Frequency and Time Error Monitoring – Quarter 3 2021

November 2021

A report for the National Electricity Market

Important notice

PURPOSE

The purpose of this report is to provide information about the frequency and time error performance in the National Electricity Market (mainland and Tasmania) for the period July to September 2021 inclusive. AEMO has prepared this report in accordance with clause 4.8.16(b) of the National Electricity Rules, using information available as at the date of publication, unless otherwise specified.

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1. Introduction

The Reliability Panel's Frequency Operating Standard (FOS)[1] specifies limits for power system frequency and time error for the mainland and Tasmanian regions of the National Electricity Market (NEM). AEMO must use its reasonable endeavours to control power system frequency and ensure that the FOS is achieved as required by clause 4.4.1 of the National Electricity Rules (NER).

This document reports on the frequency and time error performance observed during July, August and September 2021 (Q3 2021) in all regions of the NEM as required by clause 4.8.16(b) of the NER[2]. The Queensland, New South Wales, Victoria, and South Australia regions are referred to as the 'mainland' through the report.

The *Power System Frequency and Time Deviation Monitoring Report – Reference Guide*[3] outlines the calculation procedure used by AEMO to produce the quarterly Frequency and Time Error Monitoring report. Where applicable, analysis of the delivery of slow and delayed frequency control ancillary services (FCAS) presented in this report is based on 4-second resolution SCADA information derived from AEMO's systems.

Unless otherwise noted, mainland frequency data has been sampled in New South Wales at 4-second intervals using the most recent Global Positioning System (GPS) clock frequency measurement preceding each 4-second interval. All Tasmanian frequency data has been sampled at 4-second intervals using the most recent Network Operations and Control System (NOCS) frequency measurement preceding each 4-second interval.

In this report:

- Section 2 summarises frequency performance in Q3 2021.
- Section 3 collates the number of FOS exceedances in Q3 2021.
- Section 4 examines all FOS requirements and the circumstances of any exceedances in Q3 2021.
- Section 5 details the estimates of significant rate of change of frequency (RoCoF) events for Q3 2021.
- Section 6 discusses adjustments to Automatic Generation Control (AGC) undertaken during Q3 2021 and the results of these actions.
- Section 7 discusses initiatives intended to improve frequency control in the NEM.
- Appendix A lists credible generation and load contingency events from Q3 2021. The inclusion of this list is intended to highlight the NEM's aggregate frequency response capability, and to affirm that frequency control during major disturbances continues to be generally satisfactory, notwithstanding any exceptions identified in this report.

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[1] See https://www.aemc.gov.au/australias-energy-market/market-legislation/electricity-guidelines-and-standards/frequency-0.

[2] See https://www.aemc.gov.au/regulation/energy-rules/national-electricity-rules/current.

[3] See http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Ancillary-services/Frequency-and-time-error-monitoring.

2. State of frequency performance

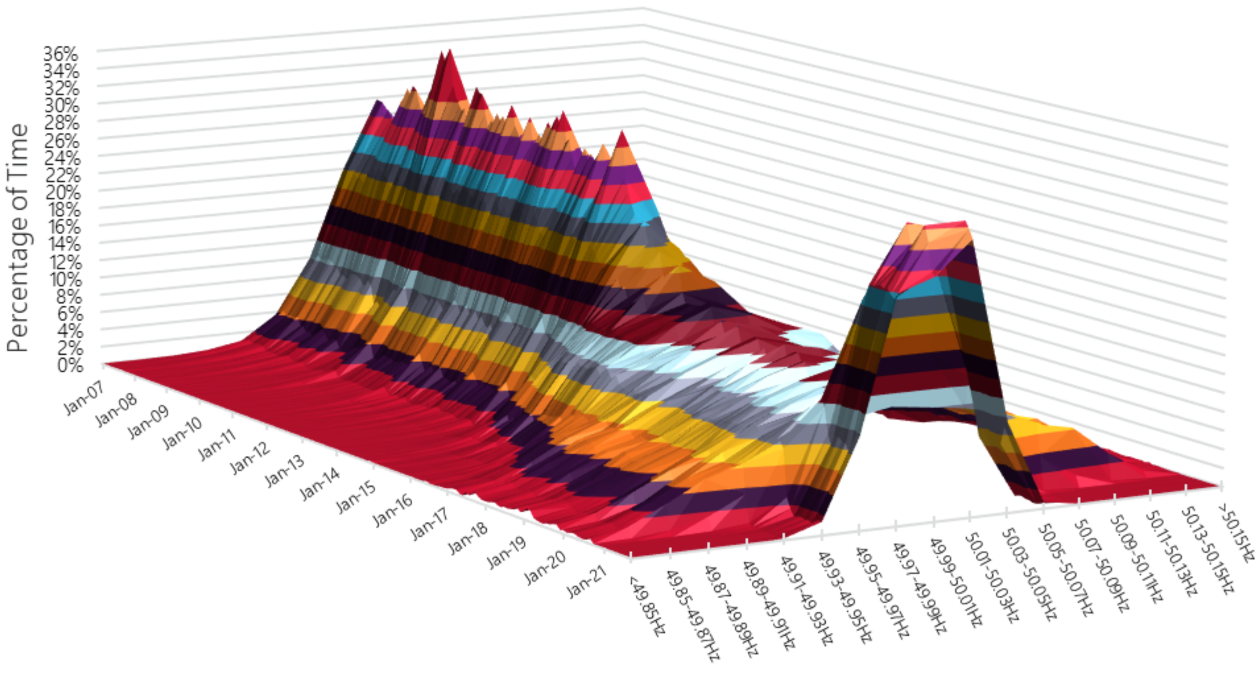
In Q3 2021, key NEM frequency performance metrics continued to remain well within their targets, demonstrating a trend of improvements that include the following:

- Frequency remained within the Normal Operating Frequency Band (NOFB) for more than 99% of the time in both the mainland and Tasmania.
- There were no exceedances of the FOS in the mainland.
- There were no occasions of frequency departing the NOFB without an identifiable cause in the mainland.
- There were no instances of time error accumulating beyond the FOS requirement of ±15 seconds (s).
- Well-contained frequency deviations and much improved recovery times following generation and load events continued to be observed.

As of 1 October 2021, approximately 39 gigawatts (GW) of scheduled generation have applied agreed settings in accordance with the Interim Primary Frequency Response Requirements (IPFRR). Updates regarding the rule change are available on AEMO's website[4].

The implementation of the rule has significantly improved the control of frequency, as shown in Figure 1.

Figure 1 Monthly frequency distribution



[4] See https://aemo.com.au/en/initiatives/major-programs/primary-frequency-response.

3. Achievement of the Frequency Operating Standard

AEMO's assessment of the achievement of the requirements of the FOS in Q3 2021 is summarised in Table 1.

Table 1 Frequency Operating Standard and assessment in the mainland and Tasmania

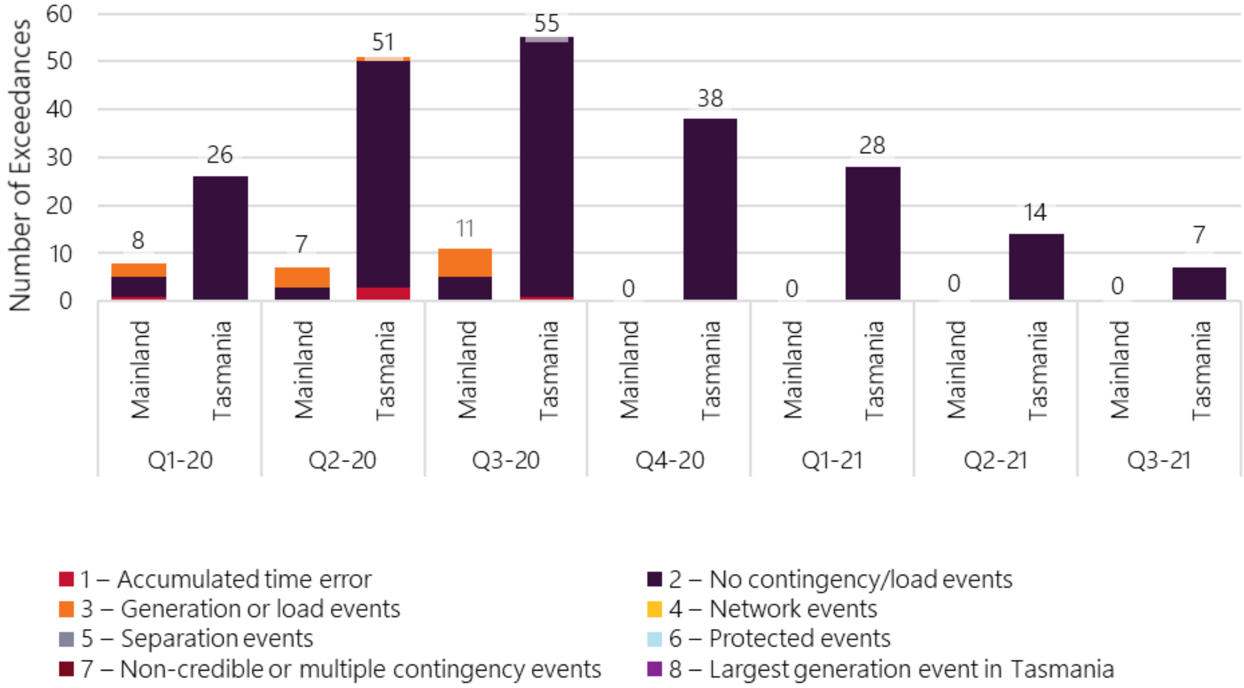
Requirement	Mainland	Tasmania	Further commentary
1 – Accumulated time error	Achieved	Achieved	
2 – No contingency/load events			
• **Within Normal Operating Frequency Excursion Band (NOFEB) at all times**	Achieved	Exceeded 7 times	See Section 4.2.1
• **Recovered in five minutes**	Achieved	Achieved	
• **Within NOFB 99% of the time**	Achieved	Achieved	
3 – Generation or load events			
• **Contained**	Achieved	Achieved	
• **Recovered within five minutes**	Achieved	Achieved	
4 – Network events			
• **Contained**	Achieved	Achieved	
• **Recovered within five minutes**	Achieved	Achieved	
5 – Separation events			
• **Contained**	No separation events	No separation events	
• **Managed within 10 minutes**	No separation events	No separation events	
6 – Protected events	No protected events	No protected events	
7 – Non-credible or multiple contingency events	Achieved	Achieved	
8 – Largest generation event in Tasmania	Not applicable	Achieved	

The number of exceedances of the FOS in Q3 2021 continued to remain lower than was observed in Q1-Q3 of 2020 before PFR was substantially implemented, as shown in Figure 2. Most identified exceedances throughout 2020 related to generation events, load events, or periods without an identified contingency.

It is apparent that implementation of the Mandatory PFR rule has contributed to reducing:

- The number of FOS exceedances following generation or load events, by increasing the available dynamic system frequency response to sudden and significant supply and demand imbalances.
- The number of FOS exceedances during periods without an identified contingency, by reducing the likelihood of frequency being near the NOFB boundaries and subsequently straying beyond the NOFB, while also increasing the available restorative response to such events should they occur.

