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8 July 2022

Anna Collyer
Chair
Australian Energy Market Commission
Sydney South NSW 1235

By online submission

Dear Ms. Collyer,

National Electricity Rule (NER) change requests' consultation process on "efficient reactive current access standards for inverter-based resources" – AEMC ref. ERC0272 & ERC0329

AEMO welcomes the opportunity to provide feedback on the AEMC's Consultation Paper published on 26 May 2022 regarding the combined rule change requests above.

Our feedback is set out in the annexure to this letter, and we thank the AEMC for the time extension granted as AEMO staff focused on major market events during June.

Please contact Margarida Pimentel on margarida.pimentel@aemo.com.au should there be any enquiries on the matters outlined in this submission.

Yours sincerely,

Merryn York

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Executive General Manager – System Design

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ANNEXURE – NER change requests' consultation process on "efficient reactive current access standards for inverter-based resources" – AEMC ref. ERC0272 & ERC0329

Background

Clause S5.2.5.5 of the NER in its current form came into force in 2018 following changes to the generator technical performance standards.[1]

Since then, AEMO and other stakeholders have become aware of some issues with certain aspects of this clause that are the subject of the AEMC's Rule change requests' consultation process on "efficient reactive current access standards for Inverter-based Resources". The aspects in question relate to clause S5.2.5.5(n), (o) and (u).

Since the above Rule change requests were made, members of the Connections Reform Initiative (CRI)[2] have undertaken a review of the minimum access standards in clause S5.2.5, with particular focus on the same subclauses. This work was completed in December 2021.

Following the CRI work, AEMO has undertaken further work considering obstacles to the connection of grid forming inverters and, with TransGrid, supported EnergyCo in developing Renewable Energy Zone (REZ) performance standards for the Central West Orana REZ.

AEMO's submission to this Rule change is informed by and draws on the CRI work, the additional AEMO work on grid forming inverters and the REZ performance standards. Further work on clause S5.2.5.5 is also being undertaken at present to inform the AEMO review of technical requirements for connection[3] pursuant to clause 5.2.6A of the NER.

Key requirements of the present Rules clauses S5.2.5.5 (n), (o) and (u)

Key requirements of the present Rules include the following:

- *Rise time* 40 ms and *settling time* 70 ms (essentially the same in *minimum* and *automatic access standards*)
- Measurement at the *connection point* or unit terminals
- Minimum reactive current injection and absorption levels of 2%/% voltage for the *minimum access standard*
- Reactive current injection is not required to exceed maximum continuous current
- Response is required to commence in the range 80 – 90% of *normal voltage* on the *connection point*.

[1] AEMC ref. ERC0222.
[2] As commenced by AEMO and the Clean Energy Council in early 2021 to address concerns with related to connecting to the National Electricity Market (NEM).
[3] Limited to Schedules 5.2, 5.3 and 5.3a of the NER.

Purpose of the reactive current injection requirements

Fast reactive power response to severe under-voltages and over-voltages during contingency events helps to mitigate the impact of the contingency event on the power system and maintain stability.

The reactive power is a function of the reactive current and voltage. The design of the generating system (and systems containing bi-directional units) and the control settings influence the reactive current injection during a fault and reactive current absorption for an over-voltage event.

For grid-forming inverters, like synchronous machines, the amount of reactive current injection is also affected by the impedance of the power system.

Injection of reactive power increases the voltage and is useful during a low-voltage condition such as a network fault. Absorption of reactive power reduces the voltage, which is useful in an over-voltage event. It is undesirable to absorb reactive power during a low voltage condition or inject it in high voltage conditions as this exacerbates the power system disturbance.

The voltage is largely impacted by the provision of reactive power, but as the X/R ratio of power system impedance decreases, active power has an increasing effect on the voltage response.

The optimal amount of reactive current injection or absorption (represented by the %/% voltage change) depends on the power system that it connects to. If the power system impedance is high (low system strength) then, for a certain level of reactive current injection there will be more impact on voltage change, but there could be an adverse impact on stability, compared with the same amount of reactive current injection in a low impedance (high system strength) power system. For this reason, the reactive current injection and absorption levels have a range of values from automatic to minimum access standard. It was intended that the %/% value be set to optimise performance considering power system conditions at the connection point location, although we note that the present Rule has not always been interpreted this way.

Large reactive current injection during a fault can also lead to over-voltages on clearance of a fault, when power system voltages suddenly recover towards normal levels.

