
NATIONAL ELECTRICITY RULE CHANGE PROPOSAL

Reactive current response to disturbances (clause S5.2.5.5)

Proponents:

GE International Inc



Goldwind Australia



Siemens Gamesa Renewable Energy



Vestas Australia



Table of Contents

1. Summary.....	2
2. Background.....	3
2.1. New generator connections	3
2.2. Technical considerations for large generation projects	3
2.3. Generator performance standards.....	4
2.4. Current minimum access standard for reactive current response during disturbances	5
2.5. Pending rule change - Maximum reactive current during a fault.....	7
3. Issues with current requirements - technical considerations	8
3.1. Introduction	8
3.2. Attenuation of reactive current contribution at connection point	8
3.3. Potential for generating system instability.....	9
3.4. Rise and settling time requirements are onerous	9
3.5. Active current contribution not explicitly required in the Rules	10
3.6. Unclear NER terms and assessment methodologies	10
3.7. Control of multiple generating systems in close electrical proximity	10
3.8. Definition and interpretation of CUO	11
4. Impacts of current rules on achievement of the NEO	13
4.1. Unnecessary costs will deter efficient investment.....	13
4.2. Inconsistency with the AEMC's principles for setting minimum access standards	14
4.3. Inconsistency with the AEMC's proposed system strength reforms.....	16
4.4. Potential to increase system security risks.....	16
5. Proposed changes and rationale	18
5.1. Introduction	18
5.2. Proposed changes and rationale	19
5.3. Alternatives considered	21
6. Costs and benefits and how the proposal contributes to the NEO	22
6.1. Costs and benefits of the proposal.....	22
6.2. How the proposed rule promotes the NEO.....	22
7. Contact details.....	24

1. Summary

This rule change request proposes amendments to the requirements of S5.2.5.5 of the National Electricity Rules (Rules or NER) to enable the more efficient connection of renewable generators and avoid unnecessary costs, project uncertainty and resultant delays that are caused by the current requirements.

This proposal relates to the performance standard for reactive current response during disturbances under S5.2.5.5 and the associated definitions. Amendments are proposed only in relation to certain aspects of the minimum access standard for asynchronous generating systems. No change is proposed for the automatic access standards for asynchronous generation or the standards applying to synchronous generating systems.

The current minimum access standard for reactive current response is problematic for certain types of generating systems with large internal networks. The current rules require investment in additional equipment to provide dynamic reactive response at the point of connection in order to demonstrate compliance with the access standard, irrespective of the benefit or need to the system. This can increase costs or deter efficient investment without necessarily delivering any system security or economic benefits.

This proposal is made jointly by four of the largest wind turbine manufacturers in Australia, who each have first-hand experience of the additional costs, project uncertainty and resultant delays caused by the current rules.

This proposal has also been developed with assistance from engineering and regulatory specialists to develop proposed amendments that address the identified issues while remaining consistent with the broader generator performance standards framework and the principles developed by the AEMC when it amended the standards in 2018. The proponents have also consulted on a draft version of this proposal with AEMO, the Clean Energy Council and some leading Australian renewable energy businesses and network service providers.

The proposed amendments will promote the National Electricity Objective by leading to more efficient investment in generation systems. The amendments will avoid unnecessary and inefficient investment in additional equipment, and remove barriers to the connection of larger, more efficient generating systems that risk being made uneconomic or uncompetitive under the current rules. These benefits will lead to lower generation costs and increased investment in new renewable generation, which will benefit consumers through lower prices and improved reliability.

The proposal will also increase system security and improve regulatory certainty by clarifying how the current minimum access standard and related definitions should apply. The proposal does not involve any changes to the automatic access standard – it simply provides a broader range to negotiate an access standard that suits the specific circumstances of the connection. AEMO and NSPs will continue to be able to insist that generators meet the current automatic access standard where necessary to protect system security.

2. Background

2.1. New generator connections

The Australian NEM is evolving rapidly with the development of new renewable energy projects consisting of wind, solar and battery energy storage technologies. The nature of the power grid, its planning and operations are being influenced by these newer technologies. The projects themselves are increasing in size as developers look to benefit from economies of scale and maximise available network capacity at the connection point. See Figure 1 for the total MWs corresponding to the projects currently under development.

