# Generator technical performance standards in the Australian National Electricity Market

Dr Julian Eggleston
Director – technical specialist
Australian Energy Market Commission (AEMC)
Sydney, Australia
julian.eggleston@aemc.gov.au

***Abstract*—The electrical power system that makes up the National Electricity Market (NEM) in Australia is being transformed by the increased integration of asynchronous wind and solar generation, at the same time as synchronous generation is operating less or being retired. The associated reduction in short circuit ratios at new generation connection points, and the different technical characteristics of the asynchronous generation, has resulted in the need to review the technical performance standards that connecting generators are required to meet. This review of the technical connection standards is also being informed by analysis of the black system event in South Australia in 2016.**

## I. Introduction

The NEM power system is the longest interconnected transmission networks in the world and is relatively unmeshed compared to transmission networks in many other countries. The NEM supplies approximately 10 million customers with a maximum demand of approximately 33 GW. Recently the NEM has been experiencing a period of change as traditional forms of large-scale, synchronous, generation are operating less or retiring, and being replaced by asynchronous wind and solar generation. As this shift occurs, some valuable characteristics of synchronous generating systems are becoming less available and operating the power system securely is being more challenging. In particular, it is becoming more difficult to effectively control frequency and voltage, which could lead to significant power system disturbances and potentially blackouts. As the rule maker and policy advisor for the NEM, the AEMC has an ongoing action plan to address these challenges in a coordinated manner. This plan included changes to the national electricity rules (NER) to require transmission network service providers to procure inertia and to maintain minimum faults levels, as well as requirements for generators to provide electromagnetic transient models of their generating systems where it is necessary to assess power system security.

Another important part of the action plan is a review of the technical access standards for new connecting generating systems. These technical access standards, which are embedded in the NER, were last revised in 2007 when the penetration of wind generation was increasing, especially in South Australia. From 2007 to 2017 the penetration of asynchronous generation, and the retirement of synchronous generation, has accelerated dramatically, as demonstrated in Figure 1.

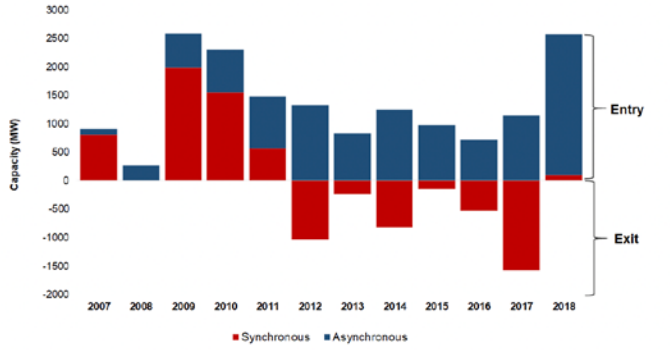


Figure 1. Entry and exit of synchronous and asynchronous generation in the NEM power system

Following the experiences gained since 2007, included from the 2016 black system event in South Australia [1], the Australian Energy Market Operator (AEMO) investigated the technical access standards that it considered should apply for new connecting generating systems.

AEMO then submitted a rule change request to the AEMC to assess whether to make changes to the NER in relation to the changes to the access standards and the associated arrangements that it considered necessary in order to maintain power system security into the future [2]. The AEMC's assessment process included extensive stakeholder consultations and independent technical assistance. The AEMC published a draft determination and draft rule on 31 May 2018 and a final determination and rule is anticipated at the end of September 2018 [3].

## II. Open access and negotiated generator performance standard

The National Electricity Market (NEM) has an open access regime in which transmission and distribution businesses have an obligation to deliver a reliable supply (in accordance with set standards and incentive arrangements) to their customers and to make offers to connect all generators and loads that wish to connect to their networks.

