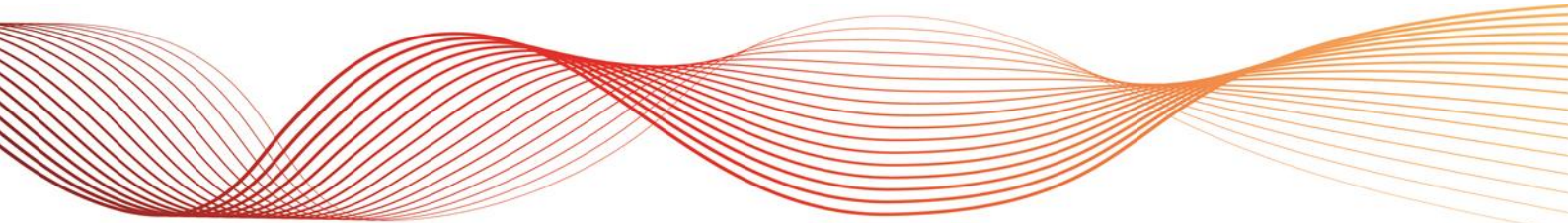




UPDATE TO RENEWABLE ENERGY INTEGRATION IN SOUTH AUSTRALIA

JOINT AEMO AND ELECTRANET REPORT

Published: **February 2016**





IMPORTANT NOTICE

Purpose

The purpose of this report is to provide information about the secure operation of the South Australian power system under specific conditions.

This report is based on information available to AEMO and ElectraNet as at 30 November 2015, although AEMO and ElectraNet have endeavoured to incorporate more recent information where practical.

Disclaimer

AEMO and ElectraNet have made every effort to ensure the quality of the information in this report but cannot guarantee that information, analysis and assumptions are accurate, complete or appropriate for your circumstances. This report does not include all of the information that an investor, participant or potential participant in the SA electricity market might require, and does not amount to a recommendation of any investment.

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EXECUTIVE SUMMARY

Background

In 2014, AEMO and ElectraNet began joint studies to identify the limits to the secure operation of the SA power system with high levels of renewable generation and low levels of conventional synchronous generation in operation.

A joint technical report¹ published by AEMO and ElectraNet in October 2014 (2014 Report) concluded that the SA power system can operate securely and reliably with a high percentage of wind and rooftop PV generation, as long as one of the following two key factors apply:

- The Heywood alternating current (AC) interconnector linking SA and Victoria is operational.
- Sufficient synchronous generation is connected and operating in the SA power system.

This technical report provides an update on the work undertaken since October 2014, and introduces AEMO's ongoing approach to exploring power system security challenges arising from the changing generation mix in SA, the National Electricity Market (NEM) as a whole, and Western Australia. The report also provides a summary of ElectraNet's work plans for exploring potential solutions to the emerging challenges of the changing generation mix.

The early findings set out in this technical report will be further tested and refined as AEMO adapts its processes and procedures to mitigate any identified risks and challenges. The findings will also be further tested as other aspects of power system operation are analysed, and changes initiated to adapt processes where necessary in coming months.

Key messages

- During 2015, AEMO and ElectraNet jointly assessed whether challenges are emerging in relation to a number of elements of operation of the SA power system. This report sets out the findings, which will be further tested as procedures are adapted. This work has been limited to identifying and understanding the technical challenges that are expected to arise, and has not yet moved to recommending solutions.
- Overall, the studies highlight the increasing importance of the Heywood Interconnector in the secure and reliable operation of the SA power system. Measures can be taken in the short term to address some of the immediate operational effects, but, as the power system continues to evolve in the longer term, there could be an increasing need for changes to market arrangements or infrastructure to continue to meet security and reliability expectations, particularly at times when SA is synchronously islanded (separated) from the remainder of the NEM.
- AEMO has not identified any issues with the management of power system security in SA provided that SA remains connected to the remainder of the NEM via the Heywood Interconnector and sufficient synchronous generation is connected in the SA power system.
 - AEMO and ElectraNet have identified potential challenges for management of the SA power system in relation to AEMO's ability to meet the Frequency Operating Standards (FOS) either during or following the loss of the Heywood Interconnector, resulting in SA being islanded from the remainder of the NEM.
- The withdrawal (either permanent or temporary) of synchronous generation and the growth in wind and rooftop PV generation in SA is:

¹ AEMO and ElectraNet. *Renewable Energy Integration in South Australia: Joint AEMO and ElectraNet Study*, 2014. Available at: [tp://www.aemo.com.au/electricity/planning/~/_media/files/electricity/planning/reports/renewable_energy_integration_in_south_australia_aemo_electranet_report_oct_2014.ashx](http://www.aemo.com.au/electricity/planning/~/_media/files/electricity/planning/reports/renewable_energy_integration_in_south_australia_aemo_electranet_report_oct_2014.ashx).



- Making the power system more susceptible to rapid changes in frequency, and to larger frequency deviations following a separation event.
- Limiting AEMO's ability to acquire Frequency Control Ancillary Services (FCAS) locally within SA when required to support islanded operation.
- These circumstances result in AEMO needing to take additional precautions at times when it believes there is a reasonable possibility of SA separating from the remainder of the NEM.
- As a result of the FOS applicable to SA, there is potential for any separation event at times of material power flow into SA to result in operation of the emergency Automatic Under Frequency Load Shedding (AUFLS) scheme. The potential for more rapid and greater frequency deviations following separation also increases the probability that the emergency under frequency and over frequency control schemes will not be able to manage the impact of separation events.
- AEMO and ElectraNet have reviewed the power system implications of the announced closure of Northern Power Station as one example of synchronous generation permanently withdrawing from the market, and:
 - AEMO has not identified any system security challenges that cannot be managed through existing processes and procedures, but notes that the services provided by Northern Power Station will now need to be procured from other sources.
 - ElectraNet has identified transmission voltage control as a matter requiring further investigation.

These key messages are discussed in more detail below.

Operation of SA pre and post islanding

AEMO has reviewed its network operating strategies for managing the SA power system should it become islanded from the remainder of the NEM, and has determined:

- The reduction in the level of inertia on the power system in SA, and the reduction in the number of generating units capable of providing FCAS in SA (either permanent or temporary), is making the efficient procurement of FCAS to maintain frequency within the FOS in SA increasingly challenging, both immediately following separation and during islanded operation.
- AEMO has procedures² in place to maintain the power system in SA within a secure operating state when loss of the interconnector is considered to be a credible contingency event. This occurs at times of a known threat to the interconnector or during some planned network outages. Recent changes have been made to these procedures to provide for purchasing additional regulation FCAS services during these periods.
 - AEMO is also developing further internal procedures that may be required to better manage power system security in SA during periods of operation as an island.
- Based on previous experience, and as demonstrated in a separation event on 1 November 2015³, maintaining the SA power system in a secure operating state is challenging if there are large changes to the supply-demand balance during a period of islanding.
 - There is a risk of automatic under frequency load shedding if SA is being operated as an island during the hot water demand peak, which occurs at 11:30 pm⁴ daily.
- AEMO is undertaking further work to understand the factors that will limit its ability to maintain power system security in SA during islanded operation. Such factors could include the level of changes to supply-demand balance, or the number of synchronous generating units that remain in service during islanded operation.

² Power System Operations (PSO) procedures.

³ Subject of a separate AEMO Power System Operating Incident Report, available on the AEMO webpage: <http://www.aemo.com.au/Electricity/Resources/Reports-and-Documents/Power-System-Operating-Incident-Reports>.

⁴ Australian Eastern Standard Time (AEST).



Automatic under frequency load shedding (AUFLS)

The AUFLS scheme is an emergency control scheme that is relied on to maintain power system frequency within the operating limits specified in the FOS following the unlikely occurrence of a non-credible contingency event. In SA, AUFLS may also operate to maintain the FOS for any event (credible or non-credible) that causes the separation of the SA power system from the remainder of the NEM.

Under frequency relay settings are determined by AEMO in consultation with ElectraNet, the Network Service Provider, to meet the requirements of the National Electricity Rules (NER).

The 2014 Report highlighted the need for improved modelling of rooftop PV in power system simulations to better understand its impact on the power system. AEMO and ElectraNet have developed models and investigated the impact of rooftop PV on the effectiveness of the AUFLS scheme in SA, and found that:

- In the event of a non-credible separation of SA from the remainder of the NEM, there is an increasing risk that the current AUFLS scheme in SA will be unable to maintain SA frequency within the FOS. Studies have shown that this risk exists when, at any given time, there is low operational consumption, low power system inertia in SA (less than 4–5 synchronous generating units operating), and high rooftop PV generation (greater than 480 MW). This risk is due to:
 - Fast Rate of Change of Frequency (RoCoF) following the separation event at times of low power system inertia leading to additional load blocks being tripped and potentially the tripping of generation, and/or
 - An insufficient amount of load being shed from the power system during low frequency events, due to the impact of rooftop PV embedded in parts of the distribution system.
- With the current AUFLS scheme design, the rooftop PV embedded within each load block will be shed at the same time as the customer load, with a greater level of AUFLS required to stop the fall in system frequency, and consequentially resulting in additional underlying consumption being shed if a contingency event occurs at times of high rooftop PV generation compared to periods when rooftop PV is not generating.⁵
- The risk of the FOS not being met for non-credible separation events will increase as synchronous generation continues to withdraw from the market or is not operating. AEMO will investigate the extent to which further changes to the settings of the current SA AUFLS scheme can maintain frequency within the FOS for the most onerous non-credible separation events.
- Subject to the outcomes of its analysis, AEMO expects that it will be necessary to consider whether more fundamental changes (other than the AUFLS settings) may be required. This may include changes to the regulatory framework and consideration of whether alternatives to the current AUFLS infrastructure are needed to meet obligations to maintain the FOS.

Over frequency generation shedding (OFGS)

A non-credible contingency event that trips both circuits of the Heywood Interconnector at times when there is high export from SA to Victoria is very unlikely, but would result in a rise in frequency within the SA power system and potentially lead to uncoordinated loss of generation. At present there is no specific emergency control scheme in place to maintain frequency within the FOS following such an event. An OFGS scheme would work to coordinate generation unit tripping and control the frequency rise.

AEMO has:

- Identified the increasing importance of having an effective OFGS scheme.

⁵ For the investigations, due to limited available data, AEMO made assumptions as to the ability of each SA generator to ride through the contingency without tripping due to RoCoF protection. Further load-shedding will occur if actual generator ride through capability is less effective than assumed. AEMO is working with plant owners to confirm actual plant capabilities.



- The risk of over frequency occurring following a non-credible separation event is increasing with progressively more wind and rooftop PV generation being installed in SA, and subsequently falling operational consumption in the region, leading to more periods of export from SA to Victoria.
- The potential impact on power system security of a non-credible separation event during periods of high export from SA is increasing as synchronous generating units exit the market and reduce the level of inertia available to the SA power system.
- Started design work on the calculation of over frequency trip settings that would need to be applied to generating plant to form a coordinated OFGS for SA. This work includes analysing the possibility of SA being islanded at a number of different separation points on the network, including in western Victoria.
 - The OFGS scheme is intended to limit the rise in frequency by tripping generating units that provide low or zero inertia prior to generating units that provide higher levels of inertia.
 - To provide confidence in the analysis, AEMO needs to verify the assumptions used in its modelling in relation to the performance of generating plant during high frequency events. Accordingly, AEMO is seeking cooperation from generators in SA to provide technical information on plant performance characteristics during such events.
 - Following completion of the analysis, AEMO anticipates there will be a need for some generators to adjust the over frequency relays on their generating units for a coordinated OFGS scheme to operate.
- Identified that reliable operation of a traditional OFGS scheme might not be achievable under some power system conditions. For example, an OFGS scheme cannot be relied on to stop a high frequency excursion in circumstances such as:
 - Very low levels of inertia in SA leading to a rapid frequency change that causes synchronous generating units to trip before the OFGS scheme can operate. AEMO requires further technical information from operators of generating plant to fully model and verify this scenario.
 - Insufficient low inertia wind generation being available to the OFGS scheme to control frequency. For example, this could occur when wind speed is low, resulting in low levels of wind generation.
- Continued to review potential power system conditions to better understand future risk in relation to OFGS scheme performance. As the generation mix in SA evolves, and the limitations of the OFGS scheme are more fully understood, AEMO will investigate the potential need for a more sophisticated scheme to maintain FOS in the longer term. This work may include considerations such as:
 - If there is an OFGS scheme design that will maintain frequency within the FOS for any trip of the Heywood Interconnector, or
 - Whether a different mechanism (other than or in conjunction with the OFGS scheme) might be required to meet the FOS.

Closure of Northern Power Station

The Northern Power Station (NPS) provides transmission network voltage support for the transmission network in the Upper North and the Eyre Peninsula regions of SA. The withdrawal of NPS will create challenges for transmission network voltage control in these regions. These challenges will be significant for a range of system conditions.

ElectraNet intends to initiate a Regulatory Investment Test – Transmission (RIT– T) to procure the most economic network or non-network solution that resolves these challenges.



Changes already implemented

AEMO has implemented a number of changes to its procedures, constraint equation sets, and network models since the 2014 Report, as detailed in Table 1.