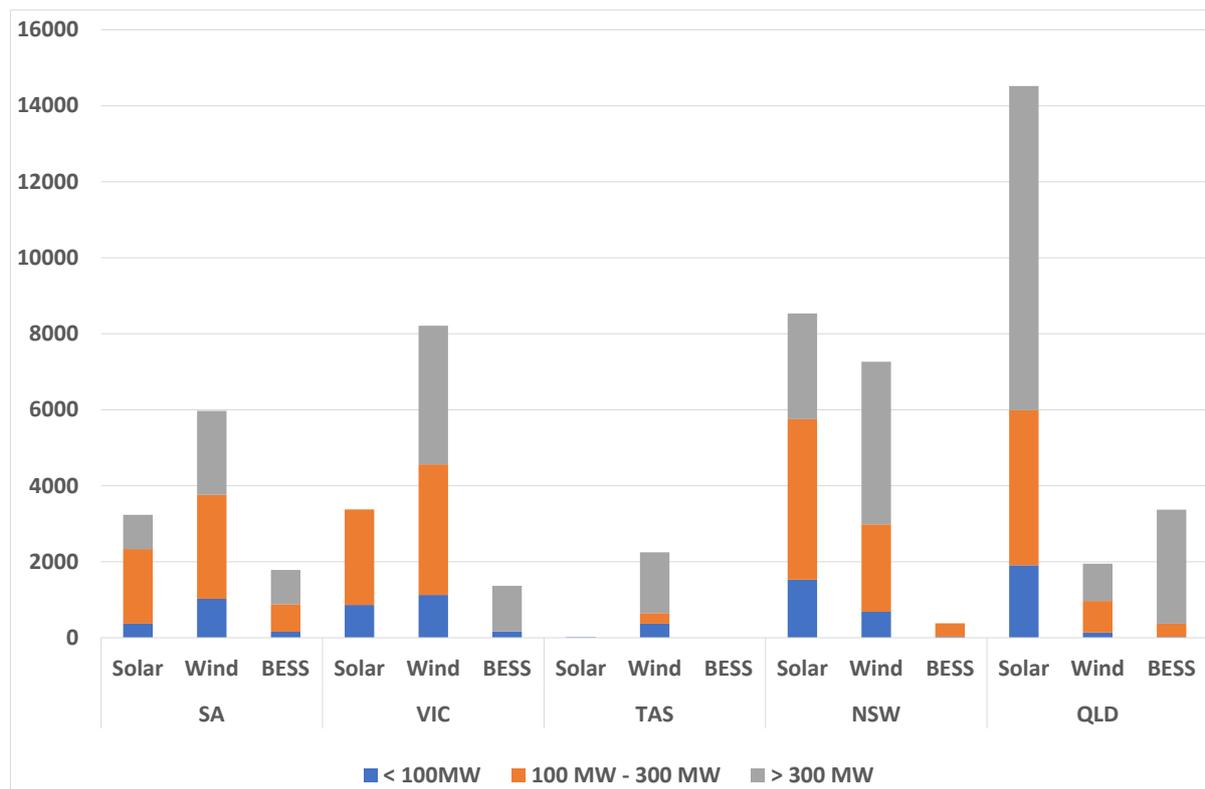


Figure 1: New generator connections in NEM, by size¹

2.2. Technical considerations for large generation projects

2.2.1. Physics and electrical characteristics of large renewable energy projects

As depicted in Section 2.1, large renewable energy projects have become increasingly common in the Australian NEM. Such projects typically have a large electrical balance of plant component that includes multistage grid transformers, long internal transmission lines and a medium voltage reticulation network with multiple collector circuits.

These large renewable energy projects require sufficient network capacity to accommodate the generation export and many connect to the extra high voltage (EHV) transmission network (usually

¹ derived from AEMO, NEM Generation Information, published November 2020

275 kV or higher), where historically thermal and voltage constraints are less likely. The EHV network is traditionally stronger than lower voltages given that it is designed for the bulk power transfer, as such it is normally more stable when transferring high volumes of power.

As described in this proposal, these high voltage connection points and all the internal electrical balance of plant (BoP) results means that these types of projects have the following characteristics:

- (i) Large internal impedance between the connection point and generating unit terminals (in some cases greater than 0.4 – 0.5 p.u. when measured on plant MVA base);
- (ii) Wide variation in active power outputs from individual generating units, particularly for large wind farms, due to the large geographical spread;
- (iii) A diverse internal voltage profile, with individual generating units operating at vastly different voltages for the similar active and reactive power dispatch; and
- (iv) Significant internal wind farm losses, particularly in reactive power.

2.3. Generator performance standards

All intending participants that seek to connect to the power system must do so under the connections framework set out in chapter 5 of the National Electricity Rules (Rules).

Part of the connections process involves negotiating the level of access and demonstrating compliance with the access standards agreed for the connection, thus setting the generator performance standards - which must comply with the requirements set out in Schedule 5.2 of the Rules. These standards are negotiated by reference to automatic, minimum and negotiated access standards that are set out in Schedule 5.2 for a number of specific technical requirements.

The current generator performance standards were introduced by the AEMC in October 2018 in the Generator Technical Performance Standards Rule 2018 (GTPS rule change).²

This rule was made following a rule change request from AEMO. The objectives of the GTPS rule change were described by the AEMC as:³

changing the way that levels of performance are negotiated for equipment connecting to the power system, and improving the technical requirements for new generating systems. The changes enhance the rules to reflect the changing needs of the power system with the objective of maintaining power system security and quality of power supply at the lowest cost to consumers.

The GTPS rule change made significant changes to many of the requirements of Schedule 5.2, including the provisions related to reactive current response during disturbances that are the subject of this proposal.

² See AEMC, Generator Technical Performance Standards Rule 2018, Final Determination, https://www.aemc.gov.au/sites/default/files/2018-09/Final%20Determination_0.pdf

³ GTPS rule change final determination, pi.

The Commission concluded that the previous provisions related to reactive current response:⁴

are appropriate for connecting synchronous generating systems that provide a reactive current response during disturbances with characteristics that are inherent to the electro-mechanical nature of the machines. However, current arrangements are not appropriate for connecting asynchronous generating systems that do not provide an inherent response. Without clear guidance in the NER on how reactive current response is coded into the control equipment, there is a risk that asynchronous generating systems may not provide sufficient reactive current response during disturbances to support the security of the power system.

Prior to the GTPS rule change, there was an automatic access standard for reactive current response, but no minimum standard. Prescriptive requirements for a new minimum access standard for asynchronous generating systems were introduced to replicate the traditional fault behaviour of synchronous machines, and the role that behaviour plays in supporting the power system through fault conditions.

The current minimum access standard that is the subject of this proposal was first introduced in the GTPS rule change.

2.4. Current minimum access standard for reactive current response during disturbances

2.4.1. Summary of current requirements

The current minimum requirements related to reactive current response during disturbances for asynchronous generating systems are in sub-clause S5.2.5.5(n)(1) and sub-clause S5.2.5.5(o) of the Rules⁵. General requirements in sub-clause S5.2.5.5(u) and the defined terms in Chapter 10 – Glossary are used to develop and negotiate the related performance standard for generating systems consisting of asynchronous generating units. The critical requirements assessed during a project's due diligence and subject of negotiations between the proponent and the NSP are:

1. Capacitive reactive current is in addition to its pre-disturbance level of at least 2% of the maximum continuous current of the generating system for each 1% reduction of voltage at the connection point below the relevant range in which a reactive current response must commence.
2. Inductive reactive current is in addition to its pre-disturbance level of at least 2% of the maximum continuous current of the generating system for each 1% increase of voltage at the connection point above the relevant range in which a reactive current response must commence.
3. Reactive current response is to commence 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.

⁴ GTPS rule change final determination, pxii.

⁵ AEMC, NER v156, published 17 Dec 2020.

