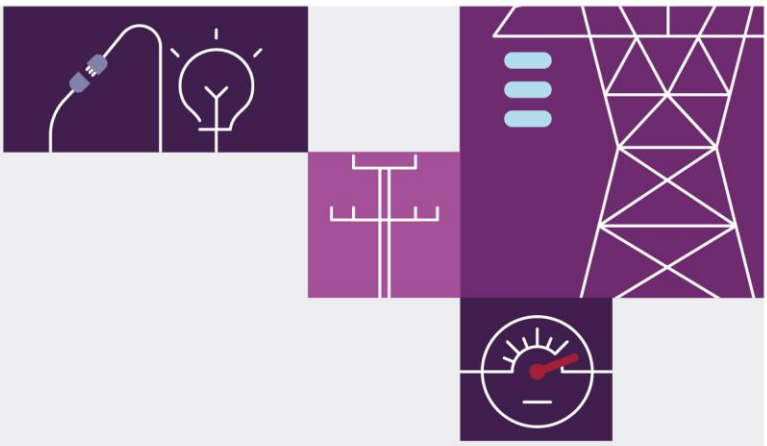
Frequency and Time Error Monitoring – Quarter 3 2022

November 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 July to September 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 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).

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
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
PFRR	Primary Frequency Response Requirements
PMU	phasor measurement unit
PSFRR	*Power System Frequency Risk Review*
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 actions

The following recently completed or in progress actions are expected to contribute to improved frequency control performance.

Recent

- AEMO published its final determination and update to the market ancillary services specification (MASS) on 7 October 2022 following the Final Rule for the establishment of new fast frequency response (FFR) frequency control ancillary services (FCAS) markets. AEMO established the specifications for Very Fast FCAS and made other important changes to the MASS including:
  - Modification of the measurement timeframe for Fast FCAS to incorporate Very Fast FCAS.
  - Revisions to the maximum allowed FCAS registration to the peak active power change.
- On 8 September 2022, the Australian Energy Market Commission (AEMC) finalised the rule change on Primary Frequency Response Incentive Arrangements. This rule change will facilitate changes to the allocation of costs for regulation FCAS, as well as a new incentive framework for the provision of primary frequency response (PFR). AEMO will shortly commence consultation on a Frequency Contribution Factors Procedure, as well as conducting a review of the Primary Frequency Response Requirements. Further information is available on the Frequency Performance Payments project page[2].
- On 26 July 2022, AEMO published the 2022 *Power System Frequency Risk Review*[3] (PSFRR) in collaboration with transmission network service providers (TNSPs) under clause 5.20A.1 of the National Electricity Rules (NER). Priority events for detailed assessment have been identified.
- AEMO is aiming to publish its *Roadmap to 100% Renewables* report in December 2022. This will set out AEMO's view of the technical, engineering, and operational actions required to prepare the National Electricity Market (NEM) to operate at 100% instantaneous renewable penetration for the first time. It builds upon the Engineering Framework[4] and aims to provide a technical base to inform industry prioritisation of steps necessary to securely, reliably and affordably transition. The report will include a section on frequency control, laying out the preconditions for the first periods of 100% renewable penetration and actions necessary to achieve these preconditions.
- The AEMC Reliability Panel is conducting a review of the Frequency Operating Standard (FOS). AEMO is currently finalising technical advice to the Panel on this review, and this advice will be available on the project

[2] See https://aemo.com.au/initiatives/major-programs/frequency-performance-payments-project.

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

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

website in due course[5]. More information may be found on the AEMC's website[6]. 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.

- AEMO continues to implement the mandatory PFR requirements introduced into the NER in 2020[7]. Implementation reports are on AEMO's website[8]. While implementation is complete at virtually all synchronous and battery energy storage system (BESS) facilities, these reports outline the challenges remaining in completing implementation at variable renewable energy (VRE) facilities.

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 and others (listed in Section 1.1) to maintain and improve power system frequency control outcomes.

Table 1 contains key metrics of frequency performance for the quarter. AEMO is encouraged by these outcomes, which indicate that, at least in terms of frequency, the system is well placed to cope with unexpected events. Tasmania was affected by some outages of the Basslink interconnection, but AEMO regards frequency performance in Tasmania to be satisfactory for the given conditions.

Table 1 Key frequency statistics from the mainland and Tasmania in Q3 2022

	Mainland		Tasmania	
	Minimum	Maximum	Minimum	Maximum
Frequency (Hz)	49.78	50.13	49.09	50.87
Time error (seconds [s])	-5.09	3.21	-11.01	7.84
Longest frequency event duration (s)*	12			

*Tasmania not estimated.

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 Q3 2022, indicating that, the vast majority of the time, the system is quite close to nominal frequency and thus would have the best capability to cope with unexpected events. Further detail on credible contingency events in Q3 2022 is available in Appendix A1.

