RECOMMENDED TECHNICAL STANDARDS FOR GENERATOR LICENSING IN SOUTH AUSTRALIA

ADVICE TO ESCOSA

Published: **31 March 2017**

AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

IMPORTANT NOTICE

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EXECUTIVE SUMMARY

Context

The South Australian electricity industry has the opportunity to demonstrate to the world how a large power system can successfully operate with high volumes of non-synchronous generation. Success will require all industry stakeholders to work together, including recognition from emerging technology providers that they are no longer fringe players and must play a central role in the future operation of the power system. All types of generators should incorporate features that will allow them to contribute towards a secure and resilient power system where it is cost-effective to do so.

The National Electricity Market (NEM) is undergoing fundamental structural changes as Australia transitions from a centrally managed power system supplied by large thermal generators to a more complex system with a variety of generation technologies at both utility and household scales. These changes have been driven by numerous factors, such as the Renewable Energy Target, the natural asset lifecycle of large generation assets, reductions in generation technology costs, and changing consumer preferences. A characteristic of this transition is the displacement of synchronous generation[1] by non-synchronous generation.[2]

These changes have occurred at a faster pace in South Australia (SA) than in the rest of the NEM. Since AEMO's previous advice to ESCOSA on generator licence conditions in 2010, the proportion of non-synchronous generation capacity in the SA region has increased from 20% to over 43%, with this trend expected to increase in the future.

With the highest level of non-synchronous generation in the NEM, both in gross terms and as a proportion of maximum/minimum demand, SA's unique generation mix affects how the power system operates both under normal operating conditions and in response to disturbances.

As a result, it is necessary and prudent to put in place a framework that has regard to current and expected future levels of non-synchronous generation in order to maximise the availability of essential system security services in SA.

In June 2016, ESCOSA commenced a review of the regulatory, licensing, and associated arrangements for connection of new electricity generators in SA. ESCOSA sought advice from AEMO in relation to two matters:

- The currency of the existing special licence conditions relating to technical standards for wind farms connecting to SA's electricity network, and
- Whether there is merit in additional or amended technical requirements being imposed on other power electronic connected generation technologies (such as photovoltaics (PV)).

This report represents AEMO's current advice to ESCOSA on these matters. It builds on the results of a number of current and recent AEMO investigations, including AEMO's Future Power System Security program[3], and analysis into the 28 September 2016 state-wide blackout in SA. It also takes into account stakeholder feedback received by ESCOSA during the consultation on its issues paper.

[1] Synchronous generators can be fuelled using coal, gas, diesel, hydro, solar thermal, or geothermal sources. They produce electricity via a rotating shaft with a stator and rotor that is directly connected to the power system by electromagnetic coupling

[2] Non-synchronous generators include wind farms, or solar PV generators, and batteries that export power to the grid. They are connected to the power system by power electronics and do not have an electromagnetic coupling directly connecting the generator to the network

[3] See https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/FPSSP-Reports-and-Analysis for information about the program and work undertaken so far.

Principles guiding AEMO's recommendations

Long term interests of consumers

ESCOSA's final decision on generator licence conditions must have regard to its primary statutory objective, which is to protect the long-term interests of SA consumers with respect to the price, quality, and reliability of essential services.

AEMO has sought to ensure that these recommendations are consistent with this objective.

A national approach to technical standards

AEMO seeks to maintain a NEM-wide, technology-neutral approach to generator performance standards, and believes that the long-term interests of consumers will be best met with a consistent national Rules framework.

The need for state-based technical standards indicates that the generator performance standards, as defined in the National Electricity Rules (NER), require updating to reflect the needs of the changing power system. AEMO believes the NER should be updated as soon as practicable, and intends to submit a Rule change to the Australian Energy Market Commission (AEMC) by July 2017, proposing appropriate revisions. AEMO is also exploring options to align technical standards for generation in Western Australia with those in the NEM.

In the interim, to guarantee the capabilities of the generation fleet in SA, AEMO sees it as appropriate to maintain special licence conditions that apply only in SA, because of the unique characteristics of its power system.

AEMO expects that its recommendations to ESCOSA in this report will form a key consideration in its upcoming Rule change request to the AEMC. Ideally, any new licence conditions imposed by ESCOSA would be transitional arrangements that are eventually able to be repealed, in whole or in part, when the technical standards in the NER are updated.

Looking to the future

In developing these recommendations, AEMO has sought to establish a set of generator technical standards that will be capable of supporting a secure power system throughout the energy transition.

AEMO has considered how system security services could reasonably be provided under a number of plausible future scenarios, including:

- Increasing periods where less synchronous generation is dispatched.
- Periods where no synchronous generation would be economically dispatched within the region.
- Periods of low, zero, or negative operational demand[4] due to increasing volumes of generation within the distribution network.

Under such scenarios, the electricity industry must seek new ways of obtaining the range of non-energy system security services[5] that have been historically provided by synchronous generators.

4 Broadly, this means SA's entire electricity demand could be offset by rooftop PV (which is treated as "negative load" because it is located behind the electricity meter, on a customer's premises). In this case, surplus rooftop PV generation would be exported interstate via an interconnector. More formally, operational demand in a region is demand that is met by local scheduled generating units, semi-scheduled generating units, and non-scheduled intermittent generating units of aggregate capacity ≥ 30 MW, and by generation imports to the region. It excludes the demand met by non-scheduled non-intermittent generating units, non-scheduled intermittent generating units of aggregate capacity < 30 MW, exempt generation (such as rooftop PV, gas tri-generation, and very small wind farms), and demand of local scheduled loads.

5 These non-energy system security services include voltage control, frequency control, synchronous inertia, and provision of fault current.

Applying technical standards only where efficient to do so

The recommendations in this paper are designed to be applied as part of a broader package of reforms.

Technological improvements over the last decade mean modern plant often includes additional functionality that can help to stabilise the power system, even though most system security services have not been an inherent characteristic of non-synchronous generators in the past.

AEMO's recommendations are designed to take advantage of technological developments that provide additional capability at low additional cost.

Higher standards have only been recommended where AEMO considers that a technical standard applied to generators is likely to be the most efficient way of addressing an identified technical issue.

It is unlikely to be efficient to require generators to solve all technical issues arising as a result of the energy transition. Where it is no longer efficient to source the requisite system security services from generation, there are a range of alternative solutions, including establishing market frameworks and/or identifying new roles for network businesses to play in maintaining a secure power system.

Conditions should apply to all generation types, not just wind

Unless there are unavoidable technical reasons why a given technology cannot provide a particular service characteristic, AEMO recommends that standards should apply consistently to all generation types (greater than 5 MW). The recommendations in this paper refer to generating systems that meet this threshold.

Any generating unit installed today is likely to remain in service for at least the next 20 years, and will plausibly need to operate when there is very little synchronous generation online. Accordingly, AEMO is recommending that ESCOSA apply consistent licence conditions on all new generators (regardless of technology), such that the SA generation fleet is equipped with the capabilities it needs to provide a secure and resilient power supply for the life of the assets.

Where there are intrinsic physical differences between synchronous and non-synchronous generators, the final licence conditions may need to articulate two similarly intentioned licence requirements.

Applying this philosophy, AEMO has focused on the fundamental needs of the system, as well as what can reasonably be expected from all generators in the future. In some cases this will increase the range of capabilities expected from synchronous generation, while also acknowledging it is no longer practical to treat non-synchronous generators as fringe players.

Application of conditions to existing generators

Much of the current generation fleet in SA will remain in service for a similar timeframe to any new generating units.

In order to improve system security and resilience outcomes in the shorter term, consideration should be given to deriving additional capability from the current generation fleet.

Accordingly, AEMO recommends that ESCOSA consider how some capabilities could be obtained from existing generation in South Australia, with due regard to:

- The physical limitations of some existing generating units.
- The likely cost of enabling the capability for each generating unit.
- The incremental benefits that would be gained by enabling existing generating units.

AEMO will work with ESCOSA and stakeholders to undertake this assessment of the existing generation fleet.

Technical recommendations

On the basis of the principles outlined above, AEMO has developed a comprehensive set of recommendations for generation licence conditions in SA, including modification of existing licence conditions where appropriate, and the incorporation of a number of new conditions.

For the fundamental system security services of inertia and fault current, AEMO does not see it as practical or efficient to source these solely from generators into the future. In these cases, AEMO has recommended ESCOSA consider licence conditions on network service providers (NSPs).

AEMO's recommendations are summarised below.

Static and dynamic reactive power requirements

AEMO recommends that ESCOSA replace the current special licence conditions relating to reactive power capability[6] with a new set of licence conditions, defined in terms of a generator's performance during and subsequent to contingency events and system disturbances.

The proposed conditions build on the existing benchmark for reactive power capability in the SA region, but will better align with the intended use of this capability. Generating systems will still be required to supply sufficient amounts of reactive power to meet performance obligations as specified within the generator performance standards negotiated under NER Schedule 5.2.5 and defined in ESCOSA's licence conditions.

Voltage control capability

Flexibility in the control characteristics of generation enables operation of the power system to be optimised. The ability to use the reactive power capability of a generating system to control voltage during normal operations allows the power transfer capability of the power system to be maximized.

AEMO recommends that the existing licence conditions relating to voltage control[7] be clarified with more precise wording, but be substantially retained.

While the licence conditions generally reflect the NER requirements, the NER do not impose mandatory voltage control for generating systems connection to systems connected at less than 100 kV. AEMO considers that voltage control within distribution networks is highly beneficial, and for this reason recommends retention of the current special licence conditions.

Performance during and subsequent to contingency events

To ensure that generating systems provide supportive and coordinated responses during and after contingency events, AEMO proposes that the performance of generating systems should be more explicitly defined than is presently covered in the NER or in the current ESCOSA generator licensing conditions.

AEMO's proposed conditions prescribe performance of generating systems during contingency (fault) events, in the recovery period following clearance of faults events, in the event of multiple contingency events occurring, and for voltage disturbance (under and over voltage) events.

AEMO recommends ESCOSA's licence conditions for disturbance ride-through be amended to cover:

- Active power and reactive power responses to a variety of network disturbances.
- Under and over voltage disturbance ride-through.
- A requirement for generating systems to remain in continuous uninterrupted operation for a number of repeated fault events.
- Partial load rejection.
- Stronger frequency disturbance ride-through capabilities.

[6] ESCOSA, Licence conditions for wind generations - model licence conditions May 2010, clauses 10.1, 10.2, 10.3, and 10.4. Available at: http://www.escosa.sa.gov.au/ArticleDocuments/800/100503-ElectricityGeneration-ModelLicenceConditions_2010.pdf.aspx?Embed=Y

[7] ESCOSA, Licence conditions for wind generations - model licence conditions May 2010, clauses 10.5, 10.6, and 10.7.

These performance requirements have been specified to ensure that all generating systems act in a coordinated manner to support the network insofar as possible during contingency events, and maximise the resources available to stabilise and secure the power system after contingency events.

Inertia

AEMO does not recommend that ESCOSA introduce any generator licence conditions associated with the provision of inertia.

A static technical obligation on generators to provide inertia when operating would not:

- Lend itself to co-optimisation of inertial requirements with other power system attributes such as system strength.
- Lend itself to optimisation of locational distribution of inertia.
- Necessarily deliver a secure power system.

The AEMC is considering a proposed Rule change regarding the arrangements for investment and dispatch of inertia and fast frequency response (FFR) services in the NEM.

However, given the importance of maintaining a minimum amount of inertia in the SA power system regardless of generator dispatch patterns, ESCOSA may wish to consider whether the procurement of inertia services for SA could be expedited through appropriate licence conditions for NSPs.

Fast frequency response

Analysis has shown that enabling FFR services in the NEM may allow the frequency operating standards to be met with a lower level of synchronous inertia, and potentially a lower long-term cost. However, there is little global experience in procuring or operating FFR, and careful consideration of the specific requirements of the NEM will be required.

AEMO's recommendations regarding active power control capabilities are seen as broadly compatible with FFR provision from generators, without (at this stage) prescribing specifically how these responses must be delivered.

Therefore, AEMO does not recommend additional licence requirements specifically for FFR capability.

System strength

AEMO currently sees a need for two sets of obligations in parallel to address the underlying drivers for reductions in system strength:

- Obligations on NSPs to provide well-defined network characteristics to all connecting parties at the connection point regardless of generator dispatch patterns and the number of synchronous generators online, and
- Efficient allocation of responsibility to parties who impact system strength.

On this basis, AEMO recommends that ESCOSA consider:

- A licence condition on NSPs to:
  - Maintain a short circuit ratio at each connection point within a range agreed in each Connection Agreement. To ensure efficiency, the agreement should be clear on the system conditions (e.g. during normal system conditions) or the percentage of time for which the NSP would agree to maintain the agreed short circuit ratio.
- Licence conditions on connecting generators to ensure that their plant is designed to maintain certain standards, taking into account the network conditions prevailing at the time, including
  - A generator licence condition to meet its GPS at the connection point for the range of short circuit ratios agreed with the NSP in the Connection Agreement (and which the NSP has undertaken to maintain).
  - An obligation that susceptible items of plant (for example, individual generating units, dynamic reactive power support plant, and battery storage units) within the connecting party's generating

system must be capable of operating in a stable manner down to a certain system strength at the terminals of each item of plant.

Active power control facilities

AEMO recommends that all new generators in SA have active power control facilities with the capability to provide the following services:

- Automatic active power response to frequency changes.
- Automatic generation control.
- Controlled rate of change of active power.
- Remote monitoring requirements.

These capabilities must be installed and fully tested at the time of plant commissioning, including the development of accurate simulation models. Where the generation is dependent on an inherently variable energy source, testing and commissioning of these capabilities must be performed under a range of energy input conditions.

These recommendations would not require the active power control capabilities listed above to be made continuously active, or bid into existing markets for frequency control services, but they must be continuously available for service. They may be used voluntarily by the generation operator, when directed to do so by AEMO, or when required to do so under other arrangements with the local NSP.

To be considered available, AEMO proposes that all new generators be required to register with AEMO for the provision of regulation and contingency frequency control ancillary services (FCAS).

Ability to assist with system restart

At its current state of development, non-synchronous generation technology is unable to provide system restart ancillary services (SRAS) capability. This primarily stems from the source intermittency and the need for a minimum system strength or fault level which is not available during black system conditions.

However, their contribution to voltage and reactive power control during system restoration could be important once sufficient synchronous machines have been restarted to provide the minimum fault level required for stable operation of non-synchronous generating units, dynamic reactive support plant, and battery storage units.

AEMO recommends that ESCOSA require certain capabilities from all new entrant generators to speed up system restoration following a major supply disruption.

Simulation models

Operational experience with the SA power system has identified a need for clearer guidelines regarding the simulation models generators need to provide during the connection process.

Until such time as these guidelines have been revised under the NER framework, AEMO recommends that, as a part of the licence application process for new generators, ESCOSA emphasise the following:

- The provision of more detailed models will be required where standard generating system models are deemed insufficient.
- Adjustment of control systems and/or settings of individual generating system elements will be required[8] if the submitted models exhibit uncharacteristic or unexpected responses.
- Pre-validation against the actual response of generating system elements, including all protection or control systems deployed with the operational generator will significantly reduce risks of non-compliance in the commissioning process set out in the NER.[9] Pre-validation of simulation models can be demonstrated using a type test approach.

8 Refer NER clause S5.2.4
9 Refer to NER clause 5.7.3 (a)

Regular updates to ESCOSA framework

The energy transition means that new technical issues affecting operation of the NEM are likely to continue to emerge. New opportunities are also likely to become available as manufacturers respond to the global energy transition. As this transition progresses, the regulatory framework must also evolve to maintain the security and reliability of the power system. In some cases, these emerging issues are most efficiently addressed via new or updated technical standards.

AEMO believes there would be merit in establishing a framework that allows the technical standards to be regularly updated to reflect changing power system needs and technological developments.

AEMO proposes that ESCOSA consider the costs and benefits of establishing a framework whereby the technical standards that apply to generator licence conditions are reviewed periodically.

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FIGURES

1. INTRODUCTION

ESCOSA is reviewing the regulatory, licensing, and associated arrangements for connection of new electricity generators in South Australia (SA), and sought advice from AEMO in relation to two matters:

- The currency of the existing special licence conditions relating to technical standards for wind farms connecting to SA's electricity network.
- Whether there is merit in additional or amended technical requirements being imposed on other inverter-connected generation technologies (for example, photovoltaics (PV)).

This report draws on the results of a number of AEMO programs, including the Future Power System Security program[10]and the investigation into the 28 September state-wide blackout in SA. It also takes into account stakeholder feedback received by ESCOSA in response to its issues paper.

This chapter sets out the background to AEMO's recommendations, by describing the:

- SA energy market transformation.
- Key principles guiding our recommendations.
- Context of the review.

AEMO's recommendations set out the technical requirements that should be addressed by ESCOSA's licence conditions, rather than proposing specific drafting of the licence conditions themselves.

AEMO understands that ESCOSA will prepare any revisions to the existing licence conditions following the publication of this report, subsequent stakeholder consultation, and consideration of feedback received during the consultation process.

1.1 South Australian energy transformation

The Australian electricity landscape is transforming rapidly. Conventional thermal generation is being displaced by wind and solar PV, at both the utility and household level. At the same time, consumers are becoming more active in how their energy demand is met.

This trend is changing the technical and operational characteristics of the power system. While these changes are taking across the whole National Electricity Market (NEM), some technical and operational challenges are emerging more acutely in SA. Partially as a result of its high quality wind and solar resources, the generation mix in SA has changed faster than in the rest of the NEM.

1.1.1 Composition of the South Australian electricity generation mix

The electricity generation mix in SA has changed in the past year, notably through the end of coal-fired generation in the state. Renewable generators now represent approximately 43% of SA's local installed capacity (2,297 megawatts (MW)), with gas-fuelled and liquid-fuelled thermal generators providing the other 57% (2,987 MW).

Energy previously supplied by Northern Power Station is now largely being provided from Victoria via the Heywood and Murraylink interconnectors. Net imports comprised more than one fifth of the total electricity consumption in the region (22%) for the six month period from July 2016 to December 2016.

Figure 1 provides an overview of capacity and generation output over this period.