Figure 2 FOS exceedances in the mainland and Tasmania



4. Frequency performance

Section 4 describes frequency performance in Q3 2021 against each of the key FOS requirements.

4.1 Time error

Table A.2 of the FOS (requirement 1) specifies that the accumulated time error should be maintained within the range ±15 s in the mainland (except for an island or during supply scarcity) and in Tasmania (except for an island or following a multiple contingency event).

The ranges of accumulated time error in the mainland and Tasmania in Q3 2021 are provided in Table 2. Time error did not exceed the FOS requirements in Q3 2021.

Table 2 Maximum and minimum time error measurements for the mainland and Tasmania

Value	Mainland	Tasmania
Highest positive time error (s)	4.44	5.82
Lowest negative time error (s)	-5.61	-7.31

Figure 3 shows the percentage of time where mainland time error was outside the ±1.5 s threshold at which accumulated time error begins to increase regulation FCAS volumes above their base values.

Figure 3 Proportion of time mainland time error was outside of ±1.5 seconds

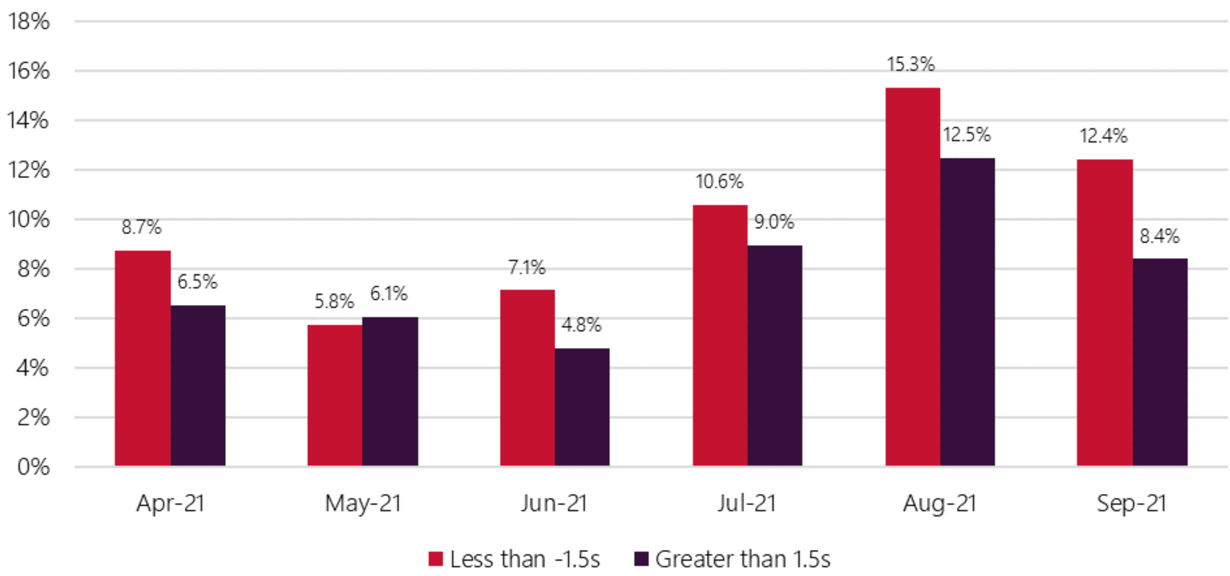
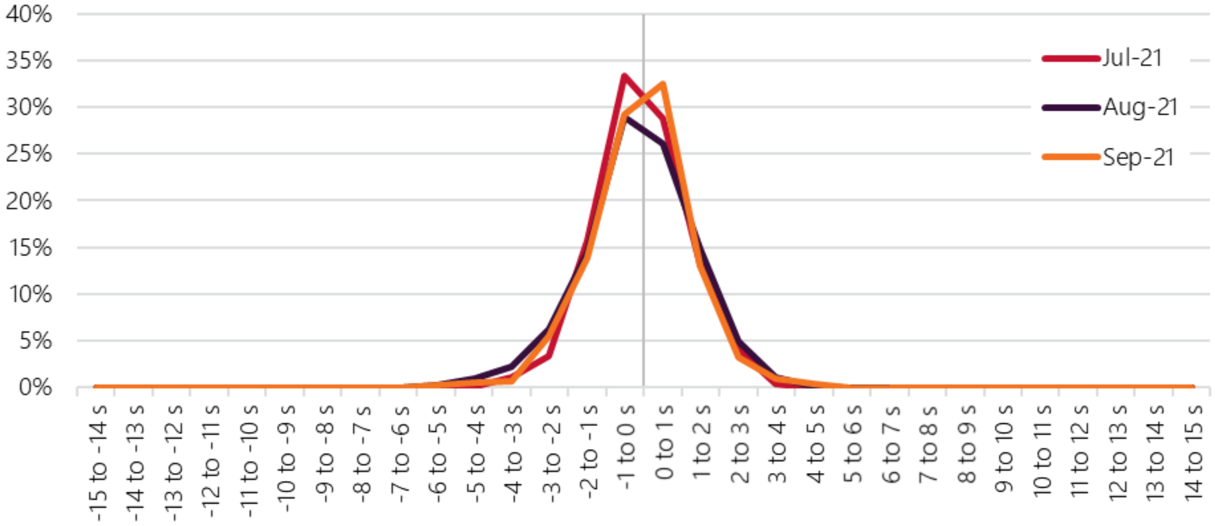


Figure 4 shows the distribution of mainland time error in the months of Q3 2021. AEMO will continue to monitor this aspect of system performance as the implementation of PFR continues with Tranche 2 (80-100 megawatts [MW]) and Tranche 3 (<80 MW) generators.

Figure 4 Mainland time error distribution



4.2 Operation during periods without contingencies or load events

When there are no associated contingency or load events in the interconnected system, table A.2 of the FOS (requirement 2) specifies that system frequency should be maintained within the applicable Normal Operating Frequency Excursion Band (NOFEB) and not remain outside the applicable NOFB for more than five minutes on any occasion or more than 1% of the time over any 30-day period[5].

These requirements are summarised in Table 3.

Table 3 FOS requirements for no contingency or load event in an interconnected system

Region	Containment	Stabilisation	Recovery
Mainland	49.75 to 50.25 hertz (Hz) 49.85 to 50.15 Hz, 99% of the time	49.85 to 50.15 Hz within 5 minutes	
Tasmania	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	

4.2.1 Frequency excursions without a contingency event outside the NOFEB

Frequency excursions outside the applicable NOFEB where an associated contingency event has not been identified are shown in Table 4 for Q3 2021.

Table 4 Number of frequency excursions without identified contingency outside the NOFEB in Q3 2021

Event	Low/high/both frequency event	Number of events mainland	Number of events Tasmania
No contingency or load event noted	LOW	0	5
	HIGH	0	2
	BOTH	0	0

[5] See https://www.aemc.gov.au/australias-energy-market/market-legislation/electricity-guidelines-and-standards/frequency-0.

Mainland

No frequency events without an identified contingency in Q3 2021 in the mainland exceeded the NOFEB. The last such event in the mainland occurred on 28 January 2020 and was discussed in the Q1 2020 Frequency and Time Error Monitoring Report[6].

Tasmania

The seven Tasmanian events where frequency exceeded the NOFEB in Q3 2021 without an associated contingency event are characteristic of the smaller Tasmania system. This is similar to last quarter; in Q2 2021, 14 frequency events without an identified contingency exceeded the NOFEB in Tasmania.

AEMO has noted that at least four of the seven instances identified in Q3 2021 are primarily due to unforecast changes in generation from Tasmania's operating wind farms – Woolnorth Wind Farm, Musselroe Wind Farm, Cattle Hill Wind Farm, and Granville Harbour Wind Farm – at times when Basslink was operating at its import limit, hence unable to provide further frequency support via its frequency controller.

The circumstances differ on each occasion, but common conditions include variable wind speeds and at other times coincident wind speed reductions.

These observations provide further evidence of the growing challenge of maintaining effective frequency control in the mainland NEM as greater penetrations of inverter-connected generation are online alongside diminishing numbers of synchronous units.

Under system normal conditions, the FOS specifies largely the same requirements for Tasmania as it does for the mainland. However, as a much smaller system, Tasmania is more sensitive to supply/demand imbalances which manifest as larger frequency deviations. As PFR is further implemented across the NEM, including in Tasmania, AEMO will monitor and adjust control settings in Tasmania as required.

4.2.2 Frequency excursions without a contingency event outside the NOFB and not recovered in FOS timeframe

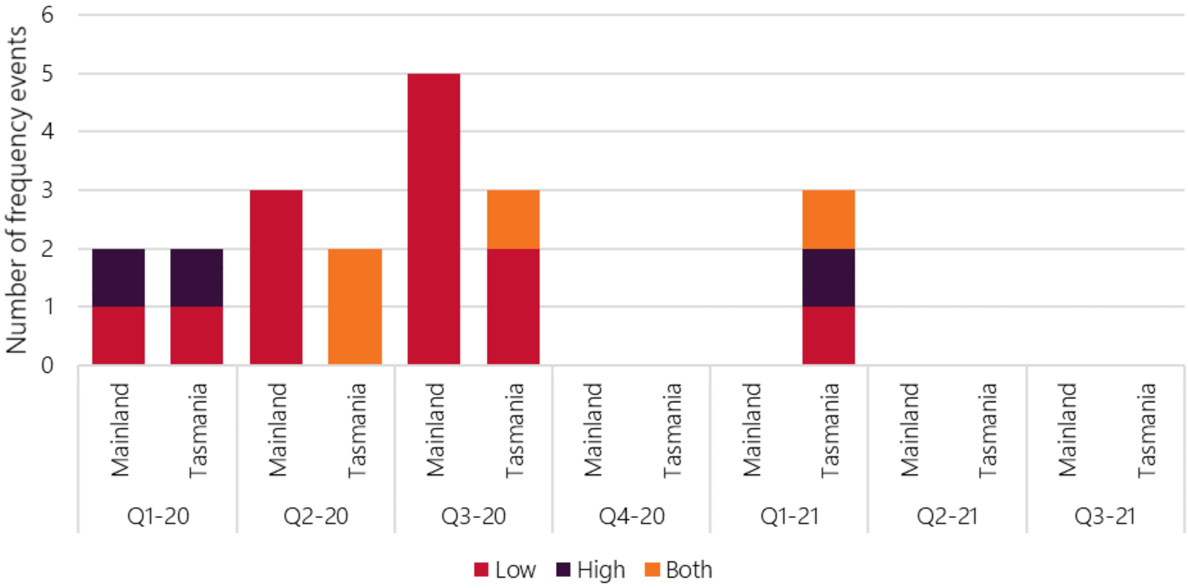
Figure 5 shows, for Q3 2021, frequency excursions outside the applicable NOFB and not recovered in the applicable FOS timeframe where an associated contingency event has not been identified.

In Q3 2021 there were no frequency excursions from the NOFB in the mainland or Tasmania without an associated contingency event that were not recovered in the FOS timeframes. This outcome is substantially improved from Q1-Q3 in 2020, as Figure 5 also shows.

