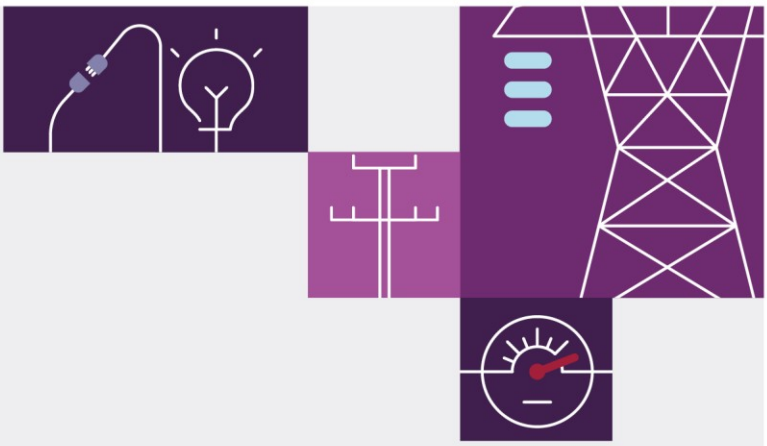
AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

Frequency and Time Error Monitoring – Quarter 1 2022

May 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 January to March 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.

Disclaimer

This document or the information in it may be subsequently updated or amended. This document does not constitute legal or business advice and should not be relied on as a substitute for obtaining detailed advice about the National Electricity Law, the National Electricity Rules, or any other applicable laws, procedures or policies. AEMO has made every reasonable effort to ensure the quality of the information in this document but cannot guarantee its accuracy or completeness.

Accordingly, to the maximum extent permitted by law, AEMO and its officers, employees and consultants involved in the preparation of this document:

- make no representation or warranty, express or implied, as to the currency, accuracy, reliability or completeness of the information in this document; and
- are not liable (whether by reason of negligence or otherwise) for any statements or representations in this document, or any omissions from it, or for any use or reliance on the information in it.

Copyright

AEMO acknowledges the Traditional Owners of country throughout Australia and recognise their continuing connection to land, waters and culture. We pay respect to Elders past, present and emerging.

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.

Contents

Tables

Figures

1 Actions to improve frequency control performance

1.1 Recent and upcoming actions

The following recently completed and upcoming intended actions are anticipated 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. AEMO is seeking industry feedback by 14 June 2022.
- On 16 February 2022 AEMO published an updated guide on Battery Energy Storage System (BESS) requirements for contingency FCAS registration[2].
- AEMO published a Final MASS Determination on 22 December 2021[3]. The new MASS came into effect from 1 February 2022 and can be found on AEMO's website[4]. The new MASS introduced the following changes:
  - Revised measurement options for the providers of Fast FCAS, especially for aggregated facilities.
  - Clarification of MASS references to the Frequency Operating Standard (FOS).
  - Improved guidance on the co-ordination of different FCAS and Primary Frequency Response (PFR).
  - Clarification of the relationship between the MASS and other instruments and institutions.
  - New requirements and improved guidance for Regulation FCAS providers.
  - A substantially modified MASS Verification Tool to incorporate the consulted changes.
- AEMO published an initial Engineering Framework Initial Roadmap in December 2021[5], to initiate an enduring process for industry collaboration to determine actions necessary to enable a secure and efficient National Electricity Market (NEM) transition as new operational conditions emerge. The December Roadmap summarises potential gaps identified through targeted engagement with industry from August 2021 to October 2021. AEMO is currently engaging with industry on prioritisation and identifying actions necessary to address potential gaps, with an initial focus on near-term priorities over the next 1-2 years[6].
- 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

[2] 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.

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

[4] See https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2021/mass/final-determination/market-ancillary-services-specification-v70-clean.pdf?la=en.

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

[6] Stakeholders wishing to engage in this process or stay informed of Engineering Framework activities can register their interest by emailing FutureEnergy@aemo.com.au.