The framework for setting and negotiating performance standards for connecting generation is a part of the overall framework for connection to a transmission or distribution network and access to the power system. Therefore, the changes to the access standards need to be assessed by the AEMC on the basis of how they would work within the broader framework and the philosophy that underpins that framework.[1]

A core aspect of the NEM framework for the connection of generation is that connection applicants have the right to negotiate a connection to a network and pay a shallow connection charge relating to the immediate cost of their connection to the shared transmission network. But there is no 'firm access' to the market for connecting generating systems, consistent with an open access regime. Generators have no guarantee that they can export all of their output to the market. Therefore, generators do not pay for the use of the transmission or distribution network.

There are two important implications for generators of the philosophy underpinning the current connection and access framework for this rule change:

- proponents of generating systems connecting to the power system should not bear the cost of future, uncertain network developments, including the risk of generator retirements or to facilitate the connection of subsequent generators, and
- the access technical standards should be sufficiently flexible to allow the specific system conditions for a given generating system to be considered so that overall system costs can be reduced without unnecessarily compromising power system security and performance.

## III. Assessment framework for the proposed rule changes

The AEMC is required to assess whether a proposed change the NER, if made, is likely to promote the National Electricity Objective (NEO):

> 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

When considering the likely impact under the NEO the AEMC considered the following factors.

### *A. Maintaining system security at the lowest costs to consumers*

The objective of this rule change is to promote efficient investment in the power system, striking a balance between system security and the quality of power supply, and the price paid by consumers for that security and power quality.

Setting access standards that are too low can impose material costs on consumers through increased risks to power system security and requirements to operate the power system in an inefficient manner, such as through constraining the dispatch process.

Conversely, setting access standards that are higher than those needed to maintain power system security and quality of supply can also unnecessarily increase costs to consumers through higher generation costs. Excessively high access standards can also conflict with the intent of open access regimes.

### *B. Appropriate allocation of costs and risk*

Regulation should seek to allocate costs and risks to the parties that are best placed to bear and manage them.

Generators are best placed to make investment decisions regarding the costs of meeting access standards and the potential revenues that are available from energy and ancillary services markets. AEMO is best placed to manage system security risks, and performance standards should reflect the current risks posed to system security. Transmission and distribution network businesses are also best placed to make investment and operational decisions to meet their obligations regarding the secure and reliable operation of their networks and quality of supply provided to network users.

### *C. Regulatory certainty and flexibility*

Regulation should provide market participants with certainty regarding their respective roles and responsibilities. This certainty needs to be balanced with the need for flexibility to account for uncertain future outcomes. The process for setting performance standards should not pose an unnecessary inefficient barrier to entry.

Generator connection applicants should have a clear idea of what levels of performance they will be expected to meet so they can effectively factor in the cost of connection when making the decision to enter the market. AEMO and network service providers also need certainty that there will be sufficient capabilities from connecting generating systems so that the power system can be operated in accordance with the system standards.

### *D. Technology neutrality*

The access standards for connecting generators should be, to the greatest extent possible, technology neutral. That is, they should not present an inefficient barrier to entry for any technology type.

As a general rule, it is desirable for the access standards to be expressed in the same way for all technology types. However, the AEMC recognises that there are some inherent physical differences between technologies, such as between synchronous and asynchronous generating systems. Access standards that do not take these inherent physical differences into account may inadvertently impose inefficient barriers to entry for some technologies, which would not be consistent with the NEO.

## IV. Negotiation process for generator performance standards

Many international jurisdictions have grid codes that set out prescriptive, and often technology specific, requirements for the performance of equipment. However, usually some

[1] A comprehensive discussion of the current transmission framework in the National Electricity Market (NEM) is available in the stage 2 discussion paper of the AEMC's Coordination of generation and transmission investment review, available at: https://www.aemc.gov.au/sites/default/files/2018-04/EPR0052%20-%20Discussion%20Paper%20for%20publication%20180413.pdf .

flexibility is retained for the requirements to be adjusted for local power system conditions.

