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Vysus Group

Proposed changes to NER S5.2.5.5 minimum access standard

VYSUS TECHNICAL NOTE

Technical Note

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1 Background

1.1 About the Connections Reform Initiative

The Connections Reform Initiative (CRI) was convened in 2021 as a joint endeavour between the Australian Energy Market Operator (AEMO) and the Clean Energy Council (CEC). The aim of the initiative is to improve the operation of Australia's National Energy Market (NEM) in meeting the National Electricity Objective (NEO) by improving the efficiency, cost-effectiveness, consistency and predictability of the network connection process.

CRI working groups were convened beginning in July 2021 with a combined membership of 51 technical and non-technical stakeholders representing CEC, AEMO, Network Service Providers, project developers, equipment suppliers, consultants, the Australian Power Institute, and regulatory authorities such as AER. These were assigned to work across several identified Reform Areas covering network access, industry collaboration, modelling requirements and quality, information asymmetry, batching of connections, processes around technical guidelines, the quality of applications, and the predictability of the connection process. Stakeholders worked in a volunteer capacity between July and December 2021 to develop a reform roadmap across each of these areas.

The work discussed in this note arises from **CRI Reform Area 1.1: Network Access**. The aim for this reform area was to improve the development of technical performance standards to be optimally consistent with both specific network performance, and the needs at a particular connection location.

A focus for the reform sub-group in this area was the minimum access standard under clause S5.2.5.5 of the National Electricity Rules (NER) [1]. This clause deals with the response of generating plants to contingency events. Industry stakeholders had identified certain requirements in this clause as presenting undue barriers to new connections for generators and energy storage systems, and potentially leading to adverse network impacts, contrary to the NEO.

This note summarises the deliberations of the Reform Area 1.1 technical working group, the proposed changes to minimum access standard clauses under NER S5.2.5.5, and the reasons for proposing these specific changes, including comparison with alternative proposals considered by the working group and in similar rule change submissions currently before the AEMC.

In particular, a close alignment will be noted between the present proposals and those recommended in the 2021 rule change submission to the AEMC by four leading wind turbine manufacturers [9], which has been consolidated into a current rule change process by the AEMC as of 26 May 2022 [10]. Similar to the present exercise, the 2021 submission limited itself to the MAS under clause S5.2.5.5. The CRI technical working group considered similar technical concerns and industry case studies and its recommendations largely include and extend those in the 2021 rule change submission [9] as a result.

1.2 The S5.2.5.5 Minimum Access Standard

Clause S5.2.5.5 of the National Electricity Rules (NER) sets out the required access standards for generating systems (including energy storage systems in discharging operation) when subjected to a contingency event in the power system. Contingency events are faults and other abnormal occurrences that cause local network voltage to exceed normal operating boundaries, including possibly dropping to zero, for short periods of time.

As with NER S5.2 technical requirements more generally, the automatic access standard (AAS) under S5.2.5.5 sets the 'default' requirements for generating systems that should be met unless there are sound technical or commercial reasons preventing this. In the event a proposed generating system has a sound justification for not meeting the automatic access standard, S5.2.5.5 also prescribes a minimum access standard (MAS) below which connection will never be permitted. Thus, the MAS functions as an *ex ante* exclusion standard that preempts the ability of the proponent, the Network Service Provider and AEMO to jointly negotiate an outcome that may fall beneath the MAS threshold. The purpose of a MAS is to prevent the connection of unsuitable technologies that, on balance, are likely to raise technical problems for future network users and operators exceeding the benefit provided to network users in the meantime.

Clause S5.2.5.5 also differs from other technical requirements in NER Schedule S5.2 in differentiating between synchronous and asynchronous generating units. As the majority of new network connections are likely to comprise solar, wind and battery storage plants utilising either DC–AC inverters or doubly-fed induction generators (DFIG), the CRI working group focussed specifically on the MAS requirements for asynchronous generating units, which are found in paragraphs (k), (l), (n), (o) and (p) of clause S5.2.5.5. Further requirements relating to the performance standard under S5.2.5.5 for asynchronous generating units are found in paragraphs (q) through (u).

The key matter of concern for the CRI working group is that experience with the current MAS under S5.2.5.5 suggests it may have adverse effects, viz:

- Acting as a barrier to connections where the only feasible performance standard falls below the current MAS threshold but might, nonetheless, reasonably be judged unlikely to raise unacceptable difficulties for system operation in the future.
- Raising the potential for adverse consequences in the network where control settings implicitly mandated by the current MAS exceed the level judged optimal in the circumstances, and where the optimal setting leads to performance below the current MAS threshold.

In either case the current MAS would fail to fulfil its purpose and could be judged contrary to the NEO.

Early deliberations by the CRI working group established the following key areas of concern based on experience with connections under the current MAS:

- **Paragraph S5.2.5.5(l) – performance under multiple disturbances.** Specifically, particular disturbance scenarios required under this clause may mandate operation unsuitable for the capabilities of certain local networks, and NSPs along with proponents require more flexibility to negotiate on a more suitable range of scenarios based on the network being considered.
- **Paragraph S5.2.5.5(n) – current injection to the network during and after faults.** Specifically, the minimum injection level mandated by this clause may not always be practically achievable and in some cases may have a negative impact on voltage stability during contingency events.
- **Paragraph S5.2.5.5(o) – commencement and settling of current injection during faults.** Specifically, rise and settling time for fault current is not always reliably measurable (particularly when considering both balanced and unbalanced conditions) and the specific times mandated may have a negative impact on voltage drop or rise in the network during contingency events.

