule 5.3a to all HVDC systems irrespective of registration classification.
- Exclude HVDC systems from the requirements of NER S5.1 where they have performance standards documented under Schedule 5.3a.
- Allow flexibility for application of the performance requirements to an offshore wind facility.

Current and committed HVDC projects will not be affected by the recommended changes to the HVDC access standards.

3.2 NER S5.3a.8 – Reactive power capability

3.2.1 Reactive power

Description of issue

At present the reactive power requirements for HVDC systems are specified as power factor range.

In addition, modern HVDC systems have the same capability to provide reactive power as those in inverter-based generation and battery energy storage systems (BESS).

The reactive power capability of HVDC systems is important when managing the voltage profiles in the AC power system in a similar manner to generating systems. Therefore, it is important the reactive power capability requirements of HVDC systems is captured in Chapter 5 of the NER and registered with AEMO.

Relevant review objective

Incorporate impact and capability of HVDC systems into technical requirements.

Align with best power system performance.

Improve power system resilience.

Support efficient investment and operation.

Update report recommendation

As final recommendation.

Final recommendation

Align the reactive power capability requirements for HVDC systems with those for generators in NER S5.2.5.1, noting the proposed changes to NER S5.2.5.1 for generating systems.

3.3 NER S5.3a.13 – Market network service response to disturbances in the power system

3.3.1 Voltage disturbances

Description of issue

Currently the voltage ride through requirement in NER S5.3a.13 for HVDC systems is for continuous uninterrupted operation for the range of voltage conditions permitted in the system standards. The system standards for voltage magnitude in NER S5.1a.4 only contemplate the allowable voltages following credible contingency events.

Modern HVDC systems have similar voltage disturbance capability as inverter-based generation and battery systems.

The capability of HVDC systems to operate continuously for events that are more severe than credible contingencies is important for the resilience of the power system. Therefore, it is important this is captured in Chapter 5 of the NER and registered with AEMO.

Review objective

Incorporate impact and capability of HVDC systems into technical requirements.

Align with best power system performance.

Improve power system resilience.

Support efficient investment and operation

Update report recommendation

As final recommendation.

Final recommendation

Align the voltage disturbance power capability requirements for HVDC systems with those for generators in NER S5.2.5.4, considering the proposed changes to NER S5.2.5.4 for generating systems discussed in this report.

3.3.2 Frequency disturbances

Description of issue

Currently the frequency ride through requirement for HVDC systems is for continuous uninterrupted operation for power system frequency within the frequency operating standards.

Modern HVDC systems have similar frequency disturbance capability as inverter-based generation and battery systems.

The frequency ride through capability of HVDC systems is important for the resilience of the power system. Therefore, it is important this is captured in Chapter 5 of the NER and registered with AEMO.

Relevant review objective

Incorporate impact and capability of HVDC systems into technical requirements.

Align with best power system performance.

Improve power system resilience.

Support efficient investment and operation

Update report recommendation

As final recommendation.

Final recommendation

Align frequency disturbance power capability requirements for HVDC systems with those for generators in NER S5.2.5.3, including the RoCoF.

3.3.3 Fault ride through requirements

Description of issue

NER S5.3a.13 defines the required performance for HVDC systems in regard to disturbances in the power system. This clause does not include a requirement for fault ride through capability.

Modern HVDC systems have similar fault ride through capability as inverter-based generation and battery systems.

The security of the power system depends on the ability of HVDC systems to operate continuously following faults that are somewhat likely to occur, including multiple faults associated with non-credible contingencies. In this respect generating systems and IRS have the requirements in NER S5.2.5.5 (response to disturbances following contingency events). Therefore, it is important this is captured in Chapter 5 of the NER and registered with AEMO.

Relevant review objective

Incorporate impact and capability of HVDC systems into technical requirements.

Align with best power system performance.

Improve power system resilience.

Support efficient investment and operation.

Update report recommendation

As final recommendation.

Final recommendation

Amend NER as follows:

- Align fault ride through and MFRT capability for HVDC systems with those for generators in NER S5.2.5.5, noting the proposed changes to NER S5.2.5.5 for generating systems discussed in this report.
- Require HVDC systems to inject or absorb reactive current during the fault.

3.4 NER S5.3a.4 – Monitoring and control requirements

3.4.1 Remote monitoring and protection against instability

Description of issue

Remote monitoring and protection against inverter instability is an important topic, and the requirement for asynchronous generating units in NER S5.2.5.10 (Protection to trip plant for unstable operation) is being considered in this review. However, remote monitoring and protection against instability for HVDC systems is not currently in NER S5.3a.4 and HVDC systems are also potentially capable of participating in power system instabilities in a similar manner to inverter-based generation systems. Therefore, it is important this is captured in Chapter 5 of the NER and registered with AEMO.

Relevant review objective

Incorporate impact and capability of HVDC systems into technical requirements.

Align with best power system performance.

Improve power system resilience.

Update report recommendation

Align remote monitoring and protection against inverter instability requirements for HVDC systems to the equivalent requirements for generating systems in NER S5.2.5.10 (noting that there were some minor changes to the final recommendations in NER S5.2.5.10.

Therefore, amend as follows:

AAS:

- A requirement to install a PMU for each connection point.
- The capability to detect instabilities and execute hierarchy of automated actions agreed with the NSP and AEMO to supress instabilities.
- The agreed hierarchy of automatic actions may include the protection system disconnecting the HVDC system if required by AEMO or NSP but it should only be triggered when all other measures have been taken and the HVDC system is contributing to the instability.
- If required, the HVDC system must have the capability to send information from the detection system to AEMO and NSP.
- If required, the HVDC system must have the capability to receive a remote tripping signal from NSP.
- If required, the HVDC system must have the capability to receive information from AEMO about plant’s contribution to instability.

MAS:

- A requirement to install a PMU, subject to request from NSP.
- The capability to detect instabilities and execute hierarchy of actions to supress instability, and which is agreed with the NSP and AEMO.
- If required, the capability to send information from the detection system to AEMO and the NSP.
- If required, the capability to receive remote tripping signal.
- A requirement for detecting the contribution to instability is not required.

Final recommendation

Align remote monitoring and protection against inverter instability requirements for HVDC systems to the equivalent requirements for generating systems in NER S5.2.5.10.

Therefore, amend as follows:

AAS:

- A requirement to install a PMU for each connection point.

- The capability to detect instabilities and execute hierarchy of automated actions agreed with the NSP and AEMO to supress instabilities.
- The agreed hierarchy of automatic actions may include the protection system disconnecting the HVDC system if required by AEMO or NSP but it should only be triggered when all other measures have been taken and the HVDC system is contributing to the instability.
- If required, the HVDC system must have the capability to send information from the detection system to AEMO and NSP.
- If required, the HVDC system must have the capability to receive a remote tripping signal from NSP.
- If required, the HVDC system must have the capability to receive information from AEMO about plant's contribution to instability.

MAS:

- A requirement to install a PMU, subject to request from NSP.
- The capability to detect instabilities and execute hierarchy of actions to supress instability, and which is agreed with the NSP and AEMO.
- If required, the capability to send information from the detection system to AEMO and the NSP.
- If required, the capability to receive remote tripping signal.
- A requirement for detecting the contribution to instability is not required.

3.5 New standards

3.5.1 Voltage control

Description of issue

Currently Schedule 5.3a does not specify the AC voltage control requirements for HVDC systems.

Modern HVDC systems have the capability to provide AC voltage control independently at each AC terminal.

A change in the active power transfer over a HVDC system will have a material impact on the AC voltage at both its AC terminals. Therefore, the HVDC system should control the voltage or reactive power at its AC terminals to compensate, in a similar manner to generating systems. Thus, it is important this capability is captured in Chapter 5 of the NER and registered with AEMO.

Relevant review objective

Incorporate impact and capability of HVDC systems into technical requirements.

Align with best power system performance.

Support efficient investment and operation.

Update report recommendation

As final recommendation.

Final recommendation

Align AC voltage control capability for HVDC systems with those for generators in NER S5.2.5.13, noting the proposed changes to NER S5.2.5.13 for generating systems discussed in this report.

3.5.2 Active power dispatch

Description of issue

The flow of active power on HVDC systems needs to be controlled in a similar manner to the dispatch and ramping of scheduled generators, and currently this requirement is not included in NER S5.3a. Therefore, it is important this capability is captured in Chapter 5 of the NER and registered with AEMO.

Relevant review objective

Incorporate impact and capability of HVDC systems into technical requirements.

Align with best power system performance.

Support efficient investment and operation.

Update report recommendation

As final recommendation.

Final recommendation

Align active power control requirements for HVDC systems with those for generators in NER S5.2.5.14, including for dispatch and ramping.

4 Final recommendations – NER Schedule 5.3

4.1 Introduction

4.1.1 Context of the review of Schedule 5.3

AEMO published an addendum to the draft report for this Review setting out its draft recommendations and reasons for proposing amendments to technical requirements of Schedule 5.3. This considers connection requirements for Customers (load)[16]. AEMO received 11 submissions on those recommendations from various industry stakeholders. A detailed summary of stakeholder positions on the draft load recommendations and AEMO's responses is set out in Appendix A5.

AEMO's final recommendations on Schedule 5.3 represent a material change from the draft recommendations. AEMO made these after considering written submissions to the draft report addendum, feedback provided at AEMO's "Large load connections Policy Framework Options Assessment" workshop held on 31 August 2023[17] and further discussions with hydrogen original equipment manufacturers and potential developers.

For each of the issues raised in the draft report addendum, this section of the Report notes the draft recommendations previously made and revised positions with the benefit of further analysis and information received during the Review consultation. Appendix A5 summarises the key issues in the written submissions on the draft report addendum and AEMO's responses.

4.1.2 High level proposal

AEMO considers that the review of Schedule 5.3, involving extensive consultation with various stakeholders, has identified many of the issues relevant to the access standards required for the future connection of large loads.

To understand the need for more detailed technical requirements for load connections, such as ride through requirements, AEMO canvassed NSPs on the criticality and urgency of such measures. While responses varied, most respondents indicated moderate to high level criticality. With regard to urgency, most NSPs indicated that detailed requirements should be in effect in the NER within five years (and five indicated within 24 months). NSPs also provided information on anticipated size, type and timing of large load connections as indicated by enquiries and applications and other sources of information about load developments. The responses identified large data centres and hydrogen projects as being most likely to be covered by additional ride-through requirements.

However, while NSPs indicated support for more detailed load technical requirements, AEMO's assessment of feedback received on fundamental aspects of its draft recommendations indicates that further consultation and analysis is required before a rule change proposal for detailed technical standards can be submitted to the AEMC.

In light of draft recommendation feedback, and other information gathered for the Review, AEMO's final recommendations are in two categories:

1. **Initial rule changes to be proposed to the AEMC immediately following this Review:**

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[16] AEMO Review of technical requirements for connection – Addendum to Draft Report, 4 April 2023, refer to: https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/aemo-review-of-technical-requirements-for-connection-ner-clause-526a/2023-04-04_technical-requirements-review_draft-report_s53-addendum_final.pdf?la=en

[17] In addition to the "Large load connections | Policy Framework Options Assessment" workshop, AEMO held an Access Standards Review webinar - Large load connections fundamental concepts on 30 August 2023.

  - A limited number of rule changes, to address issues raised by stakeholders where the solution is reasonably straightforward and non-contentious; or in one case, where there is an important issue requiring remedy in the near future. A key recommendation in this category is to introduce a limited set of highly flexible requirements, to allow the ride through capability of new load technologies to be captured in preparation for the negotiation of very large new load connections that may eventuate in the near term.

2. **Detailed technical requirements to be further developed outside of this Review:**
   - AEMO intends to further consult with industry and develop more detailed technical requirements through a separate and subsequent review (Load Technical Requirements Review) using recommendations under this review as a starting point; and propose additional rule changes to the AEMC based on the outcomes of that review.

Recommendations to address identified issues for large loads are detailed in this section, and identified as being either for immediate inclusion in a Rule change proposal; or as a starting point for the Load Technical Requirements Review).

AEMO has decided on this approach as the Review has indicated that the technologies for very large load projects in the hydrogen production area, which are most likely to impact power system security, are experiencing a period of rapid development requiring a more detailed understanding of their potential capabilities in close collaboration with the developers.

At present there are several load projects at or nearing demonstration stage, with potential to scale up to several hundred MW within the next few years. AEMO understands that the ultimate size of some individual hydrogen loads may be in the order of 1000-5000 MW in some cases.

There are a range of technologies for hydrogen production currently under development, and at this stage the performance characteristics related to operation on the power system are not fully understood. Nevertheless, the size of the projects envisaged means that their performance could materially impact the operation of the NEM, so it is critical that appropriate access standards are developed. Considering these factors, AEMO proposes the changes summarised in the following table to progress an initial rule change proposal.

In addition, AEMO's consultation so far has identified multiple potential new data centre loads more than 100 MW in size, and up to 600 MW. Several of these projects are at connection enquiry or pre-application phase and some projects propose to connect within the next two years. Considering the mature technology and scalability of data centres, the timing and scale is technically feasible.

The following table summarise AEMO's recommended initial rule changes for Schedule 5.3 and how these meet review objectives listed in section 1.1.2 of this report.

Table 7 Recommended initial rule changes for Schedule 5.3

Issue	Description of issue	Schedule 5.3 Customer Recommendation	Review objectives
Recording ride through capability of new loads	The ride through capability of some loads is not currently well understood and is likely to change as technologies mature. However, AEMO and the NSP's ability to efficiently manage system security require depends on them knowing the ride through capability of the large loads.	Provide NSPs the discretion, in consultation with AEMO, to require the ride through capability of a load intending to connect to its network (without any size threshold specified) to be established (under the existing NER connection process) and recorded in the performance standard.	• Incorporate impact and capability of large loads into technical requirements. • Improve power system resilience.

Issue	Description of issue	Schedule 5.3 Customer Recommendation	Review objectives
Short circuit ratio requirement for loads	NER S5.3.11 requires that IBL be capable of operating at a SCR of 3.0 or lower. AEMO understands that not all such loads may be able to achieve this without additional capital or operating expenditure.	Amend NER S5.3.11 to apply to IBLs that are also large inverter-based resources, and make the minimum short circuit ratio (SCR) requirements more flexible.	• Streamline the connection process. • Support efficient investment and operation.
Protection systems and settings	Some protection systems and settings may materially reduce the inherent ride through capability of the load, thus reducing the resilience of the power system.	Require protection settings consistent with performance capability, considering reasonable safety margins.	• Incorporate impact and capability of large loads into technical requirements. • Align with best power system performance. • Improve power system resilience.
Emergency under-frequency ramp down of large loads	Currently large loads must make 60% of their loads available to emergency under-frequency load shedding schemes. Some loads may be more flexible if they can ramp down their load in an emergency rather than shedding it in blocks.	In addition to the capability to shed load during an under frequency, permit fast ramp down of load where: • the load has the appropriate capability; and • AEMO and the NSP agree the scheme's settings.	• Incorporate impact and capability of large loads into technical requirements. • Support efficient investment and operation
Stability of IBL – monitoring, protection and performance	Currently loads do not require stability monitoring and protection systems. However, modern IBL may be susceptible to the same types of instabilities as inverter-based generation and HVDC systems.	Require monitoring on IBL projects for control stability.	• Incorporate impact and capability of large loads into technical requirements. • Align with best power system performance. • Improve power system resilience.

The following table summarises the recommended starting policy positions for the Load Technical Requirements Review. This review will determine load ride through requirements, which will support efficient investment and operation and improve power system resilience.

Table 8 Starting points for the recommended future Load Technical Requirements Review

Issue	Description of issue	Schedule 5.3 Customer Recommendation
Size threshold for new loads	Applying access standards for ride through requirements to large loads has potential benefits to the operation of the power system but could add significant costs to the project, the NSP and AEMO.	The access standards to single load facilities above a threshold size level, currently proposed to be set as a proportion of the smaller of the maximum load contingency size specified for the region, in the frequency operating standard, if any, and the maximum load contingency in the NEM.
Different load technologies	Applying different access standards to different technologies with different performance capabilities may or may not be efficient but may be complicated to specify and apply.	The access standards irrespective of the technology and whether the plant is an IBL.
CUO	The CUO requirements referred to in NER S5.2 for generating systems are arduous and may not be appropriate for load connections.	A light-handed definition of continuous uninterrupted operation to the access standards.
Size threshold for alterations to existing plant	AEMO is proposing that the access standards for large loads be applied for loads with a capacity greater than a size threshold. This approach requires clarification for alterations to part of load facility.	The size threshold for existing plant alterations is based on the size of the alteration rather than the size of the whole facility unless AEMO and the NSP consider that power system security would be impacted by the performance of the whole plant.

AEMO will also consider whether a voluntary technical specification for large load performance would be of value, as an interim step, considering the lead times associated with progressing the first and second stage rules changes under a standard rule change process. A voluntary specification could help developers and OEMs understand what AEMO and NSPs would want from their plant, and help AEMO and NSPs to understand what is possible from the various technologies.

The application of the voluntary technical specification by AEMO, the NSPs and the developers could be a way of testing draft proposals for potential access standards for loads without the risk associated with an inability to meet the access standards. Developers that consider the requirements of the voluntary technical specification for their initial prototype loads would be informed about preferred load performance on the power system and the capability of their plant technology to meet potential new requirements for large loads.

4.2 Assessment of the need for ride through capability for loads

4.2.1 Focus on 'ride through requirements' for large loads

Draft recommendations focused on the performance of large loads during frequency and voltage disturbances and contingency events (for brevity, described as 'ride through requirements').