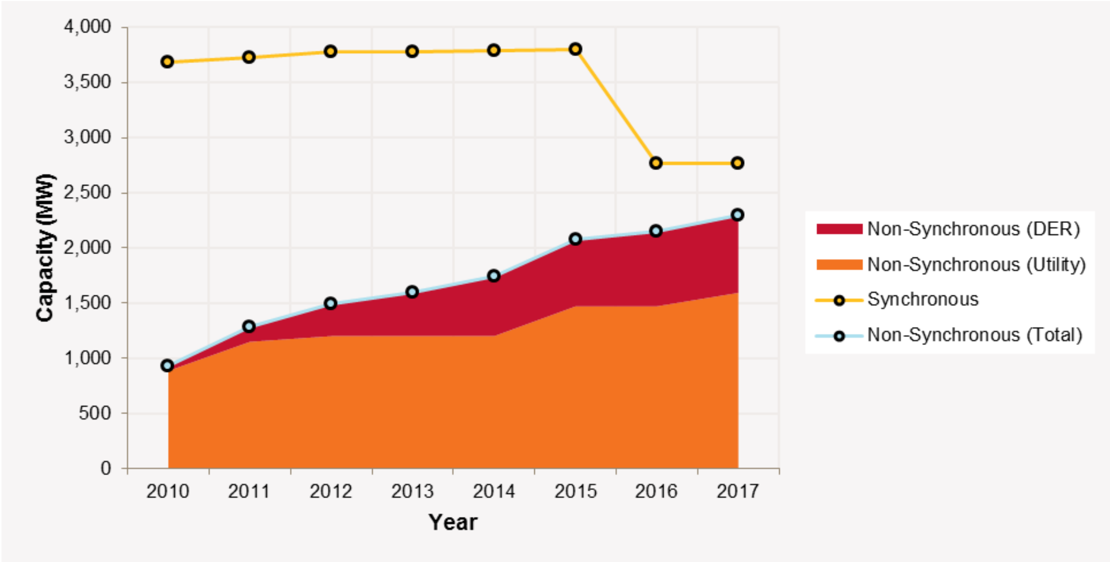
[10] https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/FPSSP-Reports-and-Analysis

Figure 1 South Australian registered capacity and generation output in July – December 2016

Note: Rooftop PV installations are not registered with AEMO, but are included here given their material contribution to generation. Estimates are from the *2016 National Electricity Forecasting Report* (NEFR).

Figure 2 shows how the SA generation mix has changed over the past seven years, with the state now having almost equal amounts of synchronous[11] and non-synchronous[12] generation capacity. The important physical distinctions between these two types of generation are discussed in Section 1.1.3.

Figure 2 South Australian generation capacity by year

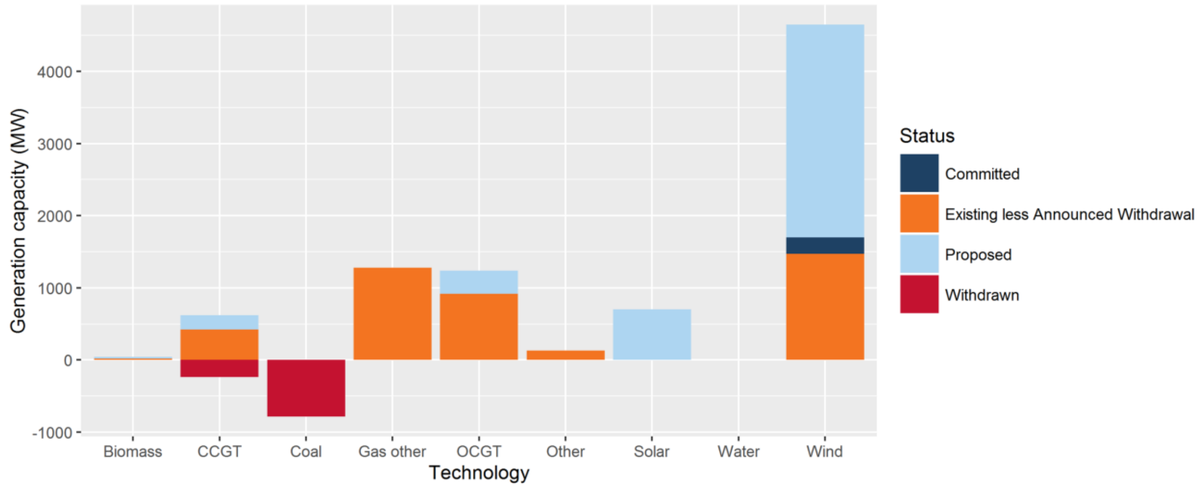


[11] Synchronous generation refers to generation whose operation is tightly 'synchronised' to the operating frequency of the power system and includes generation technologies such as coal, gas, diesel, hydro, and solar thermal. For example, in a power system operating at a normal frequency of exactly 50 Hertz (Hz), or 50 cycles per second, the rotating parts of synchronous generating units (such as the stator and rotor) will be electromagnetically coupled to the power system and spinning in step with system frequency. Synchronous machines respond exactly in lock step to any changes to power system frequency.

[12] Non-synchronous generation refers to generation whose operation is not directly synchronised to the frequency of the power system and includes wind farms, solar PV, and battery systems. These generation sources are connected to the grid through a power electronic converter which includes a conversion from direct current (DC) to alternating current (AC). Converters are typically designed to artificially create a frequency that follows the frequency of the power system.

AEMO expects that the generation mix in South Australia will continue changing. Figure 3 shows that proposed and committed projects are predominantly wind and solar, whereas withdrawn generation is either coal or gas.

Figure 3 Capacity of existing or withdrawn generation, and committed or proposed projects (MW)

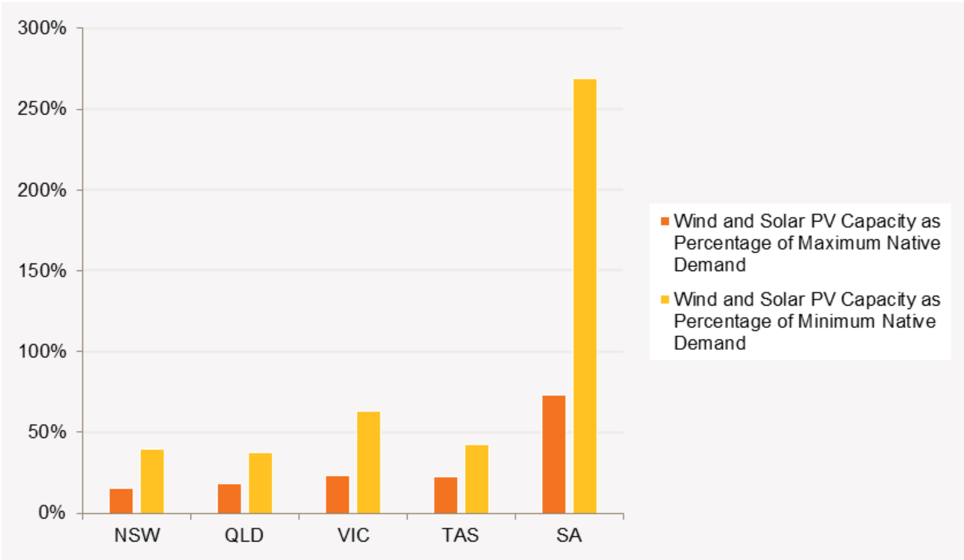


A further issue for SA is that it has only a single alternating current (AC) interconnector connecting it to the rest of the NEM. When the Heywood Interconnector trips or is unavailable, SA's power system becomes synchronously isolated (or islanded) from the rest of the NEM. In these cases, it is necessary for SA's power system to be capable of maintaining a secure operating state on its own.

1.1.2 South Australia in comparison to the rest of the NEM

Figure 4 shows each NEM region's wind and solar PV capacity as percentage of minimum and maximum native demand.[13] [14]

Figure 4 Wind and solar PV capacity as percentage of forecast 2016 minimum and maximum native demand for each NEM region



With the highest level of non-synchronous generation in the NEM, both in gross terms and as a proportion of maximum/minimum demand, SA's unique generation mix affects how the power system operates both under normal operating conditions and in response to disturbances.

As a result, it is necessary and prudent to put in place a framework that has regard to current and expected future levels of non-synchronous generation in order to maximise the availability of essential system security services in SA.

1.1.3 Declining availability of system security services

Security of supply is a measure of the power system's capacity to continue operating within defined technical limits, even on the disconnection of a major power system element such as part of an interconnector or a large generator.

In addition to the generation and transfer of energy, a range of non-energy services are required to successfully operate a power system. These include:

- Voltage control.
- Frequency control.
- Inertia.
- System strength.

These services are traditionally referred to as "ancillary services" as they have historically been provided as a by-product of energy production by conventional synchronous plant. This report refers to them as *system security services* to highlight their crucial role.[15]

[13] Native demand refers to the demand that is met by local scheduled, semi-scheduled, non-scheduled, and exempt generation (including rooftop solar PV) and by generation imports to the region, excluding the demand of local scheduled loads.

[14] Wind and utility-scale solar PV capacities are sourced from the AEMO Generation Information page at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Generation-information. Minimum and maximum native demand and rooftop solar PV capacities are sourced from the 2016 NEFR, available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Electricity-Forecasting-Report.

[15] The use of the term "ancillary services" implies that these services are less valued within the power system compared to energy. This may have been true historically, but as the generation mix changes, the role of ancillary services are increasing in importance. Internationally, there has been a shift in terminology to recognise this change, with EirGrid now referring to these services as System Services, and the NYISO referring to them as Essential Services.

As non-synchronous wind and PV generation displaces conventional synchronous generation, it becomes necessary to put in place new measures to ensure the ongoing provision of system security services.

Non-synchronous generation technologies, including wind, PV, and storage, have a number of physical attributes that differentiate them from synchronous fossil-fuelled and hydro generation technologies.

Synchronous generators have heavy rotating components, which are made to spin by varying electro-magnetic forces (an electro-magnetic coupling) at a rate that is always directly proportional to the electrical frequency of the power system as measured at the generator's terminals. Due to this direct electro-magnetic coupling, synchronous machines respond instantaneously to disturbances in the power system.

In contrast, non-synchronous generation technologies are primarily connected to the grid through power electronic converters (principally inverters), which are based on fundamentally different physical principles to conventional synchronous generation.

Some examples of different attributes include:

- The heavy rotating parts that synchronous generators utilise to produce electricity have a physical inertia that acts to resist changes to rotational speed. Because of the property of inertia to resist changes in momentum, synchronous generators are able push back against changes in frequency, providing an inherent and automatic service to the power system. Generation technologies that connect through power electronic converters do not inherently provide this service.
- Frequency regulation is a central process operated by AEMO, where generation output is adjusted over short timeframes to control power system frequency close to the nominal 50 Hertz (Hz). The capability to modify active power output to assist in frequency regulation can be enabled in most synchronous generation, but to date has not been a feature of most non-synchronous generation technologies in the NEM.
- Contingency frequency control capability is provided by generating plant configured to automatically increase or decrease its active power output in response to locally measured changes in power system frequency, in order to correct frequency back towards the nominal 50 Hz. This capability is again typically available from synchronous generation technologies, but historically has not been a feature of non-synchronous generation technologies in the NEM.
- Contribution to system strength refers to the availability of fault current to support detection of faults on the power system. The value of fault level contribution of non-synchronous generators is low compared to synchronous generators. The concept of system strength is further discussed in Chapter 5.

These different characteristics require new measures to maintain the power system in a secure operating state.

While system security services have not been an inherent characteristic of non-synchronous generators in the past, technological improvements over the past decade mean modern plant often includes additional functionality that allows it to provide some system security services.

In these circumstances, it is appropriate to consider amending the generator licence conditions to ensure South Australians benefit from these technical improvements.

1.2 Context of the review

This section outlines the context of this review. It discusses international precedents and other related reviews including AEMO's investigation into the SA system black event.

1.2.1 International precedent

SA is not alone in introducing additional technical requirements on non-synchronous generators, with a number of international jurisdictions having updated their technical requirements applicable to non-synchronous generating units.

In preparing its recommendations for ESCOSA, AEMO has reviewed relevant international grid codes to understand how other jurisdictions are specifying the future requirements of their generating fleet.

While these international standards are not necessarily indicative of the appropriate standards for Australia to adopt, due to different power system characteristics, they underline the importance of regular review of connection conditions to confirm their ongoing suitability for future conditions. Relevant international grid code examples are provided throughout this report to support AEMO's recommendations.

1.2.2 Related reviews

A key piece of context is the SA system black event that occurred on 28 September 2016. There are also a number of relevant Rule changes either underway or being prepared, and AEMO is undertaking a holistic review of frequency control ancillary services (FCAS) markets.

South Australian black system investigation

AEMO has investigated the sequence of events that caused the SA power system to collapse, including the identification of root causes and potential remedial actions.[16] This investigation has driven a number of our recommendations.

Relevant Rule change processes

The AEMC has recently finalised its decision with respect emergency frequency control schemes[17], which provides for:

- A risk assessment process to determine a class of network contingencies which should be managed as 'protected events'.
- A new regime to implement Emergency Frequency Control Schemes which would manage the system frequency when it is in the extreme band.

This new Rule will provide an improved framework for the management of risks associated with extreme power system conditions, with immediate applications in SA.

The AEMC is also currently considering Rule changes on inertia, FFR, and system strength. These decisions will affect the provision of certain system security services, and are discussed in Chapters 3 and 5.

In addition, AEMO is working on a Rule change proposal to amend the NEM technical standards, using the recommendations in this paper as a starting point. This review is intended to establish a national approach to technical standards and is discussed further in Section 1.3.2 below.

Frequency Control Ancillary Service market review

Stakeholders have raised a number of concerns about current FCAS markets. While a review of FCAS markets is beyond the scope of the ESCOSA licence condition review, ensuring all generators have the capability to provide frequency control services, whatever form future FCAS markets may take, is within scope and is addressed in Chapter 6.

[16] Reports on the event are available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Market-notices-and-events/Power-System-Operating-Incident-Reports.

[17] http://www.aemc.gov.au/Rule-Changes/Emergency-frequency-control-schemes-for-excess-gen

AEMO has been exploring challenges around frequency control and system strength as part of its FPSS program. This work has now been consolidated into a broader review of future system services to maintain a holistic approach to meeting future power system security challenges. Through its approach, this program seeks to:

- Determine the technical needs of the power system now and into the future in terms of key services ancillary to energy.
- Assess whether current frameworks are fit-for-purpose to meet these future needs (including technical and/or regulatory barriers, or practicality and market efficiency).
- Assess the capabilities of new and existing technologies and/or business models (such as aggregators of distributed energy resources) in providing these services.
- Assess whether market efficiencies can be gained by considering the capabilities of emerging technologies.
- Provide a basis to inform technical, regulatory or policy solutions.

AEMO aims to present a transparent and holistic picture to stakeholders of this work program, including the timing of current and forthcoming consultations. One of the key tools AEMO will use in order to achieve this outcome is the formation of an industry advisory group on ancillary services as a basis for industry contributions, testing of AEMO proposals and to bring new ideas to AEMO.[18]

1.3 Key principles guiding our recommendations

In preparing these recommendations, AEMO has sought to develop a set of technical standards for SA that meet the changing needs of the power system, taking into account the principles discussed below.

1.3.1 Long-term interests of consumers

ESCOSA's decision must have regard to its primary statutory objective, which is to protect the long-term interests of SA consumers with respect to the price, quality, and reliability of essential services.

AEMO has sought to ensure that these recommendations are consistent with this objective.

1.3.2 A national approach to technical standards

AEMO seeks to maintain a NEM-wide, technology-neutral approach to generator performance standards, and believes that the long-term interests of consumers will be best met with a consistent national Rules framework.

The need for state-based technical standards indicates that the generator performance standards, as defined in the NER, require updating to reflect the needs of the changing power system. AEMO believes the NER should be updated as soon as practicable, and intends to submit a Rule change to the AEMC by July 2017, proposing appropriate revisions. We are also exploring options for change in Western Australia.

In the interim, to guarantee the capabilities of the generation fleet in SA, AEMO sees it as appropriate to maintain special licence conditions that apply only in SA, because of the unique characteristics of its power system.

AEMO expects that its recommendations to ESCOSA in this report will form a key consideration in its upcoming Rule change request to the AEMC. Ideally, any new licence conditions imposed by ESCOSA would be transitional arrangements that are eventually able to be repealed, in whole or in part, when the technical standards in the NER are updated.

[18] The Ancillary Services Technical Advisory Group is open to all interested parties with technical expertise in ancillary services, though AEMO reserves the right to approve, reject, add or remove members at its discretion. The Advisory Group will initially run until the end of 2017, at which time AEMO will review the value of continuing the group taking into account its scope and objectives. Further details about the Advisory Group, including its Terms of Reference, can be found on AEMO's website or by contacting ancillaryservices@aemo.com.au.

1.3.3 Forward-looking standards that are robust to a changing generation mix

SA has made strong progress towards decarbonising its power system over the past decade, and this trend is likely to continue. In developing these recommendations, AEMO has sought to establish a set of generator technical standards that will be capable of supporting a secure power system throughout the energy transition.

AEMO has considered how system security services could reasonably be provided under a number of plausible future scenarios, including:

- Increasing periods where less synchronous generation is dispatched.
- Periods where no synchronous generation would be economically dispatched within the region.
- Periods of low or zero operational demand[19] due to increasing volumes of distributed energy resources (DER) within the distribution network.

Under such scenarios, synchronous generators alone will no longer provide sufficient system security services. Alternative means of procuring these services must be found, whether from non-synchronous generators (where it is reasonable to do so) or as network or non-network services (where services are still required under low operational demand scenarios).

Historically, system operators have relied on the inherent characteristics of synchronous generators to manage power system security. Non-synchronous generators such as wind and solar were viewed as peripheral technologies that were not expected to manage power system security. In fact, many grid codes were initially designed so these generators would trip off in response to a frequency or voltage disturbance.

With increasing penetrations of wind and PV, non-synchronous generators are no longer fringe players. These technologies are now core elements of the SA power system.

AEMO's advice recommends that all types of generators should be required to incorporate cost-effective features that will allow them to contribute towards a secure and resilient power system.

1.3.4 Apply technical standards only where efficient to do so

AEMO's recommendations to ESCOSA, if implemented, would be part of a broader package of reforms.

It is not efficient to require generators to solve all technical issues arising as a result of the energy transition. There are a range of alternative solutions, including establishing market frameworks and/or imposing conditions on network businesses.