Of these three specific paragraphs, S5.2.5.5(l) was deferred for consideration by the CRI working group at a later date. The present note sets out and discusses proposed changes to S5.2.5.5(n) and (o), and consequential changes to related clauses, arising from detailed consideration by the technical working group during the second half of 2021.

2 Reactive current injection: Paragraph S5.2.5.5(n)

2.1 Existing MAS wording

The existing paragraph S5.2.5.5(n) in the NER [1] reads as follows.

> Subject to any changed *power system* conditions or energy source availability beyond the *Generator's* reasonable control, a *generating system* comprised of *asynchronous generating units* must:
>
> (1) for the types of fault described in subparagraph (k)(2), and to assist the maintenance of *power system voltages* during the fault, have *facilities* capable of supplying to or absorbing from the *network*:
>
> > (i) capacitive reactive current in addition to its pre-disturbance level of at least 2% of the maximum continuous current of the *generating system* including all operating *asynchronous generating units* (in the absence of a disturbance) for each 1% reduction of *voltage* at the *connection point* below the relevant range in which a reactive current response must commence, as identified in paragraph (o)(1), with the *performance standards* to record the required response agreed with *AEMO* and the *Network Service Provider*; and
> >
> > (ii) inductive reactive current in addition to its pre-disturbance level of at least 2% of the maximum continuous current of the *generating system* including all operating *asynchronous generating units* (in the absence of a disturbance) for each 1% increase of *voltage* at the *connection point* above the relevant range in which a reactive current response must commence, as identified in paragraph (o)(1), with the *performance standards* to record the required response agreed with *AEMO* and the *Network Service Provider*,
>
> during the disturbance and maintained until *connection point voltage* recovers to between 90% and 110% of *normal voltage*, or such other range agreed with the *Network Service Provider* and *AEMO*, except for *voltages* below the relevant threshold identified in paragraph (p); and
>
> (2) return to at least 95% of the pre-fault *active power* output, after clearance of the fault, within a period of time agreed by the *Connection Applicant*, *AEMO* and the *Network Service Provider*.

In brief, the salient points in this clause are as follows.

- Generating systems are required to automatically inject capacitive reactive current for abnormal low voltage events, and inductive reactive current for abnormal high voltage events. This automatic injection of reactive current must be additional to the level of reactive current prior to the event.
- The minimum required level of reactive current injection is 2% of the 'maximum continuous current' for every 1% rise or fall in voltage below a threshold value determined from paragraph (o).
- The current injection must be maintained until the voltage at the connection point recovers to between 90% and 110% of normal voltage (the range for continuous operation), and (by implication) takes priority over the injection of active current during this period.
- After clearance of the fault the active power injection must return to at least 95% of the active power output before the event, within an agreed set period of time.

2.2 Issues considered by the working group

Preliminary discussions within the technical working group and the wider CRI steering group identified the following matters that in stakeholders' experience lead to undue barriers to connection, potential adverse consequences for the power system, or ambiguity complicating the negotiation of performance standards.

2.2.1 Required level of current injection at point of connection and at unit terminals

A key question considered for this clause by the working group, that arose from earlier deliberations among industry stakeholders for the CRI and also in prior rule change submissions to the AEMC, was the following:

a) what minimum level of reactive current injection is appropriate to require within the NER; and

b) should the requirement be imposed at the point of connection or the terminals of generating units, or both?

When the first 'fault ride through' standard was implemented for the NEM in the early 2000s, in what was then known as the National Electricity Code [5] – and from 2005, also in the ESCOSA Licensing Principles in South Australia [6] – it applied to individual generating units. This reflected the traditional practice of establishing plant performance through unit tests, and the direct tuning of unit-level controls.

However, with the development of wind farms (and later solar farms and BESS installations) comprising dozens or even hundreds of individual generating units, it was soon recognised as unwieldy to model, test and validate performance at each individual unit. Since 2007 [2], the NER S5.2 technical requirements have been formulated to apply at the level of entire generating systems, with the response to disturbances being measured and assessed for compliance at the generating system's connection point.

While the focus on entire generating systems makes sense from the viewpoint of efficiency and measurability, an unintended consequence of the shift from unit terminals to the generating system connection point is the loss of a close technical linkage between the response of the individual units making up the system, and the measured response at an often-remote connection point. This is a particular concern for fault current standards, due to the relevant control systems normally being autonomous functions of the generating units, the propensity for large generating systems to absorb substantial reactive current in the balance of plant, and for voltage at the connection point to differ substantially from that at the terminals of a typical generating unit.

As an example of this technical concern, the working group noted it was not uncommon in large wind farms for a 50% reduction in voltage at the connection point to be perceived as only a 25% reduction (or less) at the terminals of any single wind turbine. The relatively small fault current injection appropriate to a 25% voltage reduction may then not adequately compensate (for example) the near-halving in current injection from static shunt capacitors located closer to the connection point.

Under the NER technical requirements in force between 2007 and 2018, the above issue was rarely highlighted because the S5.2.5.5 MAS, and the definition of 'continuous uninterrupted operation' at the time, did not prescribe any specific behaviour from generating systems during the occurrence of a fault. While the AAS did prescribe a capacitive current injection with a 4:1 ratio of current to voltage drop for low voltage events, generators were able to perform below the AAS provided doing so was not found to have a material adverse effect on system security or quality of supply. In practice, many generator connections during this period negotiated performance standards with no requirement for any specific fault current injection.