As with AEMO's recommendations for NER S5.2 and S5.3a, it developed its recommendations for the technical requirements for large loads with reference to the NEO and therefore sought to balance efficient investment and operation of large load facilities and other electricity services, while maintaining power system security. In particular, AEMO considered when a large load customer should be required to contribute to better system outcomes through additional technical requirements on its load, or whether NSPs or AEMO can more efficiently make further investments or operational adjustments to maintain effective and secure supply for every connecting load.

The range of feedback from different stakeholders on the draft recommendations has been key to assessment of efficiency.

4.2.2 Current Schedule 5.3 requirements have no ride through requirements for large loads

There are a limited number of existing very large loads connected in the NEM, typically aluminium smelters, ore refineries, mining loads and large datacentres. To date, the impacts of these individual large loads on the operation of the power system could be considered in isolation from other loads because they have generally been electrically and geographically distant from each other. However, connection enquiries and public announcements suggest some additional very large, often co-located, loads will be developed in the near future. These may be connected in a power system dominated by inverter-based generation, which is likely to have lower inertia and less system strength than the present system. Some new loads may have dynamic behaviours that pose challenges for operation of the power system.

Location of very large loads in electrical proximity to each other or to inverter-based generation increases the risk of interactions between them or power system responses that in combination are more detrimental to the power system than the responses considered separately.

For secure operation of the power system, potential adverse impacts of these large load connections may need to be addressed on multiple fronts - by the design of the network, by constraining the power system and by adequate performance of the loads themselves. It is necessary to prepare now for the efficient connection and ongoing operability of these loads in today's power system.

Very large loads can have a significant impact on the operation and planning of the power system, because a trip of the load will impact power system frequency as well as local network voltages and power flows.

Maintenance of power system security requires the power system to be operated so that it will ‘land’ in a satisfactory operating state following any credible contingency event. The system is ‘satisfactory’ when frequency, network voltages and network current levels are all within their limits or ratings[18]. To achieve a satisfactory operating state following the trip of a very large load, it might be necessary for AEMO to procure additional frequency control ancillary services (FCAS) lower services to manage power system frequency, and for the relevant NSP to introduce additional constraints on the network flows or to augment the power system to manage voltage stability, power quality and network loading.

In addition to the impacts of individual large loads on power system security, it is necessary to consider the cumulative impact of multiple loads tripping in response to a common event such as a voltage or frequency disturbance, or a fault or sequence of faults. If the loads are unable to ride through the disturbance or faults, then multiple loads may trip, resulting in a much larger contingency event compared to the tripping of an individual large load. Where loads connect in clusters, such as in hydrogen hubs with multiple connecting parties, large amounts of load are more likely to be affected by the same power system disturbance, impacting both system frequency and the local network.

The NER currently do not require loads to ride through contingency events. Therefore, where there is a risk of multiple loads tripping for a contingency event, the potential risks to the power system are managed by the relevant NSP and AEMO through power system design and operation, and the risk to power system frequency is managed by AEMO. When planning the network, the NSP must seek to ensure the system standards are met. NER schedule 5.1 requires NSPs to apply planning criteria required to achieve adequate levels of network power transfer capability for the common good of network users[19], including various stability criteria that can be impacted by load response to power system disturbances. In the absence of technical standards for ride through of loads, the NSP must consider the likelihood of loads tripping based on historical performance of aggregate loads, and modelling based on aggregate load models. They must then plan their networks to accommodate the anticipated level of performance, recovering the associated costs from consumers in the form of network charges. This approach is justified by economies of scale for multiple small loads, compared with the cost of each load addressing its impact on the power system.

4.2.3 Potential benefits of ride through requirements for large loads

AEMO’s *Engineering Roadmap to 100% Renewables*, published in December 2022, identified challenges associated with managing significantly increased volumes of large load connections. Many new large loads are expected to be inverter-based, including data centres and hydrogen electrolysers. There is potential for them to adversely impact power system stability, power quality and resilience[20]. In particular, contingency sizes associated with unexpected disconnection of multiple new loads may need to increase, and they may increase the potential for inverter-based instability in weak parts of the grid.

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[18] The complete description may be found in NER 4.2.2.

[19] NER S5.1.1(a)

[20] AEMO, *Engineering Roadmap to 100% Renewables*, December 2022, at https://aemo.com.au/-/media/files/initiatives/engineering-framework/2022/engineering-roadmap-to-100-per-cent-renewables.pdf?la=en.

The risk of unexpected disconnection of new large loads can be reduced if they have the capability to ride through faults and disturbances in a similar manner to generating systems. This reduces the likelihood of cumulative disconnection of significant loads and the associated impacts on network constraints and FCAS costs, while increasing the resilience of the power system to more severe contingency events.

Assessing suitable ride through capability requirements implies individual dynamic models of large loads to demonstrate performance in power system studies. By modelling some of these large loads, the impact of their responses in the broader power system can be better understood, increasing confidence in the level of requirements and actions needed to maintain power system security. The modelling of large IBL is also likely to improve the tuning of their control systems and hence reduce the risk of unstable interactions between inverter-based generating systems and loads, as well as network equipment such as static compensators (STATCOMS).

Resilience of the power system to multiple loads disconnecting

The power system is likely to be more resilient to multiple loads disconnecting following a disturbance than to an equivalent amount of generation. For example, most generating systems and bi-directional units can rapidly reduce their output for an emergency over-frequency event caused by multiple load disconnecting. However, it is not generally true that generation can rapidly increase output for under-frequency events caused by multiple generating plants tripping, unless the remaining production units have a large headroom. The power system benefits from load reduction from some types of loads that naturally occurs for under-frequency conditions. In addition, emergency under-frequency events are managed using under-frequency load shedding (UFLS) which has a widespread impact on many loads, and may take much longer to restore than reduced output from generation. By comparison, over-frequency events usually do not lead to tripping of generation, so the power system can be restored to normal operation more quickly, and with less widespread impacts.

Similarly, the disconnection of multiple loads usually causes an over-voltage which can be managed before additional load or generation tripping or damage occurs, with transformer tap-changers and reactive power plant such as STATCOMs, inserting reactors and tripping capacitor banks. However, multiple generating systems disconnecting usually results in an under-voltage which can quickly evolve into a voltage collapse and major supply disruption if insufficient reactive support is not available.

Multiple large load and multiple generation disconnection can both cause angular stability issues. This risk is managed using transient stability limits when the load disconnection is a credible contingency event but can otherwise result in the power system splitting into two or more islands. The relative impact on the resilience of the power system to large quantities of load or generation disconnecting depends on the specific circumstances and the operating state of the power system.

4.2.4 Potential additional costs from imposing ride through requirements on loads

While there are potential benefits from imposing ride through requirements on some large loads, there are also some significant costs that need to be considered.

The imposition of ride through requirements on new loads could add to their capital and operating costs where the load technology does not inherently have ride through capability, or the performance requirement is inconsistent with those inherent capabilities. In many cases the cost of more expensive or additional plant to meet these requirements may be offset by efficiencies from better power system performance that benefit the load, but in others the additional investment could make the load project uneconomic.

The modelling studies required to assess the ride through capability of large loads are commensurate with the equivalent requirements for assessing a generating system connection. This will introduce a cost – relatively large for small loads compared with the project value – while the models are developed, the studies completed, and the performance standards negotiated. The additional time for the negotiation of the connection can add to the financial cost of the projects. This is especially true if the load technology is new and detailed PSCAD^{TM} models have not previously been developed, but also if the load is comprised of many different elements or technology types, which would make detailed characterisation complex and costly.

In addition, requiring ride through capability to be assessed and negotiated for a large load connection would require the dedication of additional skilled resources by AEMO, NSPs and load proponents. Those resources are limited, and already heavily utilised in the assessments of generating systems and bi-directional units connections. It is important at this stage of the energy transition to allocate these skilled resources carefully where they are most effective. Impacts from any delays to connection of new generation, as a result of resource impacts, are also likely to flow onto all consumers through higher electricity prices and potential reliability issues as thermal plants close. The alternative of prioritising the connection of generation over loads is also not desirable, however, as the efficient connection of new load technologies is also important to the transition to a lower-carbon economy.

4.2.5 Balancing potential benefits and additional costs

Access standards for large loads should be applied to maximise the net benefit of imposing access standards on selected large loads considering the costs and the benefits, which promotes the NEO.

Potential criteria that can be used to determine whether to apply the ride through capability access standards include:

- Load size (MW).
- Whether the large load technology has inherent ride through capability.
- Actual or expected proximity to other loads that may be susceptible to the same disturbances and faults.

Figure 2 illustrates the potential trade-off between the total costs and total benefits of imposing additional ride through requirements with different load size thresholds. Exact costs and benefits would, of course, vary significantly with the distribution of loads at different sizes and the specific commercial, technical and locational circumstances of the loads considered.

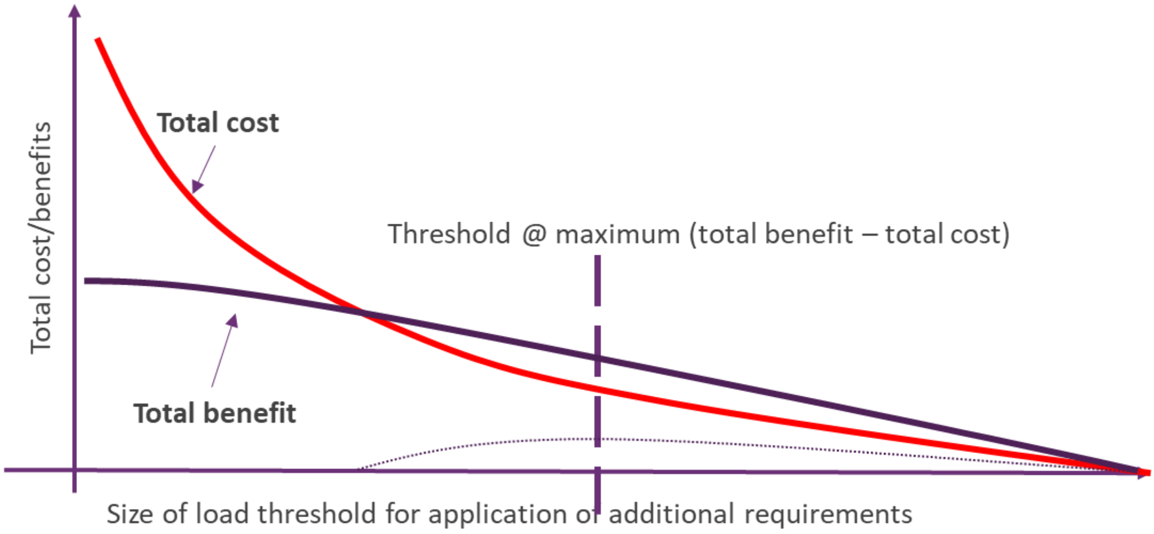
At one extreme, the costs of a low size threshold resulting in the application of additional ride through access standards to all non-retail customer load connections would be prohibitive and highly impractical. Applying access standards to a very large number of smaller loads would provide negligible individual benefits to the power system and the cumulative impacts could be more efficiently managed centrally by the NSP, as is current practice.

At the other extreme, with a very high size threshold, virtually no loads would be captured by the technical requirements, meaning all supply and security risks associated with cumulative load disconnection continue to be the responsibility of the NSP and AEMO through the design and operation of the power system with an inefficient allocation of risk, benefit and cost.

At an optimal size threshold, sufficiently large loads are captured and assessed under the ride through access standards, with additional requirements imposed when it is efficient to do so, realising the greatest potential benefits for proportionately low costs (expected to be economic for the impacted projects). Cumulative impacts will still be managed by the NSP and AEMO, but there will be a better basis on which assumptions can be made.

Larger loads will have greater responsibility for their performance impacts, but will also derive greater benefits from improved cumulative load performance.

Figure 2 Conceptual illustration of cost and benefit trade-off by load threshold size



Conceptually, the optimal threshold would be when the total net benefits from applying the additional ride through capability access standards is maximised, as indicated by the vertical dotted line in Figure 1. However, in practice the optimal value of the threshold cannot be determined precisely, as it would depend on many factors including:

- Numbers of loads of different sizes and technologies.
- Location of the loads larger than the threshold in the network, and hence the size of the impact if they are unable to ride through disturbances and faults.
- The project-specific nature of connection assessment and delay costs.
- The cost of centralised NSP solutions to potential cumulative load disconnection risks.

4.3 Recommendations

AEMO has revised its draft recommendations contained in its addendum to the draft report following submissions and further engagement with stakeholders.

AEMO recommends further development of the recommendations in this section when it pursues its Load Technical Requirements Review. Therefore, the discussion in this section provides stakeholders with AEMO's final position on these matters under the Review. These positions will be the starting positions under the subsequent Load Technical Requirements Review, which would inform a future rule change proposal to amend the access standards in NER S5.3 to include detailed ride through requirements for large loads.

In addition to the recommended Load Technical Requirements Review, AEMO proposes a number of rule changes, with a limited set of highly flexible requirements, to allow the ride through capability of new load technologies to be captured in preparation for the negotiation of very large new load connections that may eventuate in the near term.

4.3.1 Definition of single facility load

Draft report recommendation

AEMO recommended a definition of a single load facility as:

A single facility load is a load that forms part of a single installation (as distinct from the connection between a transmission and distribution network).

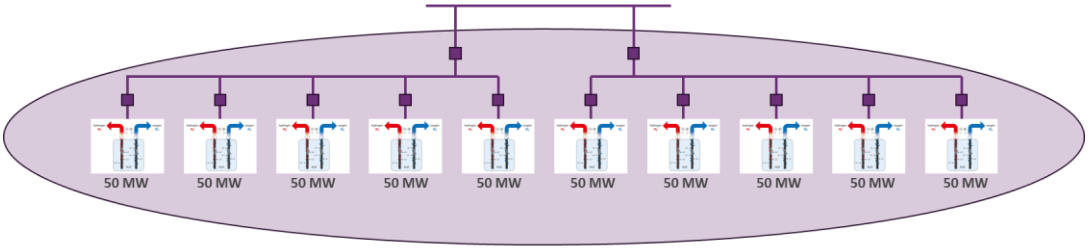
It may have one or more physical connection points, which are in electrical proximity to each other, and the plant within the facility can be described as one geographical location, so that most power system disturbances affect the facility as a whole. A single facility load may have different types of load technologies. For the purposes of the technical requirements of Schedule 5.3, a single facility load is 5 MW or greater.

Further analysis

Large loads should be considered on a facility basis, rather than the size of the loads behind each of the individual connection points that supply the facility. The load size at individual connections is important for determining the size of the largest credible contingency caused by a fault or equipment failure within the load itself, but the total load within the facility is relevant when considering its response to disturbances and faults originating from the power system.

For example, consider a facility comprising 10 electrolysers, each rated at 50 MW with a separate connection to the network, as illustrated in Figure 3. The normal credible contingency size for a fault within the load would be 50 MW, but the 500 MW if the loads could not ride through a disturbance originating from a credible contingency event on the power system. Therefore, when considering the need for ride through capability, the size of the whole facility is more important than the individual electrolysers.

Figure 3 Example of a single facility load with multiple electrolysers



Through a consultation forum with large load stakeholders it was questioned whether distributed facilities like railway facilities would be captured if a single fault affecting signalling at one location could cause a safety shutdown of the rail network. While such an event could potentially affect a significant portion of the rail facilities, AEMO considers that an impact that is distributed over a large geographic area, and not directly caused by a power system event rather a safety system, should not be considered under the proposed definition of single facility load. AEMO has proposed a minor wording amendment to clarify that the definition is intended to cover direct power system disturbance impacts.

Note that while the whole facility would be considered when assessing the disturbance ride through capability, it is important for the operation of the power system that the largest plant contingency (i.e. the amount of power that can be disconnected as a result of a fault or failure within the plant) is managed appropriately, considering the size of the plant. This is because the largest amount of plant that can trip needs to be considered in defining the limits on power system operation (network limits). This is affected by the design of the plant and its connection(s) to the grid. If the impact on the grid is large, there will likely be an impact on the cost of connection, as network upgrades may be required for the project. It is therefore important to optimise the connection and plant design so that the overall cost is minimised.

Final recommendation

AEMO has revised its draft report recommendation to include a clarification as follows:

A single facility load is a load that forms part of a single installation (as distinct from the connection between a transmission and distribution network).

It may have one or more physical connection points, which are in electrical proximity to each other, and the plant within the facility can be described as one geographical location, so that most power system disturbances affect power delivery to the facility as a whole. A single facility load may have different types of load technologies. For the purposes of the technical requirements of Schedule 5.3, a single facility load is 5 MW or greater.

AEMO will use this working definition in the next phase of work on the Schedule 5.3 technical requirements.

4.3.2 Treatment of different load technologies and types

This section collates learnings from AEMO’s consultation with industry, before discussing the draft report recommendation and AEMO’s analysis and proposed way forward.

Complexity of load installations compared with generation

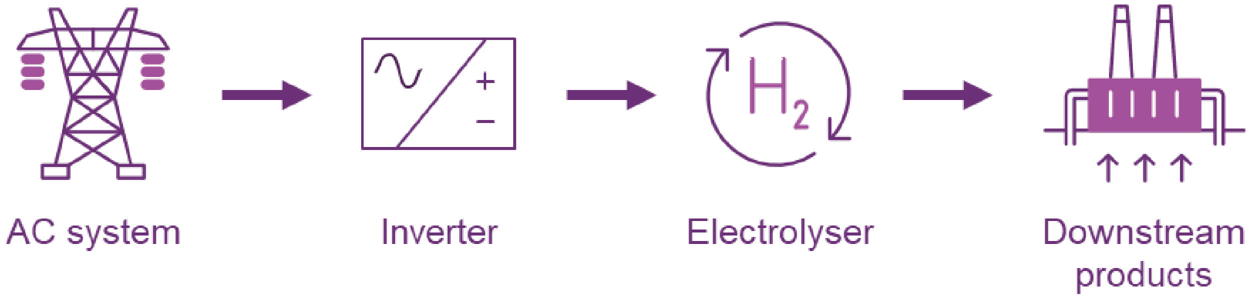
Inverter based generation and bi-directional units are required under NER Schedule 5.2 to be able to ride through relatively severe non-credible contingencies, as specified in S5.2.5.3, S5.2.5.4 and S5.2.5.5 for frequency, voltage and multiple contingency events. This capability is important to maintain the security and resilience of the NEM power system. This performance is possible because of:

- The advanced technology and control algorithms used in the inverters.
- The robustness of the DC generation source (such as the battery or PV system) to disturbances in the operation of the inverter.