For instance, while it would be possible to require all generators to provide a certain amount of inertia, the issue of reduced inertia may be more efficiently resolved through investment by a network service provider (NSP).

AEMO's recommendations are designed to take advantage of technological developments that provide additional capability at low additional cost.

Higher standards have only been recommended where AEMO considers that a technical standard applied to generators is likely to be the most efficient way of addressing an identified technical issue.

[19] Broadly, this means SA's entire electricity demand could be offset by rooftop PV (which is treated as "negative load" because it is located behind the electricity meter, on a customer's premises). In this case, surplus rooftop PV generation would be exported interstate via an interconnector. Operational demand in a region is demand that is met by local scheduled generating units, semi-scheduled generating units, and non-scheduled intermittent generating units of aggregate capacity ≥ 30 MW, and by generation imports to the region. It excludes the demand met by non-scheduled non-intermittent generating units, non-scheduled intermittent generating units of aggregate capacity < 30 MW, exempt generation (such as rooftop PV, gas tri-generation, and very small wind farms), and demand of local scheduled loads.

1.3.5 Conditions should apply to all generation types, not just wind

Unless there are unavoidable technical reasons why a given technology cannot provide a particular characteristic, the standards should apply consistently to all generation types (subject to a size threshold[20]).

In this respect, AEMO's recommendations have been developed with a view that they will apply to both synchronous and non-synchronous generation.

Any generating unit installed today is likely to remain in service for at least the next 20 years, and will plausibly see the scenarios proposed in Section 1.3.2. The consistent application of the proposed licence conditions across all generation technologies should give the SA generation fleet the capabilities it needs to provide a secure and resilient power supply for the life of the assets.

AEMO acknowledges that the final licence conditions may need to be adjusted for different technologies where there are fundamental physical differences between generation technologies.

With regard to the size threshold noted above, AEMO understands that ESCOSA may, on case-by-case basis, elect not to apply special licensing requirements for generators with nameplate capacity of 5 MW or less. AEMO supports this approach, which is broadly consistent with AEMO's standing registration exemption for small generating systems.[21]

AEMO notes however, that irrespective of plant size and whether ESCOSA waives application of special licensing conditions, all parties looking to connect generation will be obliged to engage with the relevant NSP in relation to applicable connection requirements.

Application of conditions to existing generators

Much of the current generation fleet in SA will remain in service for a similar timeframe to any new generating units.

In order to improve system security and resilience outcomes in the shorter term, consideration should be given to deriving additional capability from the current generation fleet.

Accordingly, AEMO recommends that ESCOSA consider how some capabilities could be obtained from existing generation in South Australia, with due regard to:

- The physical limitations of some existing generating units.
- The likely cost of enabling the capability for each generating unit.
- The incremental benefits that would be gained by enabling existing generating units.

AEMO will work with ESCOSA and stakeholders to undertake this assessment of the existing generation fleet.

[20] Under the SA Electricity Act 1996, all electricity generators which have a nameplate output of greater than 100 kVA must obtain a licence from ESCOSA.

[21] For more information, refer to AEMO's Guide to NEM Generator classification and exemption, available at: http://www.aemo.com.au/-/media/Files/PDF/Generator-Classification-and-Exemptions-Guide.pdf

1.4 Terminology and interpretation

The technical chapters of this report often refer to the access requirements in clause S5.2.5 of the NER. Terms shown below in italics are defined in Chapter 10 of the NER. In interpreting the generator performance standards (GPS) in the NER, it is useful to keep in mind:

- A generating system is defined in the NER as:
  - A system comprising one or more *generating units* and includes auxiliary or reactive plant that is located on the Generator's side of the connection point and is necessary for the generating system to meet its performance standards.
- Each of the defined performance requirements applies to the generating system including each of its generating units and all auxiliary and reactive plant.
- Continuous uninterrupted operation is defined in the NER as:
  - In respect of a *generating system* or operating *generating unit* operating immediately prior to a *power system* disturbance, not *disconnecting* from the *power system* except under its *performance standards* established under clauses S5.2.5.8 and S5.2.5.9 and, after clearance of any electrical fault that caused the disturbance, only substantially varying its *active power* and *reactive power* required by its *performance standards* established under clauses S5.2.5.11, S5.2.5.13 and S5.2.5.14, with all essential auxiliary and *reactive plant* remaining in service, and responding so as to not exacerbate or prolong the disturbance or cause a subsequent disturbance for other *connected plant*.
- All active power requirements are subject to energy source availability and any other requirements relating to active power control.
- Voltage levels are referenced to power frequency voltage, calculated as root-mean-squared (RMS) values.
- Voltage disturbance ride-through requirements apply to all three-phases including the phase which experiences the largest deviation from the normal voltage.
- Satisfactory disturbance ride-through must be achieved for successful and unsuccessful auto reclose events including single-pole and three-pole auto-reclosing.
- GPS requirements are applied concurrently, and, in the context of AEMO's recommendations in this report, it is of particular note that the requirements of NER clauses S5.2.5.3, S5.2.5.4 and S5.2.5.5 apply concurrently.
- The generating system must be stable and meet its performance requirements for all system conditions, including anticipated system strength.

2. REACTIVE POWER CAPABILITY

Reactive power is vital to the integrity of power systems. The provision and control of reactive power:

- Supports power flow through the transmission network.
- Manages voltages to within required limits.
- Ensures the system is able remain intact and recover from minor and major network disturbances.

2.1 Existing reactive power capability requirements

The current licence conditions describe not only the reactive power capability required from a generating system, but also the required dynamic characteristics and the *manner* of control – that is, the means through which network voltages are managed.

The manner or type of voltage control required specifies how generators can act to support voltage on the power system, both during normal operations and during and following network disturbances.

The provision of dynamic reactive power is important in ensuring control of voltages and power flow during normal operations, and in assisting with voltage recovery and stabilisation after a network fault. Small adjustments to reactive power help keep voltages within normal limits during normal operations as load and generation varies. Large adjustments in reactive power are essential to support the network during disturbance and to aid recovery after a disturbance has been removed. The provision of continuously variable and dynamic capability enables the amount of reactive power provided to the system to be accurately controlled to optimise the system condition.

At a local level, enhanced voltage recovery assists in active power recovery. On a broader system level, sufficient voltage and active power recovery supports short and longer term voltage stability, facilitating a more resilient system.

The existing wind licence conditions[22] for reactive power capability are stated below.

REACTIVE POWER CAPABILITY

10.1 The electricity generating plant operated by the licensee must at all times be capable of continuous operation at a power factor of between 0.93 leading and 0.93 lagging at real power outputs exceeding 5 MW at the connection point.

10.2 The electricity generating plant operated by the licensee must at all times be capable of providing:

(a) subject to clause 4(b), at least 50% of the reactive power required to meet the power factor referred to in clause 1 on a dynamically variable basis; and

(b) the balance of the reactive power required to meet the power factor referred to in clause 10.1 on a non-dynamic basis.

10.3 At generation levels below full rated output the electricity generating plant operated by the licensee must be capable of:

(a) absorbing reactive power at a level at least pro-rata to that of full output; and

(b) delivering reactive power at a level at least pro-rata to that of full output.

10.4 For the purposes of clause 2(a):

(a) dynamically variable means continuous modulation of the reactive power output over its range, with an initial response time or dead time of less than 200 milliseconds and a rise time (as defined in clause S5.2.5.13 of the NER) of less than 1 second following a voltage disturbance on the network; and

[22] ESCOSA, Licence conditions for wind generations - model licence conditions May 2010. Available at: http://www.escosa.sa.gov.au/ArticleDocuments/800/100503-ElectricityGeneration-ModelLicenceConditions_2010.pdf.aspx?Embed=Y

(b) for a period of not more than 2 seconds on any single occasion, a short-term overload capability may be used to meet the 50 percent requirement, provided that use of that short-term overload capability does not cause a breach of any other licence condition.

10.5 The reactive power capability of the electricity generating plant operated by the licensee must be capable of control by a fast-acting, continuously variable, voltage control system which is able to receive a local and remote voltage set point.

10.6 The electricity generating plant operated by the licensee must be able to operate at either a set reactive power, or a set power factor, which is able to be set locally or remotely at any time.

10.7 The power factor or reactive power control mode of the electricity generating plant operated by the licensee must be capable of:

(a) being overridden by voltage support mode during power system voltage disturbances; and

(b) automatically reverting to power factor or reactive power mode when the disturbance has ceased.

2.2 Benefits of the current licence conditions for reactive power

The existing ESCOSA special licence conditions require provision of a defined set of reactive power capabilities. This set of capabilities is currently described in terms of the required characteristics of reactive power capability used in nominal plant operation, and some additional requirements regarding the deployment of that reactive power capability to respond to voltage disturbances and provide voltage support.

AEMO considers that the capabilities of generators to provide reactive power through these licence conditions has delivered direct and indirect benefits to generating systems and to the network. These provisions provide enhanced ability to control and support local network voltages during normal operating conditions, and facilitate optimal power transfer capability within the SA network.

The existing licence conditions also ensure wind farm facilities have the inherent capability to meet other aspects of their licencing and performance obligations. Reactive power capability enables wind farms to meet some of their generator performance requirements as negotiated under the NER. While the NER does not use the term ‘dynamic’ in describing reactive power requirements, dynamic (or continuously adjustable) control of reactive power is the fundamental attribute necessary to meet numerous system and performance standards requirements.

The following NER requirements each rely on the dynamic provision and control of reactive power:

- Continuous uninterrupted operation requirements, specified in NER clause S5.2.5.4.
- Voltage support requirements, specified in NER clause S5.2.5.5.
- Voltage and reactive power control requirements, specified in NER clause S5.2.5.13.

Static (or ‘non-dynamic’ in the existing ESCOSA licence conditions) reactive support devices are ordinarily used to provide harmonic filtering capability, facilitating a generator’s ability to meet the performance obligations negotiated under NER clause S5.2.5.2.

A power system requires reactive support in many forms and locations. Reactive power support from wind farms and other generating systems is as important in managing network stability as reactive support plant operated by NSPs from within transmission and distribution networks.

The amount of reactive power required at each connection point will vary over time, based on many factors such as the local network characteristics, whether the connection is to a transmission or distribution network, and the nature of load and generation patterns. The specific requirements for provision of adequate reactive power support will vary based on whether the system is operating normally or abnormally as a result of a disturbance in the power system.

The existing ESCOSA conditions specify an amount of reactive power, equivalent to a power factor of 0.93 leading and lagging. The required amount of reactive power is proportional to the amount of active power being supplied.

The basis for this requirement was derived from the automatic standard for NER clause S5.2.5.1, although the level of performance necessary to meet the licence requirement is lower than the standard (because it is specified as a power factor).

As noted above, large adjustments in reactive power are essential to support the network during disturbance and to aid recovery after a disturbance has been removed. Given the weak system conditions in SA that can allow voltage dips to propagate across much of the state's network (discussed further in Section 5.1), and the risk associated with multiple generators going into fault ride-through simultaneously (discussed further in Chapter 3), the presence of dynamic reactive support close to the point of connection for non-synchronous generation is increasingly important to prevent wide areas of generation from entering fault ride-through mode simultaneously.

As a result of the existing ESCOSA licence conditions, many wind farms in SA are supported by local dynamic reactive support. This often prevents the voltage dip resulting from a disturbance from being observed at the wind turbine terminals, helping to improve the resilience of the SA power system.

As the penetration of non-synchronous generation increases in SA, the provision of dynamic reactive support close to every connection point will become essential to operate the SA power system securely.

2.3 Technical recommendations

2.3.1 Reactive power capability

Several respondents to ESCOSA's inquiry have provided feedback on the necessity, usefulness, efficiency, and cost of the existing licence conditions in relation to reactive power capability. AEMO has taken these views into account in its overall consideration of the issues.

The reduction of synchronous generation capacity in SA since the last review of the wind licence conditions in 2010 has increased reliance on the growing amount of wind generation in the region.

AEMO notes that the reactive power capability of many non-synchronous generating systems recently connecting, or applying for connection, in other NEM regions would actually exceed the ESCOSA wind licence condition requirements. This may indicate that compliance with these conditions is not necessarily a barrier to non-synchronous generators connecting in SA.

For these reasons, AEMO recommends that ESCOSA replace current special licence conditions 10.1, 10.2, and 10.3 relating to reactive power capability with the set of recommended licence conditions described in Chapter 3.

These proposed conditions build on the existing benchmark for reactive power capability in the SA region, while better describing how it will be used. In making this recommendation, AEMO notes that generating systems will still be required to supply sufficient amounts of reactive power to meet the generator performance standards negotiated under NER schedule 5.2 and defined within ESCOSA's licence conditions.

2.3.2 Provision of dynamic reactive power

As noted above, AEMO considers the provision of dynamic reactive power fundamental to the operation of the power system.

When the ESCOSA licence conditions were first applied, the provision of dynamic reactive power by wind farms was not typical. The generation plant often had limited reactive capability, and, where reactive support was required, it was normally provided with the assistance of capacitor banks.

The specification of dynamic reactive power capability in the ESCOSA licence conditions has enabled wind farms to ride through most faults and, as a result, support operation of the SA region over the past 10 years. This condition has helped to accommodate the connection of considerable volumes of wind generation.

The technology included in modern wind turbines and inverters has now developed such that much of the dynamic reactive capability required under the existing licence condition is now inherent within the plant, and reliance on separate auxiliary reactive plant is substantially reduced. The control systems associated with modern generation plant are highly sophisticated and have developed over time to meet the needs of grids around the world.

Recognising this technical development, AEMO recommends that the current dynamic reactive power requirements conditions in clause 10.4 of the ESCOSA special licence conditions be removed and replaced with specific requirements relating to disturbance ride-through. These requirements are described in detail in Chapter 3.

2.3.3 Voltage control capability

Flexibility in the control characteristics of generation enables optimised operation of the power system. The ability to use the reactive power capability of a generating system to control voltage during normal operations allows the power transfer capability of the power system to be maximized.

AEMO recommends that the existing special licence conditions relating to voltage control be retained.

While the licence conditions generally reflect NER clauses S5.2.5.13 and S5.2.5.5, the NER do not impose mandatory voltage control for connection to generating systems rated at less than 100 kV. AEMO considers that voltage control within distribution networks is highly beneficial, and for this reason recommends retention of licence conditions 10.5, 10.6, and 10.7.

To ensure adequate voltage control and aid clarity in application of these conditions, AEMO recommends the licence conditions be reworded as shown below.

Voltage control

10.5 The generating system operated by the licensee must be capable of control by a fast-acting, continuously variable, voltage control system. The voltage control system must:

- be able to receive a local and remote voltage setpoint; and
- be negotiated to address each of the criteria listed under the automatic standards for NER clause S5.2.5.13.

10.6 The generating system operated by the licensee may operate at either a set reactive power, or a set power factor, which is able to be set locally or remotely at any time.

10.7 The voltage, power factor or reactive power control mode of the generating system operated by the licensee must be capable of:

(a) being overridden by the disturbance ride through requirements during power system disturbances; and

(b) automatically reverting to the selected control mode when the disturbance has ceased.

3. DISTURBANCE RIDE-THROUGH CAPABILITY

3.1 Statement of issues

The ability of generating systems to maintain continuous uninterrupted operation during and following system disturbances is essential to the secure and reliable operation of any power system.

The ESCOSA special licence conditions currently specify the types of disturbances for which wind generating plant must remain in continuous uninterrupted operation.

Analysis of the performance of various generating systems during recent major system disturbances has highlighted the need to ensure that all generating systems are able to provide support to the network both during and after disturbances.

As well as providing support to the network during single credible contingency events, all types of generating systems need to be resilient to repetitive disturbances. This was a significant factor in the September 2016 SA black system event. It is imperative that the learnings from assessment of that event are leveraged and incorporated into industry best practice, to minimise risk exposure of the power system in the future.

A scenario-based assessment of the impacts of simultaneous ride-through of generators is presented in Appendix X of AEMO's final report on the 2017 black system event.[23]

Finally, the response of the system to the operation of special protection schemes needs to be secured. AEMO proposes to increase the capability of the generating systems to withstand over voltage conditions and load shedding events, to ensure recovery from events that trigger special protection schemes which can have the unintended consequence of introducing short-term over voltages.

3.1.1 Existing fault ride-through requirements

The existing wind licence conditions[24] require that:

FAULT RIDE THROUGH CAPABILITY

9.1 Each generating unit which the licensee is authorised to operate under this licence must comply with:

- (a) the automatic access standards for generating system response to disturbances following contingency events specified in clause S5.2.5.5(b)(1) of the NER; and
- (b) subject to clause 9.2, the automatic access standards for generating system response to disturbances following contingency events specified in clause S5.2.5.5(b)(2) of the NER; and
- (c) subject to clause 9.3, the automatic access standards for generating system response to voltage disturbances specified in clause S5.2.5.4 of the NER.

9.2 The licensee is not required to comply with clause 9.1(b) in respect of a generating unit which the licensee is authorised to operate under this licence where:

- (a) the minimum access standard requirements specified in clause S5.2.5.5(c)(2) of the NER in relation to generating system response to disturbances following contingency events; and
- (b) the requirements of clauses S5.2.5.5(d), (e) and (f) of the NER are satisfied in respect of that generating unit.

[23] AEMO, 2017, *Black System South Australia 28 September 2016 – Final Report*. Available at: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Market_Notices_and_Events/Power_System_Incident_Reports/2017/Integrated-Final-Report-SA-Black-System-28-September-2016.pdf.

[24] ESCOSA, Licence conditions for wind generations - model licence conditions May 2010. Available at: http://www.escosa.sa.gov.au/ArticleDocuments/800/100503-ElectricityGeneration-ModelLicenceConditions_2010.pdf.aspx?Embed=Y

9.3 The licensee is not required to comply with clause 9.1(c) in respect of a generating unit which the licensee is authorised to operate under this licence where:

(a) AEMO and the relevant network service provider have agreed, pursuant to clause 5.2.5.4(c)(3) of the NER, that there would be no material adverse impact on the quality of supply to other network users or of power system security as a result of that non-compliance; and

(b) The requirements of clauses S5.2.5.4(c), (d), (e) and (f) of the NER are otherwise satisfied in respect of that generating unit.

AEMO supports retention of the existing fault ride-through capability requirements, in particular those in licence condition 9.1.