Table 1 Actions taken following the 2014 Report

2014 recommendation	Action taken
Monitor and respond to low inertia conditions in SA by limiting interconnector flows.	AEMO real time operation control rooms now have tools to monitor the inertia of the South Australian power system.
Implement constraints in SA to maintain rate of change of frequency within system protection limits.	When the loss of the Heywood Interconnector is considered a credible contingency event, AEMO limits flows on the Heywood Interconnector to maintain rate of change of frequency below 1 Hz/sec.
Enhance existing procedures to improve AEMO’s ability to assess available system frequency control capability for planned outages of the Heywood Interconnector.	When the loss of the Heywood Interconnector is considered a credible contingency event, AEMO procures 35 MW of regulation raise and 35 MW of regulation lower services locally in SA.
Analysis of the potential inertial contribution from existing wind generation in SA.	AEMO has analysed high speed data of the performance of a number of Type 2 wind turbines during frequency disturbance events. The analysis shows no inertial response from the turbines to the disturbance. When modelling the power system, AEMO does not assume any inertial response from these turbines.
Improved modelling of rooftop PV in power system simulations to better understand its impact on power system operation.	ElectraNet has developed aggregate distributed models of SA rooftop PV to enable detailed AUFLS system studies to be performed. AEMO has investigated the frequency behaviour of the installed rooftop PV inverter fleet – the outcome of this will be reported separately.

Next steps

In parallel with the work in this report, AEMO is developing an overarching work program for the adaptation of its processes to the rapidly changing generation and technology mix evident in the power system. The work program will provide a framework for AEMO’s identification and management of power system security risks and opportunities in the future, and is divided into two broad areas:

- Long-term – considering challenges that could arise within a 10-year outlook, and providing a platform for efficient and sustainable solutions to be developed in response to identified challenges, including, if needed, by making changes to the regulatory framework and Rules governing the NEM.
- Short-term – some of the challenges identified in the long-term work may need to be addressed more quickly than the desired long-term solutions can be put in place. Accordingly, AEMO will have a specific focus on developing interim measures within the current regulatory framework where necessary, to meet its power system security obligations over the next three years.

Further details of the proposed work program are still being refined, and will be communicated by AEMO shortly.

As part of the short-term work, the results of AEMO’s investigations will be published progressively in a series of reports to provide transparency on emerging technical challenges and clarity about how AEMO is addressing these challenges, and to generate discussion with industry about how these challenges might be addressed in the future.

The work carried out jointly with ElectraNet in relation to SA (this report) forms a subset of the short-term work-stream. This joint report also represents a transition point. ElectraNet will continue to focus on the specific challenges arising in SA, while AEMO’s focus will broaden to include more national challenges. ElectraNet will continue to engage with AEMO in relation to its SA specific work-streams and also conduct its own work program as the Transmission Network Service Provider (TNSP) in SA.



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1. INTRODUCTION

1.1 Background

South Australia (SA) has some of the highest levels of wind and solar (rooftop photovoltaic (PV)) generation relative to electricity demand of any region in the world, and this is expected to continue to grow in the future.

The growth of renewable energy generation combined with the withdrawal of traditional synchronous generation can, under certain conditions, present new challenges for the secure operation of the SA power system. Pelican Point Power Limited has reduced the capacity of the Pelican Point Power Station by half (to 240 MW), the Northern Power Station will be closed in the first half of 2016, and AGL has announced that the Torrens Island 'A' Power Station will be taken out of service in 2017 (subject to market conditions).

1.2 *Renewable energy integration in South Australia, joint AEMO and ElectraNet report, October 2014*

In February 2014, AEMO and ElectraNet commenced joint studies to identify the impacts of the changing market environment in SA on power system operation within the region. Such market changes included the high uptake of wind generation and rooftop PV and shifts in demand profile, as well as the potential withdrawal of existing synchronous generation.

In October 2014, AEMO and ElectraNet published the initial results of those studies, in the *Renewable Energy Integration in South Australia: Joint AEMO and ElectraNet Study*⁶ (the 2014 Report).

Specifically, the studies investigated:

- Operation of the SA power system with low levels of thermal synchronous generation online.
- Power system frequency control in SA, particularly under conditions when the SA power system is, or could become, separated from the remainder of the National Electricity Market (NEM).

The 2014 Report concluded that the SA power system can operate securely and reliably with a high percentage of wind and rooftop PV generation, including situations where wind generation comprised more than 100% of SA demand, as long as one of the following two key factors apply:

- 1) The Heywood Interconnector linking SA and Victoria is operational, or
- 2) Sufficient synchronous generation is connected and operating on the SA power system.

The 2014 Report found that there is a risk to power system security and reliability in SA when there is a high proportion of wind and rooftop PV generation and the Heywood Interconnector link to Victoria is disconnected at a time when little local synchronous generation is online. This risk exists because wind and rooftop PV generation alone are not able to provide the required services to maintain power system security. While the probability of the disconnection of SA from the remainder of the NEM is low, the potential consequence is a state-wide power outage with severe economic and possible health and safety impacts.

Since the 2014 Report, AEMO and ElectraNet have continued to investigate the emerging technical challenges arising from the changing generation mix in SA.

⁶ AEMO and ElectraNet. *Renewable Energy Integration in South Australia: Joint AEMO and ElectraNet Study*, 2014. Available at: [tp://www.aemo.com.au/electricity/planning/~/media/files/electricity/planning/reports/renewable_energy_integration_in_south_australia_aemo_electranet_report_oct_2014.ashx](http://www.aemo.com.au/electricity/planning/~/media/files/electricity/planning/reports/renewable_energy_integration_in_south_australia_aemo_electranet_report_oct_2014.ashx).



1.3 Scope of this Report

Since the publication of the 2014 Report, both AEMO and ElectraNet have undertaken further work on the challenges identified. This report provides an update on the work undertaken, and introduces AEMO's ongoing approach to exploring power system security challenges arising from the changing generation mix in SA, the NEM as a whole, and Western Australia.

This report is designed to inform industry participants, energy industry institutions, Governments, and the public on the work being undertaken to maintain power system security with the changing generation mix in SA. The report includes a glossary for a high level explanation of technical terms.



2. OPERATION OF SA PRE AND POST ISLANDING

2.1 Introduction

SA is connected to Victoria via two interconnections, the Heywood Interconnector (a double circuit alternating current (AC) interconnection) and Murraylink (a high voltage direct current (HVDC) interconnection). The Heywood Interconnector in particular allows SA to benefit from a range of operational services that help maintain power system security. Such services include:

- Frequency control⁷, for both normal frequency regulation, and for frequency control following contingency events that do not result in separation.
- Rapid power ramping, for managing rapid changes in the supply-demand balance over time frames of several minutes.
- Transmission voltage control.

Outages of transmission elements along the Heywood Interconnector can potentially cause an islanding of the SA region.⁸ If SA is islanded and the Heywood Interconnector is not available, all the services noted above must then be obtained locally within SA.

While transmission outages that place SA at credible risk of islanding from Victoria are relatively common, actual separation events are rare. There have been nine separation events since the market started in 1998, as shown in Table 2. These events have been of relatively short duration (typically less than one hour) and on each occasion the islanded SA power system was successfully operated as an island until the interconnector was restored. A number of these past separations were the result of non-credible contingencies.⁹

Table 2 SA 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

2.2 Key messages

AEMO has reviewed its operating strategies for management of the SA power system should it become islanded from the remainder of the NEM. From this work AEMO has determined:

- A reduction in the level of inertia on the power system in SA, and a reduction in the number of generating units capable of providing FCAS in SA, is making the provision of FCAS to maintain frequency within the FOS in SA increasingly challenging, both immediately following separation and during island operation.

⁷ As Murraylink is a DC link, it provides no frequency support to SA.

⁸ In the context of the Frequency Operating Standards this is referred to as an 'abnormal frequency island', where all the AC connections to other parts of the network have been disconnected.

⁹ Refer to National Electricity Rules (NER) 4.2.3(e) for a definition of non-credible contingency events.



- AEMO has internal Power System Operations (PSO) procedures in place that are followed to maintain the power system within a secure operating state when loss of the interconnector is considered to be a credible contingency event. This could occur at times of a known threat to the double-circuit interconnector, or during planned outages of one of the circuits. The PSO procedures have recently been updated to provide for the pre-contingent procurement of regulation FCAS in SA.
 - AEMO is developing further internal PSO procedures to manage power system security in SA during islanded operation.
- Based on previous experience, and as demonstrated in the separation event on 1 November 2015, maintaining the SA power system in a secure operating state is challenging if there are large changes to the supply-demand balance during a period of islanding.
 - There is a risk of automatic under frequency load shedding if SA is being operated as an island during the hot water demand peak which occurs at 11:30 pm¹⁰ daily.
- AEMO is undertaking further work to understand the factors that will limit its ability to maintain power system security in SA during islanded operation. Such factors could include the level of changes to supply-demand balance, or the number of synchronous generating units that remain in service during islanded operation.

2.3 Scope

AEMO is required to operate the power system in a secure operating state. This requires that the power system is in a satisfactory operating state, and will return to a satisfactory operating state following any credible contingency event. Following any contingency event, AEMO must take all reasonable actions to return the power system to a secure operating state as soon as possible, and in any event within 30 minutes.

AEMO has investigated the operation of the power system under the following conditions:

- When separation of SA is a credible contingency risk, and
- When SA is operating as an island.

The areas of focus of AEMO's investigations include:

- Availability of frequency control ancillary services (FCAS).
- The potential for a high rate of change of frequency following contingency events.
- Rapid changes in the supply-demand balance, which can encompass:
 - Changes in demand due to hot water switching.
 - Changes in non-scheduled generation output levels.
 - Changes in generation output from wind farms and rooftop PV.
 - Changes in the flow across the Murraylink Interconnector.
- Fault ride through characteristics of wind generation.
- Transmission voltage control.

¹⁰ AEST.



2.4 Methodology

AEMO reviewed historical SA separation events, and current operating procedures, to determine the potential for power system security challenges to arise as a consequence of operating SA when at risk of separation and when SA is required to be operated as an island.

The power system security challenges were then analysed to determine potential mitigation measures. Where solutions were determined, AEMO's internal procedures were updated to reflect the new requirements. Where solutions were not immediately available, further work has been identified.

2.5 Results

2.5.1 Availability of FCAS in SA

While FCAS can normally be sourced from anywhere in the NEM, if a region or sub-region becomes islanded, FCAS for that part of the transmission network can only be sourced from within the island. Sufficient FCAS is required to maintain the FOS in SA, both upon separation and for ongoing islanded operation.

When the SA region is at risk of separation as a credible contingency event, AEMO enables sufficient contingency FCAS¹¹ in SA to maintain the FOS in the event of separation. A recent change to AEMO's internal PSO procedures also requires regulation FCAS to be enabled in SA when that region is at risk of separation, rather than only after islanding has occurred.

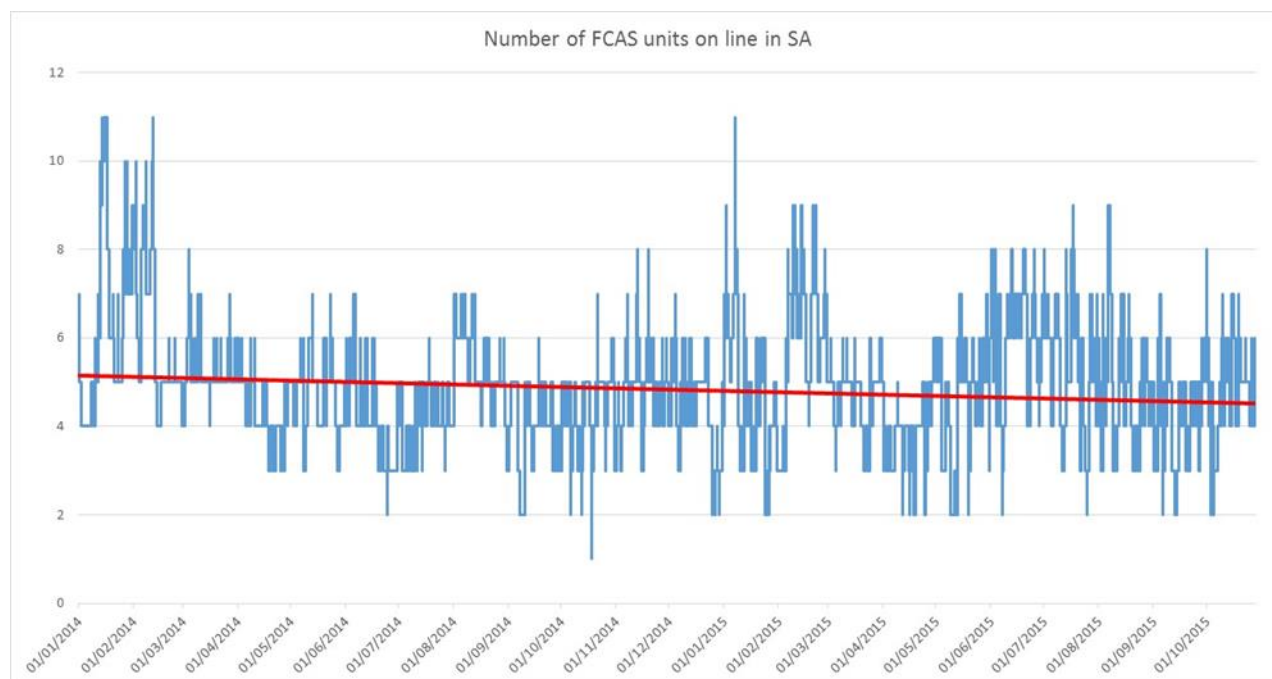
Following formation of an electrical island in SA, AEMO will, in accordance with internal PSO procedures, enable contingency FCAS sufficient to meet the risks in the island locally in SA. This will generally take 10–15 minutes to action.