That is, the DC generation source provides a steady DC voltage which allows the inverter to ride through disturbances and continue to operate normally following the disturbance.

Figure 4 shows a simplified representation of an IBL. The inverter draws active power (and reactive power) from the AC system and supplies DC power to the DC load (for example a hydrogen electrolyser and downstream hydrogen processing facility). A disturbance in the AC system has the potential to interrupt the operation of the inverter and hence the supply of power to the DC load. Therefore, while the inverter’s operation may be robust, the ability for the IBL to continue to operate following a disturbance depends greatly on the capability of the DC load.

Figure 4 Simplified model of an inverter-based load



In generator facilities the installations are generally dominated by the generating units. There are some relatively small auxiliary loads, which may include pumps and compressors, the performance of which must be considered when assessing the capability of plant to remain in operation during power system disturbances. Loads by contrast can have a wide range of technologies and combinations, which make their performance for power system disturbances much more difficult to generalise:

- Multiple different technologies used for loads have quite different characteristics for ride through and other performance that will be of importance for connection to the grid. Very large loads often include several different types of load, which may need to be considered individually or in combination.
- For continuous operations containing sequential processes, the inability of one element of the facility to remain in continuous operation during a power system disturbance may cause part or the whole load to significantly reduce its active power consumption or even trip.
- Even where the processes are not sequential, interdependencies between various parts of the plant (for example, a cooling system, which is required to prevent another plant overheating), could affect the ride through performance of part or all of the load facility.
- In cases where the technology is rapidly evolving, as is the case for hydrogen production, most focus is on making the processes more efficient and cost effective, with relatively little consideration given to their interaction with the grid.
- Whereas generator OEMs are familiar with providing models suitable for simulation studies, OEMs for loads are often not familiar with this requirement.

Inherent capability of IBL compared to other types of load

Inverter based load under the NER is defined as 'a load that is supplied by power electronics, including inverters, and potentially susceptible to inverter control instability, and that is classified as an IBL applying criteria specified in the system strength impact assessment guidelines'. In this section AEMO considers whether IBL has more ride through capability in the context of hydrogen production technology, which clearly meets these criteria, and is of particular interest in this review. The findings can be generalised to other types of IBLs.

AEMO has been consulting with industry to better understand the capability of hydrogen-related loads for continuous operation during power system disturbances. A key finding is that the ability to ride through depends on a combination of variables, including:

- Type of technology used in the inverter.
- Type and design of the hydrogen electrolyser.

- Characteristics and design of downstream processing facilities.

Inverter-technology impact

The two existing options for inverter technology are thyristor-based or insulated gate bipolar transistor (IGBT)-based.

Thyristor-based inverters are more likely to be used in applications with very high currents because of their lower losses, compared to IGBTs. However, thyristor-based inverters have a number of disadvantages including:

- Producing higher levels of harmonic currents, which may require mitigation such as harmonic filters.
- Acting as a sink of reactive power in the absence of harmonic filters or other ancillary reactive equipment.
- Limited ability to control their reactive power consumption.
- Commutation of the thyristor devices during inverter operation potentially requires higher system strength conditions (higher SCR), possibly necessitating synchronous condensers or STATCOMs to support their operation.
- May require a DC to DC converter between the DC output of the inverter and the electrolyser to improve the waveform provided to the electrolyser.

IGBT-based inverters have greater flexibility than thyristor-based inverters and are more capable of the levels of performance provided by inverter-based generation. For example, IGBT-based inverters can be designed to:

- Provide reactive power, including for voltage control.
- Inject reactive current during fault conditions to support the local voltage.

In addition, it may be possible for IGBT-inverters to also provide grid-forming services subject to the performance of the electrolyser and downstream processes[21].

However, there still may be differences in performance of hydrogen production facilities employing IGBT-based inverters compared to the same types of inverters in generating systems, because of the behaviour of the DC-connected elements and the downstream processes.

Electrolyser impact

The two main types of hydrogen electrolysers being considered are alkaline electrolysers (AEL) and polymer electrolyte membrane (PEM) electrolysers, also known as proton exchange membrane. Other technologies are being developed such as solid oxide electrolysis cells (SOEC)[22] [23] [24].

Alkaline electrolysers have been used in industry for over a century and their design has evolved over this period[25]. However, the many designs used to date are generally not well suited for load changes within seconds or for longer downtimes in intermittent operation. Being less flexible, alkaline electrolysers are also less likely to be able to ride through significant disturbances in the power system.

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[21] Tavakoli,et al “Grid-Grid-Forming Services From Hydrogen Electrolysers”, Accepted for the IEEE Transaction on Sustainable Energy, 2023.

[22] VDE Discussion Paper “Grid-serving integration of electrolysers”, December 2022 available at https://www.vde.com/en.

[23] IRENA (2018) “Hydrogen from renewable power – technology outlook for the energy transition”, September 2018, available at https://www.irena.org.

[24] GHD and ACIL ALLEN “Hydrogen to Support Electricity Systems”, prepared for Department of Environment, Land, Water and Planning, February 2020, available at https://www.irena.org.

[25] IRENA (2020), “Green hydrogen cost reduction: Scaling up Electrolysers to Meet the 1.5ºC Climate Goal,” 2020, available at https://www.irena.org.

PEM electrolyser technology is newer and generally considered as state of the art. PEM can respond more rapidly to load changes than AEL or SOEC. However, dynamic operation causes greater degradation of the expensive catalytic converters, thus shortening the service life. In addition, the capital cost of PEM is higher than an equivalent AEL, although the cost is falling. AEMO anticipates the PEM electrolyser technology is more likely to have some inherent ride through capability.

SOEC electrolysers use ceramic membranes and operate at 500°C to 850°C, which is much higher than AEL and PEM that operate at 50°C to 80°C. Consequently, SOEC electrolysers require longer ramp-up from cold following an outage. While more efficient than other hydrogen electrolysers, AEMO has no information to indicate whether they will have ride through capability.

There have been several investigations into using hydrogen electrolysers for inertia, frequency control and voltage control, and in some cases including grid-forming capability when allowed by the downstream facilities. However, very few studies have considered their ride through capability. The main conclusions of one study in 2023 relating to the operation of electrolysers were[26]:

- The hydrogen electrolyser inverter needs to be protected by limiting the current during faults (low voltage) conditions.
- The hydrogen electrolyser inverter can only contribute reactive current during a fault or low voltage condition.
- The performance of the hydrogen electrolyser inverter will depend on the control mode prior to the fault.
- The active power consumption of the hydrogen electrolyser will slowly return to its pre-disturbance value.
- An example of an internal fault that caused the hydrogen electrolyser inverter to separate from the AC system, even when the internal fault was cleared.

AEMO notes that the ability for the electrolyser to operate continuously when the output of the inverter is interrupted during a power system fault or disturbance may be improved if some storage is introduced to the DC system between the inverter and the electrolyser. This could potentially be a capacitor or small battery to buffer the supply to electrolyser. However, this would likely increase the cost of the facility both directly through the costs of the capacitor or battery, and indirectly through the increased fault level in the DC system.

Hydrogen processing facilities impact

The output of a hydrogen electrolyser can be used for many different purposes, including:

- bulk storage for later use or transportation for remote use.
- conversion to ammonia or methanol, for storage or further processing.

This means there will be many other types of load-consuming equipment in a hydrogen processing facility, in addition to inverters and hydrogen electrolysers. These items of equipment will also need to operate continuously following a disturbance or fault in the power system for the facility as a whole to operate continuously. This will depend on the ability of all components of the facility to both:

- Continue to operate with variations in the output of the hydrogen electrolyser due to interruptions originating the AC power system.
- Ride through voltage and frequency disturbances and faults from the power system.

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[26] Tavakoli,et al “Grid-Grid-Forming Services From Hydrogen Electrolysers”, Accepted for the IEEE Transaction on Sustainable Energy, 2023.

The susceptibility of the items of equipment in a hydrogen processing facility to interruptions to the operation of the electrolyser, and hence the supply of hydrogen, might be improved with local hydrogen storage at the facility. Likewise, the ability of the electrolyser to remain in operation may be impacted by the ride through capability of downstream plant. Hydrogen storage could buffer the supply of hydrogen and maintain its pressure to the processing facility. However, AEMO understands that adding additional hydrogen storage can be expensive and reduce the economic viability of the facility.

One type of equipment likely to be used in hydrogen facilities that may be susceptible to voltage and frequency disturbances is a large compressor. Compressors are used to increase the pressure of the hydrogen for storage or use elsewhere within the processing facility. Their motors can stall if the connection point voltage is low for a prolonged period, potentially during a fault, which can result in the supply of compressed hydrogen being interrupted to downstream parts of the facility. This would necessitate the electrolyser reducing its output or shutting down. The ability of large compressors to ride through power system disturbances could potentially be improved with a flywheel to increase the inertia or using a power electronic variable speed drive to increase its ride through capability. These types of changes to the plant would obviously add to the cost of the facility.

Overall inherent ride through capability of the hydrogen facility

As discussed, the ride through capability of a hydrogen facility will depend on the combined operation of the inverter, electrolyser and the downstream hydrogen processing facilities. While the operation of an IGBT inverter itself is likely to be robust in the presence of power system disturbances, both the electrolyser and some parts of the processing facility are likely to be susceptible to disturbances or faults. Therefore, it is likely that many hydrogen facilities will have limited inherent ride through capability due to the combined characteristics of all their components. It could be expensive to reduce this susceptibility to faults and disturbances through additional equipment, however AEMO notes that increased ride through capability may also have commercial benefits to the load.

In summary, considering the hydrogen production process as a whole as an example of IBL, it is not clear that IBL has materially better ride through capability than other types of load. Available information so far suggests that performance will vary from one load facility to another, although performance may also develop over time, as the technology is further developed and becomes more mature.

Draft report recommendation

AEMO recommended that IBL ride through requirements and general requirements for load should be considered separately.

Further analysis

AGL, Ausnet, Energy Queensland, TasNetworks and Transgrid supported the draft recommendation to treat IBL differently to general loads by having different access standards. In addition, there was some stakeholder support for this in the Options Assessment Workshops AEMO facilitated before issuing the draft report addendum.

While TasNetworks supported the draft recommendation for separate access standards for IBL, it also considered that the rules should not prevent other load types that have ride through capability from also being required to provide this capability if required. TasNetworks indicated that it will need to negotiate solutions with parties regardless of the technology type as appropriate.

AMP Energy observed that the impact on the power system from a load disconnecting does not depend on the technology but on its size. AMP also considered that the definition of IBL is quite broad, which means there are likely many different types of IBL with different capabilities, and it is not appropriate to set technical requirements until this is better understood through further experience with the connection of new load technologies.

AEMO has considered stakeholders' views and further examined the associated issues. There could be advantages to having different performance standards for IBL and non-IBL load if the IBL load had common performance characteristics or consistently better performance characteristics. However, initial findings, described above, indicate this is not the case. There are also disadvantages to be considered, including:

- The impact on the system does not depend on the type of load, only its size, location, ride through capability and the risk of a cumulative effect following disturbance. Therefore, as observed by AMP, the technical requirements in the access standards need not depend on the type of load but the size and specific circumstances of the load would be more aligned with the impact. To illustrate, a 100 MW IBL tripping has the same impact as a 100 MW traditional load at the same location and power factor.
- Separate access standards for IBL would require a robust and appropriate definition of IBL. Different types of IBL loads have different characteristics, and this will evolve over time. The NER definition of IBL is quite broad and it is unclear whether separate IBL access standards would be an impediment to connection for some types of IBL. While AEMO guidelines could be more specific about what constitutes IBL, they cannot differentiate between classes of IBL for different purposes under the NER.
- The application of more onerous access standards to IBL at a smaller threshold than traditional loads would mean that the inherent capability of some traditional loads would not be captured. To illustrate, under the draft recommendation the ride through capability of a 100 MW single facility load would only be considered if it met the definition of IBL, but not considered if it was a traditional load.

Given the above considerations, the specific circumstances of individual loads, including their technology and location in the network should be considered in determining performance standards. This means that any MAS should be sufficiently flexible to allow for the connection of any load when its performance does not have a material adverse impact on the power system.

Final recommendation

Based on the conclusion that IBL, like other types of loads, has potentially a wide range of performance characteristics, AEMO does not currently propose to develop technology-based detailed ride through requirements for large loads going forward. This will be a starting point for AEMO's Loads Technical Requirements Review.

4.3.3 Technology-based thresholds for ride through capability requirements

Draft report recommendation

AEMO recommended different thresholds for traditional loads and IBL, defined as:

- A large single facility load – a "single facility load" equal to or greater than a size threshold that is the minimum of the regional maximum load contingency size and [200 MW].
- A large single facility IBL – a "single facility load", or portion of a "single facility load", that contains [30 MW] or more IBL with discretion for the NSP to use a threshold down to 5 MW, depending on circumstances in the network.

A large single facility load is a load that forms part of a single installation (as distinct from the connection between a transmission and distribution network).

Further analysis

As discussed in Section 4.3.2, AEMO has revised its draft position and considers that all types of loads need to be considered in a similar way. This means any size thresholds for the application of an access standard to IBL and other loads would be the same, and the recommended definition of “large single facility inverter-based load” is unnecessary.

Final recommendation

Based on the conclusion that IBL has potentially a wide range of performance characteristics, as for other types of load, AEMO does not propose to apply technology-based thresholds based on whether or not the load is an IBL. This will be a starting point for AEMO’s Loads Technical Requirements Review.

4.3.4 Treatment of different load technologies within a load facility

Draft report recommendation

In the draft report AEMO recommended to apply thresholds based on the size of the load component which is IBL and the size of is the traditional load component, with the agreement of the NSP and AEMO.

Further analysis

As discussed in Section 4.3.2, AEMO has revised its position to consider all types of loads equally. This means a large load facility would be treated as a single facility, with a single size threshold (discussed in the next section).

Final recommendation

AEMO recommends to proceed on the basis that different types of loads within a facility are considered equally. This will be a starting point for AEMO’s Loads Technical Requirements Review.

4.3.5 Continuous uninterrupted operation (CUO) requirements

Draft report recommendation

AEMO recommended a light-handed CUO which requires a large load not to:

- Disconnect for the specified conditions.
- Operate unstably, or change its active power by more than [20%] following the disturbance, or as agreed with the NSP and AEMO, except where it is required to participate in load-shedding or frequency response.
- Materially exacerbate or prolong the disturbance or cause a subsequent disturbance for other connected plant, except as required or permitted by its performance standards.

Most stakeholders supported the draft recommendation for a light-handed CUO, but two areas of concern were raised, regarding “materially exacerbating”, and the size threshold.

Further analysis – exacerbate or prolong the disturbance

In regard to “not exacerbate or prolong the disturbance”:

- AGL supported a light-handed approach to CUO but considered that it should exclude the requirement not to exacerbate or prolong the disturbance or cause a subsequent disturbance for other connected plant. This was because it considered that it was not always possible to attribute causality to a specific load.
- Energy Queensland and TasNetworks, on the other hand, considered this to be an important requirement of the light-handed CUO.

AEMO notes that the recommended definition of light-handed CUO includes a materiality qualification for exacerbating or prolonging a disturbance, thus providing for some additional flexibility in its interpretation[27]. While AEMO acknowledges that in some instances causality can be difficult to attribute precisely, and may result from a combination of interactions, it is nevertheless important to establish that a connection will not have these outcomes. AEMO considers it would not be prudent to remove this requirement.

Further analysis – active power threshold

AusNet questioned why the recommended active power threshold of 20% for load was different to the requirement for generators, and AMP Energy suggested further analysis of threshold size. The EUAA questioned the need for any active power recovery requirement.

The purpose of the ride through requirement is to reduce the impact of the active and reactive power flows in the network following a disturbance or fault. Therefore, the light-handed CUO needs to include a requirement that the active power return to a value following the disturbance that is consistent with best outcomes for the power system. An active power change that supports the operation of the power system is desirable, such as reduction of active power for a frequency reduction and increase of active power consumption for a frequency rise, whereas the disconnection of a large load during a fault or voltage excursion is likely to exacerbate the disturbance.

In view of the proposed change to consider all load technologies under a single set of technical requirements, a wide negotiation range will be required. Therefore, AEMO has concluded it is not necessary to specify an active power threshold within the CUO definition, but instead deal with the specific active power requirements for each type of ride through clause individually. The light CUO definition would retain a concept of maintaining active power, but with reference to the levels permitted or required by the relevant clauses.

Final recommendation

AEMO has revised its the draft report recommendation to apply a light-handed CUO. AEMO recommends that a large load would be required not to:

- Disconnect for the specified conditions, except as permitted by the relevant performance standard.
- Operate unstably.
- Change its active power except as permitted or required under its performance standards following the disturbance[28].

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[27] There is always a tension between flexibility and certainty in the technical standards. Flexibility requires engineering judgement to be exercised, but a lack of flexibility can sometimes lead to perverse outcomes where otherwise acceptable outcomes may be rejected because of a rigid rule wording.

[28] Individual performance standards may permit or require a change in the active power.

- Materially exacerbate or prolong the disturbance or cause a subsequent disturbance for other connected plant, except as required or permitted by its performance standards.

This will be a starting point for AEMO's Loads Technical Requirements Review.