The implementation of the Mandatory PFR rule is considered to have reduced the likelihood of frequency being near the NOFB boundaries. This outcome markedly reduces the likelihood that frequency strays beyond the NOFB, while also increasing the available restorative response to such events should they occur.

[6] See https://www.aemo.com.au/-/media/files/electricity/nem/security_and_reliability/ancillary_services/frequency-and-time-error-reports/quarterly-reports/2020/frequency-and-time-error-monitoring-quarter-1-2020.pdf.

Figure 5 **Frequency excursions without identified contingency outside the NOFB and not recovered in the FOS timeframe in the mainland and Tasmania**



4.2.3 Frequency within the NOFB over 30-day rolling average

AEMO calculates daily the percentage of time that frequency remained inside the NOFB in the preceding 30-day window. The minimum daily estimate from each month is reported in Figure 6 and Figure 7. The figures show the estimated time inside the NOFB, both including and excluding data during contingency events. The FOS requirement excludes periods where contingency events have occurred.

Figure 6 **Frequency in NOFB since January 2013, minimum daily time percentage in prior 30-day window**

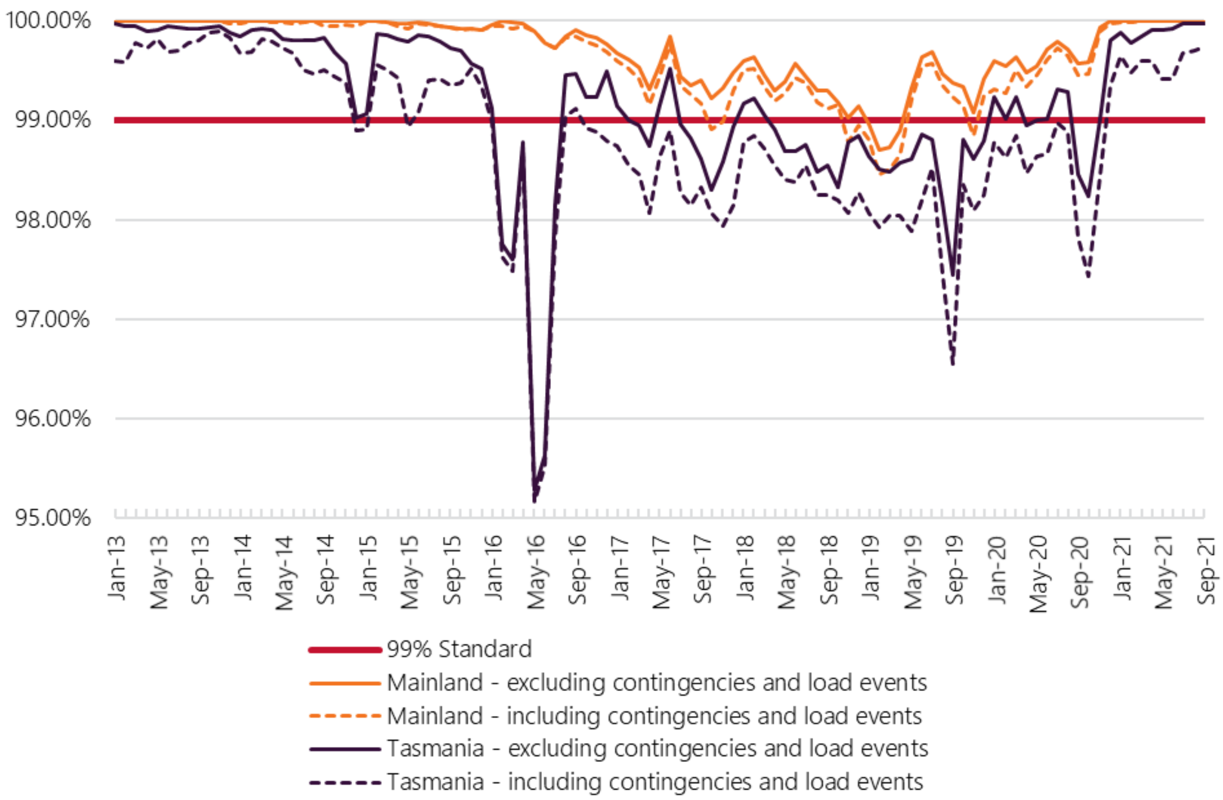
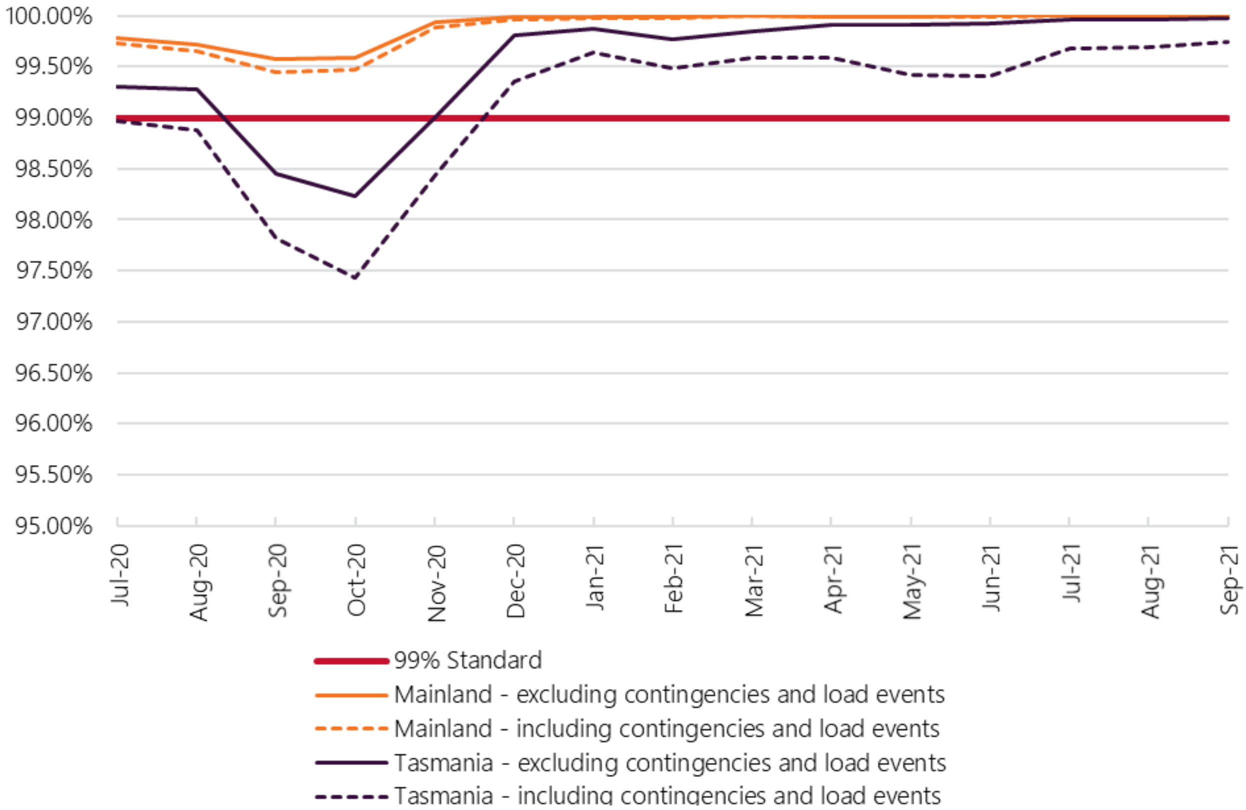


Figure 7 Frequency in NOFB since June 2020, minimum daily time percentage in prior 30-day window



Frequency in the mainland and Tasmania remained within the NOFB for more than 99% of the time in Q3 2021. Since the implementation of the Mandatory PFR rule commenced, there has been a reduction in the number and length of frequency excursions from the NOFB and a corresponding increase in time spent within the NOFB. When contingency events did occur, frequency was contained earlier or recovered to the NOFB faster than experienced during similar events before the mandatory PFR commencement.

Further detail on credible contingency events in Q3 2021 is available in Appendix A.

4.2.4 Frequency performance within the NOFB

The FOS does not include specific requirements for the control of frequency within the NOFB. However, frequency performance within the NOFB is important, because it demonstrates the overall tightness and stability of frequency and indicates the likelihood of frequency being close to nominal (50 hertz [Hz]) when a contingency event occurs, increasing the prospects of good containment and fast recovery.

Figure 8 and Figure 9 show the frequency distribution in the mainland and Tasmania in Q3 2021, compared with data from 2010 as an example of a period where frequency control was tighter than that observed in recent years. The comparison of the frequency distribution during Q3 2021 to that observed in 2010 is one clear indicator of the significantly improved frequency control since the widespread implementation of PFR.

Figure 10 shows that when the frequency is within the NOFB in the mainland, the proportion of time that frequency is closer to the boundaries of the NOFB decreased sharply throughout Q4 2020, to below 10%, and remained there throughout Q1, Q2 and Q3 2021. Meanwhile the proportion of time that frequency remained near 50 Hz (between 49.95 Hz and 50.05 Hz) continued to be substantially above 90%.