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

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

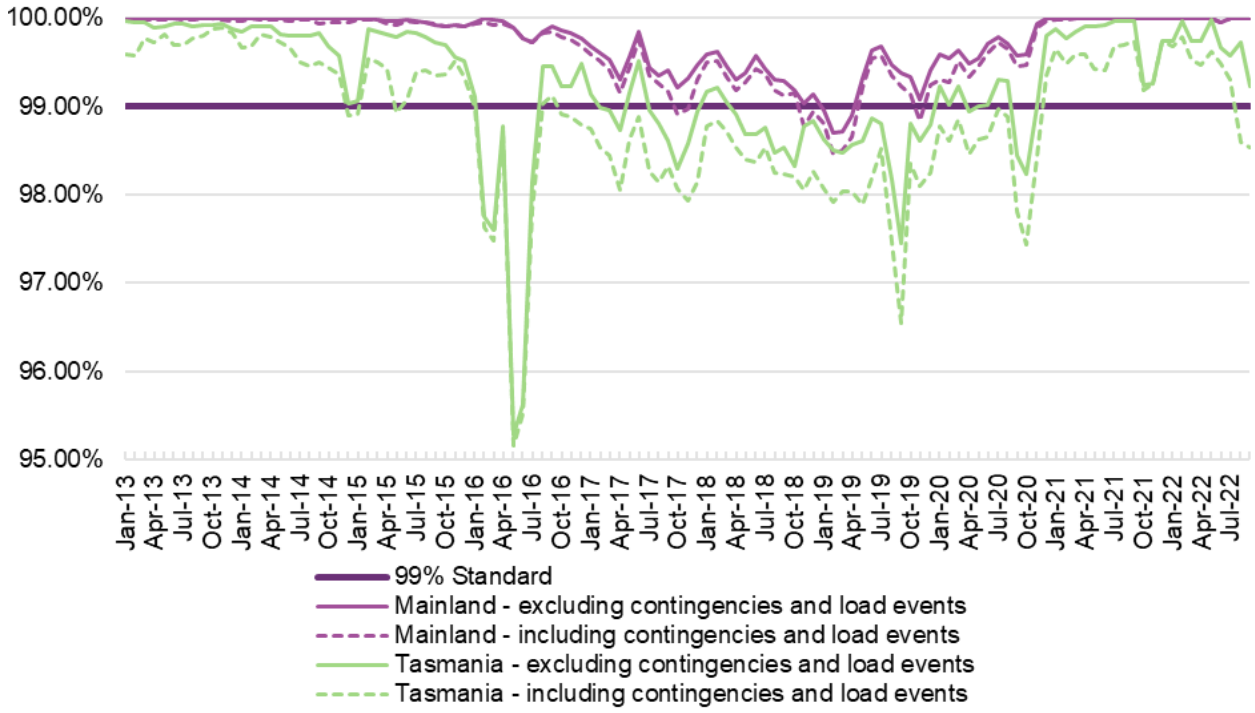


Figure 2 shows the distribution of mainland frequency within the NOFB since 2007.

