Frequency and Time Error Monitoring – Quarter 4 2020

February 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 October to December 2020 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 October, November and December 2020 (Q4 2020) 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' throughout 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 Q4 2020.
- Section 3 summarises the lower number of FOS exceedances in Q4 compared to earlier quarters of 2020, demonstrating the material improvement in power system performance.
- Section 4 discusses in detail all instances where the requirements of the FOS were not met in Q4 2020.
- Section 5 displays the latest estimates of significant rate of change of frequency (ROCOF) events for Q4 2020.
- Section 6 discusses adjustments to Automatic Generation Control (AGC) undertaken during Q4 to better align with the changed system frequency behaviour, and the results of these actions.

AEMO, with support from the industry, is continuing to progress other initiatives intended to improve frequency control in the NEM. Progress on these initiatives is discussed in Section 7 of this report.

Appendix A lists credible generation and load contingency events from Q4 2020. 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] At 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

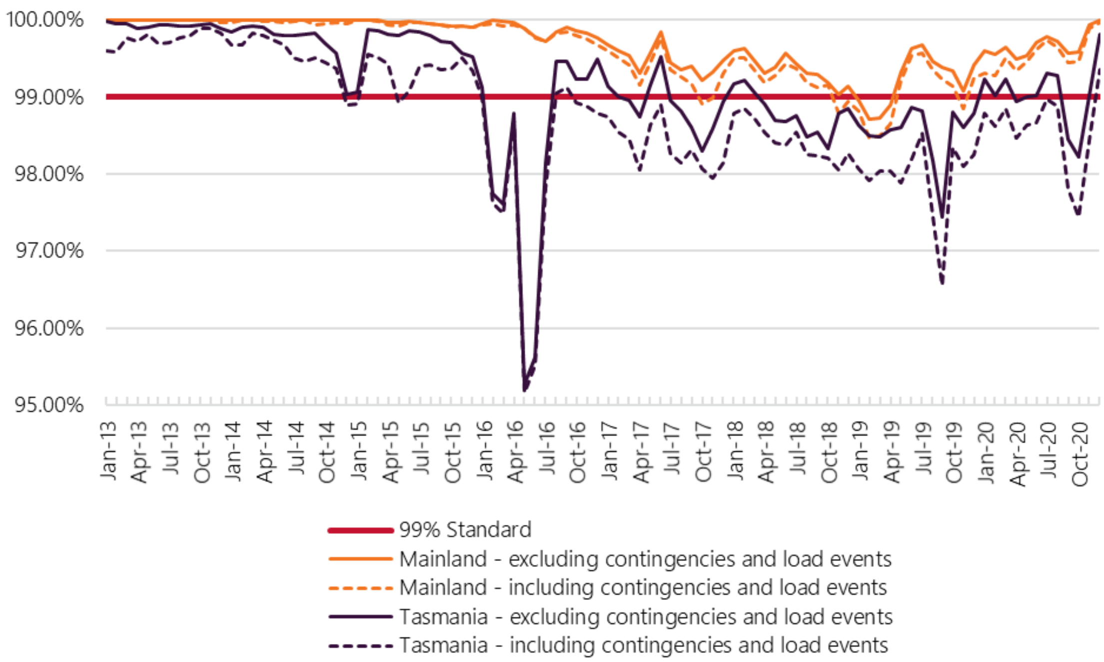
The implementation of primary frequency response (PFR) settings on a substantial portion of the NEM generation fleet began in earnest in late September 2020. As of 1 January 2021, approximately 28.8 gigawatts (GW) of scheduled generation have applied agreed settings in accordance with the Interim Primary Frequency Response Requirements (IPFRR). Updates regarding the rule change are available on AEMO's website[4].

Significant improvements in NEM frequency performance metrics have been observed over Q4 2020, which may be largely attributed to the industry's considerable collective effort to implement the Mandatory PFR rule[5]. AEMO considers this to be a very positive and welcome change in power system management. Ongoing evaluation of the implications of these observations will continue to be undertaken and reported.

In Q4 2020, there were fewer exceedances of the FOS, and indeed none in the mainland. Notably improved metrics include:

- Increased time frequency remained in the Normal Operating Frequency Band (NOFB) – see Figure 1.
- Fewer occasions of frequency departing the NOFB, and not recovering within the required timeframe, without an identifiable cause.
- Tighter frequency nadirs and shorter recovery times following generation and load events.
- No instances of time error accumulating beyond ±15 seconds.
- Improved system performance observed by time error correction through AGC tuning, resulting in a rebalance of lower and raise regulation utilisation.

Figure 1 Frequency in NOFB since 2013, minimum daily time percentage in prior 30-day window



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

5 NER clause 4.4.2A, introduced by the *National Electricity Amendment (Mandatory primary frequency response) Rule 2020 No. 5.*

3. Achievement of the Frequency Operating Standard

AEMO's assessment of the achievement of the requirements of the FOS in Q4 2020 is summarised in Table 1.

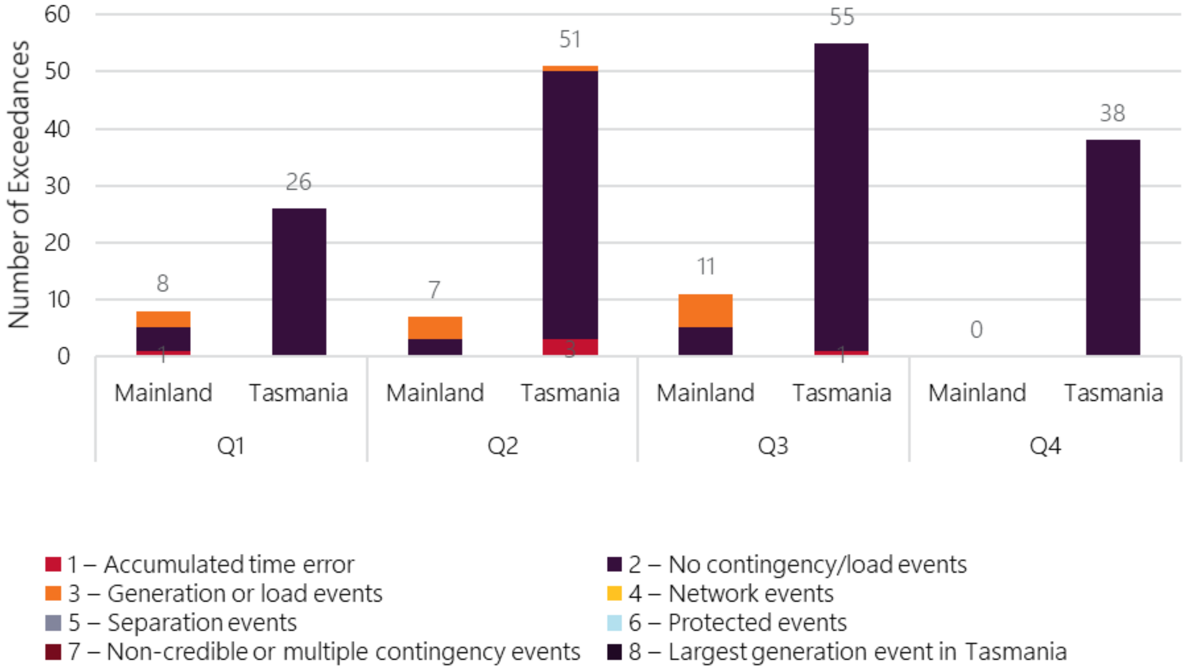
Table 1 Frequency Operating Standard and assessment in the mainland and Tasmania

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 38 times	See Section 4.2.1
• Recovered within five minutes	Achieved	Achieved	
• Within NOFB 99% of the time	Achieved	Not achieved	See Section 4.2.3 regarding Oct 2020
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 Q4 2020 is notably lower than was observed in the preceding quarters of 2020, as seen 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 substantially 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 to begin with and subsequently wandering 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 Q4 2020 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 seconds in the mainland (except for an island or during supply scarcity) and in Tasmania (except for an island or following a multiple contingency event).

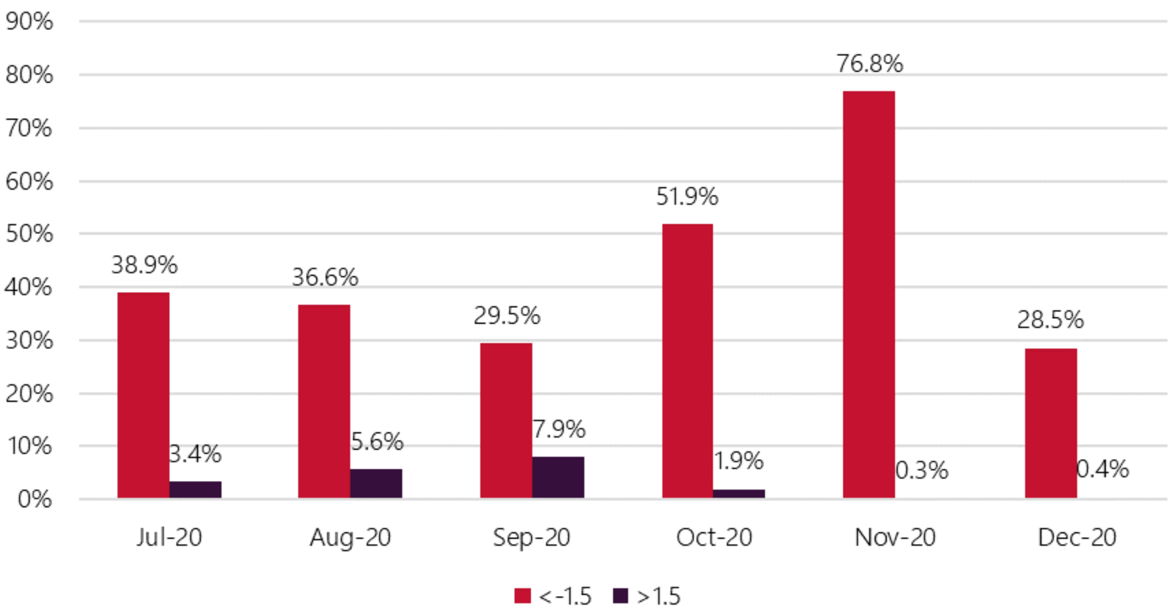
The ranges of accumulated time error in the mainland and Tasmania in Q4 2020 are provided in Table 2. Time error did not exceed the FOS requirements in Q4 2020.

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

Value	Mainland	Tasmania
Highest positive time error (seconds)	2.86	10.70
Lowest negative time error (seconds)	-11.67	-14.36

Figure 3 shows the percentage of time where mainland time error was outside the ±1.5 second threshold at which accumulated time error begins to increase regulation FCAS volumes above their base values. During Q4 2020, the incidence of time error being less than -1.5 seconds increased over October and November relative to Q3 2020. The corresponding incidence of time error exceeding +1.5 seconds decreased to near-zero.