Figure 8 Mainland frequency distribution

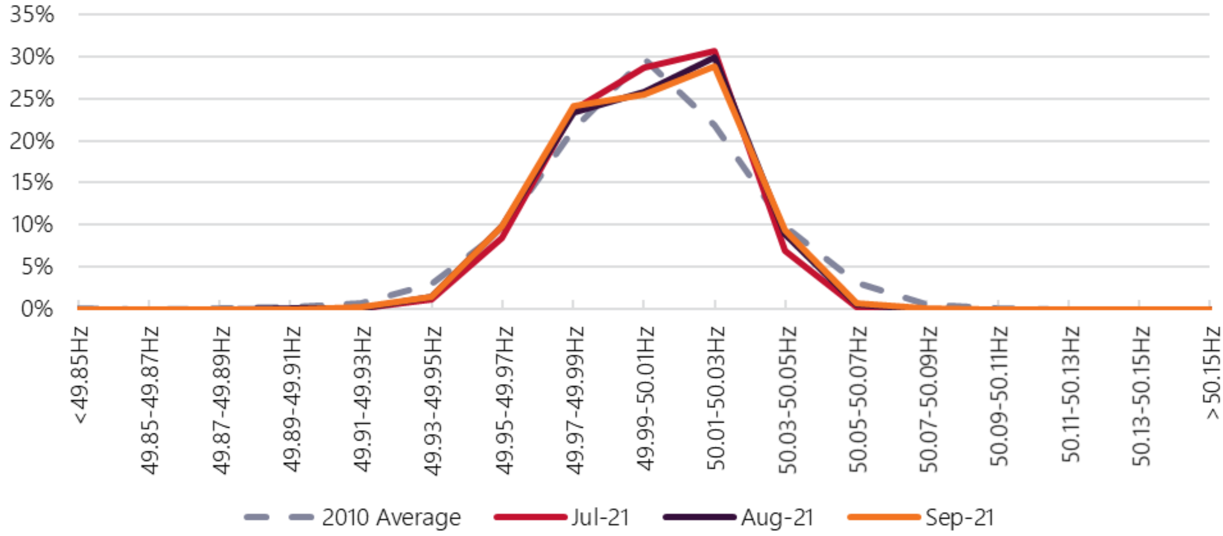


Figure 9 Tasmania frequency distribution

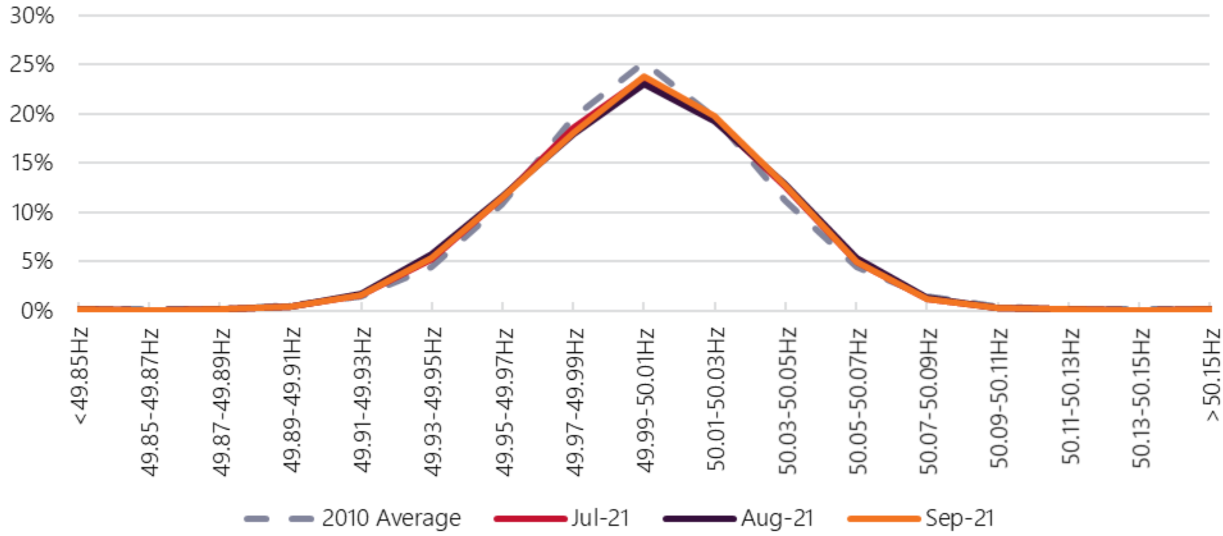
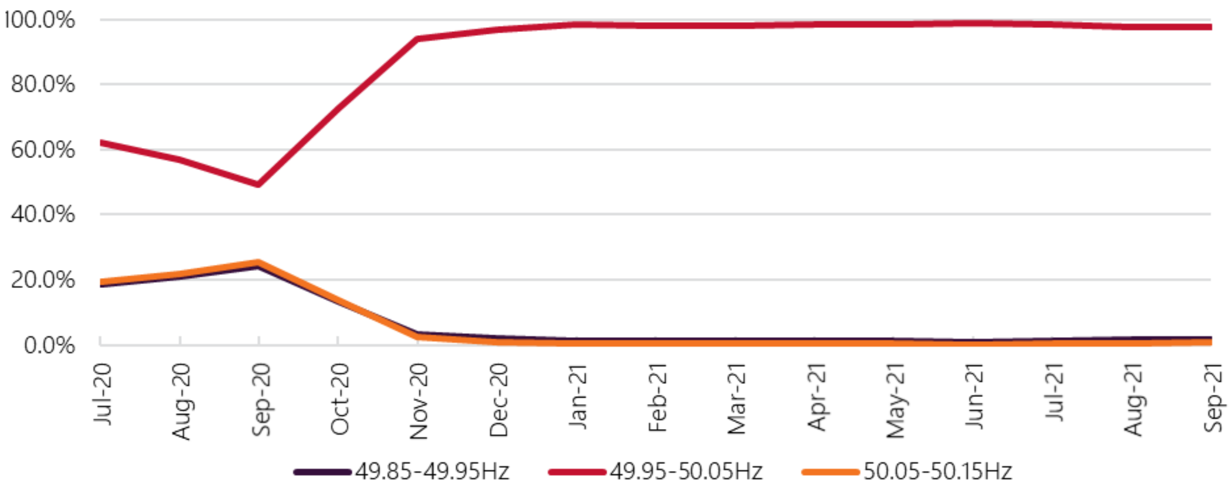


Figure 10 Mainland frequency time percentage spent within selected bands within the NOFB



4.3 Operation during generation or load contingency events

When there is an associated generation or load event in an interconnected system, table A.2 of the FOS (requirement 3) specifies that system frequency should be maintained within the applicable Generation and Load Change Band (GLCB) and not remain outside the applicable NOFB for more than five minutes in the mainland or more than 10 minutes in Tasmania, as described in Table 5.

Table 5 FOS requirements for a generation or load event in an interconnected system

Region	Containment	Stabilisation	Recovery
Mainland	49.5 to 50.5 Hz	49.85 to 50.15 Hz within five minutes	
Tasmania	48.0 to 52.0 Hz	49.85 to 50.15 Hz within 10 minutes	

4.3.1 Frequency excursions following a generation or load event outside the GLCB

In Q3 2021, there were no frequency excursions following a generation or load event where frequency exceeded the GLCB.

4.3.2 Frequency excursions following a generation or load event not recovering to the NOFB within the FOS timeframe

In Q2 2021, there were no instances where a frequency excursion following a generation or load event was not recovered to the NOFB within the applicable FOS timeframes of five minutes in the mainland and 10 minutes in Tasmania.

4.3.3 Frequency performance following generation or load events

AEMO assesses frequency performance over time with metrics that complement the requirements of the FOS. Several generation and load events occurred in Q3 2021 which demonstrate the current frequency response characteristics of the NEM, despite these events remaining within the requirements of the FOS. Appendix A has detailed information about frequency outcomes following these generation and load contingency events.

4.4 Operation during separation contingency events

When there is a separation event, table A.2 of the FOS (requirement 5) sets out expectations for the initial frequency containment, recovery, and revised requirements for further contingency events in the islanded region. AEMO is required to maintain system frequency within the applicable containment band and should recover frequency in the NOFB within the FOS timeframe.

No separation events (as defined by the FOS) occurred during Q3 2021 in the mainland or Tasmania.

4.5 Operation during network, protected, non-credible, or multiple contingency events

When there is a network contingency, protected event, non-credible contingency, or multiple contingency event in an interconnected system, table A.2 of the FOS (requirements 4 to 7) specifies that frequency should be maintained within the applicable containment band and recover to the NOFB in the FOS timeframe.

4.5.1 Frequency excursions following network, protected, non-credible or multiple contingency events not within the FOS

There were no instances in Q3 2021 in the mainland or Tasmania where a frequency excursion following a network event, protected event, non-credible event, or multiple contingency event was not contained within the applicable containment band and/or not recovered to the NOFB within the FOS timeframe.

4.5.2 Frequency performance following network events

AEMO assesses frequency performance over time with metrics that complement the requirements of the FOS. Several network events occurred in Q3 2021 which demonstrate the frequency response characteristics of the NEM system, despite these events remaining within the boundaries of the FOS.

25 August 2021

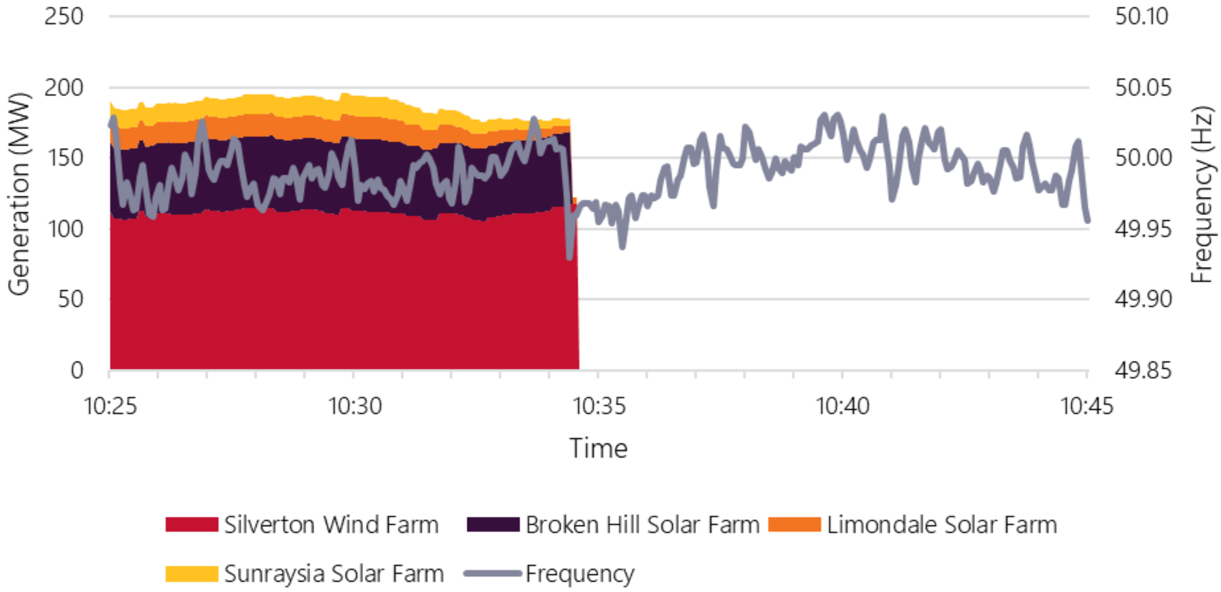
At 1034 hrs on 25 August 2021, a trip of the Darlington Point – Balranald X5 220 kilovolt (kV) line occurred. Multiple generating units, including Silverton Wind Farm, Broken Hill Solar Farm, Limondale 1 Solar Farm, and Sunraysia Solar Farm, simultaneously reduced their generation due to the action of control schemes. The generation affected was estimated to be 175 MW. Mainland frequency remained within the NOFB. Figure 11 shows the frequency and generation of the multiple units during the event.

The combined total capacity of the four generators is 671 MW. Such an event could represent one of the largest credible contingencies in the New South Wales region, were the same event to occur at a time of high wind speed and solar radiation in this zone of the NEM. For example, at 0932 hrs on 5 May 2021, the instantaneous aggregate output from these same four generation units was 462 MW.

The following constraints were implemented on 4 December 2020 to manage the related network contingency of the trip of the Darlington Point – Wagga 63 330 kV line[7], which also covers the trip of the Darlington Point – Balranald X5 220 kV line:

- F_I+TTS_TG_R6/R60/R5, F_MAIN++TTS_TG_R6/R60/R5, F_MAIN+TTS_TG_R6/R60/R5.