4.3.6 Treatment of loads with uninterruptible power supplies

Draft report recommendation

AEMO proposed to treat a large load with a UPS consistent with any other load, either as a traditional load or an IBL depending on the technology used for the UPS. The same thresholds as other loads would apply for determining what ride through requirements would be required.

Four submissions were received on this topic, which supported the proposed position. No submissions opposing it were received.

Final recommendation

AEMO proposes to retain the draft report recommendation to treat a large load with a UPS consistent with any other load. This is consistent with its approach of not recommending different access standards for different types of load technology. This will be a starting point for AEMO's Loads Technical Requirements Review.

4.3.7 AEMO advisory matters

Draft report recommendation

AEMO proposed to prescribe load access standards that relate to AEMO's system security functions under the NEL to be AEMO advisory matters.

Further analysis

AEMO advisory matters are those that relate to AEMO's power system security functions under the NEL. At present none of the access standards under schedule 5.3 except NER S5.3.11 "Short circuit ratio (customers)" is an AEMO advisory matter.

AEMO remains of the view that those load access standards that have the potential to affect power system security should be AEMO advisory matters. Ride through requirements fall within this category because the ability of plant to remain connected and in operation following power system disturbances can enhance or reduce the ability to maintain power system security.

As set out in section 2, AEMO is not intending to proceed with a change to add a threshold of 30 MW/30 MVA for its advisory role in relation to the negotiation of access standards for connection and plant alterations at this stage, pending further review

Final recommendation

AEMO recommends that:

- Load ride through requirements should be further considered as AEMO advisory matters in undertaking the Loads Technical Requirements Review.

This will be a starting point for AEMO's Loads Technical Requirements Review.

4.4 Threshold for application of technical requirements

Draft report recommendation

AEMO proposed to apply different thresholds for traditional loads and IBL, with:

- a large single facility load – a "single facility load" equal to or greater than a size threshold that is the minimum of the regional maximum load contingency size and [200 MW],
- a large single facility IBL – a "single facility load", or portion of a "single facility load", that contains [30 MW] or more IBL with discretion for the NSP to use a threshold down to 5 MW, depending on circumstances in the network,

where a large single facility load is a load that forms part of a single installation (as distinct from the connection between a transmission and distribution network).

Stakeholder feedback

The EUAA considered that AEMO should undertake further work to demonstrate that the 200 MW and 30 MW (or lower) thresholds were justified, considering the historical performance of loads. TasNetworks considered that the large single facility load should be defined by the regional maximum load contingency size. However, TasNetworks also considered that any inherent capability to remain in operation for a disturbance of some limited magnitude and duration should be required to be provided to the extent possible, which would imply a lower threshold. ElectraNet considered the definition of an arbitrary MW threshold across wide areas would be counterproductive and suggested that NSPs should define their own localised MW thresholds suited to the network configuration. AusNet supported the proposed definition. Transgrid asked for more information on how the threshold was set.

Given the feedback received, in combination with the revised recommendation above not to distinguish between load technologies, AEMO has undertaken further analysis and has considered an alternative approach for determining the threshold for the application of technical requirements to both new and modified connections, as described in the following subparagraphs.

4.4.1 Threshold based on largest contingency size

As discussed in Section 4.2.5, theoretically the optimal size of the threshold for large single facility loads can be determined by considering the trade-off between the costs and benefits of applying ride through requirements at different size thresholds, but there is a lot of uncertainty in assessing the costs and benefits.

As discussed in Section 4.2.2, large loads tripping for the same power system disturbance may have a cumulative effect on the power system, but the key consideration for technical standards is whether this cumulative impact is more efficiently managed by the individual loads or by the relevant NSP and AEMO. Of particular relevance is when a fault or disturbance would cause more load to trip than size of the largest single credible contingency in that part of the power system. The largest single credible contingency size influences the amount of contingency FCAS required to manage power system frequency, and the impact on the local network voltage.

Therefore, one approach to setting the size threshold is to set it as a portion of the largest contingency for that part of the power system. For example, where the largest single contingency is 500 MW, 10 large loads greater than 50 MW each could have a cumulative impact on the power system that is greater than the single largest contingency, depending on their ride through capability. This situation could be managed by either:

- Requiring each load to have sufficient ride through capability to limit their impact on power transfer capability[29].
- The NSP managing the cumulative impact on power transfer capability with a central solution such as dynamic reactive power compensation, depending on the nature of the power system impact.

Thus, where each individual load represents a significant portion of size of the largest contingency, say 10% to 20%, it should be more cost-efficient overall for the loads to manage their own impact. However, as discussed in Section 4.2.5, when the individual loads are smaller, a centralised NSP solution to manage the cumulative impact may be more efficient. However, there are challenges in determining the optimum threshold.

Assessment costs

The cost of assessment will depend on the level of detail required and, in particular, the extent of modelling required. Modelling could be quite complex and challenging for load facilities that combine multiple processes and technologies. Protection settings for voltage and frequency and rate of change of frequency (RoCoF) will give one measure of ride through capability, but inherent capability may be lower than the settings and the load could trip for reasons other than voltage and frequency protection settings. In addition, the interdependencies between sequential processes also need to be considered to estimate the overall capability of the plant.

Fault ride through considering actual power system conditions would be more costly to assess than ride through capability based on a voltage profile and a frequency profile, because the actual network topology, protection and clearance times and the dynamics of other plant would need to be included in the assessment.

The cost impost of assessing the ride through capability will not have a direct relationship with load size; instead it is likely to depend more on the characteristics of the load technology as discussed above, with the total likely to be higher for connections or alterations involving multiple processes and technologies that are subject to the additional performance assessments.

AEMO has undertaken some analysis of a set of forecast load data from information provided by NSPs to AEMO for other forecasting purposes. The dataset is likely incomplete for new loads, and assumptions to convert energy consumption to demand were made. Based on this limited dataset, a threshold of 30 to 50 MW seems unlikely to impose material incremental burden on NSPs' and AEMO's resources for connection assessments due to the small number of projects in the known pipeline of load connections.

Cost of improved capability

Naturally, there is a cost to individual loads to provide improved performance, which must be considered against the relative costs of network investment or the market impact of operating the power system more conservatively to allow for individual loads not providing enhanced capability. For some types of load, individual improvement costs may be marginal, for example improved tuning of control systems, while for others there may be more substantial cost.

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[29] Note that to manage a power system security impact, one or more network constraints may be applied to the operation of the power system. The network constraints impact the power transfers across parts of the network.

AEMO notes that the existing NER access standard negotiation framework[30] provides that:

> *"…a Connection Applicant must propose a standard that is as close as practicable to the corresponding automatic access standard, having regard to:*
>
> *(1) the need to protect the plant from damage;*
>
> *(2) power system conditions at the location of the proposed connection; and*
>
> *(3) the commercial and technical feasibility of complying with the automatic access standard with respect to the relevant technical requirement."*

In addition, a negotiated access standard must be above the minimum access level and:

> *"…*
>
> *(2) be set at a level that will not adversely affect power system security;*
>
> *(3) be set at a level that will not adversely affect the quality of supply for other Network Users".*

In the case of ride through capability, the larger the plant, the more likely that its inability to ride through could adversely affect power system security. It is unlikely that a reasonable negotiated access standard proposal would be rejected for a small plant with no measurable effect on power system security, provided the connection applicant establishes that its performance is as close to automatic access standard as it can be, noting that regard must be had to commercial and technical feasibility. While the negotiating framework means that a performance standard for a relatively small load should not give rise to significant additional cost, AEMO observes that there is also limited value in negotiating a performance standard for smaller loads.

Larger loads, particularly where there is potential for multiple loads to trip from a common cause, will require more assessment of their proposed performance and its impact on power system security. Again, while there may be some additional cost to improve performance, this should be within the bounds of commercial and technical feasibility as provided in the NER.

Size of the largest contingencies in the NEM

The size of the largest normally credible contingency on the mainland is approximately 750 MW (for a generating unit trip) and 600 MW for a load trip[31], while the maximum contingency size in Tasmania is limited to 144 MW (for both the largest single load and largest single generation event) in the Frequency Operating Standard, as determined by the Reliability Panel[32]. The largest credible contingency size is an indication of the size and robustness of the power system to contingencies, and is therefore a measure (although imperfect) of the tolerance of the power system to tripping of plant. The size threshold for ride through of loads could be a fraction of this number, to account for the cumulative impact of simultaneous common cause tripping of loads, while balancing this against the cost and benefits of performance assessments for individual loads, compared with the alternative of NSPs and AEMO managing load performance in aggregate.

In its Large Loads workshop on 31 August 2023, AEMO canvassed with participants whether a threshold based on the largest contingency (load or generation) or just the largest load contingency should be applied.

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[30] NER 5.3.4A

[31] The largest load contingency on the mainland of 600 MW is based on a long-standing reclassification of the loss of both APD potlines in Victoria as a single credible contingency.

[32] The NEM frequency operating standard is available on the AEMC's website, at https://www.aemc.gov.au/regulation/electricity-guidelines-and-standards. The final determination of the Frequency Operating Standard review from 2022 is available at https://www.aemc.gov.au/market-reviews-advice/review-frequency-operating-standard-2022.

Stakeholders preferred the largest load contingency. The actual largest load or generation contingency may change over time, but for very large loads or generators it will probably be necessary for them to design their plant to manage the contingency size, so as to manage the impact of a trip on the power system.

Establishing performance standards for hydrogen and other large loads

The dilemma facing AEMO, NSPS and industry at present is that:

- There are no present requirements for large loads to provide any level of ride through performance.
- A clear need to do so has been identified, noting the expectation that a greater number of very large load projects will seek connection to the NEM in the near to medium term.
- A workable minimum and automatic set of load access standards is challenging to establish, given the range of load technologies and processes, and the rate of change of technology, for which capabilities and behaviour in the power system is not fully understood in some cases.

In the case of hydrogen production, the initial size of demonstration plant is likely to be modest, but the final plant size is likely to be very large. Therefore, in order to develop access standards, the industry needs to learn from the early demonstration plant, what the plant performance capability can be. At least initially, this will require the NER to provide a framework to recognise that capabilities will need to be specified, but with flexibility for detailed requirements to be determined through a workable process.

While AEMO’s analysis so far suggests that a size threshold should apply to the ride through requirements for large loads once detailed access standards are implemented, it also considers that in the interim NSPs and AEMO should have the flexibility to develop performance standards based on the facilities ride through capability and the impact on the power system.

Final recommendation

AEMO recommends:

- A Rule change to provide an NSP with the discretion, in consultation with AEMO, to require the ride through capability of a load connecting to its network to be established (under the existing NER connection process) and recorded in the performance standard, without any size threshold specified.
- The development of detailed access standards, through the Loads Technical Requirements Review, to which a threshold, based on a proportion of the largest single load contingency, would apply. An indicative form and threshold level (which may be updated as a result of the subsequent review) is a MW threshold for defining a large single facility load as the smaller of:
  - 120 MW, which is 20% of the largest single contingency event on the mainland of 600 MW; or
  - 20% of the largest single load contingency event defined in the Frequency Operating Standard for the region (if any)[33].

4.4.2 Application of threshold to existing plant

The EUAA expressed concerns that the proposed ride through access standards would apply to modifications to existing load facilities and that this would impose a material burden. Of particular concern would be replacing a

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[33] Under the recommendation the threshold for a large single facility load in Tasmania would be 20% of 144 MW, which is 28.8 MW.

small item of plant, or a small expansion of the facility, when the existing facility exceeded the size threshold for a large single facility load.

Consistent with the NEO, the application of access standards should be appropriate to promote the maintenance of system security and quality of supply, without becoming a disincentive to efficient and prudent improvements of load facilities. AEMO agrees that the ride through access standards should not be applied to a replacement or an expansion at an existing large load facility, unless the size of the new or replacement plant exceeds the size threshold for a large single facility load. For example, with a size threshold of 120 MW, upgrading a 10 MW motor at a 200 MW mining or industrial facility should be treated as a 10 MW replacement rather than the whole facility of 200 MW. A 130 MW augmentation of a 200 MW mining load, on the other hand, would be required to meet the additional requirements under the updated recommendations.

This approach is recommended on the basis that the power system should be able to operate in a secure operating state with the existing facility operating, assuming that the replacement or expansion can only introduce an additional risk to power system in proportion to the size of the new plant. An exception to this could be where the total size of the plant exceeds the threshold because of the change, and AEMO or the NSP considers the combined plant’s performance would be a risk to power system security or quality of supply to other users.

For example (assuming a 120 MW threshold), if a 119 MW plant had no ride through capability and was augmented with another component of 119 MW, the total plant could have 238 MW with no ride through capability. In this case it would be reasonable to require the augmentation to meet the current performance standards.

AEMO notes that many new facilities are likely to be developed in stages. For example, the facility described in Figure 3 consists of 10 electrolysers, each of 50 MW, which are likely to be commissioned one at a time. This would mean that each increment in size is only 50 MW, which may be below a relevant size threshold, but the site as a whole would ultimately be 500 MW. In this instance AEMO considers it reasonable that the NSP or AEMO should be able to exercise discretion to require performance standards for the increments.

Final recommendation

AEMO recommends that ride through standards should apply to a modification of an existing facility if:

- the incremental change in size exceeds the threshold for application of those requirements, or
- the total size of the expanded facility will exceed the threshold, and AEMO or the NSP consider that without application of additional performance requirements, the performance of the combined facility could adversely impact power transfer capability, power system security or quality of supply to other network users.

4.4.3 Review of application threshold

The concept of reviewing the size threshold for application of ride through requirements did not arise in submissions on the draft report, because AEMO had proposed different treatment for IBL and general load technologies, with a lower threshold for large single facility IBL.

AEMO acknowledges that the determination of an appropriate threshold for large single facility loads using an approach based on the size of the largest contingency is not a precise exercise. The costs and benefits of imposing fault ride through requirements on single facility loads are not well understood and will vary significantly, meaning the optimal size threshold for large single facility loads can only be a reasonable estimate considering general data, trends and forecasts.

In this uncertain context, it is important that the size threshold for ride through capability in large single facility loads is not set too low. A low threshold that captures more loads would increase the resources required to manage the connections process, potentially introducing significant delays, and may slow the processing of other connections such as generation and storage.

On the other hand, the costs of applying ride through access standards to large loads such as hydrogen electrolyser facilities could be expected to reduce as their technology matures and the industry gains experience applying ride through controls to these loads. It is also possible that the optimal size threshold for large single facility loads would also reduce over time based on similar considerations. It is therefore useful to consider the mechanism by which the threshold could be reduced from an initial conservative number.

AEMO has considered options for reducing the size threshold for single facility large loads including:

1. Reducing the size thresholds by predetermined amounts on a defined schedule, to be specified in the NER.
2. Include in the NER an ability for a market body to resize the threshold periodically without requiring a rule change.
3. Including a NER requirement for AEMO to review the size thresholds within three years from commencement.
4. Specifying the size threshold in Schedule 5.3, so it would be reviewed by AEMO at least every five years under NER 5.2.6A.

Option 1 would give certainty to stakeholders as the progression of future levels of the size threshold would be known, unless changed by a subsequent rule change. However, it suffers from the same lack of information about actual costs as the current situation. Better information on costs and benefits will become available as the access standards are applied and the technology evolves which might lead to more efficient outcomes. These might be inconsistent with the pre-determined schedule.

Option 2 would provide flexibility to alter the threshold at any time but could introduce uncertainty for loads (although consultation obligations, potentially mandating targeted groups to be consulted, may address these concerns). It would also mean that the threshold was considered outside of the context of the obligations when they are reviewed.

Option 3 would be a one-time requirement. Considering that it relies on having some time to gain experience with application of the threshold, less than three years is probably too short, and if it is more than three years, then it is probably not worth having another review ahead of the one required under NER 5.2.6A.

Option 4 effectively represents the status quo. It would have the advantage that the size threshold would be considered in the context of a more comprehensive review of Schedule 5.3, plus Schedules 5.2 and 5.3a, when the experience gained in applying the access standards and the state of technology maturity will be better understood. This would not preclude an earlier review, should circumstances change.

While Options 3 and 4 in theory involve slightly more uncertainty as to future values of the size threshold, uncertainty is inevitable in any event given the prospect of a rule change at any time, and flexibility to adapt to new information and experience should be considered paramount in the interests of all users in a transformative period. It should be noted that the impacts of uncertainty are reduced by the typical policy approach of effectively grandfathering existing requirements for committed projects as part of rule changes.

Final recommendation

AEMO recommends that:

- A size threshold for large single facility loads be defined in Schedule 5.3.
- Any changes to the threshold could therefore be made through a rule change at any time, but would (by default) be part of the five-yearly (or less) review requirement under clause 5.2.6A, with the advantage that the threshold would be considered in conjunction with the technical requirements themselves.

4.5 New/amended clauses for ride through requirements

Draft report recommendation

The Draft Report provided recommendations for ride through requirements for large single facility loads for voltage disturbance, frequency disturbances and contingency events.

Further analysis

AEMO's initial consultations have revealed that:

- Considering the proposed scale of new loads, particularly for hydrogen production, access standards for ride through requirements are needed.
- The technology is rapidly evolving, and performance capability is not yet fully understood.
- Further investigation and consultation is required.

AEMO's revised position is that it will not propose detailed access standards for ride through requirements at this stage, but will undertake further work after this review, with the intention of developing access standards for ride through requirements.

Final recommendation

AEMO recommends to:

- Provide an NSP with the discretion, in consultation with AEMO, to require the ride through capability of a load intending to connect to its network to be established (under the existing NER connection process) and recorded in the performance standard, without any size threshold specified.
- Develop detailed access standards for large load response to power system disturbances through the Loads Technical Requirements Review.