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

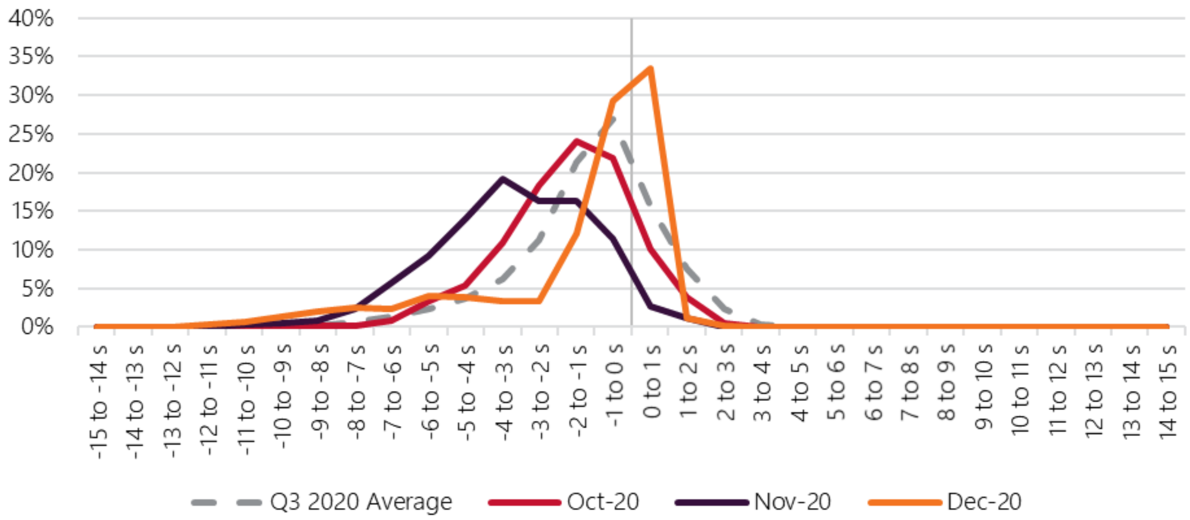


Following investigation, AEMO believes the implementation of the Mandatory PFR rule from the end of Q3 2020 interacted with the existing AGC settings in a manner that had a small but persistent effect where AGC was unable to actively assist with slight under-frequency. As system frequency was generally close to 50 hertz (Hz), AGC's measure of area control error (ACE) hovered inside the internal dead-zones of the AGC system more often than previously. Without AGC action, negative time error accumulated slowly but persistently.

Throughout Q4 2020, AEMO operational staff frequently implemented an offset (+0.03 Hz) to the base frequency (50 Hz) to reverse the accumulations of negative time error. Tuning of the AGC system from 9 December 2020 (discussed in further detail in Section 6 and Section 7.5) appears to have re-oriented time error to be more evenly distributed around zero in the month of December. No further manual time error offsets were required for the remainder of the quarter.

Figure 4 shows the distribution of mainland time error in the months of Q4 2020 compared with Q3 2020. The deterioration of time error in the negative direction over October and November 2020 is apparent, as is the re-balancing following AGC tuning in December. AEMO will continue to monitor time error for evidence of further PFR/AGC interaction.

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[6].

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 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	

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

4.2.1 Frequency excursions without a contingency event outside the Normal Operating Frequency Excursion Band

Frequency excursions outside the applicable NOFEB where an associated contingency event has not been identified are shown in Table 4 for Q4 2020.

Table 4 Number of frequency excursions without identified contingency outside the Normal Operating Frequency Excursion Band

Event	Low/High/Both frequency event	Number of events	
		Mainland	Tasmania
No contingency or load event noted	Low	0	31
	High	0	2
	Both	0	5

Mainland

No frequency events without an identified contingency in Q4 2020 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[7].

Tasmania

The number of Tasmanian events where frequency exceeded the NOFEB in Q4 2020 without an associated contingency event is characteristic of the smaller Tasmania system and is in line with performance in recent quarters.

Last quarter (Q3 2020), 51 frequency events without an identified contingency exceeded the NOFEB in Tasmania (37 low, 11 high, and three both), compared to 38 this quarter. 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.

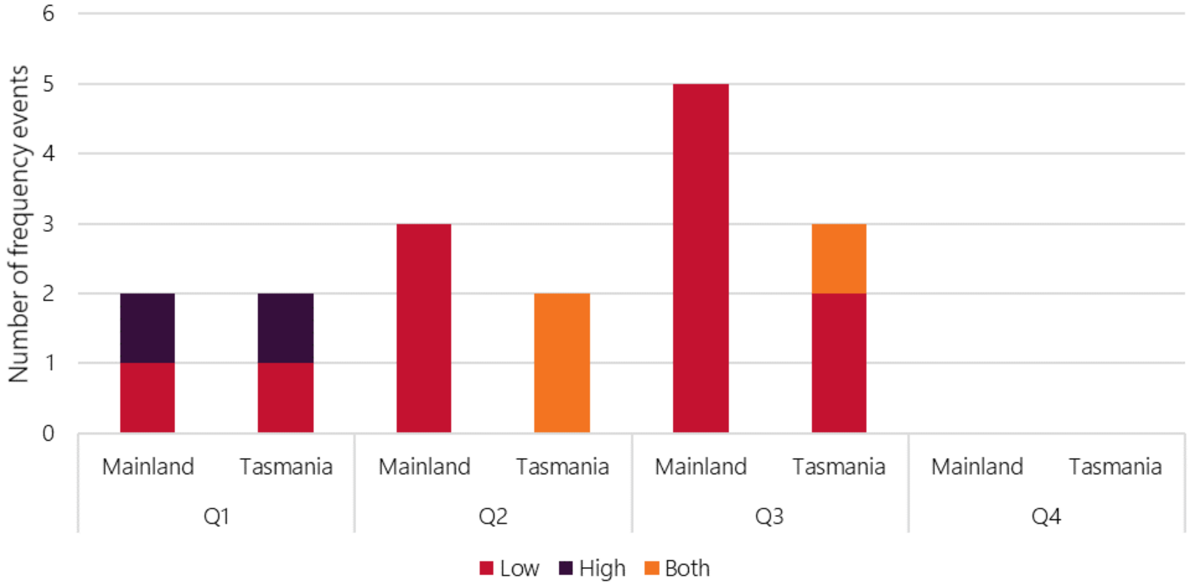
During the extended outage of Basslink from 14-16 October 2020, Tasmanian frequency performance was less consistent than typically observed while connected to the mainland. However, the FOS was not exceeded in Tasmania at any time during this outage due to the relaxed FOS requirements for such an islanded situation.

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

In Q4 2020, all frequency excursions without an associated contingency event were recovered in the FOS timeframes. This outcome is substantially improved from previous quarters in 2020, as seen in Figure 5. 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 wanders just beyond the NOFB, while also increasing the available restorative response to such events should they occur.

[7] 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 of contingency or load events.

Frequency in the mainland remained within the NOFB for more than 99% of the time in Q4 2020. Since the implementation of the Mandatory PFR rule commenced, there has been a significant reduction in the number and duration of frequency excursions from the NOFB and a corresponding increase in the time spent within the NOFB, as shown in Figure 6.

There were notably fewer events in Q4 2020 where frequency drifted outside the NOFB where no specific contingency event was identified. When contingency events did occur, frequency was often contained within the NOFB or recovered to the NOFB faster than experienced during prior quarters for similar events. Further detail is available in Appendix A.

The percentage of time that Tasmania's frequency was within the NOFB did not meet the FOS requirement of 99% for the month of October, as seen in Figure 7. An extended Basslink outage from 14-16 October 2020 was a notable period of poorer frequency performance in Tasmania during Q4 2020. However, a substantial improvement in frequency performance in Tasmania occurred throughout November and December, concurrent with the major improvement in mainland performance.

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

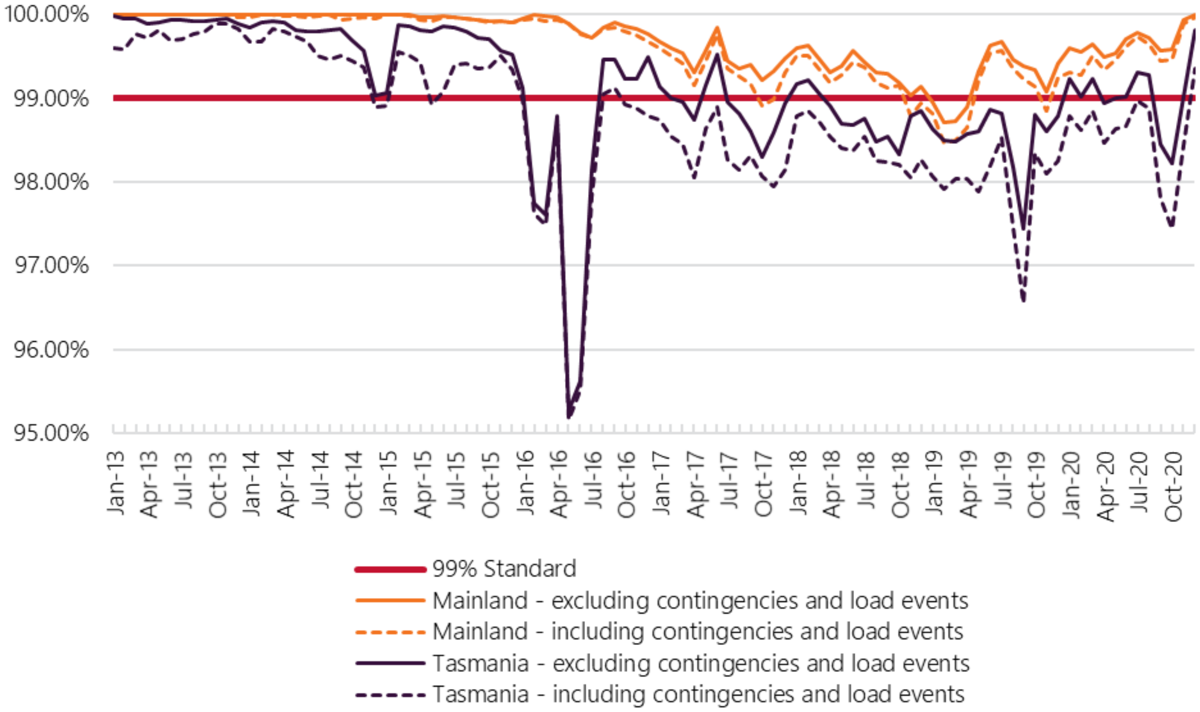
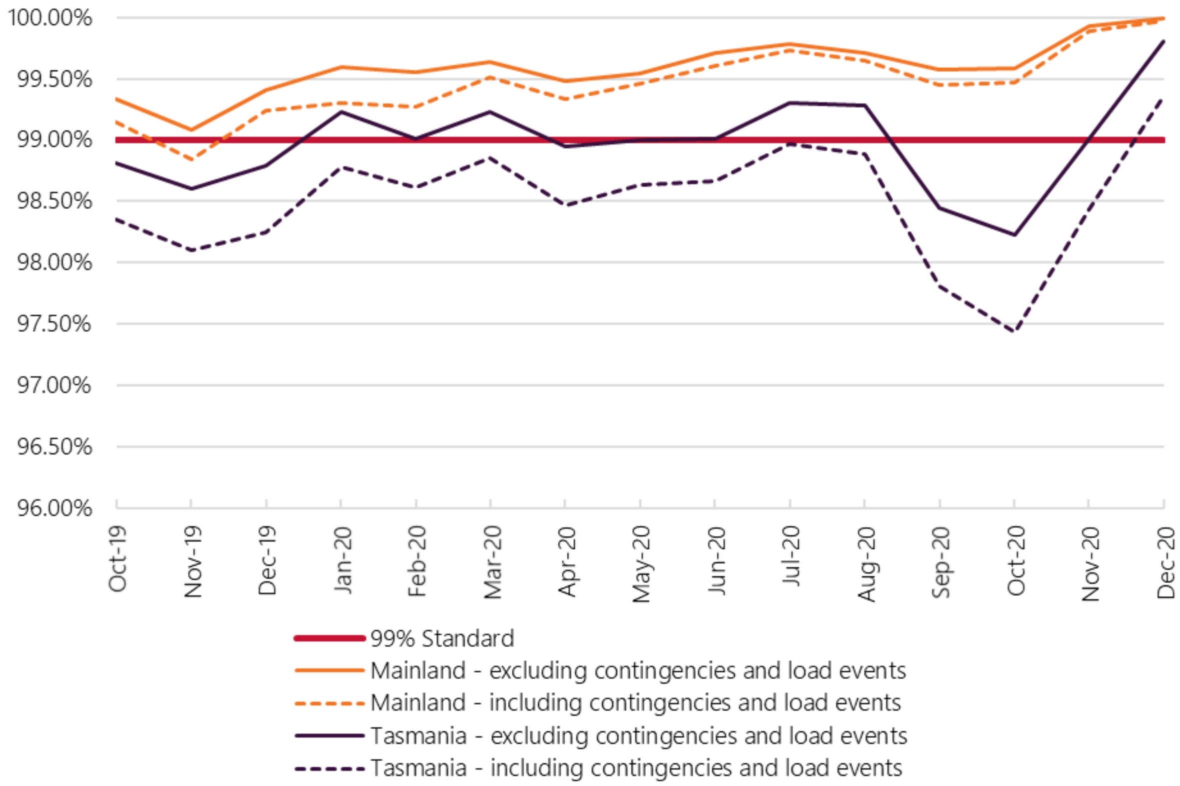