Further clarity in terms of the scope of the licence conditions and the performance of generating systems during and immediately following clearance of a fault would help to enhance the resilience of the SA network.

It is also important that the licence conditions refer to generating systems, rather than only generating units, to ensure the overall performance of all plant within a facility is coordinated and supports the network.

The current licence conditions nominally require wind farms in SA to meet the automatic access standards specified under NER clauses S5.2.5.5 and S5.2.5.4. The licence conditions allow for certain aspects of the automatic standards to be waived, should the requirements for negotiated access standards specified under NER clauses S5.2.5.5 and S5.2.5.4 be met. As AEMO must always ensure that negotiated access standards meet the minimum NER requirements, items 9.1(b) and 9.1(c) of the licence conditions as presently specified are rarely applied.

Model licence condition 9.1(b) relates to the automatic access standard defined under NER clause S5.2.5.5(b)(2), which describes the required capacitive current contribution during a fault, reactive power support during fault recovery, and active power recovery of a generator after fault clearance. Each of these matters are material to power system security during and following disturbances.

Active power recovery

NER clause S5.2.5.5(b)(2)(iii) requires generating systems to recover their active power output to 95% of the pre-disturbance level from 100 milliseconds following fault clearance. While synchronous generators can normally achieve this, wind farms take between 100 milliseconds and more than 1 second to fully recover their active power output.

AEMO is concerned that slow active power recovery from generation within SA after a major disturbance would result in an increased power transfer across the Heywood Interconnector. This, in turn, leads to greater risk of the interconnector suffering loss of synchronism and disconnection, which would lead to islanding of the SA region. SA is particularly exposed to these risks under conditions of high imports from Victoria.

The phenomenon of transient instability due to major loss of generation in SA will inherently lead to voltage instability.

To manage the root cause of this risk, AEMO recommends that a minimum active power recovery level and associated time period are a mandatory component of the licence conditions. This recommendation is discussed in detail in Section 3.3.1 – Active power injection requirements.

Reactive current injection and reactive power support

NER clause S5.2.5.5(b)(2)(i) specifies that a generating system and each of its generating units must be able to supply capacitive reactive current of up to 4% of the maximum continuous current of the generating system (in the absence of a disturbance) for each 1% reduction of connection point voltage.

Further, NER clause S5.2.5.5(b)(2)(ii) requires that, after disconnection of a fault, a generating system is able to supply or absorb sufficient reactive power to ensure the connection point is within the range for continuous uninterrupted operation under clause S5.2.5.4.

Each of these reactive power requirements is necessary to support power system recovery from disturbances. While not all plant may be able to meet the automatic standard, specification of an adequate level of performance is important to system security.

AEMO recommends minimum reactive power support requirements during and after faults be included in the licence conditions. These recommendations are discussed in detail in Section 3.3.1 – Reactive current injection requirements.

Voltage disturbance ride-through

NER clause S5.2.5.4 defines the continuous uninterrupted operation requirements for a range of voltage disturbances. As the SA power system operates with a relatively lower level of system strength, it is expected that voltage disturbance events may become more widespread.

For this reason, AEMO considers that the highest level of performance for voltage disturbances be mandatory. These recommendations are discussed in detail in Section 3.3.1 – Voltage disturbance ride-through.

3.2 Risks and opportunities

The NEM is now operating with a technology mix and demand profile that was not envisaged when arrangements were being made to establish an interconnected Australian electricity market in the 1990s.

It is clear from assessment of the changes made to international grid codes in the last decade, and from recent operational experience in the NEM, that important learnings are derived from operation of power systems under extreme conditions, and that supporting technical standards must be suitably updated to consider risks to the power system where these are exposed. This is particularly true when detailing requirements for generator performance during and after faults.

As large proportions of non-synchronous plant with similar disturbance response characteristics are regularly dispatched in the SA power system, the risks associated with poorly specified disturbance ride-through behaviour can be considerable:

- Failure to thoroughly specify performance requirements for plant under multiple fault conditions may expose elements of the power system to unnecessary damage or disconnection following multiple contingency events. If not addressed, this has the potential to cause economic loss in NEM regions, particularly if plant operation under extreme conditions leads to cascading generation failures and widespread load disconnection.
- Slower than necessary active power recovery in a region may place increased stress on interconnectors and other generating systems following disturbances, increasing risks to system security.
- Inadequate local voltage support through lack of reactive power injection during and following contingency events causes risk of transient voltage instability.

Without a reasonable and robust criteria for disturbance ride-through capability, the power system will be operated more conservatively under NER principles[25], resulting in reduced inter-regional transfer capabilities and potential constraints on generation under some conditions. This may result in diminished market access for some generators.

[25] For example NER 4.3.1 (e) and (f) require AEMO to observe the boundaries of the technical envelope and ensure the power system is operated within its limits.

For example, in Ireland, EirGrid responded[26] to risks caused by slow active power recovery of some wind farms following fault clearance by placing a constraint on the level of non-synchronous generation dispatched.

Considerable opportunities for more efficient power system operation could be realised through the introduction of more detailed disturbance ride-through requirements:

- Clear performance requirements for plant during and following contingency events will support expansion of the NEM technical envelope, allowing more efficient dispatch of available energy within a given region of the power system.
- Clear generator performance standards for operation during and after contingency events will provide opportunities for greater inter-regional transfer capability, and support economically efficient use of the generation fleet across the NEM as a whole.
- A proactive response to the trip of multiple generating units in SA in September 2016 will yield opportunities to avoid cascading tripping of generation in the future, minimising the risk of future significant supply disruption and consequential economic loss.

3.3 Technical recommendations

AEMO recommends that all new entrant generating systems in SA must have the disturbance ride-through capabilities described below.

The recommendations build upon the existing fault ride-through and reactive power provisions that have been applied in ESCOSA wind generation licenses since 2005.

The capabilities described here must be included in simulation models used by NSPs and AEMO to assess plant performance. This principle is consistent with AEMO's Rule change proposal on Generator Model Guidelines.[27]

Recommended requirements for simulation models are discussed further in Section 7.3.1.

3.3.1 Performance during and subsequent to contingency events

To ensure generating systems provide supportive and coordinated responses during and after contingency events, AEMO proposes that the performance of generating systems be more explicitly defined than in the current NER or ESCOSA generator licensing conditions.

Conditions are proposed to prescribe performance of generating systems during contingency (fault) events, in the recovery period following clearance of faults, in the event of multiple contingency events occurring, for voltage disturbance (under and over voltage) events.

AEMO recommends that both active power and reactive power responses to a variety of network disturbances are specified in ESCOSA's licence conditions for all plant.

Finally, AEMO recommends additional conditions to specify the requirement for generating systems to remain in continuous uninterrupted operation for a number of repeated fault events.

These performance requirements have been specified to ensure that all generating systems act in a coordinated manner to support the network insofar as possible during contingency events and ensure that in the period following contingency events, all available resources can be used to stabilise and secure the power system.

[26] *All Island TSO Facilitation of Renewable Studies*, 2009, available at: http://www.eirgridgroup.com/site-files/library/EirGrid/Facilitation-of-Renewables-Report.pdf
[27] Available at: http://www.aemc.gov.au/Rule-Changes/Generating-System-Model-Guidelines.

General principles

To provide context for our recommendations with respect to disturbance ride through capability, it is useful to understand the following aspects of the current NER framework:

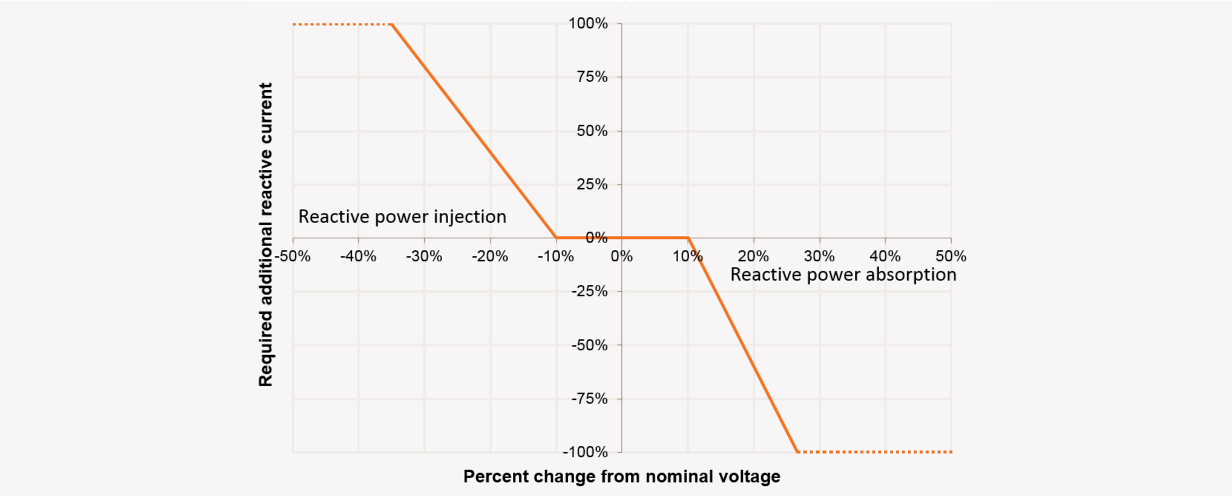
- While low voltage ride-through (LVRT) and high voltage ride-through (HVRT) requirements in the NER are defined at the connection point, the withstand capability of individual generating units is defined at the low voltage (LV) side of the generating unit's transformer. All individual generating units must remain connected for connection point voltages within the LVRT/HVRT withstand requirements, irrespective of generating system transformer's tap position.
- The LVRT activation threshold defined at LV terminals of the generating units/dynamic reactive support plant/battery storage units (if applicable) must not be less than 85% of normal voltage.
- As discussed in section 1.4, continuous uninterrupted operation means that for voltage disturbances within the continuous operating range (i.e. connection point voltage fluctuating within 90% and 110% of normal voltage), active power must be maintained (unless there has been a change in the intermittent power source) and reactive power must be managed to meet voltage control requirements.

Reactive current injection requirements

AEMO recommends that:

- The generating system must supply additional capacitive reactive current (reactive injection) of up to 4% of the maximum continuous current of the generating system (in the absence of a disturbance) for each 1% reduction of connection point voltage below 90% of normal voltage, as shown in Figure 5. Note that this requirement is defined at LV terminals of the generating units/dynamic reactive support plant/battery storage units (if applicable).
- The generating system must supply additional inductive reactive current (reactive absorption) of up to 6% of the maximum continuous current of the generating system (in the absence of a disturbance) for each 1% increase in connection point voltage above 110% of the normal voltage, as shown in Figure 5. Note that this requirement is defined at LV terminals of the generating units/dynamic reactive support plant/battery storage units (if applicable).
- The required reactive current may be limited to 100% of the rated current of the generating system (for example, maximum reactive current is required to be injected for connection point voltages of less than 65% normal voltage or for connection point voltages of greater than 135% of normal voltage).
- The reactive current injection must be maintained until the connection point voltage returns to within the range of 90% to 110% of normal voltage.

Figure 5 Recommended reactive power response requirements



The amount of reactive current injection required may be calculated using phase-to-phase, phase-to-ground, or sequence components of voltage. For the last method, the ratio of negative-sequence to positive-sequence current injection must be confirmed with AEMO and ElectraNet for various types of voltage disturbances.

Response characteristics

AEMO recommends that:

- A r*ise time*[28] no greater than 30 milliseconds (ms) and a s*ettling time*[29] no greater than 60 ms (consistent with German Gird Code requirements VDE-AR-4120) applies to reactive current injection requirements.
- The reactive current injection requirements described above apply for all pre-disturbance reactive power control modes (voltage control, power factor control, or reactive power control).
- The reactive current response must be *adequately damped*[30] as defined in the NER.
- Reactive power consumption upon application of a fault must not exceed 5% of maximum continuous rated current of the generating system and limited to the duration of rise time.
- The post-fault reactive power contribution of the generating system must be sufficient to ensure that the connection point voltage is within the range for continuous uninterrupted operation under clause S5.2.5.4.

Active power injection requirements

NER Clause S5.2.5.5 (b)(2)(iii) sets out a minimum active power recovery time of 100 ms following disconnection of faulted element. However, it does not set out the maximum permissible rate of active power recovery. AEMO proposes that active power should restore to at least 95% of the level existing just prior to the fault between 100 and 500 ms after disconnection of the faulted element. The exact active power recovery time should be determined by AEMO and ElectraNet for each specific connection depending on specific requirements.

Transient active power consumption upon application of a fault should not exceed one power frequency cycle and must not exceed 5% of the maximum continuous rated current of the generating system.

Multiple low voltage disturbance ride-through

The generating system – including each of its generating units, dynamic reactive power support plant, and battery storage units – must be capable of withstanding any combination of voltage disturbances resulting in the voltage at the respective LV terminals of the equipment to drop below 85% of the nominal for a total duration of 1,800 ms[31] within a 5-minute interval, regardless of disturbance type, duration, and residual voltage at the generating unit's terminals.

Note that this requirement applies in addition to the S5.2.5.4 requirements with respect to long-duration, shallow voltage disturbances.

Examples of conditions where successful fault ride-through response is required include:

- 15 faults each cleared within 120 ms.
- 18 faults each cleared within 100 ms.
- 5 faults each cleared within 220 ms + 7 faults each cleared within 100 ms.

The requirement on overall duration of multiple faults overrides what is currently applied by some equipment manufacturers in terms of number of successive faults. Where it is necessary to include protection settings that act on the number of faults, three or more different settings must be applied

[28] As defined in clause S5.2.5.13 of the NER.
[29] As defined in clause S5.2.5.13 of the NER.
[30] See the Glossary in Chapter 10 of the NER.
[31] The proposed requirement is determined by:
- Survey of a number of wind turbine and solar inverter manufacturers.
- Accounting for the maximum number of historical faults within 2, 30, and 120 minute intervals in Electranet's transmission network, as highlighted in AEMO's final report into the 28 September 2016 SA black system.

across the generating system to minimise loss of generation due to simultaneous disconnection of all individual generating units. In any case, the generating system must successfully ride through a total disturbance duration of 1,800 ms within a 5-minute moving window.

The total fault duration is the most critical factor in setting an acceptable level of generator performance, as it determines the amount of heat dissipated across the dynamic braking chopper or dump resistor connected to the power electronic converter's DC-link. Such a scheme is universally used for all modern type 3 and 4 wind turbines for enhanced fault ride-through capability.

Table 1 below compares the proposed requirements against the capability of a number of major wind and solar equipment manufacturers to withstand multiple fault conditions, and demonstrates that this capability is included as a standard feature by many technology providers.

The Danish[32] and German Grid Codes are the only grid codes known to AEMO with precise requirements on multiple fault ride-through capability. The need for definition of requirements for repeated disturbances has been acknowledged in a special report by the United States national reliability body, the North American Electric Reliability Corporation (NERC).[33] However, at the time of writing, no specific requirements have been defined.

Table 1 Capability of various types of wind and solar plant to withstand multiple faults

Manufacturer	Total fault duration withstand capability (ms)	LVRT activation threshold (% of nominal voltage)	Pre-set limit allowing maximum number of successful ride-through events	Compliant or able to modify operation to comply with the proposed requirements
Manufacturer 1	1,800–2,400	80	N/A	Yes
Manufacturer 2	Unknown	80	N/A	Unclear
Manufacturer 3	1,800-2,000	90	15	Yes
Manufacturer 4	>2400	90	20	Yes
Manufacturer 5	2000	60-80	N/A	Yes
Manufacturer 6	2000	85	10	Yes

High voltage disturbance ride-through

Measured responses obtained from the five relevant islanding events that have occurred in the SA power system indicate high temporary over voltages of up to 120% for several seconds.

To facilitate sustained islanded operation and mitigate the risk of consequential temporary over voltages, AEMO proposes that the generating system must maintain continuous uninterrupted operation for temporary over voltages for the magnitudes and durations specified in Table 2 and Figure 6 below.

If requested by ESCOSA during its public consultation on these proposed requirements, AEMO will liaise with generators to determine any possible limitations stemming from temporary over voltage withstand capability of surge arresters.

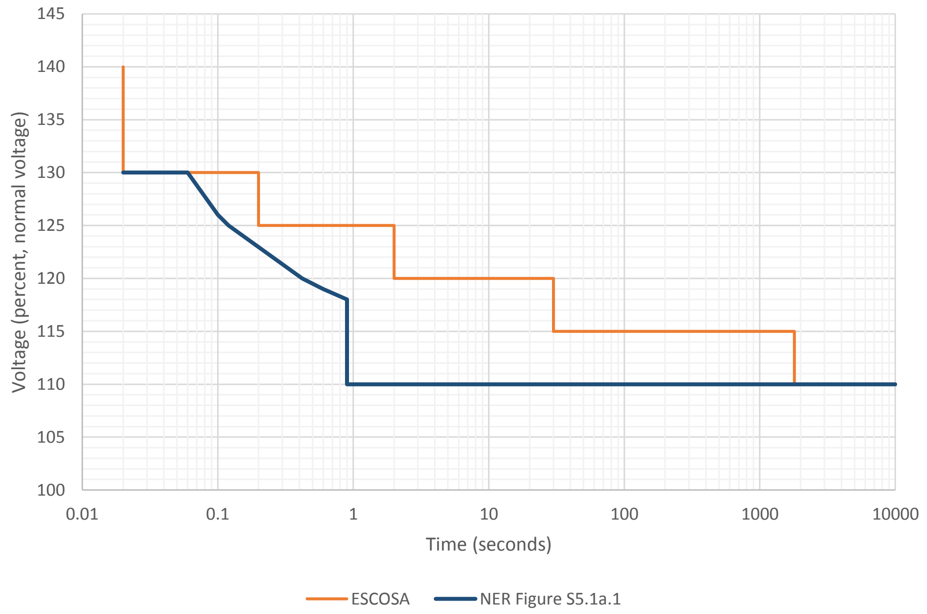
Table 2 Required over voltage withstand capability

Temporary overvoltage (% of normal voltage)	110–115	115–120	120–125	125–130	130–140
Duration(s)	1,800	30	2	0.2	0.02

[32] Energinet.DK, 2016,Technical regulation 3.2.5 for wind power plants above 11 kW, available at: https://www.energinet.dk/SiteCollectionDocuments/Engelske%20dokumenter/El/55986-10_v1_Grid%20Code%203%202%205_v%204%201-30%20%20September%202010.pdf

[33] NERC, 2012. *Special Assessment Interconnection: Requirements for Variable Generation,* available at: http://www.nerc.com/files/2012_IVGTF_Task_1-3.pdf

Figure 6 Comparison of proposed over voltage withstand requirements and present NER requirements



These requirements for operation under over voltage conditions have been developed by considering system study results and comparing these with the stated capability of a number of major wind turbine and solar inverter manufacturers, and two international grid codes. A comparison of over voltage withstand capability from equipment manufacturers and the international grid standards is in Table 3. Note the HVRT capability quoted by the OEMs is defined at the LV terminals of the generating units.