Flexibility in the technical performance requirements is provided in the NEM by allowing connecting generators to negotiate the levels of technical performance of their generating system with the market operator (AEMO) the relevant transmission system operator (TSO). This approach was adopted because it is considered that:

- Mandating a single set of standards would be inefficient as the cost of meeting mandated standards would vary dramatically for different types of plant.
- Some types of plant could be designed and built to significantly overachieve a mandatory standard at low cost, while other plant may be unable to achieve that standard other than at a prohibitive cost
- Although standards are defined for the system as a whole, the characteristics of the power system at individual connection points may be able to accommodate greater flexibility in some aspects of the standards.
- The need for technical standards to drive the integrity of the power system while facilitating the objectives of the market, including a level playing field for all technologies

When negotiating access standards, different parties to the negotiation have different objectives. Network service providers and AEMO have regard only to the needs of the power system at that location, whereas generators have regard to the cost and speed of the connection process. The ability to negotiate allows for both of these competing incentives to be balanced in a way that maintains system security at least cost.

The outcome of the negotiation process is bound by the ranges of allowable performance under each aspect of the access standards. These ranges are generally bound by an automatic access standard and a minimum access standard (see further below). Connecting generators have the choice to:

- Meet the automatic standard in cases where their chosen equipment can meet this standard easily or at low cost, which increases the speed of the connection process and meets the system security needs of the power system.
- Propose a negotiated access standard that can be lower than the automatic access standard but not lower than the minimum access standard, which may incur negotiation costs and potential delays to generator connection due to the negotiation process.

Given the incentives faced by connecting generators, they will only choose to enter into these negotiations when the associated costs are lower than the costs of meeting the automatic standard or if their chosen plant cannot meet the automatic access standard. This is a commercial decision for connection applicants.

AEMO and network service providers only have regard to the security needs of the power system and the quality of supply for network users. They can insist on a higher standard (up to the level of the automatic standard) if they consider that the proposed negotiated access standard is not sufficient to maintain system security and/or quality of supply, taking into account the power system conditions at that connection point.

In its draft determination the AEMC indicated what it considered where the appropriate roles of the automatic, minimum and negotiated access standards.

### *A. The automatic access standard*

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.

This means the automatic access standard should be set at a level that is a 'safe harbour' for connection applicants, and more importantly, for the power system and other network users. The automatic access standard is the level of performance that would be appropriate in any location of the power system, including under the poorest network conditions (relevant to that technical requirement) that are foreseeable across the power system.

### *B. Minimum access standard*

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) that are currently seen across the power system. This is the key distinguishing factor between the automatic and minimum access standards.

As the access standards should reflect local power system conditions, it may be appropriate to set a minimum access standard for some technical requirements at no capability. However, for other requirements such as fault ride through capability, the access standards should set the minimum level of performance that is acceptable when connecting to the power system.

### *C. Negotiated access standard*

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.

## V. Key Technical Changes Being Considered

The changes to the generator technical access standards being considered include the generating systems':

- ability to control their active power output, and capability to respond to changes in frequency if they choose to do so
- ability to supply and absorb reactive power, when needed for the power system, and capability to control voltage and reactive power
- ability to inject and absorb reactive current during disturbances, outside the normal voltage range

- ability to maintain continuous uninterrupted operation in the face of certain frequency and voltage disturbances, to manage the risk of cascading failures
- ability to operate at a low short circuit ratio (referred to as system strength) considered system strength.

This section will discuss some of these aspects of the proposed changes to the access standards.

*A. Reactive power capability*

In the NEM the responsibility for the provision of reactive power services has traditionally been shared between generators, network service providers, and loads. The current minimum access standards in the NER do not require a connecting generating system to provide any reactive power capability unless it is shown to be necessary to maintain power system security. As the generation-mix changes, some synchronous generating systems that have provided significant quantities of reactive power are operating less and exiting the power system.