Meanwhile, the need to identify and closely manage technical risks that might be posed to the system by increasing penetration of renewable (asynchronous) generation was highlighted by the South Australia system black event in September 2016, where the failure to thoroughly document new generation controls and test performance in multiple contingency events was found to play a proximate role. Although fault current from asynchronous generators (or lack thereof) did not play any apparent role in the 2016 event, the lack of substantive minimum standards for behaviour *during* faults as new technology replaces synchronous machines was identified as a potential technical risk. Accordingly the present S5.2.5.5 MAS (based on a 2:1 minimum injection ratio) was put in place from 2017, initially through AEMO advice to the inquiry into generator licensing requirements in South Australia [4][7], then as part of the 2018 revisions to NER Schedule 5.2 [3].

The above question of ‘connection point versus unit terminals’ gained new prominence with this 2018 rule change. The AEMC in its draft determination provided for the S5.2.5.5 reactive current injection to respond to voltage at individual generating units by default, but with flexibility to apply the standard at the connection point on a case-by-case basis. This followed advice in industry consultations that specifying the response at unit terminals better reflects the nature of autonomous response from asynchronous generating units, and also aligns more closely with the way synchronous units are presumed to respond naturally to unit terminal voltage. However, some submissions in response to the draft determination argued it was inconsistent and confusing to apply some standards at generating unit terminals and others at the connection point, and the latter should prevail when defining performance to support the power system. Accordingly in its final determination [3], the AEMC reversed the default application of the standard, now formulated as responding to voltage at the connection point, but with flexibility to apply at unit terminals instead.

The principle established from 2007 of defining performance for an aggregate generating system at a single connection point is valuable and efficient from the perspective of power system operation. Unfortunately, the AEMC final determination now applies to the connection point a numerical standard for current injection that had been formulated and agreed with the industry based on behaviour of individual generating units at their terminals. While there is little doubt that contemporary asynchronous generator technology can achieve large current injection ratios *at the terminals of a generating unit* by autonomous control during faults, this may not always be consistent with a minimum 2:1 injection ratio *at the connection point*.

Analysis and practical experience also demonstrate that even where a 2:1 injection ratio is achievable at the connection point, the (often very aggressive) level of current injection this requires at generating units can be adverse to secure performance of the network under consideration. Indeed, a 2020 CIGRE paper by Vysus [8] pointed out that in weak radial networks, fixing a nonzero level of reactive current injection during certain types of severe fault may be incompatible with voltage stability in the network, and the faults in question are not necessarily distinguishable by inspection of the voltage either at the generator’s connection point or at its unit terminals.

Subsequent experience has borne out these concerns, with a number of projects requiring design and control system setting choices with arguably adverse consequences for system performance during faults, but necessary to achieve strict compliance with the current MAS. In other cases, system costs have increased due to the need for generators to procure auxiliary equipment driven by MAS compliance rather than by actual improvements in power system performance. The flexibility provided in S5.2.5.5(u)(2) to measure reactive current and voltage at unit terminals has proved difficult to apply in practice, and negotiations on this point have led to further delays in the connection process.

These concerns were detailed further in the 2021 rule change submission by four leading wind technology suppliers to the Australian market [9], now the subject of a current AEMC consultation [10]. Some of these suppliers are also represented on the technical working group, and it is considered that the recommended rule changes here agree closely with or extend those in that earlier submission.

In formulating a suitable alternative minimum standard, the working group stressed the enduring need for generators to contribute fault current wherever practical, and agreed with the general principle of defining system performance at a single connection point, but also had regard to the argument in [8] from electrical first principles, that in some circumstances the only suitable level of reactive current injection during a fault is zero. The working group also gave due consideration to the role of a MAS, which is to prevent the connection of unsuitable and risky technologies, and not to pre-empt negotiations in practically relevant ‘edge cases’.

The approach adopted by the working group was to retain the principle that performance be defined by a set ratio between the required current injection and the fall or rise in voltage at the connection point, but to allow this ratio to be negotiated down as far as zero where necessary. The principle was retained that any required fault current injection be additional to the level of reactive current existing at the time of a disturbance, and that reactive current not change so as to exacerbate the disturbance (for example, by shifting current in an inductive direction during a low voltage disturbance). It was considered that although the connection point can be remote from any individual generating unit, an appropriately configured generating system will, as a minimum and without onerous effort, be capable of maintaining the prevailing level of reactive current at that connection point during a disturbance without driving that current in an adverse direction.

The working group also considered the desirability of retaining in the MAS a reference to some nonzero level of injection, such as the existing 2:1 ratio, as a 'target' to guide negotiations. Concern was expressed that without some specified nonzero 'target' level, applicants would default to negotiating a zero level of injection. However, it was concluded that under the post-2018 framework, where applicants *must* meet an AAS unless sound reasons are given for why this is infeasible, such a 'target' is already provided by the 4:1 and 6:1 ratios in the AAS. Prescribing any other 'target' level less than this is redundant given the applicant must already, in accordance with clause 5.3.4A(b1), propose a standard approaching the AAS as closely as practicable given the specific circumstances, and agree this with the NSP and AEMO.

The working group nevertheless suggested that to anchor expectations, guidance could be provided on a nonzero injection level that would typically be accepted as suitable for a negotiated access standard below the AAS. But it was agreed such guidance is most appropriately provided in a guideline document in parallel with the NER (a subject of other CRI reform areas) and not in the NER itself.

2.2.2 Definition of 'maximum continuous current'

The 'maximum continuous current' is a key quantity that determines the standard required for reactive current injection, but it is not an NER defined term, nor does it have a single agreed 'natural' meaning. The working group agreed in principle that this quantity should be defined in the NER, to provide more certainty in the agreement of performance standards.

An alternative approach, to leave 'maximum continuous current' undefined in the NER but have the parties to a connection explicitly agree a figure for the current and document it with the performance standard on a case-by-case basis, was considered by the working group but ultimately discounted as a measure that would unnecessary complicate individual connections.