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 anticipated 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 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 first half of 2022.
- The Draft Determination for PFR incentive arrangements was published on 16 September 2021, with a Final Determination expected on 7 July 2022. The Australian Energy Market Commission (AEMC) is currently engaging with AEMO and industry on changes to the allocation of regulation FCAS costs to institute credits as well as debits. A further consultation paper is expected in May 2022.
- AEMO published an update to the Frequency Control Work Plan[7] in September 2021, reporting on task progress and also identifying sub-tasks better reflecting requirements for task completion.
- AEMO continues to implement the PFR rule change. 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.

Upcoming

- AEMO is preparing the 2022 *Power System Frequency Risk Review* (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. This work is planned for completion mid-2022. The previous 2020 PSFRR can be viewed on AEMO's website[9].
- The Reliability Panel is planning to initiate a review of the FOS in the current calendar year[10].

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.

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

[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.

[10] See https://www.aemc.gov.au/about-us/reliability-panel/current-forward-work-program.

Table 1 Key frequency statistics from the mainland and Tasmania in Q1 2022

	Mainland		Tasmania		Further commentary
	Minimum	Maximum	Minimum	Maximum	
Frequency (Hz)	49.78	50.12	49.06	51.05	
Time error (s)	-4.46	4.04	-8.61	4.28	
Longest frequency event duration (s)*	16				

*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 Q1 2022. Further detail on credible contingency events in Q1 2022 is available in Credible generation and load .

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

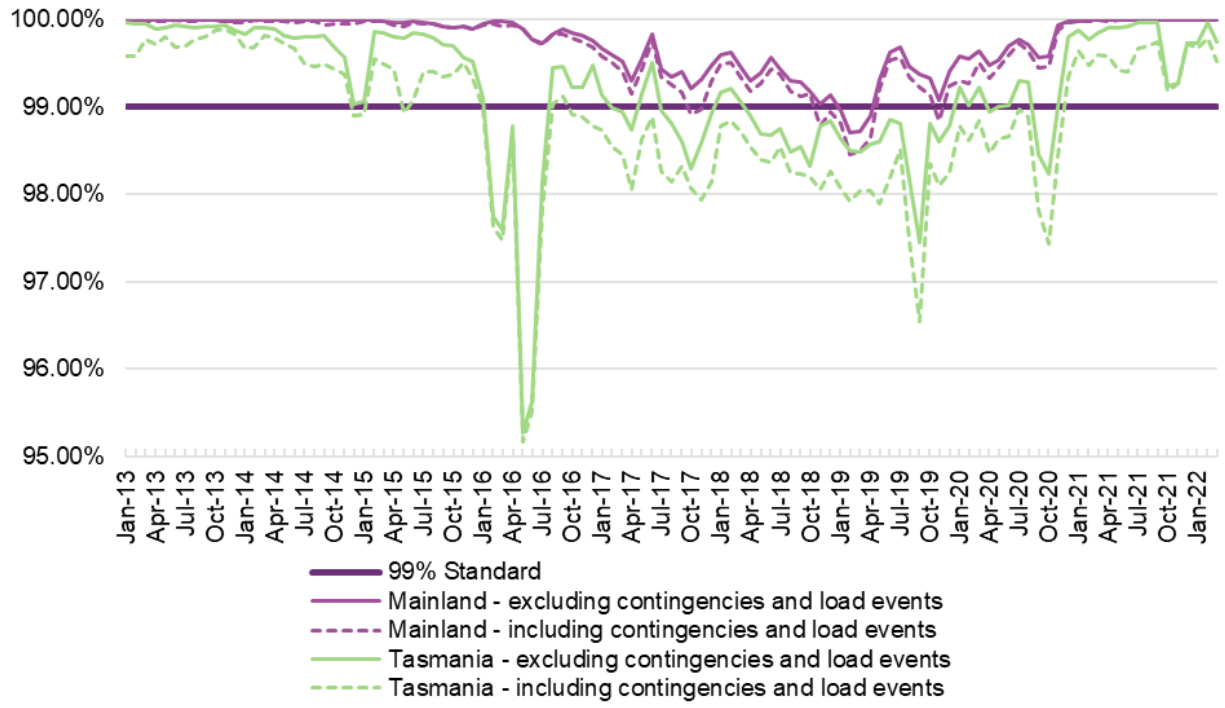


Figure 2 shows the distribution of frequency within the NOFB since 2007.

