Frequency Monitoring – Quarter 2 2024

August 2024

A report for the National Electricity Market

Important notice

Purpose

The purpose of this report is to provide information about the frequency performance in the National Electricity Market (NEM) for the mainland and Tasmanian regions for the period April to June 2024 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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We acknowledge the Traditional Custodians of the land, seas and waters across Australia. We honour the wisdom of Aboriginal and Torres Strait Islander Elders past and present and embrace future generations.
AEMO Group is proud to have launched its first Reconciliation Action Plan in May 2024 (scan QR code to read).

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
FOS	Frequency Operating Standard
GPS	Global Positioning System
GPSRR	General Power System Risk Review
Hz	hertz
Hz/s	hertz per second
IBR	inverter-based resource/s
kV	kilovolts
L1	Very Fast Lower
MASS	Market Ancillary Services Specification
ms	millisecond/s
MW	megawatt/s
MWs	megawatt second/s
NEM	National Electricity Market
NER	National Electricity Rules
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
R1	Very Fast Raise
RoCoF	rate of change of frequency
s	second/s
SCADA	Supervisory Control and Data Acquisition
TNSP	transmission network service provider
VRE	variable renewable energy
VPP	virtual power plant
VF	Very Fast

Introduction

The Reliability Panel's Frequency Operating Standard (FOS)[1] specifies limits for power system frequency 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).

AEMO is required to report weekly and quarterly on these endeavours and the frequency performance of the NEM as required by clause 4.8.16 of the NER. Furthermore, in accordance with clause 4.8.16(d) of the NER, the methodology and assumptions in the preparation of the weekly and quarterly Frequency Monitoring reports are provided in Appendix A2 of this report.

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 is 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. In comparison, Tasmanian frequency data is sampled at 4-second intervals using the most recent network operations and control system (NOCS) frequency measurement preceding each 4-second interval. Time error measurements are calculated from these frequency measurements. Additionally, high-speed data for the calculation of the rate of change of frequency (RoCoF) is sourced from the AEMO/transmission network system provider (TNSP) Phasor Measurement Unit (PMU) system, and the Area Control Error (ACE) data is from AEMO's Automatic Generation Control (AGC) system.

High-speed data from frequency control ancillary services (FCAS) meters is used to assess the delivery of very fast and fast FCAS. In comparison, analysis of the delivery of slow and delayed FCAS in this report is based on 4-second resolution supervisory control and data acquisition (SCADA) information from AEMO systems or provided by participants. Further information regarding the Market Ancillary Services Specification (MASS) and the FCAS Verification Tool is available on AEMO's website[2].

[1] See https://www.aemc.gov.au/sites/default/files/2023-04/FOS - CLEAN.pdf.

[2] See https://www.aemo.com.au/energy-systems/electricity/national-electricity-market-nem/system-operations/ancillary-services/market-ancillary-services-specification-and-fcas-verification-tool.

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1 Actions to improve frequency control performance

1.1 Recent and in progress actions

The following recently completed or in progress actions are expected to contribute to maintaining or improving frequency control performance:

- AEMO has updated the Primary Frequency Response Requirements (PFRR) document effective from 3 June 2024[3]. AEMO continues to implement the mandatory primary frequency response (PFR) requirements that were introduced into the National Electricity Rules (NER) in 2020[4] and made enduring in 2022. Implementation reports are on AEMO's website[5], and 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.
- AEMO published the final 2024 General Power System Risk Review (GPSRR) on 25 July 2024[6]. The purpose of the GPSRR is to review a prioritised set of power system risks, comprising events or conditions that, alone or in combination, would likely lead to cascading outages or major supply disruptions. The frequency performance of the National Electricity Market (NEM) during the identified scenarios was assessed and priority actions for further study or resolution were recommended.
- AEMO engaged Vysus Group as part of the Engineering Roadmap to study the future role of inertia in the NEM. *The Role and Need for Inertia in a NEM-like System* was published on 9 May 2024[7]. The report summarises an independent simulation-based analysis on frequency and angle stability using a simplified network model to inform the ongoing investigation of power system stability under low levels of synchronous inertia. The study highlights the value of further analysis to improve understanding of these phenomena in the context of the NEM. *The Role and Need for Inertia in a NEM-like System* report summarises the findings of this high-level study, including:
  - The extent to which the geographic distribution of synchronous inertia across the power system impacts various stability phenomena in the power system.
  - Whether the power system could run entirely at zero or very low levels of synchronous inertia.
  - At what level of synchronous inertia would AEMO need to consider other power system stability phenomena in the calculation of inertia requirements.
- The Very Fast (VF) frequency control ancillary services (FCAS) raise and lower markets each commenced operation on 9 October 2023 with a global NEM system normal requirement, which is set at 350 megawatts

[3] See https://aemo.com.au/-/media/files/initiatives/primary-frequency-response/2024/primary-frequency-response-requirements-clean.pdf?la=en.

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

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

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

[7] See https://aemo.com.au/-/media/files/initiatives/engineering-framework/2024/ao_geas-role-of-inertia-in-a-nem-like-system.pdf.

(MW) for the VF Raise service and 225 MW for the VF Lower service at the time of this report. AEMO is reviewing levels of registered capacity that are committed for VF FCAS market participation on a monthly basis to decide whether the capped procurement volumes can be incremented. More information can be found on the AEMO VF FCAS market transition page[8].

1.2 Impact of frequency control actions

The mainland frequency performance observed over the quarter from 1 April 2024 to 30 June 2024 (Q2 2024) indicates that from a frequency control perspective, the system is well placed to cope with both regular frequency behaviour and unexpected incidents.

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 Q2 2024.