Table 3 Comparison of over voltage withstand capability of various wind and solar plant manufacturers and international grid standards

		Temporary overvoltage (%)				
		110–115	**115–120**	**120–125**	**125–130**	**130–140**
Duration (s)	**Manufacturer 3**	Continuous up to 114%, 60s thereafter	60	60	Not specified	0
	Manufacturer 5	Continuous	Continuous	2	2	1
	Manufacturer 6	3600	3600	2	2	0.1
	ENTSOE	Continuous up to 118%, 1200-3600 s thereafter	Not specified	Not specified	Not specified	Not specified
	Hydro Quebec	300	30	2	0.1	0.1
	NER Figure S5.1a.1	0.9	0.4-0.9	0.1-0.4	0.02-0.1	0.02 s for 130% only
	ESCOSA proposed	1,800	30	2	0.2	0.02

3.3.2 Partial load rejection

To facilitate the operation of SA as an island subsequent to a separation event including potential load shedding, it is essential that all generation is able to remain connected and contribute resources to restore stable and secure operation.

NER clause S5.2.5.7 (Partial load rejection) deals with generating systems' response to load reduction events, and the automatic standard requires that a generating unit maintain continuous uninterrupted operation for an event that results in a 30 % load reduction. NER clause S5.2.5.7 does not apply to non-synchronous generating units[34]. Given the heavy reliance by the SA power system on asynchronous generation, there is a risk that a separation or load shedding event could result in insufficient generation resources available to restore stable operation.

AEMO recommends that all generating systems in SA meet the automatic standard defined under NER clause S5.2.5.7.

3.3.3 Frequency disturbance ride-through

Wherever possible, a technology-neutral approach is preferred, applying identical standards to all technologies. However, the fundamental capabilities of synchronous and non-synchronous technologies to withstand rate of change of frequency (RoCoF) during extreme frequency disturbances differs significantly. This needs to be recognised, in order to target the highest possible capabilities for the future power system, without creating an unreasonable barrier to entry for certain technology types.

On this basis, the following technical standards are recommended, distinguishing between synchronous and non-synchronous technologies.

For non-synchronous (inverter-connected) technologies, the generating system must be capable of continuous uninterrupted operation for the following rate of change of frequencies:

- ±4 Hz/s for 250 ms.
- ±3 Hz/s for 1 s.

This is equivalent to meeting the existing automatic S5.2.5.3 standard, but with a higher level of performance required over a 1 second time period.

For synchronous technologies, the generating system must be capable of continuous uninterrupted operation for the highest feasible rate of change of frequency for the technology. Unlike non-synchronous generators that interface with the network via a converter, synchronous generation is directly connected to the power system via magnetic coupling. As a result, there are physical limits to the intensity and duration of RoCoF exposure that each synchronous generator can withstand before suffering damage.

For synchronous generators, AEMO recommends a negotiated access standard for continuous uninterrupted operation, for a range of RoCoF intensities as close as possible to the standard for non-synchronous generation shown above.

3.3.4 Voltage phase angle shift

The proposed requirements on voltage disturbance ride-through applies irrespective of the size of the positive - and negative - sequence phase angle shifts.

Additionally, the generating system must not include any vector shift or similar types of relays which might operate for phase angle changes less than 20 degrees.

It is noted that some European countries[35] use vector shift relays for anti-islanding at the distribution system level, which is typically set at 6–12 degrees. Such settings would result in premature tripping of the generating system which would have otherwise sustained larger phase angle jumps, and must not be included as part of the anti-islanding scheme for the generating system. Other suitable forms of anti-islanding will be assessed on a case-by-case basis.

[34] The actual text of S5.2.5.7 refers to 'asynchronous generating units'- for the purpose of interpreting this clause, the terms 'asynchronous' and 'non-synchronous' are equivalent

[35] For example, EirGrid and National Grid

4. INERTIA AND FAST FREQUENCY RESPONSE

4.1 Statement of issues

In an electrical power system, inertia can be thought of as a measure of the mass of all the rotating generating units synchronously connected to the power system. If a synchronous generating unit is online, it provides a fixed amount of inertia to the power system; if it is not operating, it provides no inertia.

A power system is made up of many generating units and motors connected together electrically (electromagnetically coupled) to the transmission and distribution networks. All generation connected together on the electrical system (synchronised) must spin at the same relative speed, or frequency. The rotating parts of synchronous generating units or motors provide inertia (a tendency to resist a change in motion, or a change in frequency) to the power system. This maintains synchronisation through power system disturbances that occur from time to time.

Synchronicity enables synchronous generation to provide an inertial response to deviations in power system frequency that could occur due to faults on the transmission system causing generation trips or load trips, which then cause an imbalance between supply and demand:

- If supply exceeds demand at an instant in time, system frequency will increase.
- If demand exceeds supply at an instant in time, system frequency will decrease.

How quickly the frequency increases or decreases is referred to as the “rate of change of frequency” (RoCoF)[36], and it depends on the size of the generation or load loss (contingency) that caused it, and the amount of inertia in the power system. The larger the contingency, the faster the frequency changes, while RoCoF is inversely proportional to the amount of inertia available on the power system. High system inertia resists the change in frequency and results in a slower, more manageable RoCoF.

If the power system has low inertia, its frequency will slow down or speed up very quickly if generation or load is lost, meaning less time is available for actions required to maintain frequency within acceptable limits.

Generation and load have automatic controls that trip in response to frequency reaching certain thresholds. If the RoCoF remains within acceptable limits, this tripping of load or generation can be utilised to arrest the frequency deviation, and help to return the power system to the normal frequency range. If, however, the RoCoF is outside those limits, the controls may not arrest frequency deviations in time, ultimately leading to a cascading failure of the power system.

The management of power system frequency within the limits in the Frequency Operating Standards (FOS)[37] will be an increasing challenge in operating a low inertia power system. To help address this challenge, new technologies are capable of providing a very rapid active power response to rapidly changing power system frequency conditions, referred to as fast frequency response (FFR).

AEMO has recently published the results of a study by GE Energy Consulting (GE), which explores the technical capabilities of non-synchronous sources to provide FFR[38], particularly with reference to controlling power system frequency under conditions of high RoCoF.

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[36] This is often also referred to as df/dt.

[37] The NEM Frequency Operating Standards are determined for the mainland NEM and Tasmania by the Reliability Panel. The mainland standard is available at: http://www.aemc.gov.au/Australias-Energy-Market/Market-Legislation/Electricity-Guidelines-and-Standards/Frequency-Operating-Standards-(Mainland)

[38] GE Consulting, *Technology Capabilities for Fast Frequency Response*, available at: http://aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/2017-03-10-GE-FFR-Advisory-Report-Final---2017-3-9.pdf AEMO cover note available at: http://aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/FFR-Coversheet-2017-03-10a.pdf.

Two key findings from this study were:

- Synchronous inertia and FFR are technically distinct services, due to the timescales over which they act, and the different effect they have on power system frequency control. The two services are therefore not fully interchangeable, and a minimum quantity of synchronous inertia will continue to be required in the short to medium term, to allow adequate control of power system frequency.
- FFR can help mitigate the effects of reduced synchronous inertia on power system frequency control. FFR services in the NEM may therefore help meet the FOS with lower levels of synchronous inertia. Trade-offs between these two services may be possible, considering the cost and availability of each service.

4.2 Risks and opportunities

While inertia has historically been provided predominantly by synchronous generators, in the future it may be more efficient to procure this service by alternative means. [39]

Some new sources of inertia (such as synchronous generation or synchronous condensers) will require long-term investment signals. Existing generators that provide inertia may also need to justify investment in maintaining their capacity or entering into new fuel contracts. Providing long-term certainty to potential service providers may reduce the overall cost of inertia delivery, and provide increased confidence that the inertia requirement will be met at all times.

There is likely to be value in developing an option that facilitates a “layered” approach to procuring inertia, consisting of a mix of short-term and long-term procurement strategies and incentives, with the aim of:

- Encouraging efficient outcomes in both long-term investment and short-term operation.
- Being responsive to changing power system and market conditions.
- Providing an opportunity for inertia procurement and dispatch mechanisms to adapt and mature over time in light of practical experience.

The balance between short-term and long-term procurement would need to be determined through careful market, technical, and economic analysis, as well as industry consultation. This could be adjusted over time in response to experiences in the market.

Initial analysis by AEMO suggests there may be future opportunities to co-optimise the amount of inertia procured with other services or power system parameters, such as FFR or prevailing contingency sizes. This would require flexibility in the volume of inertia dispatched at any given time, ideally in response to actual market conditions (for example, five minutes to 24 hours ahead of time). A means of comparing the marginal cost of additional inertia with the cost of other options, including potentially applying network flow constraints, would also be needed.

This could be achieved through a market mechanism, or through contracts with zero or low fixed availability payments. However, only a portion of the total inertia requirement is likely to be able to be substituted by other services, due to the technical requirements of grid operation, so procuring at least some inertia through long-term contracts may be most efficient in this regard.

Longer-term contracts might also facilitate the procurement of inertia in specific locations (for example, to assist with system strength, or to support regions at risk of islanding).

As the required level of inertia is not directly related to either the installed generation capacity or the instantaneous demand, relying solely on a static technical standard for generators is unlikely to deliver the flexibility required to achieve the most efficient outcome.

[39] This matter is discussed in AEMO’s recent submission to the AEMC’s System Security Market Frameworks Review: - http://www.aemc.gov.au/getattachment/94177d01-4833-413e-b012-99ba52113452/AEMO.aspx

4.3 Technical recommendations

4.3.1 Inertia

AEMO does not recommend that ESCOSA introduces any generator licence conditions associated with the provision of inertia. A static technical obligation on generators to provide inertia when operating would have drawbacks, as it would not:

- Lend itself to co-optimisation of inertial requirements with other power system attributes such as system strength.
- Lend itself to optimisation of locational distribution of inertia.
- Necessarily deliver a secure power system.

The AEMC is currently considering a proposed Rule change regarding inertia and FFR services in the NEM.

However, given the importance of maintaining a minimum amount of inertia in the SA power system regardless of generator dispatch patterns, ESCOSA may wish to consider whether the procurement of inertia services for SA could be expedited through appropriate licence conditions for NSPs.

4.3.2 Fast frequency response

The GE analysis recently published by AEMO (see Section 4.1) showed that enabling FFR services in the NEM may allow the FOS to be met with a lower level of synchronous inertia, and potentially a lower cost in the long term.

However, there is little global experience in procuring or operating FFR, and careful consideration of the specific requirements of the NEM will be required.

AEMO cautions against immediately committing to prescriptive or long-term procurement options for FFR. It would be preferable to start out with a series of trials to demonstrate the technical capabilities and potential benefits of FFR delivery for real-world frequency control. This could be transitioned to a more structured market or tendering process over time. AEMO has made similar recommendations to the AEMC.

While there is still work to do to prove the role of FFR in managing power system frequency in a low inertia power system, mandatory standards that guide new entrant generators towards the provision of services such as FFR may aid the transition to market-based solutions in the future.

AEMO's recommendations in Chapter 6 regarding active power control capabilities are seen as broadly compatible with FFR provision from generators, without prescribing at this time specifically how these responses must be delivered.

5. SYSTEM STRENGTH

5.1 Statement of issues

System strength is an inherent characteristic of any power system – it is an important factor contributing to the stability of a power system under all reasonably possible operating conditions, and can materially impact the way a power system operates.

Low system strength could result in stability issues emerging, with areas of particular concern being voltage control, short circuit current, inertia and synchronising torque.

An indicative measure of system strength is the available fault current or the short circuit ratio (SCR) at a given location. Higher fault current levels are found in a stronger power system, while lower fault current levels are representative of a weaker power system.

Similarly, a high short circuit ratio at a point in the grid is a measure of the strength of the response to any faults in that area.

Further, a low X/R ratio (ratio of system inductive to resistive impedance) would also have some impact in degrading system strength.

Fault currents vary around the grid, both by location and network voltage, with fault currents being higher in areas close to synchronous generation.

Low system strength in areas of the network can degrade elements of system performance, or threaten power system security, due to factors such as:

- Inability to control voltage during normal system and market operations such as switching of transmission lines or transformers, switching reactive plant (capacitors and reactors), transformer tap changing, and routine variations in load or generation. However, the proposed dynamic reactive power support requirements in Chapter 3 is expected to assist in limiting steady-state voltage changes.
- Manufacturers' design limits on power electronic converter interfaced devices such as wind turbines, solar inverters, and static Var compensators. Operation of these devices outside their minimum design SCR limits could give rise to generating systems' instability and consequent disconnection from the grid.
- Protection systems which rely on measurement of current (excluding differential protection) or current and voltage during a fault to achieve two basic design requirements:
  - Selectivity (that is, to operate only for conditions for which the system has been installed).
  - Sensitivity (that is, to be sufficiently sensitive to faults on the equipment it is protecting).
- Propagation of voltage dips. A voltage dip (also called a voltage sag) is a drop in network voltage following a fault or switching event. In a weak network area, voltage dips are deeper, more widespread, and can last longer than in a strong network. For example, the transient voltage dip resulting from a short circuit event will be more severe, more widespread, and slower to recover in a weak system than in a strong system. This would mean that more non-synchronous generators are likely to see the fault and go into fault ride-through at a similar time. However, the proposed dynamic reactive power support requirements in Chapter 3 is expected to assist in limiting the spread and depth of the voltage dips.

System strength reduces with increasing amounts of non-synchronous generation operating on the system, and also with the displacement of synchronous generating units which contribute more to the level of available fault current. Both these drivers can lead to a system-wide weak grid.[40]

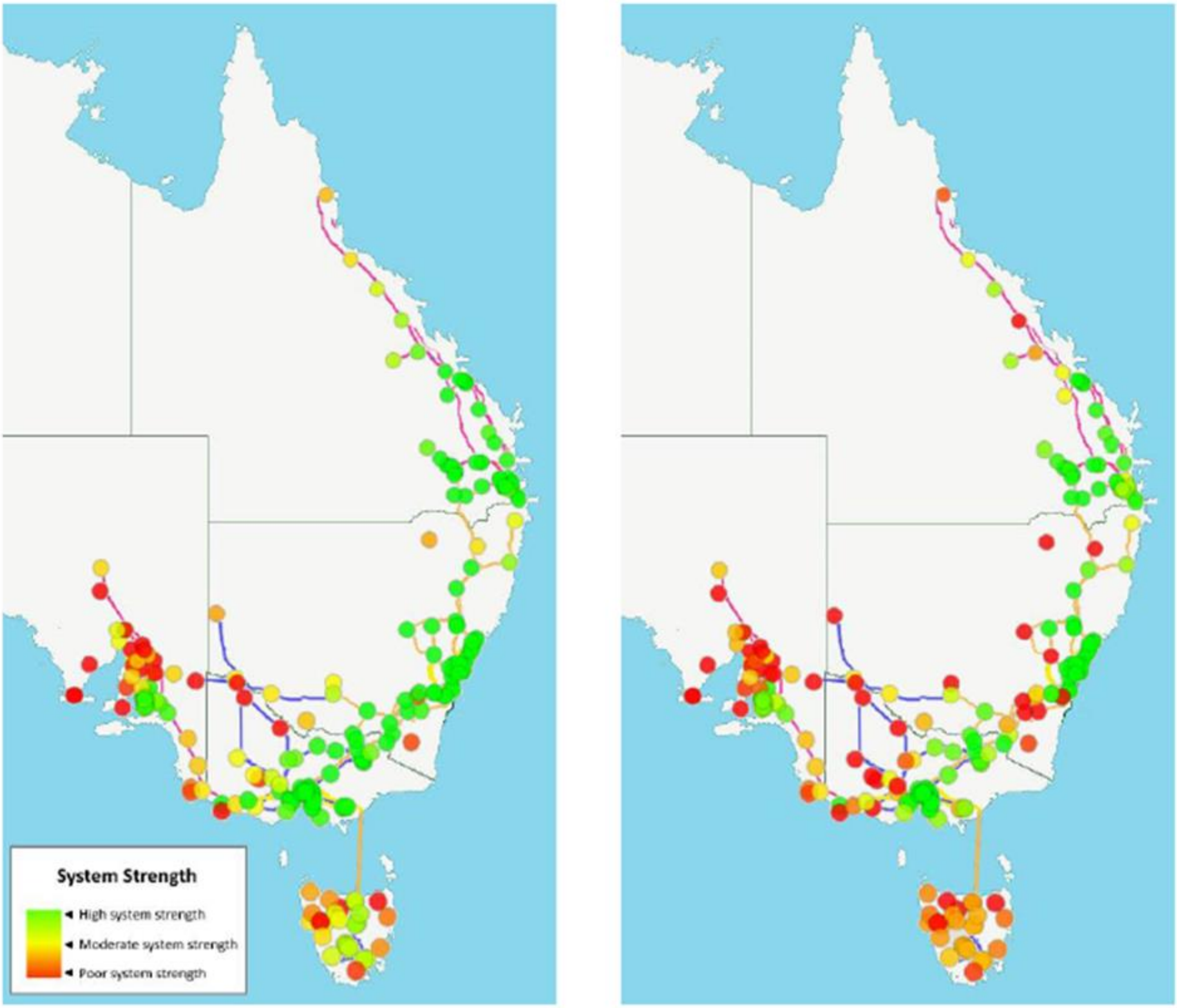
These two drivers for reduced system strength – increased levels of non-synchronous generation and reductions in synchronous generation – can occur simultaneously or on their own, meaning the regulatory framework needs to address both drivers, and provide clear obligations on appropriate parties to address both issues.

[40] Local weak grids can also occur, generally in areas where the connection point is in a remote part of the network.