Figure 11 New South Wales generators during 25 August 2021 credible network event

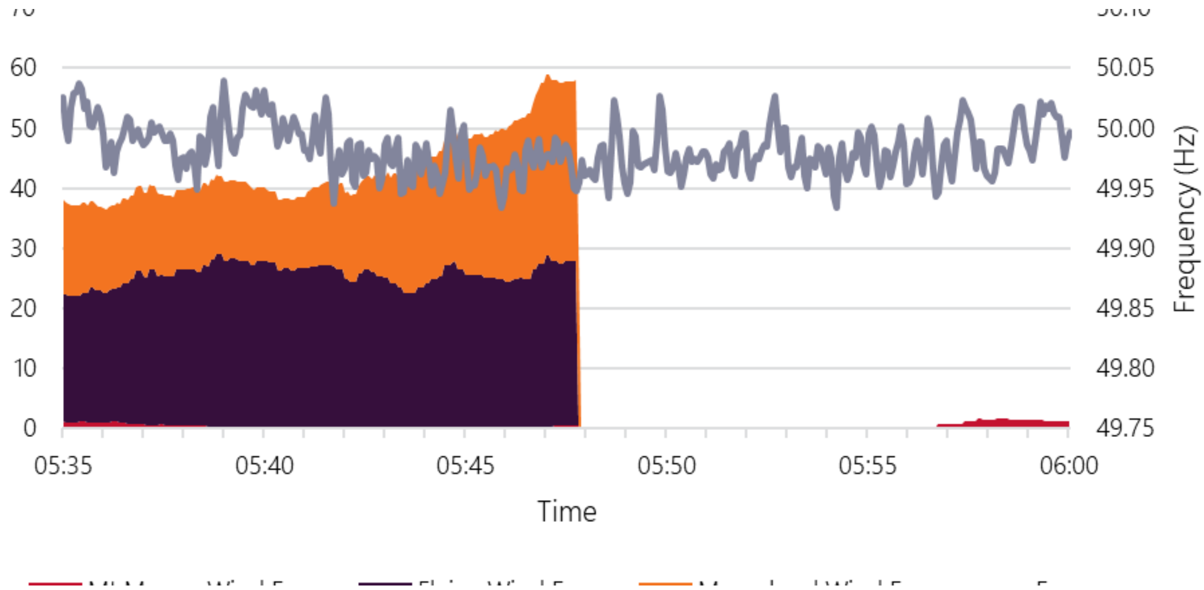


[7] See Market Notice 80672: https://aemo.com.au/market-notices?marketNoticeQuery=80672&marketNoticeFacets=.

29 August 2021

A trip of the Ballarat – Elaine – Moorabool 220 kV line occurred at 0547hrs on 29 August 2021. Multiple generating units, including Mt Mercer Wind Farm, Elaine Wind Farm, and Moorabool Wind Farm, simultaneously reduced their generation due to being disconnected. The generation affected was estimated to be 58 MW. Mainland frequency remained within the NOFB. The combined total capacity of the three generators is 525 MW. Figure 12 shows the frequency and generation of the units during the event.

Figure 12 Victorian generators during the 29 August credible network event



4.6 Reviewable operating incidents

AEMO is required to review power system incidents that meet the criteria in the NER and Reliability Panel guidelines for identifying reviewable operating incidents[8]. Mainland frequency exceeding the Operational Frequency Tolerance Band (OFTB) is the existing guideline for identifying a reviewable operating incident which affected power system frequency and is one basis for inclusion in this section. Other reviewable operating incidents may be included here at AEMO's discretion.

There were no reviewable operating incidents in Q3 2021 where frequency exceeded the OFTB.

[8] See https://www.aemc.gov.au/sites/default/files/2018-02/Final-revised-guidelines.pdf.

5. Rate of change of frequency

5.1 Rate of change of frequency (RoCoF) methodology

The RoCoF following a frequency event is an indicator of the evolving system response to frequency disturbances. Measuring a system variable such as RoCoF is influenced by several assumptions concerning the available data and measurement methodology. This RoCoF methodology uses snapshots of measured frequency from the AEMO/transmission network service provider (TNSP) Phasor Measurement Unit (PMU) system at 1-second intervals. This is a higher resolution than is available from the GPS clock system and is therefore more appropriate for assessing RoCoF.

For the purposes of this report, RoCoF has been assessed as the recorded change in frequency per second over an interval of one second, or over an interval of two seconds when a measurement is not available. RoCoF assessment has not been attempted for periods longer than two seconds without data. For the purposes of this report, the maximum RoCoF recorded between five seconds prior and 30 seconds after each frequency event is considered to be the RoCoF associated with that event.

$$If\ 1s\ data\ available\ then\ RoCoF_{\ t} = MAX\left(ABS\left(\frac{f_{t+1} - f_t}{t_{t+1} - t_t}\right)\right) \forall\ t$$

$$else\ \ if\ 2s\ data\ available\ then\ RoCoF_{\ t} = MAX\left(ABS\left(\frac{f_{t+2} - f_t}{t_{t+2} - t_t}\right)\right) \forall\ t$$

$$else\ no\ measurement\ attempted$$

where:

- **f** is system frequency.
- **t** is time in seconds.

5.2 RoCoF during frequency events

The maximum RoCoF recorded in the mainland each month in Q3 2021, and any other RoCoF exceeding the standard frequency ramp rate for the mainland (as specified in the market ancillary services specification [MASS]) of 0.125 hertz per second (Hz/s), is provided in Table 6.

Table 6 RoCoF during frequency events in the mainland

Month	RoCoF (Hz/s)	Associated event	Event time
July	-0.106	Trip of Loy Yang B unit	24/7/2021 21:51
August	-0.069	Trip of Bayswater unit	21/8/2021 12:17
September	-0.076	Trip of Loy Yang A unit	24/9/2021 14:38

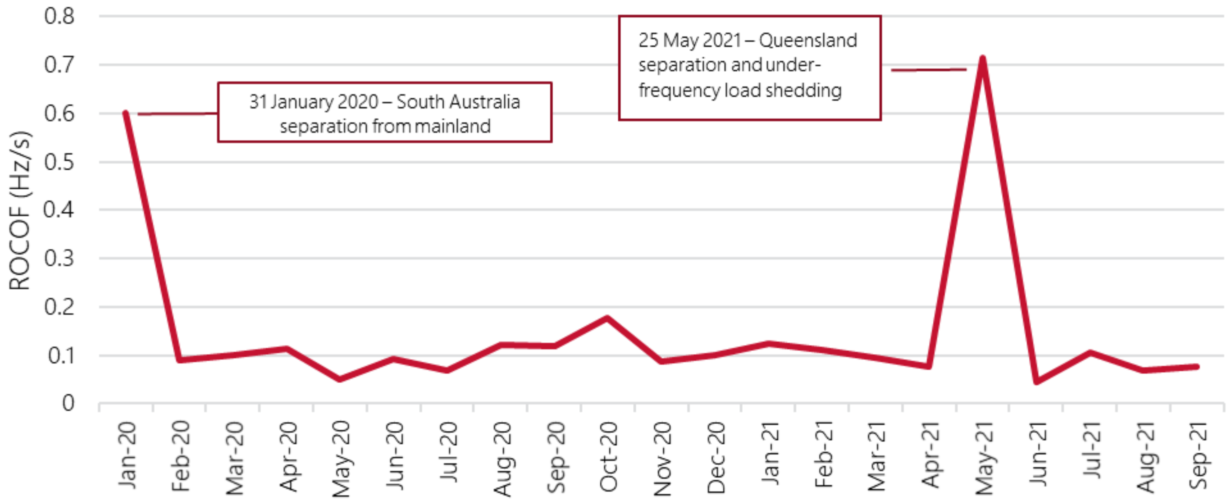
Note: Estimates of RoCoF may vary depending on data source, sampling window and calculation method.

Figure 13 shows the maximum RoCoF recorded in the mainland NEM since Q1 2020. AEMO employs a value called the 'standard frequency ramp rate' in the MASS as a standardised way of assessing FCAS capability. In real events, and in islanded systems, the actual RoCoF can be quite different. Under substantially different RoCoF conditions, FCAS capability for some plant could vary.

Based on the data above (and previous quarters), the MASS's value of 0.125 Hz/s for a credible contingency appears to remain fit for purpose, as the maximum RoCoF in most months has been less than or near 0.125 Hz/s. The notable exceptions in Figure 13 occurred on:

- 31 January 2020, when South Australia separated from the mainland NEM; however this was a non-credible event.
- 25 May 2021, when Queensland separated from the mainland NEM following the loss of multiple Queensland generators.

Figure 13 Monthly maximum RoCoF recorded in any mainland region in 2020 and 2021



Note: 25 May 2021 RoCoF as measured in Queensland and 31 January 2020 RoCoF as measured in South Australia.

6. Automatic Generation Control

6.1 Area Control Error (ACE) methodology

As per the Regulation FCAS Contribution Factors Procedure[9], AEMO calculates an ACE representing the MW equivalent size of the current frequency deviation and accumulated frequency deviation (time error) of the NEM system. ACE may be considered to represent a rough proxy for the required regulation FCAS volume.

$$ACE = 10 \cdot Bias \cdot (F - FS - FO)$$

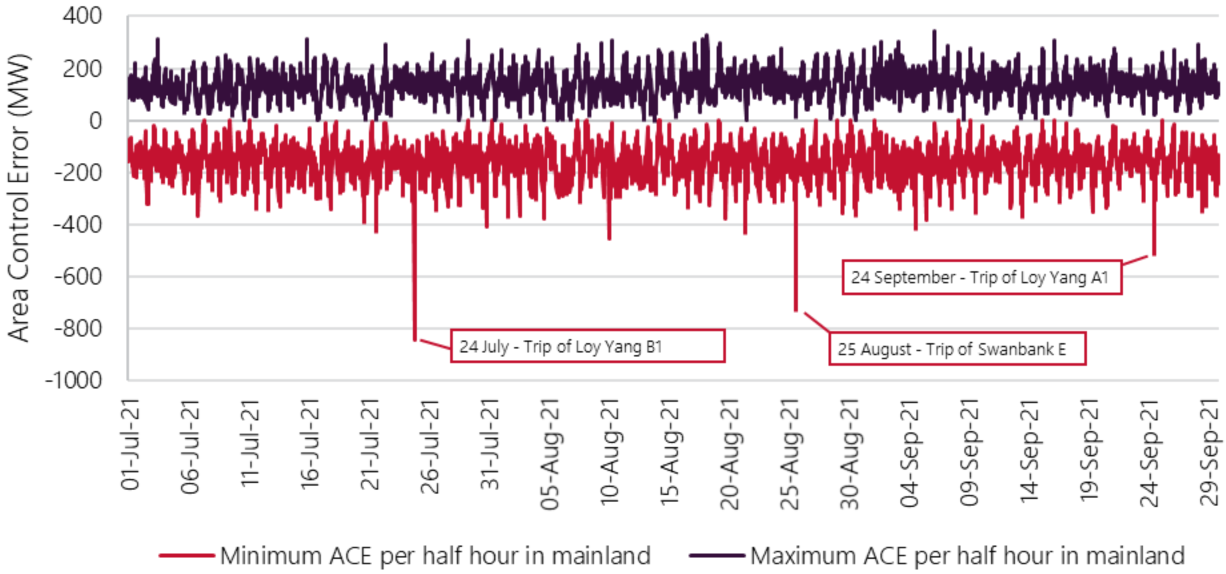
where:

- **Bias** is the area frequency bias and is a tuned value that represents the conversion ratio between MW and 0.1 Hz of frequency deviation.
- **F** is the current measured system frequency.
- **FS** is the scheduled frequency (50.0 Hz).
- **FO** is a frequency offset representing accumulated frequency deviation, that is, time error.