Figure 2 Monthly frequency distribution

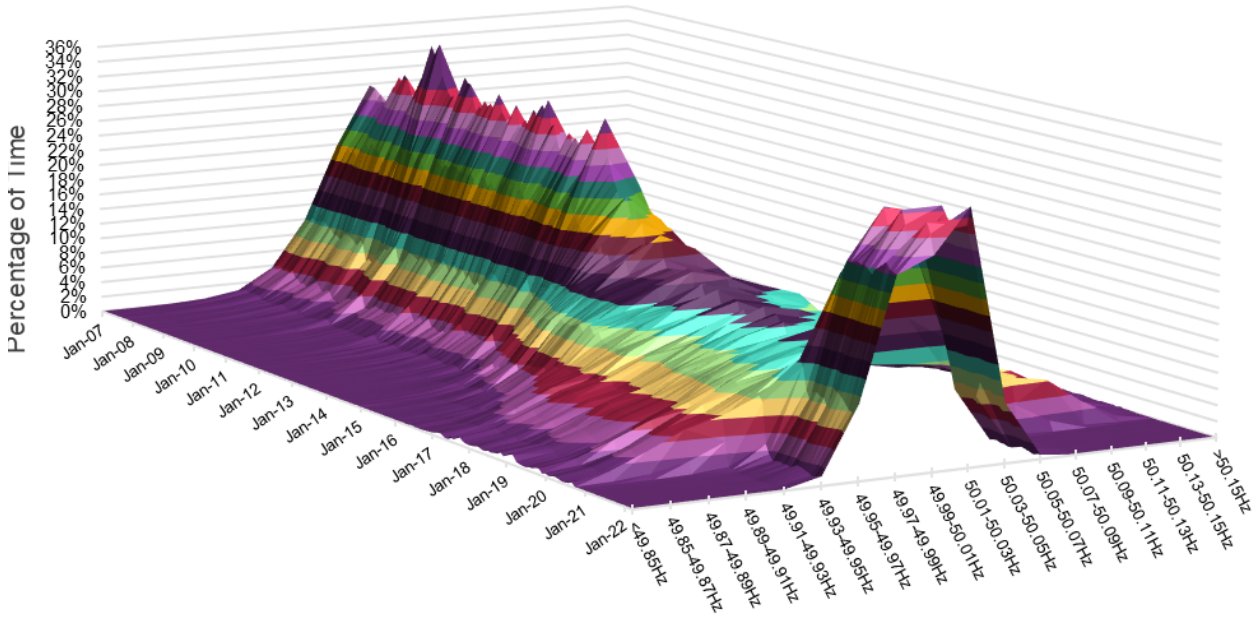
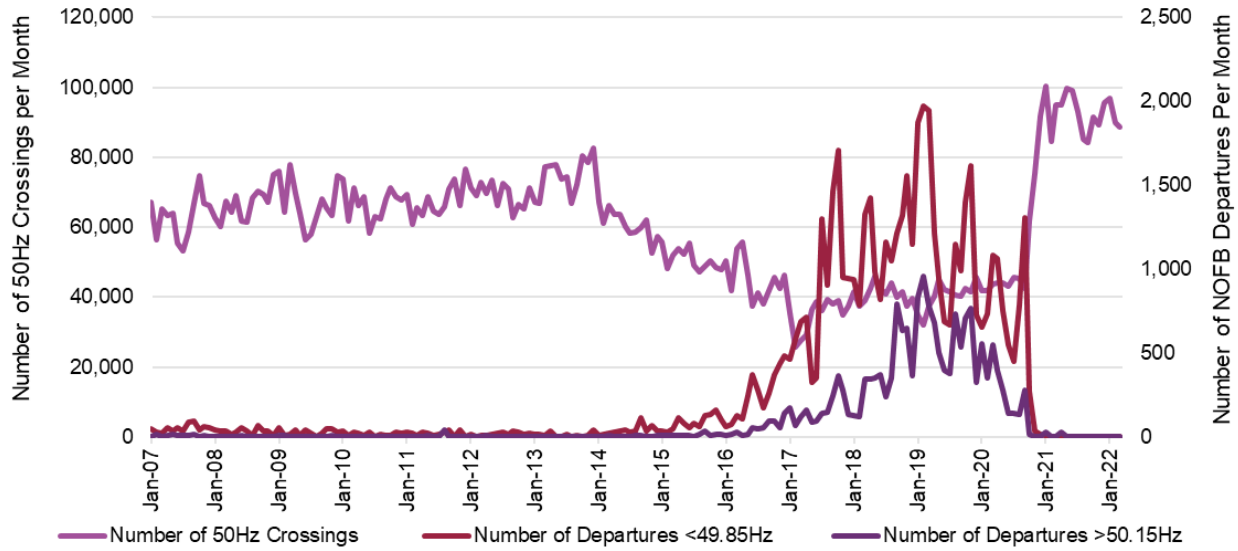


