RELIABILITY PANEL AEMC

REVIEW

Reliability Panel AEMC

ISSUES PAPER

Review of the Frequency Operating Standard

14 July 2017

Submissions due 1 August 2017. Reference: REL0065 Issues Paper

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About the Reliability Panel

The Panel is a specialist body within the Australian Energy Market Commission (AEMC) and comprises industry and consumer representatives. It is responsible for monitoring, reviewing and reporting on reliability, security and safety on the national electricity system, and advising the AEMC in respect of such matters. The Panel's responsibilities are specified in section 38 of the National Electricity Law.

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1 Introduction

1.1 Purpose

Under the National Electricity Rules (NER), the Reliability Panel (Panel) is responsible for determining the power system security standards, including the frequency operating standards (FOS) that apply to the National Electricity Market (NEM).[1] The Reliability Panel has been directed by the Australian Energy Market Commission (AEMC) to undertake a review of the FOS that apply to the NEM mainland and Tasmania.

The purpose of this paper is to explain the role and function of the FOS, to seek stakeholder comment on the content of the FOS and the Panel's proposed approach for assessing them.

1.2 Review of Frequency Operating Standard

NER clause 8.8.1(a)(2) requires the Reliability Panel to review and, on the advice of the Australian Energy Market Operator (AEMO), determine the power system security standards. These standards govern the maintenance of system security and reliability in the NEM; at present the only power system security standards that apply in the NEM are the FOS for the mainland NEM and for Tasmania. The FOS define the range of allowable frequency for the power system under different conditions, including normal operation and following contingency events.

The FOS include defined frequency bands and timeframes in which the system frequency must be restored following different events, such as the failure of a transmission line or separation of a region from the rest of the NEM. These requirements then inform how AEMO operates the power system, including through applying constraints to the dispatch of generation or procuring ancillary services.

The FOS also defines the frequency bands and timeframes which are referred to by the performance standards that apply to generator and network equipment in the NEM. In combination with the FOS, these performance standards align the power system frequency managed by AEMO with the capability of NEM power system equipment, including generating and network systems.

The FOS does not set out the specific arrangements for how frequency is managed, such as the arrangements for generation and load shedding and the specification and procurement of Frequency Control Ancillary Services (FCAS).

The current FOS for the NEM Mainland are set out in appendix B and for Tasmania in appendix C.

1.3 Terms of reference

On 30 March 2017, the AEMC provided Terms of Reference to the Panel to initiate a review of the FOS (the Review).

Among other things, the Terms of Reference require the Panel to give consideration to:

1 Clause 8.8.3(a)(1) of the NER.

- Whether the terminology, standards and settings in the FOS remain appropriate.
- What amendments to the Standard may be necessary in light of the AEMC's final determination of the Emergency frequency control schemes (EFCS) rule change published on 30 March 2017.
- Whether further guidance can be provided regarding the definition of what part of the power system the FOS is to be applied following separation from the rest of the NEM. Specifically, whether the FOS should refer to a separated region, or some smaller subsection of a region, for maintenance of frequency following a separation event.

The Panel is required to complete its Review by 22 December 2017.

The Terms of Reference for this Review can be seen in Appendix A.

1.4 Timetable for the Review

In carrying out this review, the Panel will follow a consultation process that is consistent with clause 8.8.3 of the NER and the Terms of Reference. The Panel will consult with stakeholders through seeking submissions on this issues paper and a subsequent draft report. The Panel will also carry out face to face meetings and a public forum may be arranged as required at the request of stakeholders.

The Panel is proposing to complete this review in a staged manner. These two stages of the review will be commenced at different times and will cover different subject matter. This staged approach reflects the various ongoing reviews of market and regulatory arrangements that are likely to have an impact on the Panel's ability to effectively assess the FOS.

Stage 1 of the Review will consider what amendments to the FOS may be necessary in light of the recent emergency frequency control scheme rule change, . which includes the introduction of the protected event contingency category made in the recent emergency frequency control schemes rule change.[2] Furthermore, there are a number of technical changes to the FOS that can be assessed immediately. Stage 1 of the review will commence with the publication of this issues paper.

Stage 2 of the Review will include a general consideration of the various components of the FOS, including the settings of the frequency bands and time requirements for maintenance and restoration of system frequency.

The Panel's ability to meaningfully and effectively progress stage 2 will require it to assess the costs and benefits associated with making changes to the settings of the FOS. However, this assessment will depend on the progression of a number of ongoing reviews of the market and regulatory frameworks that are relevant to the settings of the FOS bands and timeframes.

Firstly, the AEMC's *System security market frameworks review* has proposed new requirements for system inertia and fast frequency response services. The associated draft rule determination, *Managing the rate of change of power system frequency* sets out the

2 AEMC, Emergency frequency control schemes, Rule Determination, 30 March 2017.

Commission's approach for minimum inertia requirements associated with maintaining system security to be provided by Transmission network service providers (TNSPs).[3]

Secondly, the *System security market frameworks review* has also identified further changes to be considered by the AEMC through its subsequent *Frequency control frameworks review*. The *Frequency control frameworks review* was initiated on 7 July 2017 and includes consideration of:[4]

- whether mandatory governor response requirements should be introduced
- whether existing frequency control arrangements remain fit for purpose and whether the FCAS markets are appropriately structured.

In addition, AEMO's *Future power system security work program* includes a focus area looking at addressing current and future challenges related to frequency control in the NEM. One such issue is frequency control and the effectiveness of ancillary services at providing frequency control.

To inform this work program, AEMO convened the Ancillary Services Technical Advisory Group (AS-TAG), to bring together technical experts from the power industry to investigate solutions for current and future issues relating to ancillary services. Frequency monitoring data presented to AS-TAG has shown that in recent years, system frequency has become less tightly held to 50Hz within the normal operating frequency band (49.85Hz to 50.15Hz).

AEMO has commissioned the specialist power system consulting firm, DIgSILENT, to investigate the cause(s) and consequences of this degraded frequency performance. It is currently anticipated that the findings of this investigation will be presented to the AS-TAG in August 2017.

The Panel considers that these two pieces of work will shed further light on issues that will be relevant to any review of the FOS and may result in changes (or recommendations for) to the market and regulatory frameworks that will need to be incorporated and/or reflected in the FOS. Accordingly, until these issues and possible framework changes are sufficiently progressed, it is not possible for the Panel to meaningfully or effectively assess their implications for the FOS.

For this reason, the Panel will commence stage 2 of the FOS review at a later date when the above work programs have been further progressed. As part of its considerations in stage 1, the Panel will map out the various market framework changes to be considered, and their potential implications for the FOS, for further assessment in stage 2. At this stage the Panel anticipates that Stage 2 of the Review will be completed before mid 2018.

Table 1.1 Timetable for the review

Milestone	Proposed Date
Publication of Issues Paper	11 July 2017

3 AEMC, *Managing the rate of change of power system frequency*, Draft rule determination, 27 June 2017, p.ii.

4 See: http://www.aemc.gov.au/Markets-Reviews-Advice/Frequency-control-frameworks-review

Milestone	Proposed Date
Close of submissions to Issues Paper	1 August 2017
Publication of Draft Determination and Standard – Stage 1	29 August 2017
Close of submissions to Draft Determination – Stage 1	26 September 2017
Publication of Final Determination and Standard– Stage 1	31 October 2017

1.5 Submissions

The Panel invites written submissions on this Review and issues paper from interested parties by no later than 1 August 2017. All submissions received will be published on the AEMC's website (www.aemc.gov.au), subject to any claims for confidentiality.

Electronic submissions must be lodged online through the AEMC's website using the link entitled "lodge a submission" and reference code "REL0065". The submission must be on letterhead (if submitted on behalf of an organisation), signed and dated.

Upon receipt of electronic submissions, the AEMC's website will issue a confirmation email. If this confirmation email is not received within three businesses days, it is the submitter's responsibility to ensure the submission has been delivered successfully.

If choosing to make submissions by mail, the submission must be on letterhead (if submitted on behalf of an organisation), signed and dated. The submission may be posted to:

Reliability Panel
PO Box A2449
Sydney South NSW 1235
Or by Fax to (02) 8296 7899.

1.6 Structure of the paper

The remainder of this Issues Paper is structured as follows:

- Chapter 2 describes the background for this review.
- Chapter 3 sets out the approach and assessment criteria the Panel proposes to use in examining the FOS, including the rationale for staging the review.
- Chapter 4 examines the key issues to be considered when determining the FOS and invites stakeholder feedback on the questions enclosed.

2 Background

The chapter sets out the background for the review. This chapter examines:

- Section 2.1: the role of the FOS in the NEM
- Section 2.2: the elements of the FOS
- Section 2.3: the governance and institutional arrangements for the frequency control in the NEM
- Section 2.4: observed changes to the NEM frequency distribution profile

A general description of the power system frequency and the principles for frequency is controlled is included for reference in appendix D.

2.1 The role of the FOS in the NEM

The purpose of the frequency operating standards is to define the range of allowable frequencies for the electricity power system under different conditions, including normal operation and following contingencies. Generator, network and end-user equipment must be capable of operating within the range of frequencies defined by the frequency operating standards, while AEMO is responsible for maintaining the frequency within the ranges defined by these standards.

This section outlines the role of the FOS in the NEM and the regional characteristics that relate to the management of system security and power system frequency.

2.1.1 What is the role of the FOS?

The NER allows for the development of power system security standards which define the regulatory arrangements for power system security in the NEM.[5]However, to date the only power system security standards are the FOS for the NEM mainland and for Tasmania.

The FOS sets out the frequency limits within which AEMO operates the power system. This includes defined frequency bands and timeframes in which the system frequency must be restored following different events, such as the failure of a transmission line or separation of a region from the rest of the NEM.

The frequency bands defined in the FOS are also used to define the operating range for power system equipment, including generation equipment, transmission and distribution equipment and consumer equipment. The frequency requirements that form part of a generator and network performance standards are discussed in further detail in section 2.3.4.

Using the frequency control methods described in section 2.3, AEMO then operates the power system in accordance with the FOS.

5 The power system security standards are defined in chapter 10 of the NER: "The standards (other than the reliability standard and the system restart standard) governing power system security and reliability of the power system to be approved by the Reliability Panel on the advice of AEMO, but which may include but are not limited to standards for the frequency of the power system in operation and contingency capacity reserves (including guidelines for assessing requirements).

2.1.2 Regional characteristics of the NEM

There are currently two separate frequency operating standards defined for the NEM: one for the mainland NEM, and one for Tasmania. This reflects the regional network characteristics of the Tasmanian region as opposed to the mainland NEM.

The power system frequency is common throughout the mainland interconnected transmission network, with frequency centrally controlled during normal operation and the impact and response to frequency disturbances spread throughout the network and the corresponding market participants.

Tasmania is connected to the NEM via Basslink, an HVDC undersea cable. This cable allows power transfer between the mainland NEM and Tasmania but does not transfer the AC frequency between the two regions. As a result Tasmanian power system operates at its own electrical frequency, separate from the mainland NEM.

The NEM electricity transmission network

The mainland NEM transmission network incorporates the interconnected regions of Queensland, New South Wales, Victoria and South Australia with a combined installed generation capacity of over 45 Giga-Watt (GW). Across the NEM as a whole there is a wide diversity of generation that is distributed throughout a meshed network that delivers inbuilt redundancy and stability.[6] The transmission network and regional boundaries for the NEM are shown in Figure 2.1.

Due to the historical development of the transmission network, there are only a limited number of electrical interconnectors between the NEM regions. These interconnectors provide economic, security and reliability benefits by increasing the overall size of the generation pool available to supply demand and increasing the overall inertia of the interconnected power system.[7] However, interconnectors create security risks of their own, especially where the number of transmission circuits is small and there is a potential for the failure of the interconnector. Such an interconnector failure may lead to the separation of the connected regions, with the smaller separated region then referred to as an "electrical island".

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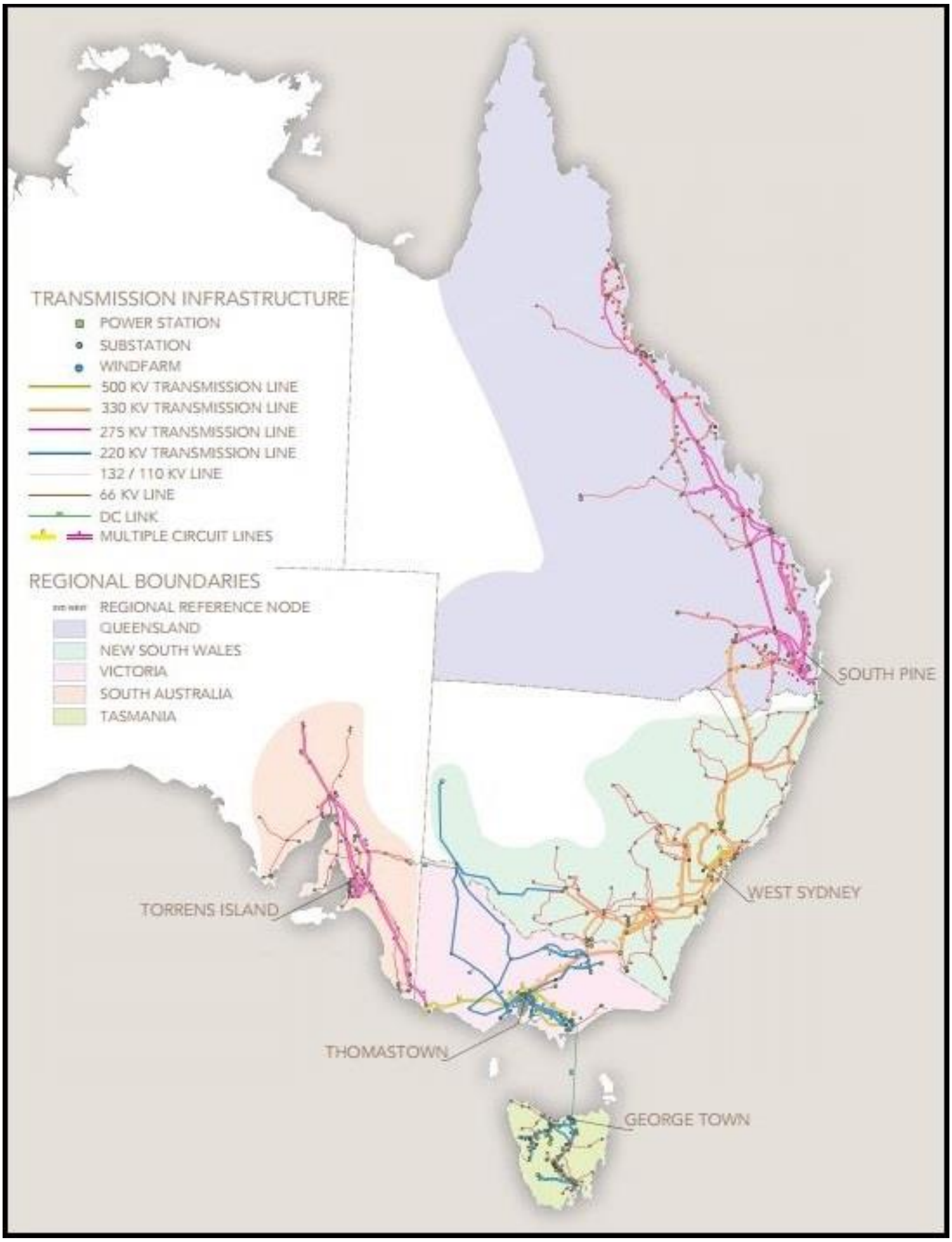
6 AEMO, May 2017,51% of large scale generation capacity in the NEM is coal fired, 23% gas fired, 16% hydro power, 8% from wind and 2% other sources. AEMO, May 2017. See: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Generation-information)

7 AEMO, 2016, *National Transmission Network Development plan*, p.6.

Figure 2.1 NEM transmission network



This is the case for the Heywood interconnector that provides a double circuit alternating current (AC) connection between South Australia and Victoria. When the Heywood interconnector is operating, the high levels of inertia in the broader power system assist in maintaining system security in South Australia. However, when the interconnector is affected by an outage, risks to power system security increase significantly. This is in part due to the sudden change in load immediately following the separation. In addition, high import through the Heywood interconnector at the time of the outage is likely to be correlated with fewer synchronous generating units operating in South Australia and therefore lower system inertia in that region.

The FOS includes specific standards that specify the required frequency performance of an island system. The modes of operation covered in the FOS, including operation of an island system, are discussed in section 2.2.1.

Tasmania and the NEM

Tasmania joined the NEM in May 2005, following the construction of the Basslink which joined the Tasmania power grid to the mainland NEM. While the Basslink cable allows two way power transfers between Tasmania and the mainland NEM the direct current technology is asynchronous, which means that the frequency in each of the two regions can be different. As a result the regions continue to operate within the NEM as separate regions with respect to power system frequency.

The Tasmanian power system differs significantly from that of the NEM mainland in that it:

- with 3 GW of installed generation capacity, is relatively small in overall size
- has relatively large load, generator and network contingencies, as a proportion of the total system size
- is predominantly supplied by hydro generating units, which are inherently strong and relatively capable of tolerating frequency disturbances
- can have a relatively low inertia, particularly when Tasmanian demand is low and local supply is dominated by wind power and/or imports of energy via Basslink[8]
- experiences shortages of fast acting FCAS because of the relatively slow response of hydro generators to frequency disturbances.

Due to these characteristics, frequency control within narrow tolerances is relatively difficult in Tasmania; however the dominance of hydro generation and its ability to withstand wider frequency deviations has meant that historically this situation has been a non-issue.[9]

2.2 The elements of the frequency operating standard

The FOS incorporates a range of criteria that establish the frequency performance in the NEM for a range of operating conditions. The elements of the FOS include:

- sets of frequency bands that apply to special modes of power system operation, such as an “island system” and “during supply scarcity”
- the range of allowable frequencies in bands corresponding to the operating state of the power system, such as whether a contingency event has occurred
- times for the stabilisation and recovery of the power system frequency following a frequency deviation as a result of a contingency event

8 As Basslink operates via a direct current power transfer it does not transfer inertia between the mainland NEM and Tasmania.

9 State of Tasmania, Electricity Supply Industry Expert Panel, 2001, Technical Parameters of the Tasmanian Electricity Supply System, p. 24.

- the accumulated time error which is allowed in the NEM, which is related to the historical nature of some clocks that operate based on the frequency of the power system.

Each of these elements of the FOS is described in more detail below.

2.2.1 Power system modes

The FOS includes a set of frequency bands that apply for each of the following power system modes:

- interconnected system
- island system
- during supply scarcity (NEM Mainland only)

Each of these modes is described below.

Interconnected system

The FOS for Tasmania and the mainland NEM include a base case for normal operation as an interconnected system. Under this set of conditions all regions covered by the particular FOS are electrically interconnected and the power system frequency is common throughout that system.[10]

Island system

Separate frequency settings for an island system are included in the FOS for both the mainland and Tasmania. An island system refers to an electrical island that may form as a result of a separation event. The definition of the term "electrical island" in the FOS for the mainland is:

> "a 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)."

An example of a set of events that may lead to the formation of an electrical island, is the failure of both circuits of the Heywood interconnector between South Australia and Victoria at the same time, resulting in South Australia becoming an electrical island, separate to the rest of the NEM.

For an island system that occurs within the mainland NEM, the normal operating frequency band becomes 49.5 to 50.5 Hz and the operational frequency tolerance band becomes 49.0 to 51.0 Hz. For an island system that occurs within Tasmania, the normal operating band becomes 49.0 to 51.0 Hz and the operational frequency tolerance band becomes 48.0 to 52.0 Hz.

During supply scarcity

10 The failure of Basslink is not considered a "separation event" for the purpose of the FOS, as the NEM mainland and Tasmania are independent in terms of frequency.

In 2008 following significant blackouts that affected Victoria during the 2007 bushfire season, the reliability panel amended the FOS for the mainland NEM to include separate arrangements for when the power system is in a state of supply scarcity.

A situation of supply scarcity is defined by the FOS as applying when there has been either manual or automatic load disconnection and that load is yet to be reconnected.

The intent of this variation of the FOS for the mainland NEM is to allow for more generation capacity to be targeted towards restoration of load by reducing the amount of reserve generation required to be set aside for managing contingency events during the restoration process. The result of this approach is that the time to restore the power system can be reduced, while the additional risk associated with the reduction of contingency reserve is considered to be minor.[11]

This applies to the mainland NEM only, not for Tasmania; as the advice provided by NEMMCO at the time did not recommend any change to the Tasmanian FOS on account of supply scarcity.[12] Such an approach in Tasmania was seen as unnecessarily increasing the risk of a further cascading outage.[13]

2.2.2 Frequency Bands and recovery times

The FOS defines the frequency bands and recovery times that apply for NEM operation, during normal operation and in response to contingency events. These frequency bands include the following terms defined in the NER:

- normal operating frequency band
- normal operating frequency excursion band
- operational frequency tolerance band
- extreme frequency excursion tolerance limit

The frequency bands that are outside the normal operating band allow for the operation of the power system within a wider range of frequency following contingency events. The stabilisation and recovery times limit the amount of time that AEMO can allow the system to operate in that wider band. Below is a description of each of the frequency bands within the FOS. The existing FOS for the mainland NEM is included in appendix B and the existing FOS for Tasmania included in appendix C.

Normal operating frequency band and normal operating frequency excursion band

The normal operating frequency band and normal operating frequency excursion band define the allowable power system frequency under the condition that all major system elements are operating as expected.

The current requirement in the FOS for the mainland NEM and for Tasmanian is that, for 99%of the time, the power system is maintained within the range of 49.85 –

11 Reliability Panel, 15 April 2008, *Application of Frequency Operating Standards during periods of Supply Scarcity*, pp.13-14.

12 NEMMCO was the market operator prior to the formation of AEMO on 1 July 2009.

13 Ibid. p.2.

50.15Hz.[14] During normal operation, in the absence of a contingency or load event, there is an allowance for brief excursions outside this band, but within the normal operating excursion band of 49.75 - 50.25 Hz. Under these conditions, if the power system frequency deviates outside the normal operating frequency band, it must be returned to the normal operating frequency band within 5 minutes.

Operational frequency tolerance band

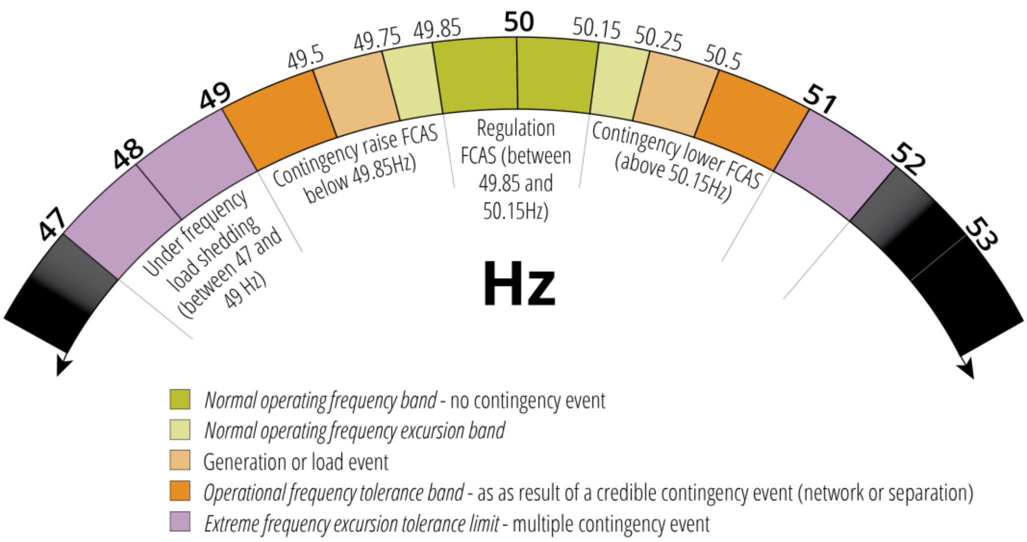
The operational frequency tolerance band defines the range of allowable power system frequencies in the event of a credible contingency event such as the failure of a single generation or network element. The current FOS for the NEM mainland and Tasmania define different frequency boundaries that apply for different types of contingency events as described in box 2.

