FUTURE POWER SYSTEM SECURITY PROGRAM

PROGRESS REPORT

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AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

IMPORTANT NOTICE

Purpose

AEMO is responsible for overseeing the vital system operations and security of the National Electricity Market (NEM) power system across Queensland, New South Wales, the Australian Capital Territory, Victoria, Tasmania, and South Australia. From July 2016, that responsibility has extended to the South West interconnected system (SWIS) in Western Australia. This means operating the power systems within safe and technical limits to manage the secure and reliable transmission of power through the electricity supply chain from generators to consumers.

AEMO has prepared this document to provide information about the Future Power System Security program, as at the date of publication.

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Version control

Version	Release date	Changes
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EXECUTIVE SUMMARY

The purpose of this report is to:

- Outline AEMO's Future Power System Security (FPSS) program and its strategic alignment with AEMO's business-as-usual operational studies and processes.
- Present the long-term technical challenges to maintaining power system security as identified, prioritised, and tested in consultation with an industry technical advisory group.
- Canvass these challenges with the broader community by inviting feedback on this work.
- Outline the current short-term operational solutions being developed and implemented to address immediate challenges and risks to power system security.
- Provide an update on the work conducted by AEMO and the industry to date to develop strategic, technical solutions to maintaining power system security over the long term.

Future Power System Security program overview

AEMO is responsible for overseeing the vital power system operations and security of the National Electricity Market (NEM). From July 2016, that responsibility was extended to include the South West interconnected system (SWIS) in Western Australia.

As an independent power system operator, AEMO is fuel and technology neutral in performing its functions and adapts its capability to manage technology developments, within the legislated policy and market frameworks of the day.

AEMO is operating in a rapidly transforming electricity landscape as synchronous generation is progressively being displaced by non-synchronous generation, changing the operational characteristics of the power system. Consumers are also becoming more active about how their electricity demand is met and managed, resulting in increasing amounts of distributed energy resources (DER), such as rooftop photovoltaic (PV), generating to the power system.

Against this backdrop, AEMO established the FPSS program to formalise and accelerate the work it has undertaken in the last few years to address operational challenges arising from the changing generation mix.[1] If left unaddressed, these challenges will test the efficiency and adequacy of current operational and market processes.

The FPSS program focuses entirely on power system security. It aims to adapt current processes to address immediate risks, while promoting solutions to maintain power system security over the next 10 years.

To date, AEMO has not identified any NEM-wide power system security concerns during normal operation. Each NEM region has a different generation mix, network configuration, and demand characteristics, which lead to different challenges or different timing. AEMO is focused on determining those particular conditions and times where challenges are expected to arise.

Initial challenges are more acute in South Australia, due to the combination of its generation mix and risk of separation from the rest of the NEM. The risk of separation has itself not changed, however, the potential consequences have. Over time AEMO anticipates that challenges will become more prevalent in other NEM regions, particularly those that are also vulnerable to separation from the rest of the NEM such as Tasmania and Queensland.

The FPSS program takes a strategic approach to studying future power system security requirements, and will evolve to accommodate new challenges and changing context as new products and services enter the market.

[1] These studies are available at http://aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/FPSSP-Reports-and-Analysis

The program applies three core phases to each technical challenge, which will be conducted in parallel:

- **Identification and definition** – The qualitative identification and prioritisation of emerging and potential future technical challenges has been completed and tested in consultation with an industry technical advisory group. AEMO has begun quantitative analysis of those challenges categorised as high priority.
- **Specifying technical solutions** – AEMO has identified an initial range of technical solutions for the high priority challenges, and will conduct further analysis to understand the technical requirements of these solutions and their capability to deliver the projected needs of the power system.
- **Implementation of solutions** – This phase will include an assessment of how the technical solutions could be delivered, either under the current regulatory regime, or identifying new regulatory, market, legislative, and competitive options that may be required. Options for implementation will be assessed against the National Electricity Objective (NEO) and AEMO will provide technical input to the relevant decision-making authority where appropriate.

AEMO will continue to leverage industry expertise through close consultation, collaboration, and engagement throughout the program. It has recently formalised collaboration with two key industry stakeholders:

- **Australian Energy Market Commission (AEMC)** – On 14 July 2016, AEMO and the AEMC formalised a collaboration to address challenges in the NEM as a result of the changing generation mix. Through its own review on power system security, the AEMC will address the related regulatory and market framework challenges that will arise, with technical input from the FPSS program. The AEMC and AEMO will maintain close collaboration and cooperation to ensure their activities deliver a coordinated package of measures to complement the increasing volume of non-synchronous generation and the need to maintain future power system security.
- **Energy Networks Association (ENA)** – AEMO has formalised a collaboration with ENA based on the synergies between the FPSS program and ENA's Network Transformation Roadmap.

Identified high priority areas

AEMO enlisted the expertise of a technical advisory group, with representatives from all industry sectors, regulatory and government agencies, and consumers, to inform its qualitative challenge identification and definition. Four areas have been immediately progressed following this consultation:

- Frequency control.
- Management of extreme power system conditions.
- Visibility of the power system (information, data, and models).
- System strength.

Frequency control

Frequency control is critical to power system security, and AEMO is responsible for enabling sufficient frequency control ancillary services (FCAS) to maintain frequency within prescribed operating standards. This task currently relies heavily on the technical characteristics and services provided by synchronous generation, including an inherent inertial response to rapid frequency deviations that slows the rate of change of frequency (RoCoF). A reduction in inertial response can challenge the effectiveness of existing frequency control mechanisms, which can reduce under high RoCoF.

AEMO has commenced an assessment of the suitability of current frequency control mechanisms to deliver the power system's needs over the longer term. This includes:

- Identifying any underlying RoCoF limits of the power system.
- Exploring a fast frequency response service as an alternative way of managing RoCoF.

- Assessing whether current FCAS specifications will present technical barriers to the use of existing and new technologies in the delivery of FCAS into the future.
- An international review to understand how other system operators have adapted, or are adapting, frequency control measures to changing operating environments.
- Projecting future FCAS requirements.

AEMO has engaged international experts to provide input into these studies, and will publish the outcomes of this work over the course of the next six months.

Management of extreme power system conditions

AEMO performed a review to assess how frequently the South Australian system has been exposed to high RoCoF if a non-credible[2] separation event (loss of the Heywood Interconnector) occurred. This has been affected by the recent withdrawal of synchronous generation in South Australia, which reduces the inertia in the region. AEMO's assessment indicated that, following a non-credible separation event:

- The likelihood of the power system operating in a mode that is susceptible to high RoCoF has increased with the upgrade of the Heywood Interconnector (which increases the size of the largest single contingency event) and the closure of Northern Power Station (which decreases inertia).
- Current emergency frequency control schemes (such as under-frequency load shedding (UFLS)) are increasingly unlikely to prevent a black system[3] across South Australia.

To address this risk, AEMO is:

- Undertaking an immediate redesign of the existing UFLS scheme, in addition to designing an over frequency generation shedding scheme.
- Assessing the need to clarify expectations around these types of events and roles, responsibilities, and mechanisms to implement those expectations. This may involve promoting a Rule change.
- Reviewing procedures for operating South Australia as an island.

Visibility of the power system (information, models and tools)

The ability to model the power system effectively requires information and understanding of the electrical characteristics of all components of the power system that can have a material impact on its dynamic behaviour. This becomes increasingly important and complex as the market shifts to include increasing amounts of DER, because:

- There is currently no formal mechanism to collect, store, and make available information regarding the location, type, and performance of DER. Although small individually, in aggregate DER can have a material impact on the network, so knowledge of them is required.
- The representation of DER in power system operational and planning tools becomes more important as their penetration increases. Appropriate methods of representation and aggregation, as well as forecasts of DER generation output, are vital inputs to power system operations.

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

[2] Non-credible contingency events are defined in the National Electricity Rules, and broadly refer to events that are very rare and unexpected, such as the loss of multiple generating systems/units or multiple lines.

[3] A black system is defined in the National Electricity Rules as the absence of *voltage* on all or a significant part of the *transmission system* or within a *region* during a *major supply disruption* affecting a significant number of customers.

System strength[4]

A reduction in system strength has been observed in certain parts of the power system as the generation mix has changed. Reduced system strength can:

- Affect the ability of new generation to connect to the network.
- Compromise the effectiveness of protection systems that detect and clear equipment faults, and the ability of non-synchronous generation to operate as designed.
- Result in greater difficulty in maintaining stable voltages in some parts of the network, particularly during disturbances.

As part of the FPSS program, AEMO is developing capability to better model the dynamics of reduced system strength to analyse these potential challenges in detail.

Key deliverables over the next six months

In the FPSS program, AEMO:

- Will publish detailed outcomes from analysis of the technical challenges and solutions in a series of technical or other reports as the program progresses. This will also include any changes to operational procedures or processes.
- Will publish a progress report every six months, summarising the key outcomes and next steps for the broad FPSS program.
- Will propose options to manage extreme power system conditions, and establish data collection processes for DER, to the Council of Australian Governments (COAG) Energy Council at its December 2016 meeting.
- Is assessing the need to promote a Rule change to address challenges identified in managing extreme power system conditions.
- Is re-designing the current UFLS schemes in South Australia, and is designing a similar emergency control scheme for over frequency events.
- Is seeking strategic collaborations with relevant entities to progress all aspects of the FPSS program, and will continue to consult with stakeholders via forums, publications, leveraging international networks, and other industry events.
- Will embed analysis of these challenges where relevant into existing AEMO studies, such as the *NEM Electricity Statement of Opportunities* and *NEM National Transmission Network Development Plan*.

[4] System strength broadly is a measure of the maximum current that is expected to flow in response to a short-circuit at a given point in the power system.

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FIGURES

1. INTRODUCTION

The Future Power System Security (FPSS) program is a body of work established in December 2015 that aims to adapt AEMO's processes, allowing sufficient flexibility so AEMO can continue to maintain security in Australia's power system into the future. This involves adapting current processes to address immediate risks, while promoting long-term solutions to maintain power system security over the next 10 years.

Context

Australia's (and the world's) electricity industry is undergoing transformational change. Fossil-fuelled, synchronous generation[5] is being displaced by non-synchronous generation at both the utility scale and the residential level as customers become more active about how their demand is met.

Table 1 shows current installed generation capacity in each National Electricity Market (NEM) region[6], as well as each region's level of interconnection with the rest of the NEM.

Table 1 Installed generation capacity in the NEM in terms of physical attributes as at June 2016

<table>
<tr><th>Generation capacity
(MW) (% of total)</th><th>Queensland</th><th>New South Wales</th><th>Victoria</th><th>South Australia</th><th>Tasmania</th></tr>
<tr><td>Synchronous (registered)</td><td>12,459 (89%)</td><td>15,416 (88%)</td><td>11,050 (83%)</td><td>2,999 (58%)</td><td>2,672 (87%)</td></tr>
<tr><td>Non-synchronous (registered)</td><td>12 (0.1%)</td><td>897 (5%)</td><td>1,230 (9%)</td><td>1,473 (29%)</td><td>308 (10%)</td></tr>
<tr><td>Non-synchronous (distributed)</td><td>1,585 (11%)</td><td>1,301 (7%)</td><td>957 (7%)</td><td>683 (13%)</td><td>97 (3%)</td></tr>
<tr><td rowspan="6">Interconnection</td><td colspan="2">Double-circuit AC connection NSW–Qld</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">3 cable DC connection NSW–Qld</td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="2">5 AC lines connecting NSW–Vic</td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Double-circuit AC connection Vic–SA</td><td></td></tr>
<tr><td></td><td></td><td colspan="2">DC connection Vic–SA</td><td></td></tr>
<tr><td></td><td></td><td colspan="3">DC connection Vic–Tas</td></tr>
</table>

AEMO projects a continuing shift from large-scale, synchronous, centrally-dispatched generation, towards distributed, intermittent generation, connected to the power system through solid state inverter systems[7], including a growing proportion of non-dispatched distributed generation. Consumer choice, increasing availability of distributed energy resources (DER), and the policy landscape will affect the speed and shape of the transformation.

This change in generation mix challenges the designs built into the power system and the regulatory framework within which it operates. The National Electricity Rules (Rules) largely reflect the operational governance of a "traditional" power system, where generation is centralised and roles and

[5] Synchronous generation refers to generation whose operation is tightly 'synchronised' to the operating frequency of the power system. 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 most synchronous generating units (such as the turbine and rotor) connected to the power system will be spinning in step with the system frequency. Synchronous machines respond exactly in lock step to any changes to power system frequency.

[6] The synchronous and registered non-synchronous generation capacity is at 15 April 2016, adjusted to include the closure of Northern Power Station (South Australia) and commissioning of Moree Solar Farm (New South Wales). Both occurred in May 2016 (see AEMO's generation information page: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Generation-information). The non-synchronous distributed capacity is the rooftop and commercial PV installed capacity source from APVI, http://pv-map.apvi.org.au/historical#4/-26.67/134.12 accessed 27 July 2016.

[7] An inverter is an electrical device that converts direct current into alternating current.

responsibilities are clear. It is possible that the Rules do not provide the necessary parameters or incentives for both existing and new technologies to provide a broad range of technical capabilities, in addition to energy, that could be required in future to maintain power system security.

For example, synchronous generation has a range of physical attributes that have, to date, been relied on in the fundamental design and operation of the power system. One such property is the "inertia" provided by the large rotating masses of the generator and turbines. These rotate with the system frequency (synchronous), and their mass resists changes to frequency almost instantaneously.

Although some non-synchronous generation, like wind, also has rotating turbines, these technologies are increasingly connected to the power system via power electronic converters, so the mechanical movement is decoupled from the power system. It is important to note that this decoupling of the mechanical motion does not mean that wind generation cannot provide similar responses to inertia. There has been much interest in the ability of wind power technologies that could provide synthetic inertia that mimics the inertial response of synchronous generation. A similar response is being pursued by utility-scale photovoltaic (PV) generation, as well as other services that could be provided by technologies such as storage. These are explored further in Chapter 8.

The FPSS program formalises and broadens work initiated by AEMO over the last few years to explore and adapt to the changing generation mix. In 2013, for example, AEMO investigated the operational challenges of integrating large volumes of wind generation and the capabilities of these technologies. AEMO also undertook joint studies with ElectraNet on the potential impacts to system security in South Australia due to the high penetration of non-synchronous generation.[8] These studies have been formalised into this broader program of work, because the landscape is changing more quickly.

This transformation is not unique to the NEM, with many other power systems around the world experiencing high penetrations of non-synchronous generation. While these can make for worthwhile case studies on integrating non-synchronous generation, it is important to recognise that most are strongly interconnected (Germany and Denmark, for example). The challenges are quite different to the NEM, where the transmission network is very long and regions can be disconnected. It is during separation where the challenges are most pronounced, and international experience is of more limited application.

AEMO is exploring what lessons can be drawn from international experience, and has been working with international colleagues on power system challenges. For example, AEMO has been:

- Taking a lead role in developing techniques for measuring and assessing the impact of reducing system strength, working closely with the International Council on Large Electric Systems (CIGRE).
- Playing an active role in GO15, in which the world's 18 largest power system operators address the operational, technological, communication, and financial aspects of power systems.

While the NEM is unremarkable in its current overall level of non-synchronous generation, South Australia has one of the world's highest proportions of non-synchronous generation relative to its load. The February 2016 joint AEMO and ElectraNet report[9] highlighted South Australia's increasing reliance on the Heywood Interconnector, which connects the region to the rest of the NEM. South Australia's level of non-synchronous generation also means that its power system is more susceptible to rapid changes in frequency, and to larger frequency deviations following a separation event. This makes power system operations for South Australia very different to most of the international experience.

To date, AEMO has not identified NEM-wide challenges or challenges that are apparent all the time. Each NEM region has a different generation mix, network configuration, and demand characteristics, which lead to different challenges or different timing. The FPSS program aims to identify when and where these challenges could arise.