Table 1 Key frequency statistics from the mainland and Tasmania in Q2 2024

	Mainland		Tasmania	
	Minimum	Maximum	Minimum	Maximum
Frequency (Hz)	49.7	50.1	48.8	51.2
Time error (seconds [s])[A]	-2.367	1.926	-7.155	8.860
Longest frequency event duration (s)[B]	124 s outside the NOFB over 256 s		404 s outside the NOFB over 1,560 s	

A. AEMO will continue to report time error, but there are no longer formal limits on accumulated time error in the Frequency Operating Standard (FOS) from 9 October 2023. For clarity, AEMO is reporting on the Automatic Generation Control (AGC) time error.
B. Frequency may return to the normal operating frequency band (NOFB) briefly during the period AEMO considers to constitute the event.

The frequency event of longest duration in the mainland occurred on 3 April 2024, due to a trip of Eraring Units 1 and 2, during which frequency oscillated in and out of the normal operating frequency band (NOFB) during the frequency recovery.

The frequency event of longest duration in Tasmania occurred on 27 June 2024, due to a period of repeated cycling of Tasmanian frequency in and out of the NOFB when Basslink was undergoing a flow reversal.

AEMO calculates the percentage of time that frequency remained inside the 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 Frequency Operating Standard (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 2024, indicating that the system is quite close to nominal frequency most of the time and thus is well positioned to cope with unexpected events. Further detail on credible contingency events in Q2 2024 is available in Appendix A1.

[8] See https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/system-operations/ancillary-services/very-fast-fcas-market-transition.

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

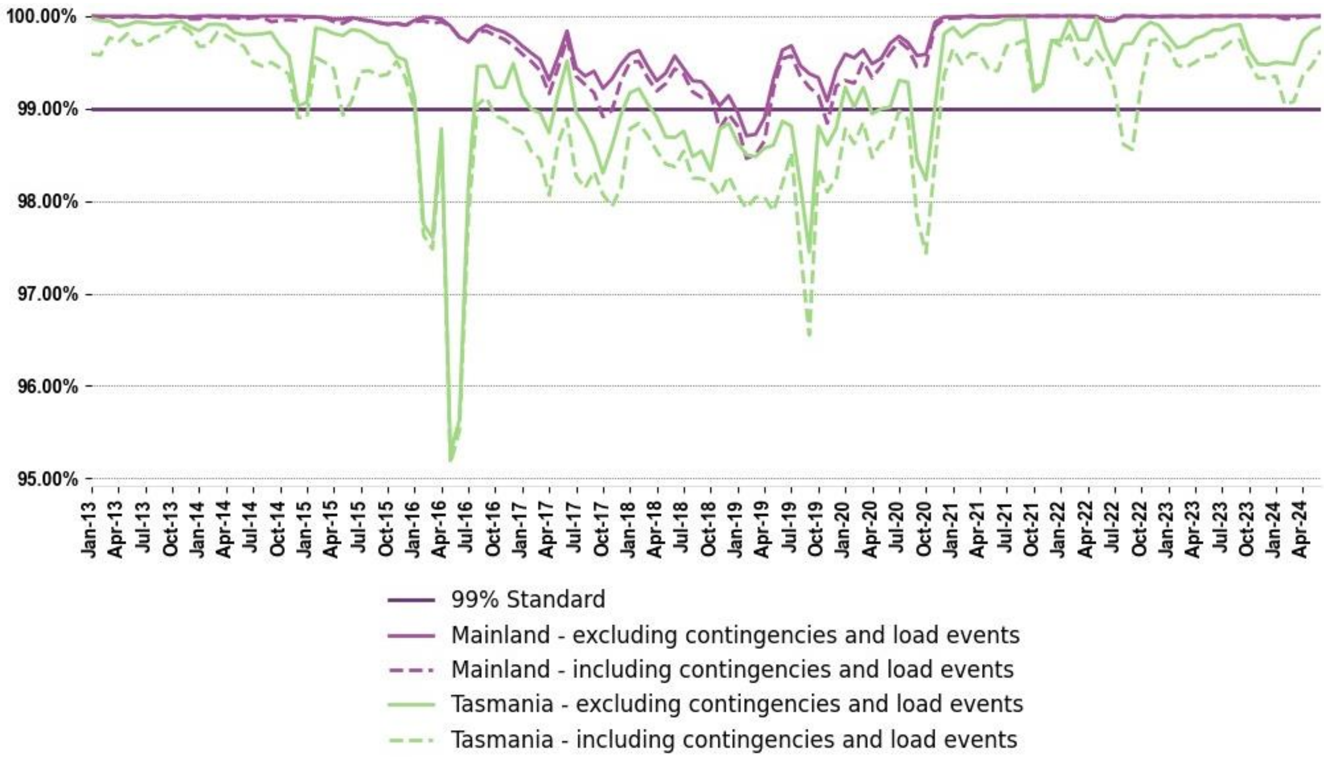


Figure 2 shows the distribution of mainland frequency within the NOFB since 2007.

