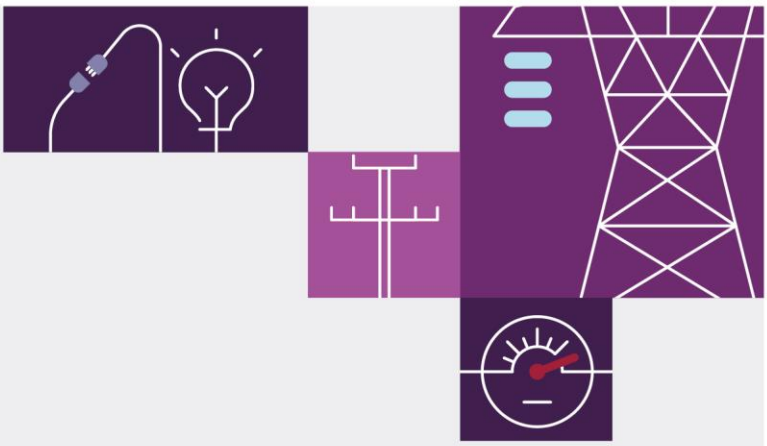
Frequency and Time Error Monitoring – Quarter 2 2022

August 2022

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 (NEM) for the mainland and Tasmanian regions for the period April to June 2022 inclusive. AEMO has prepared this report in accordance with clause 4.8.16(b) of the National Electricity Rules (NER), using information available as at the date of publication, unless otherwise specified.

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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 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 NER.

Where applicable, analysis of the delivery of slow and delayed frequency control ancillary services (FCAS) in this report is based on 4-second resolution SCADA information derived from AEMO's systems. Any analysis of fast FCAS is based on a combination of the best available data from FCAS meters and AEMO's systems.

The Queensland, New South Wales, Victoria, and South Australia regions are referred to as the 'mainland' throughout the report. Unless otherwise noted, mainland frequency data was 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 was sampled at 4-second intervals using the most recent Network Operations and Control System (NOCS) frequency measurement preceding each 4-second interval.

Abbreviations

Abbreviation	Full term
ACE	Area Control Error
AGC	automatic generation control
AEMC	Australian Energy Market Commission
BESS	Battery Energy Storage System
FCAS	frequency control ancillary services
FFR	Fast Frequency Response
FOS	Frequency Operating Standard
GPS	Global Positioning System
MASS	market ancillary services specification
NEM	National Electricity Market
NEMDE	NEM Dispatch Engine
NER	National Electricity Rules
NOCS	Network Operations and Control System
NOFB	Normal Operating Frequency Band
NOFEB	Normal Operating Frequency Excursion Band
OFTB	Operational Frequency Tolerance Band
PFR	Primary Frequency Response
PMU	Phasor Measurement Unit
PSFRR	*Power System Frequency Risk Review*
PV	photovoltaics
RoCoF	rate of change of frequency
TNSP	transmission network service provider
VRE	variable renewable energy

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

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1 Actions to improve frequency control performance

1.1 Recent and upcoming actions

The following recently completed and upcoming intended actions are expected to improve frequency control performance.

Recent

- AEMO initiated a consultation on the market ancillary services specification (MASS) by publishing a MASS issues paper on 2 May 2022 following the Final Rule for the establishment of new Fast Frequency Response (FFR) frequency control ancillary services (FCAS) markets. The draft determination[2] and the draft MASS[3] were published on 22 July 2022 and AEMO is seeking industry feedback by 19 August 2022. AEMO proposed the specifications for Very Fast FCAS and other important changes to the MASS such as a compressed timeframe for Fast FCAS, capping the registered FCAS capacity to the peak active power change, the sampling rate requirements for Very Fast FCAS, and certification requirements for FCAS meters.
- On 16 February 2022, AEMO published an updated guide on Battery Energy Storage System (BESS) requirements for contingency FCAS registration[4]. Depending on the outcome of the MASS consultation, the guide may need to be updated to reflect the new specifications for Very Fast FCAS such as a fast frequency ramp rate of +/-1 hertz per second (Hz/s) to be applied during testing.
- On 8 June 2022, AEMO released the Engineering Framework Priority Actions publication[5] outlining the near-term priority actions needed to prepare the National Electricity Market (NEM) for future operational conditions, including operation at 100% instantaneous penetration of renewables. The report details AEMO's commitments for FY23 and potential implementation pathways.
- On 22 October 2021 and 29 November 2021, AEMO progressively reduced the gate-closure for submission of information for use in dispatch from 67 seconds to 40 seconds and then 15 seconds. These changes allow the submission of information such as participant re-bids or semi-scheduled generator self-forecasts to occur closer to the start of the dispatch interval, improving the accuracy of the information used by the NEM Dispatch Engine (NEMDE). Since the change to the gate-closure of dispatch, the semi-scheduled generator self-forecasts that are taking advantage of the later gate-closure are demonstrating an improved forecast accuracy of up to 12%, which is expected to improve frequency performance through closer matching of supply and demand.
- On 21 September 2021, AEMO adjusted and tuned the load forecast models used by NEMDE. These changes have improved the accuracy of the load forecasts particularly under conditions of high load variability (for

[2] See https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/amendment-of-the-mass/second-stage/notice-of-second-stage-of-consultation-and-draft-determination.pdf?la=en.

[3] See https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/amendment-of-the-mass/second-stage/market-ancillary-service-specification.pdf?la=en.

[4] See https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Ancillary_Services/Battery-Energy-Storage-System-requirements-for-contingency-FCAS-registration.pdf.

[5] See https://aemo.com.au/-/media/files/initiatives/engineering-framework/2022/nem-engineering-framework-priority-actions.pdf.

example, intra-day variability as a result of cloud variability causing rapid changes to distributed photovoltaics [PV] generation levels). Further improvements to the load forecast models used by NEMDE are being developed as part of AEMO's forecast improvement process and are expected to be implemented in the second half of 2022.

- After publishing a Draft Determination in September 2021, the Australian Energy Market Commission (AEMC) released a Directions Paper explaining changes to the allocation of regulation FCAS costs. These changes institute credits, rather than just debit participants. A Final Determination is expected on 8 September 2022.
- The AEMC commenced a review of the Frequency Operating Standard (FOS) on 28 April 2022, for which AEMO is providing technical advice. The four key issues this review intends to examine are:
  - Settings in the FOS for normal operation.
  - The potential inclusion of standards for the rate of change of frequency (RoCoF).
  - The settings in the FOS for contingency events.
  - The limit on accumulated time error.

  Further information may be found on the AEMC's website[6].
- AEMO continues to implement the mandatory Primary Frequency Response (PFR) requirements introduced into the National Electricity Rules (NER) in 2020[7]. Implementation reports can be accessed on AEMO's website[8]. While implementation is complete at virtually all synchronous and BESS facilities, these reports outline the challenges remaining in completing roll-out at variable renewable energy (VRE) facilities.
- On 26 July 2022, AEMO published the 2022 *Power System Frequency Risk Review*[9] (PSFRR) in collaboration with transmission network service providers (TNSPs) under clause 5.20A.1 of the NER. Priority events for detailed assessment have been identified.