4. 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.
5. Reactive current contribution may be limited to the maximum continuous current of a generating system, including its operating asynchronous generating units.
6. Reactive current contribution and voltage deviation described may be measured at a location other than the connection point (including within the relevant generating system) where agreed with AEMO and the Network Service Provider, in which case the level of injection and absorption will be assessed at that agreed location.
7. The generating system is to maintain Continuous Uninterrupted Operation (CUO) during the disturbance contributing active and reactive current as required by its performance standards established under clause S5.2.5.5.

2.4.2. Location at which compliance is assessed

Compliance for asynchronous generation systems for certain characteristics has historically been assessed at the connection point. However, dynamic response was always appropriately assessed at the terminals of the units, this is consistent with synchronous generators.

The original technical rules in place prior to the GTPS rule change were based on several principles adopted by the Technical Standards Reference Group that was led by NEMMCO. Principle three stated “Terminology used in the technical standards should support their appropriate application.” The relevant parts of the principle state:

“Most of the technical standards are applied to generating units, but for wind farms, which are comprised of numerous small units there may be some scope to define performance requirements in terms of generating systems, or the effect of the plant as measured at the connection point to the power system.

Depending on the way the plant is controlled and the configuration of its connection, performance can be considered in some cases a function of the generating system, and in others a characteristic of the generating unit. The terminology used in the technical standards should therefore be specific, and support their appropriate application, allowing flexibility to define performance in terms of generating systems, and take effect at the connection point where this is appropriate.”

With the GTPS rule change introduced in 2018, the vast majority of the NER Schedule S5.2 technical requirements in the NEM have lifted the assessment of project grid compliance to the connection point. An unintended consequence, particularly in relation to the requirements for reactive current response during faults is that the response occurs dynamically at the terminals of units and is proportional to the voltage seen by that unit, yet the requirement is expecting a fixed amount of reactive current injection at an arbitrary connection point dependent on the size and distance of the project from the shared network.

The issue of where compliance with the reactive current response requirements should be measured was considered by the AEMC as part of the GTPS rule change.

AEMO's rule change request proposed that compliance should be measured at the generating unit terminals. In its draft determination and draft rule, the AEMC agreed with this proposal and provided that compliance is to be measured "at the terminals of a generating unit".

However, in the final determination the AEMC amended its approach to instead require compliance to be measured at the connection point. The AEMC considered that measurement at the connection point was more consistent with the general approach taken across other access standards and provides greater certainty for AEMO and NSPs.⁶

The AEMC final determination changed the location of where compliance is measured but did not consider the full range of technical implications. This late change to the requirements had material impacts, particularly large generators with large internal networks that result in the generating unit terminals being a long distance from the connection point. These impacts do not appear to have been foreseen by the AEMC at the time of making this change.

2.5. Pending rule change - Maximum reactive current during a fault

In April 2019, Renewable Energy Revolution Pty Ltd submitted a rule change to the AEMC to amend clause S5.2.5.5(u) of the Rules⁷ that relate to the maximum reactive current contribution during power system disturbances. The proponent in its rule change request has stated that the current requirements while suitable for connection points with high X/R characteristics, do not adequately consider the need for supplying active current and compensating for the considerable voltage drop across the resistive network impedance in a low X/R grid. This rule change proposes for active and reactive current contributions during disturbances based on the applicable local grid X/R characteristics.

There is some overlap between the issues in our proposed rule change and the rule change request from Renewable Energy Revolution, and the AEMC may wish to consolidate the two requests and consult on them together. However, the issues raised in our proposal would not be addressed by making the rule change proposed by Renewable Energy Revolution.

We recognise the importance of active current in low X/R grids and have detailed this as an issue Section 3.5. Our proposed rule changes in Section 5 will, if implemented, reduce the reactive current injection requirements in the minimum access standard. This in turn will allow inverters of solar and wind farms to be tuned to contribute a higher active current, should the local grid characteristics so require. Our proposed rule change may be a more comprehensive response to the issues raised by Renewable Energy Revolution.

⁶ GTPS rule change final determination, pp162-165.

⁷ <https://www.aemc.gov.au/rule-changes/maximum-reactive-current-during-fault>

3. Issues with current requirements - technical considerations

3.1. Introduction

As described in Section 2.4.1, the Rules require generating systems to support the connection point voltage both during and after a fault or disturbance in the connecting network. Generating systems must provide capacitive reactive current injection up to the combined rating of the individual generating units for a sufficiently deep fault, and in proportion to the reduction in voltage for shallower faults.

Projects assessed against current requirements face challenges in both reaching agreement on the performance standards and then demonstrating compliance. Below is a discussion on the key challenges, underlying causes and the resulting outcomes.

Due to commercial confidentiality issues, this section does not contain specific examples of the impacts of the current rules on recent or current generation projects. However, the proponents would be happy to meet individually with AEMC staff to provide examples of the impacts on specific projects on a confidential basis.

3.2. Attenuation of reactive current contribution at connection point

Most modern, commercially available inverter based generation technologies have low voltage ride through (LVRT) logic that is triggered when the voltage at the generating unit terminals drop below a threshold. The amount of current injection during the fault is determined by the specific LVRT logic. The reactive current injection is typically determined by converter gains or *k-factors* that are a function of the current injected for per unit drop in terminal voltage or the residual voltage at the generating unit terminals. During the fault duration and for a short period after fault clearance, the voltage control is performed locally and independent of the Power Plant Controller or connection point measurements.

In case of projects with significant internal plant impedance, two issues that are directly tied to the physics of the power system are observed:

- (i) The generating system impedance (Z), X/R ratio of the generating system impedance and any auxiliary reactive plant (e.g.: capacitor banks) causes the current profile (magnitude and phase angle) as observed at the PoC to be different from the terminals. For example, a k -factor of 6% at the generating unit terminals may result in a much lower current contribution at the connection point, let us say 2% or lower.
- (ii) Generating units, based on their electrical distance from the PoC and their pre-disturbance voltages may see faults of differing severity and at different times. This variation may cause significantly different response from the individual generating units for the same external fault. Some shallow faults at the connection point may not cause the generating unit terminal voltages to drop below the LVRT threshold and as a result may not provide adequate current injection.