Figure 2 Monthly mainland frequency distribution since 2007

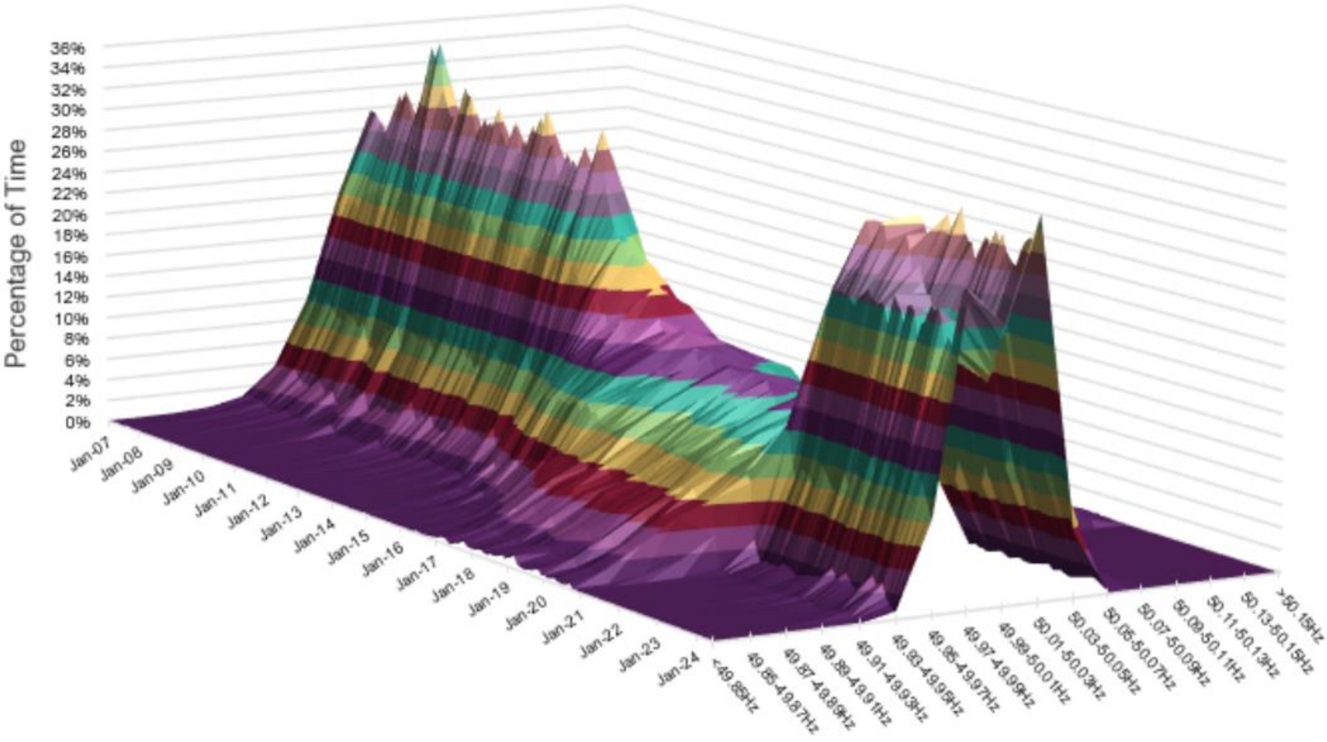
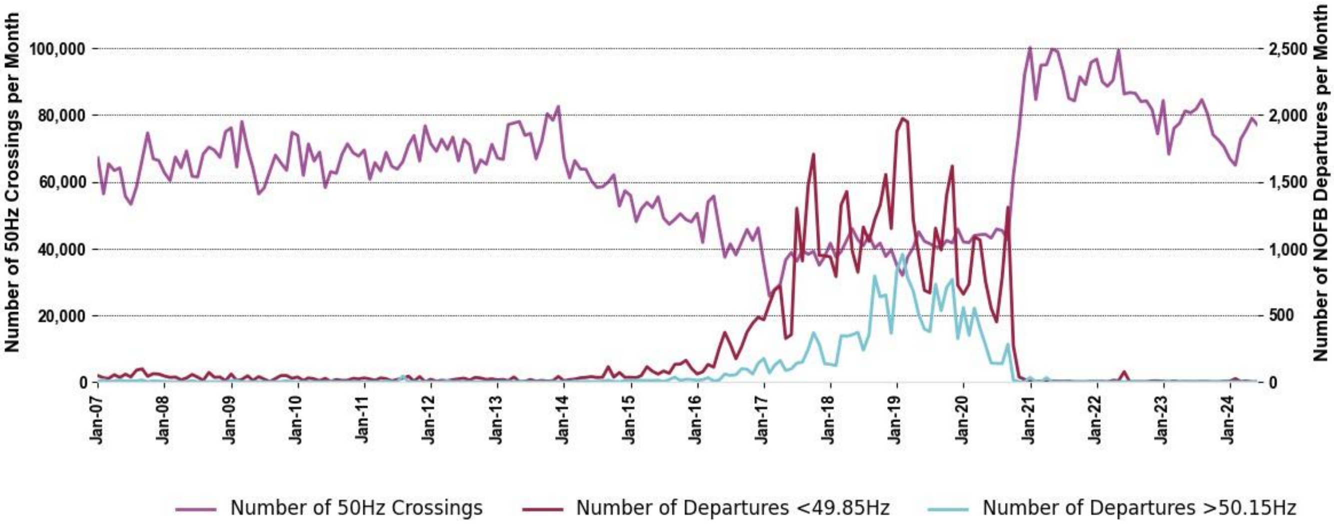


Figure 3 shows the number of times mainland frequency has crossed the nominal 50 hertz (Hz) target and how often frequency has departed the NOFB since 2007.