1.2 Impact of frequency control actions

This section illustrates the historical and latest frequency performance in the NEM, and the impact of the actions taken by AEMO (listed in Section 1.1) to improve power system frequency control outcomes. Table 1 contains key metrics of frequency performance for the quarter.

Table 1 Key frequency statistics from the mainland and Tasmania in Q2 2022

	Mainland		Tasmania		Further commentary
	Minimum	Maximum	Minimum	Maximum	
Frequency (Hz)	49.75	50.13	48.92	50.78	
Time error (seconds [s])	-11.04	2.56	-6.76	5.47	
Longest frequency event duration (s)*	516				The frequency cycled around the NOFB for 516 s on 18 June

*Tasmania not estimated.

[6] See https://www.aemc.gov.au/market-reviews-advice/review-frequency-operating-standard-2022.

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

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

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

AEMO calculates daily the percentage of time that frequency remained inside the Normal Operating Frequency Band (NOFB) in the preceding 30-day window. Figure 1 reports the minimum daily estimate from each month, showing the estimated time inside the NOFB, both including and excluding data during contingency events. The FOS requirement excludes periods where contingency events have occurred. Frequency in the mainland and Tasmania remained within the NOFB for more than 99% of the time in Q2 2022. Further detail on credible contingency events in Q2 2022 is available in Appendix A1.

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

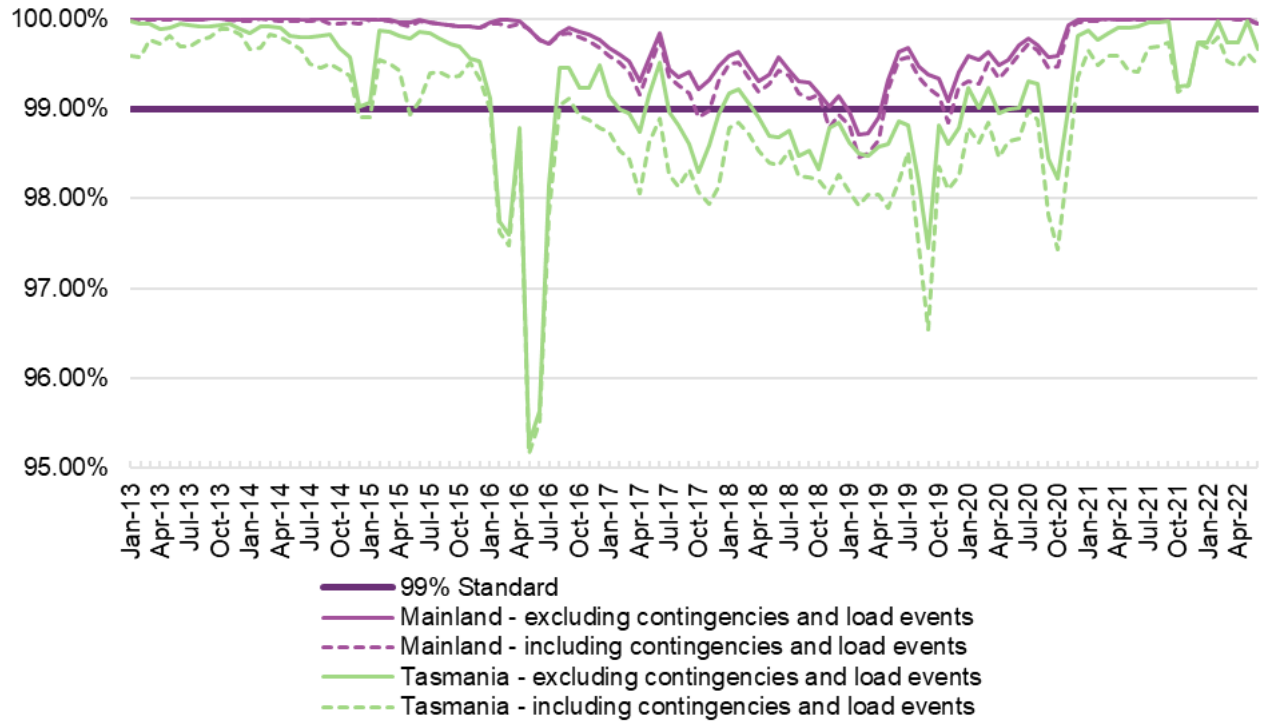


Figure 2 shows the distribution of frequency within the NOFB since 2007.

Figure 2 Monthly frequency distribution

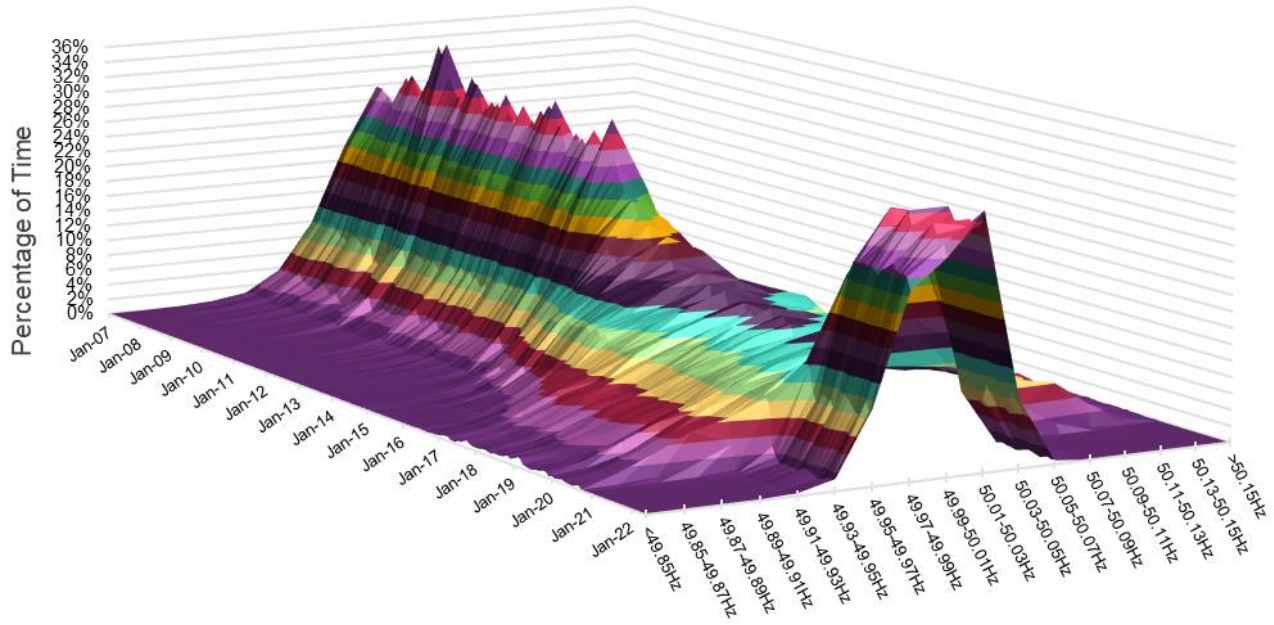
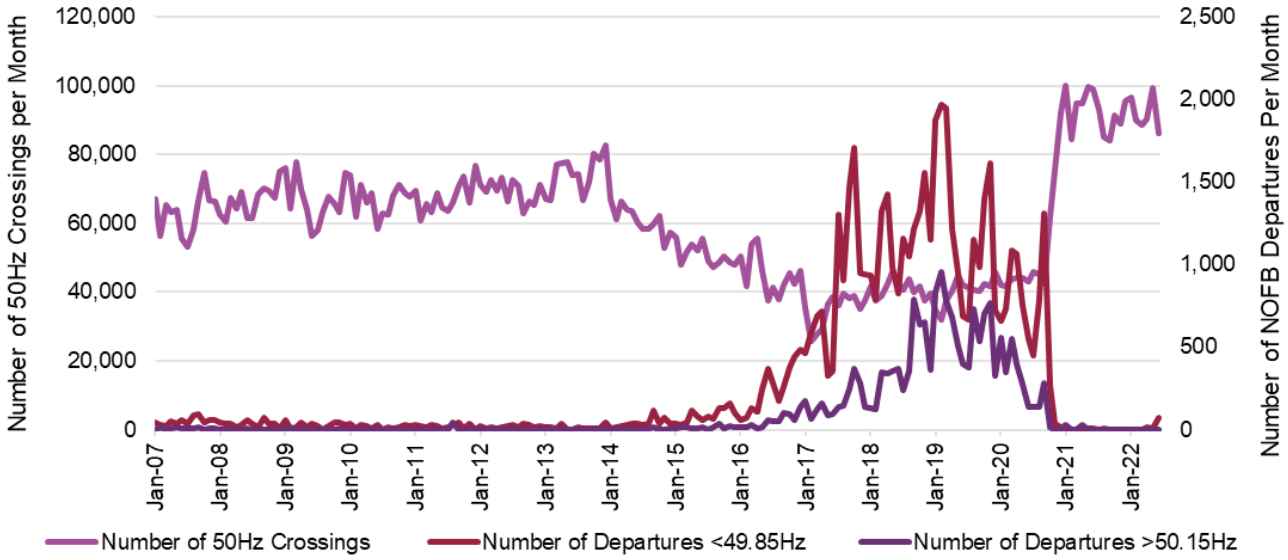