Figure 2 Monthly mainland frequency distribution

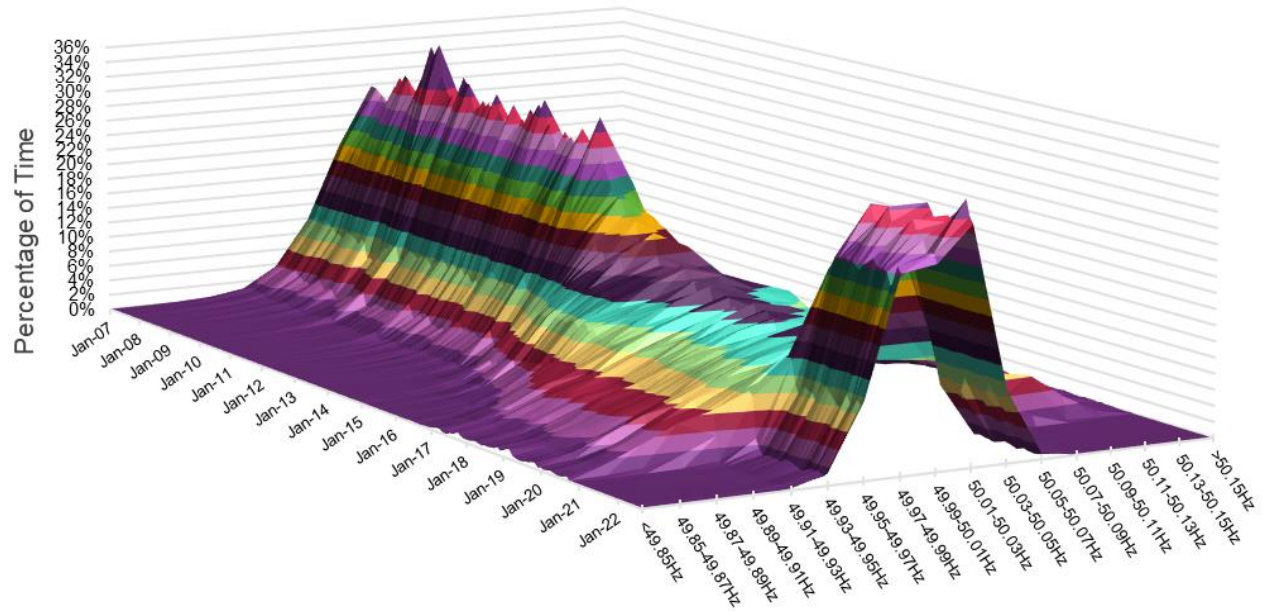
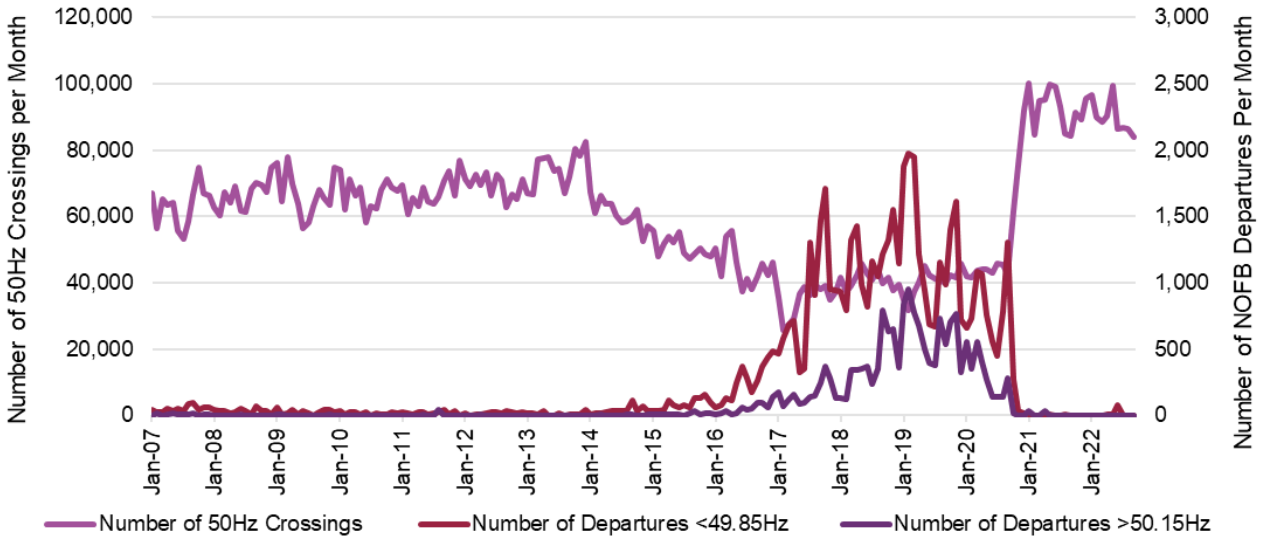


Figure 3 shows the number of times mainland frequency has crossed the nominal 50 hertz (Hz) target and how often frequency has departed the NOFB since 2007.