In its draft determination, the AEMC retained the current minimum access standard for connecting generators of no reactive capability. This is consistent with the shallow connection framework in the NEM but still allows AEMO or the network businesses to require up to 39.5% reactive power injection and absorption where this is required for power system security at the time of connection. The AEMC considers this provides flexibility so that an appropriate level of performance can be negotiated so the needs of the power system can be met at the lowest cost to consumers.

*B. Withstanding disturbances – continuous uninterrupted operation*

It is important for power system security that generating systems have the ability to keep operating when faced with a voltage or frequency disturbance. In the NER this is referred to as maintaining 'continuous uninterrupted operation'. Generating systems that cannot maintain continuous uninterrupted operation when faced with certain disturbances may increase the extent and severity of the disturbance experienced by other generating systems, potentially causing cascading failures and widespread blackouts.

Several of the access standards refer to continuous uninterrupted operation, including those in relation to frequency and voltage disturbances, multiple disturbances and load rejection.

At the start of the NEM the majority of generation was synchronous and the definition of continuous uninterrupted operation was simply focused on the generating unit not disconnecting. In 2007 the access standards were amended to accommodate asynchronous wind generation and the definition of continuous uninterrupted operation was changed to also require generating systems to support the power system with active and reactive power following the clearance of the fault causing the disturbance [4].

The increasing penetration of asynchronous generation in the NEM since 2007 has the potential to contribute to more frequent and severe disturbances in the power system. Therefore, AEMO's rule proposal and the AEMC's draft determination included further amendments to the definition of continuous uninterrupted operation, including a requirement to provide reactive power support during faults and disturbances.

*C. Reactive current response during disturbances*

Synchronous generating units inherently provide a response to a voltage disturbance by injecting or absorbing reactive current to support the power system voltage. Other types of generation, particularly asynchronous generation, do not inherently respond, as effectively if at all, and a response needs to be coded into their control systems.

The current automatic access standard in the NEM includes a requirement for reactive current injection, but not for absorption. As the existing access standard was designed in a time when synchronous units were the predominant generation type in the NEM, there were no specific response parameters included in either the automatic or minimum access standards. However, the above-mentioned changes in the generation mix means that voltage control is becoming more difficult and specifically defined requirements will become necessary for the reactive response magnitude, response thresholds, response duration, response speed and limits of asynchronous generators.

Therefore, in its draft determination, the AEMC retained the current access standard for synchronous generating units as it does not cause any system security concerns and these units have limited ability to alter their reactive current response during disturbances without incurring significant cost. However, as asynchronous units do not provide a similarly inherent response and can set their reactive response during a disturbance to meet specified parameters. In addition, the draft determination includes the new automatic and minimum access standard requirements listed in Table I, which apply solely to asynchronous units.

The AEMC received many submissions on its draft determination and is considering further refinements to these requirements prior to finalizing the changes to the NER in relation to the reactive current response required of generating systems during disturbances.

TABLE I. DRAFT ACCESS STANDARDS FOR REACTIVE RESPONSE DURING DISTURBANCES

| Draft access standard | | |
|---|---|---|
| ***Response*** | ***Automatic*** | ***Minimum*** |
| Magntude:<br>• capable of the maximum continuous rated current of the generating system for each 1% reduction in voltage<br>• capable of the maximum continuous rated current of the generating system for each 1% increase in voltage | 4%<br><br>6% | 2%<br><br>2% |
| Response speed:<br>• rise time of no greater than<br>• settling time of no greater than<br>• must be adequately damped | 40 ms<br>70 ms | 40 ms<br>70 ms |
| is maintained until the connection point voltage recovers to between 90% and 110% of normal voltage | | note a |

a. the minimum access standard includes exemptions to the response duration requirements for over-voltages below 120% and under-voltages below 80%. This is to accommodate inverter based generating systems that rely on fast acting under-voltage and over-voltage ride through modes to deliver a reactive response during a disturbance.