Figure 7 Frequency in NOFB since Oct-19, minimum daily time percentage in prior 30-day window



4.2.4 Frequency performance within the NOFB

The FOS does not include 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 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 Q4 2020, compared with data from 2010 as an example of a period where frequency control was tighter. The progressive return to a frequency distribution more akin to that observed in 2010 is evident over the months from October 2020 to December 2020.

The data below is substantive evidence that actions over this time, and especially the implementation of the Mandatory PFR rule, have materially improved control of frequency in the NEM.

Figure 8 Mainland frequency distribution

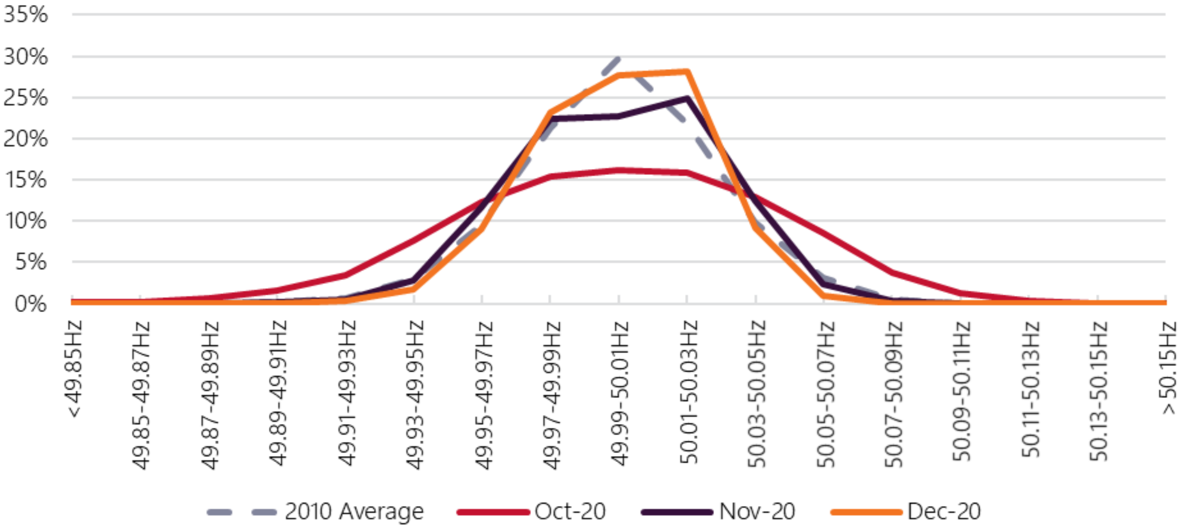


Figure 9 Tasmania frequency distribution

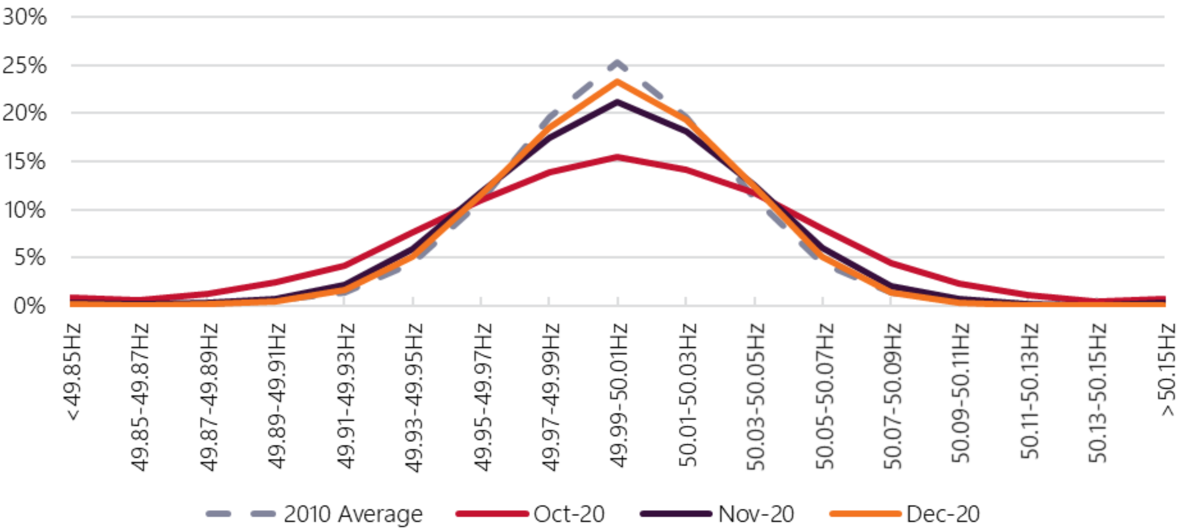
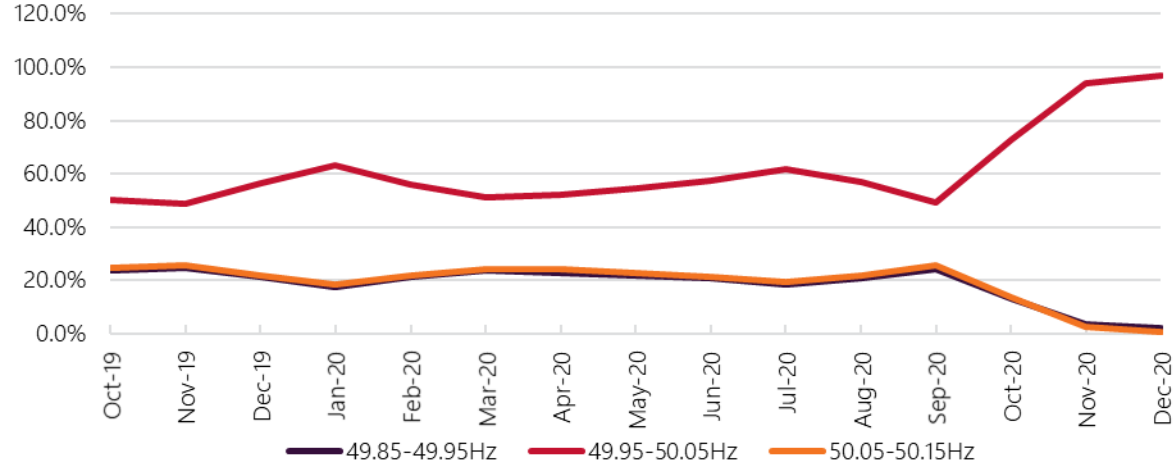


Figure 10 shows that when the frequency is within the NOFB in the mainland, the proportion of time that frequency is closer to the boundaries of the NOFB decreased sharply throughout Q4 2020 to below 10%. The proportion of time that frequency remained near 50 Hz (between 49.95 Hz to 50.05 Hz) increased to substantially above 90%.

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 Generation and Load Change Band

In Q4 2020, 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 Q4 2020, there were no frequency excursions following a generation or load event where frequency was not recovered to the NOFB within the applicable FOS timeframe (typically five minutes in the mainland, and 10 minutes in Tasmania).

This outcome is a substantial improvement on previous quarters in 2020 where several credible generator contingency events resulted in protracted recoveries of frequency. In Q3 2020, there were six such frequency excursions following a generation event that did not recover to the NOFB within the FOS timeframe.

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 Q4 2020 which demonstrate the frequency response characteristic of the system, despite these events remaining within the boundaries of the FOS.

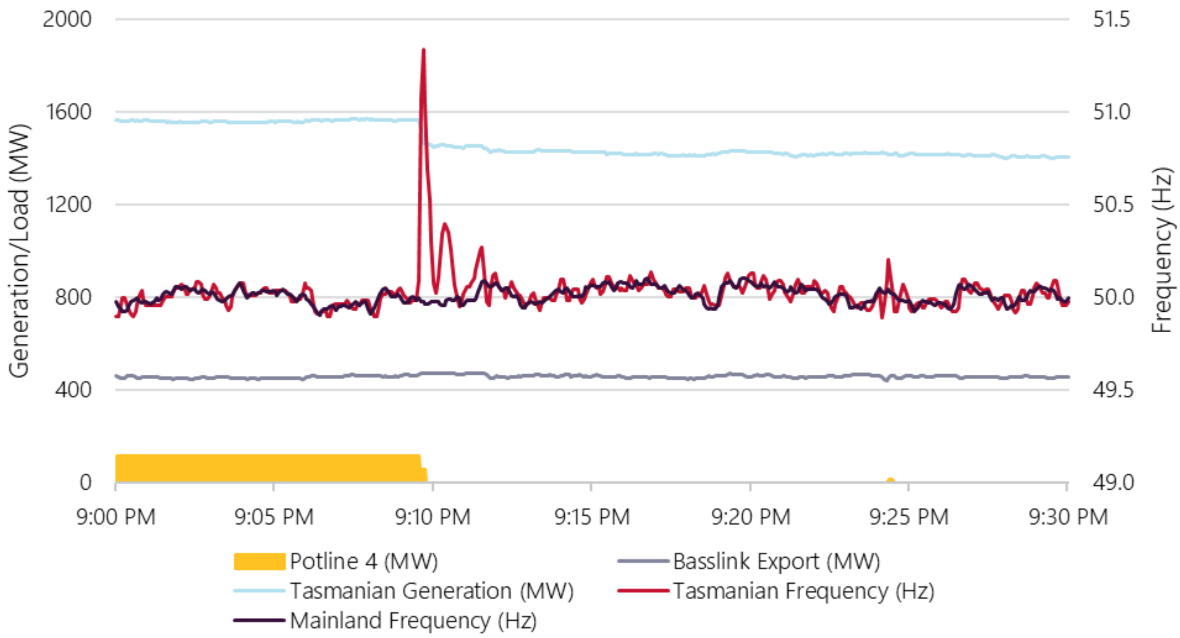
Events AEMO considers particularly notable and interesting are described in this section. Appendix A has detailed information about frequency outcomes following other selected generation and load contingency events.