Likewise, depending on how reactive current is injected on each phase, the design of the generating system and the impedance of the power system it connects to, high current injection may result in abnormally high voltages on unfaulted phases during a fault. Excessively high voltages may damage equipment or cause over-voltage tripping.

The connection point is the interface between the generating system and the power system. Reactive current injected or absorbed at the connection point provides support to voltages within the power system for abnormal voltage conditions. There is a difference between reactive current as measured at the terminals of the generating units and the connection point because of the reticulation network and reactive power devices (e.g. harmonic filters) of the generating system itself. In particular, cables, capacitors and dynamic reactive power plant can significantly affect the reactive current at the connection point, particularly for large wind farms which have large collector systems.

Mechanical switching of devices such as capacitor banks can provide effective control of steady state reactive power but is not fast enough to respond to a voltage disturbance caused by a fault.

AEMO recognises that there is a cost associated with provision of reactive current injection at the connection point. Nevertheless, AEMO's position is that it is appropriate for most generating systems to make at least some contribution to supporting the network during faults or over-voltages. Such a contribution can only be measured at the connection point. In general, this support makes the power system more resilient and stable during contingency events and assists the generating system itself to remain in operation, due to improved power system conditions. There may be exceptions for unusual circumstances where the power system performance is improved with lower or no reactive current injection, such as high levels of background voltage unbalance, which should be considered case by case.

Desired outcomes

The desired reactive current response to a power system disturbance is:

- Response as soon as possible after the commencement of a voltage disturbance
- Rapid injection/absorption of reactive current to support the network voltage
- Continued support over the duration of the fault (response does not need to be constant)
- Acceptably controlled response during the fault:
- Minimise overvoltages on unfaulted phases during an unbalance fault
- Minimise overvoltages on clearance of a fault
- Response should be *adequately damped* after the fault.

Examples of unacceptable response during a fault include:

- Loss of phase- locked loop (PLL) synchronism affecting the current control stability
- Large swings in active or reactive power
- Limit cycling due to improper hysteresis settings
- Instability due to improper selection of gains in positive and negative sequence control loops.

The performance standard should be technology agnostic (for example, avoid stating that the injection response should commence at a particular voltage level, which may be counter to the desire for a fast response).

Experience with application of the present clauses and proposed changes

1, Rise time and settling time

General issues

The rise and settling time requirements implicitly require a step response as an output, but the present Rule does not specify the input conditions for the test. In practice, a real fault is seldom a step and the performance standards framework requires compliance with the standards for actual power system events.

For shallow faults, the error band calculation of the settling time can lead to misleading calculated settling times. Other circumstances can also lead to calculations of longer settling times where the control response is nevertheless satisfactory. These can include, but are not limited to, faults that are not 'step-like' and slow dynamics associated with active power controllers acting during a fault.

There is no one value of settling time that would be appropriate to apply as a minimum access standard for all of these circumstances.

Likewise, when a response does not settle to a steady value during a fault, due to the behaviour of external or internal control systems, the rise time calculation may exceed the present 40 ms requirement for a response that is otherwise satisfactory from an engineering perspective. There is no one value of rise time that would be appropriate to apply as a minimum access standard for all circumstances.

The present clause specifies a requirement for the response during a fault to be adequately damped, but in practice the voltage during a fault is affected by external factors (such as fluctuating fault impedance and the response of other generators and dynamic reactive plant) beyond the generator's control. The generator may correctly respond to these external phenomena in a way that appears not to be adequately damped.

Technology-specific issues

The present Rule allows the rise time and settling time to be applied at the connection point, even though the term *rise time* as defined in the NER pertains to a 'control system', which implies that it was intended to be applied at the unit terminals. The Rule change request by the relevant consortium of wind turbine original equipment manufacturers (OEMs)[4] raises some concerns about wind farms meeting the 40 ms rise time requirement, due to a delayed response. This may be partly a result of the capacitance of the collector system, and very often associated with correct disturbance detection methods, in instances where filtering and time delays are used.

Another issue, which affects both wind farms and grid forming inverters that emulate synchronous machines, is that the response is affected by slow dynamics during the fault, which interact with the reactive current injection controls. This can mean that the response, while stable, does not settle to a constant value within the fault duration. When this occurs the settling time cannot be calculated, and the rise time may be longer than 40 ms.