Although it is evident that 'maximum continuous current' can be defined from the aggregate nameplate (MVA) rating of the generating units and a suitable nominal voltage, the working group observed this could also have adverse consequences. The working group considered the case of two generating systems with the same production capacity in MW, where one had sized the total MVA of its inverters to the minimum required for compliance with the NER, while the other chose a total MVA 10% greater (by expanding the number and type of inverters) to provide additional headroom for network voltage control. The latter generating system delivers a higher standard of performance to the network, but as a direct consequence of this faces a more onerous standard for fault current injection under an MVA-based definition of 'maximum continuous current'.

For this reason, the working group favoured the approach of defining 'maximum continuous current' not from the rated MVA of the units themselves, but instead from the MVA capability required from the generating system under its S5.2.5.1 performance standard. This is a capability determined from the production capacity in MW (at least under the automatic access standard) rather than from the units' actual MVA. This approach has the added advantage of creating an explicit logical linkage between the transient capability under S5.2.5.5 and the steady-state capability under S5.2.5.1, similar to the linkage already existing in the NER between the steady-state capability under S5.2.5.1 and the dynamic control capability under S5.2.5.13.

Given the flexibility to define S5.2.5.5 performance at the terminals of generating units under certain circumstances, the working group also considered there should be an explicit definition for 'maximum continuous current' of a generating unit. This would not refer to S5.2.5.1 (as this does not apply at the unit level) but instead refer to a maximum deliverable current under continuous operation, with a method for calculating this from the unit MW or MVA rating and the relevant voltage level agreed between the proponent and the NSP. The working group considered there should be fewer adverse consequences from defining this quantity from the nameplate MVA rating at the single unit level, as the rating of a single unit is independent of the number of units making up a generating system.

Physically, the calculation of current from a power quantity in MW or MVA relies on a baseline voltage quantity. In the present context, this might be either the nominal voltage (as standard for per-unit calculations), the 'normal voltage' set at the connection point by the NSP, or 90% of the normal voltage (giving a measure of the maximum current requirement consistent with a given power rating over the required voltage range for operation). While there are cogent arguments for any of these alternatives, the working group settled on the nominal voltage as the most straightforward and least ambiguous choice, in keeping with the objective of a simple and efficient connection process. Use of either alternative voltage quantity amounts to a fixed scaling of the corresponding current injection requirement, which is considered to be a suitable matter for negotiation on a case by case basis.

2.2.3 Timing of active power recovery

Implicit in the access standards for asynchronous generators under S5.2.5.5 is that the reactive current injection take priority over the 'active power' component of current injection, in order that the 'maximum continuous current' is utilised to approach the AAS reactive current ratio of 4:1 as nearly as practicable.

However, both the AAS and MAS also stipulate that this reactive current injection be "maintained until *connection point voltage* recovers to between 90% and 110% of *normal voltage*". This creates an inconsistency with subclause S5.2.5.5(n)(2), which stipulates that following a disturbance, the time allowed for recovery of 95% of active power is measured from "clearance of the fault".

In real systems it is common for voltage to remain at a depressed level for a period of time after a fault is cleared. During this period, clause S5.2.5.5 stresses as it should the importance of maintaining capacitive current support to support recovery of network voltage. In other situations (such as lightly loaded networks), voltage may recover to a higher level than desirable upon fault clearance, in which case it is equally important for generating systems to provide inductive current injection to assist in restoring voltage to a safe level. In both cases, the reactive current response may be considered to outweigh the need for rapid restoration of active power. However, when active power restoration time is measured from fault clearance, this may result in very large restoration times being nominated in the performance standard that do not reflect the actual capability of the plant, and depend on the circumstances of specific network operating scenarios in a way more complicated than necessary.

To allow for clearer and more efficient performance standards that reflect plant capability rather than contingent factors, the working group proposed that the 'timing point' for active power recovery take into account the recovery of voltage as well as the clearance of the fault. This is when the generating units would be likely to commence active power recovery in practice, as they no longer need to prioritise reactive current. Accordingly, in subclause (2) the working group proposed replacing the words "after clearance of the fault" with "after clearance of the fault and recovery of positive sequence *voltage* at the *connection point* to settle between 90% and 110% of *normal voltage*". (See 2.2.4 below for the reference to 'positive sequence'.)

Again for reasons of clarity and efficiency, the working group also recommended explicitly allowing the nominated recovery time to vary with the type of fault, making clear that performance standards are not required to nominate a single 'worst case' recovery time that may not be typical for the majority of fault scenarios.

Lastly, it was noted that certain system events may exhibit an abnormal voltage condition in conjunction with a frequency disturbance. In the event of an overfrequency after voltage recovery, it is not desirable for active power to return to its pre-disturbance level as a strict reading of S5.2.5.5 requires. The working group proposed further additional wording for subclause (2) allowing for an alternative active power recovery level in the event of a frequency disturbance.

2.2.4 Definition of 'voltage' during fault conditions

Clause S5.2.5.5(n), as well as numerous other clauses in Schedule 5.2, contains numerous references to 'voltage' as a defined term, but the NER Glossary's definition of 'voltage' – as "the electronic force or electric potential between two points that gives rise to the flow of electricity" – is not useful for practical engineering purposes.

The need to clarify the meaning of 'voltage' is particularly acute in clause S5.2.5.5 as the voltage disturbances it contemplates are transient in nature and often involve phase asymmetry. A specific performance standard under S5.2.5.5 calls for precision when describing how the physical voltages into the network are translated as inputs to a calculation of required (and possibly asymmetrical) reactive current response.