[8] These studies are available at http://aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/FPSSP-Reports-and-Analysis

[9] *Update to Renewable Energy Integration in South Australia – joint AEMO and ElectraNet report*, February 2016. Available at: http://aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/-/media/CACEB2122362436DAC2CDD6E8D3E70D0.ashx

AEMO's focus to date has been mainly on South Australia because of the high penetration of non-synchronous generation (see Table 1). Challenges are anticipated to then emerge in other regions that are vulnerable to separation from the remainder of the NEM, that is, Tasmania and Queensland. As the system evolves, these challenges could become more prevalent in other NEM regions.

Structure of report

This report presents the outcomes to date of the FPSS program, including an update on actions committed in the February 2016 joint AEMO and ElectraNet report. It also outlines work currently underway and priority focus areas until the end of 2016, and invites stakeholders to comment on these.

- Chapter 2 describes the process of achieving outcomes through the FPSS program. It provides a high level overview of the identification process AEMO worked through with the technical advisory group to qualitatively identify the technical challenges that could emerge and decide which challenges are an initial priority for further analysis.
- Chapter 3 outlines the high priority challenges identified.
- Chapters 4 to 7 detail the identified challenges, the work AEMO has completed in quantitatively understanding them, and work currently underway.
- Chapter 8 briefly touches on some of the technical solutions that may be appropriate for high priority challenges.
- Chapter 9 documents activities to date across the program.

As the FPSS program progresses through its phases, AEMO will publish the outcomes in a series of reports. Some will be technical reports, and others high level overviews like this one, as AEMO aims to make the program as consultative as possible.

Inviting stakeholder comment

In the program's first stage, a technical advisory group of industry representatives helped AEMO identify and qualitatively prioritise the technical challenges that need investigating.

AEMO now wants to make sure the program captures the experience and perspective of all interested stakeholders.

AEMO invites stakeholder feedback on the FPSS program, and specifically the technical challenges and actions identified in this report. Stakeholders wanting to provide input can:

- Email submissions to StakeholderRelations@aemo.com.au by 16 September 2016.

2. APPROACH OF THE FPSS PROGRAM

2.1 Scope

AEMO recognises that other challenges are arising for stakeholders, such as rising electricity prices, wholesale price volatility, or difficulty in securing retail contracts or investment finance. While these are also important concerns, AEMO's FPSS program focuses on maintaining power system security.

In analysing the potential challenges and solutions of the power system of the future, the FPSS program will identify and assess challenges in terms of their technical attributes, and frame solutions around the technical needs of the power system.

Implementation frameworks for the technical solutions (for example, redesigning existing market or regulatory structures, or introducing new standards or market mechanisms) will consider the costs and benefits of changes via consideration of the National Electricity Objective (NEO).[10] These frameworks will be the remit of the appropriate decision-making authorities. AEMO will work closely with the Australian Energy Market Commission (AEMC), the Australian Energy Regulator (AER), and the Council of Australian Governments (COAG) Energy Council to promote changes where justified and to inform these processes.

2.2 Objectives

Power system security is a key objective of power system operations. It is concerned with:

- Maintaining the power system within safe and technical operating limits.
- The power system's resilience to potential credible failures of generation, large loads, and network equipment.

AEMO employs a number of mechanisms to maintain power system security. These include (but are not limited to):

- Procuring frequency control ancillary services (FCAS).
- Forecasting demand and intermittent generation.
- Dispatching controllable generation in five minute intervals.
- Utilising real system analysis to predict system responses to disturbances, and planning to minimise the impact of disturbances.

Most of the actions available to AEMO to maintain power system security currently involve utility-scale synchronous generation plant.[11] The potential future withdrawal of this plant from the system will remove some of AEMO's levers for maintaining the power system within the required operational bounds, unless existing and new generation can provide these functions.

Change is usual for market systems, including the NEM. Many changes go unnoticed, as the market and system adapt to underlying requirements. However, the challenges investigated here may not be resolved within existing frameworks, in which case modifications would need to be made.

The broad objectives of the program are divided into two streams:

- The first continues AEMO's business as usual operations in analysing the operating characteristics and limits of the power system. It addresses any potential operational challenges that can be foreseen in the next two to three years, through the review of current operational procedures or the development of new ones if required. It also analyses the performance of AEMO's power system tools and models to ensure they continue to reflect the changing dynamics of the system.

[10] The National Electricity Objective, as stated in the National Electricity Law, is: *to promote efficient investment in, and efficient operation and use of, electricity services for the long term interests of consumers of electricity with respect to – price, quality, safety, reliability, and security of supply of electricity; and the reliability, safety and security of the national electricity system.*

[11] AEMO does dispatch down some intermittent generation such as wind farms if required for system security purposes.

- The other stream has a longer-term focus, to provide AEMO, and the industry, with the ability to assess holistically what procedural, policy, regulatory, or other changes will be required to maintain power system security in the most efficient manner.

Further information can be found on the program website.[12]

2.3 Process

As the FPSS program is considering long-term strategies to maintain power system security, the approach needs to be flexible enough to capture new products and services that could emerge in the market, or new challenges that haven't been previously identified.

To reflect this, the program has three broad phases. These are likely to run concurrently, because, for many challenges, understanding their likelihood and impact if not addressed will be progressed in parallel with analysis of potential technical solutions (see below and Figure 1 for a summary).

Identification and definition

AEMO established a Power Systems Issues Technology Advisory Group (PSI TAG) of technical experts representing each relevant sector to assist in the qualitative identification and prioritisation of technical challenges. The PSI TAG had representatives from:

- Owners/operators of synchronous generation plant.
- Representatives of owners/operators of non-synchronous generation plant.
- Owners/operators of transmission and distribution networks.
- Retailers.
- Consumers.
- The AER.
- The AEMC.
- The COAG Energy Council Senior Committee of Officials (SCO).

The PSI TAG convened several times over the last six months. Over that period of time it developed a comprehensive list of emerging future technical challenges. The challenges it identified as high priority are detailed in this report, and challenges it assessed as less urgent are listed in Appendix A.

AEMO is now undertaking quantitative analysis to understand the risk posed by each of the challenges including timing, likelihood, impacts, and linkages with other challenges. This analysis will inform how the operational bounds of the power system could change over time, and define the technical specifications that will be required by solutions to the challenges. Many of the challenges could have the same underlying drivers.

Given the pace of change in the operating environment, and the lengthy process for changing Rules, standards or procedures, some challenges may emerge in NEM regions before these changes can be implemented. In these instances, AEMO would need to adapt its operational processes and procedures to manage the challenges as they emerge.

Specification of technical solutions

AEMO has drafted an initial list of the range of potential technical solutions to the identified high priority challenges. These potential solutions are outlined in Chapter 8. In parallel with the quantitative analysis of the challenges, the potential technical solutions need to be understood in terms of their technical characteristics and the extent to which they can address single or multiple challenges.

[12] Program information is available at http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability.

This analysis will inform whether current policy or regulatory frameworks are adequate to address the challenges as they emerge, or whether they inadvertently create barriers for some technologies to participate in the mechanisms currently used to maintain power system security. If current commercial or policy/regulatory frameworks are found not to be adequate, the analysis will provide technical specifications to assist in the design of these frameworks so they provide solutions into the future.

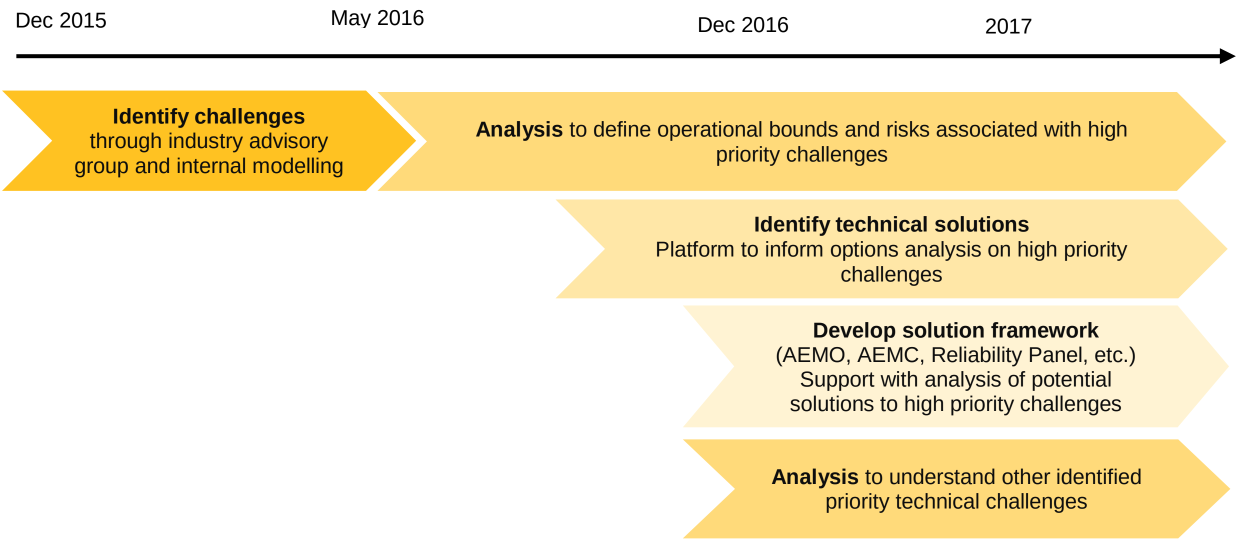
Implementation of solutions

The implementation of technical solutions is likely to be possible via a range of frameworks. This phase will explore whether they could be delivered either under the current regulatory regime, or new commercial, regulatory, market, and competitive options. Fed by the technical risk assessment of the challenge and the details of potential technical solutions, this phase would consider the relative cost-benefit of various combinations of frameworks and their alignment with the NEO of efficiency, effectiveness, and long-term interest of consumers.

This phase may be led by entities other than AEMO (such as the AEMC or the Reliability Panel), with AEMO providing technical input into the analysis of potential changes to regulatory or market frameworks.

Some challenges might not occur very frequently, and it could be more appropriate to apply an operational risk management approach to the challenge. Importantly, some challenges are interlinked, so solutions that address a single challenge might not be effective on their own, or resolving one challenge could also resolve others.

Figure 1 Indicative timeframe for analysing future power system security



Collaboration with the Australian Energy Market Commission

Complementary to the FPSS Program, on 14 July 2016 the AEMC launched a review into the suitability of existing wholesale energy market frameworks to maintain power system security as the industry transforms to accommodate the evolving generation mix.[13]

The review follows, and will be coordinated with, ongoing technical work on these and related issues conducted through the FPSS program.

[13] AEMC. "Review of market frameworks for power system security", 14 July 2016. Available at: http://www.aemc.gov.au/News-Center/What-s-New/Announcements/AEMC-starts-a-review-of-market-frameworks-for-powe?utm_medium=email&utm_campaign=AEMC+Weekly+Update+-+14+July+2016&utm_content=AEMC+starts+a+review+of+market+frameworks+for+power+system+security&utm_source=www.vision6.com.au.

As part of the review, AEMO and the AEMC have formalised a collaboration to address these challenges in the NEM. Each market agency will, within the scope of their role, address the related technical, regulatory, and market framework challenges that arise. While each organisation has its own governance and accountabilities, the AEMC and AEMO will maintain close collaboration and cooperation to ensure these activities deliver a coordinated package of measures to complement the increasing volume of non-synchronous generation and maintain power system security in the future.

3. THE HIGH PRIORITY CHALLENGES

AEMO has focused on identifying and understanding the *underlying technical challenges*, making sure they are specified in terms of the fundamental properties of the power system.

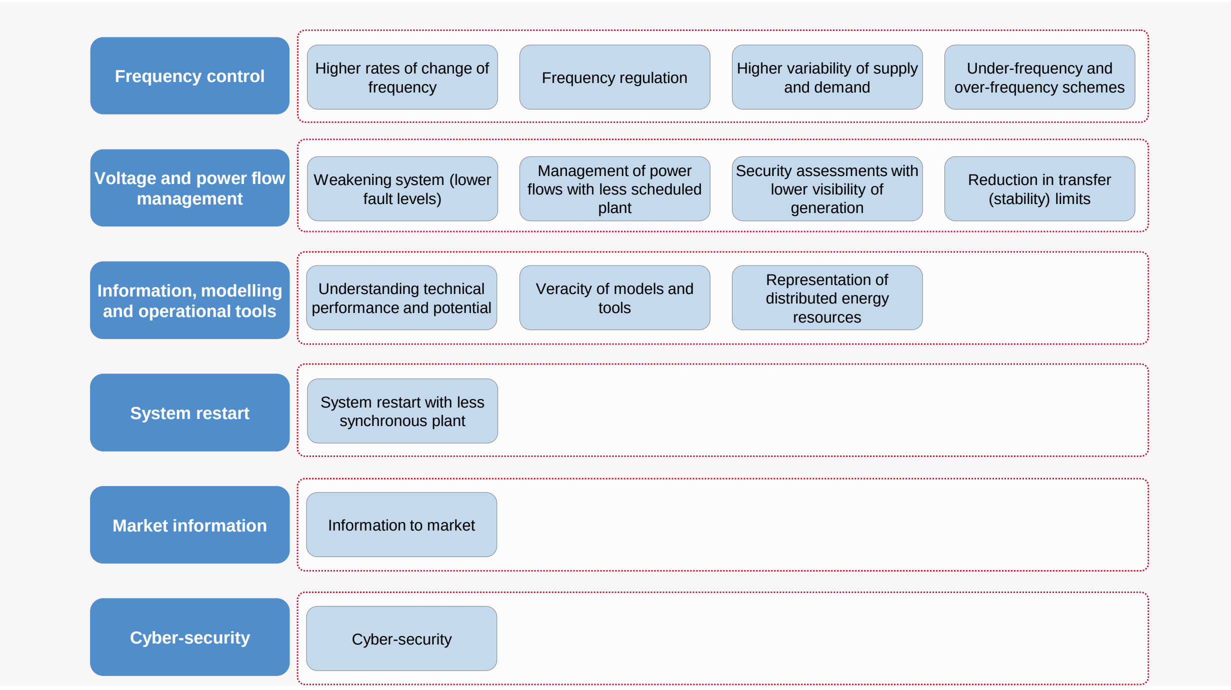
For example:

- Chapter 1 outlined the role inertia has played to date in dampening changes in frequency. Picturing the future energy market having less synchronous generation, it would be tempting to say the potential challenge is a "lack of inertia".
- This is not the problem, but, as the level of system inertia reduces, the *underlying technical challenge* becomes more apparent.
- The *underlying technical challenge* is managing frequency deviations – inertia provides a means to do this, but not necessarily the only means.

AEMO and the PSI TAG employed this approach in distilling and testing the potential technical challenges.

AEMO seeded the discussion with an initial list of challenges, and the group discussed these in detail in the context of potential changes to the generation technology mix and more active customer involvement. This process tested the initial list of challenges, and determined whether additional challenges should be on the list, and whether they can be managed within the existing regulatory context. Figure 2 summarises the outcome of these discussions.

Figure 2 List of potential technical challenges



The qualitative mapping of the technical challenges developed in consultation with PSI TAG identified four broad high priority areas that should be the initial focus of quantitative assessment, and these are detailed in this report (see Table 2).