Figure 3 examines the number of times frequency has crossed the nominal 50 hertz (Hz) target and how often frequency departed the NOFB since 2007.

Figure 3 Monthly frequency crossings – under 49.85 Hz, across 50 Hz, beyond 50.15 Hz



2 Achievement of the Frequency Operating Standard

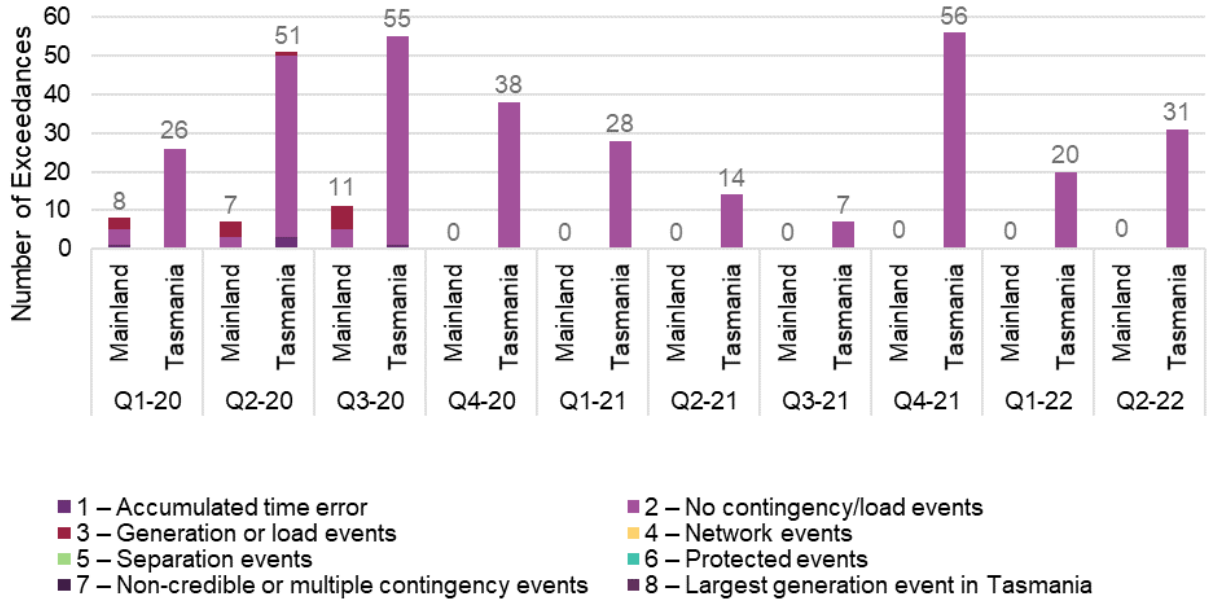
AEMO's assessment of the achievement of the requirements of the FOS in Q2 2022 is summarised in Table 2. The FOS exceedances since 2020 are displayed in Figure 4.

Table 2 FOS 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 31 times	See Section 2.1.1
• **Recovered in five minutes**	Achieved[10]	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	

[10] Unusual long frequency events that occurred on 17 and 18 June are described in Section 2.1.2.

Figure 4 FOS exceedances in the mainland and Tasmania



2.1 Operation during identified FOS exceedances

Section 2.1 describes exceedances of the FOS identified in Table 2.

2.1.1 Frequency excursions without a contingency event outside the NOFEB

Frequency excursions outside the applicable Normal Operating Frequency Excursion Band (NOFEB) where an associated contingency event has not been identified are shown in Table 3 for Q2 2022.

Table 3 Number of frequency excursions without identified contingency outside the NOFEB in Q2 2022

Event	Low/high/both frequency event	Number of events Mainland	Number of events Tasmania
No contingency or load event noted	LOW	0	28
	HIGH	0	2
	BOTH	0	1

Tasmania had an increase in events where frequency exceeded the NOFEB without an associated contingency event compared to Q1 2022, totalling 31 events in Q2 2022 compared to 20 events in Q1 2022.

At least 28 of the 31 instances identified in Q2 2022 occurred during outages of the Basslink high voltage direct current (HVDC) interconnector. The frequency in Tasmania observed during this period was characteristic of the smaller Tasmanian system without the support of the Basslink frequency controller.

AEMO has noted that at least one of the remaining three instances identified in Q2 2022 occurred at times when Basslink was operating at its import limit, hence unable to provide further frequency support via its frequency controller. At least one of the remaining two instances identified in Q2 2022 was primarily due to unexpected changes in total wind generation from Tasmania. An underlying cause in the one remaining instance could not be identified.

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

AEMO noted that the frequency cycled around the lower limit of the NOFB for more than 5 minutes on 17 June and 18 June. There were no clear breaches of the FOS as the frequency did not remain outside the NOFB continuously for more than 5 minutes. The frequency nadir was 49.79 Hz on 17 June and 49.81 Hz on 18 June.