To mitigate the above issues, projects have two primary options. The first option is to increase the k -factors of the generating units such that a higher contribution is available at the electrically distant connection point. The second option is for the project to install additional dynamic reactive devices

close to the connection point to augment the reactive support from the generating units. Both options carry risks in terms of impact on wider system security and generating system stability, as well as possibly increasing costs and project complexity.

3.3. Potential for generating system instability

To mitigate the attenuation in reactive current injected at the PoC, the k-factors at the unit terminals may be increased. However, in complex and large renewable energy plants this may cause the unit voltages to rise too close to normal operating levels even when the fault at the connection point has not been cleared. This has the potential to cause instability due to hunting or retriggering of the LVRT control logic and furthermore could cause issues with the generating unit's ability to detect fault clearance locally by sensing the restoration of voltages⁸.

3.4. Rise and settling time requirements are onerous

The current Rules require the generating system's current injection at the connection point in response to fault conditions to be fast enough to meet a rise time of less than 40 ms and a settling time of less than 70 ms. In practice, projects face the following difficulties in meeting the requirements.

The response times are very dependent on the type of fault (balanced or unbalanced), its severity, the X/R ratio of the fault impedance and the pre-disturbance operating scenario. In particular, the time constants of the passive reactive components can introduce a delay of 1-2 cycles (20 – 40 ms) for shallow faults at the connection point. It may not be feasible to tune the responses to satisfy the requirements in all possible operating and fault conditions.

The variance in PoC voltage and the terminal voltage profiles of the individual WTG's will result in the generating units sensing faults of differing severity and at different times – all of which contribute to a slower response time.

In some DFIG technologies, there is a large DC component in the fault current, which results in a large swing in the calculated positive sequence reactive current. It takes at least a full cycle (20ms) to eliminate the swing, hence causing more than 20ms delay in the rise time and settling time. The complexity of compliance assessment is exacerbated with the lack of clear definition for reactive current and the method by which it is calculated.

Furthermore, a fixed figure for rise and settling times does not consider the physical differences that occur across projects. Such a technical requirement is best suited as a factory type test not as a fixed requirement across all network locations as it may undermine good control tuning necessary to suit local conditions.

⁸ A. Morton, CIGRE C4-119 'Generator Fault Current Injection: Are system operators asking for the right thing?', published CIGRE Paris Session 2020.

3.5. Active current contribution not explicitly required in the Rules

The NER requirements call for a capacitive or inductive reactive current contribution during a fault in addition to pre-disturbance values but do not specify the active current response required during the fault. This incentivises generators to tune their fault response to maximise reactive current but may not be the most appropriate control depending on the characteristics of the generating system itself as well as the connecting network. AEMO in its 2018 clarification document⁹ has recognised the importance of maintaining active current at a sufficient level so as to prevent tripping of nearby generators, potential for cascading outages and large magnitude frequency disturbances due to the active power deficit.

However, there is no specific provision in the Rules to address requirements in connections where active current needs priority over reactive current. Compliance to current version of the Rules would achieve the exact opposite in such connections. Active current requirement may be considered on case to case basis only depending on the generating system and connecting network characteristics.

3.6. Unclear NER terms and assessment methodologies

Two critical terms are currently undefined in the NER Chapter 10 – reactive current and maximum continuous current. These terms and more specifically the methodologies for calculating them are not commonly agreed and are subject to interpretation. It is standard practice to perform the reactive current assessment using the positive sequence reactive current calculated by dividing reactive power by the positive sequence voltage. However, an alternative approach is to calculate it according to IEC Standard 61400-21-2008, where the negative sequence component and harmonics are separated out. Similarly, the maximum continuous current of the generating system is not a defined term and while it is commonly understood that this refers to the combined rating of the individual generating units referred to the connection point, it can become a potential source of confusion.

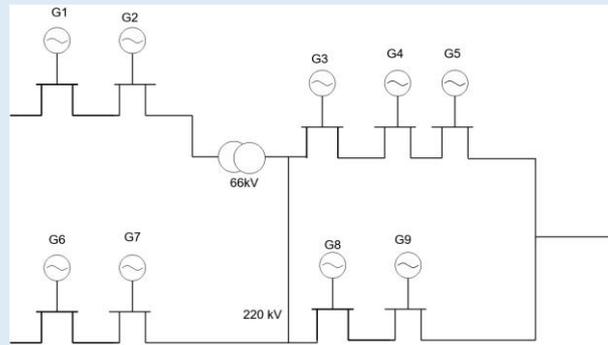
3.7. Control of multiple generating systems in close electrical proximity

In parts of the grid with multiple renewable generators, each effectively implementing high gain current controls there is potential for cause control interactions between generators and unstable behaviour, due to insufficient coordination (e.g., inverter phase locked loop (PLL) control induced fast voltage instability) between the various dynamic reactive power control devices. Such coordination issues are likely to be identified only through the wide area PSCAD studies (FIA studies), which occur quite late in the connections process resulting in potential delays for grid approvals. If the issues are not identified and resolved through individual project FIA studies, there remains the residual risk of generators having to be constrained as they are commissioned.

⁹ AEMO, Clarification Of Generator Technical Performance Requirements (S5.2.5), published 2018.

Hypothetical Case Study

Consider a hypothetical scenario with a part of the transmission grid remote to any synchronous generation. The network has been primarily designed and operated to serve local load but has increasingly connected a number of large wind and solar projects. The network is characterised by weak grid conditions, with SCR for some larger generators dropping to as low as 1.5 with X/R of as low as 5 under N-1 conditions.



To maintain system security and prevent unstable interaction between the various generating system, their respective controls need to be coordinated and tuned for a variety of system scenarios. An additional level of complexity is that some of these generators are in service, some have reached committed status and some in the planning stage. As such the modelling data for these generators have varying levels of accuracy and models for projects not yet commissioned have not been validated.