Table 2 Summary of high priority technical challenges

Broad area	Technical challenge
Frequency control (Chapter 4)	**High rates of change of frequency (Section 4.1)** Supply-demand imbalances due to any disturbance will cause larger and more rapid frequency deviations that will be increasingly hard to manage in low inertia systems. High rates of change of frequency (RoCoF) will lead to additional tripping for the same size imbalance. Relays and protection schemes on generators and feeders have inherent delays and so may not respond quickly enough to high RoCoF. Critical schemes such as under frequency load shedding (UFLS) could become compromised in maintaining the frequency operating standards (FOS).
	Insufficient amount of frequency control ancillary services (Section 4.2) The market has historically attracted synchronous generation to provide regulation and contingency frequency control ancillary services (FCAS). If this synchronous generation is displaced from the energy market (either permanently or temporarily), the level of FCAS it provided will have to be procured from other sources, which the market has not attracted to date. Additionally, the increasing variability of supply and demand is likely to be met with increased frequency control requirements from the market. If there is insufficient FCAS available, AEMO will not be able to maintain system frequency within the required standards, and at worst, the system may collapse under some contingency events.
Managing extreme power system conditions (Chapter 5)	**Emergency under frequency control schemes (Section 5.1)** The performance assumptions of UFLS schemes are being challenged by the high RoCoF under contingency conditions involving the loss of interconnection in NEM regions susceptible to islanding. The efficacy of these schemes is also being affected by the increased penetration of DER, that: • Can reduce the load available to be shed at times when distributed generation (such as rooftop PV) is generating in the parts of the network that are shed. • Can mean, in areas of high penetrations of DER, that at certain times of the day part of the distribution network could be operating in reverse, so generation is shed instead of load. The current schemes and technologies that shed load using pre-set relays are not designed to adapt to changing system conditions, such as the reversal of power flows. If UFLS schemes are ineffective, it will be difficult to prevent system collapse following rare separation events.
	Emergency over frequency generation schemes (Section 5.2) Although there are no specific provisions in the Rules, over frequency emergency control schemes could be useful to coordinate tripping of generation to manage contingencies resulting in an excess of generation. To be effective, these schemes also need to manage other technical matters, such as high RoCoF and fault levels, and avoid tripping generation that supports the management of these technical matters.
Information, models and tools (Chapter 6)	**Visibility of distributed energy resources (Section 6.1)** The customer-driven increase in DER[14] and technologies that can integrate the control of devices to manage load is not directly visible to AEMO. In aggregate these can have a material impact on the power system, and a lack of visibility affects AEMO's ability to assess the operational limits of the power system accurately. This also affects AEMO's ability to dispatch utility-scale generation to meet the residual load not met by DER. If the operational limits of the power system cannot be ascertained, AEMO would need to impose conservative limits, which create market inefficiencies.
	Tools and capabilities (Section 6.2) As the dynamics of the power system change, models of physical plant and modelling tools that are currently sufficient might in future not be capable of providing accurate system state information to underpin real-time and operational forecasts, and to support decision-making by system operators and planners. If these were inadequate, the operational limits of the power system would have greater uncertainty associated with them, and a more conservative operational approach would be necessary.
	Representation of DER (Section 6.3) As DER increases, loads (as seen by the power system operator) become more intermittent and dynamic, displaying characteristics not seen previously. Dynamic load behaviour is not effectively represented in power system models and system security studies at present. This obscures the real response of load to power system disturbances, and AEMO would have to impose conservative assumptions in the maintenance of power system security.
System strength (Chapter 7)	**Reducing system strength characterised by low fault levels (Chapter 7)** Low fault levels on the power system can reduce the effectiveness of protection systems that detect and clear faults, and the ability of inverter-connected plant to operate as designed. They could also result in greater difficulty in maintaining stable voltage levels in some parts of the network.

[14] Distributed energy resources represent both generation and load sources that can have a material impact on the network in aggregate. These can include rooftop PV, battery storage, demand management systems and electric vehicles.

The key areas in Table 2 were prioritised based on:

- The existence and likely emergence of challenges.
- Their potential impact on the power system.
- The lead time required to implement solutions.
- Perceived operational risk.

As indicated in Figure 1, AEMO plans to initiate analysis of the other identified challenges after the higher priority challenges have been progressed. If information comes to light that requires a reprioritisation of challenges now assessed as less urgent, these challenges can be analysed earlier. A description of the challenges the PSI TAG identified, but did not find to be high priority at this stage, is in Appendix A.

4. FREQUENCY CONTROL

Context

Frequency is important to the security of the power system and is a measure of the instantaneous balance of supply and demand. If supply exceeds demand, frequency will increase, and vice versa.

The NEM operates at the nominal frequency of 50 Hertz (Hz). Frequency Operating Standards (FOS) are set by the Reliability Panel and prescribe the allowable frequency deviations for different types of events:[15]

- Normal system operation.
- Credible contingency events[16] (including loss of generation or load, or forced network outage).
- Non-credible or multiple contingency events[17] (or separation from the rest of the NEM).

Some NEM regions have different frequency bands for these contingency events.

AEMO is responsible for dispatching sufficient FCAS to meet the FOS. As noted in Chapter 1, this is assisted by the presence of synchronous generation, which provides an inherent inertial response to the frequency deviations, slowing the rate of change of frequency (RoCoF).

Additional to the inertial response, AEMO employs two types of market services to manage frequency during normal operational conditions and following credible contingency events:

- Regulation FCAS, which is centrally controlled by AEMO to manage minor deviations within the five minute dispatch period.
- Contingency FCAS, which is enabled to correct relatively material frequency deviations that might arise from larger supply-demand imbalances.

Non-credible contingency events may result in larger frequency deviations than can be managed by FCAS. In this case, emergency control schemes are activated, and these are discussed in Chapter 5.

Background information about frequency control can be found in the *Frequency Control* factsheet.[18]

In identifying the potential challenges, the PSI TAG considered drivers of the increasing need for frequency control. This included a preliminary assessment of what levels of RoCoF are manageable and whether the current suite of frequency control mechanisms will remain relevant and effective.

From this initial assessment, four challenges related to frequency control were identified as a priority for further analysis. The objectives of this analysis are to understand:

- How system frequency may be affected in the longer term.
- Whether the current frameworks are likely to efficiently incentivise the required capabilities to manage a range of frequency deviations.

Understanding the system needs, the point at which the current mechanisms potentially fail, and the underlying capability of technologies to meet these system needs, will allow AEMO to determine the specifications of potential technical solutions.

Sections 4.1 and 4.2 outline two of the four identified challenges related to frequency control – high RoCoF and insufficient FCAS – and the work underway to address them. The other two frequency

[15] The FOS are available at http://www.aemc.gov.au/Australias-Energy-Market/Market-Legislation/Electricity-Guidelines-and-Standards/Frequency-Operating-Standards-(Mainland) and http://www.aemc.gov.au/Australias-Energy-Market/Market-Legislation/Electricity-Guidelines-and-Standards/Frequency-Operating-Standards-(Tasmania).

[16] Credible contingency events are defined in Clause 4.2.3 of the Rules, and broadly refer to unexpected but reasonably possible events which the power system is required to be secure against.

[17] Non-credible contingency events are defined in Clause 4.2.3 of the Rules and refer to very rare, large events against which the power system may not be secure.

[18] http://www.aemo.com.au/~/media/Files/Electricity/NEM/Security_and_Reliability/Reports/AEMO%20Fact%20Sheet_Frequency%20Control%20-%20Final

control-related challenges – under frequency and over frequency control schemes – are detailed in Chapter 5.

4.1 High rates of change of frequency

Challenge: Supply-demand imbalances due to any disturbance will cause larger and more rapid frequency deviations that will be increasingly hard to manage.

Where challenge might arise:

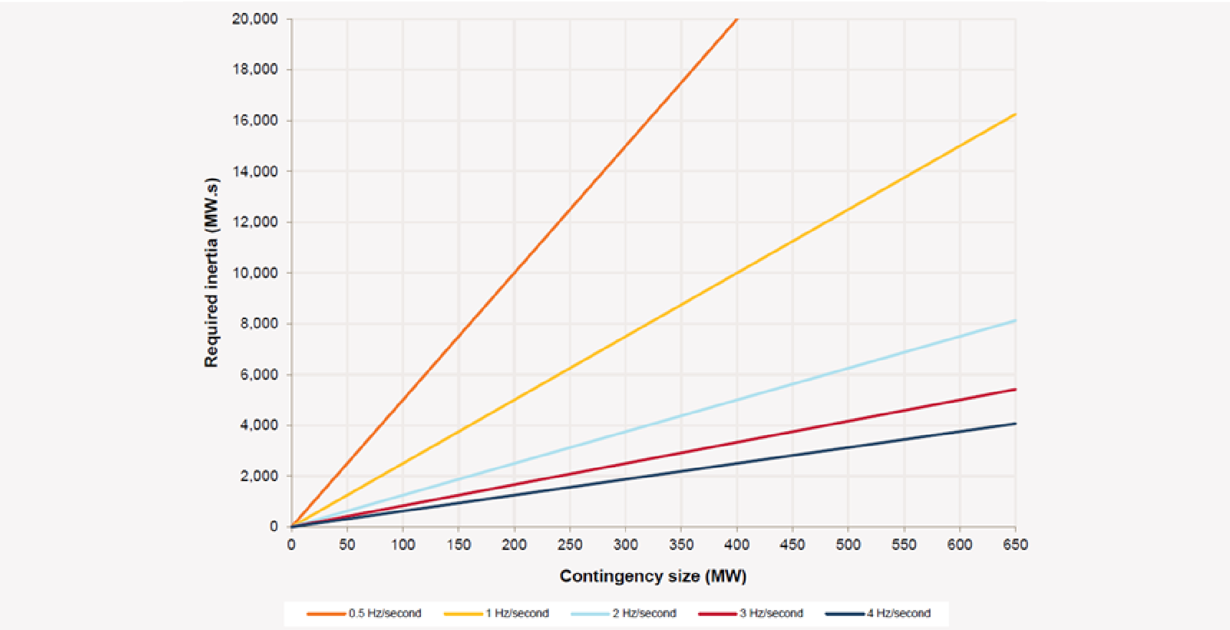
- Managing RoCoF is not expected to be a global NEM challenge in the near term, as the NEM as a whole is anticipated to have sufficient inertia from online synchronous generation.
- It is likely to first become a challenge in regions that can become separated from the rest of the NEM (South Australia and Tasmania), because these networks have lower synchronous inertia when islanded.

4.1.1 Context

The management of RoCoF is critical to maintaining power system frequency within the FOS and to maintaining the power system in a secure operating state.

To maintain a given RoCoF for different contingency sizes[19], the amount of inertia required is proportional to the contingency size. Figure 3 provides an example of a family of curves that demonstrate this relationship. For example, for a 200 MW contingency event, system inertia would need to be 10,000 megawatt-seconds (MW.s) for the RoCoF to remain at 0.5 Hz/s (orange line). If system inertia was only 1,250 MW.s, the same size contingency would result in a RoCoF of 4 Hz/s (blue line).

Figure 3 Relationship between instantaneous RoCoF contingency size and system inertia



[19] Contingency size refers to the size, in MW, of the largest contingency event that could occur – that is, the size of the resulting imbalance between supply and demand. For example, the contingency size could be the online capacity of the largest generating unit or the flow on an interconnector.

Since inertia has to date been provided by the rotating mass inherent in synchronous machines, a power system with less synchronous generation online (lower inertia) leads to a higher RoCoF than one with more synchronous generation (higher inertia).

That means the frequency changes faster following a disturbance in a power system with less synchronous generation, and this could result in the loss of additional generation or load to arrest the frequency deviation when it occurs.

The higher RoCoF will also require stabilising control systems to respond more rapidly to contain the change. For example, for a contingency event resulting in a RoCoF of 1 Hz/s, the frequency drop from 50 Hz to 49.5 Hz (the limit of the FOS for credible contingencies), would take 0.5 seconds. A RoCoF of 2 Hz/s would halve this time, meaning action would be required within 0.25 seconds to prevent the system frequency from breaching the FOS for a credible contingency event.

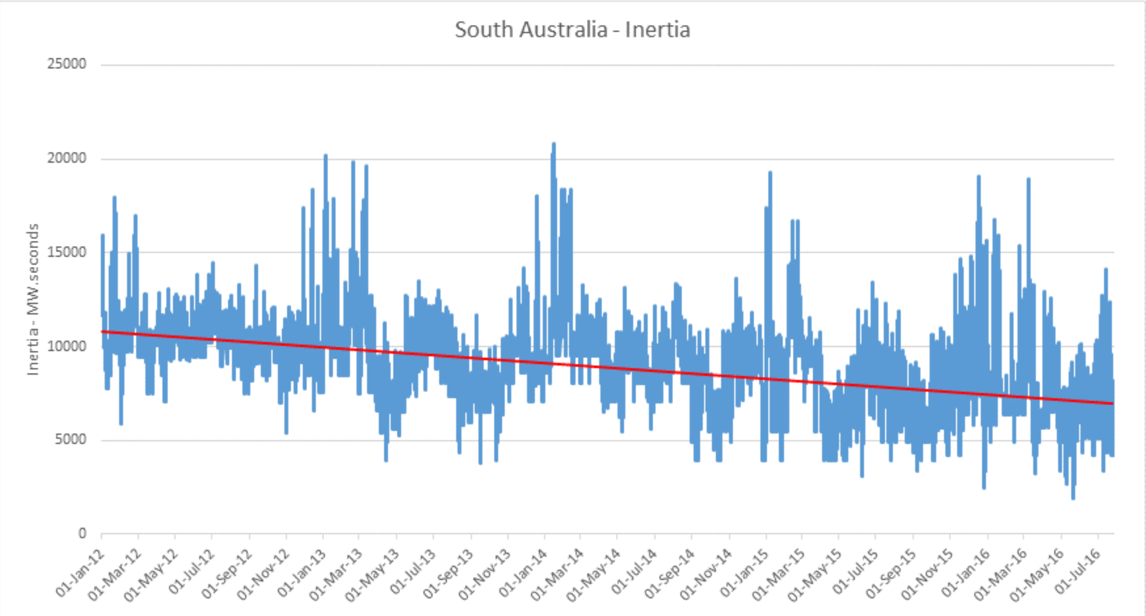
If the RoCoF is unacceptably high, it can result in a cascading trip of load or generation. For very large, rare events that produce very high RoCoF, emergency frequency control systems might not be fast enough to prevent a widespread disruption. This would impact consumers through potential loss of power as well as having an economic impact on affected regions.

At this stage of the analysis it is not clear:

- At what point the RoCoF would become unmanageable from a technical perspective.
- The probability of this occurring.

AEMO is working on the answers. Analysis by DNV KEMA for EirGrid has identified that some generators in their power system show signs of instability for RoCoF levels at 1.5 Hz/s and 2 Hz/s.[20] EirGrid is currently transitioning their generation standards from 0.5 to 1 Hz/s. Robust analysis of this nature, specific to the NEM system, is required.

Figure 4 System inertia in South Australia



In the NEM, system inertia has been decreasing with the reduction of online synchronous generation. For example, the total inertia currently available in South Australia is around 18,725 MW.s, a decline of 3,000 MW.s since the retirement of Northern Power Station in May 2016. Actual system inertia,

[20] DNV KEMA report to EirGrid. *RoCoF – An independent analysis on the ability of generators to ride through Rate of Change of Frequency values up to 2Hz/s*, February 2013. Available at: http://www.eirgridgroup.com/site-files/library/EirGrid/DNV-KEMA_Report_RoCoF_20130208final_.pdf

however, depends on the generating units in service at any point in time. Inertia in South Australia has already been observed to be as low as 2,000 MW.s.

Figure 4 illustrates the decline in inertia in South Australia since January 2012. As inertia is a global characteristic, shared between NEM regions, this reduction does not affect stable operations provided that the Heywood Interconnector is in service. Should South Australia be islanded from the rest of the NEM, however, the lower inertia would result in greater RoCoF from load or generation events.

An unexpected trip of the Heywood Interconnector when at high power flow can be the most significant event for the region, as it creates a large mismatch between supply and demand, and leaves South Australia islanded.