Figure 3 Monthly mainland frequency crossings since 2007

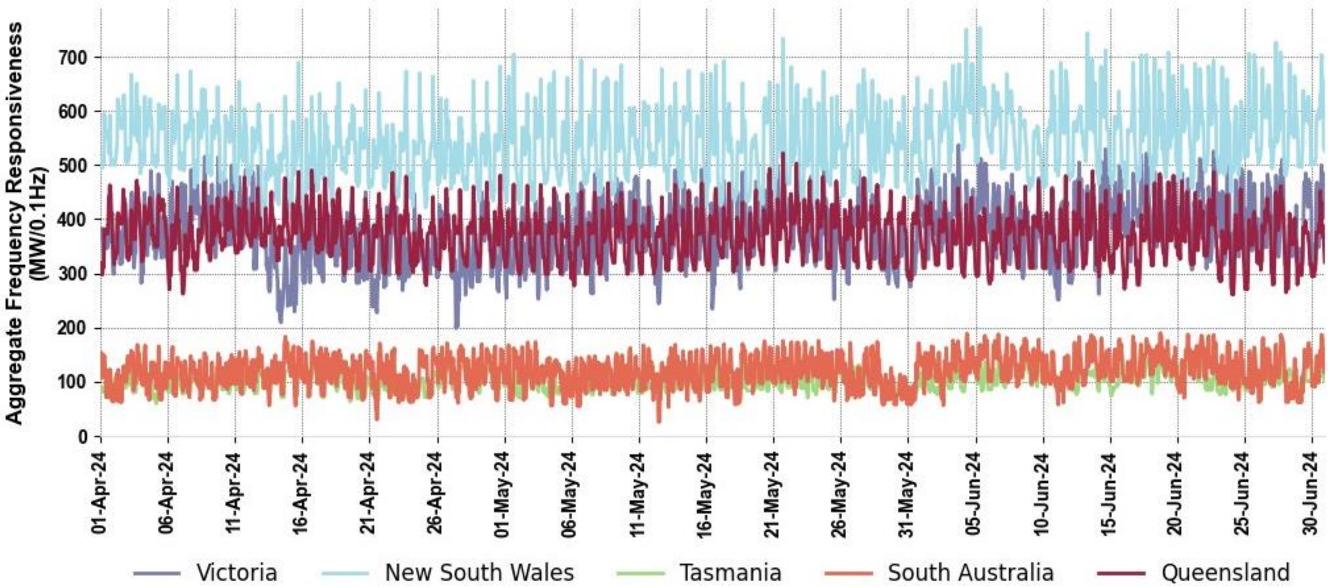


1.3 Aggregate frequency responsiveness

This section reports AEMO's assessment of the level of aggregate frequency responsiveness in the NEM in accordance with 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 in Q2 2024



1.4 Fast frequency response (FFR) reporting obligation

This section reports on the quantity and type of each market ancillary service that AEMO procures to improve power system frequency control outcomes, in accordance with clause 4.8.16(b)(1B) of the NER. A description of each service type and key purpose can be found under Table 3 of the Market Ancillary Services Specification (MASS)[9].

Table 2 below identifies the basis on which quantity of each type of service is determined, including the relationship between volume of market ancillary service and inertia where relevant. For this section, inertia is calculated as the sum of the assumed inertia contributed by generators online in all regions in the NEM.

Table 2 describes the principles used for procuring FCAS during times when the NEM system is intact and without adverse operating conditions. The quantity of FCAS procured may vary significantly for short periods of time due to changing power system needs. Further detailed information on the formulation[10], naming[11] and implementation[12] of FCAS constraints is available on AEMO's website.

Table 2 Market ancillary service quantities and relationship to inertia

Service	Determination of quantity	Relationship of inertia to volume
Raise Very Fast	Highest NEM generation unit output minus load relief (0.5% of NEM demand) multiplied by an inertia-aware factor between 0 and 1, calculated using a minimum of 3 linear equations incorporating Peak Rate of Change of Frequency (RoCoF) Risk. Notes: • Peak RoCoF Risk = 25 x Highest NEM generation unit output / NEM inertia. • Different linear equations are used for different containment bands[13], resulting in more Very Fast Raise (R1) being procured for narrower containment bands. • The volume of R1 dispatched will be capped initially and increased at AEMO's discretion after a review of levels of registered capacity that is committed for participation in each NEM region.	R1 increases in volume as inertia decreases. See Figure 5 below.
Raise Fast	Highest NEM generation unit output minus load relief (0.5% of NEM demand).	No relationship of inertia to volume.
Raise Slow	Highest NEM generation unit output minus load relief (0.5% of NEM demand).	No relationship of inertia to volume.
Raise Delayed	Highest NEM generation unit output minus load relief (30% of 0.5% of NEM demand) minus any additional Raise Regulation enabled as per co-optimisation of delayed and regulation FCAS.	No relationship of inertia to volume.
Raise Regulation	Base amount set to 220 MW based on evidence from system trial plus any additional quantity as per co-optimisation of delayed and regulation FCAS.	No relationship of inertia to volume.
Lower Very Fast	Highest NEM load unit consumption minus load relief (0.5% of NEM demand) multiplied by an inertia-aware factor between 0 and 1, calculated using a minimum of 3 linear equations incorporating Peak RoCoF Risk.	L1 increases in volume as inertia decreases. See Figure 6 below.

[9] See https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/system-operations/ancillary-services/market-ancillary-services-specification-and-fcas-verification-tool.

[10] See https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/congestion-information/2021/constraint-formulation-guidelines.pdf?la=en.

[11] See https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/congestion-information/2016/constraint-naming-guidelines.pdf.

[12] See https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/congestion-information/2016/constraint-implementation-guidelines.pdf.