4.6 NER S5.3.3 – Protection systems and settings

Draft report recommendation

AEMO proposed to set a MAS requirement that protection be set to maximise capability to remain in operation for voltage and frequency disturbances including RoCoF subject to the technical capabilities of the plant and safe operation, and modest safety margins.

This access standard was not recommended as an AEMO advisory matter. Rather, the protection systems and settings would be agreed between the connecting load and NSP.

Further analysis

AEMO considers that these requirements impose very little extra cost on connection applicants, but could improve the resilience of the power system as:

- The inherent ride through capability of connecting loads will not be restricted by conservative protection settings.
- AEMO and NSPs will better understand the ride through capability of new loads.

The proposed requirement is consistent with achieving best performance of the power system, while maintaining the safe operation of the plant.

In addition, AEMO did not receive any objections to the draft report recommendation.

Final recommendation

AEMO proposes to retain the draft report recommendation in progressing its further work.

4.7 NER S5.3.10 – Load shedding facilities

4.7.1 Emergency under-frequency ramp down of large loads

Draft report recommendation

AEMO proposed to provide the option for a load to remain connected where alternative options to ramp down are agreed instead of making its load available to be shed as part of an UFLS scheme.

AEMO proposed the access standard as an AEMO advisory matter.

Further analysis

AEMO did not receive any objections to the draft report recommendation. The option to ramp down would be subject to AEMO and NSP agreement. A combination of ramping and tripping could also be agreed.

Discussions with hydrogen industry OEMs and developers suggest that for the current hydrogen electrolyser technologies, ramp rate might not be fast enough to use as an alternative to load-shedding. However, noting that the technologies are changing, and that this option could be applicable to other types of load,

AEMO considers that the current requirement for all large loads to have the capability to be tripped as part of an UFLS scheme should be retained, even if the NSP and AEMO agree to them providing a ramped response. This means that the capability to trip the load is available if the UFLS scheme needs to be amended in the future and the speed of ramped available from the large load is no-longer adequate for effective emergency management of under-frequency events.

Final recommendation

AEMO proposes that, in addition to the capability to shed load during an under frequency, permit fast ramp down of load where:

- the load has the appropriate capability; and

- AEMO and the NSP agree the scheme's settings.

4.8 New clause for instability monitoring and prevention

4.8.1 Stability of IBL – monitoring, protection and performance

Draft report recommendation

AEMO proposed to:

- Require monitoring for single facility loads with IBL components ≥[5] MW.
- Require protection for instability for single facility loads with IBL components ≥[20] MW.
- In the AAS, require detection devices that can determine the contribution to an instability.
- In the AAS, permit alternative actions to tripping (to reduce instability).
- Require single facility loads to not to cause an oscillation that isn't adequately damped and not amplify any oscillation (amend NER S5.3.11 MAS).
- Specify access standard as an AEMO advisory matter.

Further analysis

The draft report recommendation was closely aligned with the equivalent recommendations for generators captured under NER S5.2.5.10. AEMO received extensive feedback on that clause through formal consultation on the draft report and undertook substantial further analysis, which led to a significantly revised recommendation. The detailed discussion on this subject can be found in the Draft Recommendations Update Report (Part 1) relating to NER Schedules 5.2 and 5.3a. Of note, AEMO considers that plants should aim to eliminate the instability primarily by undertaking an agreed series of actions which depend on the plant's technology type and location within the network. In this context, plant disconnection should be included but as the last step should the instability remain, and the facility is contributing to the instability.

Further, in accordance with the recommendation to remove the category of large single facility IBL, as described in Section 4.3.2, this requirement for stability monitoring, protection and performance had to be re-considered with regard to its application to all loads. Not every load technology has potential to actively participate in instabilities therefore the performance requirements should account for this, for example, by exempting loads from requirements that are not relevant if the nature of the load means it will not actively participate in instabilities.

Final recommendation

AEMO recommends the following for stability monitoring, protection and performance requirements:

- AAS (consistent with NER S5.2.5.10 AAS, but applies only where it is possible, considering the technology, that a single facility load or its parts will actively participate in instabilities), a single facility load must:
  - Have capability to detect instability in active power, reactive power and voltage at the connection point.
  - Have a facility capable of disconnecting units for unstable behaviour.

  - On detection of instability, execute a hierarchy of automated actions based on configurable trigger conditions, thresholds and timeframes agreed with NSP and AEMO, where:
    - Any action to disconnect is based on contribution to the oscillations.
    - Actions are taken automatically and promptly.
  - For load size 100 MW or greater, have a phasor measurement unit (PMU) installed at the connection point with capability to send information to AEMO and NSP, and have capability to receive and process information from AEMO relating to load's contribution to instability, when it becomes available.
  - If required by NSP or AEMO, have capability to communicate information from an instability detection system to NSP or AEMO control centres.
  - If required by NSP, have capability to receive a remote tripping signal from NSP.
- MAS (consistent with NER S5.2.5.10 MAS except it applies only where it is possible, considering the technology, that a single facility load or its parts can actively participate in instabilities), a single facility load that can change the voltage at the connection point, for system normal or planned outage conditions, by more than 1% must:
  - Have capability to detect instability in active power, reactive power and voltage at the connection point.
  - Have a process to manage instability promptly on detection, in a manner to be agreed with the Network Service Provider and AEMO.
  - For load size of 100 MW or greater and if required by the NSP or AEMO, have a PMU installed at the connection point with capability to send information to AEMO and the NSP. AEMO may also require capability to receive and process information from AEMO relating to load's contribution to instability, when it becomes available.
  - If required by the NSP or AEMO, have capability to communicate information from an instability detection system to NSP or AEMO control centres.
  - If required by the NSP, have capability to receive a remote tripping signal from NSP.

4.9 Other issues raised in submissions and discussions

4.9.1 Minimum short circuit ratio

Discussions with OEMs and stakeholders regarding hydrogen production projects identified that some types of technology employ thyristor-based converters whereas others use IGBT-based technology. Thyristor-based technology typically require a higher SCR to enable commutation of the thyristors. They may not be able to operate with an SCR of 3, as required by NER S5.3.11.

Further, NER S5.3.11 applies to a Network User where the plant to be connected includes any inverter based resource. This could capture loads containing a very small IBL or generating plant, as it does not apply any size threshold on the inverter-based resource to which it applies.

Final recommendation

To address this, AEMO proposes the following amendments to S5.3.11:

- Apply the standard in respect of an IBL that is a *large inverter based resource.*
- Allow for flexibility for the NSP and AEMO to agree that the requirement under this standard may be varied to require the *large inverter based resource* to remain in stable operation at a minimum SCR that is higher than 3.

Note that this would link the requirement to the system strength impact assessment guidelines, where one or more thresholds for large inverter based resources can be set, and which may be altered under the rules consultation procedures without need for a rule change.

4.9.2 Reliance on Australian Standards to manage load performance during power system disturbances

The EUAA suggested that an alternative approach to managing the performance requirements on loads for power system disturbances could be through Australian standards.

AEMO acknowledges that this alternative approach may be appropriate in some circumstances, such as for small loads or particular types of load, but there are some disadvantages, including:

- The process for changing standards is time consuming and is likely to take as long or longer than the AEMC rule change process.
- The resulting standards may not necessarily be consistent with the NEO or align well with the system standards in Schedule 5.1a and the access standards for other plant in Schedules 5.2 and 5.3a.
- The process could involve many Australian Standards to cover the wide range of load types.

AEMO notes that NSPs are able to require specific single facility loads to comply with relevant Australian or international standards, through their connection agreements. AEMO considers that the NSPs could require specific single facility loads greater than 5 MW, and less than the large single facility load size threshold, to comply with relevant standards, where applicable standards exist and would meet identified system needs. This would align with the requirements of Chapter 5A of the NER.

Final recommendation

AEMO makes no recommendation on this proposal.

4.9.3 Responsibility for large load modelling and associated security issues

The EUAA considers that, as large loads have not been required to consider modelling requirements and power system security in the past, they are not well placed to manage these issues into the future.

In the relatively near future, we expect there will be a number of single facility loads that are both larger and more complex than most existing loads. These could have significant impacts on the operation and security of the power system. While in the past these impacts have been generally managed by the relevant NSP and AEMO, as discussed in Section 4.2.5, it may be more efficient to impose ride through requirements on a small number of large single facility loads where these loads can have a large cumulative impact.

AEMO considers that single facility loads that are sufficiently large should negotiate ride through access standards with the NSP, subject to AEMO advice, where it is efficient to do so, and proposes to develop access standards through the Loads Technical Requirement Review. The negotiated performance standards will need to balance the needs of the power system and capability of the plant to meet the agreed ride through performance.

Generators already engage consultants to do modelling if they do not have the capability in-house. The situation is similar for loads, although the variety of loads that may exist within a facility can represent a challenge for modelling. However, this would be the case regardless of who does the modelling. For the purpose of documenting performance as recommended for the initial package of rule changes in this Final Report, some modelling may also be necessary.

Final recommendation

AEMO makes no additional recommendations on this issue.

4.9.4 Allowing a large single facility load to use nearby services to meet its obligations

Powerlink suggested large loads should have flexibility to procure services to meet NSP ride through requirements.

AEMO agrees in principle, provided that there is agreement from the NSP, and AEMO for an advisory matter.

Final recommendation

AEMO recommends further consideration, through the Loads Technical Requirements Review, of the proposal to clarify in the NER that large single facility loads be able to procure services from outside its facility to allow it to be able to meet its negotiated ride through capability[34].

4.10 Summary of recommendations for large load technical requirements

In summary AEMO proposes to develop load rule change proposals in two stages.

In the first stage, following the publication of this report, AEMO recommends the development of a rule change proposal to:

- Provide an NSP with the discretion, in consultation with AEMO, to require the ride through capability of a load intending to connect to its network to be established (under the existing NER connection process) and recorded in the performance standard, without any size threshold specified.
- Amend NER S5.3.11 to apply to IBLs that are large inverter based resources, and make the minimum SCR requirements more flexible.
- Require protection settings with performance capability, considering reasonable safety margins.
- Permit fast ramp down of load, as an option instead of, or in combination with, load shedding where appropriate ramping capability exists.
- Require monitoring on large IBL projects for control stability.

In the second stage, AEMO recommends further consultation and investigation through the Load Technical Requirements Review, to finalise detailed access standards for ride through requirements for large loads, considering the principles recommended in this report, specifically to:

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[34] This recommendation has been incorporated into the proposed technical requirements described in sections 2.4.2, 2.4.3 and 2.4.4 of this report.

- The access standards to single load facilities above a threshold size level, currently proposed to be set as a proportion of the smaller of the maximum load contingency size specified for the region, in the frequency operating standard, if any, and the maximum load contingency in the NEM.
- The access standards irrespective of the technology and whether or not the plant is 'inverter based load'.
- A light-handed definition of continuous uninterrupted operation to the access standards.
- The size threshold for existing plant alterations based on the size of the alteration rather than the size of the whole facility unless AEMO and the NSP consider that power system security would be impacted by the performance of the whole plant.

AEMO may, in its discretion, revisit some of these recommendations if merited considering further work on the ride through capabilities and requirements.

In the second stage, AEMO will also consider whether a voluntary technical specification for large load performance would be of value, as an interim step, considering the lead times associated with progressing the first and second stage rules changes under a standard rule change process.

5 Final recommendations – Other amendments

Table 9 summarises the material changes AEMO recommends to the NER either in addition to, or as a consequence of, the recommendations relating to Schedules 5.2, 5.3 and 5.3a. The corresponding revised draft recommendations or principles in the update report are also provided for comparative purposes. Please refer also to Appendix A2 a summary of stakeholder positions on the revised draft recommendations for other NER amendments, AEMO's consideration of these views, and the adjustments made.

The amendments shown in the table include a suite of structural changes to implement AEMO's recommendation to apply technical connection requirements based on plant type rather than participant status; changes applicable across multiple technical performance schedules (reference to international standards); new, amended and deleted NER definitions; and other technical drafting changes.

It is expected that AEMO's rule change proposals will include additional consequential NER drafting amendments because of the recommended amendments, as well as clarifications and corrections of a minor nature. These are not specifically included in the table, but those identified to date were captured in the initial draft NER amendments published with the update report.

Table 9 Other amendments final recommendations

Issue	Final recommendations	Draft recommendations made in update report (reference only)
Structural changes (based on drafting principles in section 5 of update report)		
C**hapter 5 and other** NER provisions **relating to access standards** require extensive changes **to implement AEMO's supported recommendation** to **apply** the technical schedules to particular types of plant or facilities, irrespective of the registration **status/**category of the owner, operator or controller**.** **It** is **also necessary to clarify the regulated processes by which the access standards are applied to registered participants and other network users under the primary rules for establishing and modifying connections in Chapter 5 and related definitions, to provide a clear and consistent NER basis for the current and ongoing application of Schedules 5.2, 5.3 and**	• Define the plant subject to each of the schedules: – Schedule 5.2 plant: Production systems (defined as generating systems, and IRS production units together with auxiliary and reactive plant), synchronous condensers both as standalone systems and part of a production system). – Schedule 5.3 plant: Loads, including loads within an IRS. – Schedule 5.3a plant: HVDC networks proposing to connect to another NSP's distribution or transmission system, or connecting between AC parts of the NSP's own network. Importantly, for Schedules 5.2 and 5.3, plant is only captured if the connection applicant is or will be a registered participant, or the NSP considers the plant will have a material impact on other network users. • Define a 'Schedule 5.2/5.3/5.3a Participant' as the person who will own, operate or control the corresponding plant. This will tie the technical obligations to the person who will enter into the connection agreement (not necessarily a registered participant), or an NSP who operates the plant within its own network. Modify the process for determination and documentation of performance standards for an NSP's own equipment. • The definition of AEMO's advisory role will be subject to further review and consultation before determining an appropriate rule change proposal. • Where connection applicants using the NER Chapter 5A connection framework are nevertheless 'Schedule 5.2/5.3 Participants', those schedules	• Define the plant subject to each of the schedules: – Schedule 5.2 plant: Production systems (defined as generating systems, and IRS production units together with auxiliary and reactive plant), synchronous condensers both as standalone systems and part of a production system). – Schedule 5.3 plant: Loads, including loads within an IRS. – Schedule 5.3a plant: HVDC networks proposing to connect to another NSP's distribution or transmission system, or connecting between AC parts of the NSP's own network. Importantly, for Schedules 5.2 and 5.3, plant is only captured if it is either above the AEMO advisory threshold (see below), the connection applicant is or will be a registered participant, or the NSP considers the plant will have a material impact on other network users. • Define a 'Schedule 5.2/5.3/5.3a Participant' as the person who will own, operate or control the corresponding plant. This will tie the technical obligations to the person who will enter into the connection agreement (not necessarily a registered participant), or an NSP who operates the plant within its own network. Modify the process for determination and documentation of performance standards for an NSP's own equipment. • Define AEMO's advisory role in relation to the negotiation of access standards and consideration of plant alterations as 30 megawatts (MW)/30 megavolt amperes (MVA) nameplate rating for Schedules 5.2 and 5.3. For plant that does not meet the relevant threshold, the schedules may still apply

Issue	Final recommendations	Draft recommendations made in update report (reference only)
5.3a to all appropriate plant. Refer to section 5 of the update report for more detail.	will still apply. AEMO recommends explicitly allowing NSPs not to apply all of the standards in an applicable schedule – only those that are reasonably necessary to minimise the impact of the plant on other network users. - AEMO will only register performance standards (for compliance purposes) for registered participants (including NSPs), but AEMO will still receive a copy of all performance standards for which it has an advisory role. Performance standards for non-registered participants are enforceable by the NSP through the connection agreement. - Use clear and consistent terminology to describe the access standards set out in the schedules and the process by which they become performance standards and are recorded in a connection agreement (or other document for relevant equipment of the NSP itself).	if the NSP considers there to be an impact on other network users, but AEMO will not be involved and the NER 5.3.4A process (where applicable) will proceed as if all AEMO functions were removed. - Where connection applicants using the NER Chapter 5A connection framework are nevertheless 'Schedule 5.2/5.3 Participants', those schedules will still apply. AEMO recommends explicitly allowing NSPs not to apply all of the standards in an applicable schedule – only those that are reasonably necessary to minimise the impact of the plant on other network users. - AEMO will only register performance standards (for compliance purposes) for registered participants (including NSPs), but AEMO will still receive a copy of all performance standards for which it does have an advisory role. Performance standards for non-registered participants are enforceable by the NSP through the connection agreement. - Use clear and consistent terminology to describe the access standards set out in the schedules and the process by which they become performance standards and are recorded in a connection agreement (or other document for relevant equipment of the NSP itself).
Multiple technical schedules		
References to superseded standards	Amend the references to AS/NZS 61000.3.6 and AS/NZS 61000.3.7 (with or without dates) in S5.1.5, S5.1.6 S5.1a.5 and S5.1a.6 to the latest versions TR IEC 61000.3.6 and TR IEC 61000.3.7, without dates.	Amend the references to AS/NZS 61000.3.6 and AS/NZS 61000.3.7 (with or without dates) in S5.1.5, S5.1.6 S5.1a.5 and S5.1a.6 to the latest versions TR IEC 61000.3.6 and TR IEC 61000.3.7, without dates.
Definitions		
production system	Add for convenience to avoid specifying in multiple instances in Schedule 5.2 a generating system and an integrated resource system to the extent of its production units. This definition excludes loads that are part of an integrated resource system.	Add for convenience to avoid specifying in multiple instances in Schedule 5.2 a generating system and an integrated resource system to the extent of its production units. This definition excludes loads that are part of an integrated resource system.
Schedule 5.2 plant, Schedule 5.3 plant and Schedule 5.3a plant	Add for convenience to specify the types of plant covered by Schedule 5.2, Schedule 5.3 and Schedule 5.3a respectively.	Add for convenience to specify the types of plant covered by Schedule 5.2, Schedule 5.3 and Schedule 5.3a respectively.
Schedule 5.2 Participant, Schedule 5.3 Participant and Schedule 5.3a Participant	Add for convenience to specify the connecting parties under the relevant schedules to whom the access standards apply.	Add for convenience to specify the connecting parties under the relevant schedules to whom the access standards apply.
synchronous condenser	Enhance definition of synchronous condenser to differentiate it from a synchronous generating unit.	Enhance definition of synchronous condenser to differentiate it from a synchronous generating unit.
synchronous condenser system	Add to provide for one or more standalone synchronous condensers to be referenced in Schedule 5.2.	Add to provide for one or more standalone synchronous condensers to be referenced in Schedule 5.2.
active power capability	Adapt for use instead of rated active power for all Schedule 5.2 access standards, and used also in relation to the use of short circuit ratio in NER 5.3.4C and 6A.23.5(j). In addition: - Clarify that the maximum value in the bid validation data should reflect the recorded active power capability in the performance standards (rather than the bid validation data defining the active power capability). - In access standards for which performance capability is affected by a reduction if in-service	Adapt for use instead of rated active power for all Schedule 5.2 access standards, and used also in relation to the use of short circuit ratio in NER 5.3.4C and 6A.23.5(j).