Figure 3 examines the number of times frequency has crossed the nominal 50 hertz (Hz) target and how often frequency departed the NOFB since 2007.

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



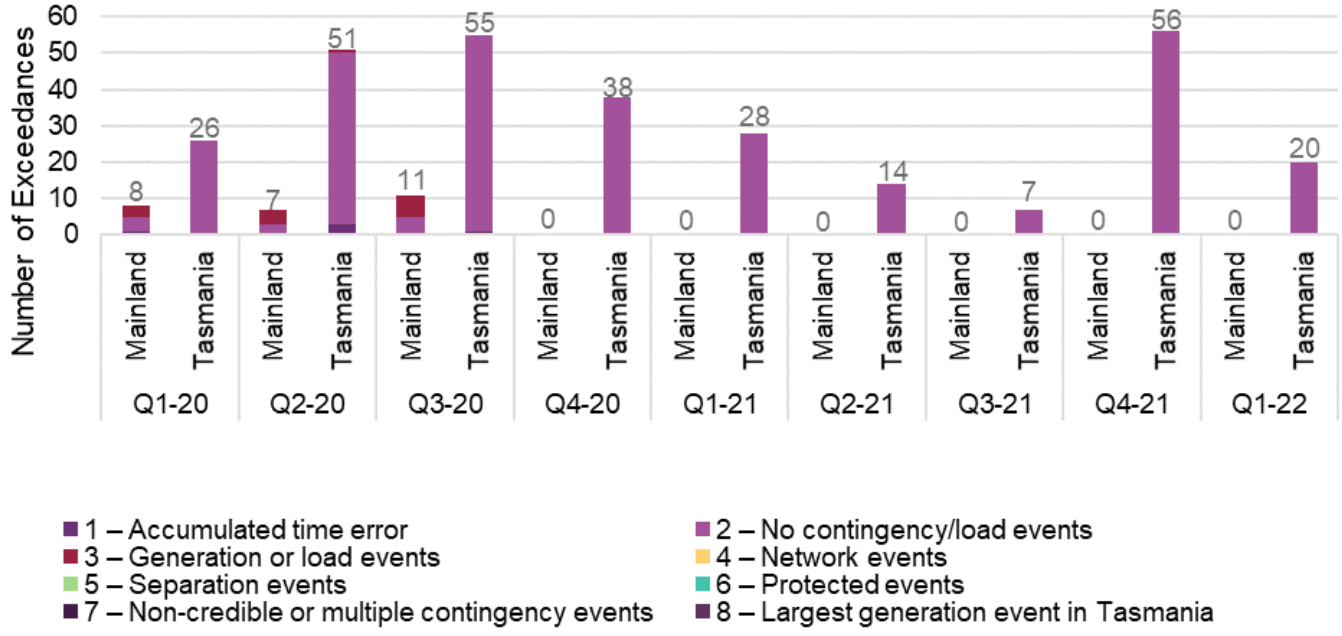
2 Achievement of the Frequency Operating Standard