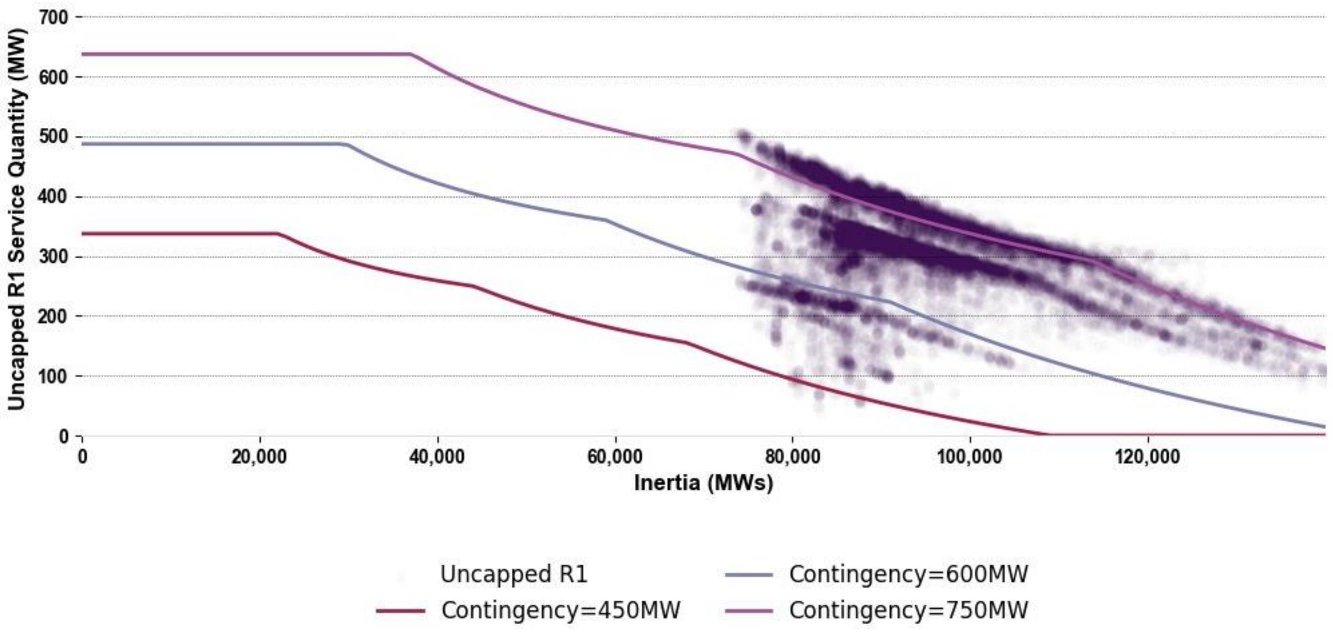
[13] Containment bands are specified under Section A.1 of the FOS.

Service	Determination of quantity	Relationship of inertia to volume
	Notes: • Peak RoCoF Risk = 25 x Highest NEM load unit consumption / NEM inertia. • Different linear equations are used for different containment bands, resulting in more Very Fast Lower (L1) being procured for narrower containment bands. • The volume of L1 dispatched will be capped initially and increased at AEMO's discretion after a review of levels of registered capacity that is committed for participation in each NEM region.	
Lower Fast	Highest NEM load unit consumption minus load relief (0.5% of NEM demand).	No relationship of inertia to volume.
Lower Slow	Highest NEM load unit consumption minus load relief (0.5% of NEM demand).	No relationship of inertia to volume.
Lower Delayed	Highest NEM load unit consumption minus load relief (30% of 0.5% of NEM demand) minus any additional Lower Regulation enabled as per co-optimisation of delayed and regulation FCAS.	No relationship of inertia to volume.
Lower Regulation	Base amount set to 210 MW based on evidence from system trial plus any additional quantity as per co-optimisation of delayed and regulation FCAS.	No relationship of inertia to volume.

Figure 5 and Figure 6 show the relationship of the uncapped quantities of the Very Fast Raise (R1) and Very Fast Lower (L1) services to the level of inertia in the NEM in Q2 2024, and the potential variation due to prevailing contingency size. For the given contingency sizes, it is assumed that load relief is 113 MW, which represents the load relief (0.5%) for an average NEM load quantity of 22,543 MW as observed in Q2 2024.

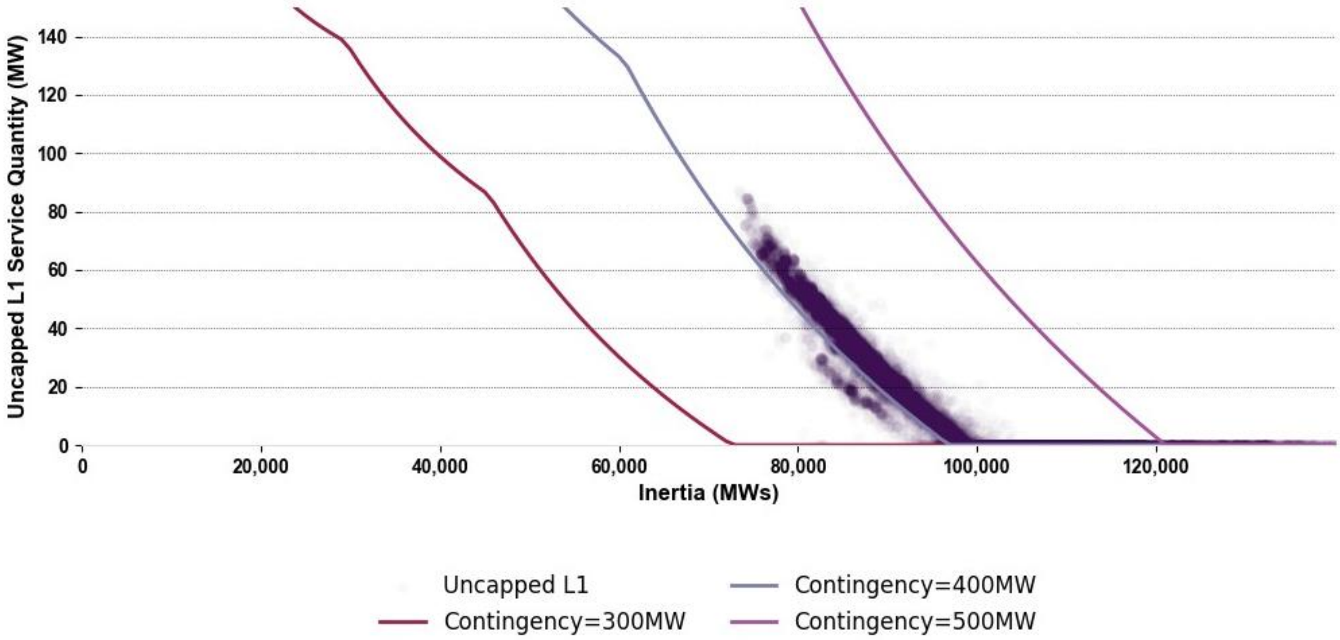
As noted in Section 1.1, AEMO commenced the very fast FCAS markets with a capped system normal requirement and continues to review the levels of VF FCAS participation on a monthly basis to determine whether the capped procurement volumes can be incremented. For this reason, actual procured quantities of VF FCAS were lower than the uncapped quantities shown in Figure 5 and Figure 6 most of the time for the R1 service and occasionally for the L1 service.