If generators G4, G5 and G8 are required to install additional STATCOM or syn-cons to meet the S5.2.5.5 reactive current requirements, these will be different technologies from different suppliers. Traditional power system studies required at the time of connection application may not be able to identify any adverse power system security impact such as voltage or oscillatory instability. Detailed wide area PSCAD modelling and possible controller tuning with such models are needed.

Such studies are needed even without the additional STATCOM or syn-cons but the complexity of modelling and associated risks of control mis-coordination increases if these additional plant are needed. As described in Section 4.3 below, if the TNSP constructs a scale-efficient syn-con in this same area in line with the system strength reform, the generator STATCOM or syn-cons could possibly become stranded assets.

3.8. Definition and interpretation of CUO

The definition and interpretation of CUO – continuous uninterrupted operation has created considerable ongoing debate between NSPs and project proponents.

Part (c) of the definition states that after clearance of any electrical fault that caused the disturbance, the generating system should only substantially vary its active power and reactive power as required or permitted by its performance standards established under clauses S5.2.5.5,

S5.2.5.11, S5.2.5.13 and S5.2.5.14. For large wind farms with significant generating system impedances, it is critical that the generating units are first able to locally stabilise voltages on fault clearance. But this may result in reactive power swings or transients at the connection point for a certain period until the response settles and the plant Power Plant Controller is able to assume control. As there is no settling time requirement on fault clearance, the CUO has been interpreted to be instantaneous in case of some projects , which may not be practically feasible.

Part (d) of the CUO definition states that the generating system should not exacerbate or prolong the disturbance or cause a subsequent disturbance for other connected plant, except as required or permitted by its performance standards, with all essential auxiliary and reactive plant remaining in service. In some cases, the "exacerbating or prolonging the disturbance" has been interpreted as any change in voltage or a power system quantity when compared to the pre-project scenario without allowing for any margin. In our view, the intent of the definition is to prevent any adverse impact on other generators, network users or in general operations of the power system but has been strictly interpreted in some cases without a view to the transient behaviour of power systems during and just after a disturbance.

4. Impacts of current rules on achievement of the NEO

4.1. Unnecessary costs will deter efficient investment

The current rules can result in unnecessary investment, which will increase costs or deter otherwise efficient investment without delivering any system security benefits.

As a result of the technical issues discussed above, the current minimum access standard for reactive current response in S5.2.5.5 and related definitions will result in connecting parties incurring additional expenditure that is inefficient and will not deliver any system security benefit.

The impact of defining compliance at the connection point rather than the generating unit terminals is that these requirements are much more onerous for large generating systems with large internal networks. In order to demonstrate compliance with the minimum access standard, those types of generators will be required to install additional equipment such as large STATCOMs or synchronous condensers very close to the connection point.

The requirement to install this additional equipment will lead to outcomes that are inconsistent with the objective of promoting efficient investment in electricity services under the National Electricity Objective. It risks:

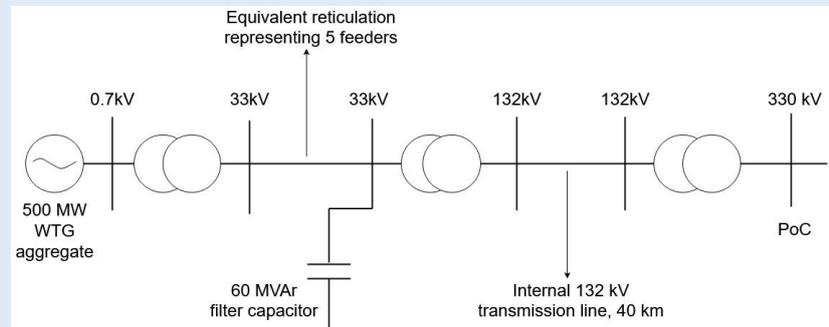
- leading to increased costs, which will be passed through to consumers through higher wholesale electricity prices
- deterring efficient investment
- leading proponents to connect smaller, less efficient generating systems that do not encounter these issues, or split a large generating system into several smaller systems so that it is easier to demonstrate compliance, which will lead to less efficient investment and higher costs for consumers
- delaying investments due to the need to procure additional equipment and the increased complexity of the design and commissioning processes.

The extra equipment that is required by the current rules will not improve system security, and as explained in section 4.4 below, it may increase system security risks and contribute to instability through poor control tuning and undesirable interaction between systems.

These outcomes appear to be an unintended consequence of the AEMC's change between the GTPS rule change draft and final determinations to require compliance to be measured at the connection point rather than the generating unit terminals. The proponents of this rule change agree that there may be benefits in measuring compliance at the connection point and understand that the preference of the AEMC, AEMO and NSPs continues to be to measure compliance at the connection point. Consideration must be given to the distinction between steady state compliance and dynamic response that generation control systems provide to disturbances. Measuring, simulating and predicting the dynamic response of the generating unit is best done at the terminals of the unit without the non-linear influences of the network.

Hypothetical Case Study

Consider a hypothetical scenario of a 500 MW wind farm connecting to the 330 kV transmission network. The wind farm has a large internal network with an internal transmission line and two stage voltage transformation, resulting in an impedance of 0.5 p.u. on plant MVA base.



The wind turbine generators are configured with a capacitive k-factor of 6% at their unit terminals. However due to the large internal impedance, the capacitive current injection at the connection point is 0% under some system conditions and operating scenarios. The 60 MVAR static filter capacitors compound the issue as their contribution during a fault reduces significantly, depending on the voltage at their terminals.

An 80 MVA STATCOM connecting at or close to the connection point will mitigate the issue by increasing the wind farm's capacitive current contribution to at least 2% at the connection point. The design, supply and install costs for a STATCOM system of this size including associated balance of plant infrastructure can be expected to be in the order of \$30 – 45 million, which can represent a sizable portion of the overall capital costs for the project when compared to small projects thereby deterring efficient investments.

A similarly sized syn-con could also provide a comparable technical solution but would cost about the same and additionally would have a longer lead time resulting the possible project delays.