Extreme frequency excursion tolerance limit

The extreme frequency excursion tolerance limit sets the upper and lower limits within which generation and network elements are expected to be able to operate.[15] If the power system frequency exceeds this limit it is considered to be an abnormal condition, and automatic protection mechanisms commence activation to disconnect network and generation elements to limit equipment damage.

Figure 2.2 and Figure 2.3 display frequency settings defined by the frequency operating standard for the Mainland NEM and Tasmania respectively. These figures display the frequency bands for normal operation, along with the operating bounds that apply in the event of contingency events. The figures also show the frequency ranges within which FCAS and under-frequency load shedding schemes will operate.

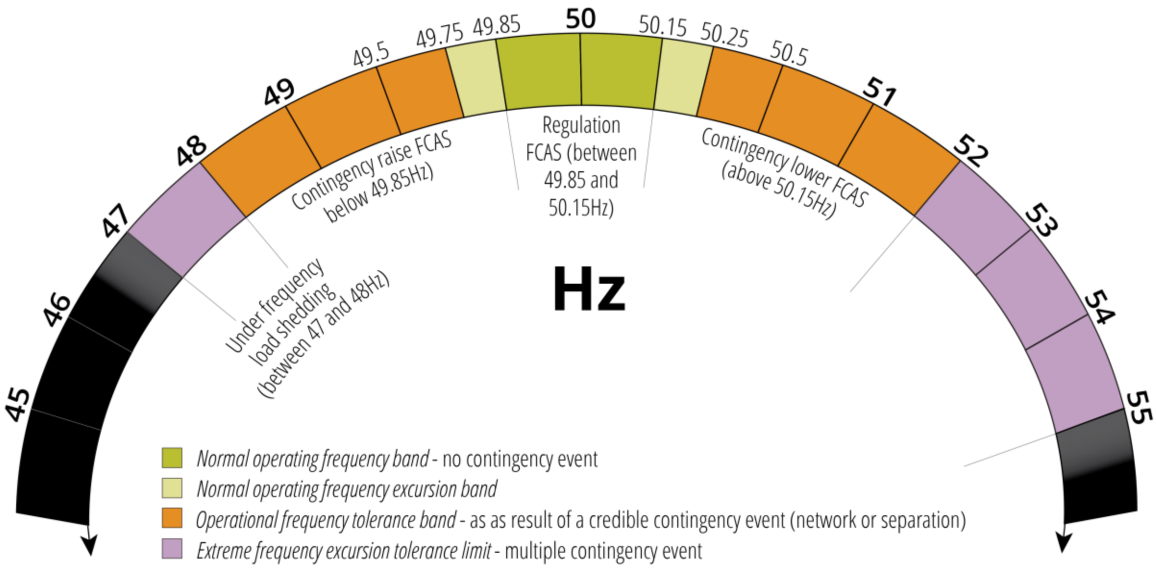
Figure 2.2 Frequency bands - Mainland NEM



14 Over any 30 day period

15 S5.1.3 of the NER states that "A Network Service Provider must ensure that within the extreme frequency excursion tolerance limits all of its power system equipment will remain in service unless that equipment is required to be switched to give effect to manual load shedding in accordance with clause S5.1.10, or is required by AEMO to be switched for operational purposes or is required to be switched or disconnected for operation of an emergency frequency control scheme."

Figure 2.3 Frequency bands - Tasmania



The operational frequency tolerance band for Tasmania at 48Hz – 52Hz is wider than that for the mainland NEM at 49Hz – 51Hz. This is due to the wider tolerance of Tasmanian generators to frequency variations and the intention at the time the standard was set to limit the cost of FCAS procurement.[16]

Similarly the upper end of the extreme frequency tolerance band for of 47Hz – 55Hz is significantly higher for Tasmania than the 52Hz in the mainland NEM. Again this is related to the wider tolerance of Tasmanian generators to frequency variations.

Box 2.1 Generation, network and load contingency events in the FOS

In recognition that different types of system events may result in different severity of system disturbance, the FOS differentiates between different types of credible contingency events such as a generation event, a load event or a network event. The definitions provided in the FOS for the mainland, for each of these events are as follows:

16 This issue was discussed by the Panel in its determination of the Tasmanian FOS, where the Panel stated that "aligning the Tasmanian frequency operating standards with those that apply on the NEM mainland would be significantly more difficult, and costly,[…] due to the very large quantities of contingency FCAS that would be required. Such large quantities of FCAS are unlikely to be available at a reasonable cost in Tasmania for the foreseeable future. Therefore, the Panel did not consider aligning the Tasmanian frequency operating standards with those of the NEM mainland as appropriate." AEMC Reliability Panel, 18 December 2008, *Tasmanian Frequency Operating Standard Review* – Final Report., pp17-18. For similar reasons the FOS for Tasmania also includes a limit on the maximum generation contingency size of 144MW. Ibid. p. 22.

A **generation event** is “a *synchronisation* of a *generating unit* of more than 50 MW or a *credible contingency*, not arising from a *network event*, a *separation event* or a part of a *multiple contingency event*.”[17]

A **load event** is “an identifiable connection or disconnection of more than 50 MW of customer load (whether at a *connection point* or otherwise), not arising from a *network event*, a *generation event*, a *separation event* or a part of a *multiple contingency event*.”[18]

A **network event** is “a *credible contingency* event other than a *generation event*, a *separation event* or a part of a *multiple contingency event*.”[19]

A **separation event** is "a *credible contingency* in relation to a *transmission element* that forms an *island*."

A **multiple contingency event** “means either a *contingency event* other than a *credible contingency event*, a sequence of *credible contingency events* within a period of 5 minutes, or a further *separation event* in an *island*.”

Table 2.1 and Table 2.2 show the current frequency band settings in the FOS for the NEM mainland and Tasmania (interconnected system).

17 This is commonly interpreted to mean: a credible contingency event relating to the failure or disconnection, of a generating unit of more than 50MW. Note that the definition of a generation event in the FOS for Tasmania is worded slightly differently as: “a *synchronisation* of a *generating unit* of more than 50 MW or a *credible contingency* event in respect of either a single *generating unit* or a *transmission element* solely providing *connection* to a single *generating unit*, not arising from a *network event*, a *separation event* or a part of a *multiple contingency event*.”

18 The definition of a load event in the FOS for Tasmania is defined differently as: “either an identifiable increase or decrease of more than 20 MW of customer load (whether at a *connection point* or otherwise), or a rapid change of flow by a *high voltage* direct current interconnector to or from 0 MW for the purpose of starting, stopping or reversing its power flow, not arising from a *network event,* a *generation event*, a *separation event* or a part of a *multiple contingency event*.” This is interpreted to mean an identifiable increase or decrease of more than 20MW of customer load or a rapid change of flow by a high voltage DC interconnector to or from 0MW for the purpose of starting, stopping or reversing its power flow.

19 A network event may include “the unexpected *disconnection* of one major item of *transmission plan*t (e.g. *transmission line*, *transformer* or *reactive plant*) other than as a result of a three phase electrical fault anywhere on the *power system*.” as described in cl.4.2.3(b)(2) of the NER.

Table 2.1 Current NEM Mainland frequency operating standards - interconnected system

Condition	Containment (Hz)	Stabilisation	Recovery
no contingency event or load event	49.85 to 50.15 Hz – 99% of the time		
	49.75 to 50.25 Hz	49.85 to 50.15 Hz within 5 minutes	
generation or load event	49.5 to 50.5 Hz	49.85 to 50.15 Hz within 5 minutes	
network event	49.0 to 51.0 Hz	49.5 to 50.5 Hz within 1 minute	49.85 to 50.15 Hz within 10 minutes
separation event	49.0 to 51.0 Hz	49.5 to 50.5 Hz within 2 minutes	49.85 to 50.15 Hz within 10 minutes
multiple contingency event	47.0 to 52.0 Hz	49.5 to 50.5 Hz within 2 minutes	49.85 to 50.15 Hz within 10 minutes

Table 2.2 Current Tasmanian frequency operating standards - interconnected system

Condition	Containment (Hz)	Stabilisation	Recovery
no contingency event or load event	49.85 to 50.15 Hz – 99% of the time	49.85 to 50.15 Hz within 5 minutes	
	49.75 to 50.25 Hz		
generation or load event	48.0 to 52.0 Hz	49.85 to 50.15 Hz within 10 minutes	
network event	48.0 to 52.0 Hz	49.85 to 50.15 Hz within 10 minutes	
separation event	47.0 to 55.0 Hz	48.0 to 52.0Hz within 2 minutes	49.85 to 50.15 Hz within 10 minutes
multiple contingency event	47.0 to 55.0 Hz	48.0 to 52.0Hz within 2 minutes	49.85 to 50.15 Hz within 10 minutes

2.2.3 Accumulated time error

Historically, certain clocks operated as synchronous machines, relying on an accurate power system frequency in order to measure time accurately. These synchronous clocks were common between 1940 and 1980.[20] Synchronous clocks are sensitive to power

20 From 1980 onwards the quartz method of time keeping largely replaced synchronous clocks. Some consumer electronic appliances, such as ovens, still use the power system frequency to keep time.

system frequency and after a period of low system frequency will read time as "slow" when compared to a reference time such as Coordinated Universal Time.[21]

In order to correct this time error, AEMO runs the power system marginally faster than the nominal frequency for a period of time to reduce the accumulated time error. AEMO operates the system to limit the accumulated time error subject to a maximum level defined in the FOS. The existing accumulated time error limits are:

- 5 seconds for the mainland NEM
- 15 seconds for Tasmania.

The previous reviews of the FOS for Tasmania and the mainland NEM by the Reliability Panel in 2008 and 2009 left the relevant accumulated time error settings unchanged. However the 2001 review of the FOS considered the appropriateness of a tight time error standard and determined that the accumulated time error standard for the mainland NEM be increased from 3 seconds to 5 seconds. In addition the 2001 review recognised that it was appropriate to make an exception to this accumulated time error requirement following a separation event where an island is formed.[22]

The Panel is aware that the need for time error correction is being reviewed by some international power system operators, such as the North American Electric Reliability Corporation (NERC). In 2015 NERC completed a review of the benefits of time error correction and published white paper which recommended that manual time error correction be eliminated. This advice was based on NERC's assessment that time error correction does not support or enhance reliability.[23]

2.3 Frequency control in the NEM

Section 2.3.1describes how the FOS relates to AEMO's responsibility for maintaining the satisfactory and secure operation of the power system.

The subsequent sections describe other elements of the regulatory framework that relate to frequency control and to the settings in the FOS:

- Section 2.3.2 describes the role of frequency control ancillary services in regulating the power system frequency and providing a capability to respond to contingencies.
- Section 2.3.3 describes the role of emergency frequency control schemes that AEMO coordinate to provide fast acting capability to rebalance the power system following extreme system events.
- Section 2.3.4 describes how the FOS relates to the technical performance standards for generators and networks.

21 Coordinated Universal Time or UTC is the current international standard for time keeping.

22 In the case of a separation event, "the standards incorporate a provision to reset electrical time rather than delay reconnection purely to allow time error in the separate parts to be aligned." NECA Reliability Panel, September 2001, Frequency operating standards – Determination, p.13.

23 NERC, September 2015, T*ime Error Correction and Reliability White Paper*

2.3.1 Managing frequency and power system security

An operational power system must be able to operate satisfactorily under a range of operating conditions including in the event of foreseeable contingency events, such as the failure of a single transmission element or generator. In the NEM, AEMO is responsible for maintaining the power system in a "secure operating state" by satisfying the following two conditions:

1. The system parameters, including frequency, voltage and current flows are within the operational limits of the system elements, referred to as a "satisfactory operating state"
2. The system is able to recover from a credible contingency event or a protected event, in accordance with the power system security standards.[24]

Frequency control is a key element of power system security. This is reflected in the NER definition of a "satisfactory operating state", which includes a direct reference to the frequency bands defined in the FOS:

> "The power system is defined as being in a satisfactory operating state when:
>
> the frequency at all energised busbars of the power system is within the normal operating frequency band, except for brief excursions outside the normal operating frequency band but within the normal operating frequency excursion band."[25]

AEMO is primarily responsible for maintaining the power system in a "secure operating state" which includes managing the power system frequency in accordance with the FOS.

Box 2.2 Initial rate of change of frequency and system inertia

The initial ability of the power system to resist large changes in frequency arising from the loss of a generator, transmission line or large industrial load is initially determined by the inertia of the power system. Inertia is naturally provided by large spinning synchronous generators that are synchronised to the frequency of the system. The physical inertia provided by the large rotating masses in synchronous generators dampens the effects of any sudden imbalances in supply and demand on frequency. Put another way, more inertia in the power system acts to reduce the initial rate of change of frequency in response to power system disturbances.[26]

24 NER cl 4.2.4(a) - Secure operating state and power system security

25 NER cl 4.2.2(a) – Satisfactory Operating State

26 Synchronous generators are large units that have rotors that are directly electro-mechanically linked to the power system and spin at a speed that corresponds to the frequency of the power system. Because the mechanical energy of a synchronous generator is directly related to the frequency of the power system, they can typically provide what is known as inertia – that is, when the frequency of

Historically, most generating units in the NEM have been synchronous and, as such, the inertia provided by these generators has not been separately valued. As the generation mix shifts to smaller and more non-synchronous generation however, inertia is not necessarily provided as a matter of course giving rise to increasing challenges for AEMO in maintaining the power system in a secure operating state.

A requirement for an operating level of inertia in the power system to help manage the rate of change of frequency was one of the areas of focus for the AEMC's *System Security Market Frameworks Review*, which is discussed further in section 3.2.1.

2.3.2 Frequency Control Ancillary Services

During normal operation of the power system AEMO uses FCAS to control the power system frequency in accordance with its system security responsibilities described in section2.3.1. FCAS allows for imbalances of supply and demand to be corrected by arresting most frequency fluctuations and restoring system frequency to 50Hz (the normal operating frequency band) within the time frames specified in the FOS.

These services include:

- regulating raise and lower services to manage small frequency deviations during normal operation of the system
- contingency raise and lower services to respond to large frequency deviations following specific events that occur outside normal operation of the system.

Regulating FCAS: frequency control during normal operation of the system

The power system frequency is continually fluctuating in response to changing generation and load conditions. To manage this fluctuation, AEMO's automatic generation control (AGC) system continuously monitors the power system frequency and sends out "raise" or "lower" signals to the registered generators and loads that are dispatched to provide FCAS to correct the small frequency deviations. These correcting services are called regulating FCAS, as they regulate the power system frequency to keep it within the normal operating frequency band defined in the FOS.[27]

- The **regulating raise service** is the service of either increasing generation or decreasing load in response to electronic raise signals from AEMO.[28]
- The **regulating lower service** is the service of either decreasing generation or increasing load in response to electronic lower signals from AEMO.[29]

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the power system drops, the electrical "drag" this places on the rotation of the rotor will be resisted by the rotor's physical inertia.

27 NER cl.3.11.2 – Market Ancillary services

28 AEMO,1 May 2012, *Market Ancillary Services Specification*, p.44.

29 Ibid.

Contingency FCAS: frequency control following unexpected events

Contingency FCAS is procured by AEMO to respond to larger deviations in power system frequency, that are usually the result of contingency events such as the tripping of a large generator or load. AEMO procures contingency response services through the FCAS markets, providers of contingency FCAS respond automatically to deviations in the power system frequency outside of the normal operating frequency band.[30]Contingency FCAS is divided into raise and lower services at three different speeds of response and sustain time: fast, slow and delayed.

- The fast service is able to reach its targeted output within 6 seconds to arrest the frequency deviation.
- The slow service is able to reach its targeted output within 60 seconds to stabilise the system frequency.
- The delayed service is able to reach its targeted output within 5 minutes to restore the frequency to the normal operating frequency band.[31]

In response to a contingency event, each type of FCAS works together to recover the power system frequency within the applicable frequency bands and timeframes defined in the FOS as displayed in Figure 2.4. The initial rate of change of frequency is determined by the contingency size and the inertia of the power system. Following the contingency event the falling system frequency is arrested and restored by automatic primary frequency control response, provided by

- generating units which have their governors set to increase their generation output in response to changes in system frequency[32]
- generators who are able to quickly increase their generation output and are enabled to provide fast raise (6 second) contingency FCAS.

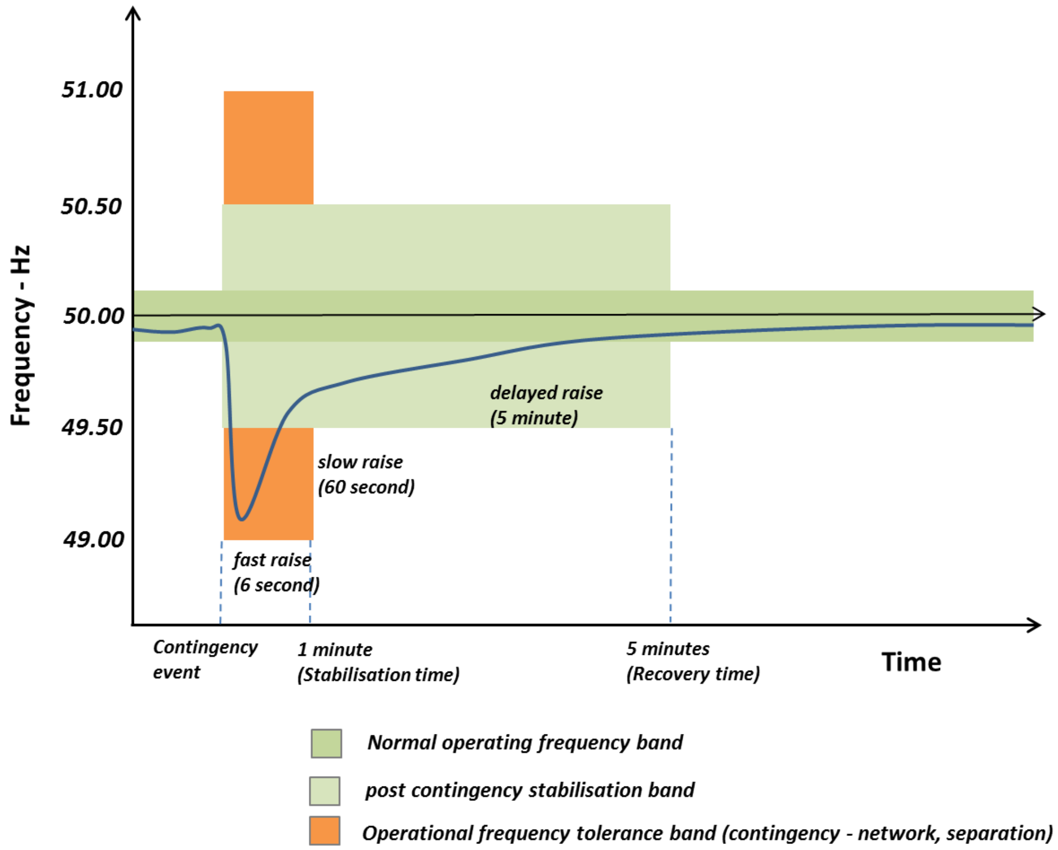
The system frequency is then stabilised by the slow raise FCAS and finally recovered to the normal operating band by utilisation of delayed raise FCAS and the subsequent dispatch of additional generation in the next dispatch interval.

30 The provider of contingency FCAS responds automatically based on a local measurement of system frequency, in comparison to regulating FCAS which is coordinated by AEMO based on a centralised measurement of system frequency. During normal operation the power system frequency is consistent throughout the network, however following sudden contingency events there can be transient variations in frequency as the power system reacts.

31 Terms described in NER cl. 3.11.2. Specific performance characteristics defined in AEMO's *Market Ancillary Services Specification*, 1 May 2012.

32 This type of governor response is not mandatory under the current NER. The current technical standards for the connection of generators are discussed in section 2.3.4. A governor is a device that regulates the speed of a machine, such as a generating unit. A governor incorporated as part of a generating system provides the capability to control the electrical output of the generator. The governor can be enabled to provide an increase or decrease in generation output in response to changes in the power system frequency. This response is determined by the governor droop and deadband settings. A description of the history of governor response in the NEM can be found in the Final Report for the AEMC's *System security market frameworks review*, p. 40.

Figure 2.4 Frequency deviation and FCAS response



FCAS Markets

The individual providers of each of the eight types of FCAS at any one time are determined by the operation of the FCAS markets. In order to participate in the FCAS market, market participants must register with AEMO, which includes verifying their capability to provide the services they wish to offer. The providers can then submit FCAS offers which include the price and quantity of each type of FCAS they wish to provide.[33]

AEMO determine the amount of FCAS required to manage the power system frequency in accordance with the FOS. For each 5 minute dispatch interval the National electricity market dispatch engine (NEMDE) enables sufficient FCAS in each market and the price for each service is set by the highest enabled bid in each case.

Providers of FCAS are paid for the amount of FCAS in terms of dollars per megawatt enabled per hour, in addition to any payments for generation or consumption through the wholesale electricity market.

33 AEMO, April 2015, *Guide to Ancillary Services in the National Electricity Market*, p.8.

2.3.3 Emergency frequency control schemes

Emergency frequency control schemes are schemes that help restore the power system frequency in the event of extreme power system events such as the simultaneous failure of multiple generators and or transmission elements. The operational goal of emergency frequency control schemes is to act automatically to arrest any severe frequency deviation prior to breaching the extreme frequency excursion tolerance limit and hence avoid a cascading failure and widespread blackout.

Traditional emergency frequency control schemes operate via frequency sensing relays that detect a frequency deviation beyond a pre-defined set point and act to disconnect any connected generation or load behind the relay. However schemes can be set up to operate based on the occurrence of a particular contingency event, such as the failure of an interconnector or may act in response to an excessive rate of change of frequency. The installation and operation of emergency frequency control schemes is responsibility of the relevant transmission network service provider (TNSP), while AEMO coordinates the overall performance of the schemes as part of its system security responsibility.

Emergency frequency control schemes can be divided into three categories depending on their operational characteristics:

Automatic under-frequency load shedding

In the event of a sudden and unexpected failure of a large amount of generation, FCAS may not be able to operate fast enough and the power system frequency will quickly fall. To arrest the dropping frequency automatic load shedding schemes are set up to disconnect load blocks and rebalance the power system supply and demand. These schemes commence operation when the power system frequency drops below the lower limit of the operational frequency tolerance band (49 Hz for the mainland NEM and 48 Hz for Tasmania). The scheme settings are staggered between the lower limit of the operational frequency tolerance band and 47Hz which is the lower limit of the extreme frequency excursion tolerance limit for the mainland NEM and Tasmania.[34]

Over frequency generation shedding schemes

Over-frequency generation shedding schemes are a particular type of emergency frequency control scheme that are used in the NEM to protect against over-frequency events. An over-frequency event is most likely to occur as the result of a separation event that leads to an excess of generation in the resultant islanded region.