AEMO has examined the frequency excursion on 17 June further in Section 5.1 as the lowest frequency nadir during the reporting period was recorded on the day.

3 Rate of change of frequency

The calculation of RoCoF by AEMO's Phasor Measurement Unit (PMU) system is outlined in Appendix A2.1. The maximum RoCoF recorded in the mainland in each month in Q2 2022, and any other RoCoF exceeding the standard frequency ramp rate for the mainland (as specified in the MASS) of 0.125 hertz per second (Hz/s), are provided in Table 4.

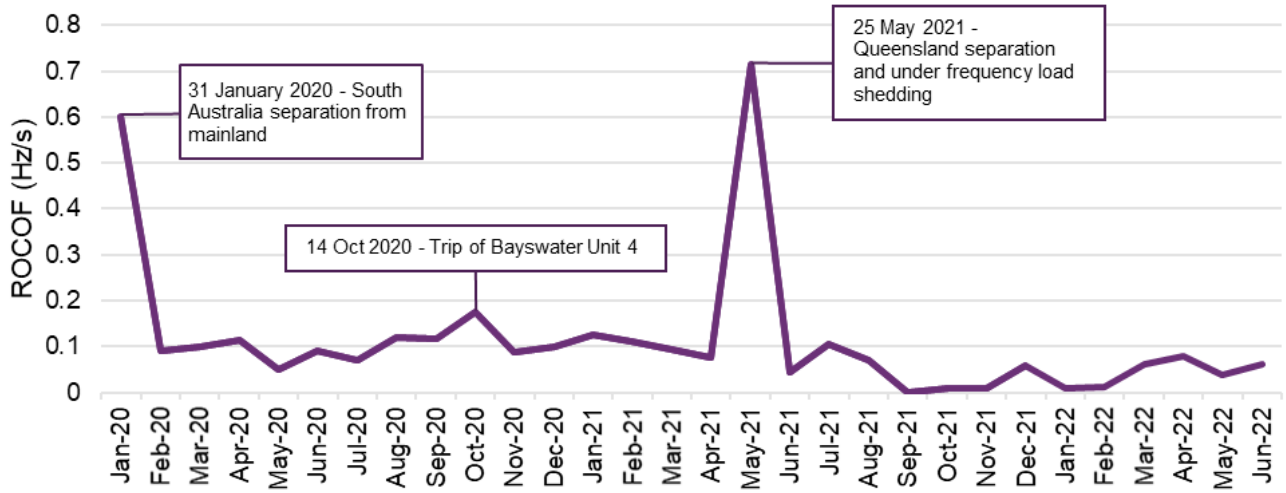
Table 4 RoCoF during frequency events in the mainland

Month	RoCoF (Hz/s)	Associated event	Event time
April	-0.079	Trip of Bayswater Unit 2 at 680 MW	25/04/2022 22:29
May	-0.038	Trip of all three Gordon Units at 355 MW	12/05/2022 13:15
June	-0.062	Trip of Tallawarra Unit at 365 MW	18/06/2022 15:31

Note: Estimates of RoCoF may vary depending on data source, sampling window and calculation method. See Section A2.1 for further detail on the methodology used to calculate RoCoF in this report.

Figure 5 shows the maximum RoCoF recorded in the mainland NEM since Q1 2020.

Figure 5 Monthly maximum RoCoF recorded in any mainland region in 2020-22



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

4 Area control error

The calculation of Area Control Error (ACE) methodology by AEMO's automatic generation control (AGC) system is outlined in Appendix A2.2. Figure 6 and Figure 7 show the minimum and maximum ACE per half-hourly trading interval in Q2 2022 in the mainland NEM and Tasmania, respectively.

Figure 6 Minimum and maximum ACE per half-hour in mainland NEM

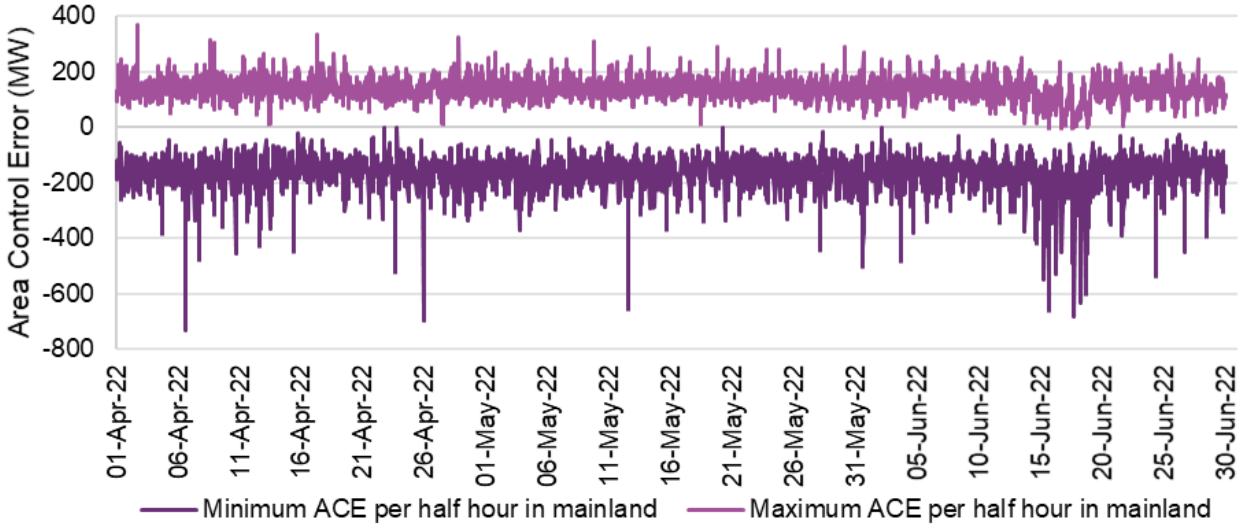
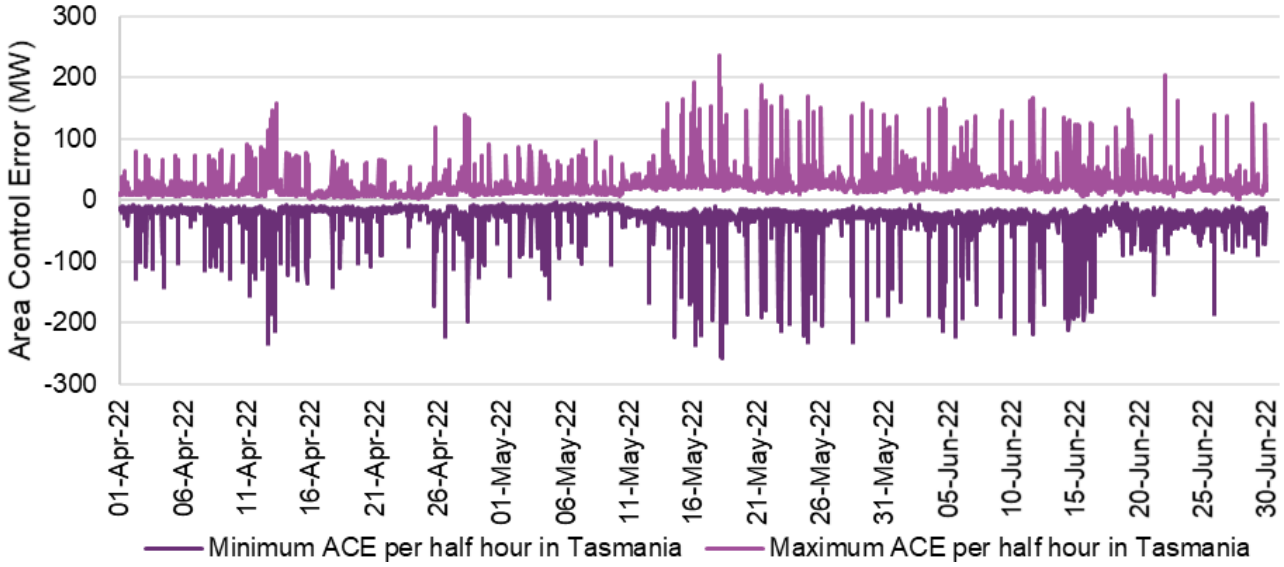