4.2. Inconsistency with the AEMC's principles for setting minimum access standards

The current minimum access standard is inconsistent with the AEMC's principles for when minimum standards are appropriate and how the level of those standards should be set.

In the GTPS rule change final determination, the AEMC explains how automatic, minimum and negotiated access standards should be set in the Rules as follows:¹⁰

¹⁰ GTPS rule change final determination, p18-19.

- "The automatic access standard reflects the level of performance required of a connection such that it does not adversely affect power system security or the quality of supply to network users, regardless of the size, technology and location of the connection point..."
- The automatic access standard is the level of performance that would be appropriate in any location of the power system, for any connection."
- "The minimum access standard reflects the lowest level of performance required of a connection such that it does not adversely affect power system security or the quality of supply to network users, taking into consideration the size, technology and location of the connection.
- In practice, this means considering the lowest level of performance that may be acceptable for a connection to do no harm in the best network conditions relevant to that technical requirement (in particular, the system strength at the proposed connection point) that are currently seen across the power system. This is the key distinguishing factor between the automatic and minimum access standards.
- The access standards should, to the greatest degree possible, reflect local power system conditions. This means that for some capabilities that are not required to be provided by all generating systems in all locations, it may be appropriate to set a minimum access standard at no capability. For those capabilities that are needed from all generators, the access standards should set the minimum level of performance that is acceptable when connecting to the power system."
- "A negotiated access standard represents the point agreed by all parties to the negotiating process within the range provided by the automatic and the minimum access standard. It is the process that maintains system security and quality of supply at an efficient cost."

Applying the principles set out above, a minimum access standard:

- is only justified for capabilities that are required to be provided "by all generating systems and in all locations"; and
- should be set at "the lowest level of performance that may be acceptable for a connection to do no harm in the best network conditions relevant to that technical requirement".

The current minimum access standard imposes requirements that are not required in order for certain types of generating systems to do no harm even in the best network conditions. The types of generating systems that are adversely impacted by the current requirements are generally connecting in very strong parts of the transmission network that have amongst the best network conditions, but they are still required to install extra equipment that is not necessary in those conditions.

Reducing the level of the minimum access standard to reflect these issues will not adversely affect system security for those types of generating systems or locations where higher capability is justified. If a connection applicant proposes to connect at the minimum standard, or between the minimum and automatic standards, it can only do so with the agreement of the relevant NSP and

AEMO.¹¹ This rule change request does not propose any changes to the automatic access standard, which AEMO and NSPs will continue to be able to insist upon in circumstances where higher performance standards are actually required.

Accordingly, the current requirements are not consistent with the NEO and the AEMC's overall aim of the GTPS rule change of "maintaining power system security and quality of power supply at the lowest cost to consumers".

4.3. Inconsistency with the AEMC's proposed system strength reforms

The current rules are also inconsistent with the AEMC's recent decisions on the system strength framework and will result in an inefficient duplication of investment by generators and TNSPs under the generator performance standards and the AEMC's proposed new system strength framework.

In its October 2020 final report for the Investigation into system strength frameworks in the NEM, the AEMC proposed a new framework for the provision of system strength services.¹² The AEMC is currently developing amended rules to implement the findings of this investigation as part of the "Efficient Management of System Strength on the Power System" rule change submitted by TransGrid.

The AEMC's proposed system strength reforms would require TNSPs to undertake regulated investments to install syn-cons and other equipment to provide system strength services. These network syn-cons can be configured to support network voltages during faults but cannot assist a generation project in meeting the S5.2.5.5 reactive current response requirements.

Retaining the current minimum access standard for reactive current response will result in a duplication of investments on the network side and the generation side and potential stranded assets. This will result in inefficient investment that will increase costs to consumers and be inconsistent with the NEO.

4.4. Potential to increase system security risks

Maintaining system security is an important aspect of the NEO. However, the current minimum access standard will require some large generators to install equipment that is not only unnecessary to maintain system security, but which could be detrimental to system security.

As explained in sections 3.3, 3.5 and 3.7 above, the current rules could negatively impact system security in several ways including:

¹¹ The GTPS rule change clarified the rules to provide that (1) when proposing a negotiated access standard, a connection applicant must propose a level of performance that is as close as practicable to the automatic access standard and (2) AEMO and the NSP may reject a proposed negotiated access standard based on certain criteria including an adverse effect on power system security.

¹² See <https://www.aemc.gov.au/sites/default/files/2020-10/System%20strength%20investigation%20-%20final%20report%20-%20for%20publication.pdf>.

- Connection of large STATCOMs, syn-cons or other dynamic reactive control devices in large numbers is likely to create difficult control and coordination issues at a system level. The AEMC recognised a very similar outcome as being a significant weakness of the current system strength framework that required generators to install their own syn-cons and other equipment and one of the reasons for recommending the new system strength framework discussed above.
- The current rules create a perverse incentive on connecting generators to prioritise reactive current response requirements over active current injection, which will lead to overall worse outcomes for the system depending on the nature of the connecting network.
- In complex and large renewable energy plants high gain current injection at the terminals may cause the unit voltages to rise to close to normal operating levels even when the fault at the connection point has not been cleared. This has the potential to cause instability due to hunting or retriggering of the LVRT control logic and furthermore could cause issues with the generating unit's ability to detect fault clearance locally by sensing the restoration of voltages. Lowering the impedance of the internal plant network between the machines and connection point to avoid such issues can be expensive with no corresponding benefit to the system.
- Fast tuned reactive current response increases the chance of interaction with nearby resources in an unstable manner, particularly in weak systems. As described in section 3.7, such issues caused due to insufficient coordination (e.g., inverter phase locked loop (PLL) control induced fast voltage instability) between the various dynamic reactive power control devices are likely to be identified only through the wide area PSCAD studies (FIA studies), which occur quite late in the connections process resulting in potential delays for grid approvals.