6.2 ACE reporting

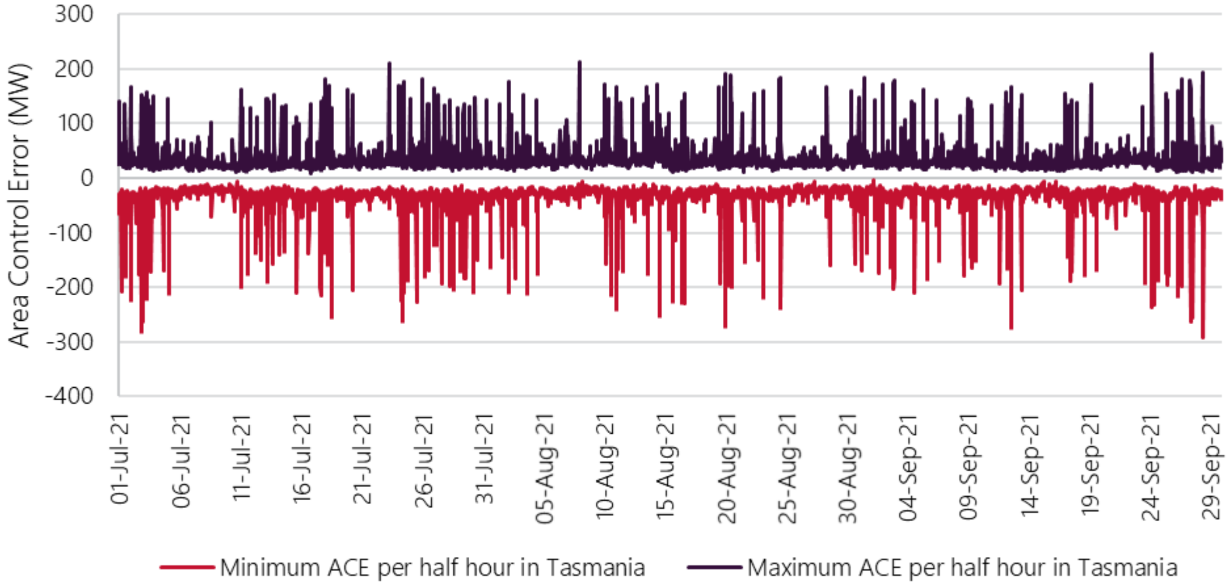
Figure 14 and Figure 15 show the minimum and maximum ACE per half-hourly trading interval in Q3 2021 in the mainland NEM and Tasmania, respectively. Relatively balanced positive and negative ACE values have been observed throughout Q3 2021.

Figure 14 Minimum and maximum ACE per half-hour in mainland NEM



[9] See http://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Ancillary_Services/Regulation-FCAS-Contribution-Factors-Procedure.pdf.

Figure 15 Minimum and maximum ACE per half-hour in Tasmania



7. Actions to improve frequency control performance

Frequency performance in the NEM has recently improved dramatically, following a long period of general decline over the period of approximately 2010 to 2020. In AEMO's quarterly frequency reports, a range of metrics are published which document aspects of frequency control that are not directly related to requirements in the FOS but are nonetheless important indicators of frequency stability and control quality.

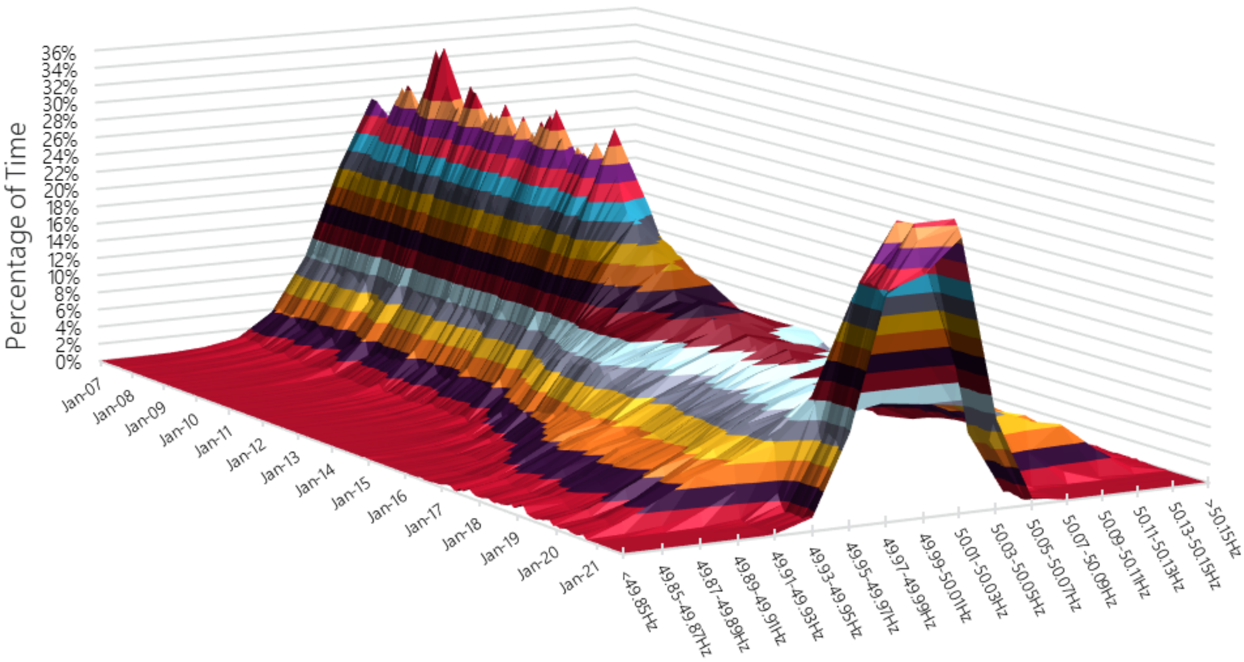
These metrics also form a basis for assessing the impacts of ongoing actions, such as the implementation of the Mandatory PFR rule. This rule came into effect from 4 June 2020, but implementation at generators commenced from the end of Q3 2020 and continues, so it remains a significant feature of this Q3 2021 report.

7.1 Measure 1 – distribution of frequency within NOFB

This measure examines the distribution of frequency within the NOFB. As Figure 16 shows, a flattening of the frequency distribution within the NOFB has been observed over time, and particularly since 2014-15, where frequency increasingly spent more time out towards the edges of the NOFB. Among other things, this meant that when a contingency event occurs, the frequency change is more likely to deviate away from 50 Hz.

A large improvement was observed in Q4 2020 and this continued throughout 2021, which can be largely attributed to industry efforts to implement the Mandatory PFR rule this period. The sharp improvement in the distribution of system frequency has returned performance to levels not seen since approximately 2014.

Figure 16 Monthly frequency distribution



7.2 Measures 2 and 3 – number of frequency crossings and NOFB excursions

These measures examine the number of times frequency crosses the nominal 50 Hz target and how often frequency departs the NOFB. Over the last few years, there has been a dramatic increase in the number of instances where frequency departs the NOFB, as shown in Figure 17 and Figure 18. Interestingly, there was also a significant decline in the number of 50 Hz crossings, which relates to the fact that frequency tended to spend much more time away from 50 Hz, and therefore did not have as much 'opportunity' to cross.

Since the implementation of Mandatory PFR, there has been a clear return of the metrics monitored below to levels previously seen prior to 2015. AEMO considers these results to indicate a material improvement in frequency control within the NEM has been achieved. In particular, frequency only tends to depart the NOFB during a clear contingency event, rather than as a result of typical frequency variation, as was increasingly the case in 2019 and 2020.

Figure 17 Monthly frequency crossings – under 49.85 Hz, across 50 Hz, beyond 50.15 Hz

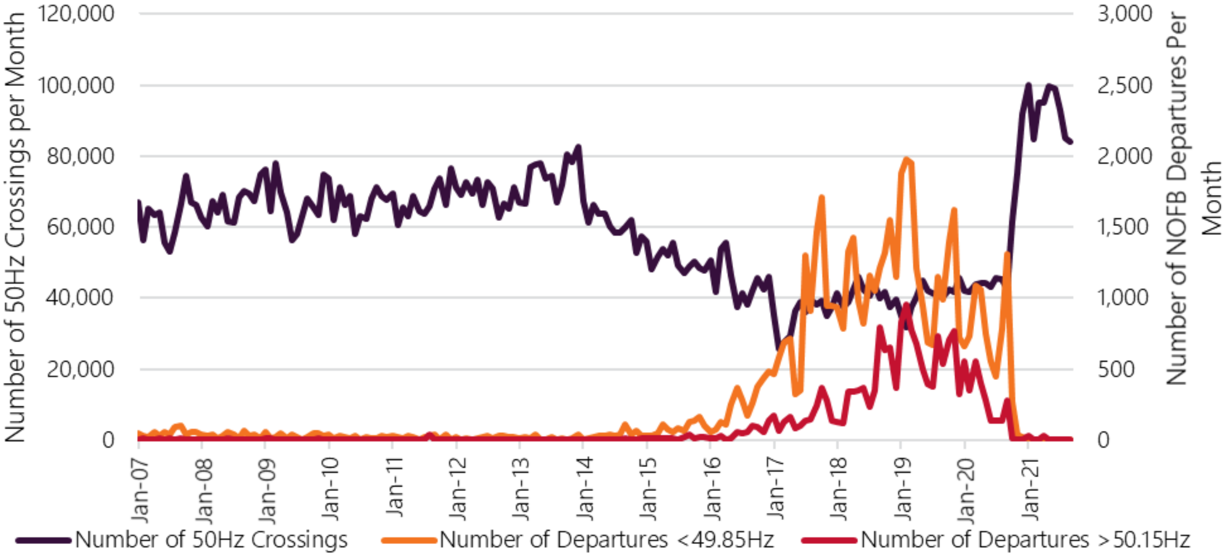
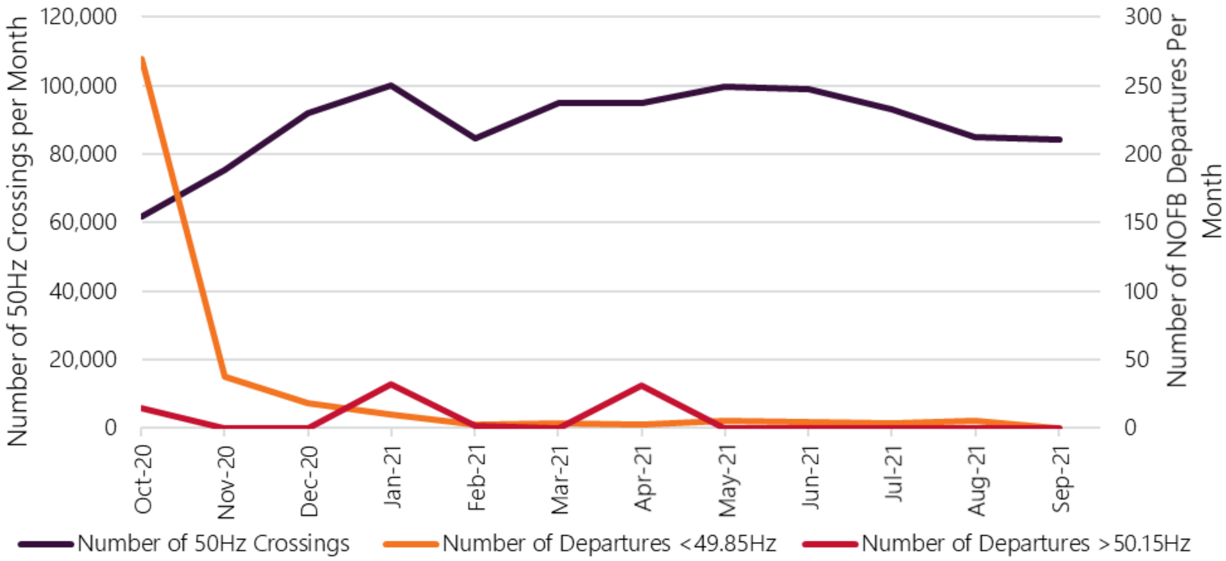


Figure 18 Monthly frequency crossings for recent 12 months



7.3 Measure 4 – frequency "mileage"

This measure examines the total amount of change in frequency over time. It is a metric that may be used as an indication of how stable frequency is; that is, more stable frequency will see a lower mileage. Table 7 provides a simple demonstration of the calculation method. The final estimate of mileage is dependent on the selection of the length of time interval. The measurements below are derived from 4-second intervals.