When a trip of the Heywood Interconnector has been classified as a credible contingency event (due to network maintenance or bushfires, for example), AEMO prepares the system for this contingency by obtaining FCAS within South Australia and invoking a network constraint equation that limits the interconnector flow to a level that limits the potential RoCoF to 1 Hz/s. (A similar constraint is always imposed in Tasmania to avoid triggering under frequency load shedding (UFLS) after a trip of Basslink.[21])

AEMO does not have the power to do this when the trip of the Heywood Interconnector is a non-credible contingency event. The mechanism available to manage extreme under frequency outcomes in these cases is UFLS.

Given the decline in inertia, AEMO has been continually monitoring the state of the power system to assess how frequently the South Australian system is exposed to high levels of RoCoF following a non-credible separation event.

There have been nine separation events since the market started in 1998, as shown in Table 3. These events have been of relatively short duration, and on each occasion the islanded South Australian system was successfully operated as an island until the Heywood Interconnector was restored.

Table 3 Historical South Australian separation events

Date and time	Duration	Load shed in SA (MW)	Credible/non-credible
30/10/1999 0602 hrs	10 minutes	0	Not known
02/12/1999 1311 hrs	26 minutes	1,130	Non-credible
25/05/2003 1702 hrs	56 minutes	0	Credible
08/03/2004 1128 hrs	43 minutes	650	Non-credible
14/03/2005 0639 hrs	22 minutes	580	Non-credible
16/01/2007 1502 hrs	40 minutes	100	Non-credible
19/10/2011 0618 hrs	35 minutes	0	Credible
13/12/2012 0707 hrs	14 minutes	0	Credible
01/11/2015 2151 hrs	35 minutes	160	Credible[22]

AEMO performed a historical assessment to indicate the exposure of the South Australian system to high RoCoF conditions if a non-credible separation event had occurred over the last six years. (Future exposure depends on the generation online in South Australia and the interconnector flow.)

[21] For more details, see Transend Networks, *Annual Planning Report*, 2014. Available at: www.tasnetworks.com.au/Aurora/media/pdf/Transend-Annual-Planning-Report-2014.pdf.

[22] Separation events can be credible if there is a planned outage of one of the lines of the Heywood Interconnector.

A three-tiered 'traffic light' classification was used to show the approximate proportion of time that the South Australian network would have been exposed to high RoCoF at the time of a non-credible separation event:

- **Green (RoCoF ≤ 1Hz/s)** – FOS of 47–52 Hz was likely to have been met

  There is a high level of confidence that the system could have withstood the non-credible loss of the Heywood Interconnector for instantaneous RoCoF levels below 1 Hz/s, without experiencing cascading failure of generation.

- **Orange (1Hz/s < RoCoF ≤ 4 Hz/s)** – uncertain if FOS of 47–52 Hz would have been met

  When operating the South Australia power system with exposure to RoCoF in this range, it is increasingly unclear whether FOS would have been met following a non-credible separation event.

- **Red (RoCoF > 4Hz/s)** – FOS of 47–52 Hz unlikely to have been met

  This level of RoCoF would have resulted in South Australia system frequency leaving the 47–52 Hz band less than one second following a non-credible contingency event. Outside this frequency band, generation is not required to remain connected. This time period is too short for automated generator governor response to moderate the frequency disturbance, and too short for UFLS to produce a well-coordinated and well-graded disconnection of load to arrest the frequency.

To provide an indicative worst case assessment of the potential exposure risk following the closure of Northern Power Station, AEMO adjusted the historical 2015 market data to mimic its absence, including an assessment of the interconnector flows and replacement generation in the following way.

At each five minute dispatch interval:

1. The historical output of Northern Power Station was assumed to be met through increased imports from Victoria up to the 650 MW Heywood Interconnector limit.
2. If the limit was reached, the remainder of the Northern Power System historical output was met within South Australia, potentially from sources that contribute some system inertia.

While worst case, this approach was considered suitable for a high level insight into the risk of a region-wide collapse upon non-credible separation.

Figure 5 Percentage of time South Australia was exposed to high RoCoF should it have separated

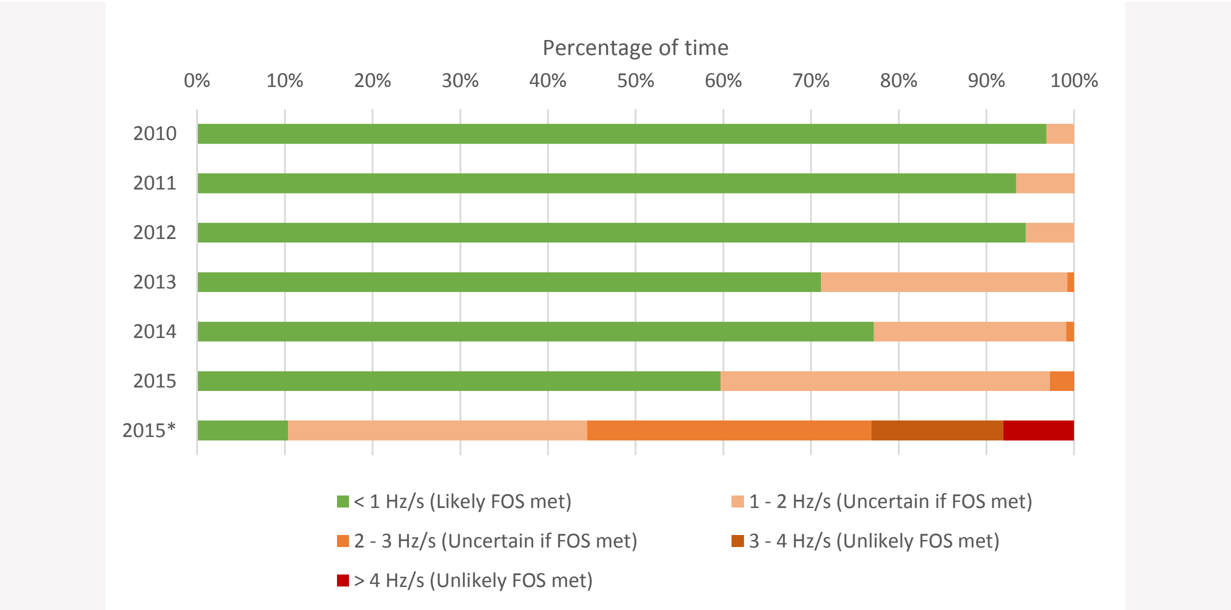


Figure 5 summarises the findings of this assessment, and illustrates that:

- There has been a material increase in the percentage of time the South Australian power system is susceptible to high RoCoF following a non-credible separation event. This increases significantly after the upgrade of the Heywood Interconnector (which increases the contingency size) and closure of Northern Power Station (which decreases system inertia).
- Emergency frequency control schemes in their current form (such as standard UFLS schemes) are increasingly unlikely to maintain the FOS. This could result in a black system across South Australia from a non-credible separation event.
- There is a large percentage of time where it is unknown how the South Australian power system would respond to a non-credible separation event.

Schedule 5.2.5.3 of the Rules requires generating units over 5 MW to remain connected for a period of one second through an event where RoCoF reaches ±1 Hz/s.[23,24] However, this technical standard only applies for generation connecting after 2007. AEMO has tried to obtain the RoCoF withstand capability of South Australian generation commissioned before 2007, but has found this is uncertain.

AEMO has analysed historical contingency events to determine which generation tripped and which did not. To date, there have not been enough high RoCoF events for AEMO to understand the limits of generation. For example, the separation event that occurred in South Australia on 1 November 2015 resulted in a RoCoF of around 0.36 Hz/s, and all but one generation plant remained connected.[25] Where there has been tripping in the past, this may not have been directly due to high RoCoF. Even where generation has sustained its operation through a high RoCoF event, its ability to do this reliably in future is unknown.

4.1.2 Objective for further analysis

AEMO is seeking to determine the underlying RoCoF limits of the power system. This analysis will provide an indication of when and where challenges are likely to arise and also the probability of their occurrence, and hence the level of exposure to risk emerging in each NEM region. This will inform the reach required by any potential technical solutions.

Further analysis will also explore alternative ways of managing RoCoF by assessing the potential value of a Fast Frequency Response (FFR) service in the NEM (FFR is described in Section 4.1.4), as well as other potential technical solutions.

4.1.3 Work completed

PSI TAG

The industry advisory group identified RoCoF as an area that requires initial focus to understand better the characteristics and quantify the challenge.

4.1.4 Key focus for July – December 2016

Indicative timeframes for all work underway are in Chapter 9.

International review

AEMO is performing an international review to understand how other power system operators have adapted (or are adapting) frequency control measures to the changing operating environment, and to learn from these experiences.

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[23] Schedule 5.2.5.3 available at http://www.aemc.gov.au/getattachment/5e088309-9b8b-4801-bfee-8afc1e59d9e6/Rule-as-made.aspx.
[24] Automatic access standards specify generation to withstand a RoCoF of 4 Hz/s for a period of 0.25 seconds.
[25] Further information about this incident is available at http://www.aemo.com.au/media/Load%20shedding%20in%20South%20Australia%20on%20Sunday%201%20November%202015.pdf.

Identifying RoCoF limits

AEMO is currently gathering information on what system elements are sensitive to RoCoF, and their operating limits. This includes network elements, load, protection systems, and all generation. A staged approach is being taken, with the initial focus on South Australian generation. In future, the analysis is expected to be extended to other system elements and areas of the NEM that can separate from the grid (Tasmania and Queensland), and finally the rest of the NEM. Understanding the response of these elements under various system conditions will help identify system RoCoF limits, and their nature and characteristics. These would also feed into AEMO's power system models.

Developing and validating high RoCoF models

AEMO is developing models of the South Australian power system that will enable studies for high RoCoF response. The analysis will seek to determine whether there is a RoCoF limit beyond which the current FCAS are insufficient to maintain the FOS. This could then inform an assessment of appropriate technical solutions.

Potential for fast frequency response or inertial support

AEMO is investigating the extent to which FFR could provide a substitute for synchronous inertia. Examples include "synthetic inertia" from wind turbines, FFR from battery storage, or fast response generation ramping.

The fastest FCAS in the NEM at the moment is the six second contingency response, but inertia is an instantaneous response that has not had a market value. FFR is a service that would aim to allow new and emerging technologies to provide a response as quickly as they can, but not necessarily as quickly as inertia.

Many inverter-connected generation technologies, such as wind turbines and batteries of various kinds, are capable of providing a fast power injection in the first few seconds following a disturbance, that can help to arrest the frequency decline. The capabilities of different technologies vary.

AEMO is assessing the capabilities and limitations of technologies that can provide a FFR service, and whether FFR provides an adequate substitute or supplement to inertia. Furthermore, the scale and type of response required to make a useful contribution to the power system is unknown. At present, synthetic inertia has not been demonstrated to be an exact substitute for mechanical inertia, but could, in combination with fast acting responses with the right characteristics, maintain the FOS with a lower level of synchronous inertia than otherwise would be required.

This work aims to clarify the power system requirements for a useful FFR service, and compare this with the potential capabilities of power electronic converter-connected resources. This will provide an initial indication of whether a FFR service could provide a valuable contribution in the NEM, and inform the development of a preliminary technology neutral specification of this service.

4.2 Insufficient amount of available FCAS

Challenge:

- The market has historically attracted regulation and contingency FCAS from synchronous generation. If this synchronous generation is displaced from dispatch (either permanently or temporarily), the level of FCAS it provided will have to be procured from other sources, which the market has not attracted to date.
- Additionally, the increasing variability of supply and demand is likely to be met with increased frequency control requirements from the market.

Where challenge might arise:

- Similar to the challenges of high RoCoF, AEMO does not expect a system-wide shortfall of either regulation or contingency FCAS in the near term.
- This challenge is likely to be restricted to regions of the power system that may become islanded, as FCAS would need to be enabled locally within those regions.

4.2.1 Context

Although any technology can participate in the FCAS market if it is technically capable, these services have historically only been provided by synchronous generation. Synchronous generation is being displaced in some regions, so, if the FCAS market does not encourage new participants to provide the service, there will come a time when insufficient FCAS is available to arrest frequency deviations. The *2016 NEM Electricity Statement of Opportunities* (ESOO)[26] includes an assessment of potential FCAS supply gaps.

One important question to answer is whether there is a technical or regulatory barrier for new participants, or if current market mechanisms for FCAS are capable of providing sufficient investment signalling to drive new entry to the FCAS markets (particularly at locations that can become islanded but are generally connected to the rest of the NEM).

Understanding the capability of technologies to provide FCAS will inform whether current ancillary service markets need to be revised to incentivise new capabilities, and how the services should be specified to cater for new providers and facilitate the broadest possible market participation. The market will only deliver the required services if the technical design is appropriate.

AEMO works to balance supply and demand by forecasting the expected demand, as well as generation from intermittent sources such as wind and solar, to determine how much scheduled generation to dispatch so demand is met.

The intermittent nature of, for example, solar generation means the operational demand forecast is becoming more reliant on forecasting rooftop solar during daylight hours. On the supply side, if utility-scale intermittent generation is also a large proportion of the generation mix, there will be more uncertainty overall in the dispatch process, and more balancing might be required to maintain frequency within the FOS. Non-scheduled generation and rooftop PV would contribute greater variability in forecasting operational demand. These could increase regulation FCAS requirements and create a need to consider whether the market is encouraging fast-acting and flexible responses to provide regulation FCAS. The exact requirements will vary depending on the technology mix and the smoothing of intermittency provided by their geographical spread. For example, if intermittent generation were integrated with storage systems, the variability might be reduced.

To date, there has been no appreciable increase in required regulation or contingency FCAS. As, however, it is a NEM-wide market with sufficient NEM-wide FCAS, the market may not provide signals of tightening availability in certain regions at the relatively infrequent times where FCAS needs to be locally enabled.

AEMO is currently performing an analysis to estimate the FCAS requirements from increased variability in both supply and demand.

4.2.2 Objective for further analysis

AEMO seeks to:

- Identify the technical capability of technology to provide frequency control services, and assess whether any technical or regulatory barriers to their participation in FCAS markets exist.

[26] Available at: http://aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/NEM-Electricity-Statement-of-Opportunities

- Estimate future requirements for regulation and contingency FCAS, on the basis of changing variability and uncertainty of supply and demand, and determine whether a shortfall in FCAS is likely to occur, particularly in areas susceptible to islanding.
- Determine whether adjustments to the FCAS framework would allow frequency control to be managed more efficiently in the future, in light of the changing generation mix.

4.2.3 Work completed

PSI TAG

The industry advisory group identified the availability of FCAS as an area that requires initial focus to understand better the challenge.

4.2.4 Key focus for July – December 2016

Indicative timeframes for all work underway are in Chapter 9.

Review of technical barriers to participation in FCAS

The Market Ancillary Services Specification (MASS) outlines the technical requirements of participants in the FCAS market. AEMO is assessing whether the current MASS present technical barriers to participation from other technologies.

Projection of FCAS requirements

AEMO is currently projecting future FCAS requirements, and how they may change. This includes an assessment of both NEM-wide and regional requirements. Specifically, AEMO is investigating:

- The ongoing adequacy of the current regulation FCAS requirement of 120/130 MW, given that the changing generation mix is introducing more variability, as a greater proportion is intermittent and thus needs to be forecast.
- The relationship between FCAS requirements and online generation, with a view to optimising the FCAS requirements based on the amount and properties of plant online (including their variability of output), to increase efficiency.
- Whether the Rules' specification that contingency FCAS can only be utilised for generation or load events is still valid, given potential rapid ramping events of intermittent generation that can be considered to be "normal" generation variability. For example, quickly changing weather conditions that affect cloud cover or wind can create swings in generation from solar and wind plant.
- Whether ramping services over periods greater than five minutes might be required in the NEM as part of regulation FCAS, by determining whether the issue will be encountered, and the potential scale and timing of the challenge.