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

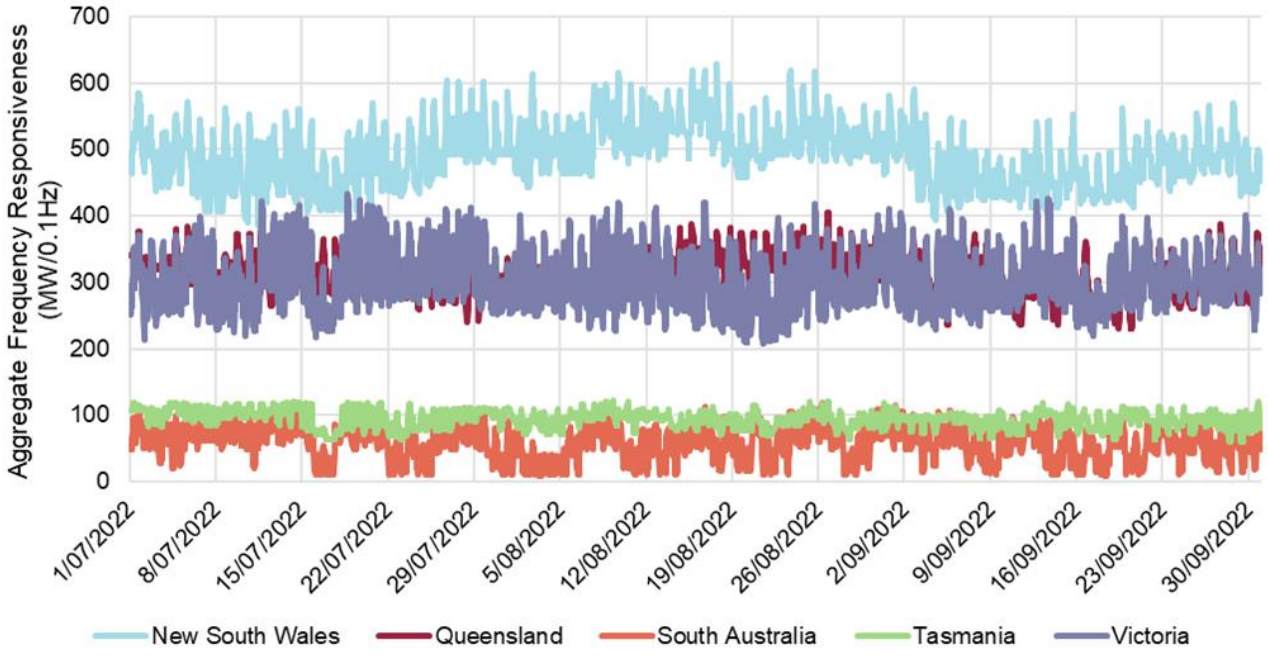


1.3 Aggregate frequency responsiveness

This is a new measure that is being included for the first time in this quarterly report to fulfill the new reporting obligation introduced in clause 4.8.16(b)(1A) of the NER.

Figure 4 shows AEMO's assessment of the highest level of aggregate frequency responsiveness available from frequency responsive plant in each NEM region. These are estimated values using a calculation methodology detailed in Appendix A2.1, which results in an upper estimate of likely aggregate frequency responsiveness.

Figure 4 Estimated aggregate frequency responsiveness in NEM regions



2 Achievement of the Frequency Operating Standard

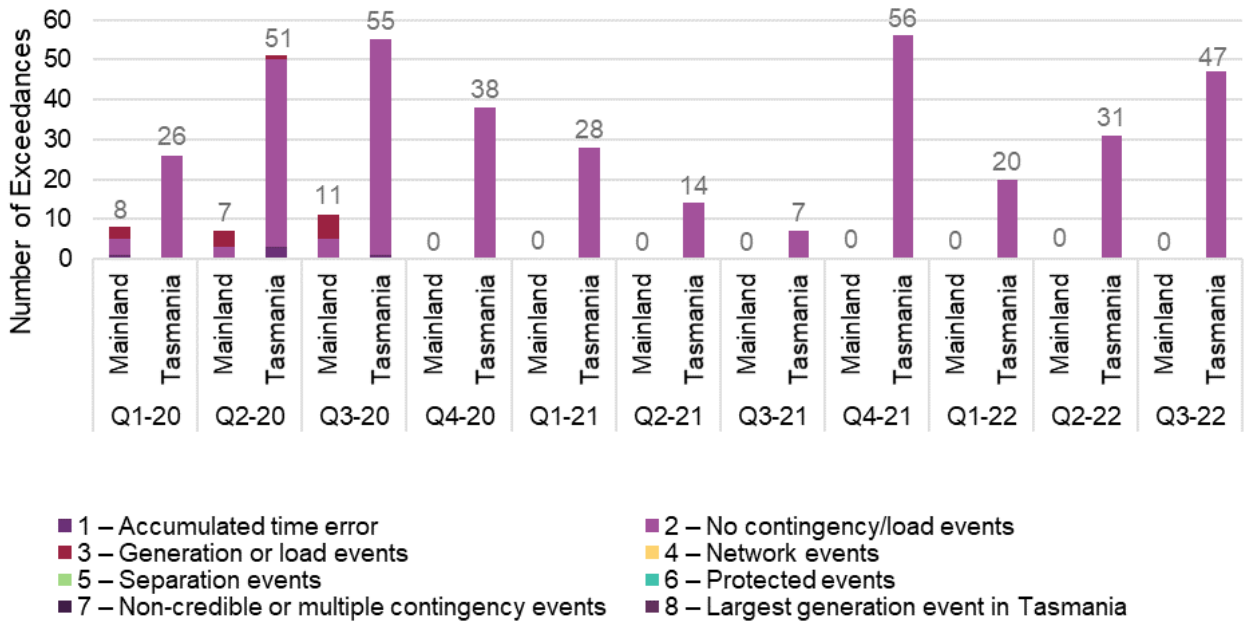
AEMO's assessment of the achievement of the requirements of the FOS in Q3 2022 is summarised in Table 2. Figure 5 shows the FOS exceedances since 2020.

Except for a single category, all FOS targets were achieved. AEMO is satisfied that the exceedances that did occur are explicable and are not of serious consequence. This is further explored in Section 2.1.1.