In order to provide for clearer and more efficient performance standards consistent with the NEO when it comes to defining the response to 'voltage', the working group proposed strengthening clause S5.2.5.5(u)(3), which currently states that current injection "may be calculated using phase to phase, phase to ground or sequence components of *voltage*s". It was proposed that "*voltage*s" here be replaced with the more specific wording "root-mean-square amplitudes of measured *voltage*s", to provide for precision in how the magnitude of an AC voltage quantity is defined. It was also proposed that the choice of voltage used in calculations (positive sequence component, phase to ground, etc.) be recorded in the performance standard.

Generally, any reference to 'voltage' in clause S5.2.5.5(n) should be understood as one of the alternatives contemplated in S5.2.5.5(u)(3), selected and recorded in the performance standard as appropriate. This permits, for example, a generating unit to deliver a phase-by-phase current injection in response to individual phase-to-ground voltages, and maintain the injection on each phase until its specific phase voltage recovers to the normal range. An exception is made for the 'timing point' for active power recovery under S5.2.5.5(n)(2); since the implied context is a return to normal steady state operation of the power system, the recovery is most appropriately defined in terms of the positive-sequence three-phase voltage specifically.

2.2.5 Effect of fault current on 'healthy' phases

Related to the definition of 'voltage' in relation to unbalanced faults (see above), the working group considered the question of unbalanced fault response and the need to avoid adverse effects resulting from the injection of large fault currents into 'healthy' phases. A similar issue arises on clearance of both balanced and unbalanced faults where residual fault current may cause excessive voltage rise on a formerly faulted phase. To date these issues have been managed informally in negotiations with NSPs and AEMO, but the working group took the view that codifying these requirements in the S5.2.5.5 MAS would provide greater certainty and consistency for connection applicants and thus contribute to the NEO.

While a MAS should not generally attempt to prescribe the detail of fault response, the working group agreed that with S5.2.5.5 now mandating the injection of substantial fault current, some minimum standards should apply to limit adverse effects on unfaulted phases during single-phase and two-phase faults, as well as to limit adverse effects due to persistent fault current after clearance. It was agreed that the most appropriate place to include this is under the 'General Requirements' in clause S5.2.5.5(u).

With efficiency and certainty for connection applicants in mind, the approach taken by the working group here was not to define and prohibit 'undesirable' current injection, but rather to define and limit the adverse effect resulting from this, namely excessive voltage rise on unfaulted or no-longer-faulted phases.

The proposal from the working group was for a new subclause S5.2.5.5(u)(4), with the existing subclauses retained and renumbered to accommodate the new subclause. This subclause would impose a general requirement for asynchronous generating systems to "not inject current that contributes excessively to voltage rise in any phase" both during an unbalanced fault on 'healthy' phases, and at the clearance of a fault on any phase.

Discussion took place on how 'excessive' voltage rise should be defined, and it was determined that this be interpreted by reference to the overvoltage range for contingency events under clause S5.1a.4. However, it was further recommended that parallel guidelines should govern the interpretation of this rule, for example by ensuring parallel generator connections appropriately share the available 'headroom' for transient voltage rise. (In this regard the term 'disproportionate' as an alternative to 'excessive' in the proposed rule was suggested but not favoured by the working group.)

2.2.6 Other matters

Certain other matters adjacent to the stipulations in clause S5.2.5.5(n) were considered by the technical working group but are considered out of scope for this proposed rule change, or deferred for action in a different forum.

- There is some technical ambiguity around the application of the various S5.2 clauses at voltage levels that are outside the 90-110% of normal voltage for continuous operation, but have not yet reached the thresholds for a prescribed low or high voltage response under S5.2.5.5. In this range the response is regulated not by S5.2.5.5 but instead by the requirement for continuous uninterrupted operation (CUO) under S5.2.5.4. While it may be desirable for generating systems to modify their power output in this region of operation there is no applicable standard for how they should do so, nor is it entirely clear whether generating systems are prevented from changing their power output level (as this turns on the interpretation of the term 'substantial'). These matters are recommended for consideration in a future review of access standards under S5.2.5.4.
- Grid-forming converters that are programmed to behave as virtual synchronous generators (VSG) can be expected to respond to system disturbances in much the same way as a machine, only with a hard limitation on maximum fault current. Under the current NER a VSG is still regarded as an asynchronous generating unit. A future review may consider whether it is appropriate to classify VSGs as synchronous generating units for NER S5.2.5.5 purposes, or whether a third category of generating unit should be defined for this purpose. However, the formulation of an appropriate fault current MAS for VSGs was considered outside the scope of the present exercise. As an interim measure it has been suggested that the definition of 'synchronous generating unit' be amended to provide AEMO the flexibility to classify any generating unit as a synchronous generating unit for the purpose of NER S5.2.5.5.

2.3 Proposed change: level of reactive current injection

The proposed changes to the wording of subclauses (1)(i) and (1)(ii) are given below. There are no other changes proposed to subclause (1) other than in these subordinate clauses.

> (1) for the types of fault described in subparagraph (k)(2), and to assist the maintenance of *power system voltages* during the fault, have *facilities* capable of supplying to or absorbing from the *network*:
>
> > (i) capacitive reactive current in addition to its pre-disturbance level of at least a nominated percentage (to be not less than zero) of the *maximum continuous current* of the *generating system* including all operating *asynchronous generating units* (in the absence of a disturbance) for each 1% reduction of *voltage* at the *connection point* (as qualified by subclause (u)) below the relevant threshold at which a reactive current response must commence, as identified in paragraph (o)(1), with the *performance standards* to record the required response agreed with *AEMO* and the *Network Service Provider*; and

(ii) inductive reactive current in addition to its pre-disturbance level of at least a nominated percentage (to be not less than zero) of the *maximum continuous current* of the *generating system* including all operating *asynchronous generating units* (in the absence of a disturbance) for each 1% increase of *voltage* at the *connection point* (as qualified by subclause (u)) above the relevant threshold at which a reactive current response must commence, as identified in paragraph (o)(1), with the *performance standards* to record the required response agreed with *AEMO* and the *Network Service Provider*,

For comment on the change to "a nominated percentage (to be not less than zero)" please refer to 2.2.1 above.