Further discussion of system strength issues was provided in AEMO's *2016 National Transmission Network Development Plan* (NTNDP), including specific analysis of SA.[41]

Figure 7 shows the results of the 2016 NTNDP analysis, where it can be seen that South Australia already has moderate to poor system strength across much of the state, particularly in regions where wind and solar developers are likely to seek connections. This is projected to worsen over the next 20 years.

Figure 7 System strength assessment in 2016–17 (left) and 2035–36 (right)



On 2 December 2016, AEMO implemented new operational arrangements to maintain power system security during periods of anticipated low fault levels.[42]

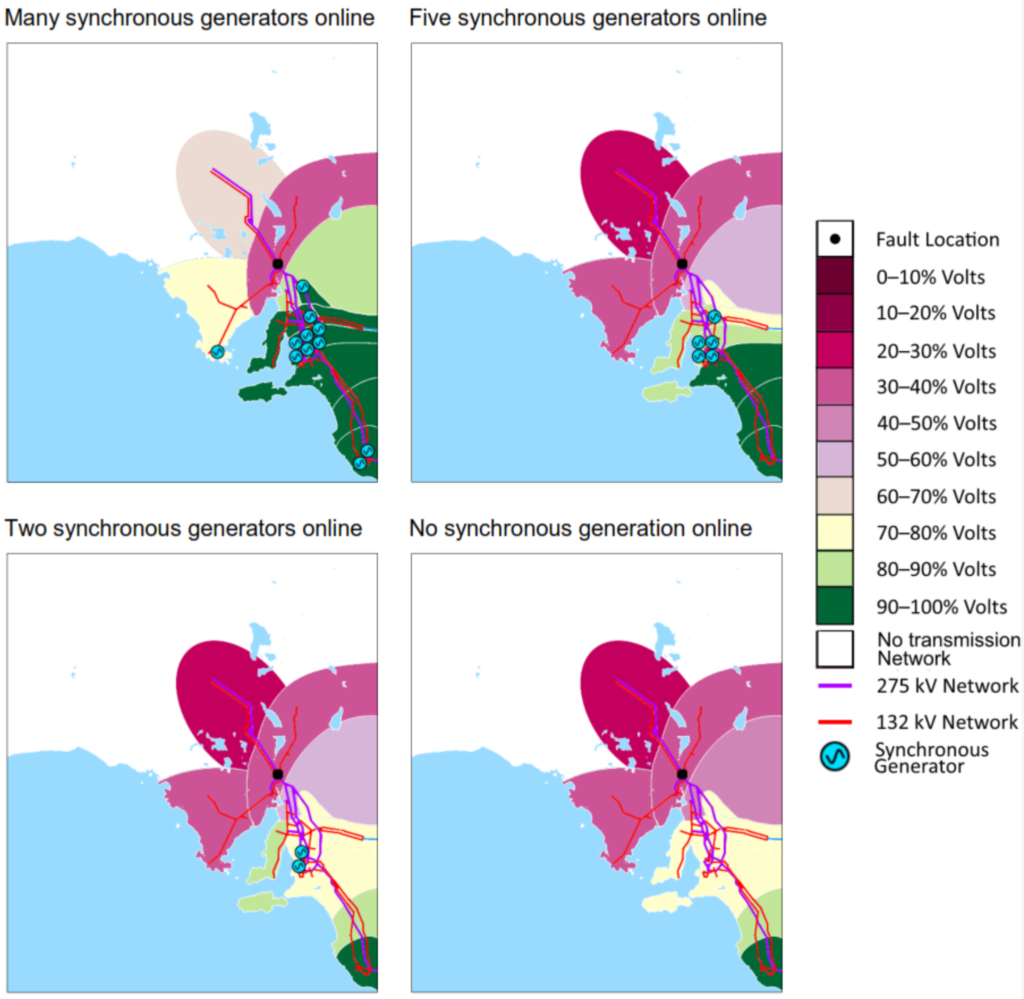
The 2016 NTNDP also presented an assessment of the spread and depth of voltage dip during transmission faults in SA, seen in Figure 8. These images illustrate the depth and spread of voltage dip during a simulated two-phase to ground fault at Davenport. The number of online synchronous generators is illustrated on each map. Comparing these figures, it can be observed that the online synchronous generators act to limit the spread of voltage dips, as they supply both fault current and dynamic reactive power support.

[41] See Chapter 4.3 and Chapter 5 of AEMO's 2016 NTNDP, available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Transmission-Network-Development-Plan.
[42] For further details see: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Power-system-operation.

By comparison, non-synchronous generating systems are able to provide dynamic reactive support (discussed further in Chapter 3 and Chapter 7), but provide limited fault current contribution,[43] therefore are unable to provide a useful amount of system strength without the addition of special additional equipment (such as synchronous condensers).

In future, rather than relying on synchronous generators to provide the service, the provision of additional system strength where needed in areas of the network could equally be provided as a network or network service using large synchronous condensers.

Figure 8 Transmission network voltage dip during a two-phase to ground fault at Davenport



Although the transmission network can experience severe and widespread voltage dips, there are lower voltage pockets where dynamic reactive support limits the reach of the voltage dip. As discussed in Chapters 2 and 3, the inclusion of such dynamic reactive capability is important for all generators operating in weak system conditions.

When considering the instability of power electronic converter interfaced devices such as wind turbines, solar inverters, and static Var compensators, it is the operation of these devices and their control systems outside their minimum design limits which could give rise to a generating system's instability, consequent disconnection from the grid, and subsequent risks to system security.

[43] Figure 1 in AEMO's System Strength Fact Sheet shows the relative contribution of fault current from synchronous generators and power electronic converter connected (non-synchronous) generators: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/AEMO-Fact-Sheet-System-Strength-Final-20.pdf

Increased tolerance of these generating system elements to low system strengths would enable the entire generating system of a non-synchronous generator to operate when system strength is low.

5.2 Risks and opportunities

Based on its work to date, AEMO currently sees a need for two key obligations in parallel to address the underlying drivers for reductions in system strength:

1. Obligations on NSPs to provide well-defined network characteristics to all connecting parties at the connection points (for example, maintaining an agreed level of system strength regardless of dispatch patterns).
2. Obligations on connecting generators to ensure their generating system is designed and operated to maintain well-defined performance standards. These obligations could potentially include some combination of:
    a. Clear definition in the connection agreement of the range of short circuit ratios agreed with the NSP (and which the NSP has undertaken to maintain) for which the generating system will maintain compliance with its performance standards.
    b. A requirement to install and maintain suitable plant, or bear the cost of others doing so if appropriate, where the NSP determines necessary to avoid the new connection causing system strength to fall outside a pre-defined acceptable range at other connection points in its network.
    c. Requirements for generating systems and susceptible items of plant within those systems (such as individual generating units, dynamic reactive power support plant, and storage interface units) within the connecting party's generating system to be capable of stable operation down to a specified system strength at the terminals of each item of plant.

Appropriate obligations on NSPs would ensure maintenance of some agreed minimum system strength regardless of generator dispatch patterns and the number of synchronous generators online, while the recommended obligations for connecting generators seek to achieve a clear and fair allocation of responsibility to parties who impact system strength. These two sets of obligations are explored further below.

Similar obligations are currently being explored by the AEMC in its consultation in the context of a proposed Rule change that would provide for new market or regulatory arrangements to procure system strength services in the NEM.[44]

Further, with regard to obligations on NSPs, in its 2016 NTNDP, AEMO identified a Network Support and Control Ancillary Services (NSCAS) gap to provide system strength in South Australia, and stated that the gap would be confirmed in early 2017 following completion of more detailed analysis.[45] This work is expected to be completed shortly.

5.2.1 Maintaining a minimum level of system strength

As noted above, adequate system strength is necessary for secure operation of the power system. Accordingly, a fundamental amount of system strength is an essential service, required by all participants, all the time.

Historically, synchronous generation has provided system strength as an inherent part of its operation. As Australia transitions towards a system with more non-synchronous generation, system strength could reasonably be seen as a system security service, whereby:

- NSPs are responsible for maintaining agreed levels of system strength across their networks; and
- AEMO is responsible for operating the power system securely within the identified system strength limits of all system elements.

[44] AEMC, System Security Market Frameworks Review Directions Paper, March 2017, available at: http://www.aemc.gov.au/getattachment/69e15462-70ca-4bb6-88e2-77eb530939a4/System-Security-Market-Frameworks-Review-Direction.aspx.

[45] NSCAS are contracts procured by Transmission Network Service Providers (TNSPs), or AEMO as a last resort, for non-market ancillary services such as voltage support, inertia, and fault level provision.

This division of responsibilities holds for a scenario where a region reaches zero operational demand (as all demand is met by embedded generation), and no large synchronous generation is dispatched. In this scenario, a certain amount of system strength is still required, and AEMO would need to operate the region in a secure manner, consistent with its NER obligations.

If viewed as a system security service, an obligation could be placed on NSPs to maintain an acceptable minimum level of system strength, within which AEMO would operate the power system.

5.2.2 Obligations on connecting parties

Obligation to not compromise system strength

The system strength available to each generating system reduces due to the connection of multiple non-synchronous generating units in close proximity (even if the background system strength remains constant). Therefore, there is a need for clear and efficient allocation of responsibility between relevant parties.

An obligation could be placed on the NSP to negotiate performance standards with connecting parties so as to not compromise the system strength seen by existing generating systems. Without this protection, new connections can reduce the local short circuit ratio, impacting the ability of existing generators to meet their performance standards.

In practice, the connecting generator might address any obligations by installing additional plant to provide local fault current, or contracting with a third party to provide the service.

When considering the most efficient long term solution for consumers, the provision of system strength at suitable locations (at designated locations around the network, rather than within individual generating systems) appears likely to allow for an optimal provision of services and avoid inefficient expenditure for the following reasons:

- Equipment can be procured that is capable of providing multiple services at once, including system strength and inertia. If a generator were to solely address its own system strength needs, there is no guarantee that optimal inertia services would also be available. [46]
- Solutions to multiple system strength problems could be addressed at once, including NSP needs for protection and providing a service that allows generators to meet their generator performance standards.
- If provided by each generator, sufficient redundancy would likely be required for each generating system, potentially resulting in a complete duplication of local solutions for system strength. If coordinated centrally, redundancy in system strength provision could be managed across a whole area of the system, achieving the most efficient solution for the network as a whole.
- If coordinated centrally, the availability of plant providing system strength and other system services could be more readily monitored. This should allow AEMO to manage the power system with fewer constraints, within the known technical envelope of the system.

Where the provision of facilities by NSPs to improve system strength to an area of the network is the most efficient and effective solution, appropriate measures would need to be considered to ensure that any cost recovery for this service from connecting generators is fair and reasonable.[47]

[46] For example, synchronous condensers can be procured to resolve system strength issues, however the standard products may provide little inertia. In order to get significant inertia from a synchronous condenser this must be specified at the time of procurement.

[47] Reasonable costs' might be defined as being less than the cost of the connecting party installing sufficient synchronous condensers (including n-1 redundancy) within their own plant to achieve the same outcome.

Costs to consumers

Costs associated with operating within agreed GPS values for system strength will be minimised for future generators (and ultimately consumers), if generators are capable of operating down to low short circuit ratios. This is because the connecting generator (if non-synchronous), will drive down the local short circuit ratio when it connects. Less resilience to low system strength in existing generators will mean the connecting generator is seen to be 'causing' a larger problem, and therefore exposed to higher costs from the NSP to maintain the available short circuit ratio above the agreed minimum for existing generators.

To improve connecting generators' resilience down to low system strength conditions, an equitable and transparent signal needs to be provided to connecting parties. While it would be ideal to specify a mandatory capability at the connection point of new generators (as the connection point forms the notional dividing line of responsibility), due to the varying nature of system strength across the grid and even within the networks which are part of the generating systems,[48] the system strength at the terminals of sensitive generating system elements will always vary.

As the performance of these elements ultimately determines the performance of the generating system at the connection point, a specified performance requirement at the HV terminals of susceptible items of within the connecting party's generating system may be the most effective way to achieve the desired outcome for consumers.

Additionally, specifying the requirement at the level of individual components of the generating system offers potential benefits to project developers, including:

- Establishing a clear benchmark that all equipment providers need to meet in future, allowing developers to utilise standard products rather than requiring bespoke designs to suit individual site conditions.
- Reducing the overall system strength that the connecting party would need to negotiate from the NSP at the connection point, minimising the connecting party's need for additional system strength and any costs associated with procuring this additional support.
- The potential for a more efficient connection process due to lower number of iterations associated with satisfying GPS requirements under weak system conditions.

5.3 Technical recommendations

5.3.1 Maintaining a minimum level of system strength

The AEMC's latest proposals for a regulatory framework to address system strength are discussed in its System Security Market Frameworks Review directions paper.[49] The AEMC proposes revisions to the NER to make it clear that NSPs are responsible for maintaining a minimum level of system strength.

In parallel with the AEMC's review, AEMO is working to confirm the NSCAS gap with respect to system strength in South Australia identified in the 2016 NTNDP (see Section 5.2). This work is expected to address the existing minimum system strength requirements in South Australia once complete.

Accordingly, AEMO is not recommending any generator licence conditions associated with maintaining minimum levels of system strength on the network.

5.3.2 Obligations on connecting parties

Where a new entrant generator is anticipated to reduce the local availability of system strength, and potentially cause an existing generator to breach its performance standards, the NSP should negotiate performance standards with the new entrant to resolve the situation.

[48] The internal collection networks within some networks can be several kilometres long.
[49] AEMC, System Security Market Frameworks Review Directions Paper, March 2017, available at: http://www.aemc.gov.au/getattachment/69e15462-70ca-4bb6-88e2-77eb530939a4/System-Security-Market-Frameworks-Review-Direction.aspx.

The resulting generator performance standard would oblige the connecting generator to make whatever design changes to its plant as might be necessary to meet the standard, or alternatively the new entrant could contract with a third party, including the NSP, to provide the necessary service.

This maintains the NSP's accountability for providing well-defined network characteristics to all connecting parties at the connection points, but places a 'causer pays' responsibility on the connecting party for addressing the identifiable network implications it brings.

This approach also provides the potential for the most efficient solution by allowing the connecting generator and a third party provider to negotiate on commercial terms for a local or regional solution. As noted in Section 5.2.2, a coordinated solution to the availability of fault current in different areas of the network is likely to be the most efficient long-term solution.

This issue is currently under consideration as part of the AEMC's System Security Market Frameworks Review. AEMO has an advisory role under the NER in respect of certain negotiated performance standards for connecting generators to maintain system security. As such, AEMO would seek to ensure that a connecting party would not cause existing generators to breach their performance standards.

Accordingly, AEMO is not recommending any additional generator licence conditions for maintaining system strength at the connection point.

However, to achieve clear accountabilities between different parties, AEMO is recommending licence conditions as follows:

- An NSP licence condition obliging the NSP to maintain a short circuit ratio at the connection point within a range agreed in the Connection Agreement. To ensure efficiency, the agreement should be clear on the system conditions (e.g. during normal system conditions) or the percentage of time for which the NSP would agree to maintain the agreed short circuit ratio; and
- A generator licence condition to meet its GPS at the connection point for the range of short circuit ratios agreed with the NSP in the Connection Agreement (and which the NSP has undertaken to maintain).

Further, as noted in Section 5.2.2, the costs associated with operating within the values for system strength defined in a connection agreement will be minimised for future generators (and ultimately consumers), if existing generators are capable of operating down to low short circuit ratios.

AEMO's current recommendation is that ESCOSA require susceptible items of plant (such as individual generating units, dynamic reactive power support plant, and storage interface units) within the connecting party's generating system to be capable of operating correctly down to the following levels at the HV terminals of each item of plant:

- Minimum short circuit ratio of 1.5.
- Minimum positive sequence X/R ratio of 2 (ratio of system inductive to resistive impedance).

The above criteria should apply in conjunction and no criterion can override another.

Until an alternative methodology can be proposed that provides an equitable and transparent signal at the connection point, this proposed capability at the HV terminals of susceptible plant within the connecting party's generating system appears the most practical way of minimising costs to future generators and, ultimately, customers.

ESCOSA may wish to consider how some or all these system strength obligations could be obtained from existing generation in SA, with due regard to:

- Physical limitations of some existing generating units.
- The likely cost of enabling the capability for each generating unit.
- The incremental system capability that would be gained by enabling existing generating units.

AEMO understands that some of the capabilities recommended here (for example, operation down to low system strength) may be obtainable from some non-synchronous generators through a control system upgrade.

6. ACTIVE POWER CONTROL CAPABILITY

6.1 Statement of issues

Control of power system frequency requires close matching of the supply and demand for active[50] power, over timeframes far shorter than the 5-minute market dispatch interval.

This has historically been achieved using the active power control capabilities provided by governors on large thermal and hydro generators. To date, wind and PV generators in the NEM have typically not provided the necessary active power control capabilities to participate in power system frequency control, although this is beginning to change.[51]

NEM frequency control capabilities are currently sourced through spot market arrangements under the FCAS framework. Participation in these FCAS markets is voluntary, and until recently these markets have been of low value, relative to the wholesale energy market. Historically, this has provided little incentive for new generators to install the necessary active power control capabilities to allow for participation in frequency control arrangements.

Frequency control capability can be considered to fall into two categories:

- Frequency raise services to address under frequency conditions.
- Frequency lower services used to address over frequency conditions.

These services are provided by increasing or decreasing active power output in a controlled manner for raise services and lower services respectively. The capability of various types of plant to provide under and over frequency response varies, and may not be symmetric, depending on the energy source and generation technology.[52]

Under current market arrangements, raise and lower *contingency* FCAS services are provided by increasing or decreasing active power output in response to measurement of frequency conditions at each generator's position in the network. Contingency FCAS services are used to both stabilize and correct power system frequency following the unexpected disconnection of a large generation or load.

Raise and lower *regulation* FCAS services are provided by increasing or decreasing active power output in response to centrally generated signals sent to generators by the NEM Automatic Generation Control (AGC) system. Regulation FCAS services are used to continually adjust power system frequency within the *normal operating frequency band.*[53]

The availability of sufficient raise and lower capability in each region of the NEM, for both contingency and regulation services, is critical in maintaining a secure power system under a range of expected conditions. Fundamentally, these capabilities are made possible through the ability of generating units to vary their active power output in a precise and controlled manner, either in response to power system conditions or to AGC signals from AEMO.