Until recently, only the generating units at Torrens Island, Pelican Point and Northern Power Stations were registered as ancillary service generating units capable of providing FCAS in SA. On 1 December 2015, Quarantine Power Station Unit 5 was registered to provide regulation FCAS.

Following the withdrawal of Northern Power Station and Torrens Island 'A' Power Station, the only remaining sources of FCAS in SA will then be Quarantine Unit 5 and the Torrens Island 'B' and Pelican Point Power Stations. This reduction in thermal generating units reduces inertia levels, potentially requiring more contingency FCAS. However at the same time, procurement of FCAS is likely to become more difficult as renewable generation currently provides little or no FCAS.

As shown in Figure 1, the number of FCAS capable units on line has been slowly decreasing over the past 12 months.

¹¹ FCAS is split into two major components, contingency FCAS and Regulation FCAS. For more details, refer to the *AEMO Guide to Ancillary Services in the National Electricity Market*, available at: <http://www.aemo.com.au/Electricity/Market-Operations/Ancillary-Services/Guides-and-Descriptions/Guide-to-Ancillary-Services-in-the-NEM>.

Figure 1 FCAS capable units on line in SA

Contingency FCAS

In 2001, the SA government requested that AEMO maintain the frequency in SA following a credible separation event within the range of 47–52 Hz, at the time when the corresponding FOS requirement was narrowed to 49–51 Hz. The effect of this request was to substantially reduce the amount of contingency raise FCAS required in SA for credible separation events. This was in recognition of the limited availability of these services to meet the maximum allowable transfer of 250 MW from Victoria to SA when SA was at risk of separation.

However, when SA is operating as an island, sufficient contingency FCAS must be sourced to meet the normal island contingency FOS (49–51 Hz).

The withdrawal of synchronous generation has reduced the level of inertia available on the power system. Lower levels of inertia result in a higher rate of change of frequency, and, ultimately, in a higher frequency deviation for a given imbalance between supply and demand. To maintain power system security during islanded operation, new constraint sets have been implemented to co-optimize the output of the largest generating unit with the contingency FCAS procured. AEMO updated constraint equations in November 2013 to implement this. These constraint sets were used for the first time during the separation event on 1 November 2015.

Regulation FCAS

If there was insufficient regulation FCAS enabled in SA immediately following an actual separation event, AEMO considers there would be a material risk of the power system being in an unsatisfactory operating state, because AEMO would not be in a position to control frequency as required by National Electricity Rules (NER) 4.2.2(a). If the power system will not be in a satisfactory operating state following a single credible contingency event, it follows that the power system is not in a secure operating state prior to the incident.

AEMO regularly reviews the regulation FCAS required for operating SA as an island. From 2003 to 2004, a variable requirement of between 50 and 150 MW was used. In 2004, this was revised to a requirement for 70 MW of raise and lower regulation FCAS. In late 2014, AEMO conducted a further



review of the regulation FCAS requirements for operating SA as an island by examining actual short term changes in Victoria–SA flow, as a proxy for the regulation/balancing requirement in SA.

Based on this analysis, the requirement for regulation FCAS was reduced to 35 MW of raise and lower regulation FCAS. In May 2015, AEMO updated its internal procedure to reflect this change.

Insufficient availability, or a delay in the availability, of regulation FCAS in SA immediately following such a credible separation event would give rise to a risk that this requirement would not be met.

AEMO has determined that, to maintain power system security in SA, regulation FCAS needs to be enabled in SA whenever there is a credible risk of SA separating from the remainder of the NEM.

AEMO further updated its internal procedure in October 2015 to reflect this requirement. This process was implemented for the first time for the October–November 2015 outages on the Heywood Interconnector.¹²

2.5.2 Rate of change of frequency

Immediately following a separation event, frequency in SA will rise or fall, depending on the direction of power flow across the separation point immediately prior to separation.

For the period immediately after separation, the Rate of Change of Frequency (RoCoF) in SA is determined by the contingency size at separation, and the inertia of the SA power system.

In March 2007, the NER was amended to introduce a requirement for all newly connected generation to be capable of withstanding, at a minimum, a RoCoF of 1 Hz/sec, for 1 second¹³, without tripping. Generation connected before this, including the majority of thermal generation in SA, may not meet this requirement.

AEMO has asked generators in SA to provide details of their ability to remain on line during frequency disturbances where the RoCoF is less than 1 Hz/sec.

If the RoCoF is too high, there is a risk that protection systems sensitive to RoCoF will trip generation in SA.¹⁴ This additional tripping of generation following separation has the potential to increase the impact of the event, increase the amount of load that is shed in SA, and lead to ongoing cascading tripping of generation in SA.

As noted above, one of the factors that determines RoCoF in SA is the inertia delivered by the online generating units. Figure 2 shows the inertia in SA since the start of 2012. There is a clear downward trend. This is due to the increase in wind and rooftop PV generation that contribute little in the way of inertia and the consequent removal from service of synchronous generation, which is the major provider of inertia.

The total inertia currently available in SA is around 16,200 megawatt-seconds (MWs).¹⁵ In 2017, without Northern Power Station and Torrens Island 'A' Power Station, the total available inertia would reduce to around 10,000 MWs.

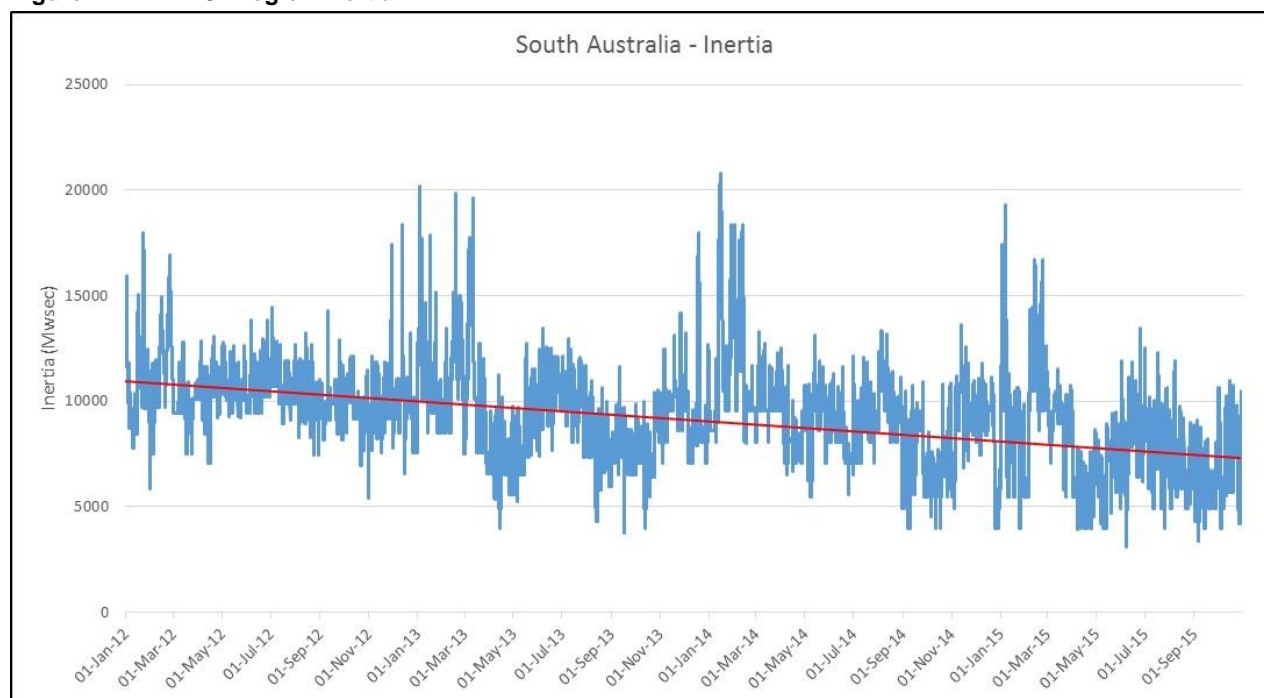
¹² For further details see the AEMO *Market Event Report – High FCAS Prices in SA – October and November 2015*; <http://aemo.com.au/Electricity/Resources/Reports-and-Documents/Market-Event-Reports/Market%20Event%20Report%20High%20FCAS%20Price%20in%20SA%20October%20and%20November%202015>

¹³ NER S5.2.5.3(c)(6).

¹⁴ During the SA islanding event on 1 November 2015, a wind farm in SA tripped due to operation of the rate of change of frequency protection. Actual RoCoF for this event was 0.36Hz/sec.

¹⁵ Excludes gas turbine and diesel generation that is normally off line.

Figure 2 SA region inertia



To limit the RoCoF to acceptable levels, when SA is at risk of separation, AEMO will invoke network constraint sets to limit flow on the Heywood Interconnector based on the amount of online inertia available in SA. This is required so that, in the event of a separation event, the RoCoF in SA will not exceed 1 Hz/sec. These constraint sets were included in the outage constraint sets associated with the Heywood Interconnector in January 2015.¹⁶

2.5.3 Rapid changes in the supply-demand balance

There are a number of factors that could result in a change to the supply-demand balance. While SA is interconnected to Victoria, these factors generally pose no power system security challenges. However, when SA is operating as an island, these events can be challenging for frequency control.

Supply or demand changes can be as a result of:

- Timer-controlled switching of electric hot water systems.
- Response of non-scheduled generation in SA to the spot price.
- Variability of wind and rooftop PV generation output due to weather conditions.

These events all manifest as short term supply-demand mismatches, and need to be managed by regulation services and the dispatch process.

Hot water demand peak

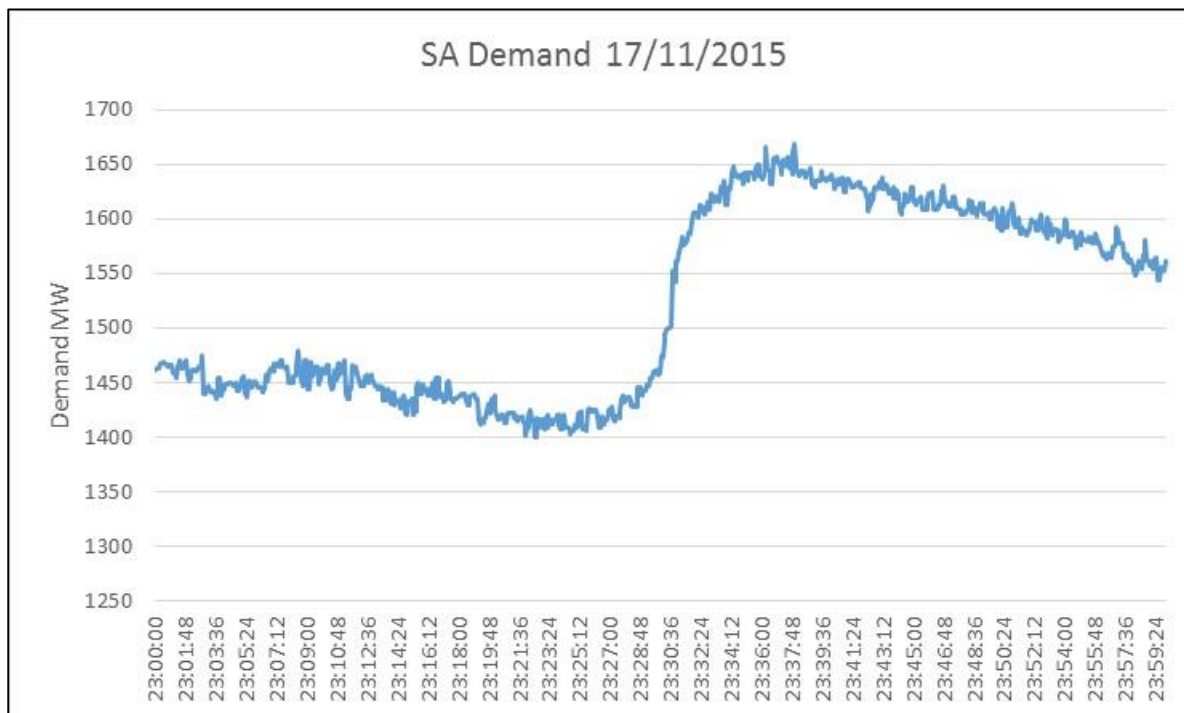
Currently the most concerning of these challenges is the hot water demand peak that occurs at 11:30 pm daily.¹⁷ This is a step change increase in demand of approximately 250 MW, shown in Figure 3.

¹⁶ Previously Victoria–SA flow was limited to +/- 250 MW when there was a risk of separation. The new RoCoF constraint sets will limit this flow to lower levels (allowable flow \approx inertia / 25 – for example, if inertia is 5500 MWs then allowable flow is approximately 220 MW) when online inertia in SA is below 6,250 MW sec.