Regions with limited interconnection to the rest of the NEM and a high ratio of domestic generation relative to domestic demand are particularly vulnerable to an over-frequency event. This is because of the potential consequences of an interconnector trip separating the region from the rest of the NEM. If this trip occurs while the interconnector is at full export capacity, this could result in a major supply and demand imbalance within the region. This could in turn cause frequency to rise very rapidly,

34 NER cl. 4.3.5(a) – Market Customer obligations

potentially tripping generation in the region and causing a cascading outage and potentially a black system.[35]

Over-frequency schemes are therefore more valuable in those regions with a greater chance of separation. The Panel notes that such mechanisms already exist to limit the consequences of over-frequency in Tasmania, while in South Australia ElectraNet and AEMO are currently working to establish an over-frequency scheme.[36]

Protected event EFCS

The declaration of a protected event by the Reliability Panel may include the specification of a new or modified EFCS; such an EFCS is defined by the NER as a protected event EFCS.[37]

A protected event EFCS is a specialised protection scheme designed to mitigate the impacts of a non-credible contingency event that has been declared to be a protected event. The technical parameters for the scheme are defined by the "target capabilities" which form part of the protected event EFCS standard. These "target capabilities" include:[38]

(a) power system conditions within which the scheme is capable of responding

(b) the nature of the scheme's response (load shedding or generation shedding for the purposes of managing frequency)

(c) the speed of the response

(d) the amount of load shedding or generation shedding that may occur when the scheme responds

(e) capability to dynamically sense power system conditions.

2.3.4 Generator and Network Performance Standards

The FOS defines elements of the performance standards that apply to generator and network equipment in the NEM. The NER performance standards define the level of performance required of the equipment that makes up, and is connected to, the NEM power system. Power system equipment must comply with these standards to enable AEMO to effectively manage the system security.

For example, the performance standards include specification of the ability of a generating unit to ride through a disturbance on the power system. If all generators adhere to these standards, a power system incident is less likely to lead to a cascading failure and endanger power system security.

The FOS defines the elements of these performance standards that relate to response and the ability to withstand frequency variations. The performance standards include specific frequency performance requirements that refer to the settings in the FOS:

- Network performance requirements – NER Schedule 5.1

35 AEMC, *Emergency Frequency Control Schemes*, Final Determination, March 2017 pp.69-70.

36 AEMO, August 2016, *Future Power System Security* - Progress Report, p. 32.

37 NER cl.8.8.4(g) – Determination of Protected Events

38 NER chapter 10 definition – target capabilities

- Conditions for the connection of generators - NER Schedule 5.2
- Conditions for connection of Market Network Services - NER Schedule 5.3a

Network performance requirements

The performance standards that apply to network equipment include the requirement that: within the extreme frequency tolerance limits defined in the FOS, all network equipment will remain in service unless that equipment is required to give effect to manual load shedding or the activation of an emergency frequency control scheme.[39]

Similarly market network services, such as Basslink which operates as a merchant interconnector, must be capable of continuous uninterrupted operation while the power system frequency is within the range defined in the FOS.[40]

Conditions for the connection of generators

The performance standards for the connection of generators after 2007 include requirements for the response of a generator unit to frequency disturbances and requirements for frequency control functionality of generator equipment.[41]

Schedule 5.2.5.3 of the NER defines the required response of a generating unit to frequency disturbances. This requirement specifies the periods of time that a generating unit must be capable of continuous operation within the operating bands defined by the FOS. These standards include a minimum access standard, an automatic access standard and the provision for a negotiated access standard.

The charts that describe the automatic and minimum access standards for the connection of generators with respect to response to frequency disturbances are included in appendix E.

Schedule 5.2.5.11 of the NER specifies the performance standards that specify how a generators output must respond to changes in power system frequency outside the normal operating frequency band.

The automatic access standard that applies to generator frequency control is:[42]

- that the generation output should not worsen any frequency deviation and
- that the generating system must be capable of automatically increasing or decreasing its output to help restore the system frequency to within the normal operating frequency band.

The minimum access standard for generator frequency control does not directly refer to the FOS. It requires that generator output must not:[43]

- increase in response to a rise in system frequency and

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39 NER S5.1.3 – Frequency Variations

40 NER S5.3a.13 - Market network service response to disturbances in the power system

41 This section summarises the requirements in the NER that apply to generators connected after the 8 March 2007, when the National Electricity Amendment (Technical Standards for Wind Generation and other Generator Connections) Rule was made. Chapter 11 of the NER contains a transitional rule, cl.11.10.3 that allows for pre-existing access standards to continue to apply.

42 NER S5.2.5.11(b) – Frequency Control

43 NER S5.2.5.11(c) – Frequency Control

- decrease more than 2% per Hz in response to fall in system frequency.

2.4 Frequency performance in the NEM

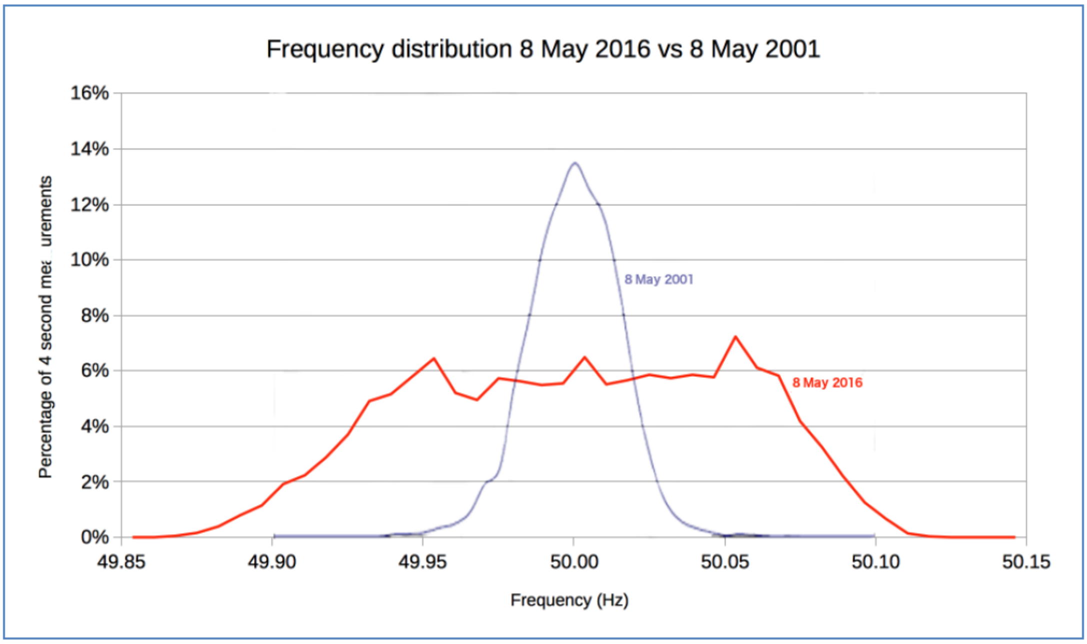
The Panel is aware that there is some evidence that the frequency performance of the power system has declined in recent times. Specifically, there is some evidence that the power system frequency is increasingly further away from the nominal frequency of 50Hz than has historically been the case.

This issue was highlighted by Pacific Hydro in its submission to the AEMC's Interim Report for the *System security market frameworks review*. In its submission, Pacific Hydro demonstrated the extent to which frequency has changed by comparing the frequency profile on 8 May 2016 relative to the same day in 2001.[44]

This comparison is shown below in Figure 2.5. The frequency profile shows the percentage of time that the power system frequency is measured at a given frequency value. The distribution profile for 8 May 2016 shows a clear flattening of the distribution profile relative to 2001.

The Panel notes that, in this example, both frequency profiles demonstrate outcomes that are compliant with the FOS, in that the amount of time that the frequency is outside of the normal operating frequency band (49.85 – 50.15Hz) is less than 1%.

Figure 2.5 Frequency distribution profile NEM mainland: 2001 - 2016[45]



Subsequent frequency performance data has been published by AEMO that provides further evidence of a change in the NEM frequency distribution between 2007 and 2017. This trend for the NEM mainland is shown in Figure 2.6 and for Tasmania in Figure 2.7.

44 The Panel notes that 8 May in 2001 fell on a Tuesday the 8 May 2016 fell on a Sunday and that a typical weekend load profile is likely to be different from a typical weekday load profile.

45 Pacific Hydro, 6 February 2017, Submission to the AEMC's Interim Report – System Security Market Frameworks Review, p.4.

Figure 2.6 NEM Mainland frequency distribution profile 2007-2017[46]

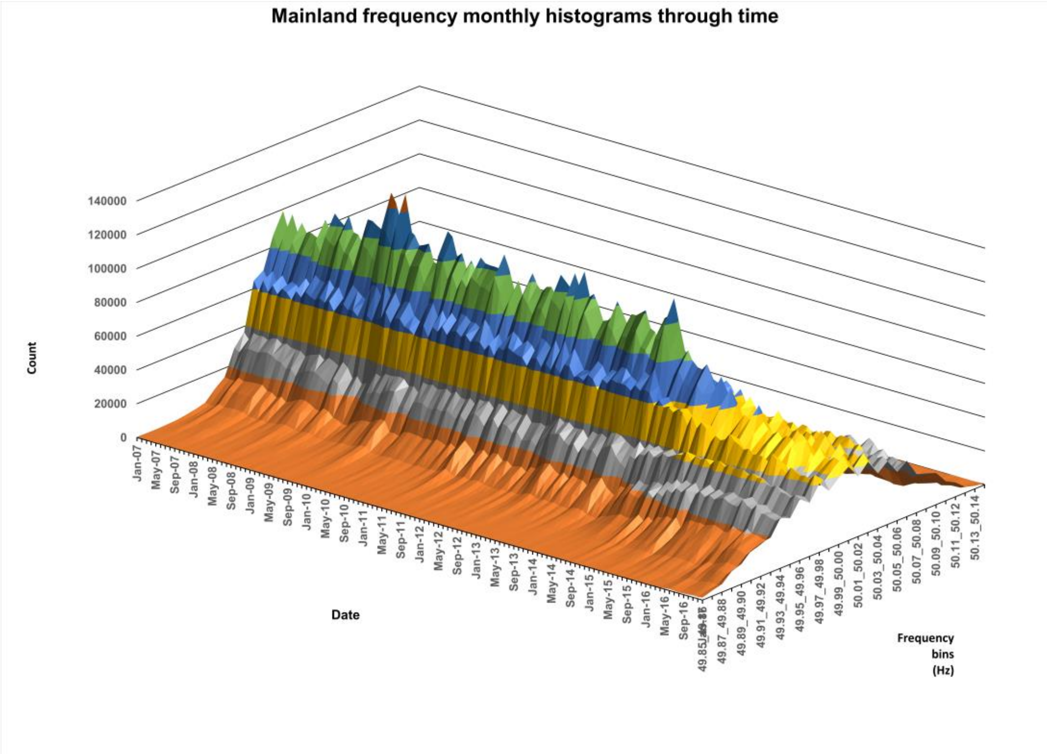
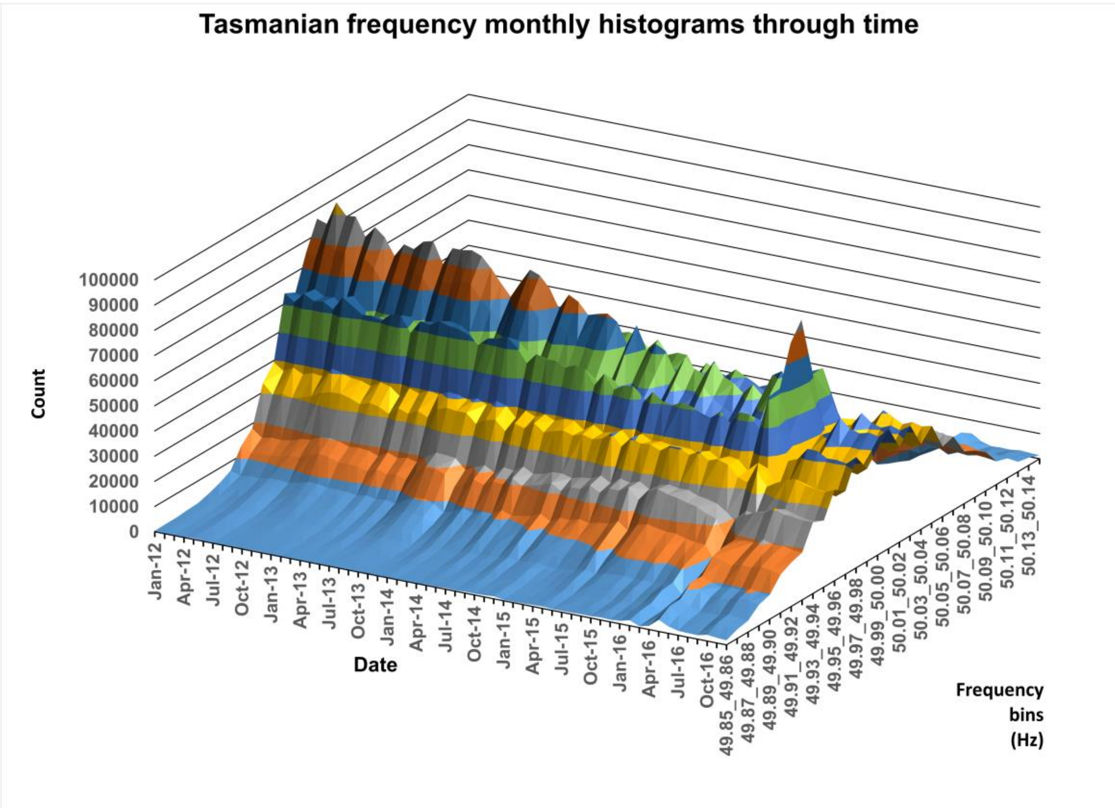


Figure 2.7 Tasmania frequency distribution profile 2007 - 2017[47]



46 AEMO, 3 May 2017, ASTAG – Meeting Pack – 3 May 2017, Presentation 2 Frequency Performance.

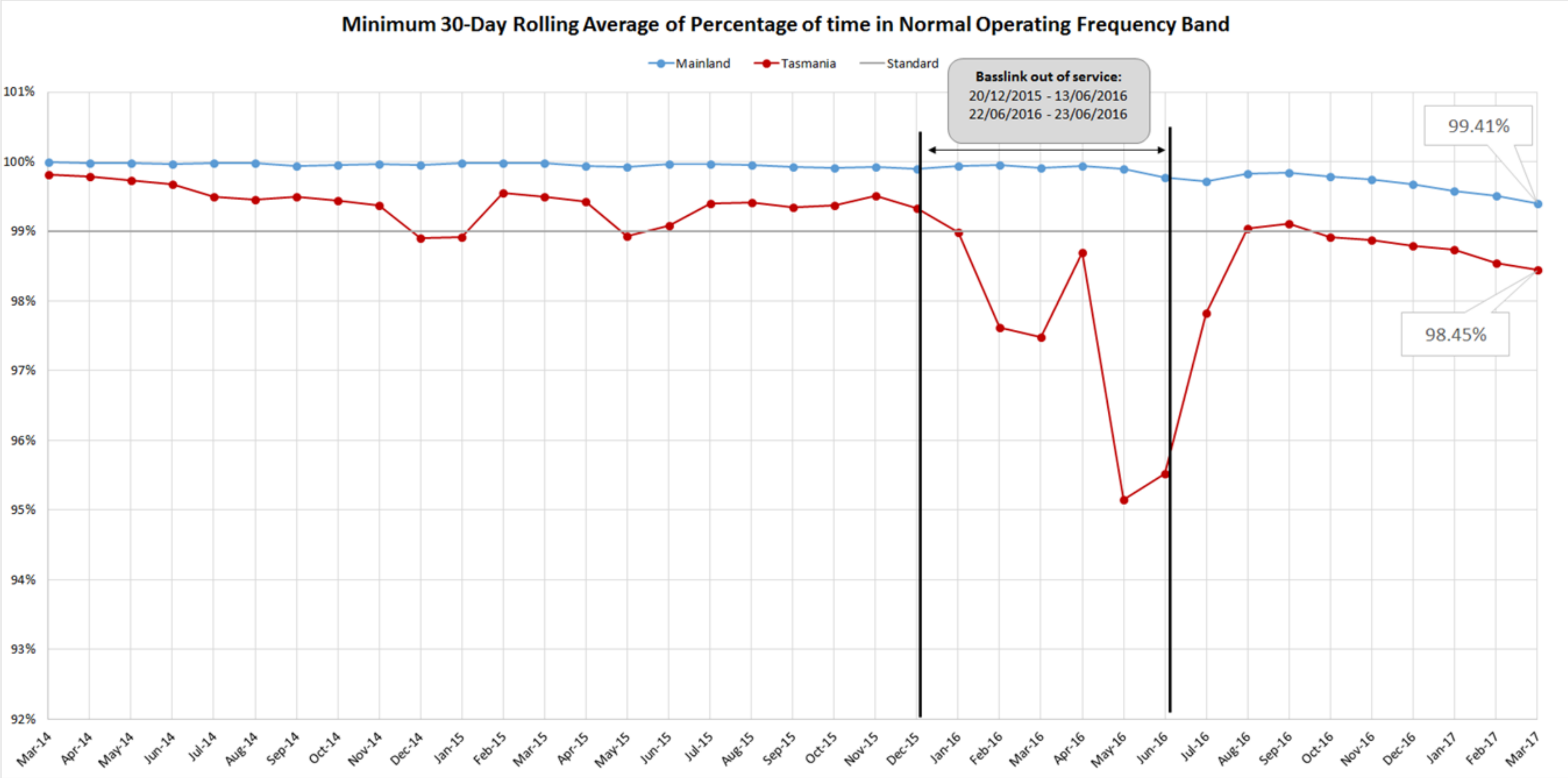
47 Ibid.

Figure 2.8 displays the performance of the NEM in terms of compliance with the requirement in the FOS that the power system frequency be maintained within the normal operating frequency band for 99% of the time over any 30 day period. This figure shows that there have been a number of 30 day periods where the frequency performance in Tasmania has not met this requirement. While the sub-standard performance between December 2015 and June 2016 coincided with the outage of Basslink, the more recent sub-standard performance from October 2016 onwards shows a steady decline in performance.

According to the data in Figure 2.8, the frequency performance for the NEM mainland is still within the range specified by the FOS, however a steady decline is apparent from September 2016 onwards. Additional frequency performance data is included in appendix F, showing an increased incidence of exceedance events (where the power system frequency falls outside the normal operating frequency band) for both the NEM mainland and Tasmania in recent months.

As part of their Future power system security work program, AEMO has engaged power system advisory firm DIgSILENT to undertake diagnostic work to explain the cause and consequence of this degraded frequency performance. AEMO's Future power system security work program is discussed further in section 3.2.1.

Figure 2.8 NEM mainland and Tasmanian Frequency Performance[48]



48 Ibid.

3 Approach and assessment criteria

This chapter sets out the Panel's approach and to reviewing the FOS, including:

- section 3.1: the Panel's objective in undertaking its assessment
- section 3.2: the Panel's proposed approach to the review including a description of other ongoing work programs related to frequency control
- section 3.3: the proposed staging approach to the review including a break-down of issues for consideration in stage one and stage two.

3.1 The objective of the Review

In undertaking the Review of the FOS, the Panel will be guided by the National electricity objective (NEO) which is set out under section 7 of the National Electricity Law (NEL). The NEO is to

> "The objective of this law is to promote efficient investment in, and efficient operation and use of, electricity services for the long-term interests of consumers of electricity with respect to:
>
> - price, quality, safety, reliability and security of supply of electricity; and
> - the reliability, safety and security of the national electricity system."

The Panel considers that the relevant aspects of the NEO for its review of the FOS are the operation of electricity services, with particular respect to the safety and security of the national electricity system and the price, quality and security of supply of electricity.

In undertaking its review, the Panel will exercise its judgement when considering potential changes to components of the FOS, with a view to striking an appropriate balance between providing improved quality and security outcomes against the cost of delivering those outcomes.[49] This is because while changes to make the FOS more stringent (such as narrowing the various bands within which the frequency must be maintained) may provide benefits to consumers by delivering enhanced power quality and system security, this may also impose additional costs on market participants which are ultimately borne by consumers.

These FOS related quality and security benefits and associated costs may arise in a number of ways. At a high level, some of the potential benefits of a more stringent FOS may include the following:

- The FOS may be "tightened" so that the system frequency is required to be closer to the nominal frequency of 50Hz. This could result in improved system security as a result of the increasing the time that the power system frequency is

49 In this sense the term "quality" refers to electrical power quality which is a measure of the uniformity of the voltage waveform which describes the fluctuating system voltage and the associated frequency. A high level of power quality relates to a stable system voltage at a steady frequency where the power system is resilient to contingency events. A low level of power quality occurs when the system voltage and frequency fluctuate more widely in response to destabilising events.

maintained close to the nominal frequency of 50Hz and away from the load shedding band and extreme frequency tolerance limits.[50]If the power system frequency is further away from 50Hz when a contingency event occurs, the resulting frequency deviation may be more severe. This could in turn lead to an increased likelihood of load shedding and potentially a cascading outage and black system.

- A more stringent FOS could also deliver improved power quality through supporting a more uniform and stable power system frequency. Such a quality improvement may deliver benefits through reducing the operation and maintenance costs of generation equipment. This reduced operation cost is a product of potential reductions in maintenance costs and improvements in generator fuel efficiency through maintaining the power system frequency close to 50 Hz.[51]

However, costs associated with tightening elements of the FOS may also include:

- Increased expense of procuring FCAS to meet the FOS. Maintaining system frequency within narrower operating bands may require more FCAS to be procured by AEMO, potentially increasing the total costs of regulation and contingency FCAS. This cost is borne by market participants and ultimately consumers through higher electricity prices.
- There is a potential that a more stringent FOS could create a barrier to the use of all possible technologies in the NEM, if certain technologies are unable comply with the technical standards that are dependent on the FOS. To the extent that this impedes participants from using all available technologies to participate in the NEM, this could preclude the use of the lowest cost technologies to meet consumer demand, reducing the efficiency of dispatch and potentially placing upwards pressure on wholesale market costs.
- Tightening the operational frequency tolerance band in the FOS would bring forward the trigger limit for load shedding and potentially have the effect of increasing the relative likelihood of load shedding occurring. This may increase costs related to unserved energy associated with load shedding.[52]

The complexity of optimising the FOS is also related to the fact that while changing any specific component of the FOS may change system security outcomes, it is also likely to impose costs on various participants through meeting more strenuous obligations, or on AEMO through a requirement to procure additional ancillary services or constrain

50 The issue of the relationship between improved system security and a tightened FOS was mentioned in the Finkel panel report into the NEM. Commonwealth of Australia, *Independent Review into the Future Security of the National Electricity Market: Blueprint for the Future*, 2017, p.58.

51 Historically, synchronous generation equipment has been finely tuned to operate at peak efficiency when the system frequency is close to the nominal value. As the frequency moves away from this value, generators operate less efficiently which may result in increased fuel usage and increased wear and tear on units.

52 The Panel notes that tightening the operational frequency tolerance band may also provide some benefits in this regard, as it would result in an under-frequency load shedding scheme having a wider frequency window of operation, which may decrease the risk of a black system event.

dispatch. The setting of each component of the FOS therefore needs to be considered in terms of the balance between these security benefits and costs.