5. Proposed changes and rationale

5.1. Introduction

As described in detail in Section 3, a number of contributing factors make it very onerous for generating systems, particularly large renewable energy plants, to meet the reactive current related requirements by tuning the converter level controls of individual generating units. To summarise, these factors include:

- High internal plant impedance between the generating unit terminals, the point at which the controls are applied and the connection point, the point at which the desired effect is to be observed.
- Nature of the fault - type (balanced or unbalanced), location (deep or shallow), severity (fault impedance and X/R ratio)
- Characteristics of the connecting network – neighbouring synchronous and asynchronous generators, dynamic reactive devices, network configuration and resulting system strength (measured as fault levels)
- Range of operating conditions – PQ operating range and partial dispatch scenarios the plant is expected to safely operate in to meet its GPS requirements
- Fundamental limitations of the existing, commercially viable technologies.

The alternatives to converter tuning include:

1. **Additional dynamic reactive plant** – A STATCOM or synchronous condenser located close to the connection point could contribute sufficient magnitude of reactive current during the fault as required by the current rules. Such response could also be tuned to be fast enough to meet the rise and settling time requirements. However, such dynamic reactive plant will need to be sufficiently large to compensate for any deficient contributions from the generating units or higher than 50-100 MVAR in case of very large projects. The additional costs will make the project economics worse, particularly if the equipment is not serving any additional purpose such as steady-state reactive power control or as a system strength remediation measure. Furthermore, the complexity of designing, commissioning, operating and maintaining the additional equipment can be expected to be an ongoing burden for the project.
2. **Dividing the large projects into smaller ones with multiple connection points** – While this option is attractive from a technical perspective, it will very likely reduce the commercial viability of many projects as well as introducing significant complexity in the interfaces between various parties during construction and operations.

With the above considerations, the proponents of this rule change propose that the S5.2.5.5 minimum access standard requirements related to reactive current contribution be modified so as to simplify related technical assessments for projects and provide clarity to proponents as well as NSPs. The proposed changes will facilitate the connection of more renewable energy projects to the NEM in a timely and efficient manner, while managing project risks for both the project proponents and the NSPs.

While we are **not** proposing to alter the corresponding automatic access standard requirements, the AEMC may wish to undertake consultation for changes to the automatic access standard, particularly

if changes to the automatic access standard are considered necessary to resolve the issue in its entirety. Regardless, the actual access standards are expected to be negotiated between the parties as per the current negotiating framework in the NER.

5.2. Proposed changes and rationale

A description of the proposed rule changes is as follows. The wording in italics below is a description of the proposed changes and is not intended as legal drafting for the amended rules.

Refer to Section 3 for the technical rationale for the proposed rule changes and Section 4 for the considerations that impact the achievement of the NEO.

1. New reactive current contribution requirement at the individual generating unit terminals

Current WTG and solar inverter technologies have the capability to supply and absorb reactive current as measured at their terminals during faults. In order to ensure that any change to sub-clause S5.2.5.5 (n)(1) as per (3) below does not remove the obligation of generators to contribute reactive current during faults, new requirements should be added to clause S5.2.5(n)(1) along the following lines:

- *capacitive reactive current at the generating unit terminals in addition to the pre-disturbance level of at least 2% of the maximum continuous current of an operating asynchronous generating unit (in the absence of a disturbance) for each 1% reduction of voltage at the generating unit terminals below the relevant range in which a reactive current response must commence, as identified in clause S5.2.5.5(o)(1).*
- *inductive reactive current at the generating unit terminals in addition to its pre-disturbance level of at least 2% of the maximum continuous current of an operating asynchronous generating unit (in the absence of a disturbance) for each 1% increase in voltage at the generating unit terminals above the relevant range in which a reactive current response must commence, as identified in clause S5.2.5.5(o)(1).*

2. Generating unit voltage thresholds for commencement of response (sub-clause S5.2.5.5 (o)(1))

The current voltage threshold requirements apply to the connection point. The proposal is for clause S5.2.5.5(o)(1) to be replaced with a requirement that:

- *Each operating asynchronous generating unit within the generating system must commence a response when the voltage at the generating unit terminals drops below a fixed LVRT voltage threshold for an under-voltage condition or exceeds a fixed HVRT threshold for an over-voltage condition.*
- *The LVRT and HVRT voltage thresholds are to be agreed with the NSP and AEMO within an under-voltage range of 80% to 90% and an over-voltage range of 110% to 120% of normal voltage respectively, as measured at the generating unit terminals.*

3. Reactive current contribution requirement at the connection point (sub-clause S5.2.5.5 (n)(1))

The current requirements in clause S5.2.5.5(n)(1) (i) and (ii) are proposed to be replaced with requirements at the connection point along the following lines:

- *capacitive reactive current at the connection point of at least its pre-disturbance level after the generating unit fault response has settled in accordance with clause S5.2.5.5(o)(1)*
- *inductive reactive current at the connection point of at least its pre-disturbance level after the generating unit fault response has settled in accordance with clause S5.2.5(o)(1)*
- *until commencement of generating unit fault response in accordance with clause S5.2.5.5(o)(1), the generating system will follow the applicable voltage and reactive power control strategy under clause S5.2.5.13 access standard*

4. Clarification for current response up to the generating unit apparent current limit (sub-clause S5.2.5.5 (u)(1))

The proposal is to clarify this requirement as below:

- *the reactive current contribution is such that the total current of the generating unit may be limited to - (i) the maximum continuous current of the generating unit during undervoltage conditions, or (ii) sufficient current to maintain rated apparent power of the generating unit during overvoltage conditions.*

5. Reactive current rise and settling time requirements to be applied to current contribution at the generating unit terminal (sub-clause S5.2.5.5 (o)(2))

The current rules require projects to demonstrate compliance to the reactive current rise and settling time requirements at the connection point. The proposal is to change the compliance point to the generating unit terminals as below. An increase in the rise and settling time requirements is proposed to account for the one to two cycle delay associated with measurement of rms quantities.