Operation of South Australia as an island

In conjunction with ElectraNet and South Australian Power Networks (SAPN), AEMO is exploring options to adjust system parameters to manage system security of an islanded South Australian region. Actions in progress include:

- Efforts to minimise rapid changes in the supply-demand balance resulting from the 11:30 pm hot water demand peak.
- Assessment of the impact of weak systems on operating the region as an island, including their potential to affect functionality of protection schemes designed to handle faults (see Chapter 7).
- Analysis of levels of both regulation and contingency FCAS necessary for islanded operation.
- Investigations to determine levels of expected RoCoF due to separation.

Technical solutions

AEMO is investigating the broader capability to provide FCAS by:

- Understanding the technical capability and limitations of inverter-connected generation and high voltage direct current (HVDC) interconnectors such as Murraylink to provide FCAS.
- Through the FFR analysis of Section 4.1.4, exploring the ability to substitute the MW requirements for other electrical responses, such as power injection, to provide frequency control services.

5. MANAGING EXTREME POWER SYSTEM CONDITIONS

As mentioned in Section 4.1.1, in regions with lower levels of synchronous generation, non-credible contingency events could result in high RoCoF that might be harder to manage with the current emergency frequency control schemes.

Although initially some challenges arise only during rare, non-credible contingency events, the potential consequences of these events are changing because it will become harder to manage them. AEMO and the industry need to address whether to increase the operational 'insurance' for these high-impact, low-probability events as the potential impacts increase in severity.

5.1 Emergency under frequency control schemes

Challenge:

- The performance assumptions of UFLS schemes are being challenged by the high RoCoF that could result under contingency conditions involving the loss of interconnection to NEM regions susceptible to islanding.
- The efficacy of these schemes is also being affected by increased penetration of DER, which:
  - Can reduce the load available to be shed at times when distributed generation (such as rooftop PV) is generating in the parts of the network that are shed.
  - Can mean, in areas of high DER penetration, that at certain times of the day part of the distribution network could be operating in reverse, so generation is shed instead of load. The current schemes and technologies that shed load using pre-set relays are not designed to adapt to changing system conditions such as the reversal of power flows.

Where challenge might arise:

- Initially in regions that separate from the rest of the NEM resulting in high RoCoF, the UFLS schemes might not react fast enough to arrest the fall in frequency and prevent cascading generation failure.
- The effectiveness of UFLS could be reduced in regions that have high penetrations of DER when they separate from the rest of the power system. The primary focus is on South Australia, Tasmania, and Queensland.

5.1.1 Context

UFLS is:

- An emergency control scheme that automatically disconnects load in response to an extreme frequency drop after a large supply disturbance. Generally, UFLS will only respond to rare, non-credible contingency events resulting in a level of demand far exceeding the available supply.[27]
- A distributed system with relays in substations to trip local load blocks if frequency falls below a given level for a set period of time. AEMO, in consultation with network service providers (NSPs) and Jurisdictional System Security Coordinators, determines the frequency settings and size of the load blocks to minimise the amount of load shedding required to meet the FOS while equitably

[27] The South Australian jurisdiction has indicated that UFLS can be used for credible under frequency events in South Australia.

distributing the amount of load shedding across the affected network area. The Rules require that 60% of customer demand is available for UFLS.

The UFLS scheme may be compromised by high RoCoF, as most installations were not designed with consideration of this. The relays have an inherent time delay to grade the response. If the RoCoF is too high, UFLS might not be triggered quickly enough, or at all, depending on the individual relays. This would render the UFLS ineffective in managing the fall in frequency.

Furthermore, UFLS was designed around a power system with relatively predictable, one-way power flows, so the relay equipment is static. The increase in DER (like rooftop PV) connected in customer premises or ‘embedded’ in the distribution network means some parts of these networks are now operating with reduced power flows at some times, and potentially in reverse flow. These are the same parts of the power system UFLS has relied on to supress frequency excursions.

This means that, during periods of high output from DER, distribution network feeders that are selected to be tripped by UFLS could have a lower impact on an under frequency condition if they have high PV penetration. If these feeders are tripped following UFLS action, the effectiveness of the scheme will be reduced, resulting in UFLS shedding more distribution feeders to arrest the frequency deviation. This means that, ultimately, more customer load would be disconnected.

If UFLS was activated while some feeders were operating in reverse, the underlying low frequency disturbance would be exacerbated. Again, UFLS would have to shed more feeders to restore frequency than would be the case in the absence of DER generating.

For example, consider a hypothetical region with five load blocks that are activated by UFLS as shown in Table 4. The blocks are tripped consecutively, depending on the level of load required to be shed.

If an event occurs in the middle of the day that requires 150 MW of load to be shed:

- If the day is extremely cloudy so no rooftop PV is generating, the first two load blocks would be shed, that is 150 MW of customer load.
- If there was some cloud cover so the PV systems were generating small amounts, the effective load that is available to meet the load shedding requirements is reduced. (Note the underlying customer load is the same as above, but some of it is met by the PV generation.) Blocks 1–3 would be activated to counteract the 150 MW event, corresponding to 200 MW of customer load (because the PV would be disconnected at the same time as the load).
- If there was no cloud cover over the area of load block one, its rooftop PV systems would be generating 10 MW in excess of its load. All five feeders would need to be tripped to stabilise the power system. That is, 300 MW of underlying customer load would be shed for a 150 MW requirement.

Table 4 Example of UFLS challenge

Load block	Net load as seen from the grid			Underlying customer load (for all)
	Load (no PV)	Load (some PV)	Load (more PV)	
1	100 MW	70 MW	-10 MW	100 MW
2	50 MW	40 MW	40 MW	50 MW
3	50 MW	40 MW	40 MW	50 MW
4	50 MW	40 MW	40 MW	50 MW
5	50 MW	40 MW	40 MW	50 MW

As this hypothetical example demonstrates, an increase in the penetration of DER results in increased requirements for load shedding for the same contingency events, effectively disconnecting more customers. AEMO’s joint report with ElectraNet estimated that up to an additional 75% of the underlying consumption would be shed at times of high rooftop PV generation in South Australia, compared to times when there was no rooftop PV generation.[28]

5.1.2 Objective for further analysis

AEMO's immediate focus is to work with NSPs to revise the frequency settings of the current UFLS and equipment to be as effective as possible under current conditions. AEMO is undertaking an immediate redesign of the existing South Australian UFLS scheme.

In parallel, AEMO is assessing the need to clarify the expectations around these types of events and roles, responsibilities, and mechanisms to implement those expectations. This may include promoting a Rule change to address any issues that are identified.

AEMO will also look ahead to assess whether these schemes will continue to be effective under expected RoCoF, and the increasing prevalence and potential for reversing power flows due to DER. AEMO expects it will be necessary to consider whether more fundamental changes (other than UFLS settings) may be required to make the scheme dynamic and adaptive to maintain frequency within required levels. This may include changes to the regulatory framework or the schemes' technical design.

5.1.3 Work completed

PSI TAG

The industry advisory group identified UFLS as an area that requires initial attention.

Analysis of exposure to high RoCoF in South Australia

AEMO completed the analysis to provide an indication of the risk exposure to non-credible separation events that would result in high RoCoF.

5.1.4 Key focus for July – December 2016

Indicative timeframes for all work underway are given in Chapter 9.

UFLS redesign

AEMO has commenced redesign of the UFLS scheme in South Australia in conjunction with ElectraNet and SAPN. The redesign work has been structured to focus on optimising the existing UFLS, to:

- Account for potential change in direction of flow of distribution network feeders in areas of high rooftop PV.
- As far as possible, include consideration of the impacts of decreased inertia in the South Australian network and associated increased RoCoF in the revised design.
- Consider how the current structure of the UFLS can be enhanced in future with the use of more adaptable schemes that change settings depending on the underlying conditions.

Promoting Rule changes

AEMO has done further work since the PSI TAG and believes there is merit in exploring Rule changes to enable a clearer framework for the implementation of control schemes for non-credible events, including which events or types of events should be protected by these control schemes. AEMO will

[28] *Update to Renewable Energy Integration in South Australia – joint AEMO and ElectraNet report*, February 2016. Available at: http://aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/-/media/CACEB2122362436DAC2CDD6E8D3E70D0.ashx

align this work as much as possible with the Rule change proposed recently by the South Australian government.[29]

5.2 Over frequency emergency control schemes

Challenge: Over frequency emergency control schemes could be useful to coordinate tripping of generation to manage contingencies resulting in an excess of generation. To be effective, these schemes also need to manage other technical matters, such as RoCoF and system strength, and avoid tripping generation that supports managing these technical matters.

Where challenge might arise: Similarly to under frequency, the challenges associated with over frequency will emerge first in regions that can be separated from the rest of the NEM (South Australia, Tasmania, and Queensland).

5.2.1 Context

Power system events that result in excess generation compared to demand will raise frequency. To protect against such events, generation has protection systems that will disconnect the generating unit on detection of over frequency conditions. (It is important to note that the generation trips to protect itself, not to assist the power system.) If too much generation tripped, it would result in an under frequency event and, potentially, subsequent load shedding.

To avoid this situation, an OFGS scheme can be designed to coordinate the tripping of generation when the frequency increases too much. This includes understanding the capabilities of generation to withstand varying degrees of RoCoF, as discussed in the previous chapter.

The Rules specify ramping down requirements that set a minimum performance of generating units to reduce their output by at least half, if the frequency exceeds a level nominated by AEMO, within three seconds.[30] This standard helps arrest the frequency rise but, like the specifications for RoCoF discussed earlier, is applicable only to generation connected since 2007. This means AEMO can rely on this reduction in generation output from only a subset of total installed generation. Even with this capability, it is unlikely to provide the fast response necessary for large frequency deviations.

If there is either insufficient online generation that is part of the coordinated over frequency emergency control scheme response to arrest changes to frequency, or the relays are not triggered, AEMO might not be able to control the frequency excursion in serious over frequency events, and in the rare, extreme case, the system could collapse. As with UFLS, this scheme is only activated during non-credible contingency events, so this challenge would only emerge on rare occasions.

There may be an increasing need for an emergency control scheme for over frequency events in some NEM regions. At present, only Tasmania has an OFGS scheme, and the Rules make no explicit provision for a framework establishing such a scheme.

In South Australia, there is an increasing risk of over frequency occurring following a non-credible separation event, due to factors leading to more periods of export from South Australia to Victoria:

- Increased capacity of the Heywood Interconnector.
- Progressively more non-synchronous generation being installed.
- Increases in rooftop PV reducing demand for electricity from the grid.

If South Australia were to be disconnected from the rest of the NEM while it was exporting large volumes of energy, the size of the over frequency challenge would increase, as there would be excess generation within the islanded region.

[29] Available at: http://www.aemc.gov.au/Rule-Changes?topicId=0&status=3
[30] National Electricity Rules, S5.2.5.8. Available at: http://www.aemc.gov.au/Energy-Rules/National-electricity-rules/Current-Rules.

5.2.2 Objective for further analysis

The immediate focus is to design an OFGS scheme to be implemented in the short term in South Australia. The OFGS will then be considered for other NEM regions.

5.2.3 Work completed

PSI TAG

Emergency frequency controls for over frequency conditions were identified as a required focus.

5.2.4 Key focus for July – December 2016

Indicative timeframes for all work underway are in Chapter 9.

Design of OFGS for South Australia

Building on preliminary design work for an OFGS scheme completed in 2013, AEMO has initiated additional design work on the calculation of over frequency trip settings that would need to be applied to generating plant to form a coordinated OFGS scheme for South Australia. The scheme will be designed to maximise the system security benefits to the South Australian region, by incorporating the results of the analysis discussed in Section 4.2.4 on *Operation of South Australia as an island*.

This is likely to lead to trips of non-synchronous generation before synchronous generation, to more reliably manage frequency deviations following islanding, and to provide regulation FCAS during operation as an island.

Discussions are currently in progress between AEMO, South Australian generation owner/operators, and South Australian NSPs on how to implement the scheme once an initial design is finalised.

Promote Rule change

The Rule change of Section 5.1.4 would also cover events resulting in over frequency conditions.

6. VISIBILITY OF THE POWER SYSTEM – INFORMATION, DATA AND MODELS

Context

Effective, efficient planning and operation of the NEM relies on the ability of AEMO and NSPs to:

- Accurately forecast demand and intermittent generation.
- Model economically efficient solutions to power system congestion.
- Predict the behaviour of the power system when it is subjected to disturbances with the potential to affect system security and place limitations on network transfer capability.
- Determine the performance standards for intending generation looking to connect to the network.

The modelling AEMO conducts also provides the market with information that influences commercial decisions. The information provided includes demand forecasts for the purposes of pre-dispatch, dispatch, short-term and medium-term Projected Assessments of System Adequacy (PASA) outlooks, and longer-term projections of reserve capacity and network constraints. For example, this information is used by generation and network owners/operators to plan maintenance.

Without accurate and reliable power system models and forecasts, there is increased risk that the operating limits of the power system will be incorrect, and the risk of insecure operation increases. Based on this uncertainty, AEMO would need to build in large (and inefficient) safety margins.

The existing suite of models and tools used by AEMO was designed around the traditional centralised power system in response to passive load, and has been progressively modified as the characteristics of the system have evolved. In light of the importance of these models in managing the power system, it is imperative that their performance and suitability are continuously assessed.

For example, the Australian Wind Energy Forecasting System (AWEFS) is a real-time wind energy forecasting tool. It was developed in response to growth in wind generation across the NEM and the increasing impact this growth was having on dispatch processes and planning tools. AEMO has since extended it to incorporate utility-scale solar, in the Australian Solar Energy Forecasting System (ASEFS)[31]. The AWEFS and ASEFS1 models allow intermittent wind and solar generation to be included as inputs to the central dispatch process.

Further detail on the importance of information in the dispatch process is in the *Visibility of the Power System* factsheet.[32]

Modelling also underpins the planning and operational functions of NSPs, including negotiating and assessing new generation connections at both the distribution and transmission levels. As the power system changes, both the needs and capability of this modelling are likely to change in their complexity.

Information describing power system elements is critical to the accuracy of these models. As the power system becomes more decentralised, the ability to access data about the system and its components will become increasingly important, and will affect AEMO's ability to maintain power system security if not addressed.

Even if new generation is operated to very high performance standards, visibility and knowledge of its electrical characteristics will still be important, given that at times of high DER generation there is less scheduled generation that makes ancillary services available to AEMO. Mechanisms and processes that allow behaviour of generation to be modelled and forecast in close to real-time transfer are already in place for utility-scale generation, but there are currently no formal frameworks to provide AEMO and NSPs with the required visibility over DER.

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[31] There are two ASEFS systems: ASEFS1 forecasts utility scale solar and ASEFS2 forecasts rooftop PV.

[32] http://www.aemo.com.au/~/media/Files/Electricity/NEM/Security_and_Reliability/Reports/AEMO%20Fact%20Sheet_Visibility%20of%20the%20Power%20System%20-%20Final

Challenges are already emerging in some modelling processes, although they are manageable at present. Because the establishment of formal mechanisms of data collection, storage, and management can take time to implement, it is important to be collecting the necessary information before challenges become more difficult to manage. For example, frameworks for emerging technologies such as residential battery storage need to be established now, before uptake becomes widespread.

Similarly, the development of new models or the modification of existing ones can be lengthy processes. Models generally rely on having sufficient historical data to allow calibration to ensure they accurately reflect the system dynamics. New models might also be predicated on access to new data.

Information, models, and data were considered a high priority because these processes have a long lead time, and because they could have a significant impact on both the operational and market efficiency of the NEM. For example, without accurate models AEMO would need to take a conservative approach in operating the power system. This could involve applying more stringent constraints on power flow, affecting the dispatch and ultimately the price of electricity.

Two key areas of initial focus agreed by PSI TAG were:

- The visibility of DER (see Section 6.1).
- The veracity of current power system models and tools (see Section 6.2).

The third area discussed, representation of DER in power system modelling, is a subset of the second focus area, and is a clear gap that was identified immediately.