Figure 7 Minimum and maximum ACE per half-hour in Tasmania



5 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[11].

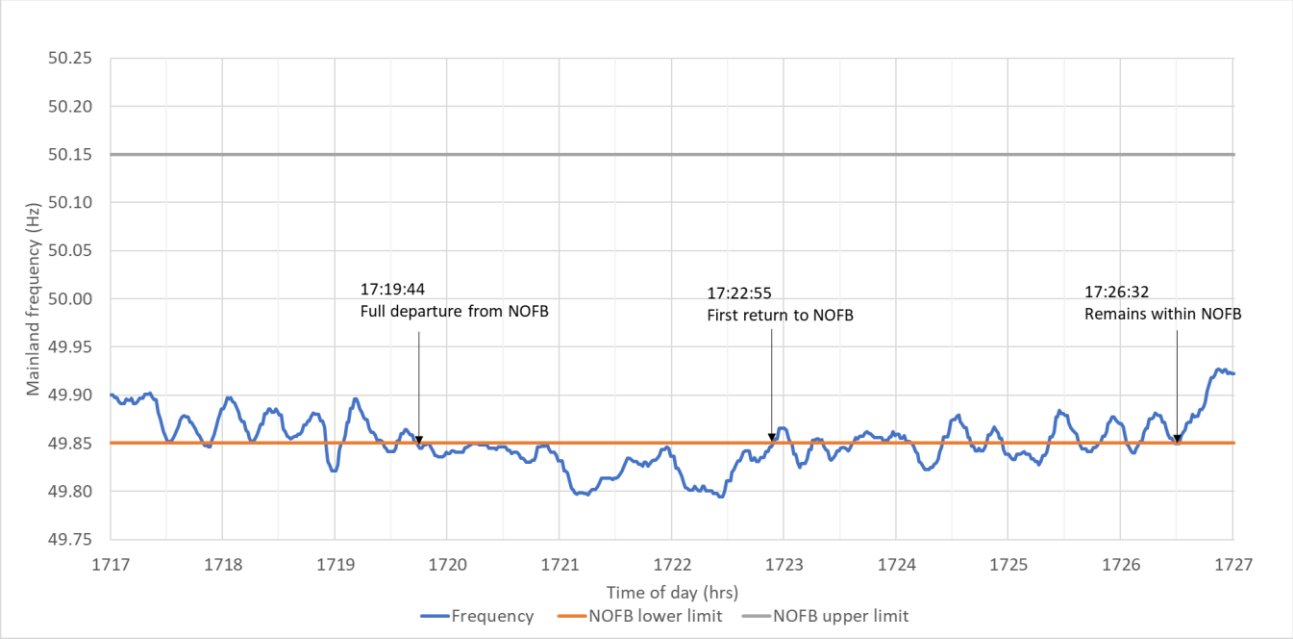
Mainland frequency exceeding the Operational Frequency Tolerance Band (OFTB) is the existing guideline for identifying a reviewable operating incident which affected power system frequency and is one basis for inclusion in this section. Other reviewable operating incidents may be included here at AEMO's discretion.

There were no reviewable operating incidents in Q2 2022 relating to frequency exceeding the OFTB. AEMO is preparing an incident report covering the period of reliability interventions and market suspension that occurred between 10 and 24 June 2022. As per the Reporting Publication Guidelines[12], a potential breach of the FOS on 17 June 2022 was noted. The following section examines this event. AEMO also plans to include this information in the upcoming incident report.

5.1 Frequency events during market suspension

Based on its review of frequency performance during the period of 10 June 2022 to 25 June 2022, AEMO has not identified any clear breaches of the frequency operating standard (FOS). There were, however, periods where frequency behaviour was outside typical operating levels. The most significant event occurred at around 1720 hrs on 17 June 2022 where a sustained low frequency event occurred. The minimum frequency reached during this time was 49.79 Hz at 1721 hrs. The NEM mainland frequency trace shown in Figure 8 was sourced from a network PMU in Sydney, however no significant difference between measurements in other mainland regions was apparent.

Figure 8 Mainland system frequency on 17 Jun 2022



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

[12] See https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-events-and-reports

In Table A.2 of the FOS, the following relevant requirements are set out:

> *Except as a result of a contingency event or a load event, system frequency:*
>
> *a) shall be maintained within the applicable normal operating frequency excursion band, and*
>
> *b) shall not be outside of the applicable normal operating frequency band for more than 5 minutes on any occasion and not for more than 1% of the time over any 30-day period.*

These requirements appear to have been met during the frequency event shown above. Assuming 17:19:44 as the start of the event[13], frequency never exceeded the normal operating frequency excursion band (49.75 Hz), and frequency did not remain outside the normal operating frequency band (49.85 Hz) for more than 5 minutes continuously, as frequency returns within the NOFB 191 seconds later at 17:22:55.

However, it is clear that frequency did not return and then remain within the NOFB; it takes until approximately 17:26:32 for this to occur, which is 408 seconds (almost 7 minutes) after the event. Therefore, while this event does not technically exceed FOS limits, it appears inconsistent with the intent of the FOS[14].

The key causes of this event appear to be:

- A significant increase in NEM demand and demand forecasts being lower than actual demand during the period of the frequency event.
- A shortage of generation available to provide frequency response and in particular regulation services (generation availability will be discussed in detail in the incident report).
- The frequency event not being deep enough to trigger much of the available Contingency FCAS employing switching controllers.

AEMO has not found any evidence of a contingency event (such as a generator trip) during the relevant time period.

Figure 9 shows the change in demand from 1700 hrs to 1735 hrs on 17 June. It is clear that at this time there was a long (but steady) increase in demand. For example, total system demand increased by approximately 900 megawatts (MW) over the 15 minutes between 1715 hrs and 1730 hrs, where the low frequency event occurred. Rapidly increasing demand presents a challenge for frequency control, as any under-forecasting or delay in generation ramping will manifest as low frequency. Indeed, it appears that the demand forecasts under-estimated the ramp up in demand, as shown in Figure 10.