AEMO's assessment of the achievement of the requirements of the FOS in Q1 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** • **Recovered in five minutes** • **Within NOFB 99% of the time**	 Achieved Achieved Achieved	 Exceeded 20 times Achieved Achieved	See Section 2.1.1
3 – Generation or load events • **Contained** • **Recovered within five minutes**	 Achieved Achieved	 Achieved Achieved	
4 – Network events • **Contained** • **Recovered within five minutes**	 Achieved Achieved	 Achieved Achieved	
5 – Separation events • **Contained** • **Managed within 10 minutes**	 No separation events No separation events	 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 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 Q1 2022.

Table 3 Number of frequency excursions without identified contingency outside the NOFEB in Q1 2022

Event	Low/high/both frequency event	Number of events Mainland	Number of events Tasmania
No contingency or load event noted	LOW	0	18
	HIGH	0	2
	BOTH	0	0

Tasmania had a decrease in events where frequency exceeded the NOFEB without an associated contingency event compared to Q4 2021, totalling 20 events in Q1 2022 compared to 56 events in Q4 2021.

At least 17 of the 20 instances identified in Q1 2022 occurred during two extended outages of the Basslink high voltage direct current (HVDC) interconnector from 8 March 2022 to 9 March 2022 and 22 March 2022 to 25 March 2022. 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 two of the remaining three instances identified in Q1 2022 occurred at times when Basslink was operating at its import limit, hence unable to provide further frequency support via its frequency controller. An underlying cause in the one remaining instance could not be identified.

3 Rate of change of frequency

The calculation of rate of change of frequency (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 Q1 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.

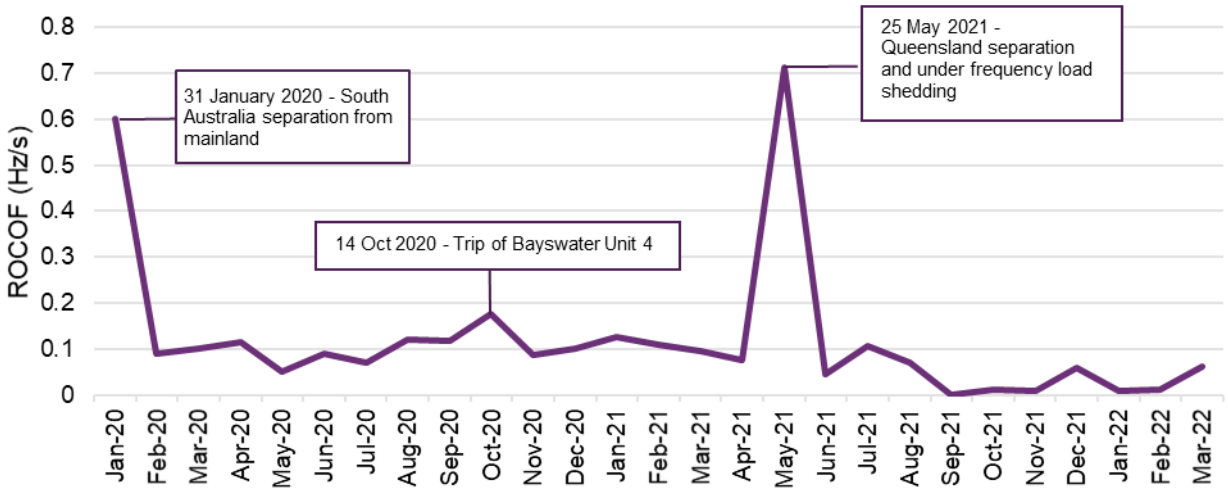
Table 4 RoCoF during frequency events in the mainland

Month	RoCoF (Hz/s)	Associated event	Event time
January	-0.009	Trip of Bayswater Unit	29/01/2022 10:43
February	-0.011	Trip of Loy Yang A Unit	8/02/2022 17:35
March	-0.061	Trip of Gladstone 3 and Gladstone 4 Units	31/03/2022 16:40

Note: Estimates of RoCoF may vary depending on data source, sampling window and calculation method. See Appendix B for further detail on the methodology 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 Q1 2022 in the mainland NEM and Tasmania, respectively.