For comment on the definition of 'maximum continuous current' please refer to 2.2.2 above and to the consequential change at 4.3 below.

For comment on the insertion "(as qualified by subclause (u))" please refer to 2.2.4 above and to the consequential change at 4.1 below.

For comment on the change from "range" to "threshold" at which a reactive response must commence, please refer to 3.2.1 below, and to the change to clause S5.2.5.5(o) at 3.3 below.

It is contemplated that parallel guidelines for application of NER technical requirements, outside the scope of the present review, may provide additional guidance on suitable current injection levels below the AAS where meeting the AAS is not feasible.

2.4 Proposed change: recovery of active power on fault clearance

The proposed changes to the wording of subclause (2) are given below.

(2) return to at least 95% of:

i. the pre-fault *active power* output, or

ii. during a frequency disturbance, a level of *active power* output consistent with the *generating system*'s *performance standard* under clause S5.2.5.11,

after clearance of the fault and recovery of positive sequence *voltage* at the *connection point* to settle between 90% and 110% of *normal voltage* (or such other range agreed with the *Network Service Provider* and *AEMO*), within a period of time agreed by the *Connection Applicant*, *AEMO* and the *Network Service Provider* and recorded in the *performance standard* under this clause S5.2.5.5. This period of time may differ according to the type of fault, in which case the differing values are to be recorded as such.

For further comment on these changes, please refer to 2.2.3 above.

3 Commencement and settling of response: Paragraph S5.2.5.5(o)

3.1 Existing MAS wording

The existing paragraph S5.2.5.5(o) in the NER reads as follows.

> For the purpose of paragraph (n):
>
> (1) the *generating system* must commence a response when the *voltage* is in an under-voltage range of 80% to 90% or an over-voltage range of 110% to 120% of *normal voltage*. These ranges may be varied with the agreement of the *Network Service Provider* and *AEMO* (provided the magnitude of the range between the upper and lower bounds remains at Δ10%);
>
> (2) where *AEMO* and the *Network Service Provider* require the *generating system* to sustain a response duration of 2 seconds or less, the reactive current response must have a *rise time* of no greater than 40 milliseconds and a *settling time* of no greater than 70 milliseconds and must be *adequately damped*; and
>
> (3) where *AEMO* and the *Network Service Provider* require the generating system to sustain a response duration of greater than 2 seconds, the reactive current *rise time* and *settling time* must be as soon as practicable and must be *adequately damped*.

In brief, the salient points in this clause are as follows.

- The range for commencing the automatic reactive current injection must be between 80% and 90% of normal voltage for low voltage events, and 110% to 120% of normal voltage for high voltage events. However, these endpoints can be varied when the NSP and AEMO agrees, as long as they continue to enclose a 10% range.
- By implication, the calculation of the required current injection under paragraph (n) will refer to a specific value of voltage within the ranges for undervoltage and overvoltage respectively, but the specific value is left undetermined by this clause.
- The reactive current response must have a rise time no greater than 40ms, and a settling time no greater than 70ms, unless the event is in a category where a response duration greater than 2 seconds is required. In the latter case the rise and settling time must be 'as soon as practicable'.
- The reactive current response in all cases must be adequately damped (a defined term).

3.2 Issues considered by the working group

Preliminary discussions within the technical working group and the wider CRI steering group identified the following matters that in stakeholders' experience lead to undue barriers to connection, potential adverse consequences for the power system, or ambiguity complicating the negotiation of performance standards.

3.2.1 Threshold for commencement of response

When the stronger requirements for fault current response from generators were introduced in 2018, it was recognised that generating units do not respond directly to voltage at the connection point. The approach taken in the rule determination [3] was to avoid specifying any particular value of connection point voltage where a response must commence, and instead state that the response must commence when voltage is at some arbitrary point within a defined range.

While this approach correctly reflects that the specific connection point voltage at which an autonomous low or high voltage response commences will depend on the specific operating condition, it introduces significant ambiguity and confusion when it comes to calculating the required reactive current injection for a fault with a specific retained voltage at the connection point. The existing clause S5.2.5.5(n) stipulates an injection of 2% "for each 1% reduction of *voltage* at the *connection point* below the relevant range", which is itself a range of voltages, not a single voltage number.

The working group proposed, for clarity and efficiency in establishing compliance with performance standards, an alternative approach to the variable activation voltage issue. It is proposed that the proponent and the NSP agree and document in the GPS a specific low voltage threshold V_L and high voltage threshold V_H, outside which a reactive current response can be relied on to occur. (Thus, these are effectively 'worst case' activation voltages at the connection point.) The required level of current injection, for a per-unit voltage V observed at the connection point, is $K_L \times (V_L - V)$ or $K_H \times (V_H - V)$, where K_L and K_H are the slope parameters for low and high voltage response respectively. These required levels would operate as lower bounds, rather than as target values for the reactive current injection.

To give effect to this alternative approach, new wording for subclause S5.2.5.5(o)(1) is proposed as in section 3.3 below. This new wording retains the principle that the thresholds must be placed within the range 80% to 90% for low voltage, and 110% to 120% for high voltage, unless the NSP and AEMO agree to thresholds outside these ranges. To provide further clarity in the performance standard, it is also proposed to state the threshold at the generating unit level, which will normally differ from the 'worst case' threshold at the connection point and will usually correspond to a literal control system setting.