[13] 17:18:55 could also possibly be treated as the start of the event, however frequency quickly returned to within the NOFB at this point and remained there until 17:19:44, where it departed and remained outside the NOFB. In any case, the same conclusions are met with either starting point.

[14] AEMO notes that the AEMC Reliability Panel is currently conducting a review of the FOS, which provides an opportunity for further consideration of FOS requirements (https://www.aemc.gov.au/market-reviews-advice/review-frequency-operating-standard-2022).

Figure 9 5 minute demand recorded on 17 June 2022

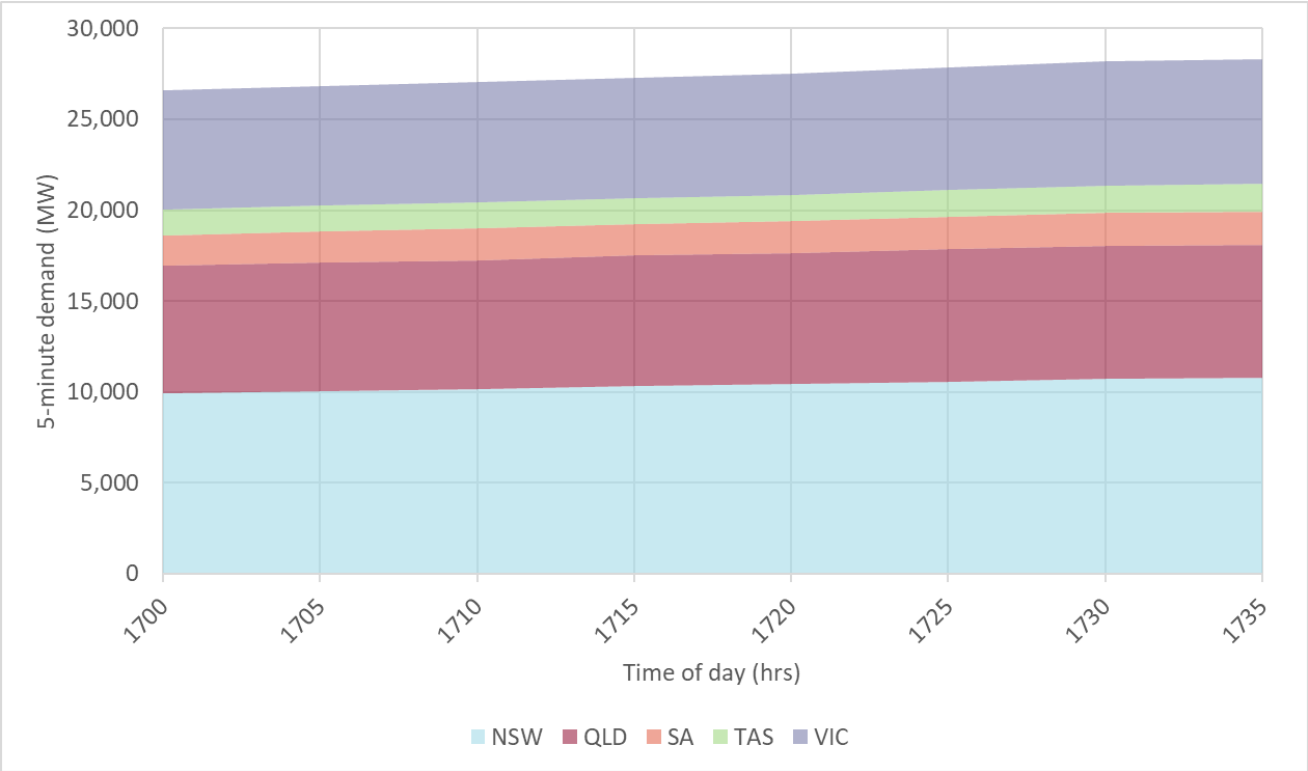
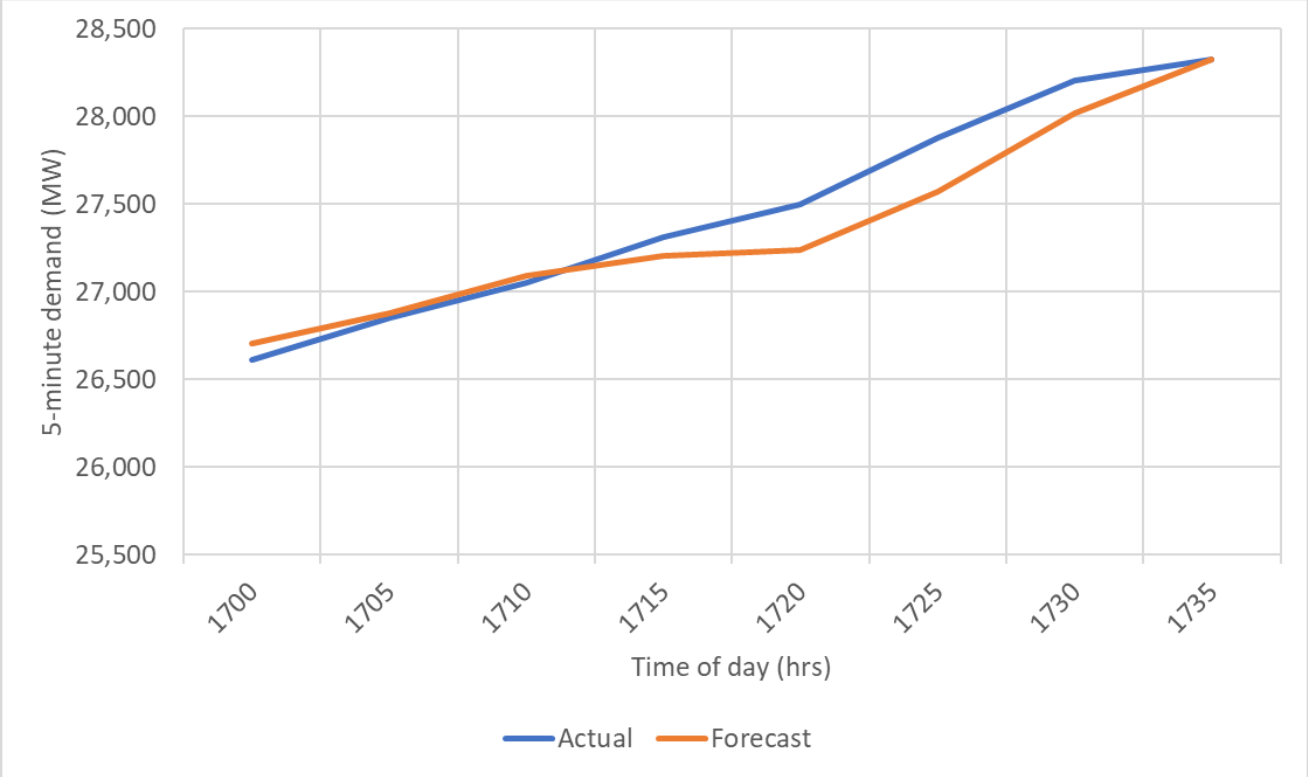