For example, widening the extreme frequency excursion limit may superficially reduce the costs of managing the system, as it would allow AEMO to operate the system over a greater frequency range and therefore reduce the costs associated with procuring ancillary services or constraining dispatch. However, operating the system in such a way could also increase the risk of some equipment being unable to function effectively and could also increase risk of damage to generation plant.

Similarly, the length of the frequency restoration timeframes must be considered in terms of security benefits and cost. Extending the recovery time (currently ten minutes) might potentially reduce the cost of managing the system but may also have significant security implications, as it may increase the risk of a cascading failure and potentially a black system as a result of subsequent contingency events.[53]

In its assessment of any changes to the components of the FOS and consistent with satisfying the relevant aspects of the NEO outlined above, the Panel will therefore give consideration to the following principles:

- S**upporting a safe and secure system:** the power system can be considered to be secure when it is operated within specified technical operating limits, including voltage and other stability limits. Maintaining the NEM power system within these technical limits allows it to operate effectively and efficiently. Operating the system within these technical limits supports the safe operation of the national electricity system. This is central to maintaining the safety of consumers with respect to the physical national electricity system. The Panel will consider how the settings of the FOS will support a safe and secure system.

  Operating the system within these technical limits supports the safe operation of the national electricity system. This is central to maintaining the safety of consumers with respect to the physical national electricity system. The Panel will consider how the settings of the FOS will support a safe and secure system.

- **Minimising consequences for the prices consumers pay for electricity:** To maintain the safety and security of the national electricity system, AEMO procures ancillary services and operates the system to keep it within specific limits, generators operate and maintain their units in accordance with performance standards, and network service providers maintain and operate their networks in accordance with system standards.

  These activities come at a cost in terms of obligations faced by participants and AEMO. The Panel will consider how the settings of the FOS are likely to impact on the costs incurred by different participants in maintaining the security of the system.

Ultimately, the Panel's responsibility in determining the FOS is to identify a reasonable, effective and efficient trade-off between the security benefits of a more stringent FOS,

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53 A longer restoration time may increase the likelihood of a subsequent generator contingency (trip) as a result of the generators decreased resilience to prolonged frequency deviations. This is discussed in appendix D.2.

against the costs that this would impose on consumers. While it is essential that minimum limits of security and safety are maintained, this should occur at the lowest possible cost for consumers. Furthermore, the Panel will exercise its judgement in deciding whether additional security benefits above this basic, minimum level are warranted, given the incremental costs of providing that additional security. These trade-offs will therefore be central to all of the Panel's consideration in both stage 1 and 2 of the review.

3.2 Approach to the review

In response to the current state of transition in the NEM, aspects of the market and regulatory frameworks are being reviewed by various market bodies. A description of the current and future work programs relevant to the review of the FOS is included in section 3.2.1.

There are a number of recently completed market framework policy changes that the Panel can assess and incorporate into the FOS, such as the introduction of the protected event contingency category made in the recent EFCS rule change.[54] Furthermore, there are a number of technical changes to the FOS that can be assessed immediately. The Panel considers both these sets of changes can be assessed through stage 1 of the review, which will commence with the publication of this issues paper.

Stage 2 of this review will include a general consideration of the various components of the FOS, including the settings of the frequency bands and time requirements for maintenance and restoration of system frequency.

The Panel's ability to meaningfully and effectively progress stage 2 of the FOS review is dependent on the existence of firm market frameworks established in the NER. This is because the settings of the FOS bands and timeframes must reflect the general design of the NER market frameworks.

There are a number of potential changes to these market frameworks currently being considered in ongoing review processes. The AEMC's system security review will be cataloguing a number of relevant issues for further assessment, such as the apparent deterioration of frequency control and the impact of deadband settings on frequency control.[55] In addition, AEMO has convened an ancillary services technical advisory group, which will be advising on potential changes to the mechanisms for frequency control.[56] Finally, the AEMC expects to receive a rule change request from AEMO to reassess the technical standards in the NER.[57]

The Panel considers it likely that these processes may identify issues that will be relevant to any review of the FOS. They could also produce recommendations for changes to the market frameworks and to the FOS itself. Therefore until these projects

54 AEMC, March 2017, *Emergency Frequency Control Schemes*, final determination.

55 see: www.aemc.gov.au/Major-Pages/System-Security-Review

56 See: www.aemo.com.au/Stakeholder-Consultation/Industry-forums-and-working-groups/Other-meetings/Ancillary-Services-Technical-Advisory-Group

57 AEMO, March 2017 *Recommended technical standards for generator licensing in South Australia*.

and any associated market framework changes are further progressed, it is not possible for the Panel to meaningfully or effectively assess their implications for the FOS.

For this reason, the Panel will commence stage 2 of the FOS review at a later date. As part of its considerations in stage 1, the Panel will map out the various market framework changes to be considered, and their potential implications for the FOS, for further assessment in stage 2. The Panel will provide further detail regarding the scope and content of stage 2 of the review once it has completed these considerations as part of stage 1.

3.2.1 Current and future work programs related to the review

The current and future work programs related to this review include:

- AEMO, *Future power system security work program* - ongoing
- AEMC, *System security market frameworks review* – final report 27 June 2017
- AEMC, *Frequency control frameworks review* – to commence July 2017

AEMO – Future power system security program

AEMO is currently developing its *Future power system security work program* to address operational challenges arising from the changing generation mix in the NEM. Progress reports for this work program were published on 12 August 2016 and 31 January 2017.[58]

The Panel is aware of the following projects currently being progressed by AEMO as part of their *Future power system security work program* which investigate specific issues related to frequency control, including reviews of the:

- Market ancillary service specification – final report published 30 June 2017
- 'Causer pays' mechanism for regulation FCAS
- Essential Services Commission of South Australia (ESCOSA) generator licensing conditions.

The Panel also understands that AEMO is in the process of scoping a larger work program to consider technical issues related to frequency control and whether or not the current market frameworks are meeting the technical requirement as the energy market transitions.[59]

As part of this broader frequency control work, AEMO has also established the ancillary services technical advisory group, to contribute to ongoing work related to ancillary services and the role they play in managing power system security in the NEM.[60] AEMO has engaged the power system advisory firm DIgSILENT to investigate and

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58 AEMO, Future Power System Security – Progress Report, January 2017. AEMO, Future Power System Security - Progress Report, August 2017.

59 AEMO, *Market Ancillary Service Specification*, Issues Paper, 25 January 2017, p. 1.

60 In February 2017, AEMO convened the Ancillary Services Technical Advisory Group(AS-TAG), to bring together technical experts from the power industry to investigate solutions for current and future issues relating to ancillary services.

report on the cause(s) and consequences of the observed changes to the NEM frequency distribution profile, discussed in section 2.4.[61]

AEMC – System security market frameworks review

On 27 June 2017 the AEMC published a final report for its *System security market frameworks review*.[62] This paper sets out the Commission's recommendations to address challenges relating to the management of power system frequency and the maintenance of system strength.[63]

The Commission's approach to addressing frequency control in this review focuses on two key areas: a required operating level of inertia and the provision of fast frequency response services.[64]

In parallel with publication of the System security market frameworks review the Commission published a draft rule, *Managing the rate of change of power system frequency*. The main features of the draft rule are:[65]

- An obligation on AEMO to determine sub-networks in the NEM that are required to be able to operate independently as an island and, for each sub-network, assess whether a shortfall in inertia exists or is likely to exist in the future.
- Where an inertia shortfall exists in a sub-network, an obligation on the relevant TNSPs to make continuously available, minimum required levels of inertia, determined by AEMO through a prescribed process.
- An ability for TNSPs to contract with third-party providers of alternative frequency control services, including fast frequency response (FFR) services, as a means of meeting a proportion of the obligation to provide the minimum required levels of inertia, with approval from AEMO.
- An ability for AEMO to enable the inertia network services provided by TNSPs and third-party providers (ie, instruct them to provide inertia) under specific circumstances in order to maintain the power system in a secure operating state.

To complement the obligation on TNSPs to provide a level of inertia associated with maintaining system security, the AEMC considered that it would be important to also introduce a mechanism to provide inertia additional to the minimum secure operating level. This would allow for greater power transfer capability across the network, resulting in realisation of market benefits.

To implement such a market benefits mechanism as soon after the system security obligations as possible, the AEMC decided to progress this mechanism through the

61 AEMO, AS-TAG – Meeting Pack – 3 May 2017.

62 AEMC, *System security market frameworks review* – final report, 27 June 2017.

63 System strength is also referred to as fault level.

64 The ability of the power system to resist large changes in frequency arising from the loss of a generator, transmission line or large industrial load is initially determined by the inertia of the power system. Inertia is naturally provided by large spinning conventional generators that are synchronised to the frequency of the system. See AEMC, *System security market frameworks review*- final report, 27 June 2017.

65 AEMC, *Managing the rate of change of power system frequency* – draft rule determination, 27 June 2017, p.iii.

Inertia ancillary service market rule change. The Panel will monitor developments with regard to this rule change, for which a draft determination is expected to be published by the Commission on 7 November 2017.[66]

Recommendation 5: Assess whether mandatory governor response requirements should be introduced and investigate any consequential impacts (including on the methodology for determining causer pays factors for the recovery of regulation FCAS costs).[67]

Recommendation 6: Review the structure of FCAS markets, to consider:

- any drivers for changes to the current arrangements, how to most appropriately incorporate FFR services, or alternatively enhancing incentives for FFR services, within the current six second contingency service; and
- any longer-term options to facilitate co-optimisation between FCAS and inertia provision.

Recommendation 7: Assess whether existing frequency control arrangements will remain fit for purpose in light of likely increased ramping requirements, driven by increases in solar PV reducing operational demand at times and therefore leading to increased demand variation within a day.

The final report for the *System security market frameworks review* noted that the Commission will consider the consequential impacts of the introduction of a requirement for mandatory governor response in the event that the frequency diagnostic work being completed for AEMO suggests that such a requirement be introduced.[68]

Another issue related to frequency control that was identified through consultation on the *System security market frameworks review* is the interaction between the 'causer-pays' methodology for FCAS cost allocation and generator behaviour relating to frequency control and compliance with dispatch instructions.[69]Currently the costs associated with the provision of regulation FCAS are recovered on a 'causer-pays' basis. This is intended to attribute these costs to those market participants who have contributed most to frequency deviations in the recent past.[70] Both of the above issues will be considered by the AEMC through the *Frequency control frameworks review*.

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66 AEMC, *System security market frameworks review*- final report, 27 June 2017, pp.36-38.

67 A governor is a device that regulates the speed of a machine, such as a generating unit. A governor incorporated as part of a generating system provides the capability to control the electrical output of the generator. The governor can be enabled to provide an increase or decrease in generation output in response to changes in the power system frequency. This response is determined by the governor droop and deadband settings. A description of the history of governor response in the NEM can be found in the Final Report for the AEMC's System security market frameworks review, p. 40.

68 AEMC, *System security market frameworks review*- final report, 27 June 2017, p. 41.

69 Pacific Hydro, 6 February 2017, Submission to the AEMC's Interim Report – *System security market frameworks review*, pp.9-10.

70 AEMC, *System security market frameworks review*- final report, 27 June 2017, p.41.

3.3 Staging of the review

The Panel is proposing to progress the review of the FOS in a staged manner, to accommodate changes to the market and regulatory arrangements arising from the work described in section 3.2.1

The first stage will address primarily technical issues and market framework changes stemming from the emergency frequency control scheme rule change. Stage one will commence with the publication of this issues paper, as this stage of the project will consider changes to the FOS reflecting the existing market and regulatory arrangements.

The second stage will include a general consideration of the various components of the FOS, including the settings of the frequency bands and time requirements for maintenance and restoration of system frequency. Stage 2 will consider changes to the FOS reflecting ongoing developments of the market and regulatory arrangements and will commence at a later date, once these developments of the market arrangements have been further progressed.

As part of its considerations in stage 1, the Panel will map out the various market framework and regulatory changes under consideration, and their potential implications for the FOS, for further assessment in stage 2. The Panel will provide further detail regarding the scope and content of stage 2 of the review once it has completed these considerations as part of stage 1.

3.3.1 Scope of stage one

As noted above, stage 1 of the review will consider what changes to the FOS are necessary in light of the emergency frequency control schemes rule. In particular, this will include consideration of how to incorporate the new contingency category of protected event. In addition, stage 1 of the review will consider a number of standalone technical issues as described below.

The emergency frequency control schemes rule was made by the AEMC on 30 March 2017. This rule introduced the protected event contingency category which is required to be included in the FOS. In stage one of the review, the Panel will consult on and consider the appropriate settings to apply for protected events in the FOS for the NEM mainland and for Tasmania.

Stage 1 will also consider various technical issues with the FOS that are independent of the ongoing work programs described in section 3.2.1, including:

- the treatment of multiple contingencies
- the characteristics of an 'electrical island' in terms of a separation event
- the specification of accumulated time error.

Furthermore, during stage one of the review, the Panel will consider the outcomes of the key market framework review processes described in section 3.2.1 and their potential implications for the FOS. The Panel will also seek stakeholder input on the issues that should be considered for further assessment in stage two.

3.3.2 Scope of stage two

Stage two of the review will involve an assessment of each of the elements of the FOS, including the boundaries of the various frequency bands and the timeframes for restoration of power system frequency following a specific event.

This assessment requires consideration of the complex interactions between the regulatory and market frameworks and the various elements of the FOS. This will in turn require consideration of the trade-offs between system security impacts and costs for consumers.

However, the Panel's ability to meaningfully undertake this analysis is dependent on the progression and further resolution of a number of ongoing reform processes to the market and regulatory arrangements. The ongoing review processes particularly relevant to the Panel's ability to review the FOS include changes that have been introduced through the *System security market frameworks review*:

- The requirement for a minimum level of inertia to manage the rate of change of frequency in the power system. The AEMC published a draft rule, *Managing the rate of change of power system frequency* on 27 June 2017. The draft rule sets out a proposed framework for the provision of a minimum level of inertia in the NEM.[71]
- Changes to the requirements for generator performance with respect to frequency, such as the potential introduction of a mandatory governor response capability.[72] The AEMC will commence the Frequency control frameworks review in July 2017, which will to consider this issue.[73]

The Panel considers that the resolution of these issues is likely to change the technical basis and cost considerations relevant to determining the different frequency bands and timeframes in the FOS.

In particular, any introduction of mandatory governor response capability from capable generators may have implications for the settings of the normal operating frequency band and the quantity of regulation FCAS that AEMO procures to maintain the frequency of the system within the normal operating frequency band. This will in turn have implications for the costs of these regulation services, with direct implications for the costs of providing system security.

The Panel also considers that the introduction of a minimum operating level of inertia in the system may impact on the quantities of both regulation and contingency FCAS that are needed to manage system frequency both during normal operation and following contingency events.

Finally, the Panel is also aware of more general considerations by AEMO and the AEMC around the appropriateness of the market frameworks and operational

71 AEMC, *Managing the rate of change of power system frequency*, draft rule determination, 27 June 2017.

72 Mandatory governor response refers to a regulatory requirement for a generator governor to be enabled to provide an automatic increase or decrease in generation output in response to changes in the power system frequency. A description of the history of governor response in the NEM can be found in the Final Report for the AEMC's *System security market frameworks review*, p.40.

73 AEMC, *System security market frameworks review*, final report, 27 June 2017, p.26.

specifications for FCAS markets. As with the introduction of a minimum inertia level and any potential introduction of mandatory governor response, the outcomes of these reform processes may be directly relevant to the Panel's assessment of the frequency bands and restoration timeframes in the FOS.

The Panel would need to consider the impacts of these market framework review processes, particularly as they impact on FCAS quantities and costs, as a key input of an economic assessment of any potential change to the frequency bands in the FOS.

It follows that the analysis needed to meaningfully assess these components of the FOS requires that the above mentioned reviews to be significantly progressed, if not finalised and implemented through changes to the NER. The Panel cannot effectively review the FOS until there is more clarity on the nature of the market and regulatory arrangements relevant to frequency control. Many of the emerging technical issues relevant to frequency control and frequency management can be addressed (in part) through possible changes to the FOS. However, any such amendments to the FOS need to be considered once the result of the considerations of the foreshadowed changes to the market and regulatory arrangements have been clarified.

The Panel will therefore monitor these ongoing market framework review processes and assess the implications of any recommended changes as the ongoing investigations progress. Stage one of the review will include a general consideration of how these ongoing market developments may be relevant to the Panel's analysis for stage two of the review. Stakeholders are also invited to comment on how these reform processes should be considered in more detail in stage two.

Section 3.2outlines the Panel's initial thoughts on a potential approach it may take to stage 2 of the review, along with a proposed approach to coordinating the review with the AEMO *Future power system security work program*.

Box 3.1 Question 1 - Issues related to the approach and assessment criteria

(a) **What settings in the FOS do stakeholders believe are best defined through a cost benefit trade-off?**

(b) **What criteria should be considered in reviewing and determining the settings in the FOS?**

(c) **Do stakeholders agree with the Panel's proposed staging approach including the distribution of issues between stage one and stage two?**

(d) **Are there any other review processes currently underway or expected to commence shortly that the Panel should be aware of in relation to the review of the FOS?**

(e) **Are there any other issues, other than those identified in this issues paper or noted for consideration in related work programs, that the Panel should be aware of in this review of the FOS?**

4 Issues for consideration in stage one

This chapter sets out the range of issues that the Panel is considering as part of stage one of the review. It also sets out, at a high level, a potential approach the Panel may follow in progressing its assessment of stage two of the review.

Each section sets out the Panel's initial considerations in relation to the particular issue and asks questions to promote stakeholder feedback.

The following is a summary of the key issues identified for consultation in stage one of the review:

- Section 4.1: Implementation of the emergency frequency control schemes rule including:
  - the inclusion of a frequency standard for protected events in the FOS
  - the treatment of multiple contingencies in the FOS.
- Section 4.2: Guidance in relation to the definition of an electrical island
- Section4.3: Other issues for consideration in relation to the FOS including:
  - The requirement for a maximum accumulated time error in the FOS
  - Consideration of the definition of terms in the FOS
- Section 4.4: A potential approach for stage 2 of the review.

4.1 Issues arising from the emergency frequency control schemes rule change

On 30 March 2017, the AEMC published its final determination for the emergency frequency control schemes rule change. This rule change request was received from the South Australian Minister for Mineral Resources and Energy. The rule change request proposed changes to the NER to improve the effectiveness of automatic load shedding schemes used to manage non-credible contingency events.[74]

Part of the rule change request related to elements of the FOS that specify the expected frequency performance of the power system following any multiple-contingency event. Specifically, the rule change request referred to Part B (f) of the FOS, which states that, "as a result of any multiple contingency event, system frequency should not exceed the extreme frequency excursion tolerance limit".[75]

74 AEMC, 2017, *Emergency frequency control schemes*, rule determination, 30 March 2017, p. 11.

75 The Frequency operating standard (Mainland) sets out this requirement in full: "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. A multiple contingency event is defined as: "either a contingency event other than a credible contingency event, a sequence of credible contingency events within a period of 5 minutes, or a further separation event in an island."

The proponent argued that this requirement for maintenance of the FOS for any multiple contingency event was not practicable, stating that:[76]

> "it is not possible to maintain the FOS for any possible multiple contingency event, (the simultaneous trip of all generation in the NEM , for example). As such, the Commission should add flexible provisions to the Rules that would allow an independent body, such as the Reliability Panel, to nominate specific events, such as the non-credible loss of interconnectors under particular conditions, for which the FOS should be maintained."

Multiple contingency events

In response to this issue raised in the rule change request, the final rule determination of the emergency frequency control schemes rule change recommended that the FOS be reassessed with a view to reconsidering the appropriateness of the requirement that AEMO maintain the FOS for all possible multiple contingency events.[77]

Some direction on this issue is provided in the NER system security principles that relate to the operation of emergency frequency control schemes load and generation shedding for the management of multiple contingency events. The NER requires that emergency frequency control schemes be available to "significantly reduce the risk of cascading outages and major supply disruptions following significant multiple contingency events."

As per the terms of reference, this review will consider whether the FOS should provide any further clarity on the management of power system frequency following multiple contingency events.

Protected events

The emergency frequency control schemes final rule also introduced into the NER a new classification of contingency event, the protected event, with new responsibilities for the Reliability Panel.

A protected event is a non-credible contingency event that is defined by AEMO and declared by the Panel. It may include any non-credible event or multiple contingency events, where the cost of managing the event as a protected event is in the long term interest of consumers, in accordance with the NEO.

As described in Appendix D.3, AEMO must manage the power system such that following a protected event, the system will return to a satisfactory operating state in accordance with the FOS. The goal of managing a protected event is to maintain the stable operation of the power system, while allowing for any necessary automatic generation and load shedding through the operation of emergency frequency control schemes.

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76 Government of South Australia, 2016, *Emergency under frequency control schemes*: rule change request, 12 July 2016, Attachment B, p. 3.

77 AEMC, 2017, *Emergency frequency control schemes*, rule determination, 30 March 2017, p. 73.

Chapter 11 of the NER includes an interim FOS that applies to all protected events, until such time as the Panel determines the frequency standard that applies for a protected event.[78]

As per the terms of reference, this review will consult on the requirements in the FOS that apply to protected events along with whether any requirements should apply to multiple and non-credible contingencies more broadly.

4.1.1 The FOS that applies for protected events

The frequency bands in the interim FOS that currently apply to a protected event were determined by the AEMC with reference to the technical characteristics of maintaining the overall security of the power system, and defined in a manner that reflects the current requirement in the FOS for the maintenance of the security of the power system following multiple contingency events.[79]

An interim FOS for a protected event is currently set out for Tasmania and for the mainland as follows:

> "For a protected event, system frequency should not exceed the applicable extreme frequency excursion tolerance limits and should not exceed the applicable load change band for more than two minutes while there is no contingency event or the applicable normal operating frequency band for more than 10 minutes while there is no contingency event."

The Commission's rationale for setting this interim standard was that, for a protected event, the power system should be maintained within the extreme frequency excursion tolerance limits that apply to a multiple contingency events under the current frequency operating standards for the NEM mainland and Tasmania.[80]

The complete interim FOS for protected events is reproduced in appendix G for reference.

The Panel invites stakeholder feedback on the whether the interim FOS for protected events is appropriate for defining the post contingency operating state following the occurrence of a protected event and whether any alternative or revised settings to this standard should be considered for protected events.

Stakeholders are also invited to comment on whether the FOS for protected events should be equivalent or different for Tasmania and the mainland.

Box 4.1 Question 2 - Incorporation of protected events into the FOS

(a) **What considerations should be taken into account when defining the FOS that applies for protected events?**

78 NER cl. 11.97.2 Interim frequency operating standards for protected events.

79 The performance for the power system frequency condition following a protected event is primarily technical; ie avoid a cascading failure and black system/major outage. However, the Panel considers an economic trade-off when determining whether a particular contingency event be defined as a protected event. See NER cl. 11.97.2

80 AEMC 2017, *Emergency frequency control schemes*, rule determination, p. 74.

(b) **What is the appropriate frequency band(s) and restoration timeframes that should apply for a protected event?**

(c) **Are there any regionally specific issues that should be taken into account when considering the treatment of protected events in the FOS?**

4.1.2 Multiple contingency events in the FOS

In contrast to protected events, which are a specific subset of non-credible contingencies, multiple contingency events include an unlimited number of potential events and as such are essentially undefinable. They may include events ranging from the simultaneous loss of two generators (a more probable event), to the simultaneous loss of all generators in a region (an extremely improbable event).