- *where AEMO and the Network Service Provider require the generating units to sustain a response duration of 2 seconds or less, the reactive current response at the generating unit terminals must have a rise time of no greater than 80 milliseconds and a settling time of no greater than 110 milliseconds and must be adequately damped;*

6. Clarification of CUO definition

Part (d) of the definition to be clarified as per below:

- *(d) not exacerbating or prolonging the disturbance such that it would result in a subsequent disturbance for other connected plant, except as required or permitted by its performance standards,*

7. New definitions for reactive current and maximum continuous current

New definitions to be introduced in Chapter 10 – Glossary

- *Maximum continuous current of the generating unit is the maximum apparent current rating of an operating asynchronous generating unit (in the absence of a disturbance and at normal operating voltages) as measured at the generating unit terminals.*
- *Reactive current is to be calculated as per the method defined in IEC 61400-21:2008, whereby the positive sequence and negative sequence reactive current components of the fundamental frequency (50Hz) are separated out.*

5.3. Alternatives considered

The proponents considered several alternatives to the proposed changes discussed above, including:

- **Changing the point at which compliance is assessed from the connection point to the generating unit terminals:** This approach would be the simplest change to draft, could have some advantages over the proposed rule, and would be consistent with AEMO's proposal and the AEMC's draft determination in the GTPS rule change. However, the proponents understand that the preference of the AEMC, AEMO and NSPs is to continue to assess compliance at the connection point for consistency with other access standards. Changing this measurement to the generating unit terminals is consistent with the original drafting and technical principles used to set performance standards prior to the GTPS rule change. The dynamic response of the generating unit is most appropriately measured at the terminals of the unit, not at a remote arbitrary distance across connection assets or more. However, this would remove all requirements for reactive current response at the connection point and may mean that for some faults the plant is absorbing reactive current at the connection point.
- **Removing all or part of the minimum access standard in S5.2.5.5:** This approach would mean all generators would either connect at the automatic access standard or agree a negotiated access standard that would be as close to the automatic access standard as is technically and commercially feasible but with no lower bound set in the rules. This approach would have the greatest benefits in terms of enabling the access standards to be tailored to each generator's circumstances and avoiding inefficient investment that may not be appropriate for certain types of generators or in certain locations. It would also be consistent with the approach that existed up until the commencement of the GTPS rule change. However, it could make the negotiation process more difficult and protracted as there would not be clear upper and lower bounds to guide negotiations.

The proponents would welcome the AEMC considering either of these options or other potential alternatives as part of the rule change process.

6. Costs and benefits and how the proposal contributes to the NEO

6.1. Costs and benefits of the proposal

The proponents consider that the benefits of the proposed rule changes will significantly outweigh the costs.

The primary benefit of this proposal is that it will lead to more efficient investment in generation systems by:

- avoiding unnecessary and inefficient investment in additional equipment;
- removing barriers to the connection of certain types of larger, more efficient generating systems that risk being made uneconomic or uncompetitive under the current rules.

These benefits will lead to:

- lower generation costs, which will flow through to lower wholesale prices and lower electricity prices for consumers; and
- increased investment in new generation, which will reduce prices and improve reliability.

The proposal will also improve regulatory certainty by clarifying how the current minimum access standard and related definitions should apply. This will improve the efficiency of the process for negotiating access standards and speed up the process for connecting new generators.

The proposal will also improve system security.

The proponents do not consider that the proposal will have any material costs for AEMO, market participants or consumers. There are not expected to be any increased costs or additional modelling for AEMO, network service providers or generators as part of the process of negotiating access standards, and those costs may reduce. Costs to generators and consumers should reduce as discussed above due to avoiding unnecessary investment and delays in connecting new generation. The proposed rule was chosen over alternatives discussed in section 5.3 above because it is expected to avoid the potential costs that could have arisen under those alternatives, which could have added additional costs or delays to the negotiating process or made it harder for AEMO and NSPs to assess compliance.

6.2. How the proposed rule promotes the NEO

When assessing a rule change request, the AEMC must consider whether the proposed changes contribute to the NEO. The NEO is:

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—

(a) price, quality, safety, reliability and security of supply of electricity; and

(b) the reliability, safety and security of the national electricity system.

The aspects of the NEO that are most relevant to this rule change are promoting efficient investment in electricity services for the long term interests of consumers with respect to price, reliability and security of supply.

For the reasons discussed above, the proposed rule will promote efficient investment in electricity services by:

- reducing the costs of investment in certain types of generation systems;
- removing inefficient barriers to connecting certain types of generating systems;
- avoiding unnecessary delays to the connection process; and
- improving regulatory certainty.

As a result, the proposed rule will promote the long term interests of consumers in relation to:

- price: by reducing generation costs, which will flow through to lower wholesale prices and lower electricity costs for consumers;
- reliability: by increasing investment in new generation and speeding up the connection process; and
- security of supply: by removing requirements that could have unintended adverse effects on system security.

7. Contact details

The proponent legal names, addresses and contact details are:

1. GE International Inc
Building 8, Level 2, 576 Swan St,
Burnley VIC 3121, Australia

Contact: Kunlun Shen (Technical Leader)
Email: Kunlun.Shen@ge.com
2. Goldwind Australia Pty Ltd
Level 25, Tower 1, 100 Barangaroo Avenue
Barangaroo, Sydney, NSW 2000, Australia

Contact: Rahul Victor (Grid Connection Manager)
Email: rahulvictor@goldwindaustralia.com
3. Siemens Gamesa Renewable Energy Pty Ltd
885 Mountain Highway
Bayswater, VIC 3153, Australia.

Contact: Archana Kher (Grid Connections Manager)
Email: archana.kher@siemensgamesa.com
4. Vestas Australia Wind Technology Pty Ltd
Level 4, 312 St. Kilda Road,
Melbourne, Victoria 3004, Australia.

Contact: Janakiraman Sivasankaran (Specialist Electrical Engineer)
Email: jasiv@vestas.com

The contact details for each of the proponents are set out above. Alternatively, if the AEMC would prefer a single point of contact it may contact Aditya Upadhye at GridWise Energy Solutions who can forward correspondence to each of the proponents.

Aditya Upadhye
Director – GridWise Energy Solutions
Mobile: +61 4 7910 7910
Email: Aditya.Upadhye@gridwiseenergy.com

Aditya can be contacted by email or on his mobile number above during normal business hours.