Figure 5 Relationship of uncapped R1 service quantities to inertia in Q2 2024



MWs: megawatt seconds

Figure 6 Relationship of uncapped L1 service quantities to inertia in Q2 2024



2 Achievement of the Frequency Operating Standard

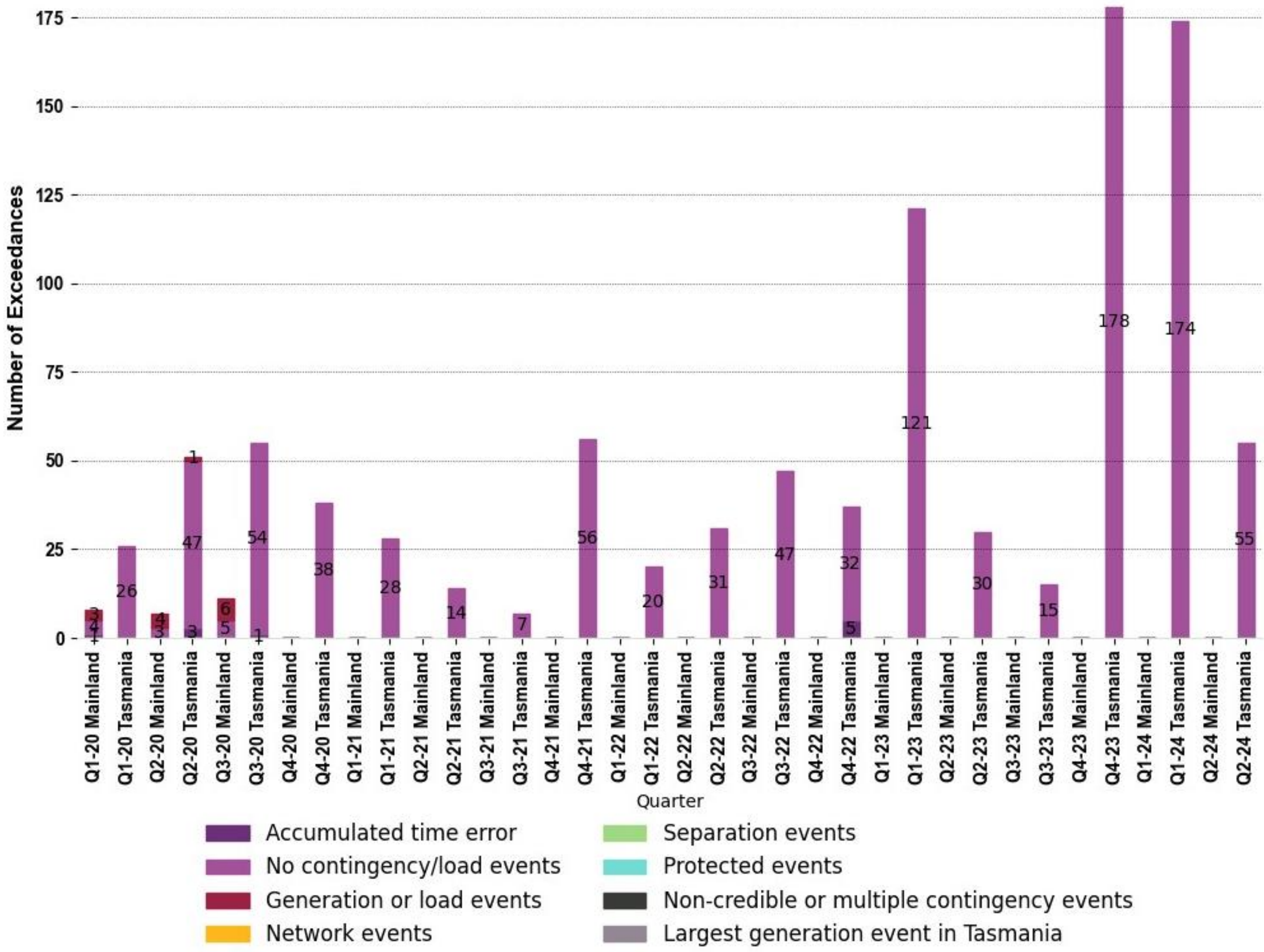
2.1 Overview

AEMO's assessment of the achievement of the requirements of the FOS in Q2 2024 is summarised in Table 3, and further information on the FOS exceedances is in Section 2.2. Figure 7 also shows the number of FOS exceedances since 2020.

Table 3 FOS assessment in the mainland and Tasmania in Q2 2024

Requirement	Mainland	Tasmania	Further commentary
1 – Accumulated time error	Achieved	Achieved	No limits on time error
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 53 times Exceeded 2 times Achieved	 See Section 2.2.1 See Section 2.2.2
3 – Generation or load events • **Contained** • **Recovered within five minutes** • **Less than RoCoF limit**	 Achieved Achieved Achieved	 Achieved Achieved Achieved	 RoCoF Limits: M - ±1 hertz per second (Hz/s) over 500 milliseconds (ms) T - ±3 Hz/s over 250 ms
4 – Network events • **Contained** • **Recovered within five minutes** • **Less than RoCoF limit**	 Achieved Achieved Achieved	 Achieved Achieved Achieved	 RoCoF Limits: M - ±1 Hz/s over 500 ms T - ±3 Hz/s over 250 ms
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 • **Contained** • **Recovered within five minutes** • **Less than RoCoF limit**	 Achieved Achieved Achieved	 Achieved Achieved Achieved	 RoCoF Limits: M & T - ±3 Hz/s over 300 ms
8 – Largest generation event in Tasmania	Not applicable	Achieved	

Figure 7 FOS exceedances in the mainland and Tasmania since 2020



2.2 Operation during identified FOS exceedances

This section provides further detail on the exceedances of the FOS listed in Table 3.