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

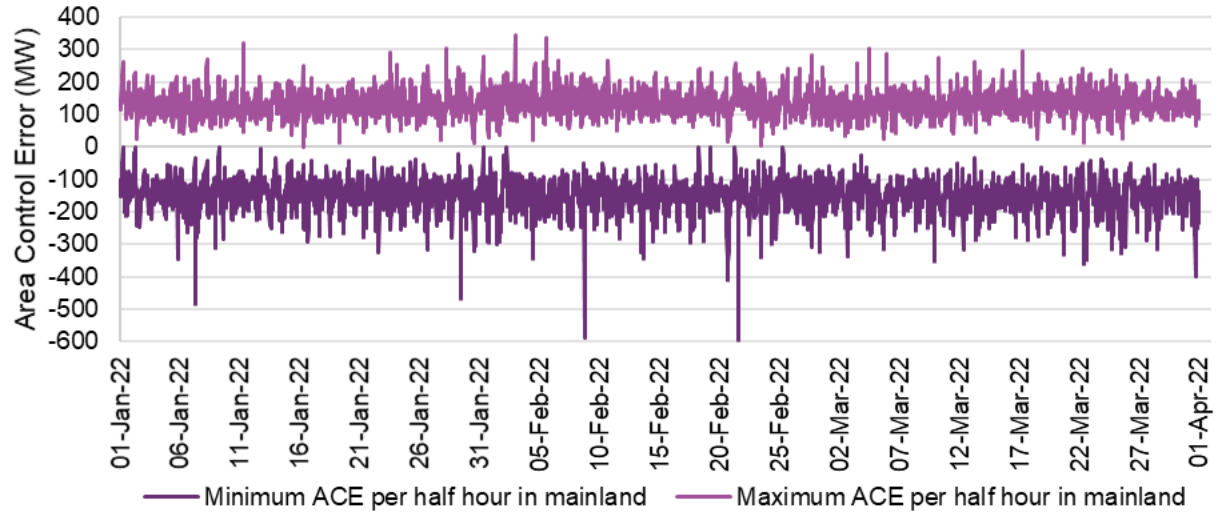
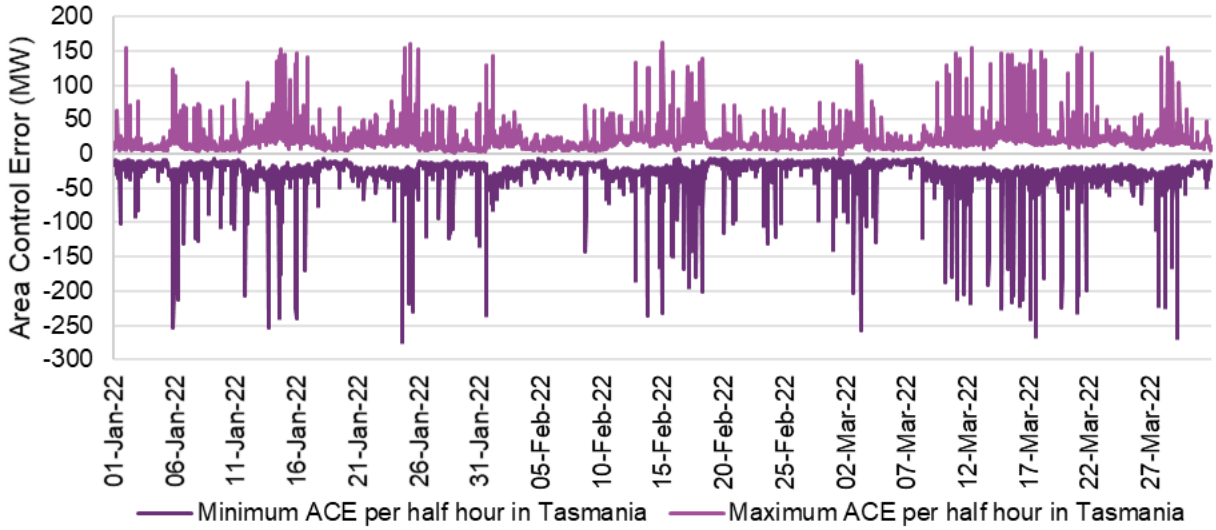