Issue	Final recommendations	Draft recommendations made in update report (reference only)
	units, confirm (in each relevant standard) that active power capability refers to the capability of the operating units.	
continuous uninterrupted operation	Change to make the definition more appropriate for clauses referencing it (rather than being very specific to S5.2.5.5) and to provide for phase angle jump response, inertial response and PFR.	Change to make the definition more appropriate for clauses referencing it (rather than being very specific to S5.2.5.5) and to provide for phase angle jump response, inertial response and PFR.
disconnection	Remove italicising from the terms disconnect and disconnection in Schedules 5.2 and 5.3 where a broader understanding of the terms than provided by the definition is appropriate considering the technical requirement.	Not considered
nameplate rating	Change to provide for synchronous condenser ratings (in MVA).	Change to provide for synchronous condenser ratings (in MVA).
negotiated access standard	Change to the definition removing reference to a connection agreement because performance standards, not access standards, are included in a connection agreement.	Change to the definition removing reference to a connection agreement because performance standards, not access standards, are included in a connection agreement.
normal voltage – definition removed	Remove the defined term 'normal voltage' along with all uses of it in Chapter 5 to simplify the rules because the concept has not proven useful and it causes confusion.	Remove the defined term 'normal voltage' along with all uses of it in Chapter 5 to simplify the rules because the concept has not proven useful and it causes confusion.
performance standard	Amend as part of structural changes to Chapter 5 described in the update report.	Amend as part of structural changes to Chapter 5 described in the update report.
plant	Change to include synchronous condensers and better reflect the range of plant that may be covered by the technical schedules.	Change to include synchronous condensers and better reflect the range of plant that may be covered by the technical schedules.
rated active power	Delete this definition. This term was problematic as it referred to production units operating at nameplate rating. As nameplate rating for inverter-based units is the same as their MVA rating, inverter based units in the NEM are not operated at nameplate rating. Similar issues can arise for synchronous machines where a generator can be rated higher than maximum permitted output at the connection point would allow.	This term was problematic as it referred to production units operating at nameplate rating. As nameplate rating for inverter-based units is the same as their MVA rating, inverter based units in the NEM are not operated at nameplate rating. Similar issues can arise for synchronous machines where a generator can be rated higher than maximum permitted output at the connection point would allow.
rated maximum demand	Delete this definition. Same issue as for rated active power above. Use the existing term *maximum demand* in relevant rules instead.	Same issue as for rated active power above. Use the existing term *maximum demand* in relevant rules instead.
reactive power capability	Change to the definition to broaden it from just production unit to other types of plant such as synchronous condensers and HVDC systems.	Change to the definition to broaden it from just production unit to other types of plant such as synchronous condensers and HVDC.
rise time	Change to the definition to make it more standard, and work more effectively for grid forming inverters (especially in NER S5.2.5.5). Clarify that the reference to external influence in the rise time definition is intended to mean external to the generating system.	Change to the definition to make it more standard, and work more effectively for grid forming inverters (especially in S5.2.5.5).
settling time	In conjunction with other changes that deal with size thresholds for error bands for active power, reactive power and voltage in NER S5.2.5.13, change the definition to make it more standard by referencing only the sustained change induced in the output quantity.	Change to make the error bands for settling time consistent as the ratio of sustained change to maximum induced change increases.
short circuit ratio	Change to address an issue with the definition of the term 'rated active power'.	Change to address an issue with the definition of the term 'rated active power'.
voltage – definition deleted	The term 'voltage' is used in various different ways in Chapter 5 and elsewhere in the rules, and is best understood from an engineering perspective in the context where it is used. As a result, the term	The term 'voltage' is used in various different ways in Chapter 5 and elsewhere in the rules, and is best understood from an engineering perspective in the context where it is used. As a result, the term 'voltage',

Issue	Final recommendations	Draft recommendations made in update report (reference only)
	'voltage', when not used in conjunction with a composite defined term, should be un-italicised throughout the NER.	when not used in conjunction with a composite defined term, should be un-italicised throughout the NER.
Technical changes		
Incorporating synchronous condensers	Incorporation of general clause that states that some requirements of NER S5.2.5 and S5.2.6 that apply to synchronous plant have been modified or excluded, as noted in the first paragraph of the relevant subclauses. The parts modified or excluded are generally those associated with active power performance requirements.	Incorporation of general clause that states that some requirements of NER S5.2.5 and S5.2.6 that apply to synchronous plant have been modified or excluded, as noted in the first paragraph of the relevant subclauses. The parts modified or excluded are generally those associated with active power performance requirements.
Additions to information provision	Additions to NER S5.2.4(b) and (e1) to incorporate additional information required from an NSP under NER S5.2.5.1, S5.2.5.5 and S5.2.5.13. Note that some of the requirements are changed from the draft recommendations, considering other changes to these clauses.	Additions to NER S5.2.4(b) and (e1) to incorporate additional information required from an NSP under NER S5.2.5.5 and S5.2.5.13.
Relevant system – in relation to small plants exempt from some requirements	Relevant system described as the lower of 30 MW or 30 MVA as applicable and the amount (in MW or MVA) that is 5% of any maximum credible contingency event size specified in the FOS for the relevant region (gives a threshold of 7 MW for Tasmania based on its 144 MW maximum contingency size).	Relevant system described as the lower of 30 MW or 30 MVA as applicable and the amount (in MW or MVA) that is 5% of any maximum credible contingency event size specified in the FOS for the relevant region (gives a threshold of 7 MW for Tasmania based on its 144 MW maximum contingency size).
S5.2.5.8 Over-frequency emergency generation reduction requirements	NER 5.2.5.8 to establish the response proportional to frequency deviation as an AAS, tripping as a MAS, and NAS specifically allowing for fast runback as an alternative, and also allowing for relaxation of the 3 second requirement for response as a NAS. Other parts of the clause previously part of the MAS to be described as general requirements.	NER 5.2.5.8 to establish the response proportional to frequency deviation as an AAS, tripping as a MAS, and NAS specifically allowing for fast runback as an alternative, and also allowing for relaxation of the 3 second requirement for response as a NAS. Other parts of the clause previously part of the MAS to be described as general requirements.
S5.2.5.8 Protection settings and relationship to ride through clauses	S5.2.5.8(a)(1) provisions to be moved to the general requirements section of S5.2.5.8.	S5.2.5.8(a)(1) provisions to be moved to the general requirements section of S5.2.5.8.
S5.2.5.8 Conditions for which the plant may trip and recording of conditions	Clause S5.2.5.8(e) conditions for which schedule 5.2 plant is permitted to trip. This list has been amended to include in accordance with an ancillary services agreement with an NSP (in addition to AEMO) and adds requirements of a special protection scheme or a runback scheme. These changes have just been made for completeness. The description of what needs to be recorded in the performance standards in relation to trip information has also been updated to clarify it.	Clause S5.2.5.8(e) conditions for which schedule 5.2 plant is permitted to trip. This list has been amended to include in accordance with an ancillary services agreement with an NSP (in addition to AEMO) and adds requirements of a special protection scheme or a runback scheme. These changes have just been made for completeness. The description of what needs to be recorded in the performance standards in relation to trip information has also been updated to clarify it.
S5.2.5.8 Network Service Provider liability	Move clause NER S5.2.5.8(f), which describes that an NSP is not liable for losses or damage incurred by a Generator or IRP, to NER Schedule 5.6.	Move clause NER S5.2.5.8(f), which describes that an NSP is not liable for losses or damage incurred by a Generator or IRP, to NER Schedule 5.6.
S5.2.5.8 Vector shift protection	NER S5.2.5.16 requirement moved to NER S5.2.5.8, since the requirement relates to protection.	NER S5.2.5.16 requirement moved to NER S5.2.5.8, since the requirement relates to protection.
S5.2.5.11 Minimum operating level	At present, NER S5.2.5.11 describes minimum operating level requirements in terms of generating systems or IRS, but minimum operating level is specifically a unit-related issue. A system level minimum operating level for frequency droop performance is only correct if all the units are operating at the same initial level above their minimum operating level. The proposed changes rectify this issue.	At present, NER S5.2.5.11 describes minimum operating level requirements in terms of generating systems or IRS, but minimum operating level is specifically a unit-related issue. A system level minimum operating level for frequency droop performance is only correct if all the units are operating at the same initial level above their minimum operating level. The proposed changes rectify this issue.

Issue	Final recommendations	Draft recommendations made in update report (reference only)
S5.2.5.11 Response direction for bidirectional units taking power from the system	Amend NER S5.2.5.3(b)(1) and (c)(1) AAS and MAS to capture when the plant is taking power from the system and not just capture power transfer to the system (for example, batteries charging).	Amend NER S5.2.5.3(b)(1) and (c)(1) AAS and MAS to capture when the plant is taking power from the system and not just capture power transfer to the system (for example, batteries charging).
Drafting changes		
Drafting changes	Make corrections, clarifications and potential drafting improvements relating directly or indirectly to the determination, application and amendment of performance standards, including: • Consequential changes, clarification and streamlining of registered participant obligations in NER 5.2. • Clarification of the application of access standards set by an NSP for protection systems and fault clearance times in NER S5.1.1(f). • A request for feedback on a proposal to separate NER S5.2.5.5 into two separate clauses, dealing respectively with (multiple) fault ride through and response. • Removing generally applicable principles and considerations relevant to the assessment of performance standards from the schedules, and instead providing for consideration of those matters on a consistently worded basis in NER S5.3.4A(b). • Consistent with the principle in NER 5.3 that AEMO advises the NSP on AEMO advisory matters, amending references in the schedules that may imply AEMO is also negotiating standards between the NSP and applicants. • Adding provision for assessments (e.g. simulation studies) as well as physical testing in NER 5.7.2, which currently allows NSPs and connected participants to require testing of each other's facilities for compliance with the NER or a connection agreement. • Amendments for consistency with revised terminology relating to plant, participants, applicants and technical requirements. • Removing or consolidating unnecessary references to registered participants, or specific categories of registered participants or plant types throughout Chapter 5. • Proposed streamlining of substantially identical clauses relating to generating systems and IRS, and correction of minor omissions or inconsistencies relating to the IESS rule amendments. • Proposed deletion of redundant, duplicated or unnecessary wording.	Make corrections, clarifications and potential drafting improvements relating directly or indirectly to the determination, application and amendment of performance standards, including: • Consequential changes, clarification and streamlining of registered participant obligations in NER 5.2. • Clarification of the application of access standards set by an NSP for protection systems and fault clearance times in NER S5.1.1(f). • A request for feedback on a proposal to separate NER S5.2.5.5 into two separate clauses, dealing respectively with (multiple) fault ride through and response. • Removing generally applicable principles and considerations relevant to the assessment of performance standards from the schedules, and instead providing for consideration of those matters on a consistently worded basis in NER S5.3.4A(b). • Consistent with the principle in NER 5.3 that AEMO advises the NSP on AEMO advisory matters, amending references in the schedules that may imply AEMO is also negotiating standards between the NSP and applicants. • Adding provision for assessments (e.g. simulation studies) as well as physical testing in NER 5.7.2, which currently allows NSPs and connected participants to require testing of each other's facilities for compliance with the NER or a connection agreement. • Amendments for consistency with revised terminology relating to plant, participants, applicants and technical requirements. • Removing or consolidating unnecessary references to registered participants, or specific categories of registered participants or plant types throughout Chapter 5. • Proposed streamlining of substantially identical clauses relating to generating systems and IRS, and correction of minor omissions or inconsistencies relating to the IESS rule amendments. • Proposed deletion of redundant, duplicated or unnecessary wording.

A1. Rule changes by proposal type

Rule change proposal	Process	Notes
Schedules 5.2 & 5.3a - majority	Fast track	Supported by extensive consultation
Schedules 5.2 & 5.3a – further consultation appropriate	Standard	For reclassified contingency events (S5.2.5.5), there are further questions to be resolved in consultation with affected parties
Schedule 5.3 immediate recommendations	Standard	Significant change between draft and final recommendations
Review extension proposal	Standard	Not consulted on as part of Review.

A2. Stakeholder positions and analysis – feedback on update report (Schedules 5.2 and 5.3a)

Refer to separate attachment to this report, *Update report stakeholder consultation analysis and revised recommendations*, which summarises stakeholder feedback received for each update report recommendation, analyses feedback received, and sets out reasons for AEMO's decision to either revise or retain update report recommendations.

A3. Impedance study

Introduction

In the context of its review of NER S5.2.5.13, AEMO has considered the requirements and information provided to proponents when determining the speed of response of schedule 5.2 plant in relation to the metrics of rise time and settling time in response to voltage setpoint change in the primary mode of operation.

The concept of apparent system impedance relates to the impedance at operating voltages as opposed to the equivalent impedance level that would be calculated considering a three-phase short circuit condition, which is more commonly understood. The apparent system impedance would give, at the connection point, the same dV/dQ and dV/dP, as would be measured with all plant in service (consistent with the dispatch pattern), including synchronous and asynchronous plant, in their normal operating modes. The difference between traditional system impedance and apparent impedance will be greatest with very high IBR penetration electrically close to the connection point.

This technical note describes a simplified study performed by AEMO during its 2023 Review under NER 5.2.6A, to explore static and dynamic methods to obtain a value of ‘apparent system impedance’.

System apparent impedance

The use of fault level as a proxy for system impedance ignores the dynamics of the power system when subject to small disturbances at operating voltages. In conventional power systems where the source is often far from the analysis point (subject plant), the equivalent Thevenin reduction with a voltage source behind the fault level impedance can often lead to good study estimates. However, with high IBR penetration and/or voltage-controlled sources close to the subject plant, the relationship between the plant and the network can’t be captured by this metric alone.

During NEM connection application, registration and commissioning processes, the results obtained in SMIB studies often cannot be reconciled with relevant plant response in the real system. In an ideal scenario, AEMO or the NSP could provide, for any connection point, a complete representation of the dynamics of the network which could be used as a proxy for equivalent wide area model. This would be simpler and quicker to use than the full wide area EMT model.

Even if connection studies are undertaken with complete system models, under rapidly evolving grid conditions, studies undertaken can quickly become obsolete in circumstances where a new plant nearby can change the system voltage response at the connection point of the subject plant.

The speed of response for voltage steps can be captured in dynamic analysis using RMS phasor-type (PSSE) simulations in the wide area, but some aspects of tuning, such as complex interaction between schedule 5.2 plants at frequencies more than a few hertz, can only be ascertained in EMT type of simulations (PSCAD). A model that emulates the dynamics of the PSCAD wide area network, but which could be run with the low overheads of a SMIB model would give proponents a convenient, efficient way to measure compliance with voltage response requirements and other aspects of the network performance such as damping capability.

Approach to measure system apparent impedance

Use of dynamic system information would be ideal, but acquiring this information comes with time and computational effort. As an attempt to use a better metric than the fault level, it is possible to capture the dV/dQ 'gain' of the network using relatively simple static studies. The dV/dQ (and dV/dP) metrics can be translated to an apparent 'Z' ('X' and 'R') impedance in the equivalent SMIB representation.

To measure 'Za', the following conditions are applied:

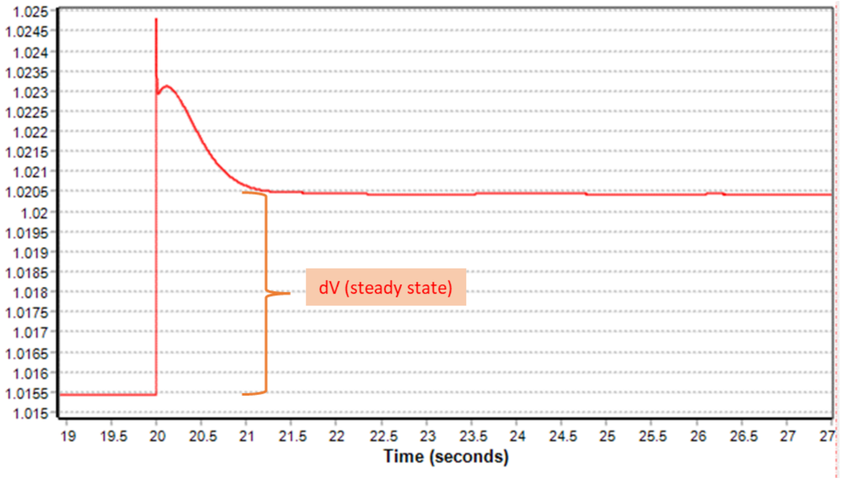
1. Adjust the case to represent a valid operational scenario (to be determined by the NSP).
2. Solve load flow and measure voltage at the connection point.
3. Switch a shunt reactive load (size of the shunt load should take into consideration network location).
4. Measure the voltage variation post load flow (taps locked and shunt operation disabled).