¹⁷ AEST.

This demand peak is controlled by fixed timers and requires considerable effort to reduce the peak through the adjustment of the time clocks at individual premises. While all new meters installed in SA will have randomised time clocks, all existing meters are set to switch at 11:30 pm.

Figure 3 SA hot water peak



In its revenue proposal for 2015–16 to 2019–20, SA Power Networks, which owns the time clocks associated with the hot water demand, identified this issue in the context of demand and power quality management. SA Power Networks included \$0.56M in its augmentation CAPEX proposal to reprogram 27,000 meters to address the hot water demand spikes observed in SA.¹⁸ The Australian Energy Regulator (AER) has approved the funding proposal. The funding proposal provides no information on when SA Power Networks will undertake this work.

Currently, if SA is operating as an island, at 11:30 pm there will be a large impact on frequency, potentially resulting in under frequency load shedding if frequency control measures are not in place. While this increase in demand is accounted for in the dispatch demand forecast process, which will pre-emptively increase generation in response to the demand peak, this might not be sufficient to control frequency to within the FOS, as the change in demand might be faster than generation can respond.

AEMO has identified a number of potential control measures to minimise the impact of hot water switching in the short term, however it is important to note that during periods of islanded operation, any or all of these options, while limiting the impact, might not prevent under frequency load shedding from occurring during the hot water peak.

These control measures include:

- Temporary increase of SA automatic generation control (AGC) reference frequency to above 50 Hz before the hot water peak occurs.

¹⁸ Refer to page 6-68 of the AER *Final decision SA Power Networks distribution determination - Attachment 6 - Capital expenditure*, October 2015. Available at: https://www.aer.gov.au/system/files/AER%20-%20Final%20decision%20SA%20Power%20Networks%20distribution%20determination%20-%20Attachment%206%20-%20Capital%20expenditure%20-%20October%202015_0.DOCX.

- Use of the Load Restoration Tool¹⁹ to artificially increase demand seen by AEMO's dispatch process, and subsequently increase dispatched generation for a period prior to the demand peak.
- Temporary increase in Raise Regulation FCAS enabled, if it is available.
- Use of AEMO's power of direction under NER clause 4.8.9 to request offline fast start generation to start up and synchronise at minimum output prior to the hot water peak. This will provide extra generation capacity, inertia, and governor response.

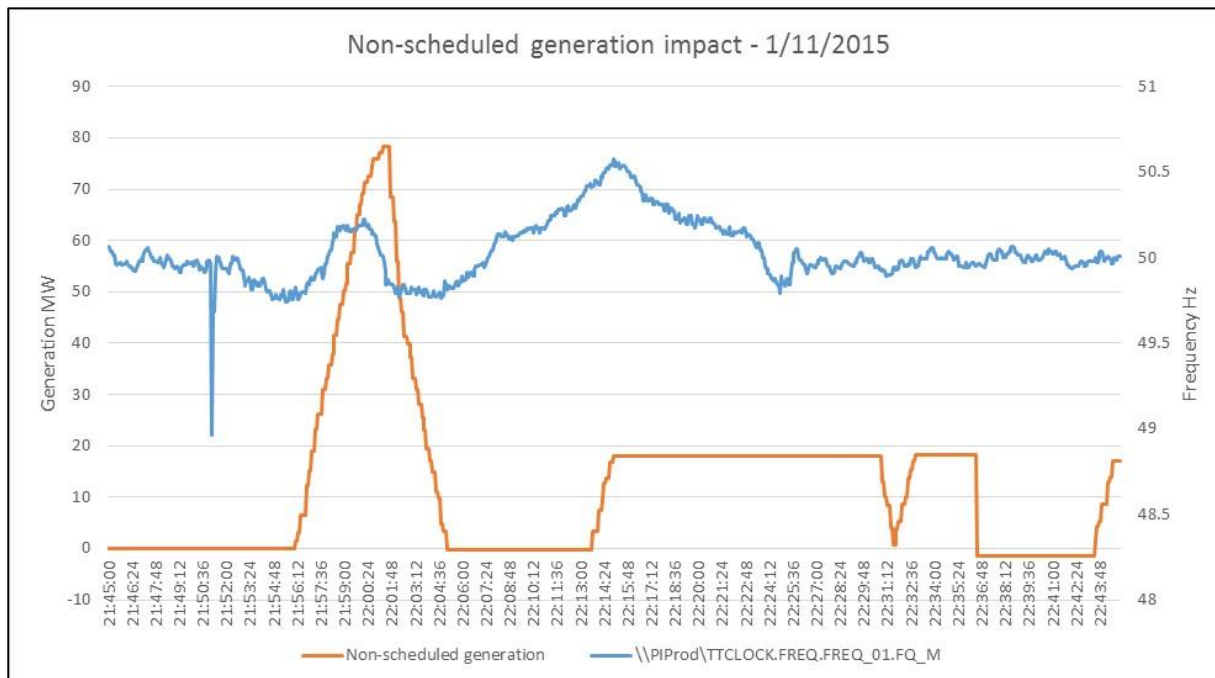
Although some of the above options are normal operating practice when dealing with expected demand increases, AEMO is developing a new internal PSO procedure for the management of the SA power system as an island, and will include the above options within that procedure. Operations staff will apply the options best suited to the power system conditions at the time. These procedures will be revisited following work by SA Power Networks to randomise the time switched.

Non-scheduled generation

The dispatch of non-scheduled generation may result in rapid changes to the supply-demand balance. This generation typically reaches full output in less than five minutes (and also shuts down in less than five minutes), and can therefore have a similar impact as the hot water switching peak, although to a lesser degree and at variable times.

During the 1 November 2015 separation event in SA, the dispatch of around 75 MW of non-scheduled generation demonstrated that even a small amount of non-scheduled generation can have a material impact of frequency, as shown in Figure 4.

Figure 4 Impact of non-scheduled generation



There is no requirement under the NER for the operators of non-scheduled generation to advise AEMO of their intended dispatch. As such, it is difficult for AEMO to put procedures or control mechanisms in place to prevent frequency violations caused by the operation of that plant type.

¹⁹ An application within AEMO's Energy Management System to coordinate load increases with the Market Management System. This application is normally used when restoring large load blocks.



However, the owner of the three major non-scheduled generating units in SA has chosen to re-classify the generating units as scheduled generating units, and this will alleviate the frequency control challenges associated with the dispatch of this type of plant in SA.

In its new internal PSO procedure for operating SA as an island, AEMO will include a process for managing any future non-scheduled generation.

Wind generation

Unforecast changes in the total output of wind generation in SA could affect frequency control, particularly if these changes are fast and large in magnitude.

Forecasting of future wind generation through AEMO's Australian Wind Energy Forecasting System (AWEFS), and the geographic dispersal of wind generation in SA, both reduce the effect of this issue.

AEMO's October 2015 *South Australian Wind Study Report*²⁰ analysed wind generation for 2014–15, assessed the changes in the total output of wind generation in the SA region over five-minute periods, and concluded that for 90% of the time SA total wind generation varied by no more than 24 MW (1.6% of registered capacity). Analysis of the performance of AWEFS also showed that the historical error in the five-minute-ahead forecast was below two percent.

This analysis indicates that changes in aggregate wind generation output within a five-minute period of greater than two percent of installed capacity (around 30 MW) are uncommon, though they are possible.

Unforecast changes in wind generation output of this magnitude are broadly within the Regulation FCAS capability determined for the SA island, and are well below the level of Contingency FCAS services AEMO will be required to hold to manage load and generation contingencies in an SA island.

If rapid ramping in the output of wind generation is observed to affect frequency control in an SA island, options to minimise the impact include:

- Constraining the output of individual semi-scheduled wind farms where large, rapid changes in output are observed.
- Curtailing the total output of all wind generation in the SA region.
- Increasing the Regulation FCAS requirement for the SA region.

Constraint sets already exist to implement all of these options.

In its new internal PSO procedure for operating SA as an island, AEMO will include a process that reflects the effective management of short-term variations in wind generation.

Rooftop PV generation

The output of rooftop PV generation depends on the level of solar radiation reaching the panels. Rooftop PV is distributed over individual premises with no central control of the generation. Unlike scheduled or semi-scheduled generation, AEMO currently has no mechanism to control the output of this distributed rooftop PV generation.

AEMO's 2015 *National Electricity Forecasting Report* (NEFR) included forecasts of minimum demand for SA and concluded that by around 2024–25, there may be short periods of zero net demand on the SA power system. This would occur during periods of low underlying customer demand, moderate ambient temperature, and high sunshine. Such periods would first be seen during public holidays, Sunday afternoons, and around the Christmas period.

During periods of this type, AEMO would be unable to match supply and demand in a SA island condition, due to its inability to control the output of the rooftop PV generation. AEMO would therefore be unable to control power system frequency in SA if it was islanded at the time.

²⁰ Available at: <http://www.aemo.com.au/Electricity/Planning/South-Australian-Advisory-Functions/South-Australian-Wind-Study-Report>.



This is not expected to be a problem in the short term (the next two to three years), however management of this scenario will need to be examined in more detail in the future and has been included in AEMO's ongoing program of work.

Operation of Murraylink Interconnector

Investigation into the operation of the Murraylink Interconnector (Murraylink), and its impact on rapid changes to supply-demand balance, found that:

- As its flow is in accordance with dispatch targets (similar to a scheduled generating unit) which can change every five minutes, there is potential for this to impact frequency in SA when islanded.
 - There are currently no network constraint sets available to limit the rate of change of flow on Murraylink.
- Murraylink is not capable of providing frequency control services, however, as it is a DC link, its rapid changes in flow could be used to assist with frequency control in SA during SA island operation. No process or control system is in place to do this.
- However, there are a number of control or runback schemes in place that can ramp Murraylink's flow to zero over a few seconds, and the trip of Murraylink is always a credible contingency so sufficient FCAS must be enabled to cover the loss of Murraylink.
 - Constraint sets are already available to manage this.

In terms of further utilising the operation of Murraylink to minimise the impact on rapid changes to supply-demand balance in SA while islanded:

- AEMO will develop constraint sets to limit the ramp rate of Murraylink.
- AEMO and ElectraNet will seek advice from APA Group (operator of Murraylink) to explore the potential option of Murraylink flow assisting with frequency control in SA.

2.5.4 Fault ride through characteristics of wind generation

If a transmission fault causes sufficient voltage depression at a wind farm, it can trigger the wind turbines to switch into a 'fault ride through' mode, the exact nature of which varies with the wind turbine type. This results in a large reduction in active power from the wind farm during and immediately after the transmission fault.

This is a known characteristic of wind generation and was highlighted in studies undertaken for AEMO in 2011–12.²¹

Clause S5.2.5.5 of the NER requires generating units or generating systems to remain in continuous uninterrupted operation for credible contingency events. However, the NER defines continuous uninterrupted operation as a generating system or generating unit operating immediately prior to the fault not disconnecting from the power system, except as allowed under its performance standards, and after the fault has cleared, only substantially varying its output as allowed under its connection agreements. That is, there is no requirement for generating units not to vary their output during the period of an electrical fault.

While all generators reduce active power output during a fault, if wind generation at the time was a large proportion of the generation mix, the slower recovery of active power from wind turbines compared with synchronous generation could have a detrimental impact on the management of frequency in an islanded network. If the transmission fault resulted in the disconnection of a generating unit, the resulting loss of generation could then be exacerbated by the short term reduction in wind generation. The result could be an amplified frequency deviation, potentially leading to under frequency load shedding.

²¹ Available at: <http://www.aemo.com.au/Electricity/Planning/Related-Information/Wind-Integration-Investigation>.



In addition to the temporary loss of active power generation by certain types of wind turbine immediately following a nearby fault, there may also be a large reactive power draw from the induction type wind turbine generators. This reactive power is drawn from the network to regenerate the field inside the generators that facilitates the conversion of mechanical to electrical energy. If insufficient reactive power is available, there may be a localised voltage collapse resulting in disconnection of wind generating plant. With the reduction of synchronous plant available in the SA network the transient recovery of transmission network voltages may also require further investigation.

The key challenges for system recovery from fault conditions in networks with high penetration of renewable generation are:

- Active power restoration following faults, and
- Transient voltage recovery following faults.

These have not been an issue at lower levels of wind generation, but they may become more critical with higher levels of penetration of wind generation.

The Essential Services Commission of South Australia (ESCOSA) Licence Conditions for Wind Generators²² require (among other things) that all new wind farms meet the automatic access standard for generating system response to disturbances following contingency events²³, and are capable of continuous operation at a power factor of between 0.93 leading and 0.93 lagging at real power outputs exceeding 5 MW at the connection point. The Licence Conditions require 50% of this reactive power to be on a dynamically variable basis. These licence conditions go some way to mitigating challenges of transient voltage recovery.

Wind turbine fault ride through has not been an issue in SA, and power system security challenges have not been identified during separation events. With further withdrawal of synchronous generation, the slower recovery in active power from wind turbines may have an impact on frequency. Further studies may be required to determine the need for further action.

Other small islanded systems around the world currently impose limits on the percentage of non-synchronous generation operating at any time. As an example, SONI (the Transmission System Operator of Northern Ireland) and EirGrid (the Transmission System Operator of Ireland) limit the system non-synchronous penetration, that is, energy from wind generation and interconnection, within the combined island systems, to a maximum of 50%.²⁴

However, before any changes are implemented, AEMO would develop detailed internal procedures.