Figure 7 Minimum and maximum ACE per half-hour in Tasmania



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 Q1 2022 where frequency exceeded the OFTB.

[11] 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 Q1 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 list 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 Q1 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 Q1 2022 meeting the criteria noted above.

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

Quarter	Number of events	Average contingency size (MW)	Average frequency nadir (Hz)	Average recovery time (s)
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 and Q1 2022

Quarter	Number of events	Average contingency size (MW)	Average frequency nadir (Hz)	Average recovery time (s)
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

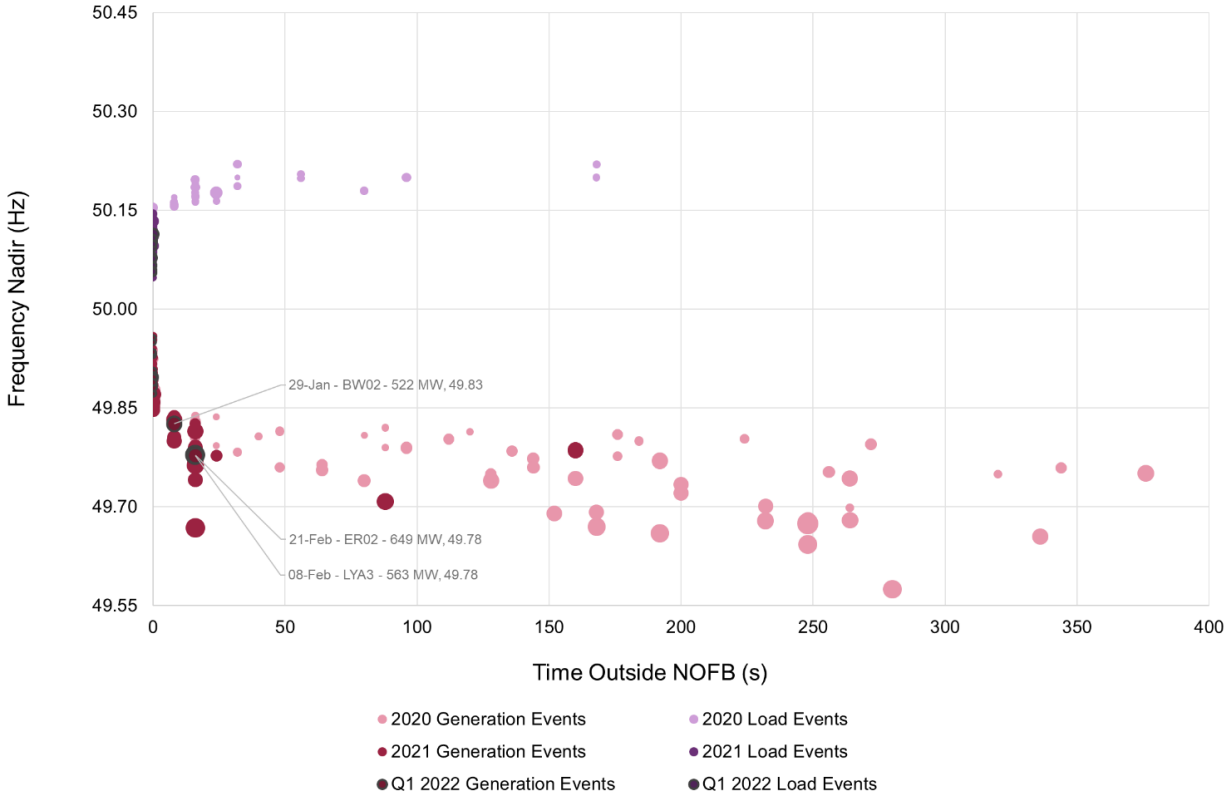
Event time	Unit	Contingency size (MW)	Frequency nadir/peak (Hz)	Recovery to NOFB (s)	FOS compliant?
05-Jan-22 17:04:40	LIMOSF11	221	49.93	N/A	YES
07-Jan-22 11:14:48	LIMOSF11	222	49.95	N/A	YES
08-Jan-22 22:32:56	MP2	224	49.89	N/A	YES