The other consequential change is in S5.2.5.5(n) subclause (1), where the term 'range' is replaced with 'threshold', thereby providing for an explicit calculation of the required current injection.

3.2.2 Use of rise time under transient fault conditions

Under the 2018 changes to NER S5.2.5.5 (and in the previous advice to ESCOSA in 2017), a new requirement was introduced to limit the maximum rise time for the reactive current response to faults – in the case of the MAS to 80 milliseconds. The purpose of this requirement is to ensure correct coordination of protection relays sensing fault current, as when the current response is produced by a synchronous machine.

This requirement has posed difficulties for connections owing to the practical difficulty of measuring rise time in simulation results, in particular EMT time-domain simulation results for unbalanced faults. The rise time can also depend on network conditions in ways that are beyond the control of the generating system.

The working group agreed to maintain the principle of ensuring an adequate rise time for fault current response to assure the correct operation of network protection. But to resolve the practical difficulties, it was proposed that in place of a blanket 80 millisecond limit, the maximum rise time be linked to the fastest clearing time for primary protection in the relevant network. Alternative wording for subclause S5.2.5.5(o)(2) is proposed to give effect to this.

The working group noted the importance of considering the *fastest applicable* protection clearing time: that is, the lesser of the expected actual clearing time of primary protection systems near the connection point, and the clearing time prescribed for the primary protection in table S5.1a.2 of the NER system standards. If actual rise time were to exceed either of these values, it would imply the desired level of fault current is not practically being provided within the relevant operating time and coordination based on this level of current may not reliably be achieved. For this reason, the concept of fastest applicable clearing time was preferred to the simpler alternative of basing the MAS on the S5.1a.2 values alone.

With this change, it is no longer necessary to distinguish faults with longer or shorter response durations as in the current MAS, as the relevant faults have correspondingly longer or shorter primary protection times.

The proposed wording also maintains the requirement for the fault current response to be damped; however, a deliberate choice was made to remove the reference to the NER defined term 'adequately damped', due to the impracticality of applying the NER adequate-damping criteria over the typical duration of a fault. The substituted requirement for the response to be 'damped' conveys that any oscillatory aspect of the response must be seen to decay in time rather than persist, while acknowledging that precise quantification of the rate of decay may not be possible. The alternative terminology 'positively damped' was also considered by the working group but ultimately discounted, as there is no effective distinction in ordinary language between 'damped' and 'positively damped'.

3.2.3 Method of determination for settling of fault response

The post-2018 S5.2.5.5 MAS imposed a requirement for the maximum settling time of fault current response. The purpose of this requirement was to ensure a suitable level of fault current could be detected and maintained during the occurrence of a fault, and would be reliably controlled so that, for example, it does not oscillate due to poor control performance during fault conditions.

However, the use of a settling time criterion to establish a well-defined fault current response has significant difficulties in practice, again owing to the difficulty of measuring and quantifying settling times correctly based on EMT time-domain simulation results, especially for unbalanced faults and faults that undergo large changes in instantaneous phase angles. The working group noted that voltage during a fault is never a 'clean' signal and 'settling time' – relying as it does on well quantified magnitudes, extents and error bands for signals, particularly for shallow faults where the relevant extents are very small even under ideal conditions – may not even have practical meaning over the typical duration of a fault.

The working group proposed replacing the settling time criterion with an equivalent criterion by which settling of the fault current above a prescribed level could be asserted. This is based on requiring that from a period of 40 milliseconds after onset of the disturbance, the reactive current injection is reliably above or below the pre-disturbance level (according to whether it is a low or high voltage disturbance). The choice of 40 milliseconds was made to ensure appropriate coordination with the revised rise time criterion as above: it is safely shorter than the expected clearing time of actual protection systems, while not so short as to be beyond the capability of state-of-the-art inverter controls to generate a response in time. (It is likely for this reason that 40 milliseconds was also chosen as the maximum rise time in the existing S5.2.5.5(o) standard.)

The working group considered the alternative of maintaining a reference to settling time but setting a maximum allowable value that could apply to all suitable technology across all operating conditions. The value proposed under this alternative was one commensurate with the expected protection clearing time under circuit-breaker-fail conditions close to the connection point. Given the rarity of such conditions, the working group saw no particular benefit to including such a large hypothetical settling time in the MAS, relative to the preferred position of dropping the reference entirely.

The working group noted that even in the absence of any reference to settling time, maintaining the requirement for damping (notwithstanding the dropping of the more precise 'adequately damped' criterion) would continue to address the need for the fault current injection to be properly controlled and without undue oscillatory behaviour. As noted in the previous section, a requirement for damping even where not precisely quantified (due to the impracticality of doing so, similar to the issue with settling time) mandates that the response does not oscillate continuously in the absence of a continuous oscillation in the grid voltage.

3.3 Proposed change: thresholds for commencement of response

The proposed changes to subclause S5.2.5.5(o)(1) are detailed below.

> For the purpose of paragraph (n):
>
> (1) the *generating system* and its generating units must commence a response when the corresponding *voltage* falls below a nominated under-voltage threshold in the range of 80% to 90%, or rises above a nominated over-voltage threshold in the range of 110% to 120%, of:
>
> > i. in relation to the *connection point*, *normal voltage*; or
> >
> > ii. in relation to the terminals of a *generating unit*, *nominal voltage*.
>
> These voltage thresholds may be placed outside the ranges above with the agreement of the *Network Service Provider* and *AEMO*. The nominated under-voltage and over-voltage thresholds must be recorded in the *performance standard* under this clause S5.2.5.5 and may take different values at the *connection point* and at the terminals of a *generating unit*;

For further comment on these changes, refer to 3.2.1 above. The working group proposed that parallel guidelines, not within the scope of this review, could clarify the meaning of the threshold and that the current injection required under subclause (n) is a minimum level rather than a precise required value.