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 47 times	See Section 2.1.1
• **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	

Figure 5 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

Table 3 shows, for Q3 2022, frequency excursions outside the applicable Normal Operating Frequency Excursion Band (NOFEB) where an associated contingency event has not been identified.

Table 3 Number of frequency excursions without identified contingency outside the NOFEB in Q3 2022

Event	Low/high/both frequency event	Number of events Mainland	Number of events Tasmania
No contingency or load event noted	LOW	0	32
	HIGH	0	8
	BOTH	0	7

Tasmania had an increase in events where frequency exceeded the NOFEB without an associated contingency event compared to Q2 2022, totalling 47 events in Q3 2022 compared to 31 events in Q3 2022.

At least 44 of the 47 instances identified in Q3 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.

One of the remaining three instances identified in Q3 2022 was primarily due to unexpected changes in total wind generation from Tasmania. The two other remaining instances identified in Q3 2022 occurred at times when Basslink was operating at its no-go zone limit, hence was unable to provide further frequency support via its frequency controller.

3 Rate of change of frequency

The calculation of RoCoF by AEMO's Phasor Measurement Unit (PMU) system is outlined in Appendix A2.2. The maximum RoCoF recorded in the mainland in each month in Q3 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.

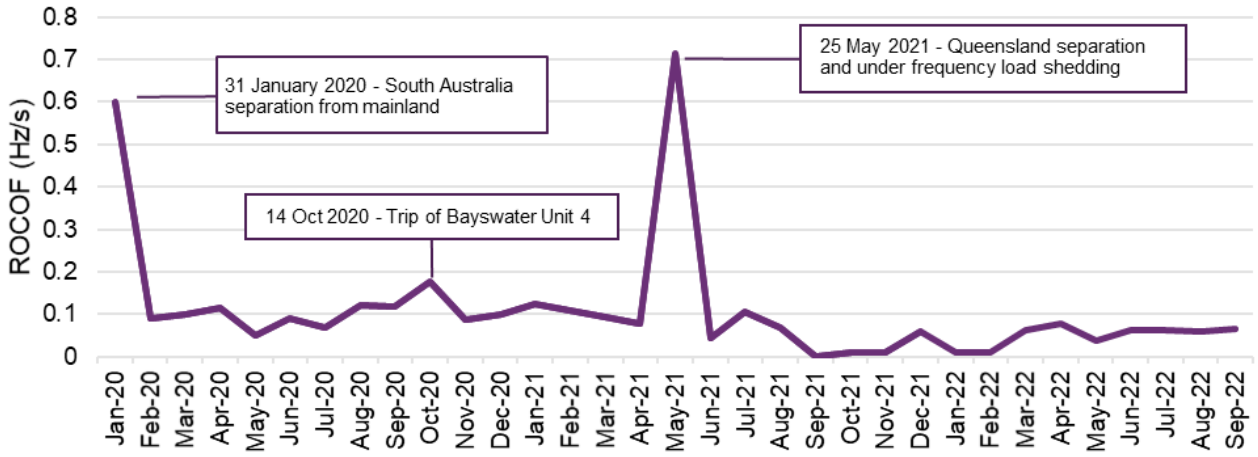
Table 4 RoCoF during frequency events in the mainland

Month	RoCoF (Hz/s)	Associated event	Event time
July	-0.062	Trip of Eraring Unit 1 at 561 MW	05/07/2022 22:13
August	-0.058	Trip of Bayswater Unit 3 at 619 MW	11/08/2022 18:53
September	-0.067	Trip of Stanwell Unit 4 at 364 MW	09/09/2022 23:18

Note: Estimates of RoCoF may vary depending on data source, sampling window and calculation method. See Appendix A2.2 for further detail on the methodology used to calculate RoCoF in this report.

Figure 6 shows the maximum RoCoF recorded in the mainland NEM since Q1 2020.

Figure 6 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 A2.3. Figure 7 and Figure 8 show the minimum and maximum ACE per half-hourly trading interval in Q3 2022 in the mainland NEM and Tasmania, respectively.