6.1 Visibility of distributed energy resources

Challenge: The customer-driven trend for DER and technologies that can integrate the control of devices to manage load is not directly visible to AEMO. In aggregate, these can have a material impact on the power system, and a lack of visibility affects AEMO's ability to accurately assess the operational limits of the power system.

Where challenge might arise: The challenge will arise in all NEM regions as their relative penetration of DER grows.

6.1.1 Context

In determining the amount of generation that needs to be centrally dispatched, AEMO forecasts the expected load, wind and solar generation, and non-scheduled generation. The central dispatch process is then used to mobilise scheduled generation required to meet the load gap. This scheduled generation also represents a valuable tool for AEMO to regulate frequency, and is currently used to respond to power system disturbances. This is because of its control systems and also its potential participation in the FCAS market (see Chapter 4).

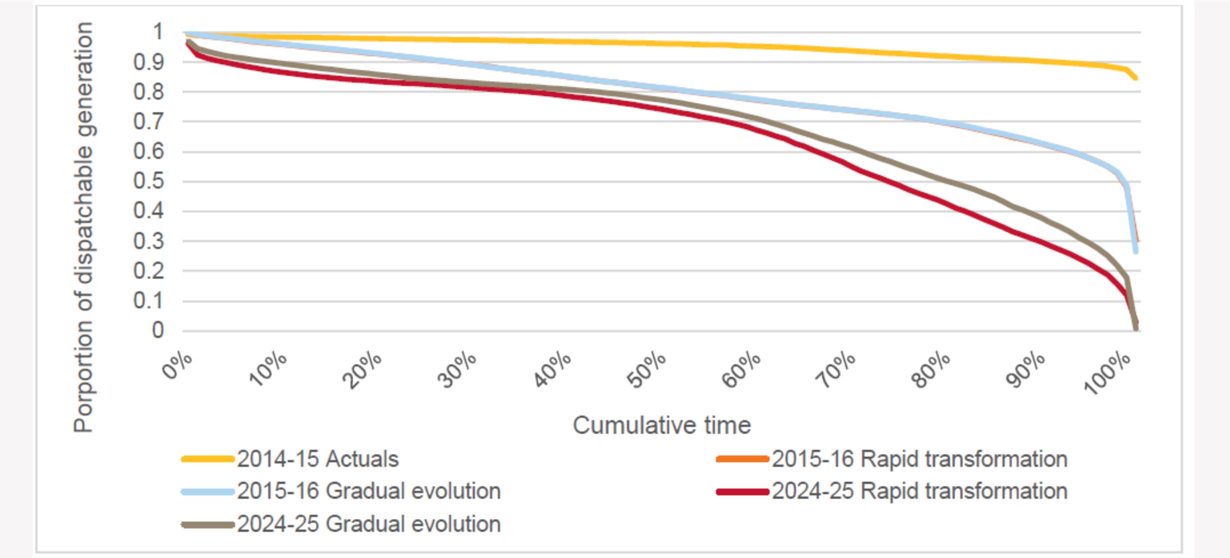
The increasing prevalence of DER is likely to reduce or remove the effectiveness of some of AEMO's levers at times when there is high DER output.

Figure 6 shows the level of dispatchable generation relative to total generation in South Australia projected in the *2015 National Transmission Network Development Plan* (NTNDP).[33] The increasing level of rooftop PV is projected to reduce the proportion of total generation controllable through the central dispatch process. Under the NTNDP Gradual Evolution scenario, for 10% of the time, less than 2,030 MW of South Australian generation was expected to be controllable in 2016 (that is, about 60% of

[33] AEMO. *2016 National Transmission Network Development Plan*. Available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/-/media/8DFD07ADFD924557AAA0D7029C8A6C70.ashx.

total local generation supply, including rooftop PV). By 2025, this controllable generation was forecast to drop to about 1,540 MW (38% of total local generation supply).[34]

Figure 6 Dispatchable generation[35] compared to total generation in South Australia



Emerging technologies, such as battery storage, provide opportunities to manage rooftop PV output. These opportunities depend on when, or if, these technologies achieve mass market penetration, and how they will be operated.

To adapt its processes successfully, AEMO needs to be prepared for a range of potential outcomes, for which it is important that AEMO and NSPs have visibility and accessibility to information about DER. This extends beyond rooftop PV and battery storage, and includes other technologies (such as electric vehicles and energy management systems) that might emerge and become widespread. Without information about these resources, it is difficult for AEMO to ascertain the aggregate response of these devices to power system dynamics. This in turn makes it challenging to identify potential issues in the power system and plan accordingly. So, even if battery storage were to alleviate some of the challenges of high rooftop PV generation, AEMO would need data on the location and technical properties of these systems to operate the power system securely.

Frameworks granting AEMO and NSPs the required visibility and information need to be NEM-wide. This is particularly important to ensure consistency across the NEM, as the uptake and constituency of DER will occur at different paces in each NEM region, and the type and quality of customer metering will vary widely.

Frameworks to access, collect, and store the data might need longer implementation timeframes, as they are likely to require regulatory changes to mandate provision of the required information.

It is likely that distribution NSPs are best placed to collect this data, but some form of incentive or compliance framework might be needed to capture relevant devices that won't necessarily register with the NSPs.[36]

[34] This projection assumed that Torrens Island A would be mothballed from 2018. It has since been announced that the planned mothballing has been deferred.
[35] Here "dispatchable" also includes semi-scheduled generation such as utility-scale solar and wind generation.
[36] The ability to access data without secondary measures will also be influenced by the type of metering that may be installed.

What data will be required?

The type and level of data required will vary depending on the purpose, and can be grouped as either *standing data* or *real-time data*.

Standing data refers to properties that remain unchanged (or change infrequently), such as location, capacity, electrical characteristics, or equipment settings.

Real-time data refers to the properties that change over each dispatch interval or a similar timeframe. For example, the output of every large-scale generation source in a given dispatch interval, or system conditions at a given point in time, can be considered as real-time data.

Standing data needs to be disaggregated for DER, as the individual systems vary in their properties and this changes how they impact the power system. AEMO would require this data either per installation or aggregated at a level that appropriately reflects the individual characteristics.

Currently, AEMO does not have a data exchange with NSPs providing real-time information about DER, even in aggregated form, say at each transmission connection point.

Furthermore, some of the data required by AEMO is not needed by the NSPs, and so is not collected. For example, the rooftop PV forecasting system, ASEFS2, relies on standing data of PV installations supplied by the Clean Energy Regulator (CER) and sampled output data from http://www.pvoutput.org/, a voluntary online repository of generation from individual systems. This generation dataset is unlikely to be a representative sample of all the PV systems currently installed[37], and it is not certain whether the voluntary website will continue to operate indefinitely, posing a large risk.

Understanding aggregate behaviour relies on visibility and knowledge

These DER acting in aggregate are becoming (or, potentially, already are) substantial sources of generation or load shifting (for example, battery storage). The capacity of rooftop PV currently installed in the NEM is over 4 gigawatts (GW). By way of comparison, Eraring Power Station is 2.9 GW and is Australia's largest coal-fired power station.

Figure 7 Maximum instantaneous (over 30 minute demand block) penetration of rooftop PV

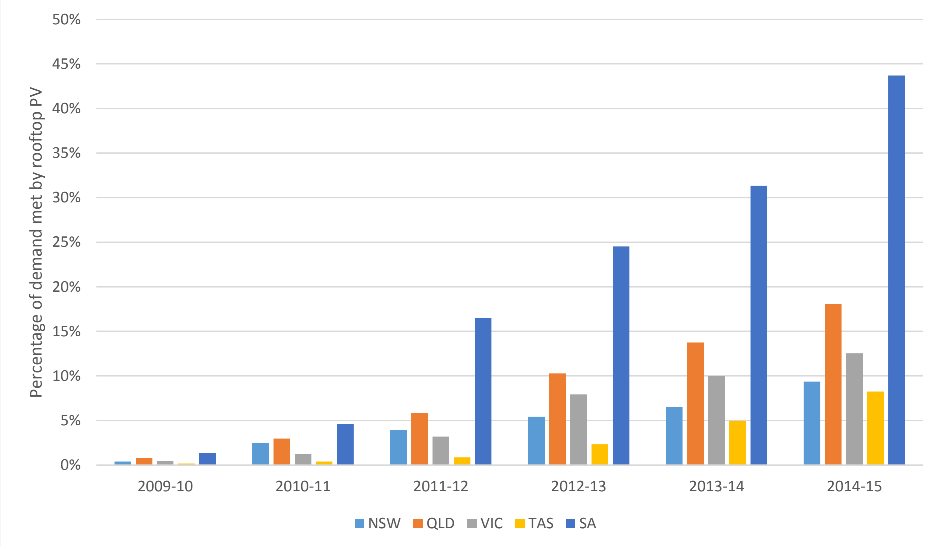


Figure 7 shows the increase in the level of demand met instantaneously by rooftop PV in each NEM region from 2009–10 to 2014–15. This is an estimate only, as AEMO has backcast the historical rooftop PV generation using historical weather data, CER installation data, and data from

[37] This is because there are many different brands of PV panels and inverter systems installed that have different performance characteristics.

http://www.pvoutput.org/. AEMO does not have data on the actual historical generation of rooftop PV across the NEM.

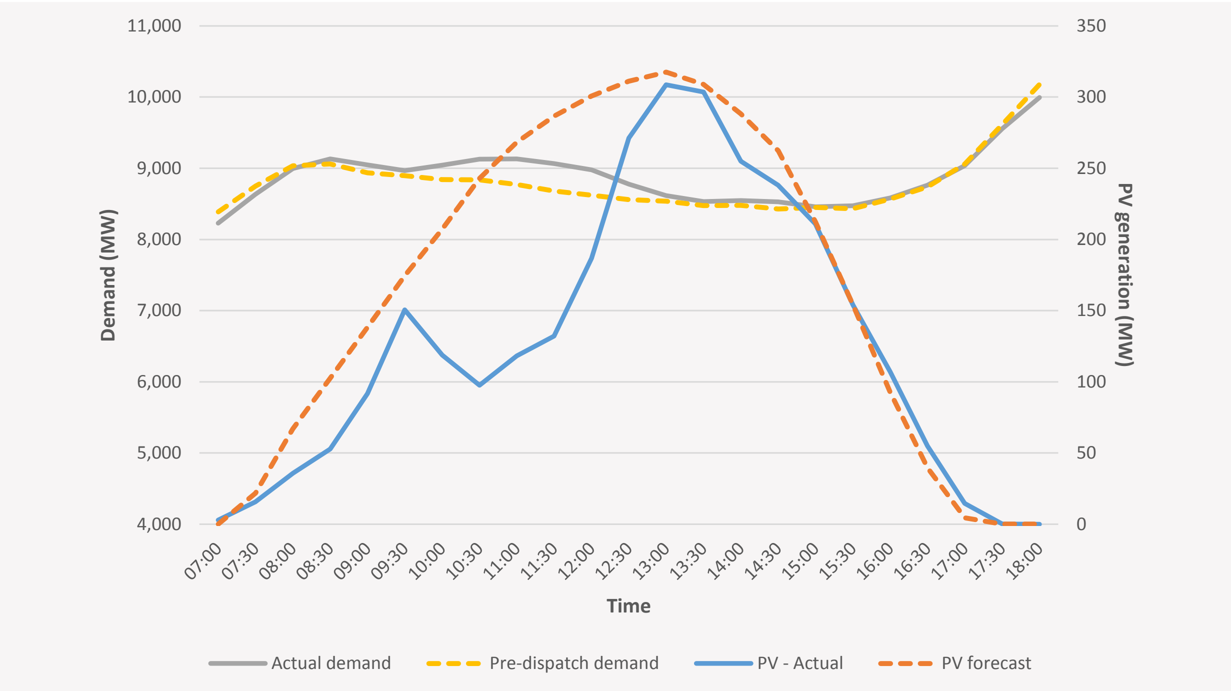
In contrast to generation that must be connected to the grid in accordance with Chapter 5 of the Rules, AEMO does not have a direct power to influence the technical standards or other performance requirements for DER. These installations are small individually and connect to distribution networks, with their performance standards set by the NSPs and Standards Australia. Connection standards at this level also tend to consider the installations in isolation, rather than considering the potential aggregate impact on the system as a whole.

Given its aggregate installed capacity, rooftop PV can be considered a large-scale generation plant over which AEMO has limited oversight, and no control over its generation output, if it was needed in response to system security considerations.[38]

The impact that rooftop PV can have on the power system was observed in Sydney on 26 May 2016. This is not the largest impact AEMO has seen historically, but provides a recent illustration of how external factors (in this case cloud cover) can impact the NEM.

Figure 8 shows the rooftop PV generation that was forecast by ASEFS2 the day before, against the estimated actual PV generation on the day, and the associated difference in demand from the pre-dispatch forecast. There was increasing cloud cover in the morning, and from 9.30 am the PV dropped off quickly, resulting in a noticeable increase in demand from the grid. While more frequent PV forecasts could help predict these deviations, AEMO cannot update rooftop PV forecasts more frequently because the current weather data is only updated every six hours. If AEMO had access to aggregated real-time data of these systems, it would be better able to manage demand changes such as this.

Figure 8 Impact of rooftop PV on NSW demand, 26 May 2016



[38] In the long term, under the current operational arrangements it is not inconceivable that DER may need to be constrained for certain operating conditions if the growth in DER continues.

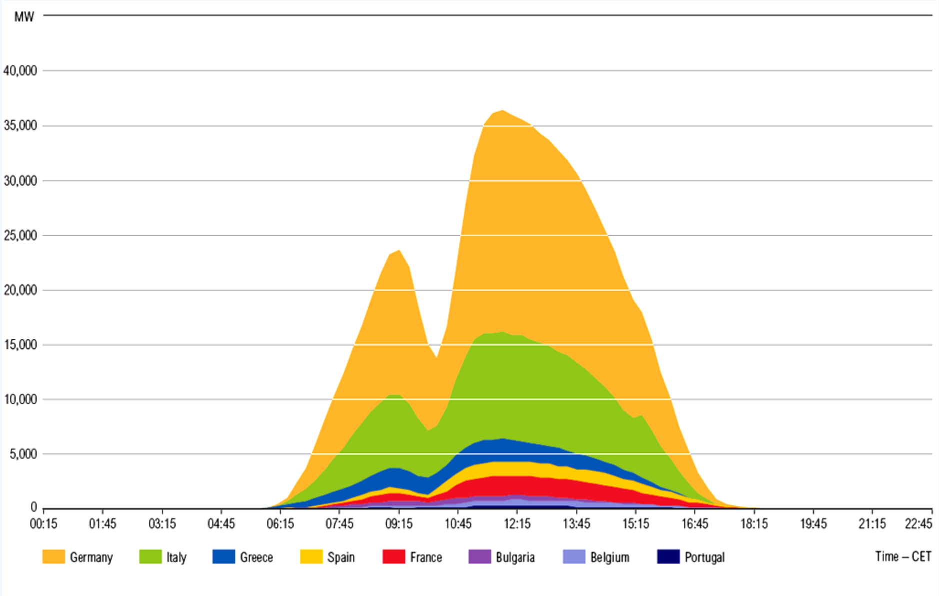
Case Study: Planning relies on visibility and knowledge of DER

An example of the need for visibility and information about DER to plan for uncontrolled events was on 20 March 2015, when Europe experienced a near-total solar eclipse. Knowing both that a disruptive event was going to occur, and the location and capacity of DER across continental Europe, system operators across 23 countries spent the preceding six months extensively planning together for the event and putting in place measures to maintain system security throughout the eclipse.

The eclipse occurred on a sunny weekday morning, and affected an area that had around 89 GW of PV installed.[39] Preliminary forecasts estimated that if the day remained clear, the PV output would decrease by around 20 GW within the first hour of the eclipse, and increase by almost 40 GW after maximum impact of the eclipse. That is the equivalent of the entire NEM system coming online.