3.4 Proposed change: reactive current rise time

The proposed new subclause S5.2.5.5(o)(2), partially replacing existing subclauses S5.2.5.5(o)(2) and S5.2.5.5(o)(3), is detailed below.

> (2) the reactive current response at the *connection point* must have a *rise time* of no greater than the fastest applicable primary protection clearance time as determined by the *Network Service Provider*, and must be damped;

For further comment on this changed subclause, refer to 3.2.2 above.

3.5 Proposed change: settling of reactive current during disturbance

The proposed additional subclauses S5.2.5.5(o)(3) and S5.2.5.5(o)(4) – in part replacing existing subclauses S5.2.5.5(o)(2) and S5.2.5.5(o)(3) – are detailed below.

> (3) the reactive current response of the *generating unit* to under-voltage must not be less than the pre-disturbance level of reactive current from 40 milliseconds after the corresponding *voltage* drops below the under-voltage threshold level specified in S5.2.5.5(o)(1); and
>
> (4) the reactive current response of the *generating unit* to over-voltage must not be greater than the pre-disturbance level of reactive current from 40 milliseconds after the corresponding *voltage* rises above the over-voltage threshold level specified in S5.2.5.5(o)(1).

For further comment on these added subclauses, refer to 3.2.3 above. The specific wording adopted is intended to also apply in cases where the level of additional reactive current injection is negotiated as zero.

4 Consequential changes: Paragraph S5.2.5.5(u) and Glossary

4.1 Calculation of reactive current contribution

The proposed addition to subclause S5.2.5.5(u)(3) is given below.

> (3) the reactive current contribution required may be calculated using phase to phase, phase to ground or sequence components, as appropriate, of the root-mean-square amplitudes of measured *voltages*. The choice of *voltage* used for the calculation purposes must be recorded in the *performance standard*. The ratio of the negative sequence to positive sequence components of the reactive current contribution must be agreed with *AEMO* and the *Network Service Provider* for the types of disturbances listed in this clause S5.2.5.5; and

For further comment on these additions to clarify the definition of 'voltage', please refer to 2.2.4 above.

4.2 Proposed addition: prohibition on excessive voltage rise

The proposed new subclause S5.2.5.5(u)(4) is given below. The existing subclauses under S5.2.5.5(u) would be renumbered to accommodate this insertion.

> (4) to limit the risk to power system security, the generating system must not inject current that contributes excessively to voltage rise in any phase (considering the range for contingency events under clause S5.1a.4):
>
> i. on un-faulted phases during an unbalanced fault; or
>
> ii. on any network element upon clearance of the fault.

For further comment on this addition to codify the requirement not to produce excessive voltage rise, please refer to 2.2.5 above. The working group proposed that parallel guidelines, not within the scope of this review, could offer additional guidance on the meaning of 'excessive' contribution to voltage rise.

4.3 Proposed definition of 'maximum continuous current'

The proposed definition of 'maximum continuous current' to be added to the NER Glossary is given below.

> ***maximum continuous current***
>
> (1) In relation to a *generating system*, the amount of current calculated to correspond at the *connection point* to the largest *apparent power* required by the *generating system*'s *performance standard* under clause S5.2.5.1 (but no greater than required by the *automatic access standard* under clause S5.2.5.1), and with the *connection point* at its *nominal voltage*.
>
> (2) In relation to a *generating unit*, the maximum magnitude of current that the *generating unit* can continuously deliver at its terminals, calculated by reference to its *nameplate rating*, its *apparent power* rating, and the permitted range of terminal *voltage* for continuous operation.

For further comment on this definition of 'maximum continuous current' please refer to 2.2.2 above. This definition is used in the revised subclause S5.2.5.5(n)(1) which can be found at 2.3 above.

5 References

[1] Australian Energy Market Commission (AEMC). *National Electricity Rules*, version 181, May 2022.

[2] Australian Energy Market Commission (AEMC). *Final Rule Determination – National Electricity Amendment (Technical Standards for Wind Generation and other Generator Connections) Rule 2007*, March 2007.

[3] Australian Energy Market Commission (AEMC). *Final Rule Determination – National Electricity Amendment (Generator Technical Performance Standards) Rule 2018*, September 2018.

[4] Australian Energy Market Operator (AEMO). *Recommended Technical Standards for Generator Licensing in South Australia: Advice To ESCOSA*. March 2017.

[5] National Electricity Code Administrator (NECA). *National Electricity Code*, version 1 amendment 8.3, 2004.

[6] Essential Services Commission of South Australia (ESCOSA). *Wind Generation Licensing: Statement of Principles.* September 2005.

[7] Essential Services Commission of South Australia (ESCOSA). *Inquiry into the licensing arrangements for generators in South Australia: 2017 Model Licence Conditions for New Generators.* September 2017.

[8] A.B. Morton. *Generator Fault Current Injection: Are system operators asking for the right thing?* Paper C4-119, *CIGRE Session 2020*, Paris, August 2020.

[9] GE Renewable Energy, Goldwind Australia, Siemens Gamesa Renewable Energy and Vestas Australia. *National Electricity Rule Change Proposal: Reactive current response to disturbances (clause S5.2.5.5)*, March 2021.

[10] Australian Energy Market Commission (AEMC). *Consultation Paper: Efficient Reactive Current Access Standards for Inverter-Based Resources*. 26 May 2022.