Event time	Unit	Contingency size (MW)	Frequency nadir/peak (Hz)	Recovery to NOFB (s)	FOS compliant?
09-Jan-22 14:17:52	STAN-1	265	49.89	N/A	YES
10-Jan-22 17:24:40	BOYNE2	249	50.07	N/A	YES
11-Jan-22 06:31:12	TOMAGO1	303	50.10	N/A	YES
12-Jan-22 14:15:52	APD1	249	50.06	N/A	YES
18-Jan-22 11:57:28	LOYYB2	382	49.90	N/A	YES
24-Jan-22 02:54:00	APD1	254	50.10	N/A	YES
26-Jan-22 14:53:12	DARLSF1	259	49.88	N/A	YES
28-Jan-22 05:14:00	APD1	254	50.11	N/A	YES
29-Jan-22 10:43:20	BW02	522	49.83	8	YES
31-Jan-22 11:30:08	APD1	252	50.07	N/A	YES
02-Feb-22 22:33:44	BOYNE3	411	50.11	N/A	YES
03-Feb-22 20:20:48	APD1	250	50.08	N/A	YES
04-Feb-22 10:07:04	DARLSF1	288	49.89	N/A	YES
05-Feb-22 12:40:08	LIMOSF11	222	49.93	N/A	YES
07-Feb-22 11:16:24	LIMOSF11	222	49.93	N/A	YES
08-Feb-22 17:35:20	LYA3	563	49.78	16	YES
11-Feb-22 15:19:28	LIMOSF11	221	49.93	N/A	YES
13-Feb-22 12:19:20	MP1	279	49.90	N/A	YES
14-Feb-22 11:00:08	APD1	252	50.06	N/A	YES
17-Feb-22 17:00:48	LIMOSF11	221	49.96	N/A	YES
17-Feb-22 17:32:40	APD1	252	50.08	N/A	YES
21-Feb-22 13:56:08	ER02	649	49.78	16	YES
25-Feb-22 17:11:36	TOMAGO1	310	50.08	N/A	YES
26-Feb-22 09:41:04	APD1	253	50.08	N/A	YES
03-Mar-22 12:18:24	PUMP1	246	50.10	N/A	YES
04-Mar-22 12:19:36	PUMP1	247	50.11	N/A	YES
05-Mar-22 10:00:08	APD1	252	50.06	N/A	YES
05-Mar-22 21:38:56	TOMAGO3	308	50.10	N/A	YES
07-Mar-22 08:27:52	LIMOSF11	221	49.94	N/A	YES
12-Mar-22 08:02:24	ER03	308	49.88	N/A	YES
15-Mar-22 13:30:08	APD1	258	50.09	N/A	YES
17-Mar-22 07:00:16	APD1	257	50.10	N/A	YES
26-Mar-22 20:19:28	ER04	266	49.91	N/A	YES
31-Mar-22 16:40:32	GSTONE3	253	49.87	N/A	YES
31-Mar-22 16:40:32	GSTONE4	225	49.87	N/A	YES

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

Figure 8 displays each event from Table 7 to illustrate the distribution of frequency outcomes following credible contingency events in Q1 2022, in comparison to 2021 and 2020.

Figure 8 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/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.

A2.2 Area Control Error (ACE) methodology

As per the Regulation FCAS Contribution Factors Procedure[12], 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.

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