These characteristics of multiple contingency events mean it is not practical or economic to operate the power system such that it would be expected to maintain satisfactory operation, following the occurrence of all possible multiple contingency events. However, this is the current obligation that is theoretically imposed on AEMO under part B(f) of the FOS.

Given the impractical nature of maintaining the FOS for all possible multiple contingencies, there may be a case for removing this existing obligation from the FOS.

However, the Panel also acknowledges that the existing requirement in part B(f) may be viewed as a general obligation for AEMO to act in a way that seeks to prevent the system from collapsing following an extreme event. Although the new category of protected event forms a partial alternative to this existing general requirement, it may also be argued that removal of part B(f) means that AEMO would face no obligation to manage the system for any event that falls outside the definition of a protected event.

The Panel is interested to hear from stakeholders as to whether or not they believe it is warranted for the FOS to include any requirements or clarification in relation to power system operation following multiple contingency events.

Box 4.2 Question 3 - Multiple contingency events in the FOS

(a) **Is there a need for the FOS to clarify the expectations in terms of the operation of the power system following a multiple contingency event?**

(b) **To what extent does the introduction of the category of protected event, and associated FOS requirements, form an alternative to this existing obligation?**

(c) **Are there any regionally specific issues that should be taken into account when considering any element of the FOS that relates to multiple contingency events?**

4.2 Guidance on the characteristics of an electrical island for the maintenance of the FOS

The FOS for Tasmania and the FOS for the mainland NEM each include frequency standards that apply to an electrical island formed as the result of a separation event. The current guidance as to what constitutes an electrical island is contained within the definitions in the respective FOS for Tasmania and the mainland NEM.

For the Tasmanian FOS, the definition of an "island" is as follows:

> "means a part of the Tasmanian power system that includes scheduled generation, networks and load for which all of its alternating current network connections with other parts of the power system have been disconnected"

In the FOS for the mainland NEM the term "island" refers to the definition of an "electrical island" which:

> "means a 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)."

The definition of electrical island in the FOS for the mainland NEM provides further guidance than that in the FOS for Tasmania, in that the maximum size of an electrical islanding is limited to half the generation from two regions. Where the mainland power system is separated so that all parts of the system are larger than this the normal mainland FOS applies. The Panel will consider whether there is a benefit in standardising, where appropriate, the definitions in the FOS for the mainland NEM and Tasmania.

There may also be linkages between the definition of an electrical island and similar concepts in other parts of the regulatory frameworks, including the definition of the protected event, the minimum level of inertia for an electrical island and the definition of a sub-network for the purposes of the system restart standard.

The Panel recognises the potential linkage between the definition of protected event and the characteristics of an electrical island. If a separation event is declared as a protected event then, following the occurrence of that event, the FOS would need to be maintained in the resulting electrical island. This is because the NER requires the power system be returned to a satisfactory operating state, following the occurrence of a credible contingency event or a protected event in accordance with the power system security standards.[81]

The Panel is also aware that in June 2017 the AEMC made a draft determination and draft rule in relation to the provision of inertia to manage high rates of change of power system frequency.[82] Under the draft rule AEMO would determine the minimum level

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81 NER cl. 4.2.4(a)(2) - Secure operating state and power system security

82 AEMC, *Managing the rate of change of power system frequency* - draft determination, 27 June 2017, p.35. The final determination and final rule is scheduled to be published in September 2017.

of inertia required for the electrical islands that can result from separation due to a credible contingency or protected event. In anticipation of the draft rule being finalised, the Panel is considering how these islands may be captured in the definition of an island used in the FOS, including whether the islands due to credible contingency or protected event should be regarded as the minimum sized islands where the FOS should apply.

The Panel acknowledges that it may be appropriate for the FOS to contain further guidance on the characteristics of a viable electrical island. For example, for an electrical island to be viable there would need to be a possibility of separation and a realistic prospect of continued operation after the separation event.[83]One approach may be for AEMO to define the viable electrical islands, based on a guiding principle in the FOS. These guiding principles may be similar in effect to the guidelines for the determination of an electrical sub-network that form part of the system restart standard.

The Panel is also assessing the potential relevance to the island FOS of the electrical sub-networks used for procurement of system restart ancillary services (SRAS).[84] The SRAS electrical sub-networks are chosen so that the procured sources of SRAS are sufficiently well distributed throughout the NEM power system, with one of criterion being,[85]

> "an electrical sub-network should be capable of being maintained in a satisfactory operating state to the extent practicable during the restoration process, and in a secure operating state from a stage in the restoration when it is practicable to do so, as determined by AEMO."

The Panel welcomes comment from stakeholders regarding potential approaches to the definition of an electrical island.

Box 4.3 Question 4 - The treatment of Electrical Islands in the FOS

(a) **What are the basic characteristics of a viable electrical island?**

(b) **If a guideline for an electrical island was defined in the FOS, what characteristics would such a guideline describe?**

(c) **How do the characteristics of an electrical island for the FOS relate to the characteristics of electrical islands formed by credible or protected events, and to the electrical sub-networks used for SRAS procurement?**

(d) **Should a minimum amount of load or generation apply to a viable electrical island? Should other factors also be considered?**

4.3 Other Issues

4.3.1 Accumulated time error

As discussed in section 2.2.3, the FOS currently requires AEMO to limit the accumulated time error in the frequency to:

83 AEMC, *System security market frameworks review* - Direction Paper, 23 March 2017, p. 45.

84 Reliability Panel, 2016, Review of the System Restart Standard, p.104.

85 Ibid.

- 5 seconds for the mainland NEM
- 15 seconds for Tasmania

As discussed in section 2.2.3, the requirement in the FOS for limiting accumulated time error is a carry-over from a time when synchronous clocks that depended on the power system frequency were common place. The Panel understands that limiting the accumulated time error does not improve the reliability or security of the power system, and customers now rely on synchronous electric clocks much less than in the past. In addition, the limit on the accumulated time error is quite separable from the remainder of the FOS. Therefore, the Panel is considering whether this requirement in the FOS is still relevant or can be removed from the FOS.

In considering the relaxation or removal of the requirement of the limit for accumulated time error, the Panel will assess the relative costs and benefits of maintaining, changing or removing this requirement. This will include consideration of the impact of any change on systems that use accumulated time error, any costs associated with changing those systems and any costs related to compliance with the accumulated time error requirement. For example the inclusion of the accumulated time error requirement in the FOS may increase the quantity and total cost of regulation FCAS. There is also the potential that the removal of this requirement may require changes to affected software systems, the updating of which will also have a cost implication.

Currently this accumulated time error requirement in the NEM mainland drives the quantity of regulating FCAS that is procured by AEMO in each dispatch interval. This relationship is described in AEMO's constraint implementation guidelines:

> "Normally, the regulation requirements will be set to a base value (130 MW for raise and 120 MW for lower). If the time error is outside the ±1.5 second band then an extra 60 MW of regulation per 1-second deviation outside this band will be added. This value is capped at 250 MW. This process applies to the global and NEM mainland regulation requirement, but does not apply to the regulation requirements for the Tasmanian region. Regulation for Tasmania is nominally set to 50 MW.[86]"

In the course of this review, the Panel will consider whether there is a basis for relaxing or removing the maximum accumulated time error requirement from the FOS.

The Panel is interested to hear from stakeholders in relation to the option to relax or remove the maximum accumulated time error requirement from the FOS for the NEM mainland and Tasmania.

Box 4.4 Question 5 - Accumulated time error

(a) **What consequences or costs may arises from the relaxation or removal of the accumulated time error requirement from the FOS for the mainland NEM and for Tasmania?**

(b) **What cost do stakeholders incur, if any, of maintaining compliance with the current accumulated time error requirement?**

86 AEMO, 2015, *Constraint Implementation Guidelines for the National Electricity Market*, June 2015, p. 27.

(c) **Are there any other comments or concerns that stakeholders wish to raise with the Panel in relation to accumulated time error?**

4.3.2 Consideration of the definition of terms in the FOS for Tasmania and for the mainland

As part of stage one of the review the Panel will consider the applicability and consistency of the definitions provided in Part D of the FOS for Tasmania and for the mainland. The Panel recognises that these definitions should accurately represent the operational reality of the power system and be consistently applied where practical to do so. While the Panel will consider the applicability and consistency of all of the definitions in the FOS, the key definitions for contingency events that relate to the frequency bands in the FOS are discussed in section 2.2.2.

The Panel is aware that the definition of the term, 'generation event' in the FOS may require particular consideration given the changes underway in the power system.

Generation event in the FOS

Through the Reliability Panel, AEMO has raised a concern relating to the definition of the term “generation event” in the FOS. AEMO’s concern relates both to the consistency of this definition between the FOS for the mainland and the FOS for Tasmania and the applicability of this definition to describe the characteristics of the current power system.

The term “generation event” is defined in the mainland FOS as:

> “a synchronisation of a generating unit of more than 50 MW or a credible contingency, not arising from a network event, a separation event or a part of a multiple contingency event.”

And in the FOS for Tasmania as:

> “a synchronisation of a generating unit of more than 50 MW or a credible contingency event in respect of either a single generating unit or a transmission element solely providing connection to a single generating unit, not arising from a network event, a separation event or a part of a multiple contingency event.”

The Panel understands that AEMO’s concern is related to the current definition of a generation event, which appears to apply only to the sudden tripping of a large generator but does not explicitly cover the sudden and unexpected increase or decrease of generation output from a generator. For example, where the size of a large scale solar photovoltaic (PV) power station exceeds 50MW there is the potential that local climatic conditions, such as changes in cloud cover, could suddenly impact the output of a large scale solar PV power station and result in operational impacts similar to the sudden failure or removal of service of a generating unit of more than 50MW.[87]

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87 Currently the largest solar PV power station operating in the NEM is the Nyngan solar plant comprising 154 generating units with a combined registered capacity of 102MW. The total installed capacity of large scale solar PV power stations is currently 234MW across 7 registered market generators. AEMO is aware of plans for the installation of an additional 6,975 MW capacity of large scale solar PV to be operated as market generators in the NEM.

The Panel is interested in receiving stakeholder comment on this issue, or other issues related to the definitions in the FOS for Tasmania and the mainland.

Box 4.5 Question 6 - Definition of terms in the FOS for Tasmania and for the mainland

(a) **Are there any particular definitions in the FOS for Tasmania and the mainland that stakeholders feel should be standardised?**

(b) **Are there any reasons why particular definitions of terms in the FOS for Tasmania should be different from the same terms in the FOS for the mainland?**

(c) **Do stakeholders have any comments on the current definition of a generation event in the FOS for Tasmania and for the mainland, as it relates to AEMO managing unexpected changes in generation output?**

(d) **Are there any other emerging scenarios or issues that support any changes to the current definitions in the FOS for Tasmania and for the mainland?**

(e) **Are there any other definitions in the FOS, that stakeholders would like the panel to pay particular attention to in relation to their applicability or consistency?**

4.4 Approach to stage two of the Review

As discussed in section 3.2, the Panel intends to progress this review of the FOS in two stages.

The review of the FOS is one part of an integrated approach to addressing current challenges relating to maintaining system security as the NEM undergoes technological transformation. The Panel will pay close attention to the progress of the related system security work packages currently underway by AEMO and the AEMC with a view to determining any changes to the FOS that may be required to support the ongoing security of the NEM power system.

This section sets out a general framework for how the Panel may approach its assessment of stage two of the review. Stage two of the review will involve consideration of the appropriate settings of the various components of the FOS, including the settings of the frequency bands and time for restoration of the frequency following different events.

As discussed in section 3.3.2, the Panel plans to commence stage two of the review when ongoing work relating to frequency control being undertaken by the AEMC and AEMO has been further progressed. The Panel will pay particular attention to the final arrangements for a minimum level of inertia to be confirmed by the AEMC's upcoming final determination for the *Managing the rate of change of power system frequency* rule change. Similarly, the Panel will have regard to any proposed change to the

See:https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Generation-information requirements for mandatory generator governor response coming out of the AEMC's *Frequency control frameworks review*.[88]

Either of these changes are likely to have a bearing on the assessment of the costs and benefits associated with varying the settings of the frequency bands and restoration timeframes in the FOS. For example, the inclusion of a minimum inertia requirement and any requirement for mandatory governor response may act to reduce the relative need for regulation FCAS, which in turn can be expected to decrease the cost of regulation FCAS. There may also be impacts from these changes on the costs and volumes of contingency FCAS. As such, the Panel considers that the current processes considering changes to these elements of the market and regulatory arrangements should be substantially resolved prior to undertaking stage two of the review of the FOS.

Stakeholders are invited to comment on this potential approach and to advise the Panel if they consider that there are other issues to be considered.

The following outlines the main steps of a potential approach that the Panel may use in completing stage 2 of the review of the FOS:[89]

1. **Define the various system frequency issues related to the settings in the FOS**

   The first step in this potential approach would be to define the underlying issues that have been identified in relation to the quality of system frequency performance in the NEM.

   This step is integrally related to the Future power system security work program being undertaken by AEMO, including the diagnostic work currently underway by DIgSILENT as part of the AS-TAG work package discussed in section 3.2.1. This work will be central to clearly defining the issues related to the current settings in the FOS.

   This step of the analysis will help identify whether changes in the generation fleet and related frequency characteristics of the NEM have affected the ongoing appropriateness of the current FOS. The current settings of the FOS were last determined almost a decade ago, when the generation mix was markedly different to today. It is necessary to consider how the current generation mix may be impacting on, or is being affected by, the settings of the FOS.

   More generally, this stage of the Panel's analysis will define the impacts on generators, customers and other market participants related to any identified degradation of frequency performance in the NEM. In particular, the Panel will be interested in understanding how frequency degradation impacts on the performance of generating units or customer equipment. This will help in assessing the relative costs and benefits associated with changing the components of the FOS, as discussed in further detail in step 4 below.

88 The issue of governor response was also identified for consideration by the Finkel review into the NEM. Commonwealth of Australia, *Independent Review into the Future Security of the National Electricity Market: Blueprint for the Future*, 2017, p. 58.

89 Items 1-3 in this list relate primarily to AEMO's *Future power system security work program* which the Panel recognises will provide important technical advice as an input into Stage 2 of the Review of the FOS.

2. **Determine the fundamental physical and operational limits of the system required to maintain system security**

The power system must be operated within a defined envelope of frequency performance, reflecting the physical and operational limits of the power system. Maintaining system frequency within this envelope is fundamental to system security and therefore forms the basis of the FOS.[90]

The boundaries of this envelope of allowable frequency performance reflect the physical capabilities and operational limits of the equipment that makes up the power system. For example, generators can only function effectively and remain connected to the power system if system frequency remains within certain limits. If the system frequency is not maintained within these limits, generators may be damaged or may trip off the system in order to prevent damage from occurring.

As the FOS defines this envelope of allowable frequency performance, it must be set with reference to these physical capabilities and operational limits. For example:

- The extreme frequency excursion tolerance limit is primarily set based on the operational capability of power system equipment. If the frequency moves outside of these limits, there is a possibility that equipment will be damaged and possibly destroyed.
- The limit of the operational frequency tolerance band marks the starting point for the operation of emergency frequency control schemes load shedding schemes. As such, this value fundamentally reflects the operational effectiveness of these schemes to limit the impact of significant multiple contingency events.

The Panel's assessment would initially identify these technical and operational limits, with a view to determining their appropriate level in order to maintain a minimum level of power system security.

As mentioned in step one, there have been significant changes in the physical makeup of the NEM since the FOS was last reviewed. These changes will be particularly relevant to an assessment of these minimum operational and technical limits.

The Panel will be informed by the outcomes of the AEMC's *Frequency control frameworks review*, especially any recommendations relating to the introduction of mandatory governor response for the provision of primary frequency control. The Panel will also seek advice from AEMO in relation to how the FOS may be modified to help improve the frequency performance in the NEM and what the current technical limits of the power system and its components are.[91]

90 The term "envelope" is used here in a general sense to reflect the physical limitations of system operation as they relate to system frequency and should not be confused with the specific meaning of the technical envelope, as defined in NER cl. 4.2.5.

91 This advice from AEMO will be informed by the ongoing diagnostic work into the degradation of the power system frequency performance, including the causes, consequences and possible solutions.

3. **Determine the settings in the standard to be set based on an economic trade-off**

   This potential approach may then consider which elements of the FOS might be set with a view to delivering a level of additional power system security, above and beyond the mandatory requirements necessary to reflect the technical and operational envelope of the power system.

   The relevant elements of the FOS that may be varied based on the outcomes of a cost benefit assessment may include:

   - The normal operating frequency band and the normal operating excursion band, including the requirement to stay within the normal operating frequency band for 99% of the time.
   - The stabilisation and restoration timeframes.

   This aspect of the Panel's analysis will set up the review to consider trade-offs between the benefits of additional security against the costs of providing that additional security. The process that the Panel is likely to follow in assessing these trade-offs are discussed in more detail in step 5 below.

4. **Definition of combinations of changes to the FOS that may deliver improved frequency performance**

   There may be a number of different combinations of settings of the components of the FOS. This may include a range of combinations of different settings for the various frequency bands and the restoration timeframes.

   It is necessary to consider changes to the FOS settings in terms of different combinations, as the settings of each of the FOS component are likely to interact with each other. For example, a change to the frequency bands for the normal operating frequency band may impact on the process of restoring the system frequency following a contingency event. This may in turn require a reconsideration of the system restoration timeframes following a contingency event.

   The Panel will seek to identify a number of options that reflect different combinations of changes to the settings of the FOS components. Specifically, these options are likely to involve different combinations of the following components of the FOS:

   - the frequency limits for:
     - the normal operating frequency band
     - the normal operating frequency excursion band
   - the percentage of time that the power system must be maintained within the normal operating frequency band (currently set at 99%)
   - the stabilisation and restoration times.

   The Panel will be guided in this task by the progress and developments of ongoing related work programs including the AEMC's *Frequency control frameworks review* and AEMO advice as to where potential improvements may be found in the FOS.

The process that the Panel is likely to follow in assessing these options is discussed in step 5 below.

5. **Assess the range of options identified in step 4 against the NEO**

   Finally the panel will undertake an economic assessment of the options identified in step 4 to support its determination of any changes to the FOS.

   The Panel's assessment of the options for revising the FOS will be guided by the framework principles outlined in the NEO. This requires that any additional security benefits provided by any changes to the FOS be considered in the context of all associated economic costs.

   Such an assessment must take into account the trade-offs associated with achieving different levels of power system frequency performance and stability. These trade-offs are typically between the beneficial outcomes for consumers of increased security (such as avoided load shedding, major supply disruption or a black system event, weighted by the probability of these events occurring), against the incurred costs associated with avoiding these events (such as the cost of ancillary services or dispatch constraints that are needed to deliver this increased security).

   The nature of this assessment is illustrated by the recommendations made in the Independent Review into the Future Security of the National Electricity Market (the Finkel Review) that the costs and benefits of tightening the FOS be considered.[92]

   As noted above, tightening of the FOS in this context could include changes such as narrowing the normal operating frequency band, which may drive an increased level of power system security by increasing the time the frequency is close to 50Hz and away from the load shedding range.[93] However, this may also come at a cost, associated with an increase in the quantity of regulating FCAS procured by AEMO to maintain the system frequency within a narrower normal operating frequency band. Factors other than FOS settings may also impact on actually achieving increased power system security, such as the rate of change of frequency following a disturbance and the speed in which regulating FCAS is actually capable of responding.[94]

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92 Commonwealth of Australia 2017, *Independent Review into the Future Security of the National Electricity Market – Blueprint for the Energy Future*, p. 22.

93 Ibid. p.58. The Panel also recognises that other regulatory and market arrangements, external to the settings of the FOS, are equally likely to impact the frequency performance of the power system. These factors include the design and operation of FCAS markets and the conditions for the connection of generators such as the required level of generator governor control and governor deadband limits. These broader market arrangements may have an equally significant impact on frequency control as any changes made to the boundaries of the frequency bands in the FOS.

94 The speed of operation of regulating FCAS is dependent upon the speed of the Automatic Generation Control system (AGC). In their submission to the System security market frameworks review, Pacific Hydro note that the effectiveness of the AGC system may be impacted by time delays associated with the frequency measurement, communications and error calculation. See: Pacific Hydro, 6 February 2017, Submission to the AEMC's Interim Report – System security market frameworks review, p. 3.

The ability to accurately assess each of the options is dependent on any future decision to introduce a mandatory governor response requirement into the NER, which is a topic for consideration as part of the AEMC's *Frequency control frameworks review*.[95]

Any introduction of a requirement for mandatory governor response may have implications for the quantity of regulation FCAS that AEMO procures to maintain the frequency of the system within the normal operating frequency band. This will in turn have implications for the costs of these regulation services.

The Panel will consider the impacts of this proposed change, particularly as it impacts on the quantities of the different FCAS types required and the associated costs of those services, as a key input of an economic assessment of any potential change to the frequency bands in the FOS.

The Panel considers that the steps outlined above will allow it to consider all of the issues relevant to reassessing the frequency bands and timeframes of the FOS. Stakeholders are invited to provide comment on this proposed approach, including whether there are any specific issues that the Panel should consider in stage 2.

Box 4.6 Question 7 - Issues related to the proposed approach to stage two of the Review

(a) **Generally, do stakeholders consider the approach defined above represents a sensible way to assess the FOS? Are there any additional issues that need to be included in the Panel's assessment?**

(b) **What are the implications for the FOS of changes to the generation mix over the last decade?**

(c) **From a generator, network or consumer perspective, have stakeholders directly observed any evidence of poor power system frequency quality impacting their operations or equipment?**

(d) **If so, please describe the characteristics of the poor power system frequency quality observed, the impacts on equipment and the costs incurred as a result?**

(e) **Is the potential approach of defining combinations of changes to the FOS components a sensible way to assess the FOS?**

95 AEMC, *System security market frameworks review*- final report, 27 June 2017, p. 38-42.

Abbreviations

AC	alternating current
AGC	automatic generation control
AS-TAG	Ancillary Services Technical Advisory Group
DC	direct current
EFCS	emergency frequency control schemes
ESCOSA	Essential Services Commission of South Australia
FCAS	frequency control ancillary services
FFR	fast frequency response
FOS	frequency operating standards
GW	Giga-Watt
MW	Mega-Watt
NEL	National Electricity Law
NEM	National Electricity Market
NEMDE	National electricity market dispatch engine
NEO	National Electricity Objective
NER	National Electricity Rules
TNSP	transmission network service provider

A Terms of Reference

Introduction

Under section 38 of the National Electricity Law (NEL) and clause 8.8.3(c) of the National Electricity Rules (NER), the Australian Energy Market Commission (AEMC) requests that the Reliability Panel (the Panel) undertake a review of the frequency operating standards that apply in the National Electricity Market (NEM). This review is related to and is intended to complement the ongoing work program that the AEMC is undertaking to enable the maintenance of power system security in the NEM.

Background

The frequency operating standards (FOS): NER clause 8.8.1(a)(2) requires the Reliability Panel to review and, on the advice of AEMO, determine the power system security standards. These standards may include various matters but at present include standards for the range of allowable frequency of the power system under different conditions, including normal operation and following contingencies. These standards are set out in the FOS.

The FOS set out the frequency standards to which AEMO operates the power system. This includes defined frequency bands and timeframes in which the system frequency must be restored to these bands following different events, such as the failure of a transmission line or separation of a region from the rest of the NEM. These requirements then inform how AEMO operates the power system, including through applying constraints to the dispatch of generation or procuring ancillary services.