The above assumes that PSSE (tool used for this study) is capable of correctly solving both the pre and post steady state of the network accurately with due consideration to the voltage control strategy of all nearby voltage-controlled sources. However, a current issue for NEM connections is the use of PSSE version 34.2+ which is not capable of solving load flow accurately when plants are dispatched using droop without the aid of extra scripting tools (such as Python scripting).

Simplified study to obtain apparent impedance

Since the current PSSE load flow solution is not capable of modelling generators in voltage droop, in the simplified study performed, instead of using load flow, the network was converted into a dynamic case and the voltage response for a step in reactive power was obtained from measuring the dynamic response from the network as shown in Figure 5**Error! Reference source not found.**.

Figure 5 System voltage response to 5 MVAr shunt load.



As part of the simplified study, only the dV/dQ component of the network is extracted and the system impedance is approximated by the respective calculated reactance 'X'. 'R' is adjusted based on the fault level impedance X/R characteristics.

The location of the wide area network chosen for the study was arbitrarily selected. In a full-NEM PSSE snapshot, a generator (GEN – 'existing generator') with 110 MW maximum capacity is already inserted in the case and its parameters can be modified in the DYRE file. GEN dynamic parameters are used to vary the generator's response while evaluating the impact on the apparent impedance metric.

The following steps were performed:

1. Obtain fault level impedance from network case (ASCC using classical approach):
    a. ~ 547 MVA, X/R 2.5
    b. Z+ = 0.06819+j0.169376, 2.48388.
2. Obtain 'Za' from network case (see plot in **Error! Reference source not found.**):
    a. 'Xa' = 0.09738 and 'Ra' = 0.03246 (using X/R = 3).
3. Test SMIB with fault level impedance and compare with apparent impedance.
4. Test SMIB with apparent impedance and compare with wide area network results.

The 'proponent' generator (or subject plant) used for this test is an 80 MW solar farm using a typical configuration and known OEM models. The results illustrate the proponent generator's response considering changes to the GEN model, with all studies undertaken in PSSE. In this test case the proponent generator and the GEN model are connected to the same bus.

Results and early discussion

The following results were obtained from the method above.

Figure 6**Error! Reference source not found.** shows the SMIB model reactive power and calculated rise time for a 5% voltage setpoint change, comparing responses for a model with source impedance derived from apparent impedance and a model using a source impedance derived from fault level impedance.

Figure 6 Apparent System Impedance (green trace) vs Fault Level System Impedance (blue trace)

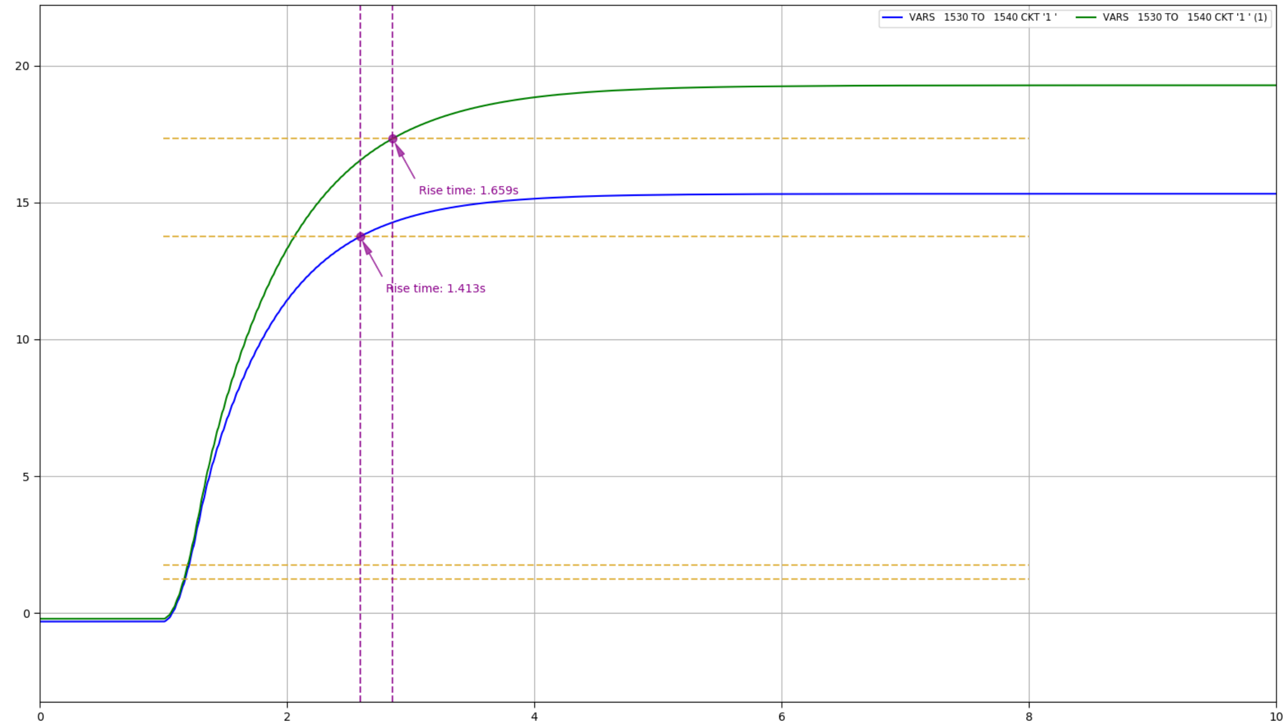
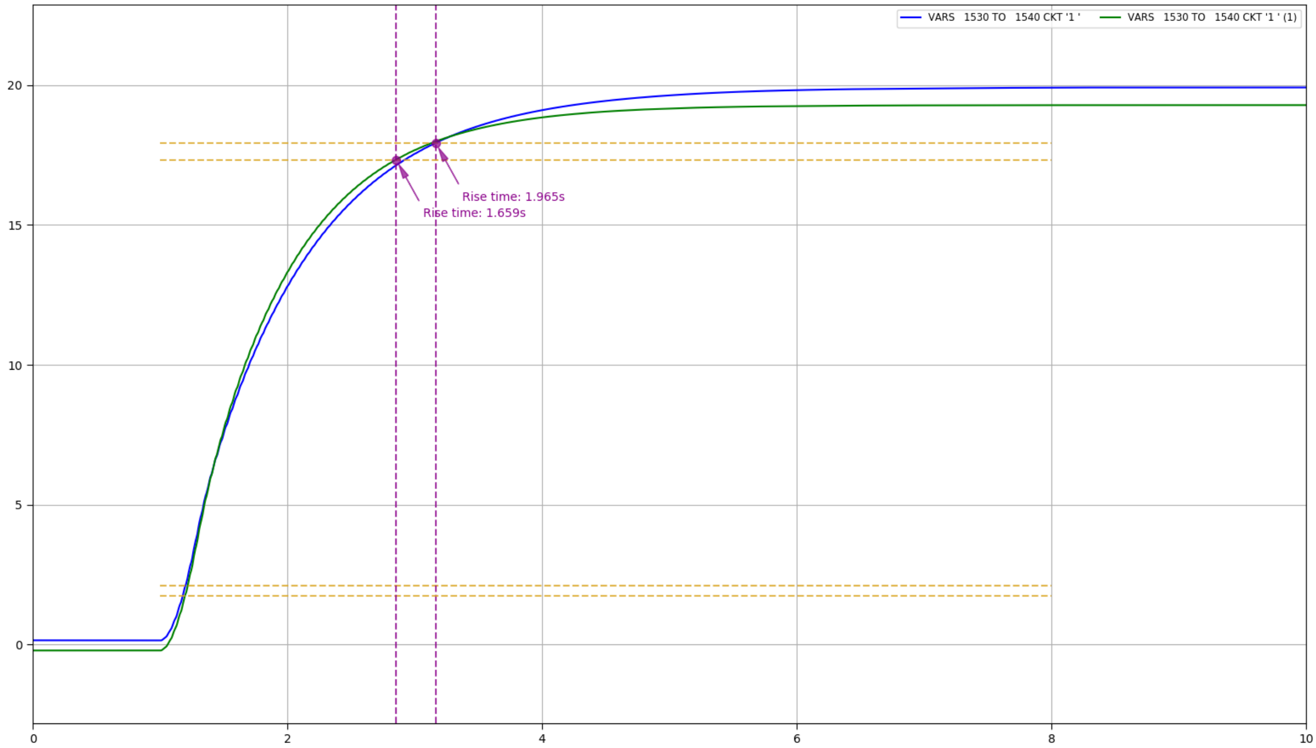


Figure 7**Error! Reference source not found.** shows the apparent impedance (PSSE SMIB) vs the wide area network model (PSSE snapshot) rise time for a 5% voltage setpoint change. As expected, results are relatively closer in terms of steady state reactive power flows.

Figure 7 Apparent System Impedance SMIB (green trace) vs wide area network (blue trace), for 5% setpoint change (both PSSE)



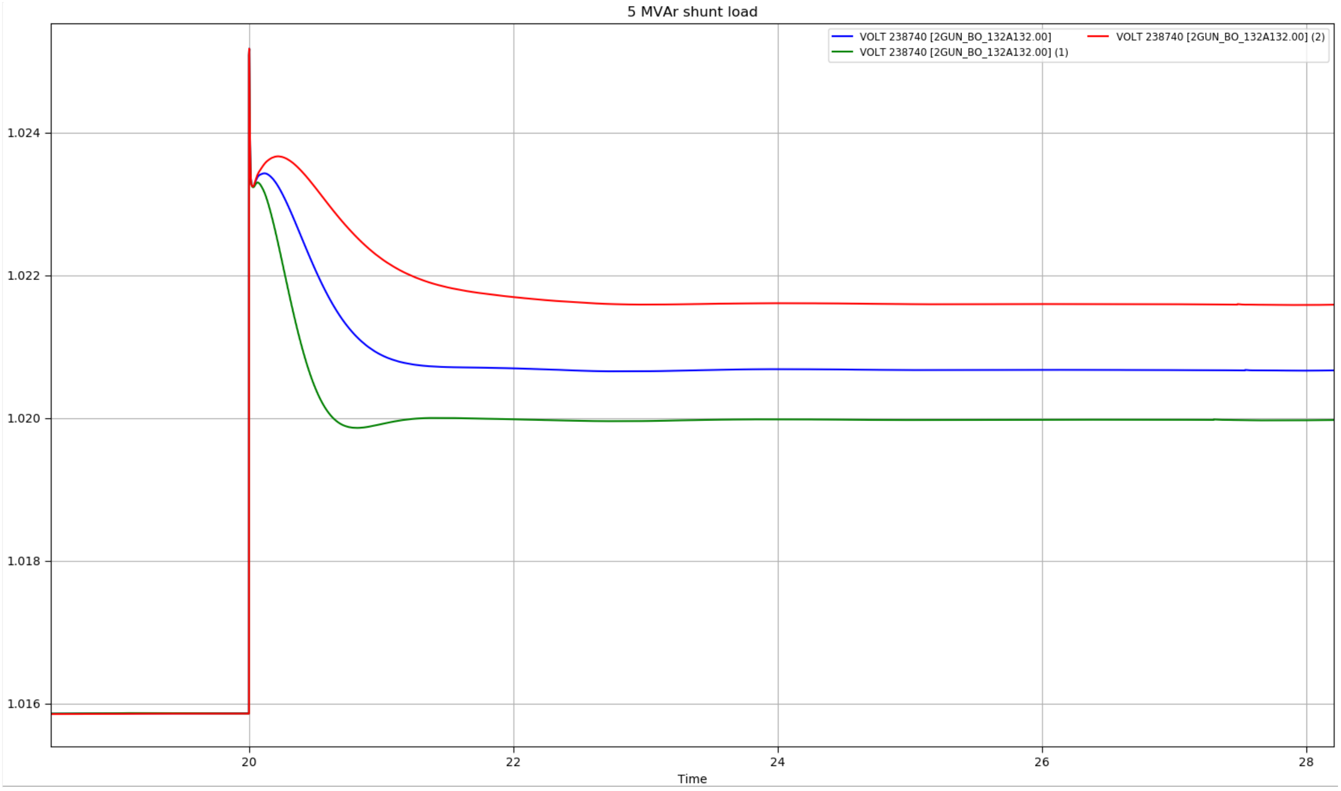
These results show that use of the apparent impedance metric leads to a closer alignment than using the fault level impedance, although still yielding different rise time measurements. To test robustness of the metric, sensitivity analysis was conducted varying some key aspects.

Sensitivity analysis – impact of the voltage droop gain of the nearby plant

As the main component of the response being considered is the effective ‘gain’ dV/dQ in steady state, a fair assumption would be to verify the sensitivity of the apparent impedance in relation to the droop setting of the nearby generator (GEN).

The GEN voltage droop parameter was adjusted to double and half (5%, 10% and 2.5% respectively) of the original value and the response to a 5 MVAr shunt load dV/dQ was measured as shown in Figure 8**Error! Reference source not found.**.

Figure 8 System voltage response to 5 MVAr shunt load with GEN droop adjusted – 5% (blue), 10% (red) and 2.5% (green)



Based on the results the calculated ‘Xa’ varied between ~9.2% and ~11.2%, these are consistent with the expected effect of increasing or decreasing the droop.

With GEN voltage droop control gain adjusted two comparisons were made, rise time results in the wide area network and in a SMIB. As shown in Figure 9 and Figure 10, the rise time is barely impacted by the effects of the voltage droop gain.

Figure 9 Reactive power rise time using ~9% (blue trace) and ~10% reactance (green trace).

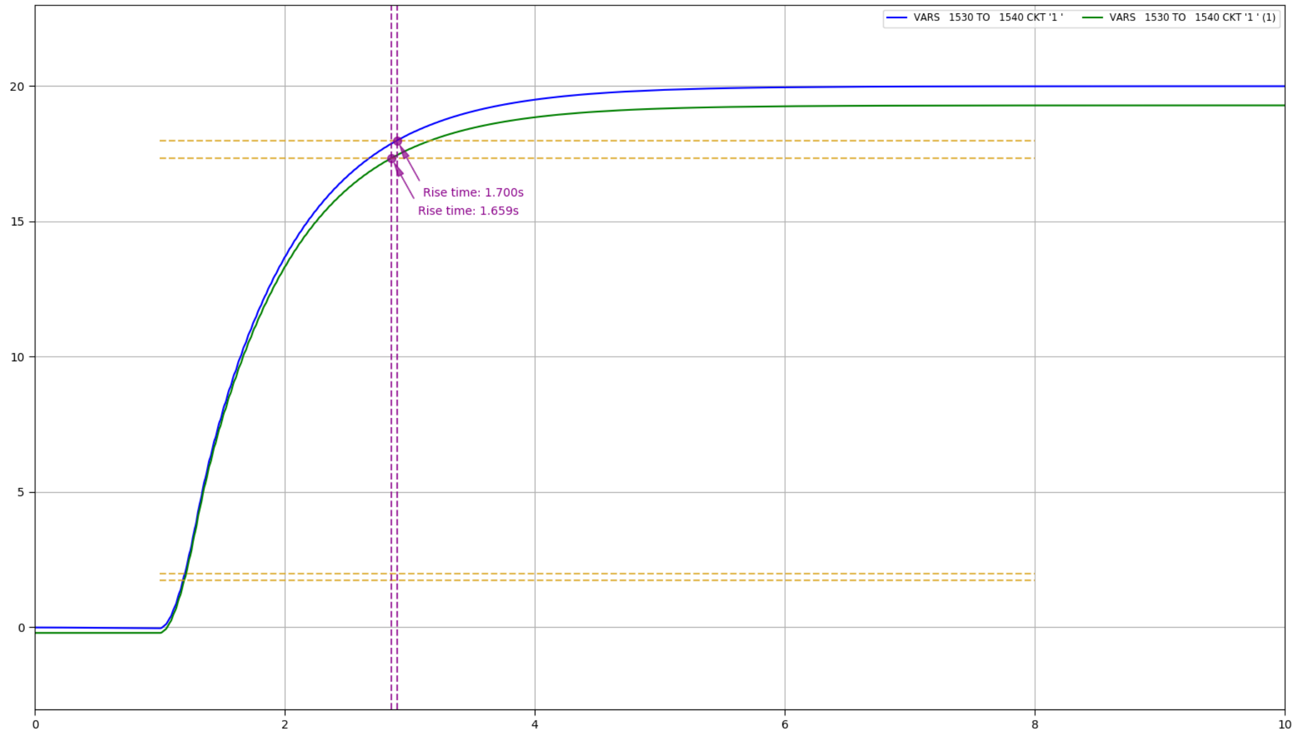
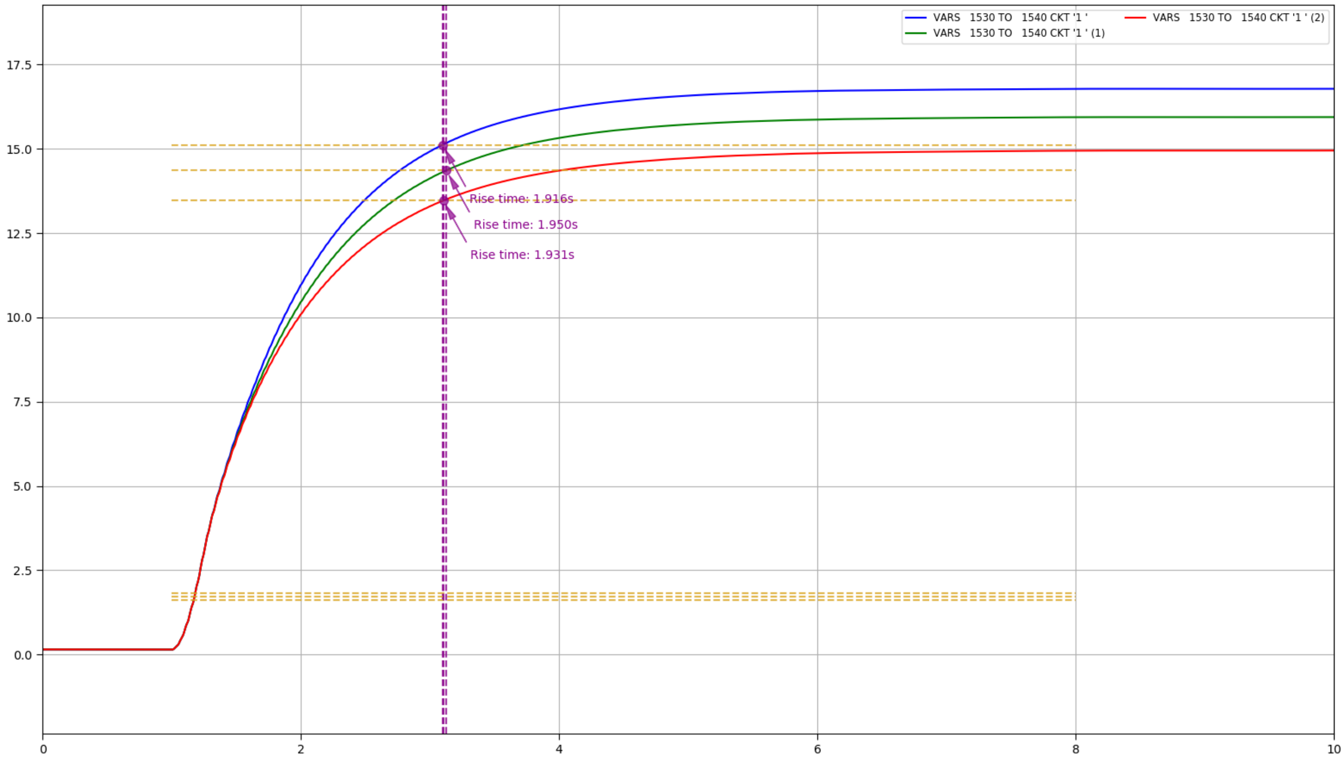