*D. Over-voltage and undervoltage disturbance withstand requirements*

Changes in the generation mix are also increasing the difficulty of managing voltages in the power system. This was observed following the recent network separation events in South Australia, including the black system event of 28 September 2016, and temporary over-voltages in future may also exceed the existing system standard. This risk has increased following the implementation of the special protections scheme in South Australia that automatically sheds load to increase the stability of the power system following a separation event.

The AEMC draft determination included the changes to the automatic and minimum access standards for over- and under-voltage presented in Table II.

Since the publication of the draft determination, the AEMC has received feedback on the voltage disturbance requirements. The main concerns raised by stakeholders included:

- the 20 minute overvoltage requirement for voltages between 110 and 115% normal voltage could impose significant costs as it would effectively be a steady-state requirement
- the over-voltage requirements of the automatic access standard for connecting generators exceed those of the system standard the network businesses must meet for credible contingencies

The AEMC will consider stakeholder views and decide on the appropriate access standards for voltage disturbance requirements in its final determination, due at the beginning of October 2018.

TABLE II. DRAFT ACCESS STANDARDS FOR VOLTAGE DISTURBANCES

| Draft access standard | | |
|---|---|---|
| ***Voltage range (% normal voltage)*** | ***Automatic*** | ***Minimum*** |
| over 130% for at least | 0.02 seconds | - |
| 125% to 130% for at least | 0.2 seconds | - |
| 120% to 125% for at least | 2 seconds | - |
| 115% to 120% for at least | 2 seconds | 0.1 seconds |
| 110% to 115% for at least | 20 minutes | 0.9 seconds |
| 90% to 110% | continuously | note a |
| 80% to 90% for at least | 10 seconds | 5 seconds |
| 70% to 80% for at least | 2 seconds | 2 seconds |

a. continuously, provided the ratio of the voltage to the frequency (as measured at the connection point and expressed as a percentage of normal voltage and a percentage of 50Hz frequency, respectively) does not exceed 1.15 for more than 2 minutes or 1.1 for more than 10 minutes.

*E. Over-voltage and undervoltage disturbance withstand requirements*

AEMO considered that all types of generating systems need to be resilient to successive disturbances, and considered that the level of this capability was a significant factor in the South Australian black system event of 28 September 2016 [2]. It is also likely that the ability of generating systems to withstand multiple disturbances from deeper faults is likely to become more important as fault levels in the NEM are reduce making disturbances propagate further. Further, it noted that the current access standards do not explicitly require a generating system to maintain continuous uninterrupted operation for multiple disturbances.

AEMO proposed changes to the automatic and minimum access standard for multiple disturbances that would require generating systems to be capable of continuous uninterrupted operation during and following up to 15 disturbances within any five-minute period for certain contingency and fault events, provided that none of the events would disconnect the generating unit from the power system by removing network elements from service. The proposed obligation would also be limited to an accumulated time below 90% voltage of 1.8 and 1.0 seconds for the automatic and minimum access standards respectively.

Many stakeholders considered that the changes proposed by AEMO were not clear and generally too arduous, particularly if it were applied to synchronous generating units. Therefore, AEMO revised its proposed changes to the requirements in Table III. Connecting generating systems must maintain continuous uninterrupted operation unless one of the four requirements in the table is exceeded.