9 October 2020

The trip of a potline at Bell Bay aluminium smelter at 2109 hrs on 9 October 2020 resulted in a spike in Tasmanian frequency to 51.33 Hz, as shown in Figure 11. This event was notable for recording the highest SCADA-captured frequency in the NEM since 7 February 2009. The Basslink interconnector was transferring power into the mainland at its maximum capability prior to the trip and thus was unable to assist in frequency recovery.

Frequency was contained due to a rapid reduction in Tasmanian generation by approximately 100 megawatts (MW) within 10 seconds. Despite Basslink's inability to assist, this was a rapid recovery well within the requirements of the FOS.

Figure 11 Tasmanian system during 9 October 2020 event

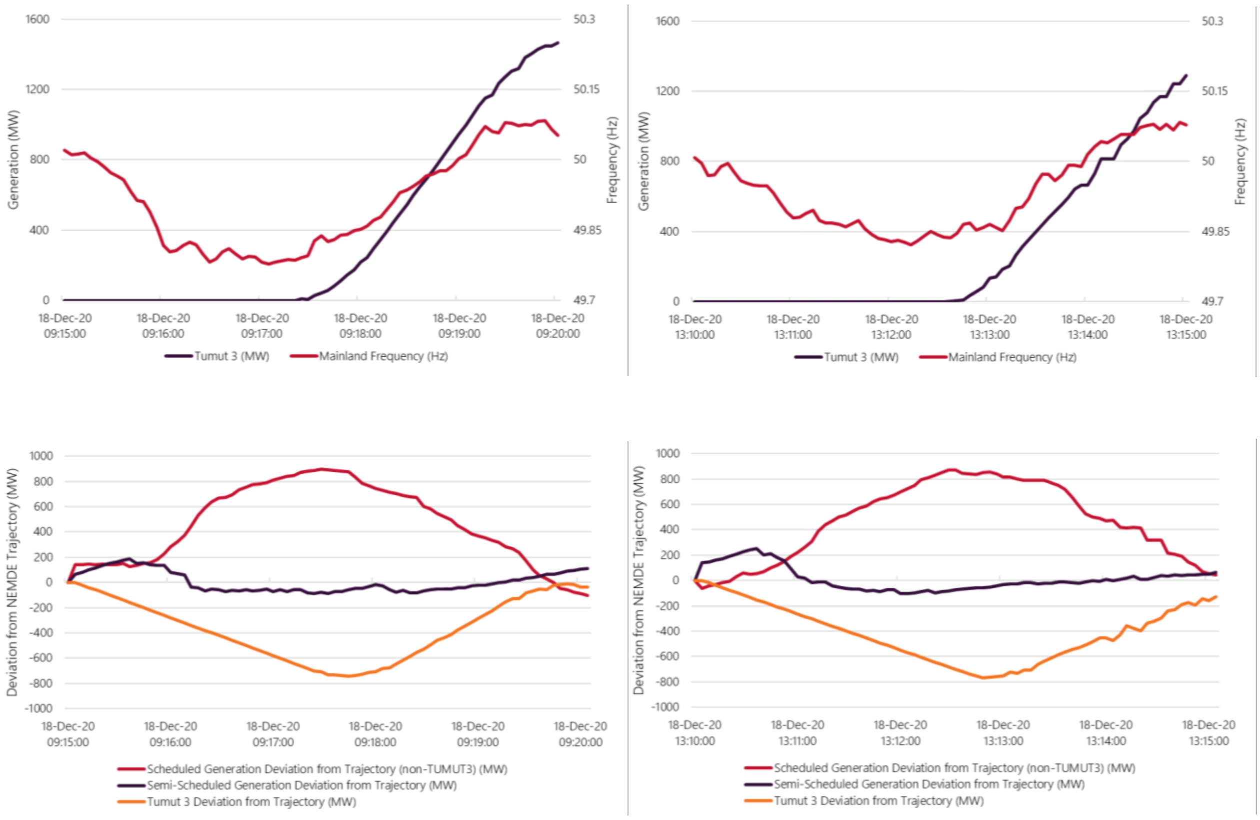


18 December 2020

AEMO noted two significant frequency events on 18 December 2020 coincident with the ramping of the Tumut 3 hydro power station, which was twice dispatched from 0 MW to greater than 1,400 MW in a single dispatch interval.

In dispatch, the market assumes that units ramp linearly between their market dispatch points. In this way, units ramping up large amounts are balanced by units ramping down. However, in reality units do not always ramp linearly, especially in the case where units are starting up. As Figure 12 shows, in both of these events, a low frequency persisted until Tumut 3 synchronised and reached its target, which it achieved in approximately 2-3 minutes. These events could be considered generation events under the FOS due to the unexpected change of active power at a generator exceeding 50 MW over 30 seconds. The temporary supply-demand deficit was met through scheduled generators deviating upwards above their linear trajectories. Note that the requirements of the FOS were met in both instances. Throughout the same intervals, the aggregate delivery of semi-scheduled generation was largely as expected, although several instances of rapid curtailment of semi-scheduled plant were noted in the early minutes of the dispatch interval.

Figure 12 NEM generation and mainland frequency on 18 December 2020 during two generation 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 occurred during Q4 2020 in the mainland or Tasmania, noting that a trip of Basslink is conventionally considered a network event and not a separation event.

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 during Q4 2020, in either 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 Q4 2020 which demonstrate the frequency response characteristics of the system, despite these events remaining within the boundaries of the FOS.

14-16 October 2020

An outage of Basslink occurred from 0448 hrs on 14 October 2020 to 1730 hrs on 16 October 2020. During this period, Tasmanian frequency remained within the applicable NOFB (49.0-51.0 Hz) at all times, as seen in Figure 13. However, the stability of frequency was notably less consistent than when connected to the mainland, and frequently exhibited a wide oscillating behaviour, as Figure 14 shows.

AEMO paused the dispatch of AGC regulation in Tasmania for two successive dispatch intervals (1245 hrs and 1250 hrs) on 14 October to check if AGC was the root cause of the significant frequency swings, but these oscillations continued. The AGC frequency bias setting in Tasmania was subsequently reduced to dampen the AGC frequency control response to avoid exacerbating the situation.

Figure 13 Tasmanian frequency during extended Basslink outage 14-16 October 2020

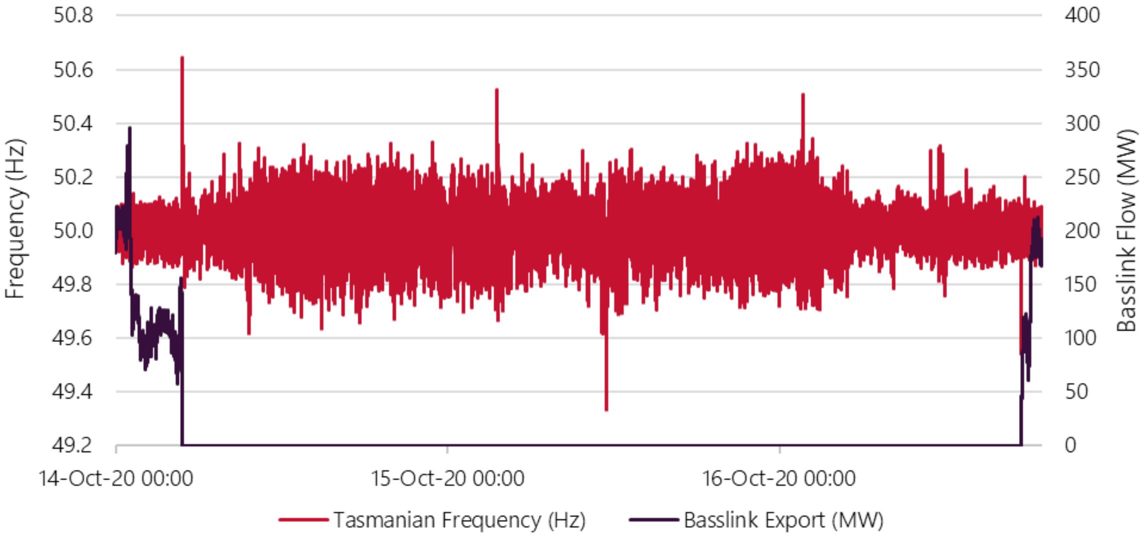
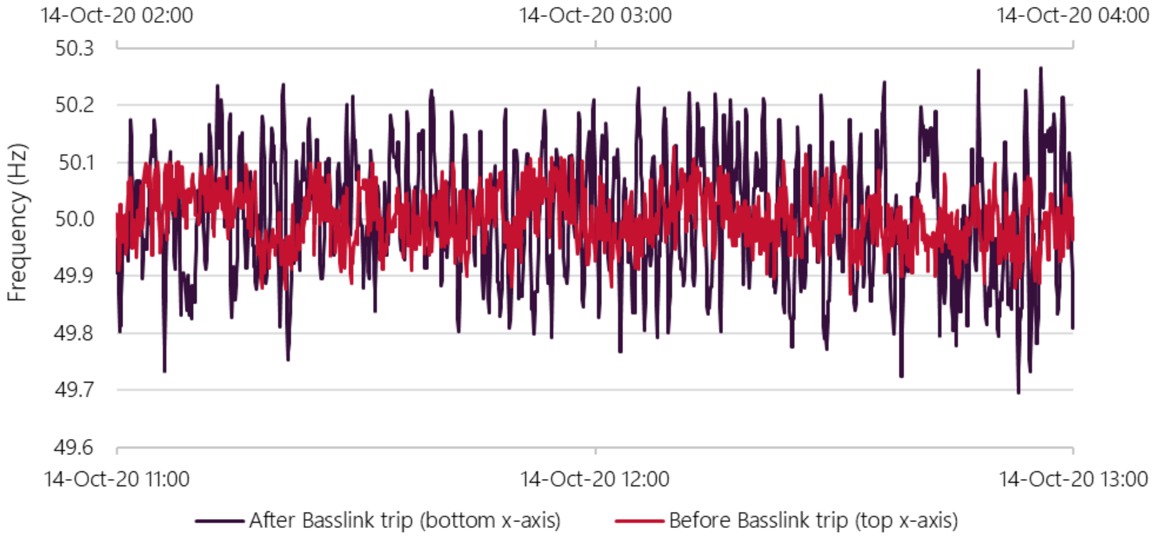


Figure 14 Tasmanian frequency before and after Basslink trip



29 November 2020

A trip of Basslink occurred at 0735 hrs on 29 November 2020. At the time, Basslink was importing 439 MW from the mainland. Frequency in Tasmania was contained within 49.61-50.40 Hz and did not remain outside the applicable NOFB (49.0-51.0 Hz) for longer than 10 minutes during the event, as shown in Figure 15 and Figure 16. Frequency in the mainland remained within the NOFB during the event. Basslink resumed operation at 1515 hrs.