Table 7 Example frequency mileage calculation for a series of 4-second intervals

Sample	0 s	4 s	8 s	12 s	Mileage sum
NSW frequency (Hz)	50	50.5	49.5	50	
Mileage (Hz)		ABS(50.5-50)=0.5	ABS(49.5-50.5)=1.0	ABS(50-49.5)=0.5	0.5+1.0+0.5 = 2.0Hz

Interestingly, as shown in Figure 19 and Figure 20, frequency mileage has remained reasonably consistent, with a recent small decline seeming to emerge over the past three quarters, although the change is not nearly as dramatic as the change in frequency performance; that is, frequency mileage does not seem to be significantly reduced by the widespread provision of PFR. This may mean that frequency mileage is a better indicator of underlying load behaviour than frequency performance itself, as suggested by an apparent seasonal trend with summer and winter being lower than shoulder periods.

Figure 19 Monthly frequency mileage since 2007

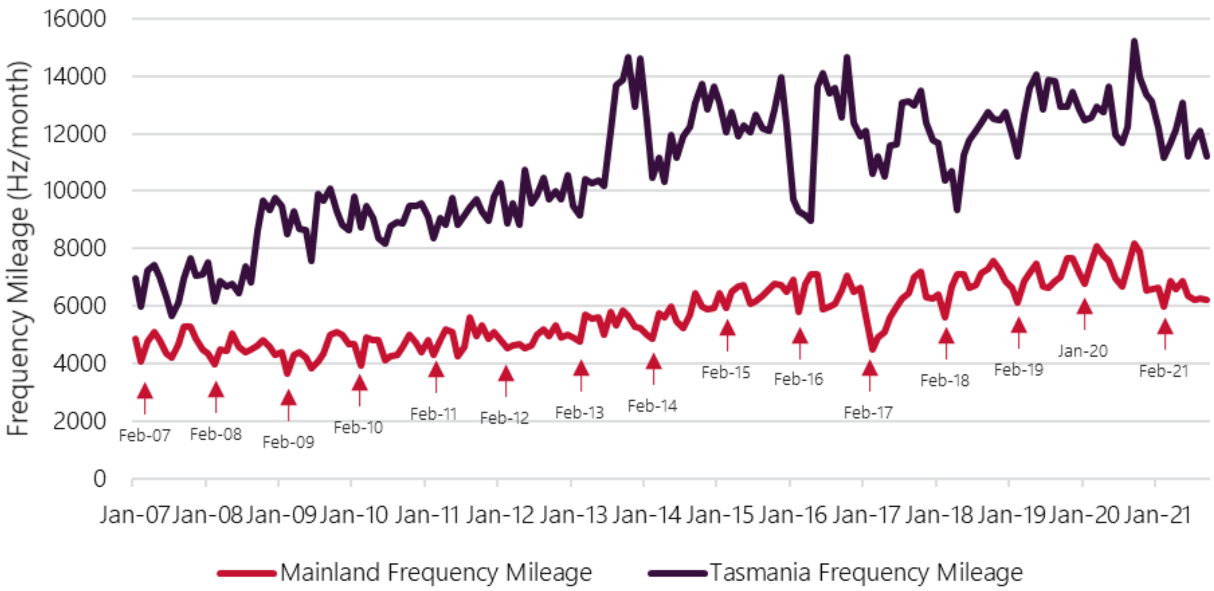
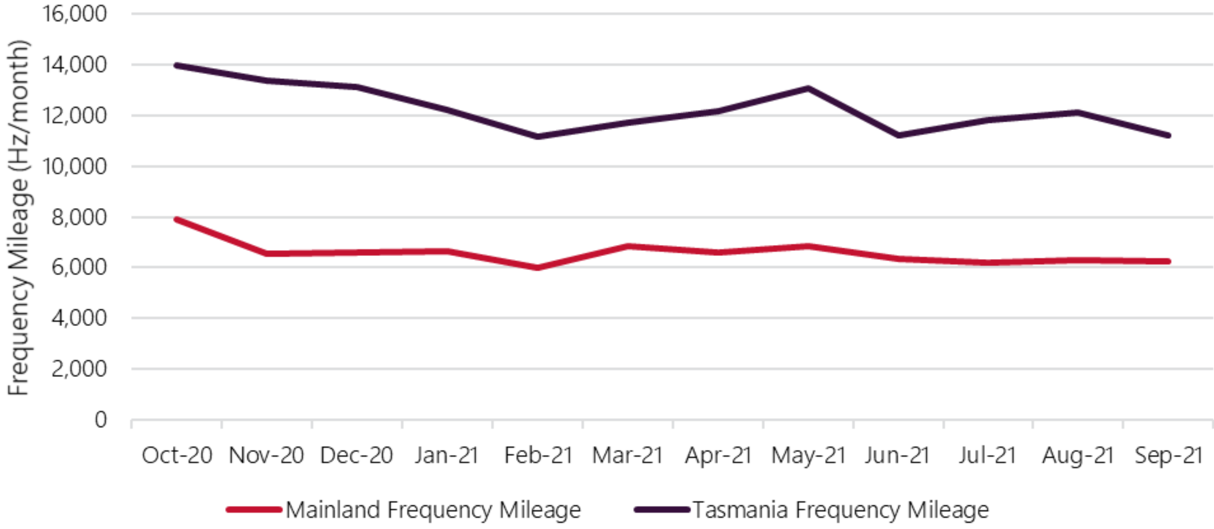


Figure 20 Monthly frequency mileage for the past 12 months



7.4 Progress on primary frequency response initiative

The implementation of the Mandatory PFR rule is a major work program currently underway involving AEMO and all affected generators in the NEM. The Australian Energy Market Commission (AEMC, or Commission) summarised the rule as follows[10]:

On 26 March 2020, the Commission made a final rule to require all scheduled and semi-scheduled generators in the NEM to support the secure operation of the power system by responding automatically to changes in power system frequency.

The final rule is designed to address the immediate need to improve frequency control as identified by AEMO and the other rule change proponent Dr Peter Sokolowski. The substantive elements of the final rule commence on 4 June 2020 and sunset after 3 years on 4 June 2023.

Key aspects of the final rule include:

- *All scheduled and semi-scheduled generators, who have received a dispatch instruction to generate to a volume greater than 0 MW, must operate their plant in accordance with the performance parameters set out in the Primary frequency response requirements (PFRR) as applicable to that plant.*
- *AEMO must consult on and publish the PFRR, which will specify the required performance criteria for generator frequency response, which may vary by plant type.*

Generators may request and AEMO may approve variations or exemptions to the PFRR for individual generating plant.

While the Mandatory PFR rule commenced from 4 June 2020, actual physical changes to generating plant controls (and therefore frequency performance) are subject to a staged implementation strategy based on generator size.

Actual physical implementation of IPFRR agreed settings at generators commenced in the final few days of Q3 2020. As at the end of Q3 2019[11]:

- Tranche 1, which affects generators 200 MW or greater, is now 85% complete (by total Tranche 1 capacity).
- Implementation of Tranche 2, affecting generators in the range 80-200 MW, is now 39% complete (by Tranche 2 installed capacity).

[10] See https://www.aemc.gov.au/rule-changes/mandatory-primary-frequency-response.

[11] See https://aemo.com.au/-/media/files/initiatives/primary-frequency-response/2021/pfr-implementation-report-v19-1-oct-21.pdf

- PFR assessments for Tranche 3 generators (<80 MW) and remaining generators in other tranches are also progressing, with around 45% of Tranche 3 completed (by Tranche 3 installed capacity)

AEMO maintains an area on its website for information and documentation relating to the implementation of the Mandatory PFR rule. This provides periodic updates on the rollout of the Mandatory PFR rule, including listings of all generation that has applied agreed PFR settings, along with any variations or exemptions that have been agreed[12].

7.5 Other recent and upcoming actions

Other notable recent and upcoming actions in the area of frequency control include:

- AEMO has consulted on the MASS, with a First Draft Determination published on the AEMO website in June 2021[13]. Having considered submissions and stakeholder feedback, AEMO extended the MASS consultation to seek further independent analysis. The publication of the Second Draft Determination on 28 October 2021 marks the commencement of the third stage of consultation. A final determination will be published in December 2021 after consideration of the formal submissions. Further details on the consultation, including published documents and options for making submissions, are available on AEMO's consultation webpage[13].
- AEMO is supporting the AEMC's work on a range of significant rule changes affecting frequency control frameworks, including Fast Frequency Response (FFR) and PFR incentive arrangements. These rule changes are in the set collectively referred to by the AEMC as the "System Services rule changes"[14]. The Final Rule for the establishment of new FFR FCAS markets was published on 15 July 2021[15]. The Draft Determination for PFR incentive arrangements was published on 16 September 2021. AEMO will engage with industry regarding plans to consult on these new markets soon.
- AEMO is preparing the 2022 *Power System Frequency Risk Review* (PSFRR) in collaboration with TNSPs under clause 5.20A.1 of the NER. Priority events for detailed assessment have been identified. This work is planned for completion mid-2022. The previous 2020 PSFRR can be viewed on AEMO's website[16].
- AEMO has identified a potential system risk with the provision of a large proportion of Regulation FCAS from a single source, and is considering whether any additional measures should be introduced into the NEM to manage this potential risk. A briefing was held on 12 August 2021 to explain the risks and potential additional measures, and to seek feedback. Further information can be viewed on AEMO's website[17].
- AEMO will be publishing an initial *Engineering Framework Gaps and Actions Roadmap* in December 2021[18]. This is intended to initiate an enduring process for industry collaboration to determine actions necessary to enable a secure and efficient NEM transition as new operational conditions emerge. The December Roadmap will summarise critical gaps identified through targeted engagement with industry from August 2021 to October 2021.
- In September 2021, AEMO published a Technical White Paper exploring the power system requirements for primary frequency response in the NEM[19], to inform the AEMC's PFR incentive arrangements rule change consultation. The AEMC has made a draft determination[20] for the current mandatory PFR

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[12] See https://aemo.com.au/initiatives/major-programs/primary-frequency-response.