TABLE III. DRAFT ACCESS STANDARDS FOR MULTIPLE DISTURBANCES

| Draft access standard | | |
|---|---|---|
| ***Criteria*** | ***Automatic*** | ***Minimum*** |
| Access standards intended for: | asynchronous generation | synchronous generation |
| 1. Total number of disturbances within five minutes (an unsuccessful auto-reclosure event is counted as two disturbances) | 15 | 6 |
| 2. Accumulated disturbance duration | 1800 ms | 1000 ms |
| 3. Sum of $\Delta V$ x $\Delta t$ | 1.0 pu seconds | 0.5 pu seconds |
| 4. Number of deep disturbances (below 50% normal voltage) | 6 | 3 |
| Sliding window reset time | 5 minutes | 5 minutes within 30 minute period |
| Minimum time difference between successive disturbances | no restriction | 200 ms |
| Fault types | up to 3 balanced | unbalanced only |
| disturbances cleared by a breaker fail protection system | 1 | 1 |
| long-duration shallow disturbances, e.g. 80% residual voltage for 2 seconds | 1 | 1 |
| deep three-phase disturbances (or two deep three-phase disturbances in parts of network where a three-phase auto-reclosing is permitted) | 1 | - |

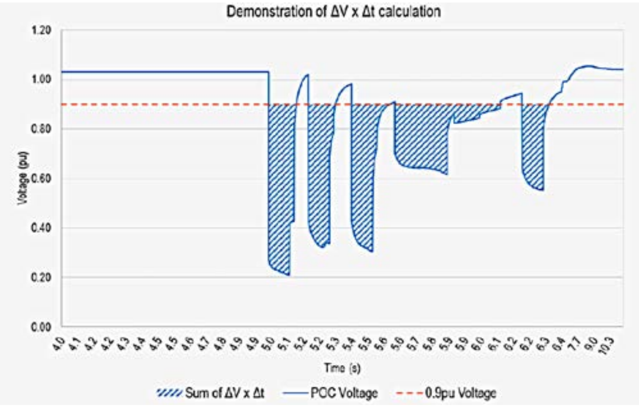


Figure 2. Illustrative example of ΔV x Δt calculation

As part of the proposed changes to the specification of the access standards, AEMO introduced a new concept of ΔV x Δt, which is illustrated in Figure 2. The blue curved line is a hypothetical voltage profile at the connection point and the red dashed horizontal line indicates 90% of the normal voltage. The shaded area is defined as the sum of ΔV x Δt for a given connection point voltage profile and is measured in per unit seconds (pu seconds). When the shaded area exceeds 1.0 per unit seconds (0.5 per unit seconds for the minimum access standard) the generating system is no longer required to maintain continuous uninterrupted operation.

Stakeholders raised a number of concerns with the approach in the draft determination for multiple disturbances included:

- the probabilistic nature of the requirements, and hence the difficulty proving compliance at the time of connection, with the potential requirement to perform an excessive number of system studies to cover the range of possible combinations of disturbances
- whether compliance would require the generating system to comply with 100% of the combinations of disturbances studies, or some lower percentage
- the difficulty for the Australian Energy Regulator (AER) to prove compliance or non-compliance following a severe system incident, given that it is unlikely that the precise combination of disturbances would have been considered at the time of connection
- whether the operation of a protection system, such as pole slip protection on synchronous generating units or instability protection on asynchronous generating systems, would provide an exemption for continuous uninterrupted operation.

At the time of writing, the AEMC is working with AEMO, the AER and other stakeholders to resolve these concerns. The AEMC will then decide on the appropriate access standards in its final determination, due at the beginning of October 2018.

### F. *Conclusions*

In addition to the issues discussed above, the AEMC considered a range of other issues as part of this rule change assessment, including active power control, frequency control, capability to operate at low short circuit ratios and remote monitoring requirements. Details on these additional issues can be found in the AEMO rule change request and the AEMC draft determination, with the final determination expected at the beginning of October 2018.

Assessing the rule change proposal, in the context of a changing generation mix, has highlighted the need for regular reviews of the technical access standards for connecting generators in the NER. Therefore, a framework for AEMO to review the access standards in the NER at least every five years is introduced as part of the draft determination, a timeframe which captures the pace at which the generation mix may change in future. Under the NEM governance arrangements, this would not preclude AEMO or any other stakeholder submitting a request for changes to the access standards within the five years.

## Acknowledgements

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