The system operators procured enough ancillary services, among other measures, to provide the support that was projected to be required to keep the system operating. Figure 9 shows the PV output before, during, and after the eclipse. There was more cloud cover over Western Europe than had been forecast so the impact was slightly subdued. Nevertheless, the large, fast decrease in PV output is evident, and, more significant, so is the ramp up in PV generation as the eclipse passed.

Figure 9 PV generation in Europe before, during and after the near-total solar eclipse



As they could forecast and plan ahead, power system operators were able to maintain the interconnected system within relevant frequency operating standards. One of their main lessons was the importance of understanding the technical characteristics of PV generation, specifically[40]:

- *A clear description of the installed PV capacity and their capabilities is needed for the accuracy of forecast studies (technical data, retrofitting campaign, disconnection/reconnection settings and logics, etc.).*
- *Real time measurement of the dispersed PV generation is the key for adapting the operational strategy in real-time.*

Because regions in the NEM have high proportions of rooftop PV, which are forecast to increase further, there is equal merit in these lessons in the NEM, as AEMO plans ahead to maintain power system security against large, uncontrolled events.

[39] Some countries, such as Italy, have mostly utility-scale PV while others, such as Germany, have predominately rooftop PV.
[40] ENTSOE, *Solar Eclipse: The successful stress test of Europe's power grid*, 2015. Available at: https://www.entsoe.eu/Documents/Publications/ENTSO-E%20general%20publications/entsoe_spe_pp_solar_eclipse_2015_web.pdf.

Need for a mechanism

AEMO only has visibility of rooftop PV because the CER has frameworks in place to collect PV data, and it is mandatory to register PV systems with the CER to receive incentives under the Small-scale Renewable Energy Scheme (SRES). Data capturing the location and size of PV installations from the CER, along with http://www.pvoutput.org/ and the models developed by AEMO, has enabled AEMO to consider PV in its operational management.

Without the data voluntarily provided by consumers to http://www.pvoutput.org/, AEMO would be limited in its ability to provide accurate forecasts. Although CER data includes the location and size of installations, limitations in customer metering prevent AEMO from discerning their generation performance.

If no one is collecting data, no one can access it. The CER only collects data on installations registering for SRES. Data will not be collected once the scheme has ended, nor are PV upgrades captured. Standing data for inverters in general (such as those used for energy storage or replacement PV installations) is not being collected by any regulatory body. Some distribution NSPs collect some data depending on the level of installations in their networks, but there is no consistent obligation across the NEM, and, as highlighted in a recent inverter study (discussed in 6.1.3 below), not all relevant information is collected.

As DER is entirely in the control of consumers, AEMO's levers to manage power system security through scheduled generation (for example, by scaling market generation up or down) will become less effective as DER represents a larger proportion of the generation mix. It will become increasingly important for AEMO to have access to appropriately aggregated data describing the performance and real-time output of DER, to prepare for events that could occur.

The urgency of visibility has been highlighted by market attention on residential battery storage. If mass uptake of battery systems occurs before any regulatory framework is in place, AEMO might be unable to obtain the necessary information for these systems, which could lead to uncertain power system security risks. Given the regularity of solar generation, the output from rooftop PV installations is easier to forecast, whereas it is likely that residential storage systems will be driven by factors external to the market such as retail tariff.

AEMO's need for information and visibility will intersect, in part, with the needs of NSPs who will need to increasingly manage two-way flows at the distribution network level as consumers become more active. This will create additional needs in managing distribution networks in new ways to provide the required network flexibility.

6.1.2 Objective for further analysis

The objective of work in this area is to develop a set of justified requirements in relation to standing and real-time data about DER, and explore avenues for obtaining access to this data. AEMO will work with NSPs and other stakeholders on their needs and ability to access this information.

AEMO seeks to inform the relevant bodies on the need to establish mechanisms to ensure sufficient information is collected, stored in a consistent and accessible form, and provided to the appropriate bodies such as AEMO and NSPs.

Such frameworks would provide AEMO with visibility and confidence in the performance of DER, so it can plan for any aggregate outcomes, and manage the reduction in generation that can be centrally-controlled at times when DER constitute large proportions of online generation.

6.1.3 Work completed

PSI TAG

The industry advisory group identified the need to establish frameworks to provide the necessary visibility of DER, where justified, for power system security purposes.

Response of existing rooftop PV inverters to frequency disturbances

Given the volume of inverter-connected rooftop PV generation in the NEM, and the lack of information on how it will respond to frequency disturbances, AEMO initiated a stocktake of the current fleet of installed PV system inverters and their frequency trip settings. The objective of the study was to ascertain the degree to which these inverters would respond simultaneously to frequency disturbances by disconnecting *en masse* at the same frequency as this would impact power system security. The work completed has indicated that this is unlikely to occur, with the fleet having a spread in their frequency trip settings.[41]

Consultation with government

AEMO has been working with the ACT Government on accessing some of the storage data that will be collected from its Next Generation Renewables Energy Storage Program.[42]

Accessing this data will give AEMO the opportunity to take some steps towards developing and calibrating its models to account for the usage patterns of residential storage systems. It will also highlight information gaps that might need to be filled to capture this sufficiently.

AEMO has also been consulting more broadly with government about data requirements for storage. However, any frameworks need to be flexible and adaptable to capture the behaviour, use, and operational performance of all DER, both existing and likely to emerge, such as electric vehicles.

Collaboration with Energy Networks Association

In July 2016, AEMO entered a collaborative agreement with Energy Networks Association (ENA) to leverage the areas of their Network Transformation Roadmap that intersect with the FPSS program. AEMO has initiated engagement on the data needs and frameworks to facilitate data collection and access.

6.1.4 Key focus for July – December 2016

Indicative timeframes for all work underway are in Chapter 9.

Data needs analysis

AEMO is cataloguing which data is required about DER, and at what level of detail, for AEMO's operational needs spanning real time operation, short-term planning and forecasting, and long-term planning and forecasting. This will include an assessment of implications if relevant data is not available to AEMO, as well as identifying gaps in current accessibility frameworks.

Industry consultation

AEMO is not the only NEM body whose needs are changing. Any mechanism for data collection should also reflect the operational needs of other stakeholders such as NSPs or the AER for example. AEMO intends to undertake further consultation to understand the information gaps within NSPs, and capture these needs within this assessment.

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[41] AEMO. *Response of existing PV inverters to frequency disturbances*, April 2016. Available at: http://aemo.com.au/Electricity/National-Electricity-Market-NEM/-/media/43BE01476E2D4992A3BDA2DA2E1A14A4.ashx.

[42] More information on the program is available at http://www.environment.act.gov.au/energy/cleaner-energy/next-generation-renewables.

Demand side participation information guidelines

In March 2015, the AEMC made a final rule determination that enables AEMO to obtain information on demand side participation (DSP) from registered participants in the NEM. The information collected by AEMO will be taken into account when developing its electricity load forecasts. AEMO is currently developing guidelines that outline the DSP information that registered participants will have to provide. A pre-consultation forum will be scheduled for September 2016.

6.2 Tools and capabilities

Challenge: Models of physical plant and modelling tools that are currently sufficient might in future not be capable of providing accurate system state information to underpin real-time and operational forecasts, and to support decision-making by system operators and planners.

Where challenge might arise: Aside from specialised studies, the process of assessing and reviewing models and modelling tools is expected to be a longer-term challenge. If not addressed, it would become difficult to define the technical limits for real time operation of the power system under some conditions. This could ultimately undermine AEMO's ability to manage the power system securely, or necessitate the establishment of conservative limits, affecting the efficient operation of the market.

6.2.1 Context

Changes in the power system are pushing the most commonly used models and modelling tools beyond their design applications under some situations, such as under reduced system strength conditions or when system frequency changes very rapidly.

Models and modelling tools might not, therefore, provide the accurate system state information needed to underpin real-time and operational forecasts and to support operational decision-making. An example of this is the ability to represent load accurately, as discussed in Section 6.3.

Some of these developments might necessitate new or increased levels of data and information to capture the changing dynamics, and these will rely on some of the inputs following the work referred to in Section 6.1.

Other modelling tools, such as wind and solar forecasting systems, may need to be developed further to improve their accuracy as the percentage of intermittent generation increases.

In areas of reduced system strength, current levels of aggregation of data might no longer be able to reflect generation patterns, necessitating more granularity of data.

Stability analyses rely on accurate models of the components within a network. New generation proponents are generally expected to provide models of their plant that, while adequate in the past, are becoming increasingly less so. For example, models simulating the performance of power electronic converter-connected[43] generation work well when system strength is high, but are not applicable when the system strength is low, and so are not fully representative of the generation characteristics (see Chapter 7).

Another challenge is how to model inverter reactions during a fault. To date, the models have been hardwired with a generic profile during the fault so that they can be used in power system studies assessing their response after the fault. This has been sufficient to date, however, with increasing penetrations of inverter-connected generation, it might become just as important to be able to model the inverter during faults to mitigate any adverse impacts.

[43] A power electronic converter is a device that can convert AC to DC and vice versa. It is commonly used to connect utility-scale intermittent generation to the network. Inverters, on the other hand, convert DC to AC only, and are used to connect DER to the network.

6.2.2 Objective for further analysis

AEMO's role as system operator requires the continual review of its models and technical modelling tools, and implementation of additional developments where required. In light of the time required to develop, implement and verify new models and systems, AEMO plans to identify its long-term needs so any requirements can be fulfilled without compromising power system security and effective operational functions.

6.2.3 Work completed

PSI TAG

The industry advisory group recognised the importance of developing the capability to model the power system more effectively as it transforms.

6.2.4 Key focus for July – December 2016

Indicative timeframes for all work underway are in Chapter 9.

Capability roadmap

AEMO is developing a roadmap on how its models and tools might need to change. This might include the development and testing of new tools, including the calibration of the tools against actual power system measurements that are collected during power system disturbances. This intersects with the need for greater information as highlighted by the Generating Systems Model Guidelines proposed revision detailed in Section 7.1.3.

6.3 Representation of distributed energy resources

Challenge: As DER increases, demand (as seen by the power system operator) will become more intermittent and dynamic, displaying new characteristics. Dynamic load behaviour is not effectively represented in power system models and system security studies.

Where challenge might arise: The challenge will arise in areas with large penetrations of DER. If the representation of DER in load models is inaccurate:

- There will be greater uncertainty in operational demand forecasts, so it will be more difficult to match supply and demand through the dispatch process, increasing the reliance on FCAS.
- AEMO's power system models will not be able to accurately determine the system security limitations without accurate representations of the behaviour of load under voltage and frequency variations.

6.3.1 Context

The representation of DER will have different effects depending on the type of operational model. In the central dispatch process, demand is treated as a passive intermittent (forecast) quantity that is met by controlled supply options. The increasing penetration of DER, and the potential emergence of new technologies, changes the passivity of the load, with some technologies more responsive to market signals such as demand incentives. The ability to forecast this dynamic behaviour will affect the accuracy of operational forecasts of demand.

Power system models are used in various applications to determine system security limitations. The models include a representation of the behaviour of load under voltage and frequency variations. DER can change this dynamic.

In areas where there are lower levels of synchronous generation, the system becomes more sensitive to voltage and frequency variations. This means accurate models of existing and future loads is critical for AEMO to accurately determine the operational limits of the power system.

6.3.2 Objective for further analysis

An objective of work in this area is to determine the required representation of DER for all of AEMO's studies. This includes verifying whether current levels of aggregation will remain appropriate as the proportion of DER increases, or whether they no longer accurately reflect the behaviour of net load.

Similarly, for system stability studies, AEMO seeks to develop more accurate load models that will reflect the system dynamics and enable effective management of power system security.

6.3.3 Work completed

PSI TAG

The industry advisory group identified a clear need to develop appropriate representations of DER.

6.3.4 Key focus for July – December 2016

Indicative timeframes for all work underway are in Chapter 9.

Assessment of requirements for load models

AEMO is assessing current load models and will seek to determine the required representation of load and DER for all real-time and longer-looking studies of power system security, and inform the data required.

7. SYSTEM STRENGTH

System strength is a quantity inherent to any power system, with strong systems having support provided by local synchronous generation. The supportive characteristics of synchronous generation are not typically provided by power electronic converter-connected generation technologies. The fundamental difference between the two is that synchronous generation contributes typically three to five times more fault level[44] than non-synchronous generation.

Fault levels are a relatively local (rather than global, like frequency) system attribute, most affected by synchronous generation in proximity to each other. The more nearby online synchronous generation there is, the higher the fault current will be, and vice versa. For example, a long rural distribution network would generally have low fault levels due to the absence of nearby synchronous machines, where the La Trobe Valley region in Victoria, being close to synchronous generation, would have very high fault levels.

As the quantity of connected synchronous generation declines and the quantity of power electronic converter-connected generation increases in a region, fault level will decline, resulting in low system strength in that region. For more detail, refer to the *System Strength* factsheet.[45]

System strength is a complex technical challenge, because weak systems can lead to a number of localised issues as well as broader power system impacts. Three important potential challenges for power system security are:

- The potential to progressively reduce the effectiveness of some types of network and generating systems' protection functions, such as over-current and distance protection relays. This can have impacts on transmission networks, distribution networks, and generating systems through undesirable operation of protection functions.
- Power electronic converter-interfaced devices such as wind turbines, solar inverters, static VAR compensators (SVCs), and static synchronous compensators (STATCOMs) require a minimum fault level to operate stably and reliably. Reduced system strength could impact their ability to ride through faults on the system. There is also a risk that power electronic converter-connected generation could trip during normal system operation.
- Voltage control in response to small and large system disturbances is also affected by system strength, with weaker systems more susceptible to voltage instability or collapse.

An example of a potential local challenge is the difficulty to meet quality of supply standards, whether voltage fluctuations when switching reactive plant or increasing harmonics.[46]

To date, AEMO has not identified any challenges to power system security related to system weakness. However, AEMO has identified areas in the network where future power electronic converter-connected generation could pose challenges due to declining fault levels and limited network capability. These are in more remote or weakly connected parts of the network (furthest from major synchronous generation sources), with areas of reduced system strength already becoming evident in South Australia, North West Victoria[47], Northern Queensland, and Northern Tasmania.

Challenges to existing regulation

As the power system evolves, emerging changes to the power system will also highlight gaps in the regulatory regime. The current frameworks will not necessarily drive the technical solutions required,

[44] Fault level is the maximum current that is expected to flow in response to a short-circuit at a given point in the power system.
[45] http://www.aemo.com.au/~/media/Files/Electricity/NEM/Security_and_Reliability/Reports/AEMO%20Fact%20Sheet_System%20Strength%20-%20Final
[46] Harmonics in the power system refer to distortion in the voltage or current waveforms.
[47] AEMO. *Victorian Annual Planning Report*, 2016. Available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Victorian-transmission-network-service-provider-role/Victorian-Annual-Planning-Report.

nor provide obvious candidates to lead some of the solutions. As it progresses its analysis of the technical challenges and potential solutions, AEMO will also highlight any key regulatory gaps.

One potential regulatory challenge is related to the connection of new plant. The Rules require new connecting generation to meet the requirements for fault ride through[48] based on a model of the power system as it currently exists. That is, new generation is required to operate based on currently observed system strength, without considering the environment of changing generation mix.

Another potential regulatory gap is the lack of clarity over who is responsible for maintaining system strength. Currently, the Rules do not impose an obligation for generation to maintain local fault levels, or for network operators or AEMO to maintain system fault levels. Generation has standards which expect particular performance – for example, fault-ride through capability, which may be impacted by changes in the faults levels at its point of connection. A reduction in fault levels would occur if nearby synchronous generation withdraws or is not online at times. There is, therefore, a possibility that fault levels could reduce to a point where existing generation is no longer compliant with its performance standards as the surrounding system has changed.