Figure 15 Frequency during trip of Basslink 29 November 2020 – initial period

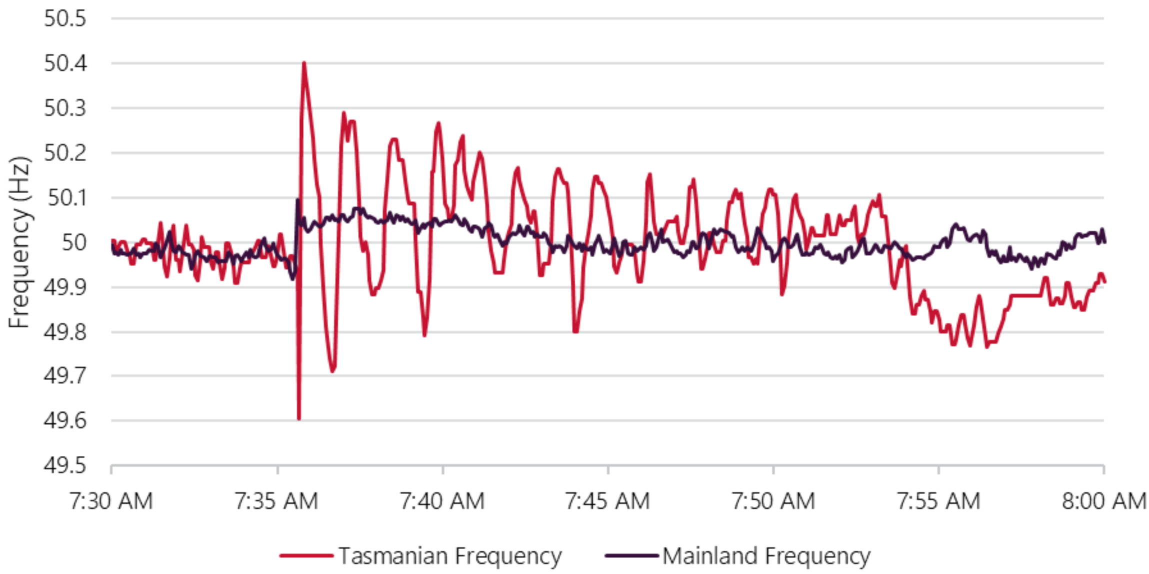
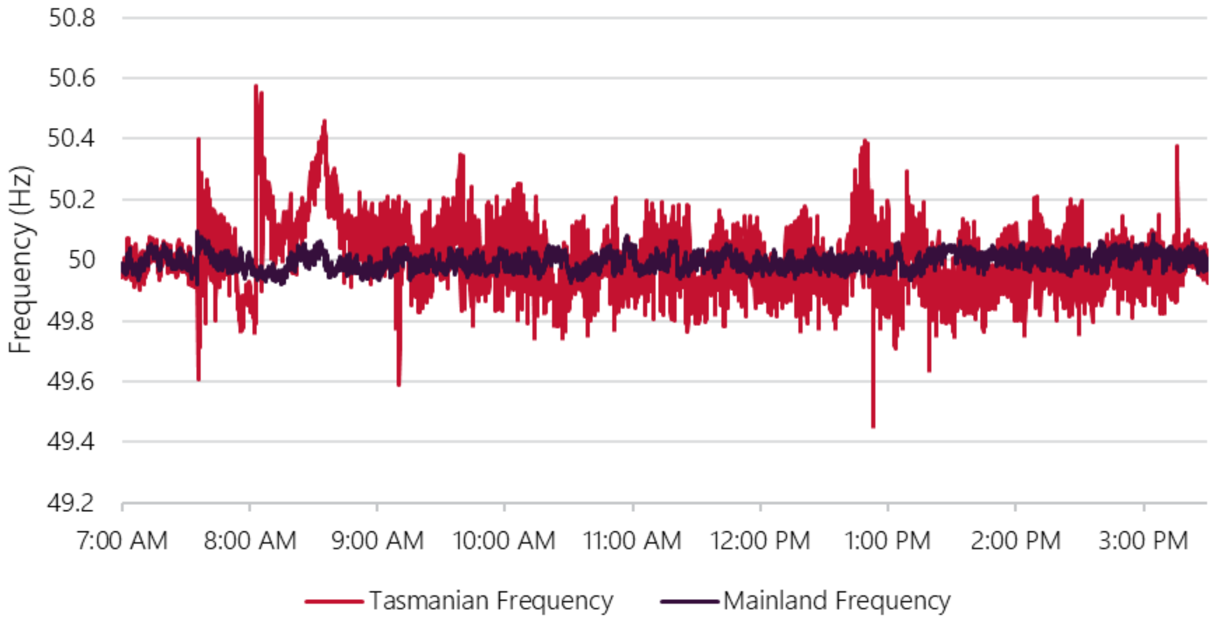


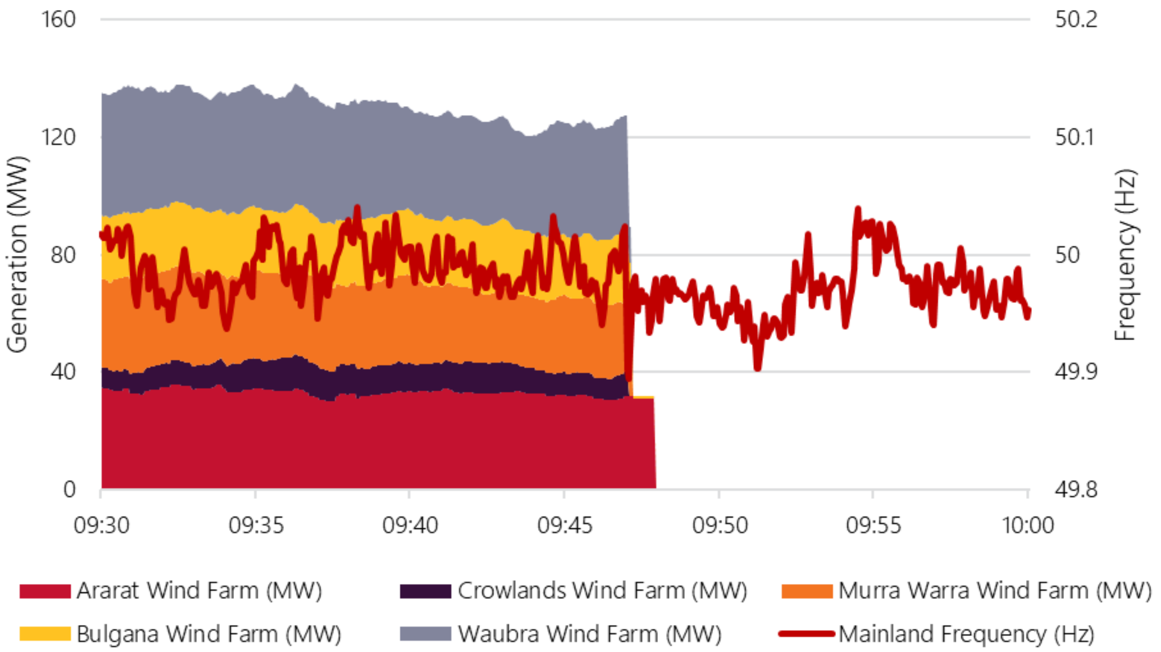
Figure 16 Frequency during Basslink outage 29 November 2020 – full period



4 December 2020

A trip of the Ballarat – Waubra – Ararat 220 kilovolt (kV) Line occurred at 0947 hrs on 4 December 2020. Four Victorian generators – Ararat Wind Farm, Bulgana Wind Farm, Crowlands Wind Farm and Murra Warra Wind Farm – were curtailed immediately by control scheme actions operating as expected, as shown in Figure 17. Waubra Wind Farm was also disconnected as a result of being connected to the tripped line. The combined loss of generation was estimated to be 126 MW due to low wind speed at the time, causing a minor frequency deviation within the NOFB.

Figure 17 Frequency and Victorian wind farm generators during trip of Ballarat – Waubra – Ararat 220 kV line on 4 December 2020



AEMO notes the combined maximum capacity of these units is 837 MW. Such an event could represent the largest credible contingency in the NEM by some margin, were the same event to occur at a time near maximum wind output in this Victorian zone of the NEM. For example, at 0500 hrs on 29 November 2020, instantaneous aggregate output was 800.4 MW from these same five generation units; the next largest contingency at that time was a trip of Kogan Creek from 723 MW.

The following constraints were implemented on 25 May 2020 to manage this network contingency.

- N^^V_NIL_ARWBBA
- F_I+GFT_TG_R6/R60/R5, F_MAIN++GFT_TG_R6/R60/R5, F_MAIN+GFT_TG_R6/R60/R5

This event highlights the increasing complexity of the NEM and the potential consequences for frequency control as the generation fleet and transmission network evolves.

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 the basis for any inclusions.

No such incidents were reported during Q4 2020.

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

5. Rate of change of frequency

5.1 ROCOF methodology

The rate of change of frequency 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, 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 Hz/s, is provided in Table 6.