As the generation mix in the NEM changes, the share of energy supplied by generation that has historically provided these active power control capabilities is reducing. This is particularly evident in SA. Inadequate active power control capability is a risk to AEMO's continued ability to operate a secure and reliable power system into the future, particularly for managing islanded portions of the NEM.

AEMO recommends that ESCOSA require all new generation (both synchronous and non-synchronous) seeking to connect in SA to have certain active power control capabilities.

Connection of plant whose active power output cannot be made automatically sensitive to system frequency, or cannot be directly controlled over short timeframes, will not act to improve the risk profile of the SA region. In the context of ESCOSA's statutory objective, the lack of sufficient active power

[50] Active power (or electrical power) is a measure of the instantaneous rate at which electrical energy is consumed, generated or transmitted. In large electric power systems it is measured in megawatts (MW) or 1,000,000 watts.

[51] Examples include Hornsdale 2 Wind Farm's involvement with AEMO and ARENA in an FCAS trial in 2017, or Musselroe Wind Farm in Tasmania.

[52] For further discussion, see Section 4.4 of *Technology Capabilities for Fast Frequency Response,* available at: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/2017-03-10-GE-FFR-Advisory-Report-Final---2017-3-9.pdf

[53] Defined as 48.85-50.15 Hz under nominal conditions. For more information refer to the *NEM Mainland Frequency Operating Standards:* http://www.aemc.gov.au/getattachment/436495bb-89b9-4da6-b258-e24437df9b8a/Frequency-Operating-Standards-(Mainland).aspx

control capability from the SA generation fleet may create an unacceptable future risk in terms of the price, reliability, and quality of electricity supply in the region.

Some of the recommended active power control capabilities put forward in Section 6.3 can potentially be negotiated under current connection arrangements[54], but some cannot.

AEMO proposes clearly defined licensing standards for new entrant plant. The active power control capabilities proposed are ultimately based on a projection of what will be required in future from all types of generation technology, to increase the ability to control power system frequency in the long term.

These capabilities will assist in allowing secure and reliable operation with the widest possible range of future generation technology mix and dispatch patterns. They have been considered bearing in mind both normal power system conditions in mind, and conditions following credible and non-credible contingency events.

Control capabilities described in this chapter have been specified with existing frequency control arrangements in mind, and are intended in the near term to allow existing arrangements to continue, with voluntary participation in real-time markets for procurement of FCAS.

Over the longer term it is unclear what combination of market mechanisms and mandatory technology capabilities or performance obligations may ultimately be used to provide adequate control of power system frequency. The active power control capabilities proposed here would allow for the future development of other frequency control arrangements, and are consistent with a wide range of alternative models for future frequency control.

The proposed control capabilities are consistent with the capabilities of synchronous generation, and understood to be within the capabilities of modern wind and PV generation, and with those of a range of energy storage technologies (such as batteries and flywheels).

A review of international grid codes indicates that the key active power control capabilities are consistent with requirements present in other major grid codes around the world.[55]

Consideration of international codes also highlights that the NEM is unusual in allowing existing active power control capability to be operated in a way that does not provide continuous and ongoing support and control of power system frequency. The NEM is also unusual in procuring essential frequency control services in real-time markets, rather than by direct technical mandates on performance.

6.2 Risks and opportunities

AEMO understands that the active power control capabilities proposed in Section 6.3 can be made available via software modifications for most types of inverter-connected generation, and in some cases via the installation of additional communication equipment. AEMO understands that major additional hardware or plant will not be required to provide these capabilities, and that the proposed capabilities can be provided by most equipment manufacturers without significant increases in the capital cost of new entrant generators.

The key risk associated with active power control capabilities for new entrant generation is seen around the procurement of capability that is installed, ultimately at increased cost to electricity consumers, and then not required or utilised over the long term.

Consideration of this risk has led to the specification of capabilities which minimise increases in capital costs for new entrant generation, while still providing valuable capability to the power system both in the short term, and into the future.

Generation commissioned in the near term may be in place for at least 20–30 years, and potentially much longer, and form part of a very different generation mix to that seen today. It is impossible to predict what methods or mechanisms will be used to provide control of power system frequency this far into the future, but AEMO's recommended active power control capabilities for all new connecting

[54] For example, frequency raise and lower capability under S5.2.5.11 of the NER
[55] Examples include droop response and ramping limits set out under provisions developed by NERC/FERC, and similar requirements set by ENSTO-E and other small grids that are susceptible to 'islanding' events.

generation will help ensure that the widest possible mix of generation can participate in the future control of power system frequency.

Availability of these control capabilities will facilitate higher levels of instantaneous penetration of non-synchronous generation, which will in turn assist in meeting long term emissions reduction targets.

Allowing the broadest possible future participation in frequency control arrangements will also minimise any future dependency on the ongoing operation of any particular class or type of generation to obtain these essential system services.

Establishing a base level of active power control capability for all new-entrant generation will minimise the long-term linkages and dependencies between the operation of wholesale energy markets and the availability of these services, and should ultimately assist end customers by obtaining these services at the lowest overall cost.

Forecasts in SA indicate increasing periods of low operational demand, during which few large transmission- or distribution-connected generators will be required to meet customer consumption. During these periods, wind or large-scale PV generation is likely to be the lowest marginal cost source of supply, but they will not be unable to operate unconstrained if they are incapable of providing sufficient active power control capabilities.

AEMO recommends that new entrant generators have the capability to limit the rate of increase and of reduction of active power output from plant. It is recognised that there is currently little international experience with the use of active power ramp rate limits outside of small, islanded power systems.

Potential applications of this capability include:

- Limiting active power ramps on start-up or planned shutdown of plant, or when a constraint on active power output is engaged or released.
- Management of electrical islands, or potential islands, with high instantaneous penetration of variable renewable generation.
- Managing the impact of rapid short-term changes in active power output on the local power network.

Depending on the level of performance required, a capability to limit the rate of reduction in active power could be met by the installation of local energy storage. However, this is not the only method understood to be possible, and is not an automatically expected or directly intended outcome of this requirement.

Careful assessment of both local and wider network needs for the application of limits to the rate of active power changes will be required at the time of connection, to minimise any unintended impacts of this requirement on the ongoing operation of new generation.

The widespread capability to provide a rapid active power response to abnormal frequency events may also assist in the future development of markets for FFR response capability (discussed in Section 4.3.2). However, it is recognised that arrangements around future provision of FFR are unclear at this time, and for this reason the requirements for rapid provision of rapid active power responses in this document have not been written in a highly prescriptive manner.

6.3 Technical recommendations

AEMO recommends that all new generators in South Australia have active power control facilities capable of providing the functionality described below.

These capabilities must be installed and fully tested at the time of plant commissioning, including the development of accurate simulation models. Where the generation is dependent on an inherently variable energy source, testing and commissioning of these capabilities must be performed under a range of energy input conditions.

These technical standards will not require the active power control capabilities detailed here to be made continuously active, or bid into existing markets for frequency control services, but they must be continuously available for service. They may be used voluntarily by the generation operator, when directed to do so by AEMO, or when required to do so under other arrangements with the local NSP.

All new entrant generators will be required to register with AEMO for the provision of regulation and contingency FCAS.

ESCOSA may wish to consider how some or all these active power control capabilities could be obtained from existing generation in SA, with due regard to:

- Physical limitations of some existing generating units.
- The likely cost of enabling the capability for each generating unit.
- The incremental control capability that would be gained by enabling existing generating units.

AEMO understands that some of the capabilities recommended here (for example, obligations to communicate active power control settings discussed in Section 6.3.4) may be provided by existing synchronous plant through minor changes to software and SCADA systems.

6.3.1 Capability for automatic active power response to frequency changes

The capability to provide an automatic active power response to frequency changes is necessary to provide contingency FCAS, or a governor-like response to changes in system frequency. AEMO recommends that ESOCSA licence conditions require all new entrant generators to have the capabilities set out below, and consider the merits of applying these conditions to existing plant where appropriate:

- Generating plant must be capable of automatically providing a proportional increase or decrease in active power output, in response to falling and rising power system frequency respectively.
- The steady state droop[56] setting of this active power response must be adjustable in the range 2% to 10%.
- The frequency dead-band for this response must be adjustable in the range from 0 to +/- 1.0 Hz.
- Generating plant must be capable of sustaining a response to abnormal frequency conditions for at least 10 minutes[57], subject only to energy resource availability, or other plant technical or regulatory limits.
- An active power response to changing power system frequency must be provided with no delay, beyond that required for stable operation, or inherent in the plant controls, once frequency leaves the dead-band.
- Response to rising and falling frequency may be different, in both dead-band and droop settings, and in the response shape or characteristics. Different levels of droop may be applied for different levels of frequency change.

AEMO acknowledges that similar capability might be available by negotiation of the automatic standard in clause S5.2.5.13 of the NER.

Notwithstanding this, AEMO recommends that ESCOSA clarify expectations for plant performance by mandating the base level of capability as expressed above. To the extent that there are any differences between these functional requirements for automatic active power response to frequency conditions and the range of capability expressed in S5.2.5 of the NER, AEMO will seek to harmonise the description of standards in the proposed review of NEM technical standards discussed in Section 1.3.2.

This recommendation is consistent with a recent submission [58] from the US Federal Energy Regulatory Commission (FERC) that seeks comment on requirements for all generators (that is, synchronous and non-synchronous plant) to have frequency response capabilities if they are to be connected to the interconnected US network.

[56] The droop characteristic is defined with respect to the registered MW capacity of the generating system (Pmax) and applies from 50 Hz (rather than from the dead-band limits).

[57] Consistent with existing 300 second contingency FCAS specification and proposals for contingency frequency response capability specified or considered in ERCOT, National Grid, and EirGrid/Soni power systems.

[58] Docket no RM16-6-000 available at: https://www.ferc.gov/whats-new/comm-meet/2016/021816/E-2.pdf.

6.3.2 Capability for automatic generation control

The capability for generation to be controlled via AGC signals is currently necessary for generators to be able to offer regulation FCAS to the market.

AEMO recommends that ESOCSA require all new entrant generators to have AGC capabilities as described below, and consider the merits of applying these conditions to existing plant where appropriate:

- Generating plant must have active power control capabilities that allow it to participate in existing NEM AGC arrangements. This includes arrangements used for automatic dispatch control of generation, and for frequency regulation.
- At a minimum, this requires:
  - The ability to receive and respond to a remotely determined active power control setpoint, updated at a rate of every 4 seconds[59], transmitted to the site via SCADA.
  - Provision of the following information to AEMO via real-time SCADA:
    - Actual active power output.
    - Maximum raise limit.
    - Minimum lower limit.
    - Maximum raise ramp rate.
    - Maximum lower ramp rate.

6.3.3 Capability to limit the rate of change of active power

The ability for generators to limit the rate of change of their active power output is important for minimising the risk of significant supply demand imbalances on timescales within a dispatch period. AEMO recommends that ESOCSA require all new entrant generators to have capabilities to control the rate of change of active power as set out below and consider the application of these conditions to existing plant where appropriate:

- Generating plant must be capable of limiting the rate of change of active power, both upwards and downwards, to below a rate of change set-point in the active power control system.
- Generating plant must be capable of implementing different active power rate limits for different events.[60]
- Generating plant must be capable of implementing different active power rate limits over different time frames.[61]
- Generating plant must be capable of meeting a specified ramp rate limit with accuracy of no more than 10%.[62]

6.3.4 Remote monitoring requirements

AEMO recommends that ESCOSA require all plant (both existing and new entrant generators) to provide real-time information about their active power control systems to AEMO.

This information will allow AEMO to more precisely define the power system *technical envelope*[63], and to better understand real-time ancillary services requirements and capabilities for power system security purposes[64].

[59] This is over and above the requirement of S5.2.5.14 of the NER, which only requires a scaling of active power setpoints.

[60] For example, different rate of change of active power limits may be defined for increases, and for decreases, in active power. Different rate limits may be specified for different events, such as responding to an abnormal frequency event, responding to a remote active power setpoint change, responding to a special protection scheme trigger, or responding to a change in input energy to the generating system.

[61] For example, different rate of change of active power limits may be defined over short time frames, to manage impacts on a local network, and over longer timeframes, to manage impacts on the total supply demand balance for active power.

[62] That is, the variation in active power within the time period specified for the active power rate limit may not deviate by more than 10% from a straight line trajectory between the initial and final active power setpoints determined by the rate limit.

[63] Refer to NER clause 4.2.5.

[64] Refer to NER clauses 4.3.1 (e) and (i).

The mode of operation of the generator's active power control system must be provided in real-time to AEMO via SCADA. The value of any key active power control system limits or settings which may change during real-time operation must also be provided.

AEMO recommends that ESCOSA consider application of this condition to both existing and new entrant generators, whether synchronous or non-synchronous.

These recommendations are consistent with Electric Reliability Council of Texas (ERCOT) requirements set out in *BAL-001 TRE -1*, which oblige all generators to notify the system operator about changes to active power control settings.[65]

6.3.5 Registration as an ancillary services generating unit

AEMO recommends that ESCOSA require new entrant generators to register as ancillary service generating units for the provision of both regulation and contingency FCAS.[66]

This would not *require* these generators to participate in FCAS markets, which is voluntary under clause 2.2.6(a) of the NER, but to be registered and capable of providing the services if required to do so.

As discussed in Section 1.2.2, AEMO is in the process of initiating a review of the existing FCAS markets. In the interim, there is considerable value for new entrants to register as ancillary services generating units, to allow their frequency control capabilities to be used if required for system security purposes, if necessary under direction from AEMO.

AEMO recommends that ESCOSA consider applying the requirement for registration as ancillary service generating units to existing generation that has the technological capability to provide regulation and contingency FCAS, having regard to the costs and operational impacts of doing so.

65 Refer to R7 in BAL-001-TRE available at: http://www.nerc.com/pa/Stand/Reliability%20Standards/BAL-001-TRE-1.pdf.

66 AEMO notes that this is consistent with the licensing conditions ESCOSA has recently applied to Hornsdale 2 Wind Farm.

7. SIMULATION MODELS

7.1 Statement of issues

7.1.1 Changing power system modelling needs

When a generator seeks connection to the grid, following negotiation of suitable performance standards between the connection applicant and the connecting NSP – with AEMO's input where required by the NER – AEMO conducts a due diligence review of the capability of a generating system to meet its performance standards.

To make this assessment, AEMO uses power system simulation tools, together with computer models of the generating system provided by the applicant. The requirements for generating system models are specified in AEMO's Generating System Model (GSM) Guidelines.[67] The simulation models of the generating system are also used to support ant assessments that are required for to ensure secure operation of the power system and to review power system incidents.

In this assessment, AEMO reviews technical studies presented by the connection applicant and/or the connecting NSP and conducts its own studies.

AEMO will generally select a subset of scenarios to consider, covering the extremes of power system loading, generation dispatch and fault severity. The faults studied are typically those that will have the greatest impact (i.e. events that will result in the lowest system voltage at the relevant connection point) and the longest clearing time. Historically, the greatest issue with fault ride-through capability has related to transient stability, which is highly dependent on these factors.

The changes to the generation mix in the NEM have implications for how the behaviour of the power system is represented in power system simulations. This is particularly the case under low system strength conditions, as discussed in Chapter 5.

Power system modelling tools that have been industry standard in the past have generally been able to produce sufficiently accurate results for generation connection studies by making simplifying assumptions about the level of granularity required to adequately represent the power system, and the associated impacts of each proposed connection. Due to the engineering considerations involved, these simplifying assumptions are only valid down to a threshold value of system strength.

Further, the increased penetration of non-synchronous plant with very fast acting digital control systems, which exhibit behaviour on timescales less than a single AC cycle (20 ms in a 50 Hz system), means shorter time steps are required to undertake a sufficiently accurate simulation of the power system.

The emergence of these factors results in the need for new and more accurate modelling techniques for power system modelling.

As discussed in Section 5.1, operation of the SA power system with the current level of installed wind generation of up to 1,700 MW, and dispatch periods with low levels of synchronous generation, implies that the SA system already has moderate to poor system strength across much of the state, particularly in regions where wind and solar developers are likely to seek connections.

In these circumstances, standard generating system models are increasingly unlikely to provide an adequate representation of generator performance.

Accordingly, AEMO needs certainty that appropriate models will be provided, and clarity for connecting generators on AEMO's requirements from their models.

[67] Available at: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Network-connections/-/media/B468B9355D4249C2A0BF55C44971B08C.ashx.

7.1.2 Lessons from the South Australian black system event

The SA black system event on 28 September 2016 revealed that many wind farms in the NEM have a protection feature that takes action if the number of ride-through events in a specific period exceeds a pre-set limit. Each wind turbine then either disconnects from the network, stops operating (remains connected with zero output), or reduces its output.

AEMO was unaware of the protection seatings before the black system event in South Australia, for the following reasons:

- This protection feature is not represented in the simulation models submitted to AEMO for any of the affected wind farms. AEMO is also unaware of this feature in any other wind turbine simulation models it has received. Accordingly, simulations of wind farm performance using the wind farm models currently available to AEMO would not display disconnection or offloading in response to a large number of faults in quick succession
- Performance with respect to fault ride-through capability is generally assessed based on recorded network fault event analysis. No previous examples of repeated fault ride-through issues with wind farms have been reported to AEMO. [68] Additionally, AEMO is not aware of any reported instances of this phenomenon internationally.

The black system event is a reminder of the importance of accurate power system models to the safe and secure operation of the power system. It is critical that any new connections to the SA power system provide accurate, sufficiently detailed models, such that system performance under all conditions can be anticipated and managed effectively.

7.1.3 Generating system model guidelines Rule change

The AEMC has recently initiated consultation on AEMO's November 2016 Rule change proposal[69] to amend the NER relating to the provision of models and data that represent generating systems in power system studies.

This Rule change seeks to broaden the set of information provided by intending participants, to include representation of models of plant protection systems, generator governors, and other any other plant that may affect performance of the generating system as a whole.

This Rule change also proposes that more detailed electromagnetic transient (EMT) type models be provided by intending participants, where there it is reasonable to expect that operation of their plant may adversely affect network capability, power system security, quality/reliability of supply, inter-regional power transfer, or the use of the network by other parties.

7.1.4 Expected model requirements for future NEM connections

Due to the changes that have taken place in SA and are ongoing, the higher level of data provision and increased modelling accuracy of EMT-type models (discussed in Section 7.1.3 above) are now necessary to assess impacts to power system security in the region.