2.2.1 Frequency excursions without a contingency event outside the NOFEB

Table 4 shows frequency excursions in Q2 2024 outside the applicable normal operating frequency excursion band (NOFEB, 49.75 Hz to 50.25 Hz) where an associated contingency event has not been identified.

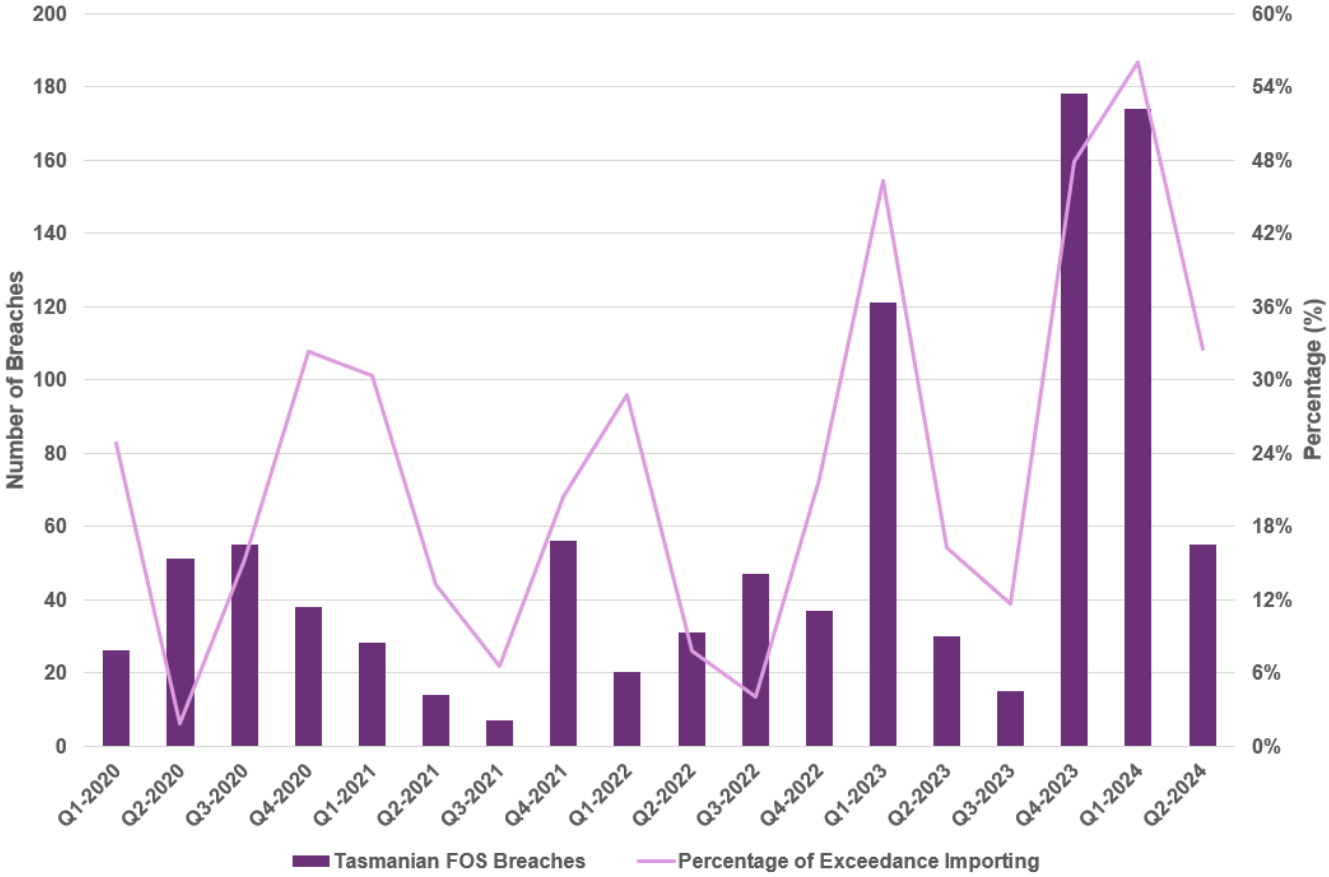
Table 4 Number of frequency excursions without identified contingency outside the NOFEB in Q2 2024

Event	Low/high/both frequency event	Number of events Mainland	Number of events Tasmania
No contingency or load event noted	LOW	0	52
	HIGH	0	0
	BOTH	0	1

Tasmania had a substantial number of events where frequency departed the NOFEB without an associated contingency event, totalling 53 events in Q2 2024.

The reduced number of frequency excursions outside the NOFEB in Tasmania in Q2 2024 relative to Q1 2024 is due to an observed decrease in the percentage of time where Basslink was operating close to its maximum import capacity. Figure 8 suggests that Tasmania's frequency performance is significantly impacted during periods when Basslink's frequency controller cannot modulate its output higher than its maximum import limit when importing energy to aid frequency control. These conditions were the main contributing factor to the 53 excursions observed during Q2 2024.

Figure 8 Tasmanian FOS breaches and percentage of time where import to Tasmania exceeded 400 MW since 2020



2.2.2 Frequency excursions without a contingency event outside the NOFB for more than 5 minutes

Table 5 shows that there were two frequency excursions in Q2 2024 outside the applicable NOFB (49.85 Hz to 50.15 Hz) for more than five minutes, where an associated contingency event has not been identified.