[13] See https://aemo.com.au/consultations/current-and-closed-consultations/mass-consultation.

[14] See https://www.aemc.gov.au/news-centre/media-releases/new-timeframes-set-system-services-arrangements.

[15] See https://www.aemc.gov.au/rule-changes/fast-frequency-response-market-ancillary-service.

[16] See https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/system-operations/power-system-frequency-risk-review.

[17] See https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/system-operations/ancillary-services/regionalisation-of-fcas

[18] See https://aemo.com.au/en/initiatives/major-programs/engineering-framework.

[19] See https://aemo.com.au/-/media/files/initiatives/primary-frequency-response/2021/enduring-pfr-requirements-for-the-nem-technical-white-paper.pdf.

[20] See https://www.aemc.gov.au/rule-changes/primary-frequency-response-incentive-arrangements.

arrangements to continue beyond the June 2023 sunset date, coupled with the introduction of a double-sided frequency performance payment and allocation arrangement to incentivise plant behaviour to support frequency control outcomes.

- AEMO published an update to the *Frequency Control Work Plan*[21] in September 2021, reporting on task progress and also identifying sub-tasks better reflecting requirements for task completion.
- AEMO continues to monitor AGC performance following the parameter adjustments that occurred between 9-17 December 2020 and 18 January 2021. Further plans to change AGC operation will be flagged ahead of time through Market Notices and other suitable channels.

[21] See https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/system-operations/ancillary-services/frequency-control-work-plan.

Appendix A

This Appendix provides information on credible generation and load events in 2020 and 2021 meeting the following criteria:

- SCADA data from generator or load is available to AEMO.
- Generator or load reduced generation or consumption by 200 MW or greater between successive 4-second SCADA scan intervals.

This list is not intended to be a comprehensive list of all credible contingency events which affected power system frequency, as some thresholds must be selected to reasonably limit the number of events included. However, AEMO intends to include enough events of system significance to form a reasonable understanding of the ongoing success or otherwise of the NEM's aggregate ability to control frequency during major disturbances.

Events not featured below may include, but are not limited to:

- Generation and load events where the abrupt change of generation or consumption was less than 200 MW, or over a timespan longer than 4 seconds.
- Network events.
- Separation events.
- Non-credible events.
- Multiple contingency events.
- Protected events.

Table 8 and Table 9 demonstrate that both generation and load events in Q3 2021 tended to have an average frequency nadir nearer to 50 Hz and average recovery time shorter than seen in Q1-Q3 2020, which is a strong indicator of better frequency response following contingency events.

Table 10 is a list of identified contingencies from Q3 2021.

Table 8 Credible generation events in 2020-21

Quarter	Number of events	Average contingency size (MW)	Average frequency nadir (Hz)	Average recovery time (s)
Q3 2021	20	338	49.88	6
Q2 2021	22	366	49.86	4
Q1 2021	20	392	49.84	21
Q4 2020	38	315	49.84	45
Q1-Q3 2020	65	385	49.79	111

Table 9 Credible load events in 2020-21

Quarter	Number of events	Average contingency size (MW)	Average frequency nadir (Hz)	Average recovery time (s)
Q3 2021	19	284	50.09	0
Q2 2021	23	225	50.09	0
Q1 2021	8	289	50.08	0
Q4 2020	17	268	50.11	0
Q1-Q3 2020	33	279	50.17	30

Table 10 Credible generation and load events in Q3 2021

Event time	Unit	Contingency size (MW)	Frequency nadir (Hz)	Recovery to NOFB (s)	FOS compliant?
03-Jul-21 11:57:36	TOMAGO3	320	50.11	0	Yes
06-Jul-21 10:18:08	CALL_B_1	350	49.88	0	Yes
11-Jul-21 18:40:08	TOMAGO3	307	50.11	0	Yes
12-Jul-21 09:04:08	YWPS3	373	49.94	0	Yes
12-Jul-21 09:04:08	YWPS4	394	49.94	0	Yes
12-Jul-21 17:44:48	TOMAGO4	217	50.07	0	Yes
12-Jul-21 21:08:32	TOMAGO4	291	50.09	0	Yes
15-Jul-21 10:00:08	APD1	287	50.07	0	Yes
15-Jul-21 22:53:12	BOYNE3	413	50.11	0	Yes
17-Jul-21 01:31:36	TARONG#1	201	49.93	0	Yes
20-Jul-21 01:40:08	APD1	251	50.08	0	Yes
21-Jul-21 17:01:28	NPS	353	49.88	0	Yes
24-Jul-21 21:51:28	LOYYB1	583	49.71	88	Yes
29-Jul-21 12:15:12	APD1	245	50.06	0	Yes
30-Jul-21 21:56:16	BW02	331	49.85	0	Yes

Event time	Unit	Contingency size (MW)	Frequency nadir (Hz)	Recovery to NOFB (s)	FOS compliant?
02-Aug-21 04:27:20	APD1	249	50.09	0	Yes
03-Aug-21 11:41:36	BW02	323	49.91	0	Yes
04-Aug-21 01:57:20	BW03	354	49.88	0	Yes
10-Aug-21 03:07:04	BW04	440	49.84	8	Yes
10-Aug-21 10:01:28	STAN-2	301	49.90	0	Yes
11-Aug-21 14:08:08	BOYNE3	397	50.10	0	Yes
15-Aug-21 07:43:36	PUMP2	272	50.08	0	Yes
15-Aug-21 10:24:08	PUMP2	273	50.08	0	Yes
17-Aug-21 22:05:12	TOMAGO3	308	50.13	0	Yes
18-Aug-21 07:30:24	APD1	249	50.09	0	Yes
19-Aug-21 11:04:24	TARONG#1	293	49.93	0	Yes
19-Aug-21 21:13:36	ER04	232	49.88	0	Yes
20-Aug-21 02:35:36	MUWAWF1	217	49.92	0	Yes
21-Aug-21 12:17:52	BW02	553	49.83	8	Yes
25-Aug-21 18:02:24	SWAN_E	347	49.77	16	Yes
27-Aug-21 12:14:48	TOMAGO4	329	50.10	0	Yes
02-Sep-21 07:05:36	MUWAWF1	218	49.93	0	Yes
03-Sep-21 07:30:16	APD1	249	50.09	0	Yes
07-Sep-21 09:05:04	TOMAGO4	221	50.08	0	Yes
22-Sep-21 15:30:24	APD1	256	50.09	0	Yes
24-Sep-21 14:39:12	LYA1	371	49.83	8	Yes
28-Sep-21 06:30:16	APD1	261	50.10	0	Yes

Event time	Unit	Contingency size (MW)	Frequency nadir (Hz)	Recovery to NOFB (s)	FOS compliant?
28-Sep-21 22:21:04	KPP_1	302	49.87	0	Yes
30-Sep-21 11:00:24	LIMOSF11	214	49.96	0	Yes

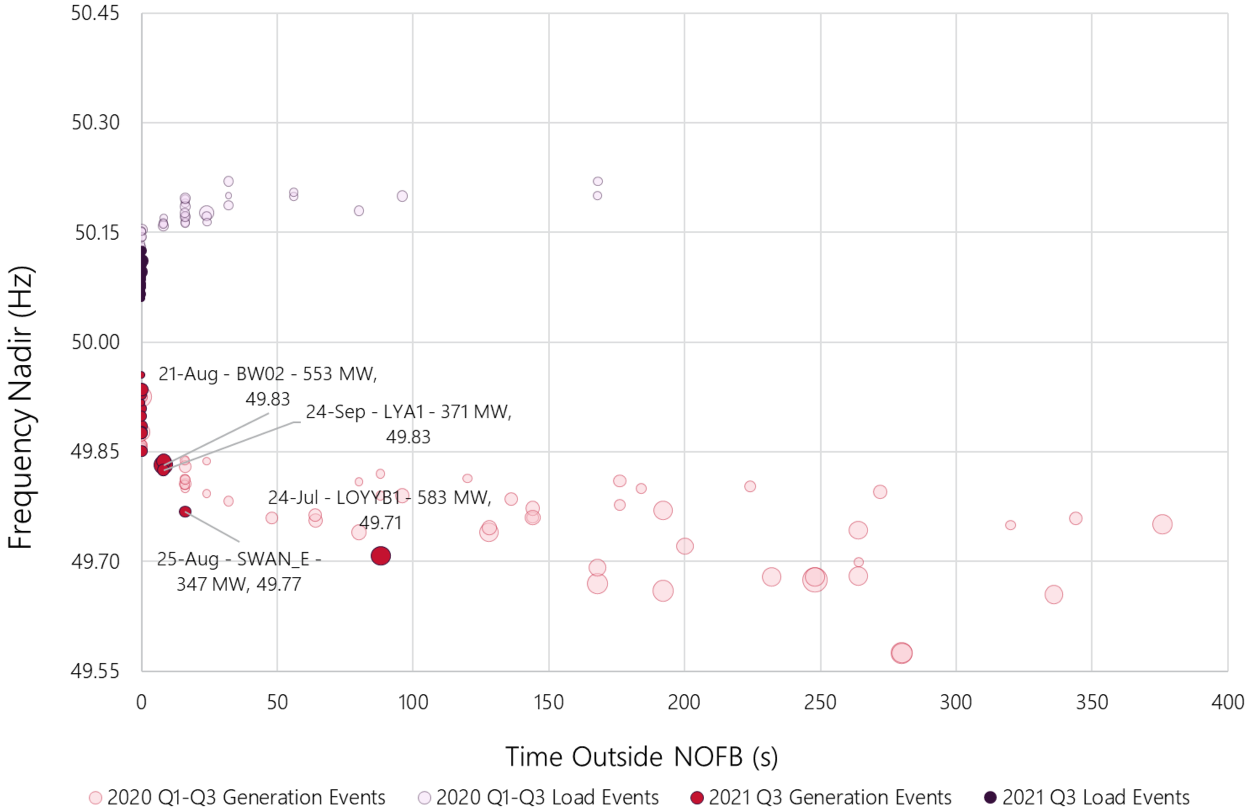
Note: TOMAGO1-4 & BOYNE1-3 are not registered dispatchable unit identifiers (DUIDs) but are included here to identify potlines of major NEM smelters.

Figure 21 displays each event from Table 10 to illustrate the distribution of frequency outcomes following credible contingency events in Q3 2021, in comparison to Q1-Q3 2020.

Generation events in Q3 2021 were contained inside the GLCB and recovered within the FOS timeframe of 5 minutes. In Q3 2021, average frequency nadir was nearer 50 Hz and average recovery time was shorter than in Q1-Q3 2020.

Load events in Q3 2021 continued to be frequently contained within the NOFB, which represents a notable shift compared to 2020, when such events would frequently cause short (and sometimes long) frequency excursions outside the NOFB.

Figure 21 Frequency outcomes of identified credible generation and load events



Size of contingency events is represented by bubble size.