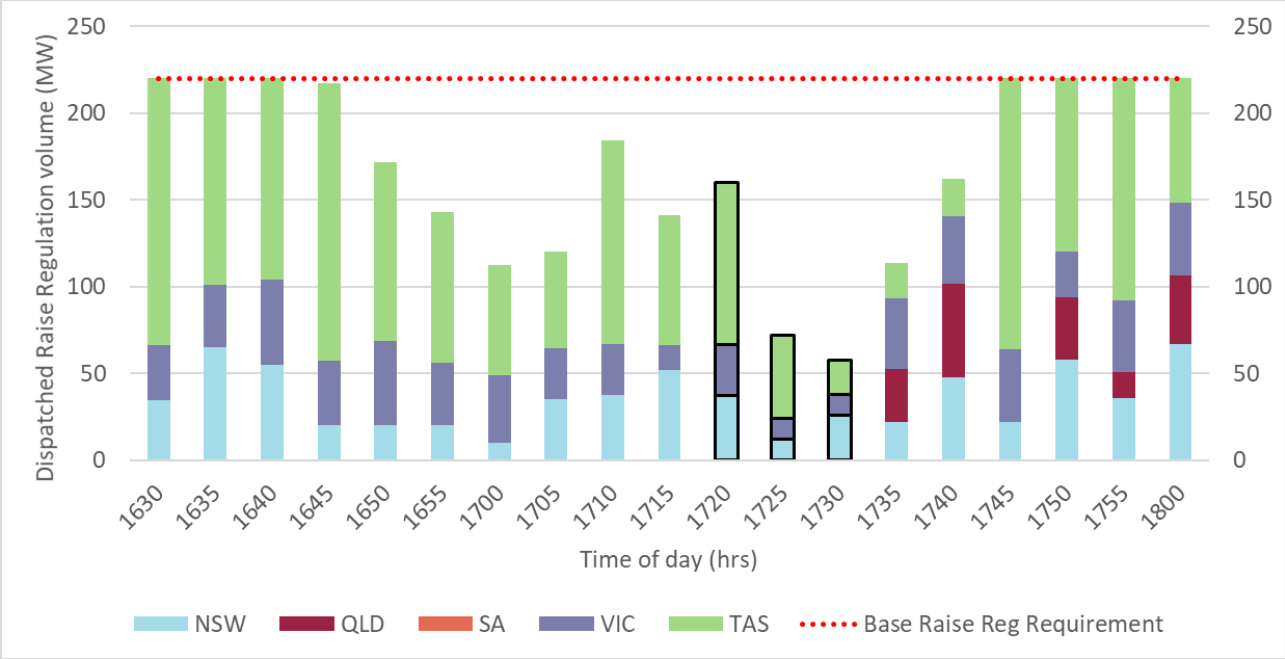
Figure 10 5 minute forecast system vs actual demand on 17 June 2022



As mentioned above, a contributing factor to the prolonged low frequency event was a lack of Regulation FCAS, with Raise Regulation being relevant for low frequency. AEMO normally dispatches at least 220 MW of Raise Regulation FCAS, but this amount was not available for dispatch during the frequency event, resulting in violating Regulation constraints and as little as 58 MW dispatched during the interval ending at 1730 hrs.

As shown in Figure 11, resources adequate for meeting the normal 220 MW minimum were not re-established until the interval ending at 1745 hrs. With only 60-160 MW available during the frequency event, AEMO's Automatic Generation Control (AGC) did not have the resources to provide as much of an influence on frequency restoration as it might usually have done. AEMO will be further investigating the causes of the inadequate available volumes of Regulation FCAS during this period, but there is little doubt they are primarily related to the general generator availability problems that occurred during the market suspension period.

Figure 11 Raise Regulation FCAS dispatch on 17 June 2022



AEMO is also conducting an FCAS performance assessment and is in the process of acquiring and analysing FCAS recorder data from facilities enabled for Contingency FCAS. The following are preliminary observations from this analysis process:

1. A significant portion of the facilities enabled at the time employ switching controllers (approximately 20%, 30%, and 50% in Fast, Slow and Delayed Raise Contingency FCAS respectively). Switching controllers in the mainland are allocated trigger points between 49.8 Hz and 49.6 Hz. As the frequency only just reached the very upper bound of this range, most of the switching controllers would not have been triggered.
2. Initial analysis points to a significant PFR response across many facilities; indeed without PFR this is likely to have been a significantly larger frequency event.
3. A few facilities may have under-delivered FCAS, or not delivered any frequency response. AEMO is investigating these matters and will take further action where appropriate according to its usual FCAS compliance procedures.

A1. Credible generation and load events

This Appendix identifies credible generation and load events in 2020, 2021 and 2022 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 more between successive 4-second SCADA scan intervals.

This is not intended to be a comprehensive list of all credible contingency events that 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 was over a timespan longer than 4 seconds.
- Network events, separation events, non-credible events, multiple contingency events, and protected events.

Table 5 and Table 6 demonstrate that both generation and load events in Q2 2022 tended to have an average frequency nadir nearer to 50 Hz and average recovery time shorter than seen in 2020, which is a strong indicator of better frequency response following contingency events.

Table 7 is a list of contingencies from Q2 2022 meeting the criteria noted above.

Table 5 Credible generation events in 2020, 2021, Q1 2022 and Q2 2022

Quarter	Number of events	Average contingency size (MW)	Average frequency nadir (Hz)	Average recovery time (s)
Q2 2022	25	382	49.87	11
Q1 2022	20	302	49.89	2
2021	72	365	49.86	9
2020	96	362	49.80	93

Table 6 Credible load events in 2020, 2021, Q1 2022 and Q2 2022

Quarter	Number of events	Average contingency size (MW)	Average frequency nadir (Hz)	Average recovery time (s)
Q2 2022	30	273	50.09	0
Q1 2022	18	270	50.09	N/A
2021	58	261	50.09	N/A
2020	50	275	50.15	20