2.5.5 Transmission voltage control

A further requirement for maintaining power system security is transmission voltage control. Unlike frequency control, the facilities used to manage transmission voltage must be available within SA for both normal and islanded operation. AEMO has relied heavily on voltage control resources provided by thermal generating units.

Transmission voltage control strategies in SA do not change significantly due to the unavailability of the Heywood Interconnector. Studies found that additional network switching outside of ordinary practices is unlikely to be required.

2.5.6 Modelling tools

The single phase RMS modelling tools used by AEMO, and the wind turbine model information provided by the turbine manufacturers, provide a simplified representation of generation performance, in particular, the response of power electronics in some wind farm equipment to single phase and

²² Available at: <http://www.escosa.sa.gov.au/library/100430-LicenceConditionsWindGenerators-FinalDecision.pdf>.

²³ NER Clause S5.2.5.5(b)(1).

²⁴ <http://www.soni.ltd.uk/Operations/DS3/>.



phase to phase faults. AEMO is investigating options for three phase models to better represent the behaviour of the plant.

With the aim of obtaining a suitable level of power system modelling information from generators and network operators, AEMO is currently reviewing:

- The modelling tools it uses. AEMO expects to complete initial benchmarking of the current NEM standard power system modelling software package against other such software by mid-2016.
- The regulatory requirements relating to the provision of modelling data, which AEMO expects to complete by the end of 2016.

2.6 Conclusions

Following its investigations, AEMO has:

- Amended its internal procedures for managing power system security in SA when SA is at risk of islanding.
- Implemented internal procedures to maintain power system security in SA post separation for periods that do not include the hot water demand peak period.

AEMO has identified a number of issues where further analysis is required:

- Management of large penetrations of renewable generation as this relates to:
 - The availability of inertia and rate of change of frequency.
 - Provision of frequency control ancillary services.
 - Generation fault ride through characteristics.
- Management of rapid changes in the supply-demand balance due to:
 - Hot water demand peak.
 - Unexpected changes in wind and rooftop PV generation.

2.7 Next steps

2.7.1 Short-term (from early 2016)

- Engage with SA Power Networks in relation to its work program for randomising time clock settings to reduce the size of the hot water demand peak.
- Develop internal PSO procedures for managing non-scheduled generation and short term wind generation changes during the operation of SA as an island.
- Develop constraint sets to limit the ramp rate of the Murraylink Interconnector during the operation of SA as an island.
- Explore the potential for rapid changes in the Murraylink Interconnector flow to assist with frequency control in SA (in conjunction with ElectraNet and the APA Group).
- Source modelling software to enable the study of fault ride through characteristics of non-synchronous generation. These studies should help determine if non-synchronous generation should be limited during the operation of SA as an island.
 - As an interim measure, where AEMO determines power system security is at risk due to high levels of non-synchronous generation, AEMO may place limits on the percentage of non-synchronous generation.



2.7.2 Long-term (from mid-2016)

- As there is currently no system standard for RoCoF, AEMO will consult with appropriate bodies on the need for such a standard.
- AEMO will investigate the options for managing frequency within an islanded SA power system at times of low inertia in SA and when rooftop PV generation is greater than the demand.
- The NER definition of continuous uninterrupted operation allows for the output of a generating unit to vary during the period of the fault. AEMO will investigate the implications to system security of this happening and the options for managing system security during a fault.



3. AUTOMATIC UNDER FREQUENCY LOAD SHEDDING (AUFLS)

3.1 Introduction

In a secure power system, it is a key requirement that the power system frequency remain within limits specified by the FOS.²⁵ This is achieved by balancing electricity generation and demand at all times. The central dispatch process in the NEM is used to procure frequency control ancillary services (FCAS) to meet the FOS during normal operation and following a credible contingency event.

For non-credible contingency events, that usually have more severe outcomes than credible contingency events, the NER require automatic under frequency load shedding (AUFLS) facilities to be installed and maintained to prevent the frequency from breaching a wider FOS (47–52 Hz²⁶ for mainland regions) than those for credible contingency events.

Part B of FOS also states that:

- (e) as a result of any separation event, system frequency should not exceed the applicable island separation band and should not exceed the applicable generation and load change band for more than two minutes or exceed the applicable normal operating frequency band for more than ten minutes; and*
- (f) as a result of any multiple contingency event, system frequency should not exceed the extreme frequency excursion tolerance limits and should not exceed the applicable generation and load change band for more than two minutes while there is no contingency event or exceed the applicable normal operating frequency band for more than ten minutes while there is no contingency event.*

3.1.1 The AUFLS scheme

The AUFLS scheme is designed to prevent the frequency from falling to such a level that the power system is not able to be restored to a stable operating state. It is intended to minimise disruption of a major disturbance on the power system, such as cascading tripping of generating units, which could otherwise lead to a total blackout of the system. The NER requires that 60% of customer demand for connection points over 10 MW is available for AUFLS.

A new AUFLS scheme design was completed in 2007, in response to a major power system event on 14 August 2004.

3.1.2 Allocation of AUFLS functions in the NEM

The need to recalibrate settings across the AUFLS scheme in the NEM, following the system event in 2004, led to discussions between a number of relevant industry sectors to clarify functions in relation to management of the AUFLS process. The discussions were co-ordinated through the Operations Planning Working Group (OPWG).

The key parties with responsibilities specifically relating to ensuring that the FOS are maintained for both credible and non-credible contingencies are:

- AEMO – which has responsibilities to:
 - Determine the requirements of the regional AUFLS characteristics including the amount of load to be shed at each frequency setting and any other special requirements.
 - Conduct regular reviews of the AUFLS arrangements (currently once every two years).

²⁵ Available at: <http://www.aemc.gov.au/Australias-Energy-Market/Market-Legislation/Electricity-Guidelines-and-Standards?type=2>.

²⁶ Known as the extreme frequency excursion tolerance limits.



- In conjunction with the relevant TNSP, consider the potential for over-voltages to occur due to load shedding and determine methods for managing such situations.
- Regional Coordinating Body (RCB)²⁷ – which has responsibilities to:
 - Obtain the prioritised lists of AUFLS load shedding blocks from the Network Service Providers (NSPs).
 - Prepare a coordinated AUFLS schedule for its region to meet the regional AUFLS characteristics specified by AEMO.
- NSPs – which have responsibilities to:
 - Prepare a prioritised list of AUFLS load shedding blocks and provide this to the RCB as requested.
 - Implement the approved AUFLS schedule provided by the RCB.
 - In conjunction with AEMO (TNSPs only), consider the potential for over-voltages to occur due to load shedding and determine methods for managing such situations.
- Market customers who have expected peak demands at connection points in excess of 10 MW – who must have at least 60% of their expected demand available for shedding, consistent with NER clause 4.3.5.

3.1.3 AEMO's two-yearly AUFLS scheme review

In January 2015, AEMO completed a NEM-wide study to determine if the current settings for AUFLS schemes were still appropriate to maintain power system security and reliability. This study was undertaken as a part of AEMO's AUFLS review, which is conducted every two years.

AEMO concluded that all current settings (those designed in 2007) were valid for low, medium, and high demand scenarios.

Since this review, a number of key developments have occurred:

- Alinta Energy has announced that Northern Power Station will cease operations from around March 2016.
- AGL has announced that Torrens Island 'A' Power Station will be mothballed from early 2017.
- Increased penetration of rooftop PV, particularly in SA and Queensland.
- AEMO has obtained rooftop PV inverter trip settings for inverters NEM-wide in order to better understand their response to system disturbances.

In mid-2015, AEMO conducted a further review of SA's AUFLS scheme in the first instance, due to the upcoming plant withdrawals and high penetration of rooftop PV in the region and further to consider the impact of rooftop PV inverter trip settings.

AEMO now considers it necessary to carry out a further, more detailed review of the AUFLS scheme, initially in SA and then extending to the remainder of the NEM.

3.2 Key messages

The following key points can be concluded from AEMO's South Australian AUFLS scheme reviews:

- In the event of a non-credible separation of SA from the remainder of the NEM, there is an increasing risk that the current AUFLS scheme in SA will be unable to maintain SA frequency within the FOS. Studies have confirmed this risk is material when there is concurrent occurrence of low operational consumption, high import from Victoria, low power system inertia in SA (less than four–five synchronous generating units operating), and high rooftop PV generation (greater than 480 MW). This risk arises due to:

²⁷ Queensland: Powerlink; NSW: TransGrid; Victoria: AEMO; Tasmania: TasNetworks; South Australia: Department for State Development.



- Fast RoCoF following the frequency event associated with low power system inertia; and/or
- Insufficient allocation of the amount of load to be shed through the load blocks, due to the impact of rooftop PV on the system.
- Due to increasing levels of rooftop PV embedded within the distribution system which will be shed as part of the AUFLS scheme, up to an additional 75% of the underlying consumption will be shed at times of high rooftop PV generation, compared to periods when rooftop PV is not generating through the current AUFLS scheme design, in order to deliver the required level of load reduction at a system level to restore frequency balance.
 - For the investigations, due to limited available data, AEMO made assumptions as to the ability of each SA windfarm to ride through the contingency without tripping due to RoCoF protection. Further load-shedding will occur if actual wind farm ride through capability is less effective than assumed. AEMO is working with plant owners to access actual plant capabilities.
- As synchronous generation continues to withdraw or be operationally de-committed from the market, the risk of the FOS not being met for non-credible separation events will increase. AEMO will investigate the extent to which further setting changes on the current SA AUFLS scheme can maintain the FOS for the most onerous non-credible separation events.
- Subject to the outcomes of this analysis, AEMO will consider whether more fundamental changes (other than the AUFLS settings) may be required to the regulatory framework. For example, it may be possible to clarify the roles and responsibilities of parties in the NEM, to address any mismatch between the expectations contained in the FOS for non-credible contingency events and the ability of current AUFLS infrastructure to meet them.

3.3 Scope

3.3.1 Load shedding requirement

Clause 4.3.5 of the NER requires retailers and other market customers having expected peak demands at connection points in excess of 10 MW to make at least 60% of their expected demand available for automatic load shedding.

Since rooftop PV will offset the underlying consumption, an important consequence is that the underlying consumption can be greater than the operational consumption by approximately the volume of rooftop PV installed.

The 2007 AUFLS scheme design was implemented at a time of minimal rooftop PV penetration. Under current conditions, where rooftop PV reduces the operational consumption, the level of underlying consumption required for load shedding will need to increase in order to meet the AUFLS design requirement.

3.3.2 Scenarios

AEMO's work included low, medium, and high demand conditions (with bias towards low levels of inertia to represent more limiting conditions) for the following scenarios:

- The impact on the SA AUFLS scheme settings with only Northern Power Station unavailable.
- The impact on the SA AUFLS scheme settings with both Northern and Torrens Island 'A' power stations unavailable.
- The impact on the SA AUFLS scheme settings with Pelican Point station at half of its capacity.²⁸

The studies reviewed settings for:

²⁸ As per AEMO's 2015 ESOO modelling.



- The intact NEM.
- South Australian islanded system.
- Varying levels of import into SA.

To be confident that the AUFLS scheme performs as intended at all times, AEMO's studies incorporated rooftop PV embedded within feeders designed to trip under the South Australian AUFLS scheme (and therefore reducing the impact of load shedding) with three different levels of rooftop PV generation:

- 0 to 200 MW – representing conditions at night time or with cloud cover.
- 400 MW – representing a medium level of rooftop PV.
- 480 MW – representing a high level of rooftop PV (approximately 80% capacity factor²⁹).

3.3.3 Rooftop PV trip characteristics

Each scenario above also included the data recently collected by AEMO on South Australian rooftop PV inverter trip settings. Of the total installed 597 MW of rooftop PV in SA, the inverter characteristics of 303 MW were identified, which showed that 65% of surveyed rooftop PV inverters in SA will not trip for frequency levels greater than 47 Hz.

Based on the sample of data collected, aggregated tripping characteristics were developed, and it was assumed that:

- 12.4% of installed rooftop PV will trip prior to the underlying AUFLS block trips.
- The remaining 87.6% of installed rooftop PV will not trip prior to the underlying AUFLS block trips. The rooftop PV will reduce the effective size of the underlying AUFLS blocks.
- To account for the distribution of remaining unknown rooftop PV installations across SA, the distribution of trip settings and size of the known rooftop PV installations was proportionally extrapolated to the total installed capacity.
- The total rooftop PV considered for each scenario is distributed in proportion to the size of the AUFLS blocks.

Further details of AEMO's investigations into the performance of the current inverter fleet installed in the NEM will be published separately.

3.4 Methodology

The current AUFLS scheme design was reviewed using a simplified model designed in 2007. The model simulates a contingency event that islands SA from the rest of the NEM for a specified import level and sheds the required load blocks to restore frequency.

3.4.1 System modelling

A simplified modelling approach includes the following representations:

- Operational consumption.
- Generation prior to islanding.
- Inertia of generating units prior to islanding.
- Load relief.
- Governor response.
- Import into SA.

²⁹ That is, 80% of the installed capacity, allowing for shading, temperature effects, clouds, and alignment.