Table 6 ROCOF during frequency events in the mainland

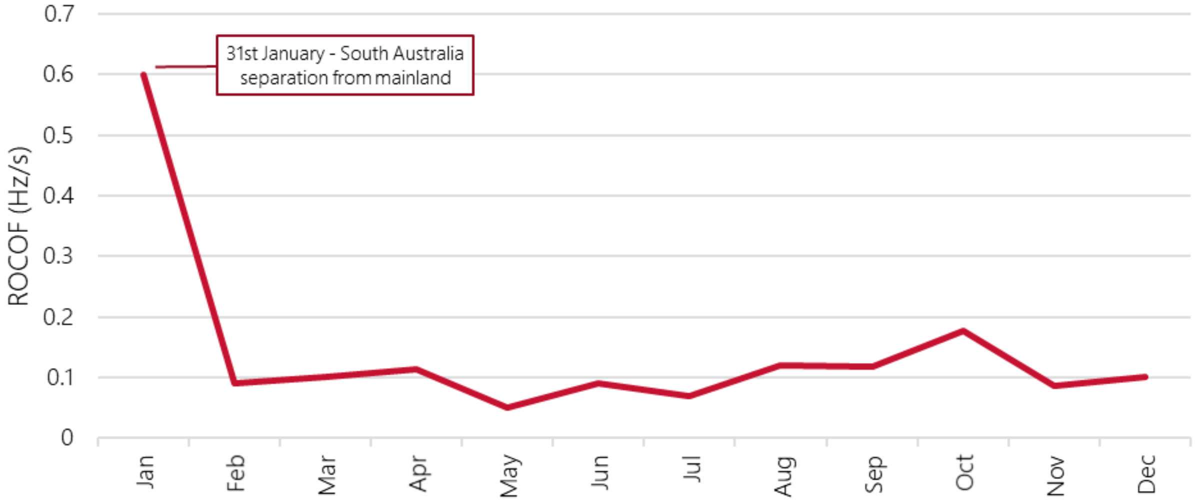
Month	ROCOF (Hz/s)	Associated event	Event time
October	-0.176	Trip of Bayswater 4 unit	14/10/2020 10:52
November	-0.086	Trip of Loy Yang B1 unit	05/11/2020 11:24
December	-0.100	Trip of Loy Yang A1 unit	14/12/2020 09:45

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

Figure 18 shows the maximum ROCOF recorded each month of 2020 in the mainland. 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 ROCOF can be quite different. Under substantially different ROCOF conditions, FCAS capability for some plant would be different.

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 near 0.125 Hz/s. The notable exception in Figure 18 occurred on 31 January 2020 when South Australia separated from the mainland NEM, however this was a non-credible event.

Figure 18 Monthly maximum ROCOF recorded in 2020 in the mainland



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 system. Over time, 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 19 and Figure 20 show a comparison of the minimum and maximum ACE per half-hourly trading interval in the mainland and Tasmania in Q4 2020.

A progressive reduction in ACE values has been observed throughout Q4, and is considered to represent the smaller average frequency error in the NEM following the implementation of the Mandatory PFR rule, as shown in Figure 19.

Adjustments to AGC area tuning were implemented from 9 December 2020. The impact of this work on the balance of raise and lower regulation is evident in Figure 19. From 9 December 2020, positive ACE values became better balanced with negative ACE values, with the flow-on effect being better balanced usage of the lower and raise regulation FCAS reserves. Refer to Section 7.5 for further details on the AGC tuning and an associated issue that has required some of the ACE improvements to be partly wound back.

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

Figure 19 Minimum and maximum ACE per half-hour in mainland

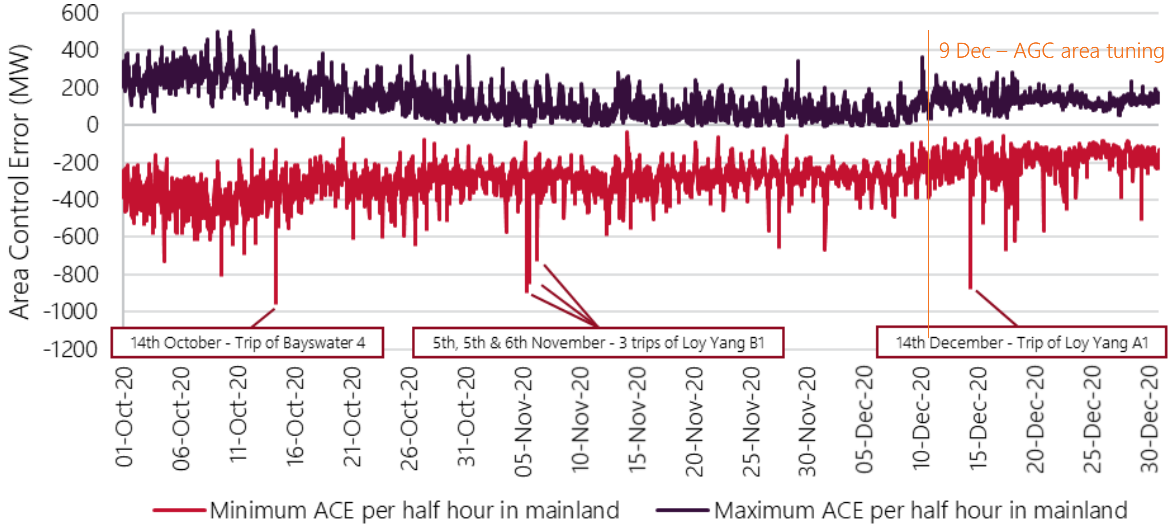
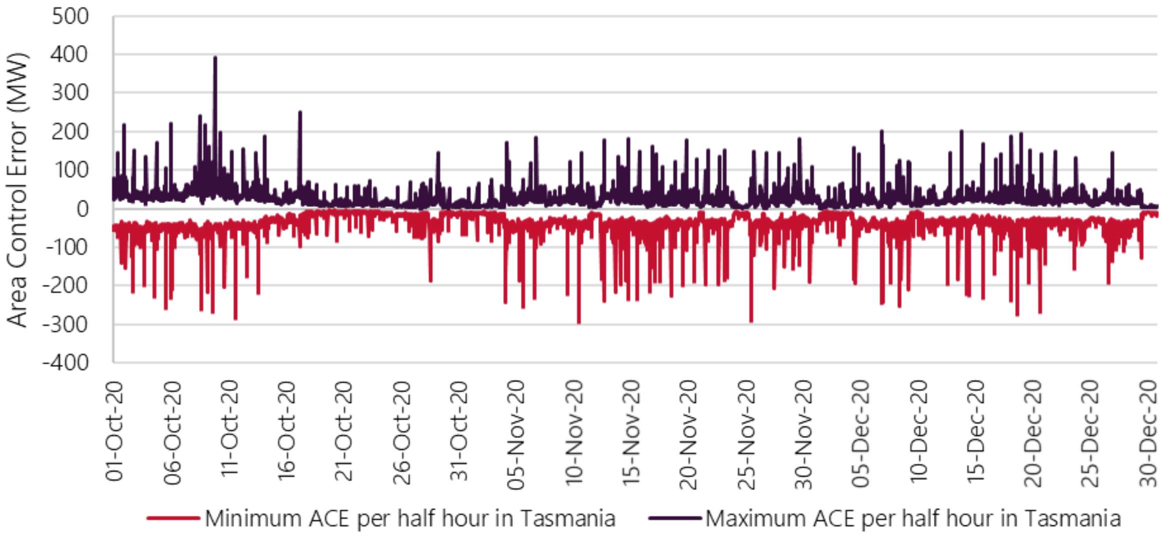


Figure 20 Minimum and maximum ACE per half-hour in Tasmania



7. Actions to improve frequency control performance

The long general decline in frequency control performance under normal conditions in the NEM has been well documented and is the subject of many inter-related areas of work.

In this report, AEMO publishes a range of metrics intended to document aspects of frequency control that are not related to requirements in the FOS but are important indicators of frequency stability.

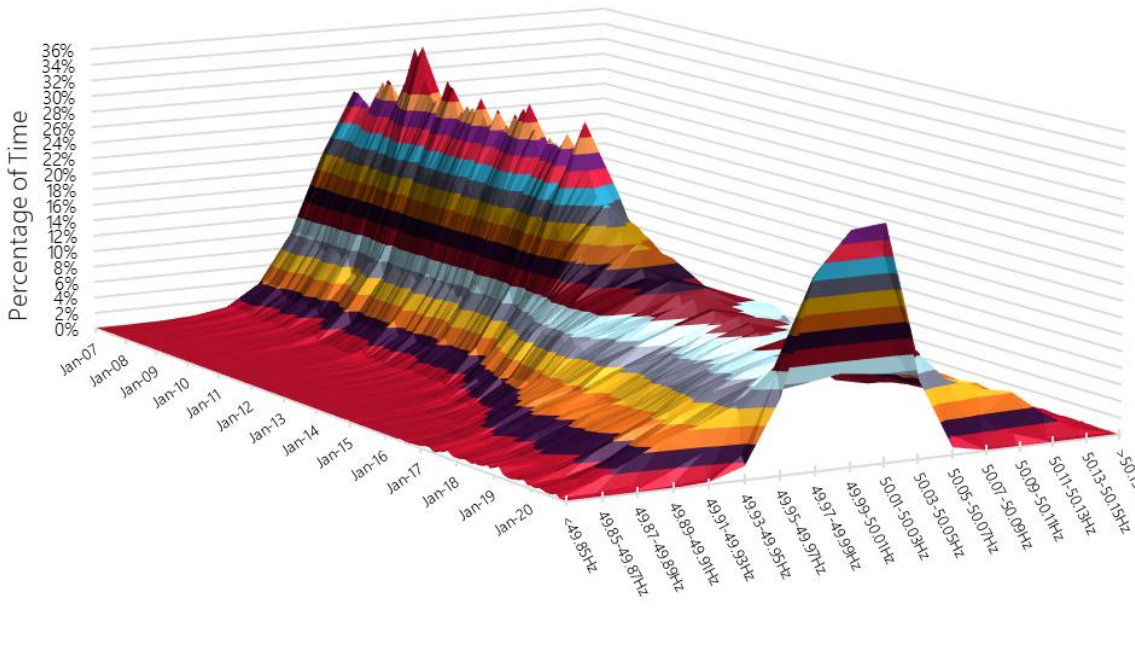
These also form a basis for assessing the impacts of current actions, such as the implementation of the Mandatory PFR rule. This rule came into effect from 4 June 2020, but implementation at generators commenced from the end of Q3 2020, and it is therefore a significant feature of this Q4 2020 report.

7.1 Measure 1 – distribution of frequency within NOFB

This measure examines the distribution of frequency within the NOFB. As Figure 21 shows, a flattening of the frequency distribution within the NOFB has been observed over time, and particularly since 2014-15, so frequency has spent more time out towards the edges of the NOFB than it used to. Among other things, this means that when a contingency event occurs, the resulting frequency change is more likely to deviate significantly away from 50 Hz.

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

Figure 21 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 was a dramatic increase in the number of instances where frequency departs the NOFB, as Figure 22 and Figure 23 show. Interestingly, there was also a significant decline in the number of 50 Hz crossings, which relates to the fact that frequency tends to spend much more time away from 50 Hz, and therefore does not have as much opportunity to cross.