Table 7 Credible generation and load events in Q1 2022

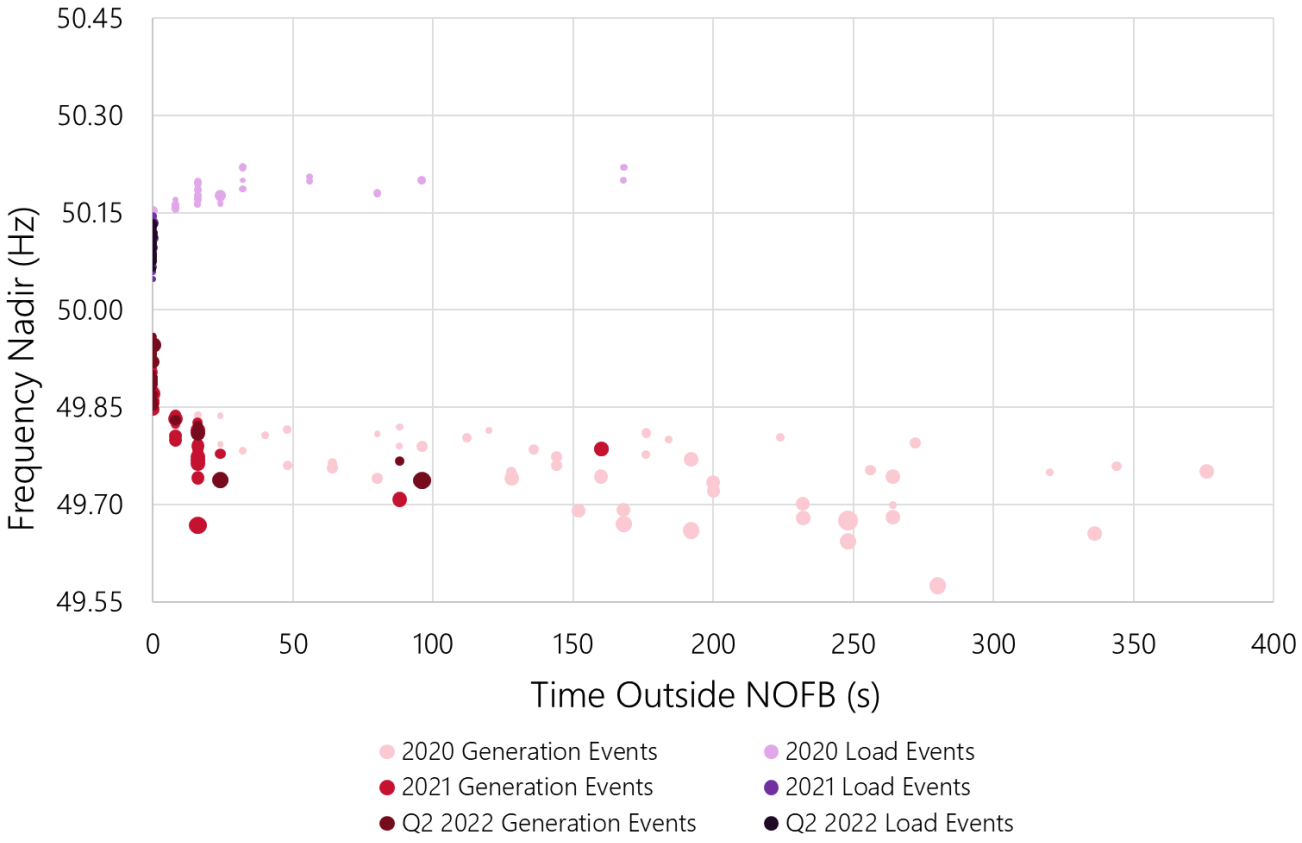
Event time	Unit	Contingency size (MW)	Frequency nadir/peak (Hz)	Recovery to NOFB (s)	FOS compliant?
01-Apr-22 9:01	LOYYB1	323	49.88	0	YES
02-Apr-22 17:59	BOYNE3	383	50.13	0	YES
06-Apr-22 15:27	BW01	635	49.74	24	YES
07-Apr-22 17:56	NPS	403	49.83	8	YES
08-Apr-22 15:34	BOYNE3	337	50.11	0	YES
08-Apr-22 23:52	BOYNE3	337	50.12	0	YES
12-Apr-22 21:44	TOMAGO2	311	50.1	0	YES
13-Apr-22 11:12	YWPS4	374	49.9	0	YES
13-Apr-22 15:28	W/HOE#1	251	49.89	0	YES
15-Apr-22 9:21	LYA2	411	49.85	0	YES
17-Apr-22 7:32	BOYNE2	253	50.11	0	YES
18-Apr-22 16:20	APD1	264	50.09	0	YES
19-Apr-22 13:02	TOMAGO1	307	50.1	0	YES
23-Apr-22 14:45	BW02	448	49.81	16	YES
25-Apr-22 22:29	BW02	683	49.74	96	YES
27-Apr-22 4:52	APD1	259	50.08	0	YES
28-Apr-22 19:03	TOMAGO4	315	50.1	0	YES
04-May-22 20:14	LD01	241	49.9	0	YES
05-May-22 6:50	ER02	512	49.92	0	YES
05-May-22 7:12	ER01	620	49.95	0	YES
06-May-22 6:35	TOMAGO1	241	50.06	0	YES
09-May-22 17:42	TOMAGO3	304	50.11	0	YES
09-May-22 17:45	APD1	250	50.11	0	YES
10-May-22 10:31	TARONG#2	292	49.9	0	YES
10-May-22 13:55	BOYNE3	276	50.08	0	YES
11-May-22 14:00	APD1	265	50.08	0	YES
12-May-22 10:36	STAN-2	294	49.93	0	YES
12-May-22 13:15	GORDON	355	49.77	88	YES
12-May-22 17:35	APD1	257	50.09	0	YES
16-May-22 18:00	APD1	264	50.09	0	YES
19-May-22 17:35	APD1	242	50.1	0	YES
20-May-22 4:28	APD1	267	50.07	0	YES
21-May-22 12:57	LD04	349	49.89	0	YES
23-May-22 17:35	APD1	248	50.09	0	YES
24-May-22 17:50	APD1	237	50.1	0	YES
28-May-22 2:02	ER04	296	49.85	0	YES
30-May-22 2:22	TOMAGO4	316	50.1	0	YES
31-May-22 14:26	TOMAGO1	305	50.13	0	YES
01-Jun-22 18:00	APD1	270	50.08	0	YES
07-Jun-22 12:31	CALL_B_1	320	49.94	0	YES

Event time	Unit	Contingency size (MW)	Frequency nadir/peak (Hz)	Recovery to NOFB (s)	FOS compliant?
08-Jun-22 17:24	APD1	242	50.08	0	YES
10-Jun-22 17:44	APD1	274	50.08	0	YES
13-Jun-22 10:06	W/HOE#2	245	49.96	0	YES
15-Jun-22 14:20	STAN-4	349	49.87	0	YES
16-Jun-22 13:53	TOMAGO2	311	50.08	0	YES
17-Jun-22 13:46	MPP_1	353	49.89	0	YES
18-Jun-22 15:32	TALWA1	368	49.82	16	YES
19-Jun-22 12:40	W/HOE#2	243	49.96	0	YES
19-Jun-22 14:10	W/HOE#2	242	49.96	0	YES
24-Jun-22 8:44	MP2	578	49.81	16	YES
24-Jun-22 21:46	TOMAGO2	325	50.09	0	YES
27-Jun-22 18:00	APD1	247	50.09	0	YES
28-Jun-22 11:57	MP2	353	49.86	0	YES
30-Jun-22 17:50	APD1	268	50.1	0	YES

Note: TOMAGO1-4 & BOYNE1-3 are not registered dispatchable unit identifiers (DUIDs) but are included here as major NEM loads.

Figure 12 displays each event from Table 7 to illustrate the distribution of frequency outcomes following credible contingency events in Q2 2022, in comparison to 2021 and 2020.

Figure 12 Frequency outcomes of identified credible generation and load events



Note: Size of contingency event is represented by bubble size.

A2. Methodology

A2.1 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/TNSP PMU system at 1-second intervals. This is a higher resolution than is available from the Global Positioning System (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 in hertz.
- **t** is time in seconds.

A2.2 Area Control Error (ACE) methodology

As per the Regulation FCAS Contribution Factors Procedure[15], 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.

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