- Current AUFLS load blocks and trip settings.
- Generation protection settings.

3.5 Results

3.5.1 Acceptance Criteria

The AUFLS scheme is designed to operate when frequency falls below 49 Hz and to stop the frequency fall before it reaches 47 Hz.

For this analysis, the South Australian AUFLS scheme design is considered sufficient if the minimum frequency following a separation event is greater than 47.4 Hz, that is, a 0.4 Hz safety margin to allow for approximations in the modelling.

3.5.2 Mainland interconnected

The current 2007 South Australian AUFLS scheme design is sufficient for all scenarios considered while SA is connected to the rest of the NEM. Studies showed the effect of rooftop PV on the design was inconsequential, because of the volume of rooftop PV in SA compared to the mainland demand.

3.5.3 South Australian islanding

The South Australian AUFLS design was reviewed for an event that separated SA from the rest of the NEM. Import into SA prior to islanding was increased up to 650 MW, that is, the maximum capacity of the Heywood Interconnector flow from Victoria following completion of the Heywood upgrade project in July 2016.

Low demand scenario³⁰

For all cases in the low demand scenario, it was observed that, as the rooftop PV generation increases, the underlying consumption that must be shed to maintain FOS following South Australian separation increases substantially. This is because the amount of effective load shed reduces as rooftop PV generation increases.

(i) Northern Power Station unavailable

The South Australian AUFLS scheme design is not sufficient under the following conditions, as the minimum frequency following South Australian separation falls below the lower design limit:

- High rooftop PV generation in SA (i.e. > 480 MW), and
- Heywood Interconnector disconnected when importing > 600 MW into SA.

The FOS is maintained at times of no (0 MW) and medium (400 MW) rooftop PV generation up to the maximum import limit.

(ii) Northern Power Station and Torrens Island 'A' Power Station unavailable

The South Australian AUFLS scheme design is not sufficient under the following conditions, as the minimum frequency following South Australian separation falls below the lower design limit:

- Rooftop PV penetration in SA > 400 MW when SA import > 575 MW into SA, or
- Rooftop PV penetration in SA > 480 MW when SA import > 525 MW into SA.

The FOS is maintained at times of no (0 MW) rooftop PV generation up to the maximum import limit.

³⁰ Pelican Point power station was assumed at half of its capacity for all scenarios.



(iii) Impact of inertia

Inertia, which is provided by thermal generating units, stabilises the power system and reduces the volatility of frequency variations during power system disturbances.

Three levels of inertia were simulated:

- High inertia – 7,327 MWs (or eight thermal units).
- Medium inertia – 6,000 MWs (or seven thermal units).
- Low inertia – 4,500 MWs (less than four-five thermal units).

The results showed that:

- As inertia reduces, the minimum frequency is lower (i.e. greater under frequency excursion) before the current AUFLS scheme design can arrest the frequency drop.
- For high rooftop PV generation, the minimum level of inertia required to maintain frequency following islanding of SA is 4,500 MWs.

Medium demand scenario

Results showed that the current AUFLS scheme design is sufficient for a medium demand, high import scenario, with South Australian inertia as low as 6,532 MWs (or six thermal units) as the minimum frequency remained above 47.4 Hz for all scenarios.

The medium demand scenario incorporated:

- 1,660 MW of South Australian underlying consumption with all levels of rooftop PV generation, and
- SA separated from the NEM while importing 650 MW.

High demand scenario

Results showed that the current AUFLS scheme design is sufficient for a high demand, high import scenario, with South Australian inertia as low as 5,272 MWs (or six thermal units)³¹ as the minimum frequency remained above 47.4 Hz for all scenarios.

The high demand scenario incorporated:

- 3,000 MW of South Australian underlying consumption with 200 MW rooftop PV generation, and
- SA separated from the NEM while importing 650 MW.

3.5.4 Additional sensitivity – Accounting for windfarm trips due to RoCoF assumptions

Following the South Australian under frequency load shedding event on 1 November 2015, it was observed that some windfarms in SA may be disconnected during low frequency events due to their low RoCoF settings.

As a result of that event, and following a recent generator survey, it appears that four South Australian windfarms have low RoCoF trip settings, that is, less than -1 Hz/sec, compared to other windfarms which have settings of ± 4 Hz/sec.

If these windfarms with RoCoF settings of up to ± 1 Hz/sec were to trip during operation of the AUFLS scheme, the minimum frequency would reduce further before AUFLS is able to stop the fall in frequency.

Consequently, the high demand scenario was simulated again, assuming the windfarms with low RoCoF settings would trip.

³¹ To simulate a high demand, high wind condition with minimal thermal units online.



Results showed that:

- The minimum frequency is reduced further if these windfarms tripped.
- More load is required to be shed when the windfarms are disconnected.
- For low inertia, the tripping of wind farms by RoCoF has less of an effect on the minimum frequency, as the AUFLS load blocks are tripped prior to the windfarms.

3.5.5 Review of AUFLS design allocation

The NER require at least 60% of customer demand at connection points in excess of 10 MW to be available for load shedding. This review showed that the current South Australian AUFLS load block allocation (according to the 2007 design) meets this load shedding requirement.

However, the AUFLS allocation sheds more load at the lower frequency settings (less than 47.9 Hz) than in the initial load blocks (49 Hz – 47.9 Hz) as required by the design.

This means changes to the AUFLS blocks are required to align it more closely to the design.

- For South Australian islanding conditions under the 2007 design of AUFLS block sizes, it was found that the minimum frequency and load shedding required under actual conditions would be more severe compared to the design requirement.

3.6 Conclusions

AEMO's study has concluded the following:

- The ability of the AUFLS scheme design to protect against low frequency excursions under non-credible tripping of the Heywood Interconnector is highly dependent on:
 - The amount of rooftop PV generation, and
 - The capability of online generation in SA being able to remain online during and after the frequency excursion, that is, their ability to withstand fast RoCoF.
- The current AUFLS scheme design for SA (from 2007) is sufficient for the following conditions studied for maximum import of 650 MW:
 - Low, medium and high demand scenarios for an intact NEM, and
 - Medium and high demand scenarios for the SA islanded system.
- The design is not sufficient for SA separated from the mainland (to cater for maximum import of 650 MW³²), for the following conditions:
 - Low Operational consumption (< 1,063 MW), and
 - Low inertia (< 5,020 MWs or four-five thermal units), and
 - High rooftop PV generation (> 480 MW).
- The likelihood of the above conditions occurring in the upcoming three years³³ is estimated to be:
 - Approximately 0.1% of the time in 2015–16.
 - Approximately 1.8% of the time in 2016–17.
 - Approximately 2.5% of the time in 2017–18.

The increase in likelihood of occurrence can be attributed to the expected withdrawal of thermal plants as well as increasing rooftop PV levels.

³² Maximum allowable level of import is approximately 360 MW (if windfarms do trip under RoCoF) for the current design to be sufficient for the separation conditions identified.

³³ Based on demand scenarios and information provided in AEMO's 2015 ESOO Update, available at: <http://www.aemo.com.au/Electricity/Planning/Electricity-Statement-of-Opportunities>.



- For 1 MW of operational consumption reduction, up to 1.75 MW of underlying consumption is required to be shed at times of high rooftop PV generation, compared to periods when rooftop PV is not generating. This ratio will increase if non-scheduled windfarms trip due to RoCoF protection.
- As inertia of the system reduces, the amount of load shedding increases with progressively lower minimum frequencies.
- Premature tripping of windfarms due to their assumed RoCoF settings (< -1 Hz/sec) will make the situation worse under high import, low inertia conditions, that is:
 - Load shedding required to maintain system security will increase.
 - The minimum frequency for the separation event will further reduce.
- Before recommendations on changes to the current design can be made, further studies in a more sophisticated model are required to define the complete technical envelope for the design to operate. The simplified modelling tool used for this analysis does not allow this level of detail to be performed. Studies include:
 - Impact of over-voltage on the network post AUFLS operation.
 - This will involve engagement with ElectraNet on their work in this area.
 - More detailed modelling of governor responses to:
 - Accurately simulate maximum frequency post UFLS.
 - Accurately simulate the response of the delayed AUFLS block trips.³⁴
 - Impact of individual rooftop PV inverter trip settings (rather than a regional approximation), particularly in response to over-voltage situations.
 - Low voltage ride through performance of windfarms causing temporary reduction in active power from a fault on the Heywood Interconnector.
 - Incorporating accurate RoCoF settings of both thermal generating units and windfarms to understand their response to under frequency events both during and after the fault.

3.7 Next steps

3.7.1 Short-term (from early 2016)

- For AEMO to determine AUFLS characteristics that will maintain FOS under non-credible contingency conditions, AEMO will:
 - Determine all relevant scenarios the AUFLS scheme should operate for due to current and potential system conditions in SA. Once these scenarios have been defined, AEMO will engage with ElectraNet and SA Power Networks to obtain feedback on these.
 - Obtain key information from all generators in SA on their capability to withstand a fast RoCoF so that AUFLS characteristics can be determined with greater level of confidence
 - Conduct analysis using more sophisticated non-linear modelling to define the complete technical envelope that determines the AUFLS characteristics.
- AEMO will need to engage with ElectraNet and SA Power Networks to:
 - Investigate if feeders that constitute AUFLS blocks can be chosen to minimise the impact of rooftop PV.
 - Confirm that the required amount of load shedding per AUFLS block is achievable.

³⁴ The current simplified model may be exaggerating the number of delayed block trips triggered.



- Identify alternative mechanisms in addition to, or in place of, a new AUFLS design which may need to be considered if feedback from the NSPs indicates that the new characteristics determined by AEMO are not achievable.

3.7.2 Long-term (from mid-2016)

- Although there are obligations in place to maintain system frequency for non-credible contingencies (through clauses within the NER, the FOS, and those agreed by industry through the OPWG), AEMO will consider whether more fundamental changes (other than the AUFLS settings) may be required. This could include:
 - A review of the NER and/or the FOS so expectations on the objective and implementation of the AUFLS scheme are clear and consistent throughout the market.
 - A review of the adequacy of the system and generation performance standards with the changing generation mix, including such challenges as RoCoF.
 - Clarification on the roles and responsibilities of maintaining system frequency within the NER or FOS in the event that an AUFLS scheme is not capable of doing so.
 - Whether alternatives to the current AUFLS infrastructure are needed to meet the FOS for non-credible contingency events.
- There are concerns that the current AUFLS scheme may not operate as intended, and AEMO will perform a similar review for the remainder of NEM regions' AUFLS scheme designs to account for current and potential system conditions relevant to each region.



4. OVER FREQUENCY GENERATION SHEDDING (OFGS)

4.1 Introduction

AEMO's previous work has identified that the trip of both circuits of the Heywood Interconnector at times when there is high export from SA to Victoria remains non-credible, but would cause an over frequency event in SA. An over frequency event could lead to tripping of a number of generating units due to the operation of their protection systems. If generation trips of this type are not well coordinated, there is potential for too much generation plant to trip, resulting in an under frequency event and potentially subsequent load shedding.

At present there is no specific emergency control scheme in place in SA to maintain frequency within the FOS following such an event.

Continued installation of rooftop PV generation and wind generation in SA will increase the potential for SA to be exporting electricity to Victoria, so could increase the probability that a non-credible interconnector trip (although unlikely in its own right) could lead to an over frequency event.

Managing the consequences of this type of potential over frequency event would generally involve the use of an emergency control scheme such as an over frequency generation shedding (OFGS) scheme, or generation run-back scheme. An OFGS scheme is designed to coordinate the tripping of generation to avoid cascading failures which can lead to severe network disruption. In the specific circumstances where SA could experience a high frequency event, an OFGS scheme would attempt to maintain high inertia synchronous machines online to stabilise the power system, while shedding low inertia wind farm generation in a coordinated manner.

Successful implementation of such a scheme would require a number of generators to modify the frequency protection relay settings on their generation units, currently provided as part of their generation performance standards.

4.2 Discussion

While AEMO is generally required to manage the consequences of a credible contingency event, NER clause S5.1.8 requires that, where the consequences of a non-credible contingency are likely to cause severe disruption to electricity supply, a Network Service Provider and/or a Registered Participant must install emergency controls within the Network Service Provider's or Registered Participant's system or in both, as necessary, to minimise disruption to any transmission or distribution network and to significantly reduce the probability of cascading failure.

AEMO is in the process of developing settings for an OFGS scheme for SA. This section provides an update on the key findings from AEMO's preliminary work on the design of an OFGS scheme for SA, and an overview of ongoing activities.

- AEMO has identified the increasing importance of having an effective OFGS scheme, because:
 - The risk of over frequency occurring following a non-credible separation event is increasing, with progressively more generation being installed in SA, and falling operational consumption in the region leading to more periods of export from SA to Victoria.
 - The potential impact on power system security of a non-credible separation event during periods of high export from SA is increasing, as synchronous generating units exit the market and reduce the level of inertia available to the SA power system.
- AEMO has started 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 SA. This work includes



analysing the possibility of SA being islanded at a number of different separation points on the network, including in western Victoria.