The FOS currently consists of two separate standards: one for the mainland NEM, and one for Tasmania. This reflects the different physical and market characteristics of the Tasmanian region as opposed to the mainland NEM. The frequency operating standard for Tasmania was last reviewed and determined by the Reliability Panel on 18 December 2008. The frequency operating standard for the mainland was last reviewed and determined by the Reliability Panel on 16 April 2009.

The Panel's role and responsibility in relation to the FOS: Clause 8.8.1(a)(2) of the National Electricity Rules (NER or the rules) requires the Reliability Panel to: "review and, on the advice of AEMO, determine the power system security standards". The reliability panel is required to determine the FOS as a subset of the power system security standards.

The Emergency frequency control scheme rule change: On 30 March 2017 the AEMC published the final rule and accompanying final determination for the Emergency Frequency Control Schemes rule change (ERC0212).

A number of issues relevant to the Panel's review of the FOS were identified or addressed in the final rule determination of the emergency frequency control schemes rule change. These include:

- A review of the appropriateness of the requirements in the FOS that relate to multiple contingency events.[96]Currently, the FOS defines the standard to which AEMO manages the power system following any multiple contingency event. AEMO has argued that this is impractical, as it is not possible to maintain the FOS for all multiple contingencies.
- How the new event classification for "protected events" can best be incorporated into the FOS. The Emergency frequency control schemes rule change introduced a new category of contingency event, the "protected event". AEMO is now required to maintain the frequency of the power system within certain bands for these events. These requirements will be defined in the FOS.

The final rule for the Emergency frequency control schemes rule change includes an interim frequency standard that shall apply for any protected event(s) that may be declared prior to this review of the FOS being completed. Accordingly, following the review, the revised FOS for protected events may replace this interim requirement.

Scope of the review

The Panel is requested to undertake a review of the NEM mainland and the Tasmanian frequency operating standards.

In undertaking this review, the Panel should give consideration to key system security issues currently being addressed by the AEMC and AEMO. This should include, but is not limited to, the consequences of the changing NEM generation fleet, including the impacts of decreased system inertia and associated rates of change of frequency following a contingency event.

In particular, the Panel should give consideration to the findings and recommendations of the following work programs:

- The AEMC's system security market framework review; and
- AEMO's Future Power System Security review.

Given these key issues and the ongoing work program, in undertaking this review, the Panel should give consideration to:

- Whether the terminology, standards and settings in the FOS remain appropriate.
- What amendments to the FOS may be necessary in light of the AEMC's final determination of the Emergency frequency control schemes rule change published on 30 March 2017.
- Whether further guidance can be provided regarding the definition of what part of the power system the FOS is to be applied following separation from the rest of the NEM. Specifically, whether the FOS should refer to a separated region, or some smaller sub-section of a region, for maintenance of frequency following a separation event.

The Panel's review of the FOS must consider and determine FOS to apply to both Tasmania and the mainland regions of the NEM. This must include consideration of the

96 Part B(f) of the Frequency Operating Standard for the mainland. Part B(g) of the Frequency Operating Standard for Tasmania.

different physical and market characteristics relating to the power system. Given that Tasmania and the mainland are electrically separated in terms of frequency, the review shall consider the different physical and market characteristics of each of these regions in determining the settings for the FOS.

Timing and Consultation Process

The Panel must carry out the review to develop the FOS in accordance with the following process:

- Give notice to all registered participants of commencement of this review.
- Publish an issues paper for consultation with stakeholders following the notification of the commencement of the review and invite submissions for a period of at least four weeks. This paper should outline the key issues and questions the Panel will consider when determining the FOS.
- Publish a draft report and invite submissions for a period of at least six weeks.
- At the time of publishing the draft report, notify stakeholders that they may request a public meeting on the draft report within five business days of the draft report being published.
- If stakeholders have requested a public meeting, notify stakeholders that a public meeting will be held. At least two weeks' notice of the public meeting must be given.
- Publish a final report and submit this report to the AEMC no later than six weeks after the period for consultation on the draft report has closed.

The Panel may decide on its own timing for delivery of the review, provided the review is completed by 22 December 2017.

B Current Frequency Operating Standard for the NEM Mainland

B.1 Part A Summary of the FOS

The NEM Mainland *frequency operating standards* set out in Part B are summarised in the following tables for convenience. To the extent of any inconsistency between these tables and Part B below, Part B prevails. The following table applies to any part of the NEM Mainland *power system*, other than an *island* or during periods of supply scarcity during load restoration:

Table B.1 NEM Mainland Frequency Operating Standards – interconnected system

Condition	Containment	Stabilisation	Recovery
Accumulated time error	5 seconds	n/a	n/a
No contingency event or load event	49.75 to 50.25 Hz, 49.85 to 50.15 Hz - 99% of the time	49.85 to 50.15 Hz within 5 minutes	
Generation event or load event	49.5 to 50.5 Hz	49.85 to 50.15 Hz within 5 minutes	
Network event	49 to 51 Hz	49.5 to 50.5 Hz within 1 minute	49.85 to 50.15 Hz within 5 minutes
Separation event	49 to 51 Hz	49.5 to 50.5 Hz within 2 minutes	49.85 to 50.15 Hz within 10 minutes
Multiple contingency event	47 to 52 Hz	49.5 to 50.5 Hz within 2 minutes	49.85 to 50.15 Hz within 10 minutes

Table B.2 NEM Mainland Frequency Operating Standards – island system

Condition	Containment	Stabilisation	Recovery
No contingency event, or load event	49.5 to 50.5 Hz		
Generation event, load event or network event	49 to 51 Hz	49.5 to 50.5 Hz within 5 minutes	
The separation event that formed the island	49 to 51 Hz or a wider band notified to AEMO by a relevant Jurisdictional Coordinator	49.0 to 51.0 Hz within 2 minutes	49.5 to 50.5 Hz within 10 minutes
Multiple contingency event including a further separation	47 to 52 Hz	49.0 to 51.0 Hz within 2 minutes	49.5 to 50.5 Hz within 10 minutes

Condition	Containment	Stabilisation	Recovery
event			

Table B.3 NEM Mainland Frequency Operating Standards – during supply scarcity

Condition	Containment	Stabilisation	Recovery
No contingency event or load event	49.5 to 50.5 Hz		
Generation event, load event or network event	48 to 52 Hz (Queensland and South Australia) 48.5 to 52 Hz (New South Wales and Victoria)	49 to 51 Hz within 2 minutes	49.5 to 50.5 Hz within 10 minutes
Multiple contingency event or separation event	47 to 52 Hz	49.0 to 51.0 Hz within 2 minutes	49.5 to 50.5 Hz within 10 minutes

The mainland *frequency operating standards* during *supply scarcity* apply if:

1. A situation of *supply scarcity* is current.
2. In cases where an island incorporates more than one region then the critical frequency to be adopted be the maximum value of the critical frequencies for these regions (e.g. for an island comprised of the regions of Victoria and South Australia the critical frequency would be 48.5 Hz)
3. The power system has undergone a contingency event, the frequency has reached the Recovery frequency band and NEMMCO considers the power system is sufficiently secure to begin load restoration.
4. The estimated amount of load available for under-frequency load shedding within the power system or the island is more than the amount required to ensure that any subsequent frequency excursions would not go below the proposed Containment and Stabilisation bands as a result of a subsequent generation event, load event, network event or a separation event during load restoration.
5. The amount of generation reserve available for frequency regulation is consistent with NEMMCO's current practice.

B.2 Part B - The Frequency Operating Standards

For the purposes of Chapter 4, 5 and 10 of the Rules, the *frequency operating standards*, forming part of the power system security and reliability standards, are:

(a) except in an island or during load restoration, the accumulated time error should not exceed 5 seconds;

(b) except as a result of a contingency event or a load event, system frequency should not exceed the applicable *normal operating frequency excursion band* and should not exceed the applicable *normal operating frequency band* for more than five minutes on any occasion and not for more than 1% of the time over any 30 day period;

(c) as a result of a generation event or a load event, system frequency should not exceed the applicable generation and load change band and should not exceed the applicable *normal operating frequency band* for more than five minutes;

(d) as a result of any network event, system frequency should not exceed the applicable *operational frequency tolerance band* and should not exceed the applicable generation and load change band for more than one minute or exceed the applicable *normal operating frequency band* for more than five minutes;

(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.

B.3 Part C - Application of Rules Terms

For the purposes of these frequency operating standards and Chapters 4, 5 and 10 of the Rules, a term shown in Column 1 of the following table has the corresponding range shown in Column 3 of the table for an island and has the corresponding range shown in Column 2 of the table otherwise.

Table B.4 NEM Mainland Frequency Operating Standards – Rule terms

Column 1	**Column 2**	**Column 3**	**Column 4**
Term	**Normal range (Hz)**	**Island range (Hz)**	**Restoration range (Hz)**
normal operating frequency band	49.85 to 50.15	49.5 to 50.5	49.5 to 50.5
normal operating frequency excursion band	49.75 to 50.25	49.5 to 50.5	49.5 to 50.5
operational frequency tolerance band	49.0 to 51.0	49.0 to 51.0	48.0 to 52.0
extreme frequency excursion tolerance limit	47.0 to 52.0	47.0 to 52.0	47.0 to 55.0

B.4 Part D - Definitions

Words and phrases shown in Italics in this document have the meaning given to them in the following table:

Table B.5 Mainland Frequency Operating Standard - Glossary

Term	Meaning
abnormal frequency island	means 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).*
accumulated time error	means, in respect of a measurement of *system frequency* that NEMMCO uses for controlling *system frequency*, the integral over time of the difference between 20 milliseconds and the inverse of that *system frequency*, starting from a time *published* by *NEMMCO*.
available capacity	has the meaning given to it in the Rules.
connection point	has the meaning given to it in the Rules.
contingency event	has the meaning given to it in the Rules.
credible contingency event	has the meaning given to it in the Rules.
electrical island	means a 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	has the meaning given to it in the Rules.
frequency operating standards	has the meaning given to it in the Rules and are the standards set out in Part B of this document.
generating unit	has the meaning given to it in the Rules.
generation	has the meaning given to it in the Rules.
generation and load change band	means the frequency range of 49.0 to 51.0 Hz in respect of an island and the frequency range of 49.5 to 50.5 Hz otherwise .
generation event	means a synchronisation of a generating unit

Term	Meaning
	of more than 50 MW or a credible contingency, not arising from a network event, a separation event or a part of a multiple contingency event.
island	means either an electrical island or an abnormal frequency island.
island separation band	means: (a) in respect of a part of the *power system* that is not an island, the *operational frequency tolerance band;* (b) in respect of an *island* that includes a part of the power system to which no notice under paragraph (c) applies, the *operational frequency tolerance band;* and (c) otherwise in respect of an *island*, the frequency band determined by the most restrictive of the high limits and low limits of frequency ranges outside the *operational frequency tolerance band* notified by *Jurisdictional Coordinators* to NEMMCO with adequate notice to apply to a nominated part of the *island* within their respective jurisdictions.
Jurisdictional Coordinator	has the meaning given to it in the Rules.
load	has the meaning given to it in the Rules.
load event	means an identifiable connection or disconnection of more than 50 MW of customer load (whether at a *connection point* or otherwise), not arising from a *network event, a generation event, a separation event* or a part of a *multiple contingency event*.
multiple contingency event	means either a *contingency event* other than a *credible contingency event,* a sequence of *credible contingency events* within a period of 5 minutes, or a further *separation event in an island.*
NEMMCO	has the meaning given to it in the Rules.
network	has the meaning given to it in the Rules.
network event	means a *credible contingency event* other than a *generation event*, a separation event or a part of a *multiple contingency event.*
normal operating frequency band	has the meaning given to it in the Rules.
normal operating frequency excursion band	has the meaning given to it in the Rules.
operational frequency tolerance band	has the meaning given to it in the Rules.

Term	Meaning
power system	has the meaning given to it in the Rules.
power system security and reliability standards	has the meaning given to it in the Rules.
publish	has the meaning given to it in the Rules.
region	has the meaning given to it in the Rules.
separation event	means a *credible contingency* event in relation to a *transmission element* that forms an *island.*
supply scarcity	means the condition where *load* has been disconnected either manually or automatically, other than in accordance with dispatch instructions or service provision, and not yet restored to supply.
synchronisation	has the meaning given to it in the Rules.
system frequency	means the frequency of a part of the *power system,* including the *frequency* of an *island.*
transmission element	has the meaning given to it in the Rules.

C Current Frequency Operating Standard for Tasmania

C.1 Part A Summary of the Standards

The Tasmanian frequency operating standards set out in Part B of this appendix are summarised in the following tables for convenience. To the extent of any inconsistency between these tables and Part B below, Part B prevails. Table A1 applies to any part of the Tasmanian power system:

Table C.1 Tasmanian frequency operating standards – interconnected system

Condition	Containment	Stabilisation	Recovery
Accumulated time error	15 seconds		
No contingency event or load event	49.75 to 50.25 Hz 49.85 to 50.15 Hz, 99% of the time	49.85 to 50.15 Hz within 5 minutes	
Load event	48.0 to 52.0 Hz	49.85 to 50.15 Hz within 10 minutes	
Generation event	48.0 to 52.0 Hz	49.85 to 50.15 Hz within 10 minutes	
Network event	48.0 to 52.0 Hz	49.85 to 50.15 Hz within 10 minutes	
Separation event	47 to 55 Hz	48.0 to 52.0 Hz within 2 minutes	49.85 to 50.15 Hz within 10 minutes
Multiple contingency event	47 to 55 Hz	48.0 to 52.0 Hz within 2 minutes	49.85 to 50.15 Hz within 10 minutes

Table A2 applies to an island within the Tasmanian power system:

Table C.2 Tasmania frequency operating standards – island operation

Condition	Containment	Stabilisation	Recovery
No contingency event or load event	49.0 to 51.0 Hz		
Load and generation event	48.0 to 52.0 Hz	49.0 to 51.0 Hz within 10 minutes	
Network event	48.0 to 52.0 Hz	49.0 to 51.0 Hz within 10 minutes	
Separation event	47 to 55 Hz	48.0 to 52.0 Hz within 2 minutes	49.0 to 51.0 Hz within 10 minutes
Multiple contingency event	47 to 55 Hz	48.0 to 52.0 Hz within 2 minutes	49.0 to 51.0 Hz within 10 minutes

C.2 Part B: the Frequency operating standards

For the purposes of the Rules, the frequency operating standards, forming part of the power system security and reliability standards, that apply in Tasmania are:

(a) except in an island or following a *multiple contingency event,* the *accumulated time error* should not exceed 15 seconds;

(b) except as a result of a *contingency* or a l*oad event, system frequency* should not exceed the applicable *normal operating frequency excursion band* and should not exceed the applicable *normal operating frequency band* for more than five minutes on any occasion and for not more than 1% of the time over any 30 day period;

(c) as a result of a *generation event, system frequency* should not exceed the applicable *generation change band* and should not exceed the applicable *normal operating frequency band* for more than 10 minutes;

(d) as a result of a *load event, system frequency* should not exceed the *load change band* and should not exceed the applicable *normal operating frequency band* for more than 10 minutes;

(e) as a result of any *network event, system frequency* should not exceed the applicable *operational frequency tolerance band* and should not exceed the applicable *load change band* for more than one minute or the applicable *normal operating frequency band* for more than 10 minutes;

(f) as a result of any *separation event, system frequency* should not exceed the applicable *island separation band* and should not exceed the applicable *load change band* for more than two minutes or the applicable *normal operating frequency band* for more than 10 minutes;

(g) as a result of any *multiple contingency event, system frequency* should not exceed the applicable *extreme frequency excursion tolerance limits* and should not exceed the applicable *load change band* for more than two minutes while there is no *contingency event* or the applicable *normal operating frequency band* for more than 10 minutes while there is no *contingency even*t;

(h) the size of the largest single generator event is limited to 144 MW,[97]which can be implemented for any *generating system* with a capacity that is greater than 144 MW by the automatic tripping of load;

(i) these frequency operating standards will take effect on completion of the following:

    (i) under frequency load shedding scheme (UFLS); and

    (ii) over-frequency generator shedding scheme (OFGSS); and

    (iii) revised FCAS trapeziums and control settings for Tasmanian generating units; and

97 NEMMCO may in accordance with clause 4.8.9 direct a Generator to exceed the 144 MW contingency limit if NEMMCO reasonably believes this would be necessary in order to maintain a reliable operating state.

(iv) frequency control special protection scheme (FCSPS); and

(v) Basslink frequency controller;

which must be no later than 31 December 2009, or a date agreed by the *Reliability Panel* in accordance with the consultation process under clause 8.8.3.

C.3 Part C Application of Rules terms

For the purposes of these frequency operating standards and the Rules, a term shown in column 1 of the following table has the corresponding range shown in column 3 of the table for an island and has the corresponding range shown in column 2 of the Table otherwise.

Tasmanian Frequency Operating Standards – Rule terms

Term	Normal range (Hz)	Island range (Hz)
normal operating frequency band	49.85 to 50.15	49.0 to 51.0
normal operating frequency excursion band	49.75 to 50.25	49.0 to 51.0
operational frequency tolerance band	48.0 to 52.0	48.0 to 52.0
extreme frequency excursion tolerance limit	47.0 to 55.0	47.0 to 55.0

C.4 Part D Definitions

Words and phrases shown in italics in this document have the meaning given to the in the following table:

Table C.3 Revised Tasmanian frequency operating standards – glossary

Term	Reference	Meaning
Accumulated time error		*Accumulated time error* means, in respect of a measurement of *system frequency* that NEMMCO uses for controlling *system frequency*, the integral over time of the difference between 20 milliseconds and the inverse of that *system frequency*, starting from a time published by NEMMCO
Rules		The Rules means National Electricity Rules
Connection point	Glossary - NER	The agreed point of supply established between *Network*

Term	Reference	Meaning
		Service Provider(s) and another *Registered Participant,* NonRegistered Customer or franchise customer.
Contingency event	Clause 4.2.3(a) – NER	A *"contingency event*" means an event affecting the power system which NEMMCO expects would be likely to involve the failure or removal from operational service of a *generating unit* or *transmission element.*
Credible contingency event	Clause 4.2.3(b), Schedule 5.1 – NER	A "*credible contingency event* " means a contingency event the occurrence of which NEMMCO considers to be reasonably possible in the surrounding circumstances including the technical envelope. Without limitation, examples of *credible contingency events* are likely to include: • the unexpected automatic or manual disconnection of, or the unplanned reduction in capacity of, one operating generating unit; or • the unexpected disconnection of one major item of *transmission plant* (e.g. transmission line, transformer or reactive plant) other than as a result of a three phase electrical fault anywhere on the *power system*.
Extreme frequency excursion tolerance limits	Glossary - NER	In relation to the frequency of the *power system,* means the limits so described and specified in the *power system security and reliability standards.*
Generating unit	Glossary - NER	The actual *generator* of electricity and all the related equipment essential to its functioning as a single entity.
Generating system	Glossary - NER	(a) Subject to paragraph (b), for the purposes of the Rules, a system

Term	Reference	Meaning
		comprising one or more *generating units*. (b) For the purposes of clause 2.2.1(e)(3), clause 4.9.2, Chapter 5 and a jurisdictional derogation from Chapter 5, a system comprising one or more *generating units* and includes auxiliary or reactive plant that is located on the *Generator's* side of the *connection point* and is necessary for the *generating system* to meet its *performance standards.*
Generation	Glossary - NER	The production of electrical power by converting another form of energy in a *generating unit.*
Generation change band		means the frequency range of 48.0 to 52.0 Hz in respect of an island and otherwise.
Generation event		means a *synchronisation* of a *generating unit* of more than 50 MW or a *credible contingency event* in respect of either a single generating unit or a *transmission element* solely providing *connection* to a single generating unit, not arising from a *network event,* a separation event or a part of a *multiple contingency event.*
Interconnector	Glossary - NER	A *transmission line* or group of *transmission lines* that connects the *transmission networks* in adjacent regions.
Island		means a part of the Tasmanian *power system* that includes *scheduled generation, networks and load* for which all of its alternating current network connections with other parts of the *power system* have been disconnected
Island separation band		means the *extreme frequency excursion tolerance limits*

Term	Reference	Meaning
Load	Glossary - NER	A *connection point* or defined set of *connection points* at which electrical power is delivered to a person or to another *network* or the amount of electrical power delivered at a defined instant at a *connection point,* or aggregated over a defined set of *connection points*
Load change band		means the frequency range of 48.0 to 52.0 Hz in respect of an island and otherwise.
Load event		means an either an identifiable increase or decrease of more than 20 MW of customer load (whether at a *connection point* or otherwise), or a rapid change of flow by a *high voltage* direct current interconnector to or from 0 MW for the purpose of starting, stopping or reversing its power flow, not arising from a network event, a *generation event, a separation event* or a part of a *multiple contingency event*
Market network service provider	Glossary - NER	A *Network Service Provider* who has classified any of its *network services* as a *market network service* in accordance with Chapter 2 and who is also registered by *NEMMCO* as a *Market Network Service Provider* under Chapter 2.
Multiple contingency event		means either a *contingency event* other than a *credible contingency event,* a sequence of *credible contingency events* within a period of 5 minutes, or a further *separation event* in an island
National grid	Glossary - NER	The sum of all *connected transmission* and *distribution systems* within the participating jurisdictions
NEMMCO	Glossary - NER	National Electricity Market Management Company

Term	Reference	Meaning
		Limited A.C.N. 072 010 327.
Network	Glossary - NER	The apparatus, equipment, *plant* and buildings used to convey, and control the conveyance of, *electricity to customers* (whether *wholesale* or *retail*) excluding any connection assets. In relation to a *Network Service Provider,* a network owned, operated or controlled by that *Network Service Provider*
Network event		means a *credible contingency event* other that a *generation event,* a *separation event* or a part of a *multiple contingency event*
Normal operating frequency band	Glossary - NER	In relation to the *frequency* of the *power system,* means the range 49.85 Hz to 50.15 Hz or such other range so specified in the *power system security and reliability standards.*
Normal operating frequency excursion band	Glossary - NER	In relation to the *frequency* of the *power system,* means the range specified as being acceptable for infrequent and momentary excursions of *frequency* outside the *normal operating frequency band,* being the range of 49.75 Hz to 50.25 Hz or such other range so specified in the *power system security and reliability standards.*
Operational frequency tolerance band	Glossary - NER	The range of *frequency* within which the *power system* is to be operated to cater for the occurrence of a *contingency event* as specified in the *power system security and reliability standards.*
Power system	Glossary - NER	The electricity *power system* of the *national grid* including associated *generation* and *transmission* and *distribution networks* for the supply of electricity, operated as an integrated arrangement.
Power system security and reliability standards	Glossary - NER	The standards governing *power system security and reliability* of the power system

Term	Reference	Meaning
		which are approved by the *Reliability Panel* on the advice of *NEMMCO.* They may include but are not limited to standards for the frequency of the power system in operation, contingency capacity reserves (including guidelines for assessing requirements and utilisation), *short term capacity reserves, medium term capacity reserves* and *system restart.*
Publish	Glossary - NER	Make available to Registered Participants electronically.
Separation event		means a *credible contingency event* in relation to a t*ransmission element* that forms an island.
Synchronisation	Glossary - NER	The act of synchronising a *generating unit* or a scheduled network service to the *power system*
System frequency		means the *frequency* of a part of the *power system,* including the *frequency* of an island.
Technical envelope	NER Clause 4.2.5	means the technical boundary limits of the *power system* for achieving and maintaining a *secure operating state of the power system* for a given demand and *power system* scenario.
Transmission line	Glossary NER	A power line that is part of a *transmission network.*
Transmission element	Glossary - NER	A single identifiable major component of a *transmission system* involving: (a) an individual *transmission circuit* or a phase of that circuit; (b) a major item of *transmission plant* necessary for the functioning of a particular *transmission circuit or connection point* (such as a transformer or a circuit breaker).
Transmission network	Glossary - NER	A network within any participating jurisdiction

Term	Reference	Meaning
		operating at nominal voltages of 220 kV and above plus: • any part of a network that operates at *nominal voltages* between 66 kV and 220 kV that operates in parallel to and provides support to the *high voltage transmission network;* • any part of a network that operates at *nominal voltages* between 66 kV and 220 kV that is not referred to in paragraph (a) but is deemed by the AER to be part of the *transmission network.*

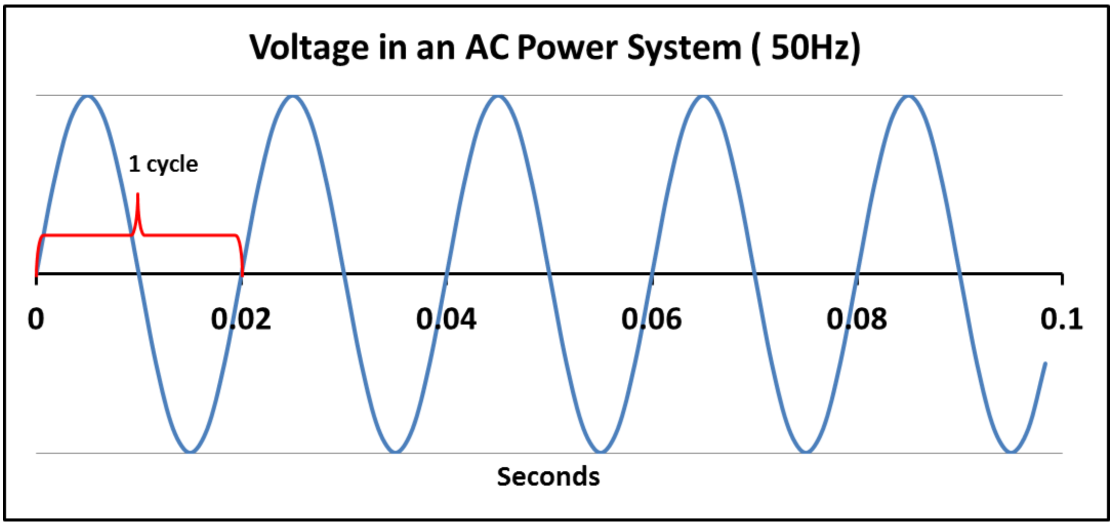
D What is power system frequency and frequency control

D.1 What is power system frequency?