Figure 10 Reactive power rise time in wide area network for different GEN droop gains



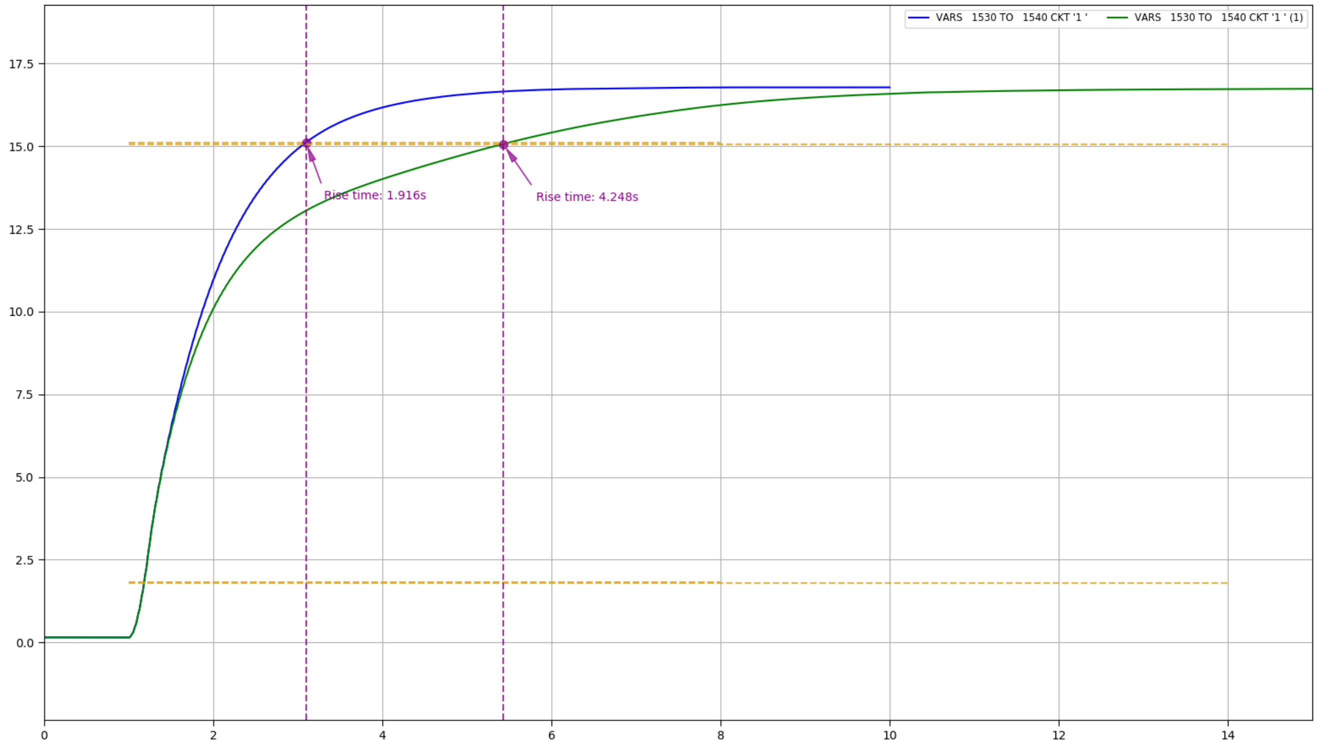
These results are of importance as they provide an indication that the steady state ‘gain’ is not the main factor contributing to the difference in the speed of response. This is demonstrated by the other sensitivity test, described in the next section.

Sensitivity analysis – impact of reactive power control loop gains in the nearby plant

The studied connection point is directly influenced by GEN and its voltage control strategy; this means that the dynamic response of the reactive power control loop of GEN must be examined when looking at an approximation of the system impedance.

Figure 11**Error! Reference source not found.** shows the impact of changing the reactive power control gains from GEN (slowing its response). Given GEN has comparable size in relation to the network fault level (effective SCR of 4.9), the speed of response of GEN will directly impact the speed of response of any nearby generator as GEN is impacting the evolution of the network voltage at the connection point.

Figure 11 Rise time results for wide area network with GEN original controls (blue trace) vs GEN reduced controller gain (green trace)

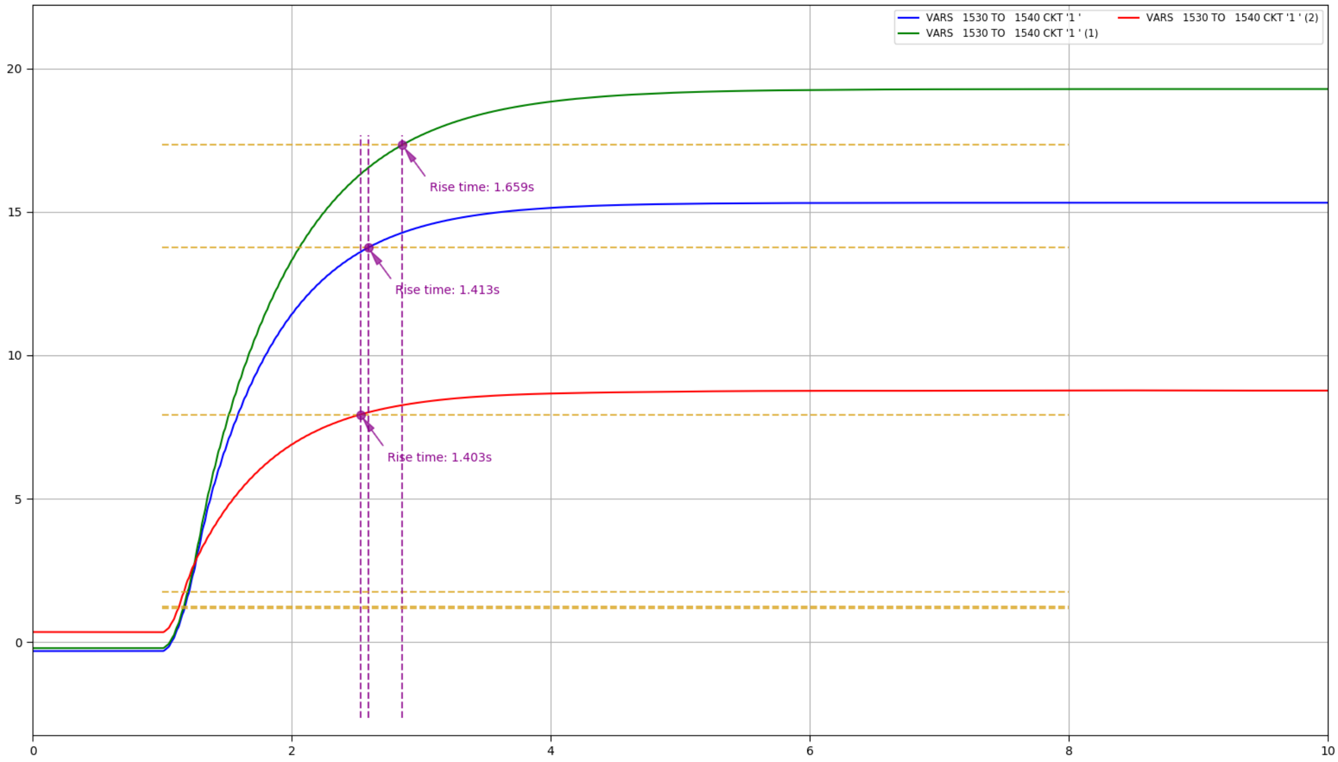


The result indicates that the dynamic response of nearby plant can have a more significant impact on the measured reactive rise time of the proponent generator than the difference between apparent impedance and source impedance derived from fault level.

The result above could be considered reason enough to discard the use of methods that do not represent the dynamics of nearby plant. If a base case incorporating the dynamics of nearby plant is available, performing studies with that model is likely to be more accurate than using a SMIB, even with the apparent impedance.

Further illustrating the dependency of nearby generators, Figure 12**Error! Reference source not found.** shows the rise time response in the wide area network when GEN is out of service (no other plant with voltage controllers nearby) and the counterpart in the SMIB with impedance being approximated by fault impedance. Although the dV/dQ gain is not aligned, the speed of response is closely related as the proponent generator is the main voltage control source in both studies. Similar rise times might also be achieved if GEN response could be “sped up” to the point it would not interact with the proponent generator, but this was not possible in this particular instance due to slow PPC control action.

Figure 12 Rise time with GEN OOS (and no other nearby plant with voltage controllers) for wide area network (red), SMIB based on FL impedance (blue) and apparent impedance (green)



Implications for the technical requirement review and compliance assessment

The test results suggest that there is not sufficient benefit in requiring NSPs to provide the range of apparent impedances to assist with tuning of voltage controllers under NER S5.2.5.13 that was proposed in the draft report for the Review. The results indicate that where there are nearby generators, the voltage response of the subject plant is likely to be affected by the dynamics of nearby plant more than by the difference between the fault impedance and the apparent system impedance.

The apparent impedance can be derived from a full system RMS model and used to achieve the same dV/dQ, but a SMIB PSCAD model may not provide a reliable indicator of dynamic response if there are nearby plants in voltage control. This suggests that a PSCAD or PSSE SMIB model without representation of nearby plant dynamics is not suitable for ascertaining a value for reactive power rise time for a setpoint change for a performance standard.

Where there are other generators or dynamic reactive plant in electrical proximity to the subject plant , a PSCAD SMIB model is also unlikely to yield accurate results for overlaying against a test result for a voltage step test (or voltage disturbance test), as it will not capture the impact of the dynamic response of nearby plant. A playback method may go part way to resolving this but has its own limitations.

On the other hand, if there is no relevant plant in electrical proximity to the plant under test, then the SMIB model can provide a reasonably accurate result for dynamic response.

These results also call into question the value of reactive power rise time as a measure for compliance assessment, as it is influenced by external factors such as the connection of other generators in its vicinity, and may change with the plant connected to the power system over the life of the plant.

Other tools such as system identification and impedance scans were not analysed and are not presented here. Such tools might aid tuning speed of response, but also the damping capability of schedule 5.2 plant provided the base case generating the proxy impedance is of sufficient quality.

A4. Rise time and settling time requirements by mode

Mode	AAS/ MAS	Primary Mode			Secondary mode		
		Speed	Stability		Speed	Stability	
		V disturbance	Setpoint	V disturbance	V disturbance	Setpoint	V disturbance
Voltage control	AAS	Rise time Not into a limiter: • 3s for: • Reactive power • 2-5% voltage disturbance • typical to high impedance.	Settling time Not into a limiter: • 5s and Into and out of a limiter: • 7.5s for • voltage, reactive power and active power • for 5% setpoint change • typical to high impedance • setpoint input ramp rate limit disabled, if applicable.	Settling time Not into a limiter: • 5s and Into and out of a limiter: • 7.5s for • voltage, reactive power and active power • 2- 5% voltage disturbance • typical to high impedance.	N/A	N/A	Settling time Not into a limiter: • 5s Into and out of a limiter: • 7.5s for • voltage, reactive power and active power • 5% voltage disturbance • typical impedance.
	MAS	N/A	N/A	Settling time: Not into a limiter: • 7.5s or greater time agreed with NSP for: • voltage • 5% disturbance • typical to high impedance.	N/A	N/A	Settling time Not into a limiter: • 7.5s or greater time agreed with NSP for: • voltage • 5% disturbance • typical impedance.

Mode	AAS/ MAS	Primary Mode			Secondary mode		
		Speed	Stability		Speed	Stability	
		V disturbance	Setpoint	V disturbance	V disturbance	Setpoint	V disturbance
Power factor control	AAS	N/A	Settling time Not into a limiter: • 5s if conditions where response overshoots the sustained change or is oscillatory • Otherwise, 30s or other number agreed with AEMO and the NSP for: reactive power and active power a setpoint step equivalent to at least half of the range (absorbing to injecting) of reactive power agreed in S5.2.5.1 typical to high impedance.	Settling time Not into a limiter: 5s. Into a limiter: 7.5s for: reactive power and active power 2-5% voltage disturbance typical to high impedance.	N/A	N/A	Settling time Not into a limiter: 5s and Into a limiter: 7.5s for: reactive power and active power 5% voltage disturbance typical impedance.
	MAS	N/A	N/A	Settling time Not into a limiter: • 7.5s or greater level agreed with the NSP and AEMO for: reactive power and active power, 5% voltage disturbance, typical to high impedance.	N/A	N/A	Settling time Not into a limiter: 7.5s or greater time agreed with the NSP and AEMO for: reactive power and active power, 5% voltage disturbance, typical impedance.

Mode	**AAS/ MAS**	**Primary Mode**			**Secondary mode**		
		Speed	**Stability**		**Speed**	**Stability**	
		V disturbance	**Setpoint**	**V disturbance**	**V disturbance**	**Setpoint**	**V disturbance**
Reactive power control	AAS	N/A	Settling time Not into a limiter: • 5s if conditions where response overshoots the sustained change or is oscillatory • Otherwise, 30s or other number agreed with AEMO and the NSP for: • reactive power • setpoint step equivalent to at least half of the range (absorbing to injecting) of reactive power agreed in S5.2.5.1 • typical to high impedance.	Settling time Not into a limiter: • 5s and Into a limiter: • 7.5s for: • reactive power • 2-5% voltage disturbance • typical to high impedance.	N/A	N/A	Settling time Not into a limiter: • 5s and Into a limiter: • 7.5s for: • reactive power • 5% voltage disturbance • typical impedance
	MAS	N/A	N/A	Settling time Not into a limiter: • 7.5s or greater number agreed with the NSP and AEMO for: • reactive power • 5% voltage disturbance • typical to high impedance.	N/A	N/A	Settling time Not into a limiter: • 7.5s or greater time agreed with the NSP and AEMO for: • reactive power • 5% voltage disturbance • typical impedance.

A5. Stakeholder positions and analysis – feedback on addendum to draft report (Schedule 5.3)

Refer to separate attachment to this report, *Stakeholder consultation analysis and revised recommendations – NER Schedule 5.3*, which summarises stakeholder feedback received for each recommendation set out in the addendum to the draft report, analyses feedback received, and sets out reasons for AEMO’s decision to either revise or retain recommendations.

Glossary

This document uses many terms that have meanings defined in the NER. The NER meanings are adopted unless otherwise specified.

Term	Definition
AAS	Automatic access standard
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
BESS	Battery energy storage system
CRI	Connections Reform Initiative
CUO	Continuous uninterrupted operation
DC	Direct current
dV/dQ	Differential voltage
EMT	Electromagnetic transient
FCAS	Frequency control ancillary service
GFL	Grid following
GFM	Grid forming
HVDC	High voltage direct current
IBR	Inverter-based resource/s
IESS Rule	National Electricity Amendment (Integrating energy storage systems into the NEM) Rule 2021
IRP	Integrated Resource Provider
IRS	Integrated resource system
MAS	Minimum access standard
MFRT	Multiple fault ride through
MNSP	Market Network Service Provider
NAS	Negotiated access standard
NEM	National Electricity Market
NEO	National electricity objective
NER	National Electricity Rules
NSP	Network Service Provider
OEM	Original equipment manufacturer
PFR	Primary frequency response
PMU	phasor measurement units
POD	Power oscillation dampers
PPC	power plant controller
PSCAD	Power Systems Computer Aided Design (PSCAD™)
PSSE	Power System Simulator for Engineering (PSS®E)
pu	Per unit
Review	AEMO review of technical requirements for connection (pursuant to NER 5.2.6A)
REZ	Renewable Energy Zone
RMS	Root mean square

Term	Definition
RoCoF	Rate of change of frequency
SMIB	Single machine infinite bus
VSC	Voltage source convertor