- The OFGS scheme is intended to limit the rise in frequency by tripping generating units with zero or low inertia before generating units that provide higher levels of inertia.
- To provide confidence in the analysis, AEMO needs to verify the assumptions used in its modelling in relation to the performance of generating plant during high frequency events. Current technical standards define what system conditions a generating unit must ride through, rather than the exact settings at which it will trip. Accordingly, AEMO is seeking cooperation from generators in SA and Western Victoria to provide technical information on the plant performance characteristics during such events.
- Following completion of the analysis, AEMO anticipates there will be a need for some generators to adjust the over frequency relays on their generating units for a coordinated OFGS scheme to operate.
- AEMO has identified that reliable operation of an OFGS scheme may not be achievable under some power system conditions. For example, an OFGS scheme cannot be relied on to stop a high frequency excursion in circumstances such as:
 - Very low levels of inertia in SA leading to a high RoCoF that causes synchronous generating units to trip before the OFGS scheme can operate. AEMO requires further technical information from generators to fully model this scenario.
 - Insufficient low inertia wind generation being available to the OFGS scheme to control frequency. For example, this could occur when wind speed is low, resulting in low levels of wind generation.
- AEMO has continued to review potential power system conditions to better understand future risk exposure in relation to OFGS scheme performance. As the generation mix in SA evolves and the limitations of the OFGS scheme are more fully understood, AEMO will investigate the potential need for a more sophisticated scheme to maintain FOS in the longer term. This work would include considerations such as:
 - If there is an OFGS scheme design that will maintain the FOS for any trip of the Heywood Interconnector.
 - Whether a different mechanism (other than or in conjunction with the OFGS scheme) might be required to meet the FOS.
 - Whether more fundamental changes may be required, such as clarification in the NER or FOS on the roles and responsibilities of parties in the NEM to address any mismatch between the expectations contained in the FOS for non-credible contingency events and the ability of emergency control schemes to meet them.

4.3 Next steps

4.3.1 Short-term (from early 2016)

- In order to proceed with investigations, AEMO is requesting SA and Western Victorian generators to provide further information on the current frequency trip settings (including rate of change of frequency) settings and configuration of over frequency and RoCoF protection.
- AEMO is developing the detailed models required for the analysis of the power system following a trip of the Heywood Interconnector for a range of transfer levels and a range of generation online at the time. These will be refined once AEMO has a more detailed understanding of the settings and configuration of the over frequency and rate of change of frequency protection.



- AEMO will develop the recommended OFGS scheme design with the optimum generation in designated tripping bands to manage system security, and in the process investigate:
 - If there is an OFGS scheme design that will maintain the FOS for any trip of the Heywood Interconnector.
 - Whether a different mechanism (other than or in conjunction with the OFGS scheme) might be required to meet the FOS.
- Generators to adjust the over frequency relays on their generating units for a coordinated OFGS scheme to operate.

4.3.2 Long-term (from mid-2016)

- AEMO will also investigate whether more fundamental changes may be required, such as clarification in the NER or FOS, or on the roles and responsibilities of parties in the NEM to address any mismatch between the expectations contained in the FOS for non-credible contingency events and the ability of emergency control schemes to meet them.



5. CLOSURE OF NORTHERN POWER STATION

The Northern Power Station (NPS) performs an important transmission network voltage control service at the Davenport 275 kV substation in the Upper North of SA. Closure of NPS will remove this voltage control service.

ElectraNet initiated system studies to identify potential network adequacy and security limitations resulting from the withdrawal of NPS. Those studies, and a review of past operational experience, have revealed the following limitations under certain credible demand and generation scenarios:

- Reactive power margin – at times of high Olympic Dam demand, moderate to high system demand, and low wind generation in the Mid North of SA, reactive power reserve margins may not be met at the Davenport 275 kV connection point.
- Over voltage – operating the Davenport 275 kV connection point voltage above 1.05 pu (which occurs for the majority of the time to mitigate against the risk of voltage collapse at Olympic Dam) is expected to result in over-voltage at times of low wind generation in the Mid North of SA for the loss of the Olympic Dam load.
- Voltage collapse – for N-1-1³⁵ conditions the system would be at risk of voltage collapse for certain operating conditions. Further, switching a 50 MVAR reactor into service at Davenport at times of low wind generation in the Mid North of SA may cause a voltage collapse.
- Reduced wind farm output – the combined output of the two Eyre Peninsula wind farms is reduced by 20 MW (by way of an intra-regional generation dispatch limit) when NPS is not in service.

ElectraNet analysis shows that the withdrawal of NPS will create challenges for transmission network voltage control in the Upper North and the Eyre Peninsula regions of SA. These challenges will arise for a range of system demand levels at times of low wind generation in the Mid North of SA, and also for any N-1 condition in the Upper North.

ElectraNet intends to initiate a Regulatory Investment Test – Transmission (RIT-T) to procure the most economic network or non-network solution that resolves the issue.

³⁵ An N-1-1 condition is a measure of system security, and means that the system is able to withstand the consecutive loss of any two components of the power system.



6. ACTIONS TAKEN FOLLOWING THE 2014 REPORT

6.1 Introduction

Following the release of the 2014 Report, AEMO considered a number of the report's recommendations and has implemented a number of changes to its internal PSO procedures, constraint equations, and network models.

6.2 Credible risk of SA islanding

In the 2014 Report, AEMO committed to improve its own systems and processes to:

- Monitor and respond to low inertia conditions in SA by limiting interconnector flows.
- Implement rate of change of frequency constraints in SA to maintain them within system protection limits.
- Enhance existing internal procedures to improve AEMO's ability to assess available system frequency control capability for planned outages of the Heywood Interconnector.

Following that report, AEMO has:

- Developed tools that are used by the AEMO real time operations control rooms to monitor, in real time, the inertia of the South Australian power system.
- During periods when the loss of the Heywood Interconnector is considered a credible contingency event (see Chapter 2), developed and implemented new constraint equation sets:
 - To limit on the flow on the Heywood Interconnector. These constraints consider the amount of inertia on line in SA in real time, and limit the flow on the Heywood Interconnector to a maximum of 250 MW or a lower level that is required to limit the RoCoF to a rate below 1 Hz/sec should the interconnector trip.
 - To improve AEMO's ability to assess available system frequency control capability for planned outages of the Heywood Interconnector, and any other periods when the trip of both circuits is a credible contingency, by procuring 35 MW of regulation raise and 35 MW of regulation lower FCAS locally in SA.
 - To enable sufficient contingency FCAS at the least cost in SA during island operation by co-optimising the level of risk (largest generating unit at risk) against contingency FCAS requirements.

6.3 Wind turbine inertia

In the 2014 Report, AEMO undertook to analyse the potential inertial contribution from existing wind generation in SA. AEMO has undertaken this work and has found:

- While the earlier type 1 wind turbines (induction generator unit – fixed speed) do provide the same inherent inertial response as other induction motors or generating units, their inertia contribution is relatively small, and there are only a small number of type 1 turbines connected in the NEM.
- AEMO has analysed high speed data on the performance of type 2 wind turbines (wound-rotor induction generating unit with adjustable external rotor resistance – variable slip) during actual frequency disturbances in the NEM, and has found no evidence of inertial response acting to restrict the change in frequency.



- Type 3 turbines (double-fed induction generators (DFIG) – variable speed) and type 4 turbines (full converter system with permanent magnet synchronous generating unit – variable speed) inherently provide no inertial support to the power system because power electronic converters isolate the wind turbine from grid frequency.
- While it is possible for some of the control systems in type 3 and type 4 wind turbines and other power electronic devices to be adapted to inject additional active power in a manner that simulates inertial support (sometimes known as synthetic inertia), there is currently no incentive for a generator to provide this service, and no such systems currently exist in Australia.

As a result of this analysis, AEMO's modelling of system performance does not consider any inertial response from the current fleet of wind turbines.

6.4 Rooftop PV response to changes in frequency

AEMO and ElectraNet also committed to undertake further work on:

- Improved modelling of rooftop PV in power system simulations to better understand its impact on power system operation, and
- A model of the rooftop PV response to changes in frequency to incorporate into OFGS implementation.

ElectraNet has developed aggregate distributed models of rooftop PV UFLS scheme behaviour which enabled detailed UFLS system studies to be performed.

AEMO is investigating the frequency behaviour of the installed rooftop PV inverter fleet – the outcome of this will be reported separately. The results of this work will be included in the modelling work undertaken in the design of the OFGS scheme and the review of the AUFLS scheme.



7. NEXT STEPS

7.1 Looking ahead

As system operator, AEMO is responsible for maintaining power system security through a period of rapid and continuing transformation, and is therefore looking at short-term and long-term opportunities and challenges for operating the power system of the future.

As the TNSP in SA, ElectraNet has a role to play in assisting AEMO to maintain power system security in SA.

This report, on short-term work carried out jointly between AEMO and ElectraNet in relation to SA, also represents a transition point. ElectraNet will continue to focus on the specific challenges arising in SA, while AEMO's focus will broaden to include more national challenges.

7.2 ElectraNet work program

Building on the work described in this report, ElectraNet's work program over the next six to twelve months revolves around assessing the identified emerging challenges that ElectraNet may, as the SA TNSP, have a role in addressing over the next three to seven years.

Planned work includes:

- Commencement of a RIT – T consultation in early 2016 on the need for improved voltage control in the north of SA, following the closure of the Northern Power Station. As part of this, ElectraNet will engage with potential proponents who may be capable of providing non-network solutions to meet the identified need.
- A high-level assessment of the potential technical and economic benefits of a new high capacity interconnector between SA and the eastern states (to New South Wales or Queensland, for example), to determine whether a more detailed investigation into the feasibility of such a project is warranted.
- As part of the ESCRI-SA consortium (consisting of AGL, ElectraNet and Worley Parsons), continuing to examine the contribution that transmission-connected electrical storage can make to the successful integration of renewable generation in SA, including frequency control, with a view to implementing a demonstration project within the next two to three years.
- Investigating the impact that reduced minimum fault levels may have on the power system. This will include consideration of:
 - Whether protective devices and power electronic devices can continue to perform satisfactorily under conditions with low levels of synchronous generation operating.
 - Whether existing wind farms can continue to ride through system faults without being disconnected.
 - Whether reactive plant such as reactors and capacitors can continue to be switched without breaching power quality limits.
- Ongoing engagement with AEMO to complete the review of the SA AUFLS and OFGS schemes.
- Engagement with APA (operator of Murraylink), and with AEMO in its capacity as the Victorian transmission network planner, to consider the technical feasibility, cost, and potential benefits of implementing frequency control through the Murraylink interconnector.

ElectraNet will report progress against these and other items related to the changing generation mix in SA in the *South Australian Transmission Annual Planning Report* and other reports as needed.



7.3 AEMO work program

Beyond identifying and acting on challenges posed in SA, AEMO has a broader responsibility for maintaining power system security in the NEM. Given energy sector transformations, including the growth in renewables and the withdrawal of synchronous generation, AEMO has developed an overarching work program for the adaptation of AEMO's functions and processes to deliver ongoing power system security and to manage supply reliability.

This program will continue to place a high priority on the most immediate challenges. Initially, this will include parts of the network considered most at risk of islanding from the remainder of the NEM (e.g. SA, Tasmania, and Queensland).

The sections below give an overview of the draft AEMO program structure.

7.4 AEMO program structure

The overarching objective is to adapt AEMO's functions and processes to deliver ongoing power system security and to manage supply reliability.

The work program will provide a framework for AEMO's identification and management of power system security risks and opportunities in the future. It is divided into two broad areas:

- Long-term (see Section 7.4) – considering challenges that could arise within a 10-year outlook, and providing a platform for efficient and sustainable solutions to be developed in response to identified challenges including, if needed, by making changes to the regulatory framework and Rules governing the NEM.
- Short-term (see Section 7.3) – some of the challenges identified in the long-term work may need to be addressed more quickly than the desired long-term solutions can be put in place. AEMO will therefore have a specific focus on developing interim measures within the current regulatory framework where necessary, to meet its power system security obligations over the next three years.

Figure 5 provides a diagrammatic overview of the work program. Further details of this work program are still being refined, and will be communicated by AEMO shortly.

Figure 5 Program overview

Adapt AEMO's functions and processes to deliver ongoing power system security and reliability		
	Short-term 3-year outlook	Long-term 10-year outlook
Objective	Transparency and clarity in how AEMO intends to meet its obligations for system security and reliability as the generation mix changes.	To identify, rank and promote resolution where appropriate of long-term technical challenges of operating the power system to inform the need for policy, procedural or regulatory changes.
Approach	Initially focussed on South Australia as the region likely to first experience challenges, then considered NEM-wide focus. Review of procedures for operational management of the power system for a range of operating conditions including system normal, credible and non-credible contingencies by testing operational limits and identifying potential challenges. Where issues are identified, development of modified strategies within the current regulatory framework if necessary.	Consult with industry technical experts to identify and prioritise technical challenges. Research, modelling and analysis to confirm the nature and timing of any power system risks. Promotion of regulatory change with appropriate agencies where appropriate.
Outcomes	Clear operational strategies for the next three years with procedures in place for any identified risks.	Prioritised list of issues, and recommendations for progressing their resolution through changes to policy, regulatory, rules, procedural, technical or other mechanisms as appropriate.

The two work-streams have strong inter-relationships and will be managed as parts of a cohesive program. The information and analysis required to assess potential technical challenges is similar across both work-streams, and in some cases, the analysis needs to be carried out before AEMO can determine whether the challenges are likely to arise in the three-year outlook period or beyond.