Figure 7 Minimum and maximum ACE per half-hour in mainland NEM

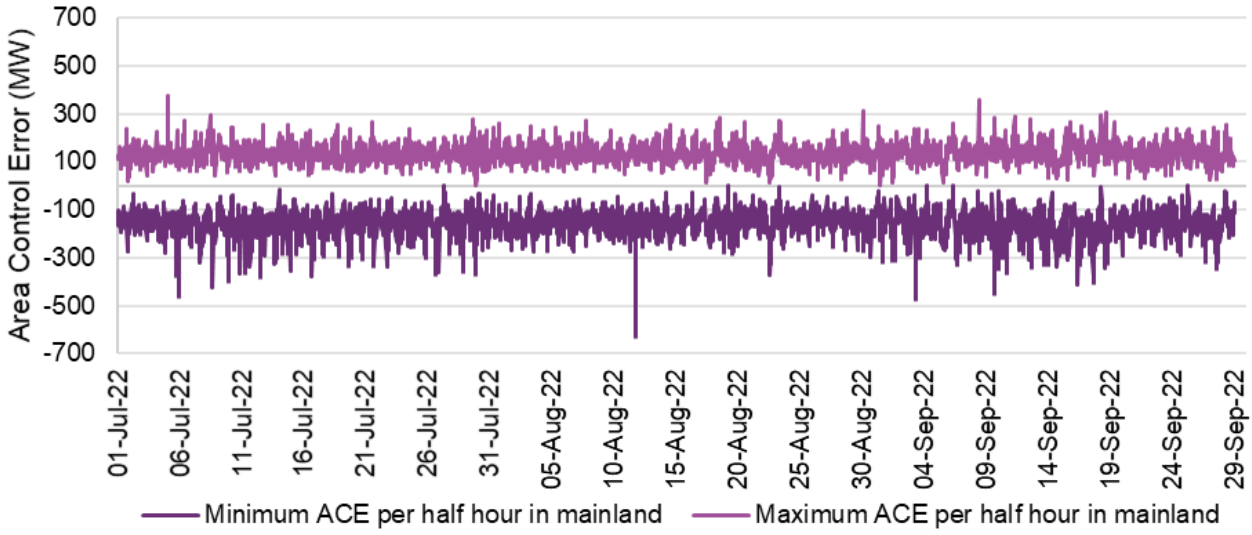
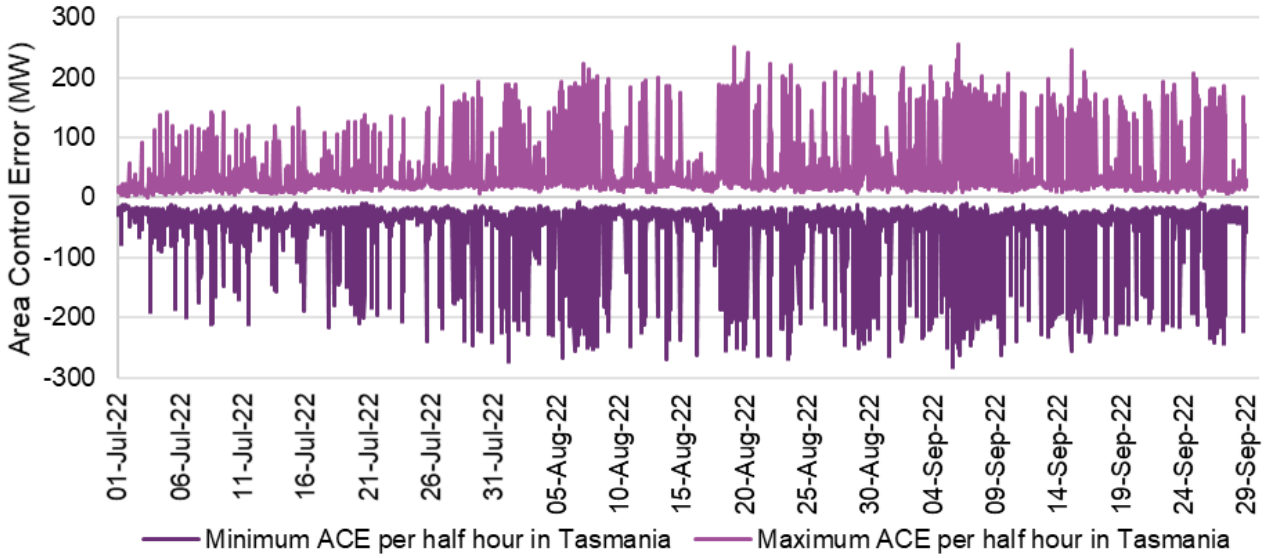


Figure 8 Minimum and maximum ACE per half-hour in Tasmania



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[9].

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 2022 relating to frequency exceeding the OFTB.

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

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 megawatts (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 Q3 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 Q3 2022 meeting the criteria noted above.

Table 5 Credible generation events in 2020, 2021, Q1 2022, Q2 2022 and Q3 2022

Quarter	Number of events	Average contingency size (MW)	Average frequency nadir (Hz)	Average recovery time (s)
Q3 2022	9	401	49.87	4
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, Q2 2022 and Q3 2022

Quarter	Number of events	Average contingency size (MW)	Average frequency nadir (Hz)	Average recovery time (s)
Q3 2022	33	277	50.08	0
Q2 2022	29[10]	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

[10] In Q2 2022 AEMO advised 30 credible load events occurred. This has been revised to 29 credible load events following further investigation.