Figure 22 Monthly frequency crossings – under 49.85 Hz, across 50 Hz, beyond 50.15 Hz

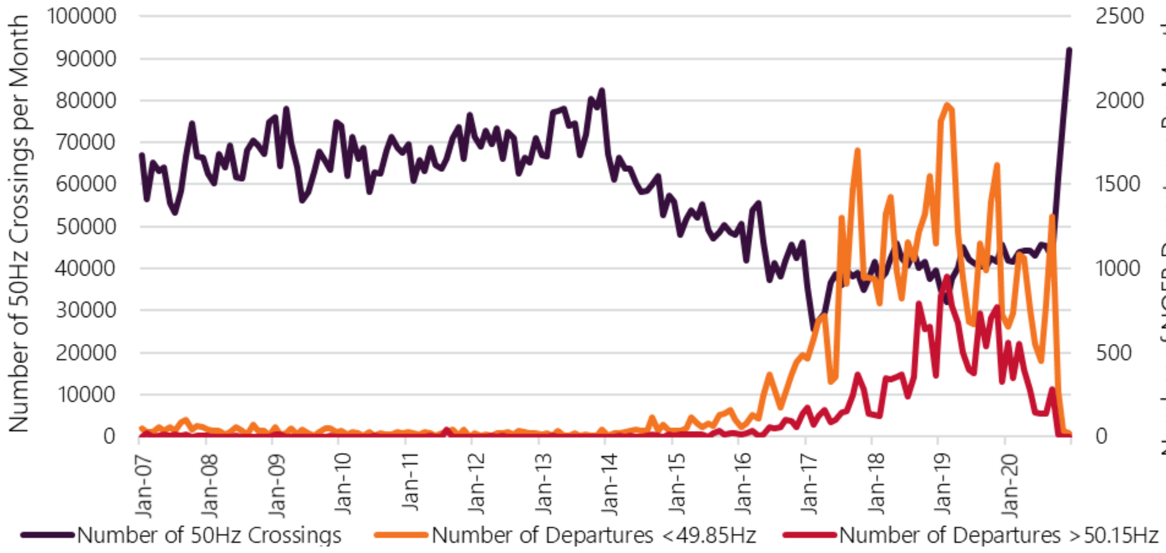
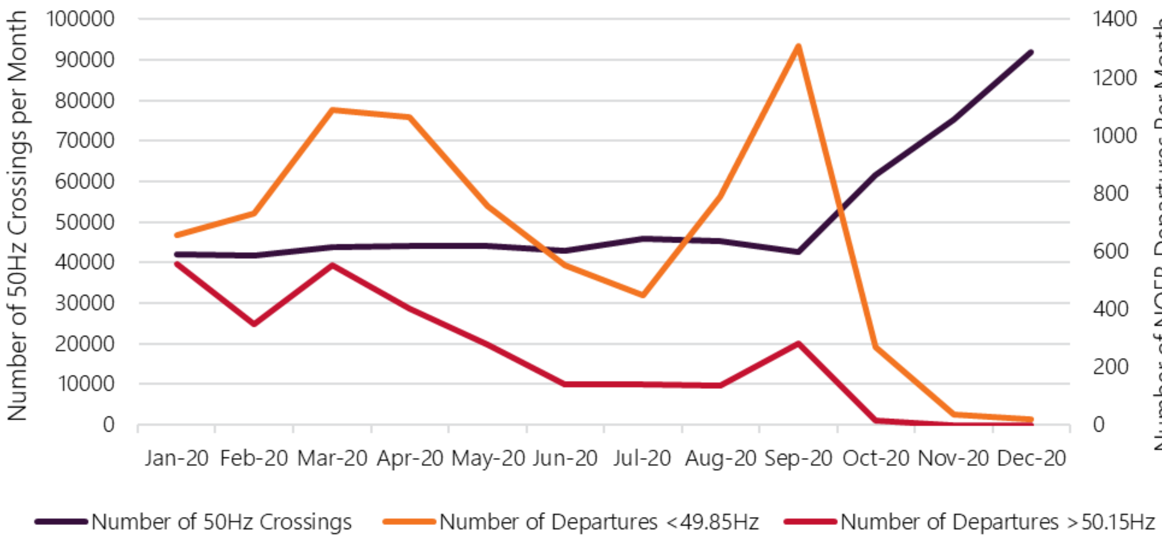


Figure 23 Monthly frequency crossings for recent 12 months



The trend of increasing departures from the NOFB has come to an abrupt end since the implementation of PFR on a significant portion of the NEM generation fleet over Q4 2020 (particularly November and December). All departures from the NOFB that occurred in November and December could be linked with associated contingency events; this represents a significant change from experience leading up to Q4 2020, when many departures had no clearly identifiable cause.

Also of interest is the rise in the number of 50 Hz crossings in Q4 2020. The incidence of such crossings is now similar to that observed prior to 2014-15 when the deterioration in frequency control began to be particularly notable. Such findings suggest the overall quality of frequency control has substantially returned to the benchmarks previously observed in the NEM.

7.3 Measure 4 – frequency "mileage"

This measure examines the total amount of change in frequency over time. It is another way of indicating 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	0s	4s	8s	12s	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

Frequency mileage per month had been increasing since 2007, as shown in Figure 24 and Figure 25. Within the long-term trend of increasing mainland frequency mileage since 2007, a seasonal cycle is observed, which is lowest in February, low over winter, and highest in the shoulder seasons of autumn and spring. This is likely due to there being more units in service over summer and winter serving the higher demands, with higher unit numbers contributing to greater overall frequency control.

Observed frequency mileage in September 2020 was estimated to be the greatest monthly mileage recorded. Interestingly, increases in regulation FCAS and contingency FCAS volumes made over 2019 through to early 2020 did not appear to have any discernible impact on frequency mileage.

Frequency mileage has fallen somewhat since the implementation of IPFRR settings on much of the NEM generation fleet over Q4 2020, although it is too early to attribute this change to the Mandatory PFR rule. This will be monitored in the coming quarters.

Figure 24 Monthly frequency mileage

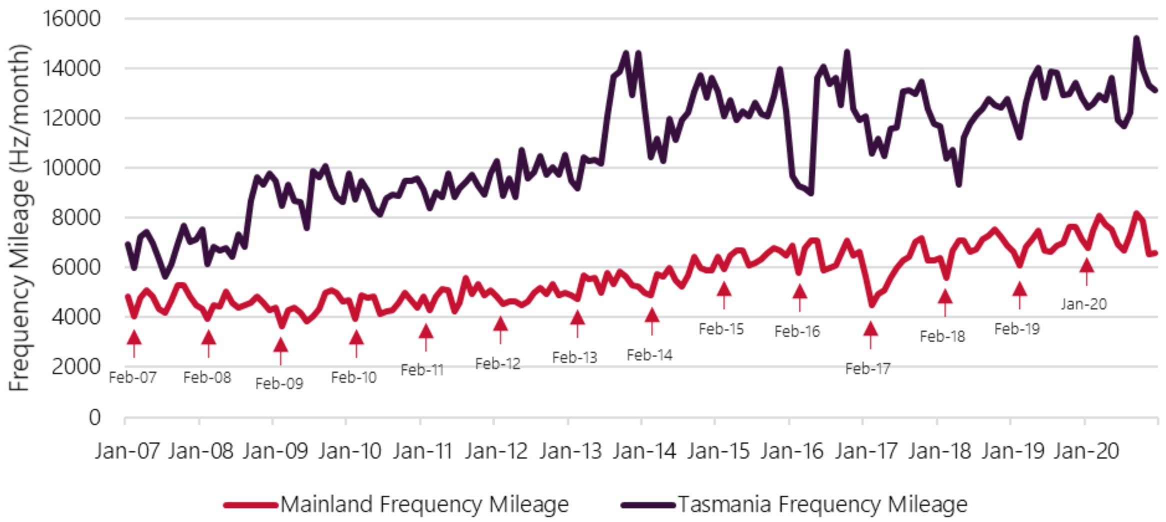
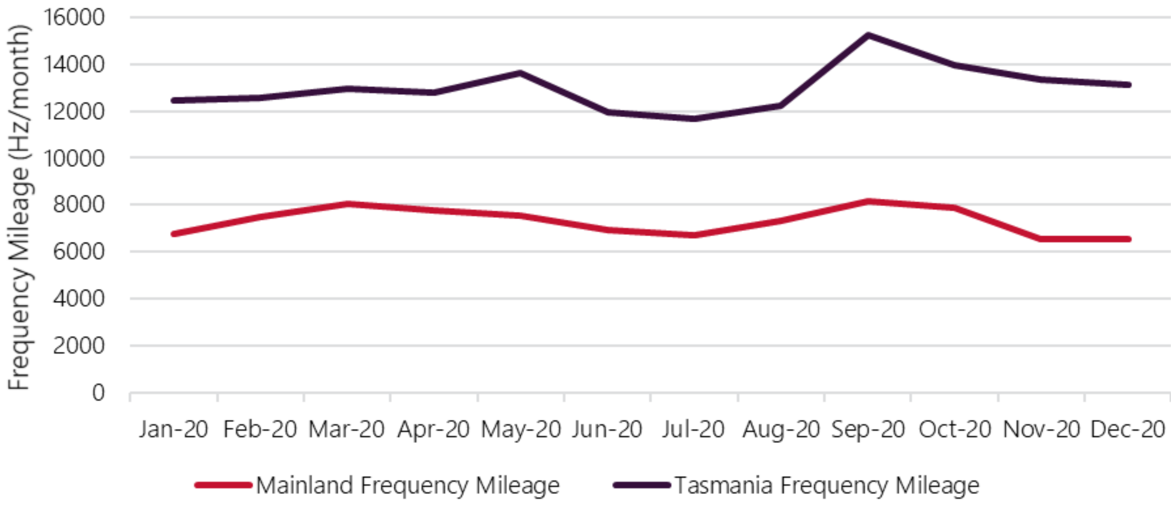


Figure 25 Monthly frequency mileage for recent 12 months



7.4 Progress on primary frequency response initiative

Implementation of the Mandatory PFR rule is a major work program currently underway. 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. Tranche 1, which affects generators 200 MW or greater, was largely completed by the end of Q4 2020 and has been an instrumental factor in the major improvements to frequency performance observed in this report. Tranche 2, affecting generators in the range 80-200 MW along with some remaining plant from Tranche 1, will be progressed in Q1 of 2021.

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

AEMO maintains an area on its website for information and documentation relating to the implementation of the Mandatory PFR rule, including periodic updates on the rollout of the Mandatory PFR rule[11].

7.5 Other recent and upcoming actions

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

- From 9-17 December 2020, AEMO undertook tuning of the AGC system in the mainland regions to better cater for the changes to frequency conditions that have occurred over the last few months. Changes involved altering AGC's behaviour to better utilise available regulation FCAS resources, and included:
  - Revision of AGC internal deadbands and minor adjustments to gains.
  - Changes to make AGC integral action more persistent.
  - Enablement of basepoint adjustment for distribution of required energy not accounted for by energy market targets amongst regulating units. The distributed total basepoint adjustment includes additional energy from PFR enabled and regulating units, and calculated load frequency response.
    - The basepoint adjustment changes were reverted on 18 January, due to an issue related to data gathering processes in the Causer Pays process. AEMO is reviewing basepoint adjustment with a view to correcting the Causer Pays issue and re-enabling basepoint adjustment if justified. AEMO will use Market Notices and other suitable channels to advise of any further changes to AGC area tuning.
- AEMO commenced a consultation on the MASS in January 2021[12]. This review proposes:
  - Improvements to MASS readability and usability and clarification of FOS references.
  - Adjustments to response ranges to improve utilisation of FCAS from frequency responsive and non-frequency responsive controllers.
  - Clarification and enhancement of requirements to improve the co-ordination of local (contingency FCAS and PFR) controls with remote (regulation FCAS/AGC) controls.
  - Clarification of the characteristics and requirements for the provision of regulation FCAS.
  - Clarification of the requirements of delayed FCAS.
  - Options on a path forward with FCAS supplied by aggregated ancillary service facilities based on learnings from the Virtual Power Plant (VPP) Demonstrations. In particular, consulted issues focus on measurement requirements for such facilities.
- Following assessment and subsequent adjustment of mainland load relief, AEMO commenced work with TNSP TasNetworks to undertake a review of load relief in the Tasmanian region. Tasmanian load relief is being adjusted down from 1.0% to 0.0% (zero) in fortnightly increments of 0.1%, beginning from 9 December 2020.
- AEMO has revised the distribution of switching controller settings across the relevant frequency bands to try and achieve a better spread of FCAS response.
- Quarterly frequency reporting has been aligned with the requirements in NER 4.8.16(b).
- AEMO is supporting the AEMC's work on a range of significant rule changes affecting frequency control frameworks. This set of rule changes is collectively referred to by the AEMC as the "System Services rule changes"[13].