Proposed alternative

Considering all the items above AEMO's preference is to omit the rise time and settling time requirements in the Minimum Access Standard and replace them with the following text:

> The reactive current response measured at the generating unit, bi-directional unit terminal, or if the reactive current response is predominantly provided by an ancillary dynamic reactive power plant, at the terminal of that plant, must commence within 30 ms of the response initiating condition.
>
> The response initiating condition must be recorded in the performance standard and may be: voltage excursion commencement, voltage traversing a voltage threshold, or another mechanism agreed with AEMO and the *Network Service Provider.*

AEMO's investigations of the performance of plant for connection studies indicate that, typically, generators of all current technologies should be capable of meeting the 30 ms requirement or less.

[4] I.e. GE International Inc, Goldwind Australia Pty Ltd, Siemens Gamesa Renewable Energy Pty Ltd, Vestas Australia Wind Technology Pty Ltd (AEMC ref. ERC0329).

This formulation would resolve the issues around the present rise time and settling time wording, whilst still requiring a fast response.

Relevantly, the present clause 5.2.5.5 (o)(2) requires the response during a fault to be 'adequately damped'. The application of this requirement presents some difficulties when applied to any fault condition on the power system, rather than controlled test conditions. An alternative might be 'adequately controlled' which is less prescriptive about a response, but still enables AEMO or the NSP to require a proponent to address response during a fault that they consider is not adequately controlled. This will allow adequate treatment and interpretation of responses observed during unbalanced fault conditions in the presence of high frequency (i.e. at 100Hz), undamped signals associated with fundamental properties of sequence components and controls behaviour occurring during asymmetric events (the 100 Hz signal can be undamped, but adequately controlled).

2. Commencement of the response

The commencement of the reactive current response is formulated in the present Rules in terms of the voltage range at the connection point. In the minimum access standard, the response is required to commence within a range 80-90% of connection point normal voltage, or other range agreed with the NSP and AEMO, provided it is within a 10% range. The range was to allow for the difference between connection point and unit terminal voltages, considering transformer tap range, but 10% is not a critical requirement.

One of the drivers for lower thresholds for reactive current injection thresholds on grid-following inverters has been the requirement to remain in *continuous uninterrupted operation* (CUO) for connection point voltage down to 0.9 pu. The definition of CUO implies that active power must be maintained for voltage down to 0.9 pu. If the inverter goes into low voltage ride through mode while the connection point is higher than 0.9 pu, it will compromise active power to provide additional reactive current injection and may not be compliant with the CUO requirement.

The concept of commencement based on a trigger voltage is technology specific, reflecting grid-following inverters, and is not desirable, as it potentially delays the response. Some technologies respond based on a threshold change in voltage. Grid-forming inverters respond almost instantaneously to the onset of the voltage disturbance.

It would be more appropriate to require the generating unit or bidirectional unit or dynamic reactive power plant to:

> commence its reactive current response as soon as practicable following the onset of a *power system* disturbance, but in any case, commencing no lower than 80% of *connection point normal voltage*, and no higher than 120% *connection point normal voltage*, unless otherwise agreed with *AEMO* and the *Network Service Provider*.

This formulation would be more flexible for the different types of initiating conditions contemplated above, while still retaining some upper and lower boundaries on the thresholds where they apply.

3. Minimum access standard for reactive current injection amount

The present Rule requires the generating system to have facilities that are capable of supplying or absorbing from the network, capacitive reactive current in addition to its pre-disturbance value of 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 in voltage of the connection point below the relevant range.

Similar wording requires inductive reactive current of 2%/% increase in voltage of the connection point above the relevant range.

The Rules' wording differentiates between facilities capable of and settings on the plant. The Rules allow for the settings to be lower than the 2%/% if required (for example, for performance of the plant under the anticipated power system impedance levels as the connection point). However, the Rule does require the plant to have facilities to achieve the 2%/% setting. There is some additional flexibility because clause S5.2.5.5 (u)(2) allows the measurement of this value to be a location other than the connection point. So, the lowest requirement is for the generating system to have facilities sufficient to provide 2%/% at the terminals.

In practice AEMO has preferred the measured reactive current injection value to be at the *connection point*, as it operates the transmission system and its performance matters most at the connection point.

The complexity of the current drafting causes some confusion. AEMO recommends that it be simplified so that:

- The plant has *f*acilities to provide at least 1%/%, measured at the connection point, unless the Network Service Provider and AEMO agree that a lower level is acceptable in the circumstances.
- The drafting clarifies that the settings are to be established to optimise the performance of the plant on the *power system* (this is both for the automatic as well as the minimum access standards). We understand that this was the intent of the current drafting, but it is not clear.
- The measurement of the response commencement time is always at the terminals of the generating unit, bi-directional unit or dynamic reactive plant as relevant.