Table 7 Credible generation and load events in Q3 2022

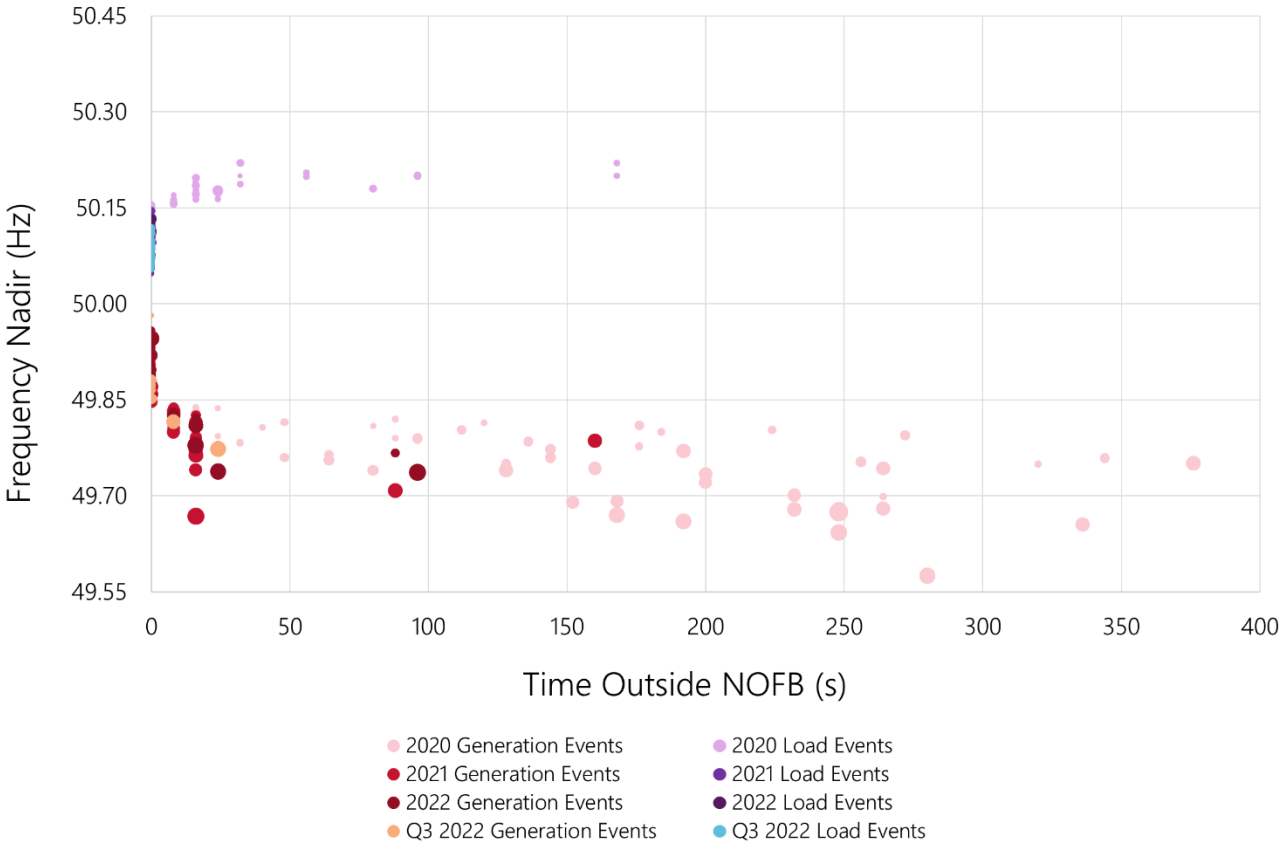
Event time	Unit	Contingency size (MW)	Frequency nadir/peak (Hz)	Recovery to NOFB (s)	FOS compliant?
01-Jul-22 17:50:24	APD1	277	50.07	0	YES
05-Jul-22 19:15:20	APD1	275	50.08	0	YES
05-Jul-22 22:13:44	ER01	562	49.82	8	YES
06-Jul-22 10:21:44	TOMAGO1	292	50.09	0	YES
08-Jul-22 18:00:08	APD1	278	50.08	0	YES
09-Jul-22 19:30:08	APD1	271	50.06	0	YES
11-Jul-22 11:28:16	BOYNE2	254	50.07	0	YES
12-Jul-22 12:56:00	STAN-3	348	49.87	0	YES
12-Jul-22 18:00:16	APD1	270	50.09	0	YES
14-Jul-22 18:00:08	APD1	278	50.09	0	YES
18-Jul-22 17:45:12	APD1	278	50.09	0	YES
19-Jul-22 12:09:20	PUMP1	246	50.05	0	YES
19-Jul-22 18:00:08	APD1	275	50.09	0	YES
20-Jul-22 18:00:08	APD1	279	50.09	0	YES
21-Jul-22 14:46:16	COOPGWF1	397	49.88	0	YES
26-Jul-22 21:56:40	COOPGWF1	350	49.88	0	YES
28-Jul-22 17:45:12	APD1	275	50.06	0	YES
28-Jul-22 20:20:40	TOMAGO4	309	50.07	0	YES
29-Jul-22 17:45:20	APD1	275	50.08	0	YES
04-Aug-22 07:30:08	APD1	279	50.09	0	YES
07-Aug-22 18:00:16	APD1	279	50.10	0	YES
07-Aug-22 20:16:00	BOYNE3	320	50.07	0	YES
08-Aug-22 17:50:08	APD1	277	50.07	0	YES
09-Aug-22 17:55:20	APD1	278	50.09	0	YES
11-Aug-22 18:00:16	APD1	278	50.07	0	YES
11-Aug-22 18:52:48	BW03	622	49.77	24	YES
18-Aug-22 13:33:36	TOMAGO3	310	50.11	0	YES
19-Aug-22 18:00:16	APD1	277	50.08	0	YES
19-Aug-22 21:11:04	BOYNE2	258	50.08	0	YES
30-Aug-22 01:29:20	TOMAGO4	308	50.11	0	YES
05-Sep-22 18:25:20	APD1	252	50.08	0	YES
06-Sep-22 18:00:08	APD1	282	50.08	0	YES
08-Sep-22 09:41:20	BOYNE3	327	50.12	0	YES
09-Sep-22 17:16:16	TOMAGO4	304	50.10	0	YES
09-Sep-22 23:18:00	STAN-4	366	49.87	0	YES
16-Sep-22 09:11:20	MURRAY	445	49.85	0	YES
18-Sep-22 19:01:36	ER04	300	49.88	0	YES
19-Sep-22 10:35:12	DARLSF1	215	49.98	0	YES
19-Sep-22 18:15:12	APD2	215	50.06	0	YES
23-Sep-22 14:26:40	BOYNE3	330	50.09	0	YES