7.5 AEMO short-term work-stream

The objective of the short-term work-stream is to provide stakeholders with clarity and transparency as to how AEMO will meet its power system security obligations over a three-year outlook.

The approach to achieving this will centre on the detailed technical examination of a range of power system operational challenges, to identify and address any challenges AEMO will face during the outlook period of three years.

Building on the conclusions and next steps from this report, AEMO has identified a preliminary list of potential investigations, which will be refined and prioritised as studies progress. By way of example, the preliminary list includes:

- Operation of emergency control schemes such as under frequency load shedding and over frequency generation shedding schemes. There is potential for the effectiveness of these schemes to reduce as the inertia of islanded parts of the power system reduces.
- The refinement of strategies for operation of parts of the NEM that can most readily become islanded, such as SA, Tasmania or Queensland. Operational strategies for islanded operation will need to be adapted to the dominant generation technologies installed in the island.
- Frequency control, including the effectiveness of current ancillary services as the primary means available to AEMO for managing power system frequency during both normal operation and contingency events.
- The effect of the changing generation mix on fault levels in the power system. This relates to the effectiveness of the protection schemes currently used to automatically safeguard power system infrastructure from damage during fault events.



As AEMO completes or makes substantial progress on each individual investigation, it will document the analysis, findings and any next steps in an informative public report on the subject, which would provide the basis for informed stakeholder engagement and feedback. As the number of reports grows, on a range of technical matters, this will collectively provide a clear picture of the challenges foreseen in operational timeframes, and how AEMO intends to manage them. The work will also inform some of the opportunities and scoping input to the long-term work-stream below.

7.6 AEMO long-term work-stream

The objective of the long-term work-stream is to identify and promote resolution of long-term technical challenges of operating the power system, to inform the need for policy, procedural, and regulatory changes.

Initially, the focus of this work-stream is on creating a clear list of technical challenges, which has been tested with industry stakeholders. AEMO has therefore formed an industry reference group – the Power System Implications Technical Advisory Group (PSI-TAG) – to provide input towards a comprehensive challenges list. PSI-TAG, which met for the first time in early December 2015, is convened by AEMO, and has nominated representatives from conventional generators, retailers, transmission and distribution businesses, the Clean Energy Council, the Standing Committee of Officials (SCO), the Australian Energy Market Commission (AEMC), and the Australian Energy Regulator (AER).

This process will provide a sound foundation for work on resolution of the highest priority challenges. Resolution of challenges could require modification to AEMO internal procedures, market mechanisms, or in some cases government policy, and could include service provision from parts of the network not currently overseen by AEMO, or indeed the NER. Other agencies could be better placed than AEMO to lead the resolution of some challenges, once they are identified and adequately described.

While the initial focus is on identifying challenges, if a high priority challenge is clearly articulated, appropriate bodies could take steps any time towards the development of regulatory change. Participation by SCO, AEMC and the AER on the PSI-TAG provides an ideal environment for such steps to be taken in a co-ordinated way.



MEASURES AND ABBREVIATIONS

Units of measure

Abbreviation	Unit of measure
\$	Australian dollar
Hz	Hertz
Hz/sec	hertz per second
MW	megawatt
MWs	megawatt-seconds

Abbreviations

Abbreviation	Expanded name
AC	Alternating current
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
AEST	Australian Eastern Standard Time
AGC	Automatic Generation Control
AUFLS	Automatic Under Frequency Load Shedding
DFIG	Double-fed induction generators
ESCOSA	Essential Services Commission of South Australia
FCAS	Frequency control ancillary services
FOS	Frequency operating standards
HVDC	High voltage direct current
NEM	National Electricity Market
NER	National Electricity Rules
NPS	Network service provider
OFGS	Over frequency generation shedding
OPWG	Operations Planning Working Group
PSI-TAG	Power System Implications Technical Advisory Group
PSO	Power system operations
PV	Photovoltaic
RCB	Regional Coordinating Body
RIT – T	Regulatory investment test – transmission
RMS	Root mean square
RoCoF	Rate of change of frequency
SA	South Australia
SCO	Standing Committee of Officials
TNSP	Transmission network service provider



GLOSSARY

Term	Definition
abnormal frequency island	A part of the power system that includes generation, networks and load for which all of its alternating current network connections with other parts of the power system have been disconnected, provided that the part does not include more than half of the generation of each of two regions (determined by available capacity before disconnection).
automatic generation control system (AGC)	The system into which the loading levels from economic dispatch will be entered for generating units operating on automatic generation control in accordance with NER clause 3.8.21(d).
automatic under frequency load shedding (AUFLS) scheme	An emergency control scheme in a region to automatically trip customer demand in a coordinated manner to arrest the fall in frequency following a contingency event.
Australian wind forecasting system (AWEFS)	A computerised system, used by AEMO to forecast the generation of scheduled and semi-scheduled wind farms.
constraint equation	The mathematical expression of a physical system limitation or requirement that must be considered by the central dispatch algorithm when determining the optimum economic dispatch outcome.
contingency event	An event affecting the power system which AEMO expects would be likely to involve the failure or removal from operational service of one or more generating units and/or transmission elements. (NER clause 4.2.3(a).)
contingency FCAS	Fast, Slow and Delayed raise and lower services used to manage frequency following a contingency event.
continuous uninterrupted operation	In respect of a generating system or operating generating unit operating immediately prior to a power system disturbance, not disconnecting from the power system except under its performance standards established under clauses S5.2.5.8 and S5.2.5.9 and, after clearance of any electrical fault that caused the disturbance, only substantially varying its active power and reactive power required by its performance standards established under clauses S5.2.5.11, S5.2.5.13 and S5.2.5.14, with all essential auxiliary and reactive plant remaining in service, and responding so as to not exacerbate or prolong the disturbance or cause a subsequent disturbance for other connected plant.
credible contingency event	Any outage that is reasonably likely to occur. Examples include the outage of a single electricity transmission line, transformer, generating unit, or reactive plant, through one or two phase faults. (NER clause 4.2.3(b))
electrical island	Part of the power system that includes generation, networks and load, for which all of its network connections with other parts of the power system have been disconnected, provided that the part does not include more than half of the generation of each of two regions (determined by available capacity before disconnection).
extreme frequency excursion tolerance limits	In relation to the frequency of the power system, means the limits so described and specified in the power system security standards.
frequency control ancillary services (FCAS)	Frequency control ancillary services (a type of market ancillary service) FCAS is split into two major components, contingency FCAS and Regulation FCAS (See Guide To Ancillary Services In The National Electricity Market: http://www.aemo.com.au/Electricity/Market-Operations/Ancillary-Services/Specifications-and-Standards/Market-Ancillary-Service-Specification)
frequency operating standards	Determined by the Reliability Panel and define the range of allowable frequencies for the power system while the load is being restored following a major power system incident.
generating system	A system comprising one or more generating units that includes auxiliary or reactive plant that is located on the generator's side of the connection point.
generating unit	The actual generator of electricity and all the related equipment essential to its functioning as a single entity.
generation	The production of electrical power by converting another form of energy in a generating unit.



Term	Definition
generator	A person who engages in the activity of owning, controlling or operating a generating system that is connected to, or who otherwise supplies electricity to, a transmission or distribution system and who is registered by AEMO as a generator under Chapter 2 (of the Rules) and, for the purposes of Chapter 5 (of the Rules), the term includes a person who is required to, or intends to register in that capacity.
Heywood interconnector	The double circuit alternating current interconnection between the Victorian and South Australian regions.
inertia	Produced by synchronous generators, inertia dampens the impact of changes in power system frequency, resulting in a more stable system. Power systems with low inertia experience faster changes in system frequency following a disturbance, such as the trip of a generator. Electrical inertia is measured in MW seconds (MWs).
interconnector	A transmission line or group of transmission lines that connects the transmission networks in adjacent regions.
Island	Either an electrical island or an abnormal frequency island.
market customers	A Customer who has classified any of its loads as a market load and who is also registered by AEMO as a Market Customer under Chapter 2.
Murraylink interconnector	The high voltage direct current interconnection between the Victorian and South Australian regions.
National Electricity Law	The National Electricity Law (NEL) is a schedule to the National Electricity (South Australia) Act 1996, which is applied in other participating jurisdictions by application acts. The NEL sets out some of the key high-level elements of the electricity regulatory framework, such as the functions and powers of NEM institutions, including AEMO, the AEMC, and the AER.
National Electricity Market (NEM)	The wholesale exchange of electricity operated by AEMO under the Rules.
National Electricity Rules (NER)	The National Electricity Rules (NER) describes the day-to-day operations of the NEM and the framework for network regulations. See also National Electricity Law.
network service provider	A person who engages in the activity of owning, controlling or operating a transmission or distribution system and who is registered by AEMO as a Network Service Provider under Chapter 2.
non-credible contingency event	A contingency event other than a credible contingency event. Without limitation, examples of non-credible contingency events are likely to include: <ul style="list-style-type: none"> • Three phase electrical faults on the power system; or • Simultaneous disruptive events such as: • Multiple generating unit failures; or • Double circuit transmission line failure (such as may be caused by tower collapse). (NER clause 4.2.3(e)).
non-scheduled generation	A generating unit with a nameplate rating of less than 30 MW (part of a group of generating units connected at a common connection point with a combined nameplate rating of 30 MW) unless AEMO has approved its classification as scheduled or semi-scheduled.
operational consumption	The electricity used by residential, commercial, and large industrial consumers, supplied by scheduled, semi-scheduled and significant non-scheduled generating units at a specific point in time measured in MW
over frequency generation shedding (OFGS) scheme	An emergency control scheme in a region to automatically trip generation in a coordinated manner to arrest the rise in frequency following a separation event at times of high import into the region.
power system operations (PSO) procedures	Internal procedures used in by AEMO real time operators to manage power system security and reliability.
reactive energy	A measure, in varhour (varh), of the alternating exchange of stored energy in inductors and capacitors, which is the time-integral of the product of voltage and the out-of-phase component of current flow across a connection point.



Term	Definition
reactive power	<p>The rate at which reactive energy is transferred. Reactive power, which is different to active power, is a necessary component of alternating current electricity.</p> <p>In large power systems it is measured in MVar (1,000,000 volt-amperes reactive). It is predominantly consumed in the creation of magnetic fields in motors and transformers and produced by plant such as:</p> <ul style="list-style-type: none"> • Alternating current generators. • Capacitors, including the capacitive effect of parallel transmission wires. • Synchronous condensers. <p>Management of reactive power is necessary to ensure transmission network voltage levels remains within required limits, which is in turn essential for maintaining power system security and reliability</p>
registered participant	<p>A person who is registered by AEMO in any one or more of the categories listed in rules 2.2 to 2.7 (in the case of a person who is registered by AEMO as a Trader, such a person is only a Registered Participant for the purposes referred to in rule 2.5A). However, as set out in clause 8.2.1(a1), for the purposes of some provisions of rule 8.2 only, AEMO, Connection Applicants, Metering Providers and Metering Data Providers who are not otherwise Registered Participants are also deemed to be Registered Participants.</p>
region	<p>An area determined by the AEMC in accordance with Chapter 2A (of the Rules), being an area served by a particular part of the transmission network containing one or more major load centres of generation centres or both.</p>
regulation FCAS	<p>Regulation raise and lower services used to manage continuous changes to frequency</p>
regulatory investment test – transmission (RIT-T)	<p>The test developed and published by the AER in accordance with clause 5.6.5B, including amendments.</p> <p>The test is to identify the most cost-effect option for supplying electricity to a particular part of the network. It may compare a range of alternative projects, including, but not limited to, new generation capacity, new or expanded interconnection capability, and transmission network augmentation within a region, or a combination of these.</p>
rooftop photovoltaic (PV)	<p>Includes both residential and commercial photovoltaic installations that are typically installed on consumers' rooftops</p>
satisfactory operating state	<p>In relation to the power system, has the meaning given in clause 4.2.2.</p>
scheduled generation	<p>A generating unit which has a nameplate rating of 30 MW or greater or is part of a group of generating units connected at a common connection point with a combined nameplate rating of 30 MW unless AEMO has approved its classification as semi-scheduled or non-scheduled.</p>
secure operating state	<p>The power system is in a secure operating state if, in AEMO's reasonable opinion, the power system is in a satisfactory operating state, and the power system will return to a satisfactory operating state following the occurrence of any credible contingency event. (NER clause 4.2.4)</p>
semi-scheduled generation	<p>A generating unit which has a nameplate rating of 30 MW or greater or is part of a group of generating units connected at a common connection point with a combined nameplate rating of 30 MW or greater, where the output of the generating unit is intermittent unless AEMO has approved its classification as scheduled or non-scheduled.</p>
separation event	<p>A contingency event in relation to a transmission element that forms an island.</p>
synchronous generation	<p>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.</p>
underlying consumption	<p>The electricity used by residential, commercial, and large industrial consumers supplied from all sources (including local rooftop PV)</p>
wind turbine types	<p>Type 1 - induction generator – fixed speed. Type 2 - wound-rotor induction generator with adjustable external rotor resistance – variable slip. Type 3 - double-fed induction generators (DFIG) – variable speed. Type 4 - full converter system with permanent magnet synchronous generator – variable speed.</p>