4. Maximum continuous current

The other matter that requires clarification is the 'maximum continuous current'. This term is not defined in the Rules but is used as a base value for the percentage calculation of the reactive current injection. Clause 5.2.5.5 (u)(1) permits the asynchronous generating system to limit its reactive current contribution to this value, including its operating asynchronous generating units.

This clause is also the subject of the Rule change proposal from Renewable Energy Revolution Pty Ltd (RER).[5] The RER Rule change proposal assumes a definition of maximum continuous current, without providing that definition. There are multiple possibilities for definition of this term, especially considering it relates to measurements at the connection point.

Possible definitions include (but are not limited to):

- The current defined by *nameplate rating* of *generating units* and *bi-directional units*, at standard temperature and pressure, considering in-service *production units*, divided by terminal *nominal voltage*.

[5] AEMC ref. ERC0272.

- The current defined by *rated active power* of the *generating system* or *integrated resource system* divided by *connection point nominal voltage*.
- The current defined by the registered maximum capacity of the *generating system* or *integrated resource system* in megawatt (MW) divided by the *connection point nominal voltage.*
- In relation to a *generating unit*, or *bi-directional unit*, the maximum magnitude of current that the unit can deliver continuously at its terminal, defined by reference to its *nameplate rating*, its *apparent power* rating and the permitted range of terminal *voltage* for continuous operation.
- In relation to a *generating system* or *integrated resource system*, the amount of current at the *connection point* corresponding to the largest amount of apparent power required by the system's *performance standard* under S5.2.5.1 of the NER with the *connection point* at its *nominal voltage.*

RER's proposal seems to assume that the term relates to the generating units' nameplate rating and terminal voltages (considering that inverters are typically rated at unity power factor), equivalent to the first dot point above. This is one potential definition, but limiting the maximum reactive current to maximum continuous current (under clause S5.2.5.5 (u)(1)) then would need to be referenced to terminal quantities. If the same base were used for measurement at the connection point, the unit would not be capable of achieving reactive current injection of 100% maximum continuous current at the connection point.

The possible definitions in the second and third dot points above are both defined for measurement at the connection point. The difference is that *rated active power* is defined for units operating at their *nameplate rating*, whereas for the maximum capacity that is registered with AEMO, the units typically operate at less than their nameplate rating. The third definition would therefore give a lower base value for maximum continuous current than the second one. As an aside, the *rated active power* definition probably should be aligned with the registered capacity, considering the use of the *rated active power* definition in NER clauses S5.2.5.1 and S5.2.5.13 is not consistent with operation of inverter-based resources or even some synchronous generation.

Both these definitions would give a lower base than the first. With either of these, an inverter would typically be able to achieve greater than 100% reactive current injection at the connection point. Using this base there is probably no need to require less than 100% reactive current for low X/R ratio conditions (as the proposed reduction is small in any case).

The possible definitions in the last two dot points are based on a definition considered by the CRI, adapted to include bi-directional units. In the system definition, the calculation would include the reactive power component provided by capacitor banks and dynamic reactive plant, to the extent that they are contributing to the reactive power capability. Capacitor banks do not contribute additional reactive current for voltage reduction. They reduce their contribution in proportion to the change in square of voltage. This would put additional burden on the generating units to provide higher reactive current injection to meet a connection point reference for %/% reactive current injection or absorption.

The unit level definition references nameplate rating or apparent power rating. These become the same if the nameplate rating is defined at unity power factor (as is typical for inverters), but the definition would be ambiguous if they were not the same.

We therefore suggest that, if the proposal to measure reactive current injection at the connection point is adopted, an appropriate definition for maximum continuous current would be as follows:

> The current defined by *rated active power* of the *generating system* or *integrated resource system* divided by *connection point nominal voltage*.

The definition of the rated active power should also be made consistent with registered maximum capacity. The definition of *rated active power* already includes reference to in-service service units, which should be retained.

If this definition is used, there should be no need to allow for slightly lower reactive current injection for a low X/R ratio.

Clause S5.2.5.5 (u)(1) should become a part of the minimum access standard, because for grid-forming inverters the provision of overload capability will be an important requirement. Grid-forming functionality is only active when the grid-forming inverter is not operating at a current limit.