Event time	Unit	Contingency size (MW)	Frequency nadir/peak (Hz)	Recovery to NOFB (s)	FOS compliant?
28-Sep-22 11:00:32	APD2	225	50.06	0	YES
29-Sep-22 10:30:08	APD2	226	50.07	0	YES

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

Figure 9 displays each event from Table 7 to illustrate the distribution of frequency outcomes following credible contingency events in Q3 2022, in comparison to 2022, 2021 and 2020.

Figure 9 Frequency outcomes of identified credible generation and load events



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

A2. Methodology

A2.1 Aggregate frequency responsiveness methodology

Estimated available aggregate frequency responsiveness in this quarterly report is calculated hourly as the sum of estimated available frequency response from all scheduled and semi-scheduled units with initial MW greater than zero at the time.

The estimated available frequency response of a unit sampled hourly is estimated in MW/0.1Hz using the following calculation.

$$\boldsymbol{If}\ D_N > 0\ \&\ MW_{N,T} > 0$$

$$\boldsymbol{Then}\ EFR_{N,T} = \frac{100}{D_N} \times \frac{0.1Hz}{50Hz} \times C_N$$

$$\boldsymbol{Else}\ EFR_{N,T} = 0$$

where:

- **D** is unit percentage droop, and zero [0] represents that no droop is implemented.
- **N** is unit N.
- **MW** is unit initial MW in trading interval.
- **T** is trading interval, ending on the hour.
- **EFR** is unit estimated frequency response.
- **C** is unit maximum capacity.
- Estimated available aggregate frequency responsiveness is estimated for each hour interval in MW/0.1Hz using the following equation

$$AFR_{R,T} = \sum_{N=1}^{G} EFR_{N,T}$$

where:

- **AFR** is regional aggregate frequency response.
- **R** is NEM region.
- **G** is the number of generators in region **R.**

Further assumptions in the calculation of aggregate frequency responsiveness include:

- Unit frequency response is calculated using the *Maximum Capacity* from AEMO registration information.
- Units are assumed to provide frequency response in accordance with their implemented droop setting as confirmed by AEMO when implementing the mandatory PFR changes.
- Units that have not implemented PFR settings are not included in the calculation.
- The calculation ignores frequency response deadband. This is equivalent to assuming no deadband.

- Internal unit limits to providing frequency response, such as ramp rates, delays or minimum and maximum operating levels, are not modelled.
- Primary Frequency Response Requirements (PFRR) variations agreed with AEMO are not modelled in the calculation.
- Frequency response is not included from distributed energy resources and units which provide FCAS but not energy.
- Load relief is not included.

A2.2 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.

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

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

$$\boldsymbol{else}\ no\ measurement\ attempted$$

where:

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

A2.3 Area Control Error (ACE) methodology

As per the Regulation FCAS Contribution Factors Procedure[11], 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:

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

- **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.