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

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

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

7.5.1 Frequency control workplan

In September 2020 AEMO published a frequency control workplan[14] to help promote visibility, coordination, and prioritisation of frequency-related tasks.

Since publication of the workplan, the following tasks have been completed:

- Task 19 – 2020 Power System Frequency Risk Review[15].
- Task 20 – Minimum inertia requirements and any shortfalls[16].

Detailed tracking of the progress of Mandatory PFR Rule implementation (Task 1) is available through regular status updates on AEMO's PFR web page[17].

A detailed update on the progression of other tasks will be provided in the draft Engineering Framework[18] due for publication in March 2020.

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

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

[16] See https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/planning-for-operability.

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

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

Appendix A

Credible generation and load events in 2020 meeting the following criteria have been identified:

- 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 to form a reasonable understanding of the ongoing success or otherwise of the NEM's aggregate ability to control frequency during major disturbances.

Unrepresented events 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 Q4 2020 tended to have an average frequency nadir nearer to 50 Hz and average recovery time shorter than seen in Q1-Q3 2020, which could be an indication of generally better frequency response following contingencies.

Table 10 is a list of identified contingencies from Q4 2020.

Table 8 Credible generation events in 2020

Quarter	Number of events	Average contingency size (MW)	Average frequency nadir (Hz)	Average recovery time (s)
Q4 2020	38	315	49.84	45
Q1-Q3 2020	65	385	49.79	111

Table 9 Credible load events in 2020

Quarter	Number of events	Average contingency size (MW)	Average frequency nadir (Hz)	Average recovery time (s)
Q4 2020	17	268	50.11	0
Q1-Q3 2020	33	279	50.17	30

Table 10 Credible generation and load events in Q4 2020

Event time	Unit	Contingency size (MW)	Frequency nadir (Hz)	Recovery to NOFB (s)	FOS compliant
02-Oct-20 07:10:48	MUWAWF1	212	49.86	0	Yes
03-Oct-20 01:00:40	MUWAWF1	212	49.88	0	Yes
04-Oct-20 14:12:08	BW03	420	49.75	256	Yes
06-Oct-20 07:39:44	TARONG#3	324	49.81	48	Yes
07-Oct-20 10:39:04	STAN-2	277	49.80	16	Yes
07-Oct-20 13:21:28	MORTLK11	270	49.81	40	Yes
09-Oct-20 11:00:08	APD01	283	50.15	0	Yes
09-Oct-20 15:46:48	YWPS4	392	49.75	128	Yes
14-Oct-20 10:53:04	BW04	645	49.64	248	Yes
21-Oct-20 04:48:24	LD04	282	49.82	8	Yes
23-Oct-20 19:26:16	LD03	248	49.82	16	Yes
24-Oct-20 13:20:40	MUWAWF1	223	49.89	0	Yes
29-Oct-20 10:17:20	ER01	343	49.82	8	Yes
30-Oct-20 20:29:52	COOPGWF1	231	49.89	0	Yes
04-Nov-20 07:22:48	APD01	209	50.10	0	Yes
05-Nov-20 11:25:04	LOYYB1	526	49.70	232	Yes
05-Nov-20 16:15:20	LOYYB1	526	49.73	200	Yes
06-Nov-20 09:29:44	LOYYB1	527	49.74	160	Yes
13-Nov-20 22:29:44	TOMAGO3	310	50.12	0	Yes
14-Nov-20 14:53:44	YWPS4	397	49.83	8	Yes
16-Nov-20 13:23:36	TOMAGO4	303	50.12	0	Yes
17-Nov-20 11:05:12	TARONG#2	283	49.88	0	Yes
19-Nov-20 22:25:44	TOMAGO4	312	50.12	0	Yes
20-Nov-20 14:25:28	TOMAGO1	308	50.11	0	Yes
20-Nov-20 17:15:20	TOMAGO3	254	50.09	0	Yes
22-Nov-20 06:20:40	MUWAWF1	223	49.95	0	Yes
22-Nov-20 07:10:40	MUWAWF1	219	49.90	0	Yes
27-Nov-20 15:50:56	CPP_4	383	49.80	112	Yes
29-Nov-20 04:05:44	MUWAWF1	227	49.92	0	Yes
29-Nov-20 05:00:40	MUWAWF1	222	49.91	0	Yes

Event time	Unit	Contingency size (MW)	Frequency nadir (Hz)	Recovery to NOFB (s)	FOS compliant
30-Nov-20 19:22:16	COOPGWF1	347	49.94	0	Yes
01-Dec-20 14:20:08	APD01	283	50.11	0	Yes
01-Dec-20 16:08:40	LD01	346	49.85	0	Yes
01-Dec-20 16:13:20	TOMAGO4	304	50.16	8	Yes
04-Dec-20 17:45:20	TOMAGO4	210	50.09	0	Yes
05-Dec-20 00:41:44	MUWAWF1	214	49.91	0	Yes
05-Dec-20 16:35:36	MUWAWF1	214	49.87	0	Yes
07-Dec-20 00:00:56	MUWAWF1	212	49.94	0	Yes
10-Dec-20 04:08:08	TOMAGO1	309	50.13	0	Yes
13-Dec-20 03:00:48	MUWAWF1	213	49.94	0	Yes
13-Dec-20 05:00:48	MUWAWF1	212	49.91	0	Yes
14-Dec-20 09:45:44	LYA1	522	49.69	152	Yes
15-Dec-20 12:40:48	ER03	287	49.82	16	Yes
16-Dec-20 15:40:16	TOMAGO3	257	50.10	0	Yes
16-Dec-20 17:27:20	TOMAGO4	203	50.11	0	Yes
17-Dec-20 13:28:48	LD03	330	49.77	16	Yes
17-Dec-20 17:40:16	TOMAGO4	211	50.10	0	Yes
18-Dec-20 03:50:48	APD01	283	50.10	0	Yes
20-Dec-20 10:20:48	SNOWYP	231	50.08	0	Yes
20-Dec-20 20:27:04	STAN-2	355	49.81	16	Yes
20-Dec-20 21:26:00	APD01	283	50.10	0	Yes
22-Dec-20 14:45:36	MUWAWF1	214	49.96	0	Yes
23-Dec-20 10:24:56	MP1	279	49.90	0	Yes
27-Dec-20 08:30:48	MUWAWF1	215	49.94	0	Yes
29-Dec-20 11:28:00	BW04	409	49.81	16	Yes

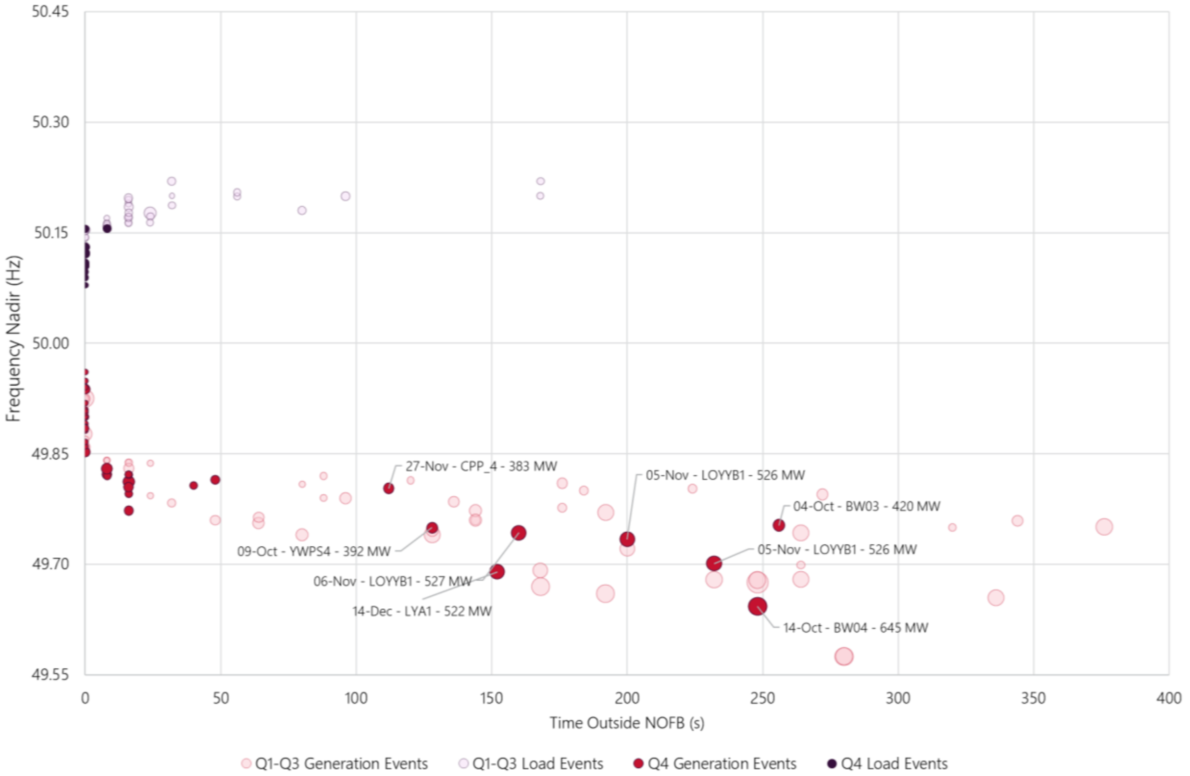
Note: TOMAGO1-4 & BOYNE1-3 are not registered dispatchable unit identifiers (DUIDs), but are included here to identify potlines of major NEM smelters.

Figure 26 displays each event from Table 10 to illustrate the distribution of frequency outcomes following credible contingency events in Q4 2020, in comparison to recent quarters Q1-Q3 in 2020.

Generation events in Q4 2020 have been contained inside the GLCB and recovered within the FOS timeframe of five minutes. In Q4 2020, average frequency nadir has been nearer 50 Hz and average recovery time has been shorter than in Q1-Q3 2020.

Load events in Q4 were more frequently contained within the NOFB which represents a notable shift compared to earlier in 2020 when such events would frequently cause short frequency excursions outside the NOFB.

Figure 26 Frequency outcomes of identified credible generation and load events



* Size of contingency events is represented by bubble size.