7.1.1 Objective for further analysis

Although system-wide operational impacts have not yet been observed as a result of reduced system strength, because of its complexity in how it may impact system security, it is important to deepen understanding of any potential challenges.

7.1.2 Work completed

PSI TAG

The industry advisory group agreed that system strength is an area that needs better understanding in relation to power system security.

7.1.3 Key focus for July – December 2016

Understanding power system dynamics under weak conditions

The extent to which the rapidly changing generation mix, and the resulting weakening effect, gives rise to power system operation and security challenges can only be determined by detailed power system modelling and analysis.

In addition to detailed modelling and analysis of connection of new generation in areas where the system is weak, AEMO is developing more detailed system-wide simulation models for NEM regions with high penetration of power electronic converter-connected generation and the potential to experience dispatch periods with very little or no nearby synchronous machines. As a proof of concept, AEMO is currently developing more detailed simulation models of South Australia.

Generating System Model Guidelines

To allow modelling and analysis of such power systems and associated phenomena, a Rule change proposal for revision of Generating System Model Guidelines is currently being finalised. The Rules do not fully cover applications of new and emerging technologies when operating under the weak conditions discussed earlier. AEMO, in consultation with industry, has drafted a Rule change related to Clause S5.5.7 in the Rules. This will expand the scope of data about plant performance in respect to different types of plant connected to the power system, that is, under different power system dynamics. The proposed changes will allow for more accurate modelling and simulation of emerging power system

[48] Fault ride through is the ability to stay connected in short periods of lower network voltage.

technologies, enabling the impact of both on system security and registered participants to be investigated in greater detail.

8. TECHNICAL SOLUTIONS

The FPSS program is focused on understanding what the future technical needs of the power system will be, and initiating a pathway to adapting to these challenges. In its analysis, AEMO will consider potential technical solutions and work to understand their capabilities, how they would sit within current frameworks, and whether barriers exist.

How these technical solutions could be implemented will vary. Options include:

- Market-based procurement of technical services (the creation of new markets or the re-design of existing ones).
- Non-market procurement of technical services.
- Regulatory requirements such as technical standards.

It is also important to consider linkages between the challenges and hence the technical solutions. Some potential technical solutions will address only one challenge, while others may address several.

Table 5 provides a high-level summary of the potential technical solutions for the challenges in frequency control and system strength discussed in this report.[49] This list is not intended to be exhaustive, but rather indicative of the range of solutions and their reach. At this stage, no potential implementation frameworks have been described.

'Unsure' in Table 5 represents uncertainty in the technical feasibility of the solution. 'Partial' indicates that the solution is either localised or might not fully address the challenges. For example, a new AC interconnector facilitates the transfer of services between regions should an existing interconnector disconnect, but will only be a solution if the services remain there to be transferred.

Table 5 Summary of potential technical solutions for the identified challenges

Technical solution	Frequency Control (including extreme power system conditions)			System strength
	High RoCoF	Insufficient FCAS	UFLS/OFGS operation (high RoCoF)	
Synchronous condenser with or without flywheels. These can be new or retrofitted to existing/retiring plant.	✓		✓	✓
Synchronous generation/storage Either new entrants or existing plant	✓		✓	✓
Batteries and other inverter-connected **storage** providing ancillary services	✓	✓		Unsure
Wind generation providing ancillary services	✓	✓		Unsure
PV and other inverter-connected generation providing ancillary services	✓	✓		Unsure
Demand management providing broader ancillary services	✓	✓		
Change **protection systems** to operate in weaker systems				✓
Allow frequency to deviate more	Unsure	Unsure	Unsure	
Adjust **RoCoF protection** settings	Unsure		Unsure	
Maintain **local ancillary services** in areas that could island	Partial			
New **AC interconnectors**	Partial	Partial	Partial	
New **HVDC interconnectors**		Partial		

[49] No technical solutions have been proposed for the challenges discussed in Chapter 6, as it is anticipated that the most efficient solutions will be regulatory or involve model development.

Technical solution	Frequency Control (including extreme power system conditions)			System strength
	High RoCoF	Insufficient FCAS	UFLS/OFGS operation (high RoCoF)	
Frequency controller on existing HVDC	Partial	Partial	Partial	
Optimise contingency FCAS requirements		Partial		
Optimise Regulation FCAS requirements		Partial		

Regardless of the solution, full cost-benefit analyses of each option (individually and in combination with others) will need to be performed by the appropriate authority to ensure the technical needs of the future power system are in alignment with the NEO.

It is AEMO's intention that its analysis in the technical needs and technical capabilities of solutions will feed into assessments performed by the AEMC, AER, COAG Energy Council, or others in determining how existing frameworks might need to change.

9. SUMMARY OF WORK SINCE DECEMBER 2015

Action No.	Action	Timeframe	Progress
General reporting			
R.01	*Update to renewable energy integration in South Australia – joint AEMO and ElectraNet report*	February 2016	Completed
PSI TAG			
PT.01	PSI TAG meeting	16 December 2015	Completed
PT.02	PSI TAG meeting	5 February 2016	Completed
PT.03	PSI TAG meeting	17 March 2016	Completed
PT.04	Communication brief of PSI TAG published	8 April 2016	Completed
PT.05	PSI TAG meeting	16 May 2016	Completed
PT.06	Communication brief of PSI TAG published	1 June 2016	Completed
Frequency control			
FC.01	Factsheet – *Frequency control*	August 2016	Completed
FC.02	International Review of frequency control adaptation	September 2016	In progress
FC.03	Potential for fast frequency response or inertial support	September 2016	In progress
FC.04	Independent expert advice on managing high RoCoF	November 2016	In progress
FC.05	RoCoF withstand capability of South Australian generation	December 2016	In progress
FC.06	Projection of FCAS requirements	2017	In progress
FC.07	Technical capabilities to provide FCAS and technical barriers to participation	2017	Not yet commenced
FC.08	Operation of South Australia as an island	November 2016	In progress
FC.09	Capability and limitations of HVDC interconnectors to provide FCAS	2017	In progress
Managing extreme power system conditions			
MEC.01	Assessment of exposure risk to high RoCoF in South Australia	July 2016	Completed
MEC.02	UFLS redesign for South Australia	November 2016	In progress
MEC.03	Design of OFGS for South Australia	September 2016	In progress
MEC.04	Promotion of Rule change	December 2016	In progress

Action No.	Action	Timeframe	Progress
Information, models and tools			
IMT.01	*Response of existing rooftop PV inverters to frequency disturbances*	February 2016	Completed
IMT.02	Factsheet – *Visibility of the power system*	August 2016	Completed
IMT.03	Consultation with government on data needs	2016	Ongoing
IMT.04	Collaboration with ENA	July 2016	In progress
IMT.05	Data needs analysis	December 2016	In progress
IMT.06	Generating Systems Model Guidelines – Rule change submission	August-September 2016	In progress
IMT.07	Modelling capability roadmap	Continuous	In progress
IMT.08	Assessment of requirements for load modelling	2017	In progress
System strength			
SS.01	Factsheet – *System strength*	August 2016	Completed
SS.02	Develop modelling capability for weak system conditions	Continuous	In progress
Stakeholder engagement			
SE.01	Wind Industry Forum	17 March 2016	Completed
SE.02	COAG Energy Council report	July 2016	Completed
SE.03	Collaborative agreement with AEMC	14 July 2016	Completed
SE.04	Presentation – Clean Energy Summit	27 July 2016	Completed
SE.05	Presentation – ENA Regulation Summit	3 August 2016	Completed
SE.06	FPSS Roadshows	15-24 August 2016	In progress
Submissions			
SUB.01	Queensland Renewable Energy Expert Panel – Issues Paper	10 June 2016	Completed
SUB.02	Queensland Renewable Energy Expert Panel – Industry Forum	20 June 2016	Completed

APPENDIX A. LOWER PRIORITY CHALLENGES

Challenge	Details	Rationale for priority rating
System restart	Inability to re-energise the system when there are limited or no capable resources to do so.	Assessed now as a medium priority, but could become a high priority on a regional basis if current providers of restart services withdraw.
Cyber-security	The emerging world of customer-centric participation will involve more internet devices and linked behaviours. Risk exposure to cyber-security and malicious software (whether targeted or consequential) will increase because: • The business models for these devices won't consider power system security needs. • In concert, individual actions can distort the system.	Seen to be beyond the remit of the FPSS program but how to progress is being considered by AEMO.
Network limits (reduced interconnector capability, oscillatory stability, transient stability)	As the level of online synchronous generation reduces, lower stability limits could eventuate on interconnectors, oscillatory stability could be reduced, and there could be a high risk for transient instability arising from a fault.	Not classified as a high priority because: • Transmission NSPs can consider their physical and economic impact and recommend a solution using current regulatory processes (regulatory investment test for transmission or RIT-T). This incentivises them to solve such problems. • Technically, if the limits can be identified, the current processes for defining security limits and converting them into constraint equations were considered adequate. The pre-condition is having appropriate models and tools to simulate the power system. This is being pursued in the challenges identified in Chapter 6.
Reduced scheduled controllability	High amounts of non-scheduled intermittent generation (both at the transmission as well as distribution level) can present challenges in managing flows, within a region and across interconnectors, as well as affecting the level of required FCAS.	Discussions centred on whether there is enough flexible generation to meet the variation, and how current settings rely on energy providing a market signal even though this is not the driver for DER. Will be revisited as higher priority areas are progressed.
Adequacy of standards	New and emerging technologies have short lifecycles so relevant standards may not be able to be put in place before mass uptake. It is also possible for a large number of compliant technologies to, in aggregate, create a non-compliance issue at the connection point due to consumer uptake, and no one entity has responsibility for this.	Decided this was more an option to address the challenges, rather than a technical challenge. The issues previously identified can be considered as risks in the use of standards as any solution.
Technical performance and potential	Emerging technologies are not fully understood in terms of their potential technical capabilities and performance (e.g. synthetic inertia, aggregated storage). This provides a challenge in the evaluation of potential options for adapting current processes for use by unproven technologies.	This is not a technical challenge, but is related to the technical solutions. These considerations have been incorporated into other work packages.

Challenge	Details	Rationale for priority rating
Strength and appropriateness of information to the market	Changing system requirements could mean current operational planning processes of ESOO, MT PASA, ST PASA, and pre-dispatch will no longer deliver the most appropriate information for efficient market operation.	There might be a need to adapt information provided, e.g. the 2016 ESOO includes information on FCAS and system restart ancillary services (SRAS) and will be improved over time. Other operational planning processes have much shorter time horizons and were given a lower immediate priority.
Technology lifecycles	The shorter development timeframe of new technologies means the technology mix might move quickly and will continuously evolve. Development times for emerging technologies could become comparable to the lead times involved in decision-making to implement appropriate frameworks.	Viewed more as contextual than a technical issue, and solutions for the other issues need to take this into account, in particular standards development. It highlights the need to act early (e.g. visibility of DER before mass adoption of energy storage behind-the-meter) and devise flexible mechanisms that can adapt quickly if requirements change.
Reduction in voltage control	Synchronous generating units are an important source of dynamic voltage support. The displacement of synchronous generation could result in local voltage control issues, particularly immediately following contingency events.	Technically solvable and superseded by system strength.

ABBREVIATIONS

Abbreviation	Expanded Name
AC	Alternating current
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
ASEFS	Australian solar energy forecasting system
AWEFS	Australian wind energy forecasting system
CER	Clean Energy Regulator
CIGRE	International Council on Large Electric Systems
COAG	Council of Australian Governments
DC	Direct current
DER	Distributed energy resources
ENA	Energy Networks Association
ESOO	Electricity statement of opportunities
FCAS	Frequency control ancillary services
FFR	Fast frequency response
FOS	Frequency operating standards
FPSS	Future power system security
HVDC	High voltage direct current
MASS	Market ancillary services specification
NEM	National Electricity Market
NEO	National Electricity Objective
NER	National Electricity Rules
NSP	Network service provider
NTNDP	National transmission network development plan
OFGS	Over frequency generation shedding
PSI TAG	Power system issues technical advisory group
PV	Photovoltaic
RIT-T	Regulatory investment test - transmission
RoCoF	Rate of change of frequency
SAPN	South Australia Power Networks
SCO	Senior Committee of Officials
SRES	Small renewable energy scheme
STATCOM	Static synchronous compensator
SVC	Static VAR compensator
SWIS	South West interconnected system
UFLS	Under frequency load shedding

GLOSSARY

Glossary Term	Definition
Ancillary services	Services used by AEMO that are essential for managing power system security, facilitating orderly trading, and ensuring electricity supplies are of an acceptable quality. This includes services used to control frequency, voltage, network loading, and system restart processes, which would not otherwise be voluntarily provided by market participants on the basis of energy prices alone. Ancillary services may be obtained by AEMO through either market or non-market arrangements.
Black system	The absence of voltage on all or a significant part of the transmission system or within a region during a major supply disruption affecting a significant number of customers.
Central dispatch	A process to dispatch scheduled generating units and scheduled loads in order to balance power system supply, and to maximise the value of spot market trading on the basis of dispatch offers and dispatch bids.
Contingency event	An event affecting the power system, such as the failure or unplanned removal from operational service of a generating unit or transmission network element.
Contingency services	Services provided by registered participants that enable the maintenance or restoration of power system security, or both. This includes, for example, actual active and reactive power capacities, which can be made available and used when a contingency event occurs.
Credible contingency event	Broadly, refers to unexpected but reasonably possible events the power system is required to be secure against.
Dispatch	The process of determining production instructions to providers of energy and market ancillary services.
Fault level	The maximum current that is expected to flow in response to a short-circuit at a given point in the power system.
Frequency control ancillary services (FCAS)	Those ancillary services concerned with balancing, over short intervals (shorter than a dispatch interval), the power supplied by generating units and the power consumed by loads.
Frequency operating standards	The standards that specify the frequency levels for the operation of the power system set out in the power system security and reliability standards published by the Reliability Panel.
Interconnector	A network flow path between NEM regions.
Intermittent generation	A description of a generating unit whose output is not readily predictable, including, for example, solar generators, wave turbine generators, wind turbine generators and hydro-generators without any material storage capability
Network Service Provider	A party that owns, leases, or operates an electricity network and is registered as such under Chapter 2 of the Rules by AEMO.
Non-scheduled generation	A generating unit with a nameplate rating of < 30 MW, or a group of generating units connected to common connection point with a combined nameplate rating < 30 MW. May have either physical or technical attributes such that it is not practicable for it to participate in central dispatch.
Non-synchronous generation	Generators that are not synchronised to the system frequency, typically wind turbines and PV cells.
Operational demand	Demand in a region that is met by local scheduled generation, semi-scheduled generation, and non-scheduled wind generation of aggregate capacity ≥ 30 MW, and by generation imports to the region, excluding the demand of local scheduled loads. Operational demand differs from native demand in that it excludes demand met by non-scheduled wind generation of aggregate capacity < 30 MW, all non-scheduled non-wind generation, and exempt generation.
Scheduled generation	A generating unit with a nameplate rating of ≥ 30 MW, or part of a group of generating units connected at a common connection point with a combined nameplate rating of ≥ 30 MW.
Secure operating state	Operation of the electricity transmission network such that, should a credible contingency occur, the network will remain in a 'satisfactory' operating state.
Semi-scheduled generation	A generating unit with a nameplate rating of ≥ 30 MW, or part of a group of generating units connected at a common connection point with a combined nameplate rated of ≥ 30 MW, where output is intermittent.

Glossary Term	Definition
Separation event	A contingency event in relation to a transmission element that forms an island, that is, separation of a region from the rest of the NEM.
Synchronous generation	The alternating current generators of most thermal and hydro (water) driven power turbines, which operate at the equivalent speed of the frequency of the power system in its satisfactory operating state.
System strength	System strength, broadly, is a measure of the maximum current that is expected to flow in response to a short-circuit at a given point in the power system.