The NEM, like most modern power systems, generates and transfers electricity via an alternating current (AC) power system.[98]

In an AC power system, voltage oscillates between negative and positive charge at a given rate. This can be represented by the following wave diagram, which shows how voltage shifts from positive to negative over a specific time. The number of complete cycles that occur within one second is called the "frequency" and is measured in Hertz (Hz).[99]The voltage waveform corresponding to a frequency of 50Hz is shown in Figure D.1.

Figure D.1 Voltage in an AC power system



In Australia all generation, transmission, distribution and load components connected to the power system are standardised to operate at a nominal system frequency of 50 Hertz (Hz).[100]

This frequency is directly related to the operation of generating equipment. Electricity in an AC system has traditionally been produced by large generators that rotate what is effectively a very large magnet within a housing of copper wire coil. This rotating magnet (called the rotor) induces a current to flow in the static coil (called a stator).

The speed at which the rotor spins in the stator corresponds to how "quickly" the oscillations between positive and negative occur.

98 By way of explanation, electrical power can be transferred by means of direct current (DC) or alternating current (AC). In a DC system the direction of current flow is constant, whereas in an AC system the direction of current flow periodically reverses. The power transfer in an AC system occurs through the oscillation of electrons in the transmission and distribution system, rather than through the direct movement or "flow" of electrons.

99 The term "Hertz" is the international standard unit for frequency named after Heinrich Rudolf Hertz who was a German physicist who proved the existence of electromagnetic waves.

100 Other power systems operate at different standard frequencies; for example the nominal power system frequency in the United States and Canada is 60Hz, while Europe and the United Kingdom operate their power systems at 50Hz.

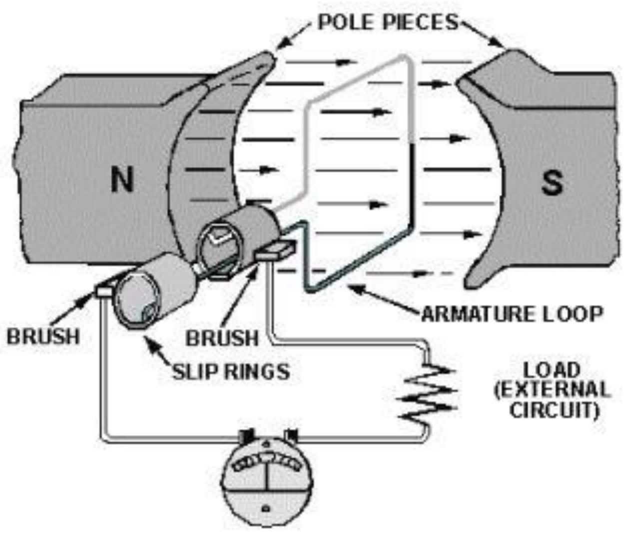
Put another way, the speed of the frequency of an AC system corresponds to the speed of rotation of generators. This is described in box 1, which explains the basic operation of an AC induction generator.

Box D.1 Principles of AC power generation

A basic AC generator produces electricity by the interaction of loops of copper wire and a magnetic field. The term "armature", refers to the electrical components that produce the output power. In order to generate electricity either the armature or the magnet can be rotating, depending on the specific generator design.

To understand the basic principles of AC generation it is useful to consider a generator comprised of a single rotating armature loop, the rotor, within a stationary magnetic field produced by the stator. This arrangement is shown in Figure D.2. In this arrangement, the armature is connected to an electric circuit, and any loads (such as lights and motors) via slip rings and brushes.

Figure D.2 Basic AC generator assembly[101]



As the generator windings rotate within the magnetic field, a voltage is induced in the windings along with the associated electric circuit. Figure D.3, displays how as the armature loop is rotated clockwise, its position and movement within the magnetic field produce the voltage wave corresponding to an AC power source.

Point A

The armature loop is perpendicular to the magnetic field. The windings in the armature loop are moving parallel to the field and the resultant voltage is zero.

101 Naval Education and Training Professional Development and Technology Center, 1998, Navy Electricity and Electronics Training Series Module 5—Introduction to Generators and Motors, NAVEDTRA 14177. Sourced at: https://maritime.org/doc/neets/mod05.pdf, 16 May 2017.

Point B

The armature loop is aligned to the magnetic field. The windings in the armature loop are cutting through the field and the resultant voltage is a maximum positive value.

Point C

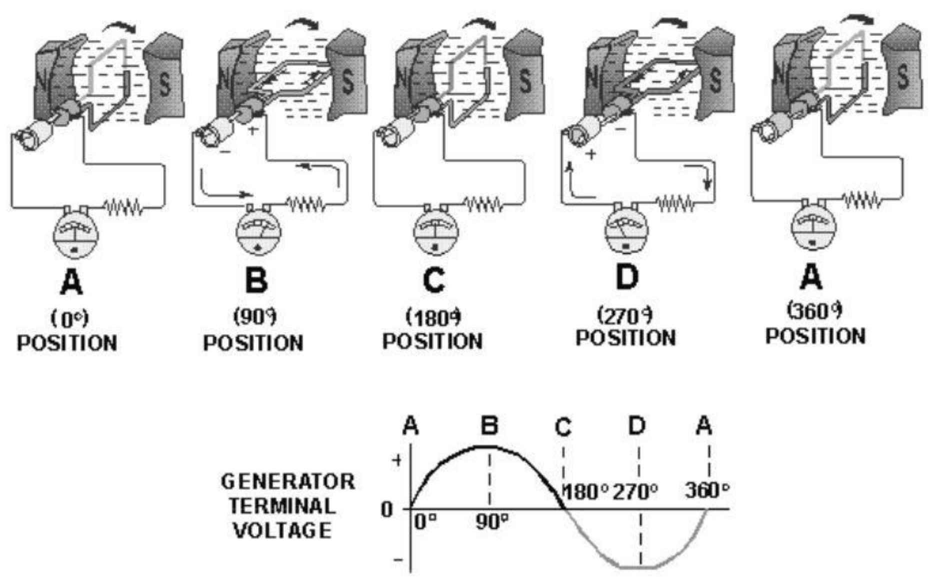
The armature loop is perpendicular to the magnetic field. The windings in the armature loop are moving parallel to the field and the resultant voltage is zero.

Point D

The armature loop is aligned to the magnetic field. The windings in the armature loop are cutting through the field and the resultant voltage is a maximum negative value.

After a complete revolution the armature loop returns to the position A and the resultant voltage returns to zero.

Figure D.3 Function of a basic AC Generator[102]



In the NEM, the standard frequency of the power system of 50 Hz corresponds to basic two pole generator rotating at a speed of 3000 rpm.[103]

102 Ibid.

103 While the above example is useful in explaining the basic principles of AC power generation, it is important to recognise that most synchronous AC generators in power systems employ a rotating electro-magnet within a stator housing comprised of the armature windings. The principle of operation is the same as for the rotating armature machine, however this arrangement avoids moving parts in contact with the output circuit and is able to create much higher voltages which is beneficial for the transmission of the electricity produced. While these examples show a single two pole magnet and a pair of armature windings, in reality there may be many magnet poles and winding loops depending on the specific generator design.

These basic operating principles of electrical generators explain how power system frequency is directly related to the rotational speed of the synchronous machines connected to the system.[104] As the frequency varies up or down so the rotational speed of synchronous machines, such as generators, also varies.

Frequency Variation

In an operating power system, the frequency varies whenever the supply from generation does not precisely match customer demand. Whenever total generation is higher than total energy consumption the system frequency will rise and vice versa. This relationship between balancing generation and load and the power system frequency is shown in Figure D.4and Figure D.5.

Figure D.4 Load exceeds generation – system frequency falls

Figure D.5 Generation exceeds load – system frequency rises

This frequency variation is similar to how a car behaves when it begins to climb a hill after driving along a flat road. In order to maintain a constant vehicle and engine speed as the car climbs the hill, the engine power must be increased to balance the increased "load". If this does not take pace the car will slow down. In this basic example, the engine power is increased by depressing the accelerator pedal which supplies more fuel to the engine to maintain the vehicle speed.[105]

In a similar way the power system frequency is also affected by changes in customer demand, or load, relative to the amount of available generation. To maintain the "speed" of the frequency following an imbalance of generation relative to load (analogous to the car beginning to climb the steepening hill), more energy is required from all generators (depressing the accelerator pedal) to maintain the system frequency at 50Hz.

Figure D.6 illustrates how this increase or decrease in frequency is related to the relative shortening or lengthening of the voltage waveform. This shortening or lengthening reflects changes in the balance between supply and demand.

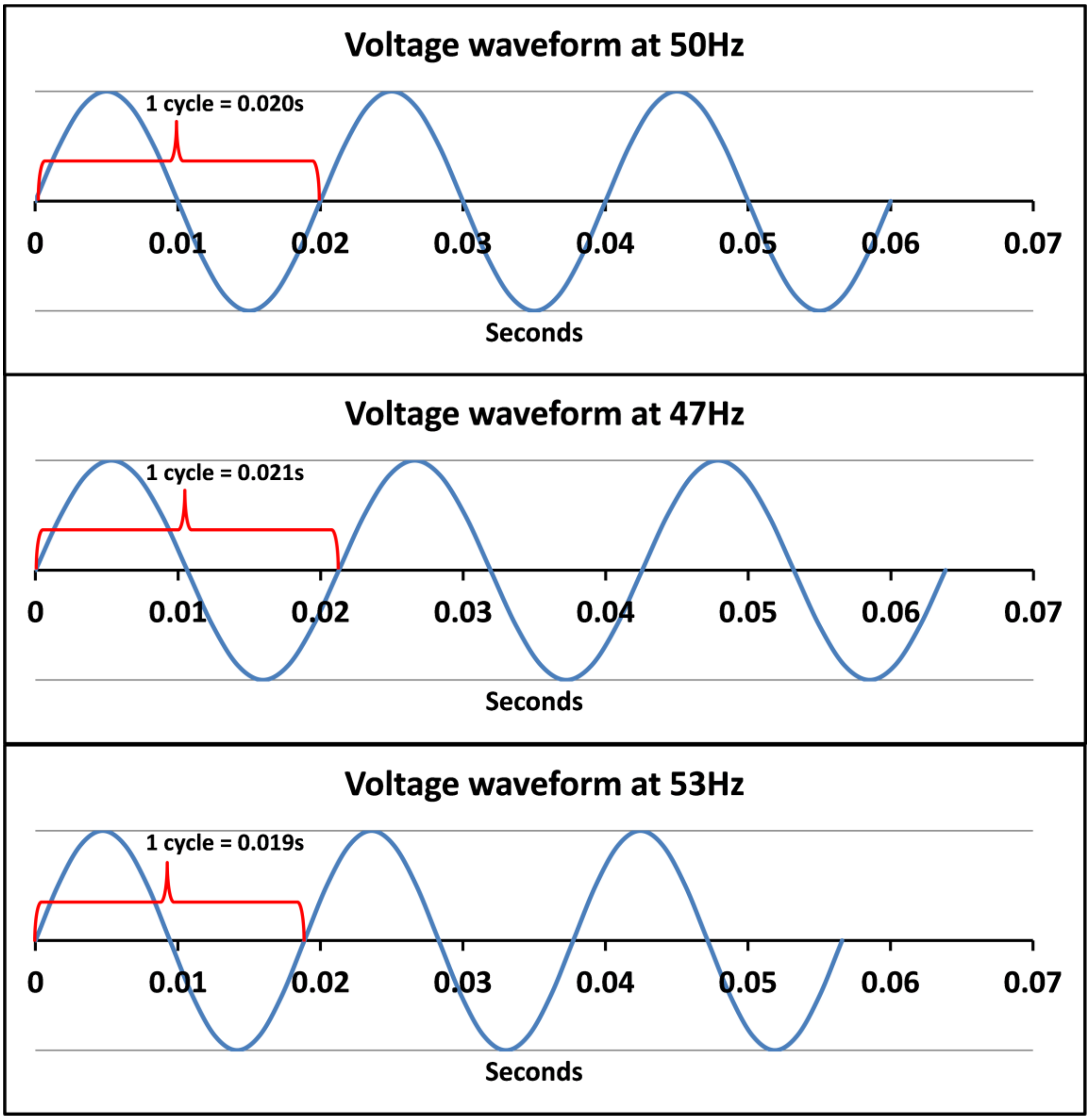
104 Synchronous generators have rotors that are directly electro-mechanically linked to the power system and spin at a speed that corresponds to the frequency of the power system.

105 This is a similar analogy to that used recently by Pacific Hydro's in their submission to Interim Report for the AEMC System Security Market Frameworks review dated 6 February 2017.

- The first panel shows that for a frequency of 50Hz supply and demand are balanced and a full cycle of voltage oscillation takes 0.020 seconds to complete.
- In the second panel where the frequency has fallen to 47Hz, demand has exceeded supply. The time taken to complete a single cycle has lengthened to 0.021 seconds.
- In the final panel, where the frequency has risen to 53Hz, supply has exceeded demand. The time taken to complete a single cycle has shortened to 0.019 seconds.

This variation of plus or minus 6% between the different cases illustrated in each panel may seem small, however the corresponding change in rotational speed of a synchronous generator spinning at 3000rpm is in the order of plus or minus 180rpm. Such deviations could have significant impacts for the functional efficiency and potentially the safety of this equipment. The impact of frequency deviations on power system equipment is discussed further in section D.2

Figure D.6 Power System Frequency Variations



In the majority of situations the changes in supply and demand that cause these changes in frequency are such that the corresponding variations in frequency are very small. Household appliances and industrial load being switched on and off are all examples of minor changes in demand happening all the time. The generation supplied into the network may also change due to the variable output of wind and solar generation.[106]

If the combined change in supply or demand is large enough the frequency of the power system may diverge materially from 50Hz. In response to small changes in frequency, power stations shift output ever so slightly to compensate, thereby maintaining the frequency within normal operating levels.

On occasion, changes in supply and demand can be more significant. Large generating units and transmission lines may trip unexpectedly and suddenly stop producing or transmitting electricity. Similar outcomes can occur on the demand side, if large industrial facilities trip off the system and suddenly stop consuming. These are referred to in the NER as contingency events. They are less common but tend to result in more significant changes in system frequency.

D.2 What is Frequency Control?

As discussed in appendix D.1, the electricity in the NEM is supplied by an alternating electric current that oscillates at or close to 50 Hz. To maintain the safe, secure and reliable operation of the power system, this frequency is controlled within narrow bands that are related to the broader system conditions. These bands and the relevant power system conditions they reflect are discussed further in section 2.2.2.

Why do we need to control frequency?

All equipment connected to the power system is designed to operate at or near the nominal frequency of 50Hz.[107] The tolerance of different machines or devices to frequency deviations varies both in terms of the size of a divergence that can be withstood and the length of time that the deviation can be ridden through;, for example, gas and steam turbines connected to synchronous generating units are particularly sensitive to frequency deviations. Synchronous rotating machinery such as steam and gas turbines used for power generation are finely tuned for operation at the specific system frequency and are prone to reduced efficiency and even damage during operation away from their design speed. Such conditions may cause equipment damage due to abnormal current flows within the electrical windings and cavitation and vibration affecting the turbine blades.

A typical steam turbine can operate continuously at ±1% away from the nominal frequency, or within a range of 49.5- 50.5Hz. The same steam turbine is only designed to withstand short periods of operation further away from the nominal frequency with a

106 In practice AEMO forecasts the expected demand and the output of variable renewable generation as part of their operation of the wholesale electricity market. Operationally, minor frequency deviation can be a result of actual demand or generation output varying from the demand or generation output as forecast. This forecast error issue has been raised in AEMO's future power system security work program through their report: Visibility of Distributed Energy Resources, January 2017, p.14.

107 This includes both synchronous generators as well as synchronous loads (large spinning machinery such as electric motors). Also includes network equipment, non-synchronous generation and customer equipment .

practical working limit reached at around ±5% or 47.5 - 52.5Hz.[108] Outside this operating frequency range the turbine may experience damaging vibrations and if allowed to operate at an excessively high speed there is risk of a catastrophic equipment failure.

As a self-protection mechanism, generation and transmission equipment are designed to disconnect from the power system during periods of prolonged or excessive deviations from the nominal system frequency. However, the disconnection of generation due to low system frequency would act to worsen the supply-demand imbalance that originally caused the frequency disturbance and potentially lead to a cascading system failure and a major blackout. Controlling frequency is therefore critically important to maintaining a secure and reliable power system.

Most consumer electronic equipment is designed to operate within a tolerance range of ±5% away from the nominal frequency, or 47.5- 52.5Hz. This is the case for computer systems, printers, VCRs, TVs, photocopiers, communications equipment, variable speed drives for electric motors, switch mode power supplies, and high-efficiency lighting.[109]

In summary, the adverse impacts of excessive frequency deviation include, in order of increasing severity:

- error or malfunction of consumer equipment
- increased wear and tear on synchronous generation equipment
- automatic disconnection of generation equipment potentially leading to a cascading failure leading and major blackout
- catastrophic failure of synchronous generation equipment, potentially leading to a cascading failure leading and major blackout.

How is frequency controlled?

To maintain a stable system frequency, the supply of electricity into the power system must balance the instantaneous consumption of electricity at all times. As discussed in section D.1, this balance between supply and demand is directly related to the frequency of the power system. When there is more generation than load, the frequency will tend to increase. When there is more load than generation, the frequency will tend to fall.

One of AEMO's primary operational objectives is to maintain the frequency of the power system by balancing supply and demand. AEMO operates the wholesale electricity market which dispatches electricity generation to meet the expected demand for electricity every five minutes. Some imbalance between supply and demand is expected to occur within the five minute dispatch process; these imbalances are managed through a market for regulation FCAS.

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108 General Electric Company, 1974, *Load Shedding, Load Restoration and Generator Protection Using Solid-state and Electromechanical Under-frequency Relays* – Section 4 – Protection of steam turbine – generators during abnormal frequency conditions.

109 National Electricity Code Administrator, 1999, *Reliability Panel Frequency Standards Consultation Paper*, Appendix 3 – University of Wollongong, Review of National Frequency Standards from a Customer's Perspective

AEMO coordinates the FCAS markets, which enables generation to be increased or decreased at short notice to restore the power system balance.[110] The FCAS market include the procurement of contingency services which provide AEMO with the ability to manage the power system frequency in response to the failure of a single generating unit or major transmission element, referred to as a credible contingency event.[111] The arrangements for FCAS are discussed further in section 2.3.2.

In the event that insufficient FCAS is available to manage the risk of a credible contingency event, AEMO may use other means to maintain the secure operation of the power system. Alternative methods include the pre-emptive constraining of interconnector flows or generation output to reduce the size of the possible contingency event and/or provide additional reserve capacity to be available to respond to a contingency event.[112] System security and contingency events are described further in section D.3.

AEMO also coordinates a range of emergency frequency control schemes as to address more substantial frequency deviations that result from more severe contingency events. These schemes operate to rapidly disconnect load or generation in order to rebalance the power system and restore the frequency. The operation of EFCS are discussed further in section 2.3.3.

D.3 Contingency Events

A key factor in maintaining system security is the definition of contingency events, which are events that involve "the failure or removal from operational service of one or more generating units and/or transmission elements."[113] Such events may lead to a temporary imbalance between generation and load in the power system and a corresponding deviation of the power system frequency. The classes of contingency event defined for the NEM are described in Box D.2

Box D.2 Contingency events

The NER includes three different classes of contingency event:

- credible contingency events
- non-credible contingency events
- protected events.

A **credible contingency event** is an event that AEMO considers is reasonably likely to occur in the surrounding circumstances. Examples of credible

110 FCAS markets are coordinated by AEMO to be able to respond to and correct frequency deviations as a result of errors in demand forecast, generation output or due to credible contingencies such as the loss of any single generation or transmission element. FCAS may take the form of fast response reserve generation capacity or controlled loads, such as major industrial loads.

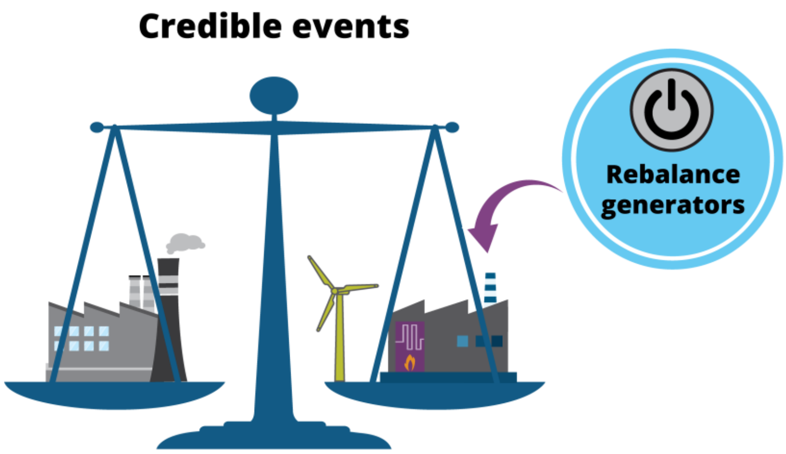
111 NER cl 4.2.3 (b) - A credible contingency event means a contingency event the occurrence of which AEMO considers to be reasonably possible in the surrounding circumstances including the technical envelope.