Similar requirements are necessary anywhere in the NEM where the system is weak.

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[68] AEMO can be made aware of any unexpected behaviour regarding fault ride-through by a number of means, including:
- Long-term monitoring and network fault event data provided by wind farms to:
  - Demonstrate wind farm compliance with respect to pertinent clauses in their generator performance standards as required in their performance monitoring plans.
  - Validate wind farm models (R2).
- Notices of non-compliance, to be submitted by wind farm owners as soon as identified, under clauses 4.15 (f), 4.15 (g) and 5.8.5 (d) of the NER.
- AEMO's investigation of historical events resulting in loss of multiple circuits and the extent to which they resulted in multiple successive faults being imposed on any wind farms.

[69] Generating System Model Guidelines Rule change, available at: http://www.aemc.gov.au/Rule-Changes/Generating-System-Model-Guidelines.

As a means of providing clarity for stakeholders, applicants seeking to negotiate a generation connection anywhere in the NEM under the existing Rules framework should be prepared to provide the following models to AEMO:

- Where the RMS-type models cannot replicate the response of generating system elements down to the required SCR and X/R ratio, EMT-type models should be used for assessing all clauses in the proposed GPS.
- Changes in the control systems and/or settings of the individual generating system elements are necessary if the submitted models exhibit uncharacteristic or unexpected responses.
- Satisfactory voltage and frequency disturbance ride-through performance, including a combination of the two, must be demonstrated using the appropriate simulation tool.
- Where required the EMT-type model must also include non-linearities (such as transformer saturation, limits, and control actions) and any other critical factors that would be necessary to simulate the response of the generating system to temporary overvoltage of up to 130% (see Section 3.3.1 for further information).

7.2 Risks and opportunities

Without accurate models of the power system, AEMO must be more conservative when accounting for the impact of new generation on network transfer capability. Such conservatism may result in:

- The observation of more stringent levels of generator performance in Generator Performance Standards agreed for each new entrant project.
- The need to use conservative limit calculations to constrain the output of new generators, which may adversely affect the business case of parties seeking to connect.
- Investment in network plant that provides a higher level of performance than what may be strictly needed.

Inadequate modelling and simulation methods will also lead to increased uncertainty on the impact of power electronic interfaced generation systems on security, and have a cumulative impact on operation of the NEM as a whole by reducing confidence in the power system technical envelope.[70]

This could increase the risk of unexpected generator disconnection, emergency load shedding, and protracted supply disruption. The black system event on 28 September 2016 provides a strong reminder about the consequences of unexpected system performance.

There are also significant opportunities to be realised from improving the level of information and modelling available and having a clear understanding of the technical envelope of the power system.

These include:

- More efficient investment in and use of electricity through:
  - Clearly establishing the impacts of proposed generating systems on power system security, and therefore reducing the risk of these parties being constrained by NSPs or AEMO.
  - Facilitating increased penetration of non-synchronous generation while maintaining power system security.
  - Reduced risk of involuntary load shedding due to incorrect operation of network and generation components of the power system or their associated protective functions.
  - More efficient procurement of contingency FCAS (and SRAS), and reduced uncertainty in evaluating the need for the new ancillary services.
- Greater efficiency of investment in transmission network services through:
  - Improved utilisation of interconnectors, by understanding and mitigating the risk of adverse interaction between transmission infrastructure and nearby generating systems

[70] Refer to NER clause 4.2.5.

- Improved understanding of the capability of network infrastructure to accommodate new generation, allowing for more accurate assessment of needs for maintenance or upgrade.
- Clear expectations regarding the generating system models required from prospective generators, which allows proponents to plan ahead and avoid potential delays to their connection process.
- Making it clear to proponents that the majority of locations for future wind and solar power stations are in weak parts of the SA grid allows for early consideration of system strength issues in the design process, and the selection of generating system components with pre-validated power system models to provide confidence of suitable operability under these conditions.

7.3 Technical recommendations

7.3.1 Simulation models

AEMO's GSM Guidelines Rule change proposal was made because the current GSM Guidelines do not cater for growing operational impact of aspects of the power system such as embedded generation, voltage support equipment/control, and protection systems.

Experience operating the SA power system has demonstrated the need for more detailed guidelines for simulation models.

In the interim, AEMO recommends that, as a part of the licence application process for new generators, ESCOSA emphasise the following:

- The accuracy and adequacy of RMS-type models (like PSS/E) for all individual elements of the generating system should be pre-validated against the actual response of these elements with identical control systems and settings for the minimum SCR and X/R criteria specified in Section 5.3.2, or against pre-validated EMT-type models (for example, PSCAD/EMTDC).
- Where the RMS-type models cannot replicate the response of generating system elements down to the required SCR and X/R ratio, EMT-type models should be used for assessing all clauses in the proposed Generator Performance Standard.
- Changes in the control systems and/or settings of the individual generating system elements are necessary if the submitted EMT-type model exhibits uncharacteristic or unexpected responses.
- Where EMT-type models are required, the accuracy and adequacy of EMT-type models submitted to AEMO for all individual elements of the generating system should be pre-validated against the actual response of these elements with identical control systems and settings for the minimum SCR and X/R criteria specified in Section 5.3.2.
- For clarity, references above to 'individual elements' include, but are not limited to, generating units, dynamic reactive power support plants, and battery storage units (if applicable).
- The pre-validation of models prior to commissioning tests of the whole generating system on site will significantly reduce risks of non-compliance in the commissioning process set out in the NER[71]. Pre-validation of simulation models can be demonstrated using a type test approach.

[71] Refer to NER clause 5.7.3 (a)

8. OTHER MATTERS OF INTEREST TO ESCOSA

8.1 Statement of issues

The NEM is currently navigating an unprecedented transitional phase, where power electronic connected non-synchronous plant at both the utility and household level is replacing traditionally designed synchronous plant that is nearing the end of its operational life. More step changes in the NEM are already starting; the uptake of innovative technologies such as electric vehicles, virtual power plants, and neighbourhood energy trading have the potential to further transform operation of the energy market in new and unexpected ways.

Against this backdrop of changing technological capability and consumer preferences, greater understanding is being developed about existing elements of the power system, through review activities such as AEMO's final report into the 28 September black system in South Australia.[72] The learnings from these review processes should be incorporated into the regulatory framework in a timely fashion.

8.2 Risks and opportunities

In a rapidly evolving market environment, there is a risk that any set of technical standards will quickly become outdated as technological capability advances and key issues affecting operation of the power system change. Regular review of technical standards provides an opportunity to resolve emerging power system issues in an efficient and timely way.

The capabilities of new control technologies for wind and solar farms are advancing quickly. Modern plant includes as standard a range of features and capabilities that previously either didn't exist, or were bespoke in design and very costly.

New systems and functionality within generating systems will continue to increase and improve. As battery storage systems become more flexible, easily integrated and cost-effective, AEMO expects it will be possible to seek provision of a broad range of capability from non-synchronous plant in a manner that recently seemed infeasible.

Another example of the speed of innovation in the NEM is the imminent implementation of the *Ancillary Services Unbundling*[73] Rule change. This Rule amendment will allow a new category of participant – a market ancillary services provider – to enter FCAS markets in the NEM, offering frequency control services through the controlled aggregation of customer loads.

AGL's recently launched SA virtual power plant[74] is a further example of emerging generation technology that could have significant impacts on how essential services are provided in SA.

Regular reviews of ESCOSA's technical standards will ensure that customers continue to be able to benefit from cost-effective licensing measures that leverage the capability of existing technology as it becomes mature and available in the market.

AEMO's final report into the 28 September black system considered areas where improvements could be made in the way that generation resources acted to restore power to the network. These findings should be leveraged proactively by ESCOSA where they offer reasonable and cost-effective means to improve security, quality and price outcomes for South Australian electricity consumers.

AEMO notes that the benefits of additional flexibility and specificity in licensing principles need to be weighed against the costs of reduced certainty if licence conditions are to be regularly reviewed.

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[72] AEMO, 2017, *Black System South Australia 28 September 2016 – Final Report*. Available at: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Market_Notices_and_Events/Power_System_Incident_Reports/2017/Integrated-Final-Report-SA-Black-System-28-September-2016.pdf

[73] Refer to the AEMC's website for further information: http://www.aemc.gov.au/Rule-Changes/Demand-Response-Mechanism.

[74] Refer to AGL's website: https://www.agl.com.au/about-agl/media-centre/article-list/2017/march/agl-virtual-power-plant-goes-live.

8.3 Technical recommendations

8.3.1 Regular updates to ESCOSA framework

As the energy transition progresses and new technical issues emerge, the regulatory framework must also evolve to maintain the security and reliability of the power system. In some cases, emerging issues will be addressed most efficiently by new or updated technical standards.

AEMO proposes that ESCOSA considers the costs and benefits of establishing a framework that allows the technical standards in generator licences to be regularly updated to reflect changing power system needs and technological developments.

This recommendation is consistent with the approach adopted by the NERC. A key conclusion of the NERC's major review of US reliability standards was that annual updates of technical standards are necessary.

8.3.2 Ability to assist with system restart

At the current stage of development, non-synchronous generation is unable to provide system restart ancillary services capability. This primarily stems from the source intermittency and the need for a minimum system strength or fault level which is not available during black system conditions.

However, their contribution to voltage and reactive power control during system restoration could be important once sufficient synchronous machines have been restarted, to provide the minimum fault level required for stable operation of non-synchronous generating units, dynamic reactive support plant, and battery storage units.

To assist with system restoration following a potential black system event, AEMO recommends that ESCOSA require the set of capabilities listed below from all new entrant generators:

- Subject to provision of minimum fault level by on-line synchronous machines, it must be possible to operate the non-synchronous generating systems for at least three hours with auxiliary loads only.
- When operating with the auxiliary load, the generating system – including each of its generating units, reactive power support plant and battery storage units (if applicable) – must be able to supply 50% of their maximum steady-state reactive power capability and full dynamic reactive power capability (as defined in Section 2.3.1).
- Successful operation with auxiliary load and provision of static and dynamic reactive power capability must be demonstrated during the commissioning and compliance testing, and must be verified following significant modifications to the generating system and its individual components.
- EMT-type simulation models submitted to AEMO must account for operation with auxiliary loads.

8.4 Other matters

The existing wind licence conditions contain a number of requirements that have been included to improve the way wind generation in SA supports efficient dispatch and maintenance of power system security within the NEM:

- Optimised Dispatch – wind generators must not apply to have the generating plant classified as non-scheduled under the NER.
- Wind Forecasting – under the NER, all semi-scheduled wind generators are required to provide data for wind forecasting. The wind licence conditions extend this to all wind generation in SA.
- Cost Allocation of Ancillary Services – to ensure that the performance of wind generators is considered in the allocation of the costs of ancillary services, all wind generators in SA must be registered as market generators.
- Small Wind Generators – the need or otherwise for wind generators of 5–30 MW nameplate rating to be classified as semi-scheduled is assessed on a case by case basis.

ESCOSA has not specifically requested AEMO to comment on these other requirements. However, the growth in smaller generating systems and energy storage systems and the potential for these to be aggregated into larger operating blocks has highlighted the need for AEMO to have access to data relating to the operation and performance of a wider range of equipment connected to the power system.

To address this challenge, AEMO has prepared a list of data requirements needed to efficiently perform its functions into the future.[75] At the same time, AEMO is consulting with industry on the need for frameworks that will capture and make available the required data, and is collaborating with the Energy Networks Association (ENA) to explore the potential role of distribution system operators in providing this visibility.

Also related to the need for visibility of smaller generating plant, in December 2015 ENGIE submitted a Rule change request to the AEMC that considers some of the issues around smaller generators and seeks to expand the range of generators that would be taken in to account or come under the control of AEMO's central dispatch process.

[75] See *Visibility of Distributed Energy Resources*, available at: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/AEMO-FPSS-program----Visibility-of-DER.pdf.

9. SUMMARY AND NEXT STEPS

9.1 Summary of recommendations

AEMO's review of ESCOSA generator licence conditions has considered the need for new conditions in the context of changes underway in the NEM, as well as the validity of existing conditions. Recommendations have been made in a variety of areas, with implications for new entrant and existing generators and both synchronous as well as non-synchronous plant.

Error! Reference source not found. below gives an overview of the range and applicability of recommendations put forward in this report:

Table 4 Summary of 2017 ESCOSA technical recommendations

Section	Focus area	Recommendation to ESCOSA	Application to all new entrants	Application to existing generators
2.3.1	Reactive power capability	Replace existing ESCOSA licensing requirements for reactive power capability set out in special conditions 10.1, 10.2 and 10.3 with more specific disturbance ride through requirements described in Chapter 3.	n/a	n/a
2.3.2	Provision of dynamic reactive power	Replace existing ESCOSA licensing requirements set out in special condition 10.4 for dynamic reactive power with more specific disturbance ride-through requirements described in Chapter 3.	n/a	n/a
2.3.3	Voltage control capability	Retain existing ESCOSA licensing requirements set out in special condition 10.5, 10.6 and 10.7 for voltage control capability. Reword to improve clarity.	Yes	To be considered by ESCOSA where appropriate
4.3	Inertia and Fast Frequency Response	No additional generator licence conditions in relation to inertia and FFR are recommended. The capabilities discussed in Chapter 6 should promote the availability of FFR services from generators in future	n/a	n/a
5.3.2	System Strength	Consider an NSP licence obligation to maintain a short circuit ratio at each connection point within a range agreed in the relevant connection agreement	n/a	n/a
5.3.2	System Strength	An additional generator licence condition to meet its GPS at the connection point for the range of short circuit ratios agreed with the NSP in the connection agreement (and which the NSP has undertaken to maintain).	Yes	To be considered by ESCOSA where appropriate
5.3.2	System Strength	Require susceptible items of plant (e.g. individual generating units, dynamic reactive power support plant, and battery storage units if applicable) within the connecting party's generating system to be capable of operating correctly down to specified system strength levels at the HV terminals of each item of plant.	Yes	To be considered by ESCOSA where appropriate
6.3.1	Active power control capability	All new entrant generators should have the capability to provide an automatic active power response to a change in system frequency	Yes	To be considered by ESCOSA where appropriate
6.3.2	Active power control capability	All new entrant generators should have the capability to be controlled by AGC signals on 4-second basis	Yes	To be considered by ESCOSA where appropriate

Section	Focus area	Recommendation to ESCOSA	Application to all new entrants	Application to existing generators
6.3.3	Active power control capability	All new entrant generators should have the capability to limit the rate of change of active power within the timescale of a dispatch period	Yes	To be considered by ESCOSA where appropriate
6.3.4	Active power control capability	All plant is required to provide real time information about their active power control systems to AEMO in order to support its role as independent system operator.	Yes	Yes
6.3.5	Active power control capability	New entrant generators should be required to register as ancillary service generating units for the provision of both regulation and contingency FCAS	Yes	To be considered by ESCOSA where appropriate
3.3.1	Disturbance ride through capability	Require new entrant generators to be able to meet clarified performance requirements during and subsequent to contingency events, including: • General principles • Reactive current injection requirements. • Active power injection requirements. • Multiple low voltage disturbance ride through requirements. • High voltage disturbance ride-through requirements.	Yes	To be considered by ESCOSA where appropriate
3.3.2	Partial load rejection	Require generators to meet the automatic access standard requirements defined under NER clause S5.2.5.7.	Yes	To be considered by ESCOSA where appropriate
3.3.3	Disturbance ride through capability	Require generators to be able to meet amended performance requirements for frequency disturbance ride-through.	To be applied to non-synchronous with a negotiated standard for synchronous generators as close as possible to these requirements	To be considered by ESCOSA where appropriate
3.3.4	Disturbance ride through capability	Restrict application of vector shift and similar types of relays	Yes	To be considered by ESCOSA where appropriate
7.3.1	Simulation models	Recommends that, as a part of the licence application process for new generators, ESCOSA emphasise to generators to the importance of providing suitable pre-validated models and data representing their generating system and all elements of associated protection systems to AEMO in accordance with principles set out on this report	Yes	To be considered by ESCOSA where appropriate
8.3.1	Other matters of interest to ESCOSA	Consider the value of amendments to the framework for generator licensing to support regular review of standard licence conditions	Yes	To be considered by ESCOSA where appropriate
8.3.2	Other matters of interest to ESCOSA	Consider whether all new entrant generators should be required to assist with system restoration processes	To be considered by ESCOSA where appropriate	To be considered by ESCOSA where appropriate

9.2 Next steps

ESCOSA will seek stakeholder views on this paper as part of its public consultation process. AEMO intends to assist ESCOSA in this process, including by engaging with stakeholders on our recommendations as required by ESCOSA.

AEMO will build on the recommendations set out in this document as part of our generator technical standards rule change proposal, and our FCAS markets review. These programs are discussed further in Section 1.2.2.

MEASURES AND ABBREVIATIONS

Units of measure

Abbreviation	Unit of measure
Hz	Hertz
kV	Kilovolt
kVA	Kilovolt-amp
ms	Millisecond
MW	Megawatt
s	Second

Abbreviations

Abbreviation	Expanded name
AC	Alternating current
AEMC	Australian Energy Market Commission
AGC	Automatic Generation Control
DC	Direct current
DER	Distributed Energy Resources
EMT	Electromagnetic transient
EMTDC	Electromagnetic transient direct current
ENA	Energy Networks Association
ERCOT	Electric Reliability Council of Texas
ESCOSA	Essential Services Commission of South Australia
FCAS	Frequency control ancillary services
FERC	Federal Energy Regulatory Commission
FFR	Fast frequency response
FOS	Frequency Operating Standards
GPS	Generator performance standards
GSM	Generating System Model
HVRT	High voltage ride-through
LV	Low voltage
LVRT	Low voltage ride-through
NEFR	National Electricity Forecasting Report
NEM	National Electricity Market
NER	National Electricity Rules
NERC	North American Electric Reliability Corporation
NSCAS	Network Support and Control Ancillary Services
NSP	Network service provider
NTNDP	National Transmission Network Development Plan
PSCAD	Power System Computer Aided Design
PSS/E	Power System Simulator for Engineering
PV	Photovoltaic

Abbreviation	Expanded name
RMS	Root-mean-square
RoCoF	Rate of change of frequency
SA	South Australia
SCADA	Supervisory Control and Data Acquisition
SCR	Short circuit ratio
SRAS	System restart ancillary services
TNSP	Transmission Network Service Provider