112 AEMO, 2017, *Power System Security Guidelines*, pp.12-13

113 NER cl4.2.3(a) - Credible and non-credible contingency events and protected events

contingency events include the unexpected disconnection of one operating generating unit or the unexpected disconnection of one major transmission plant, such as a transmission line or transformer.[114] For a credible contingency event, AEMO must operate the power system and procure sufficient responsive generation and load capacity to enable the power system to be rapidly rebalanced following the event. This includes the requirement that, following the event, the power system will return to a satisfactory operating state in accordance with the relevant frequency bands and recovery times defined in the FOS. This responsive generation or load is provided through the FCAS market arrangements which are described in section 2.3.2.

Figure D.7 Credible contingency events



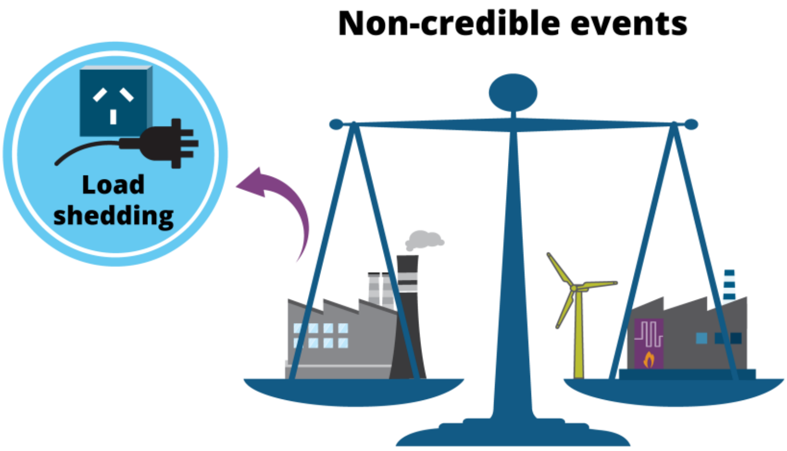
A **non-credible contingency** event is any contingency event that is not a credible contingency event, such as the simultaneous failure of multiple generating units or transmission elements.[115] For a non–credible contingency event, AEMO coordinates EFCS that enable load or generation to be progressively and automatically disconnected to "significantly reduce the risk of cascading outages and major supply disruptions".[116] These EFCS are described in section 2.3.3

Figure D.8 Non-credible contingency events

114 NER cl4.2.3(b) - Credible and non-credible contingency events and protected events

115 NER cl4.2.3(e) - Credible and non-credible contingency events and protected events

116 NER cl 4.2.6 (c)(2) - General principles for maintaining power system security



A **protected event** is special category of non-credible contingency that is declared by the Reliability Panel, on the advice of AEMO. A protected event is a high consequence, low likelihood event for which the Panel assesses the costs of mitigating the risks of the event are in the long term interest of consumers in accordance with the NEO.[117] For a protected event AEMO may use a combination of market mechanisms and EFCS to return the power system to a satisfactory operating state in accordance with the relevant frequency bands and recovery times defined in the FOS.[118]

Figure D.9 Protected events

117 NER cl. 4.2.3(f) - Credible and non-credible contingency events and protected events and NER cl8.8.4(e) - Determination of protected events.

118 NER cl. 4.2.6 (c)(1) - General principles for maintaining power system security.

E Past reviews of the FOS

E.1 Reliability Panel Review: Application of Frequency Operating Standards During Periods of Supply Scarcity 2009

Following the blackout that occurred in Victoria on 16 January 2016, related to severe bushfire activity, the reliability panel revised the FOS for the mainland NEM to support a more rapid restoration of supply following a major power system incident. An additional table was added to the FOS for the Mainland NEM to apply during periods of supply scarcity, following automatic load shedding.

This change was made in an effort to shorten the restoration time for the power system following major incidents through the increased utilisation of available generation capacity. The FOS during period of supply scarcity is wider than that for normal interconnected system conditions, which reduces the amount of FCAS that are required to manage the power system frequency, this in turn slightly increase the generation capacity available to supply load, and thus reduces the restoration time.

E.2 Reliability Panel Review: Tasmanian Frequency Operating Standard Review 2008

The FOS that applies for Tasmania was last reviewed and determined by the reliability panel on 18 Dec 2008.[119] At that time the Panel considered revisions to the Tasmanian FOS that would more closely align the FOS for Tasmania with that for the mainland NEM. A primary goal for the review was to set the standard to support a more diverse range of electricity generating technologies to increase the security and reliability of energy supplies in Tasmanian and facilitate competition.

The 2008 review made the following changes to the FOS for Tasmania:

- increasing lower limit of the extreme frequency excursion tolerance limit from 46 Hz to 47 Hz
- increasing the lower limit of the load, generator and network event band to 48 Hz, thus requiring the under frequency load shedding scheme (UFLSS) to operate between 48 and 47 Hz
- aligning the upper limit of the operational tolerance frequency band for load, generator and network events to 52 Hz, thus allowing efficient thermal generating units to meet the minimum access standards
- aligning the recovery times for load, generator and network events to 10 minutes
- reducing the over frequency limit for extreme events under island conditions from 60 Hz to 55 Hz
- a limit of 144MW was applied to the size of a contingency event that must be managed in accordance with the FOS.

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119 In 2006, the Panel conducted a review of the FOS that applies to Tasmania following the inclusion of Tasmania in the NEM. This review confirmed that the previous FOS for Tasmania would continue to apply until such time as the Panel completed a more thorough review. See: AEMC Reliability Panel, 2006, [119119] Tasmanian Reliability and Frequency Standards – determination.

E.3 Reliability Panel Review: Frequency Operating standards (Mainland NEM)

The FOS for the mainland NEM was thoroughly reviewed and determined by the reliability Panel on 30 September 2001. This review was undertaken to address the growth of the NEM, including the addition of the Queensland region into the interconnected NEM.

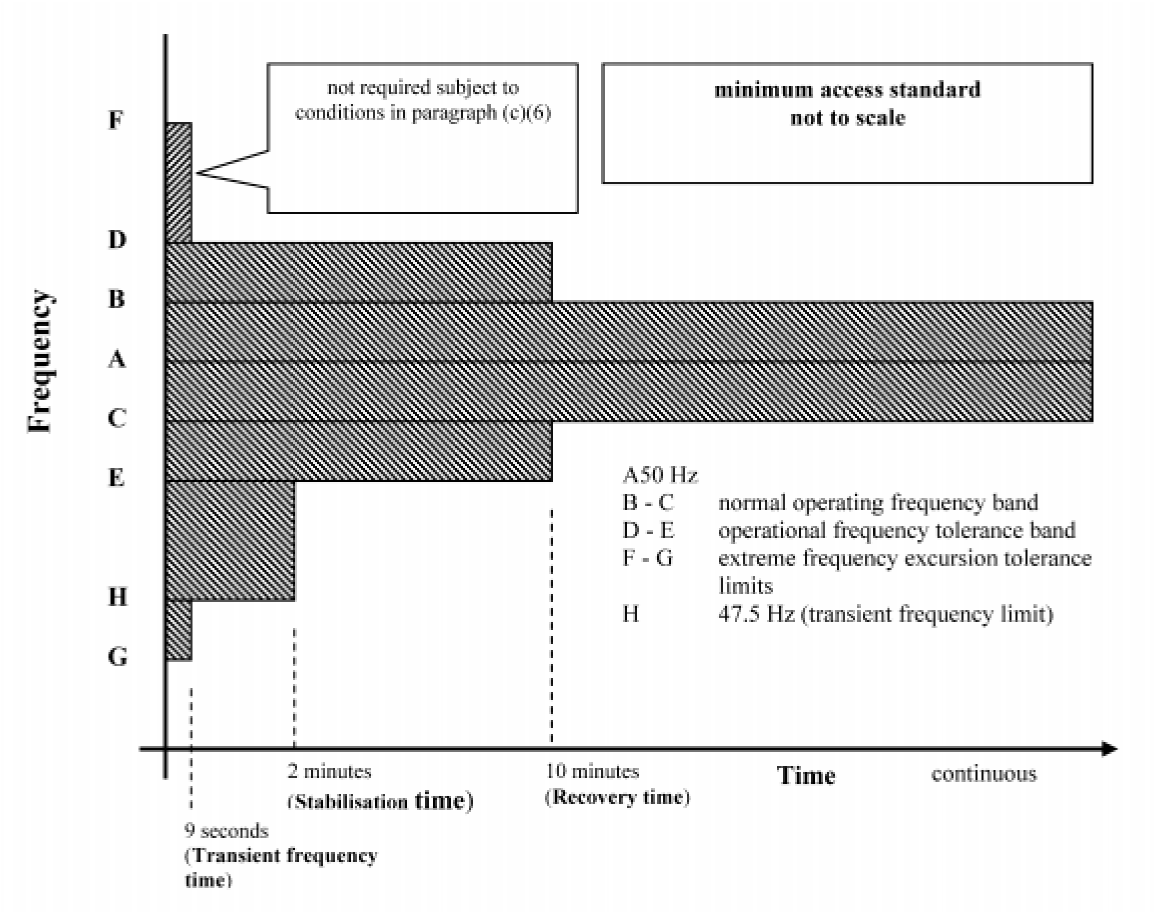
The 2001 review made the following changes to the FOS for the mainland NEM:

- relaxation of the normal frequency band from 49.9 - 50.1 Hz to 49.85 - 50.15 Hz
- creation of a probabilistic tolerance for the normal band of 99 percent of the time
- amalgamation of the standard for load disturbances with the standard for single generator disturbances
- increase of the maximum time to stabilise the power system frequency following multiple contingencies
- establishment of a uniform base standard when a contingency event may result in separation of parts of the network and provide for a Jurisdictional Co-ordinator to advise NEMMCO of a relaxation of this requirement
- tighten the standards that apply to island operation in the absence of disturbing events
- amend the allowable time error from 3 seconds to 5 seconds.

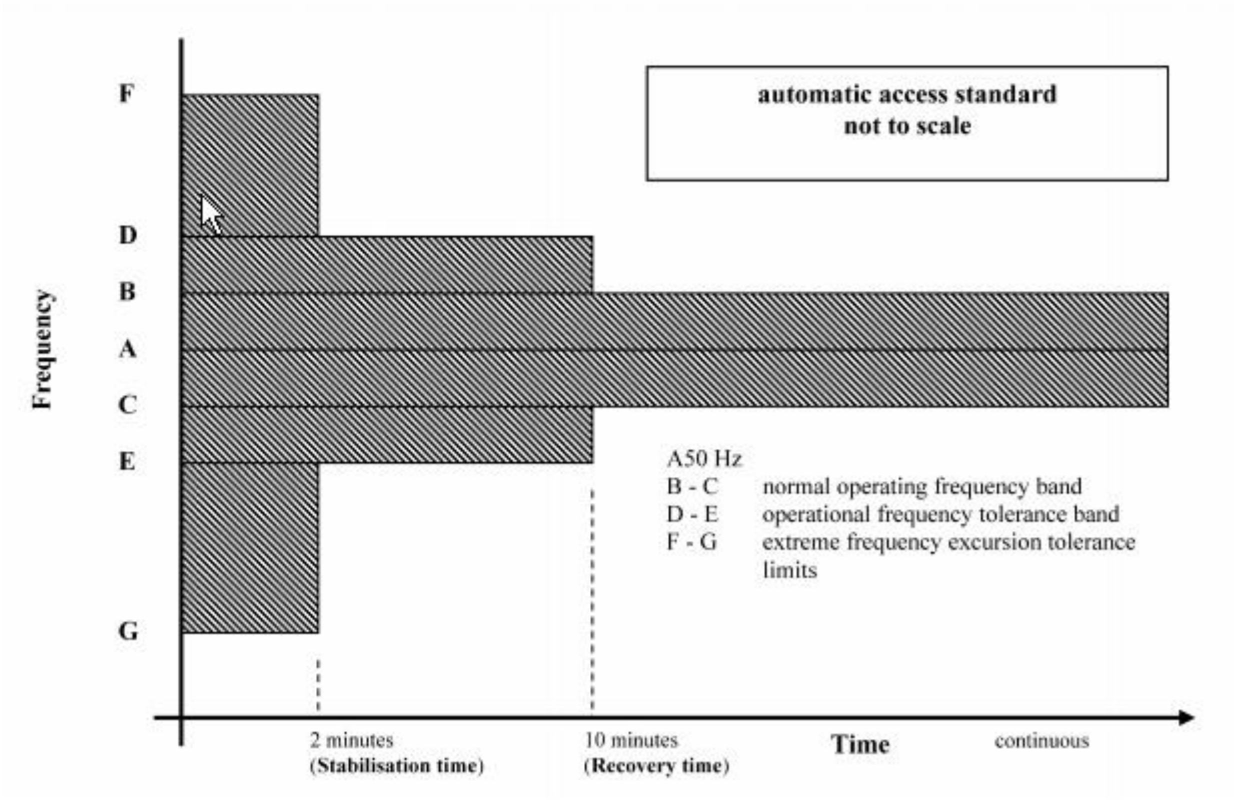
The relaxation of the normal operating frequency band and the addition of the probabilistic tolerance of 99 percent were intended to reduce the quantity of ancillary services required to be procured by the market operator. This change also allowed the market operator to, within limits, vary the amount of ancillary service in response to market price.

F Generator Performance Standards

F.1 Generator Minimum Access Standard

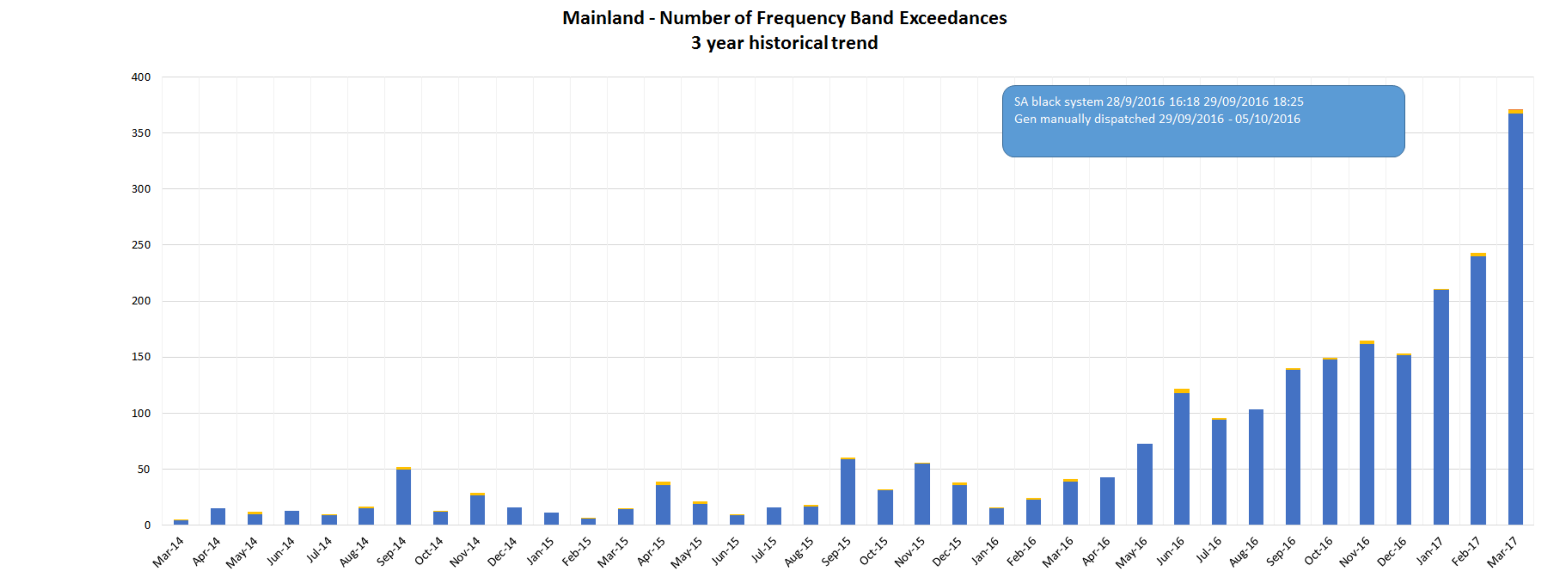


F.2 Generator Automatic Access Standard



G Frequency Band Exceedances

Figure G.1 Mainland - number of frequency band exceedances

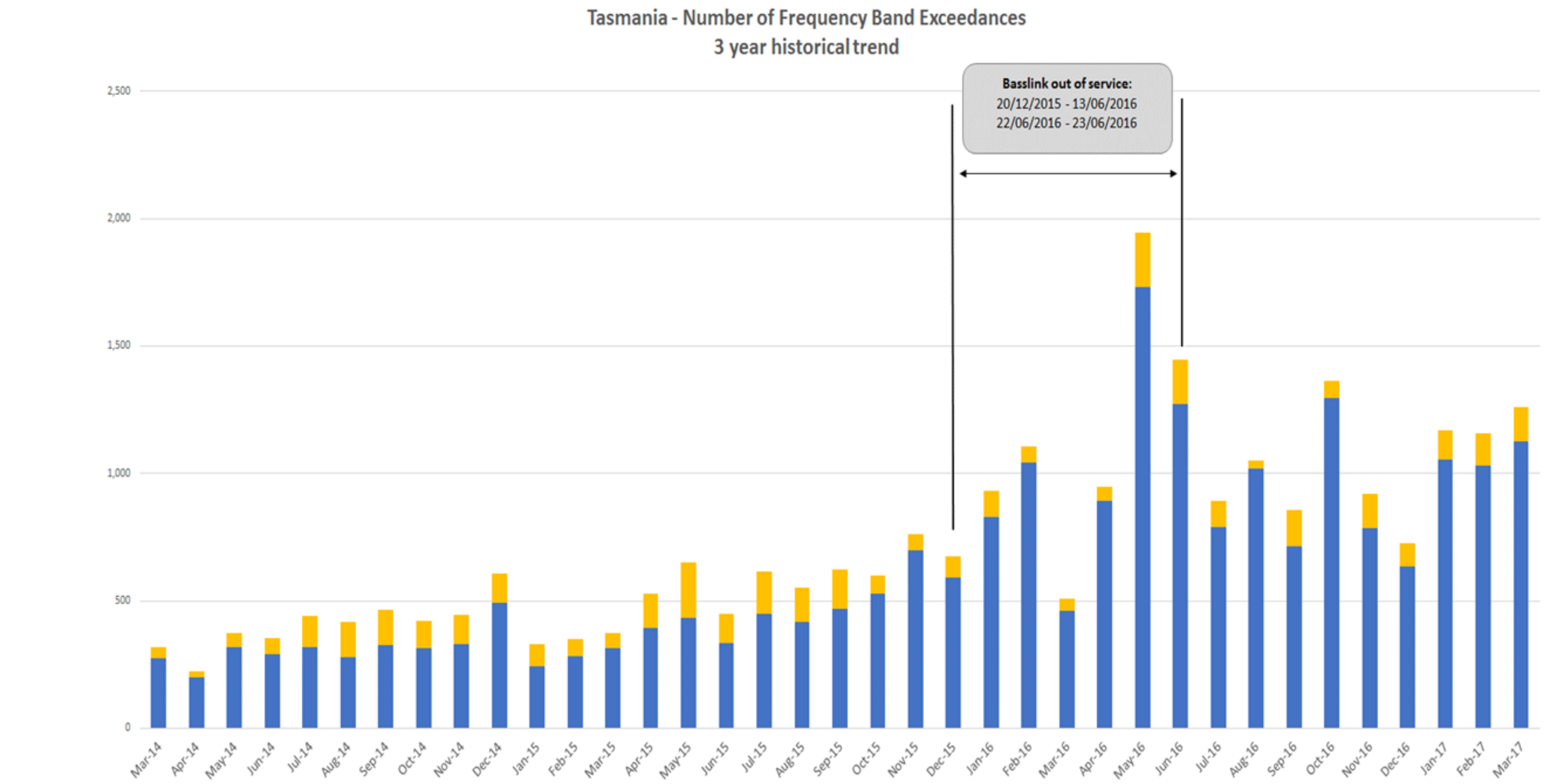


	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sep-14	Oct-14	Nov-14	Dec-14	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17
Outside 47 - 52 Hz band	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Outside +/- 1 Hz band	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Outside +/- 0.5 Hz band	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Outside +/- 0.25 Hz band	1	0	2	0	1	2	2	1	2	0	0	1	1	3	2	1	0	1	1	1	1	2	1	1	2	0	0	4	2	0	1	1	3	1	1	3	3
Outside +/- 0.15 Hz band	4	15	10	13	9	15	50	12	27	16	11	6	14	36	19	9	16	17	59	31	55	36	15	23	39	43	73	118	94	103	139	148	162	152	210	240	367

120

120 AEMO, 3 May 2017, AS-TAG – Meeting Pack – 3 May 2017, Presentation 2 Frequency Performance.

Figure G.2 Tasmania - number of frequency band exceedances



	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sep-14	Oct-14	Nov-14	Dec-14	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15
Outside 47 - 55 Hz band	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Outside +/- 2 Hz band	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Outside +/- 0.25 Hz band	44	24	57	62	121	138	139	109	113	115	87	69	59	134	215	113	167	136
Outside +/- 0.15 Hz band	273	200	318	292	319	278	325	313	331	491	243	281	314	394	434	336	450	416

	Sep-15	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17
Outside 47 - 55 Hz band	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Outside +/- 2 Hz band	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Outside +/- 0.25 Hz band	155	71	65	85	103	65	46	57	216	174	103	30	142	68	136	92	117	126	138
Outside +/- 0.15 Hz band	470	528	698	591	828	1041	462	892	1730	1273	791	1020	715	1295	785	634	1054	1031	1124

[121]

121 Ibid.

H Interim FOS for protected events

NEM Mainland

For a protected event, system frequency should not exceed the applicable extreme frequency excursion tolerance limits and should not exceed the applicable load change band for more than two minutes while there is no contingency event or the applicable normal operating frequency band for more than 10 minutes while there is no contingency event:

NEM Mainland Frequency Operating Standards – interconnected system

Condition	Containment	Stabilisation	Recovery
Protected Event	47.0 to 52.0 Hz	49.5 to 51.5Hz within 2 minutes	49.85 to 50.15 Hz within 10 minutes

This standard would only apply for an interconnected system. A different standard will apply to an islanded system and during periods of supply scarcity in respect of stabilisation and recovery:

NEM Mainland Frequency Operating Standards – for an islanded system and during periods of supply scarcity

Condition	Containment	Stabilisation	Recovery
Protected Event	47.0 to 52.0 Hz	49.0 to 51.0 Hz within 2 minutes	49.5 to 50.5 Hz within 10 minutes

Tasmania

For a protected event, system frequency should not exceed the applicable extreme frequency excursion tolerance limits and should not exceed the applicable load change band for more than two minutes while there is no contingency event or the applicable normal operating frequency band for more than 10 minutes while there is no contingency event:

Condition	Containment	Stabilisation	Recovery
Protected Event	47.0 to 52.0 Hz	48.0 to 52.0 Hz within 2 minutes	49.0 to 51.0 Hz within 10 minutes

This standard would apply for both an interconnected and an islanded system.