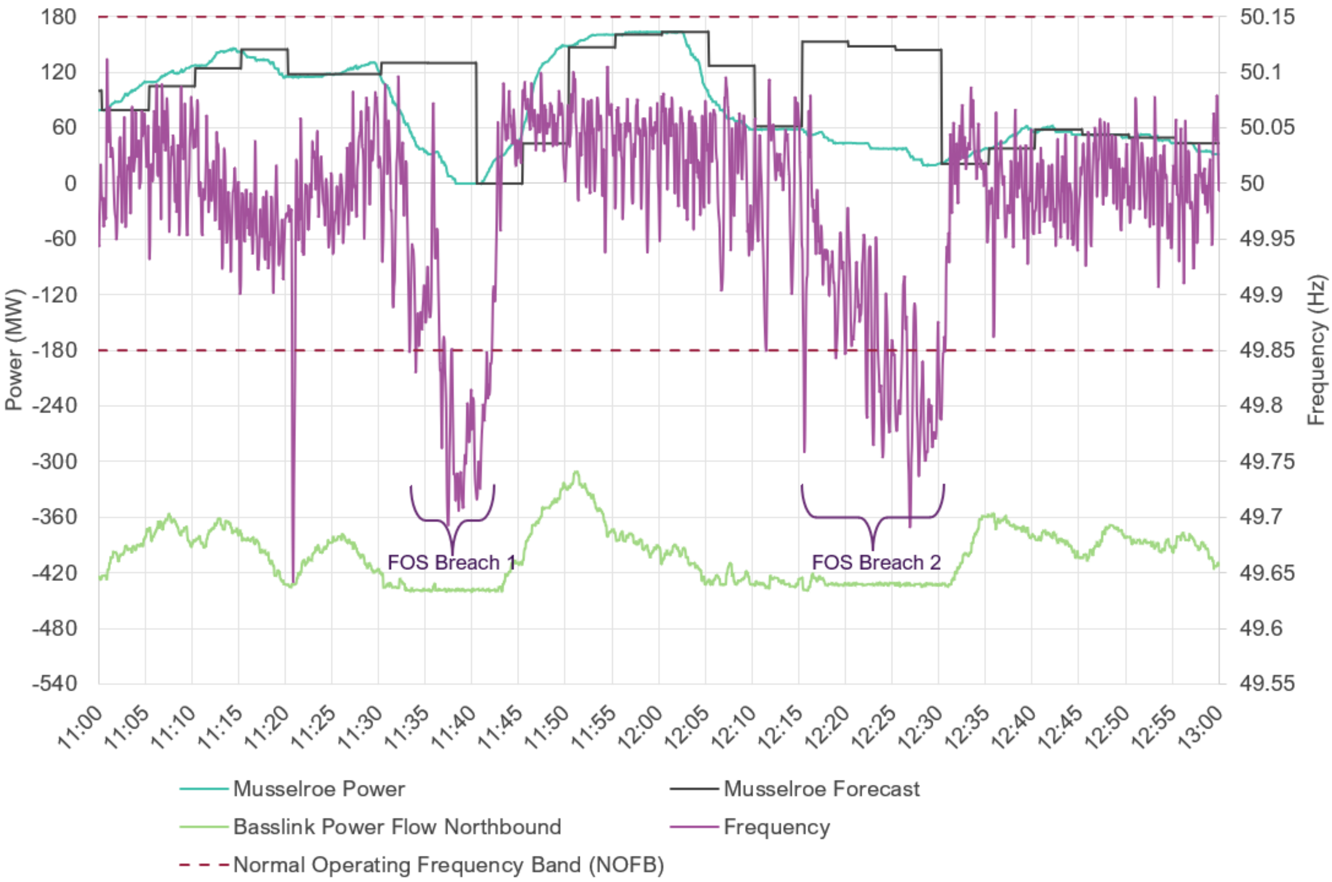
Table 5 Number of frequency excursions without identified contingency outside the NOFB for more than five minutes in Q2 2024

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

Figure 9 shows the two Tasmanian FOS exceedances identified in Table 5. Both occurred on 31 May 2024 when Musselroe Wind Farm generated less than its energy forecast for successive dispatch intervals due to intermittent high wind cut-outs.

Reduction in generation due to high wind cut-outs is challenging to forecast with accuracy when wind conditions fluctuate above and below the cut-out speed for extended periods of time. Tasmanian frequency cycled in and out of the NOFB for more than five minutes on both occasions and AEMO sums the cumulative time outside the NOFB in these circumstances. For clarity, frequency did not remain outside the NOFB for more than five minutes in any single excursion. AEMO has operational procedures in place to respond to unexpected variations in wind output resulting in high wind cut-out, and will continue to review events to inform future procedural developments.

Figure 9 Tasmanian frequency excursion on 31 May 2024



3 Rate of change of frequency

AEMO implemented a revised method to calculate RoCoF from Q4 2022. The new calculation of RoCoF by AEMO's Phasor Measurement Unit (PMU) system is outlined in Appendix A2.3. Table 6 and Table 7 shows the maximum RoCoF recorded in the mainland and Tasmania in each month in Q2 2024, and any other RoCoF event that exceeds the standard frequency ramp rate for the mainland (as specified in the MASS) of 0.125 hertz per second (Hz/s). No events exceeded the FOS limits for RoCoF in the mainland or Tasmania in Q2 2024.

Table 6 RoCoF during frequency events in the mainland in Q2 2024

Month	RoCoF (Hz/s)	Associated event	Event time
Apr-24	-0.16	Trip of Eraring Units 1 and 2 at 502 MW and 517 MW respectively	3/04/2024 13:21
May-24	0.08	Trip of Alcoa Portland Unit 2 at 284 MW	3/05/2024 7:10
Jun-24	0.07	Trip of Tomago Unit 2 at 304 MW	11/06/2024 7:00

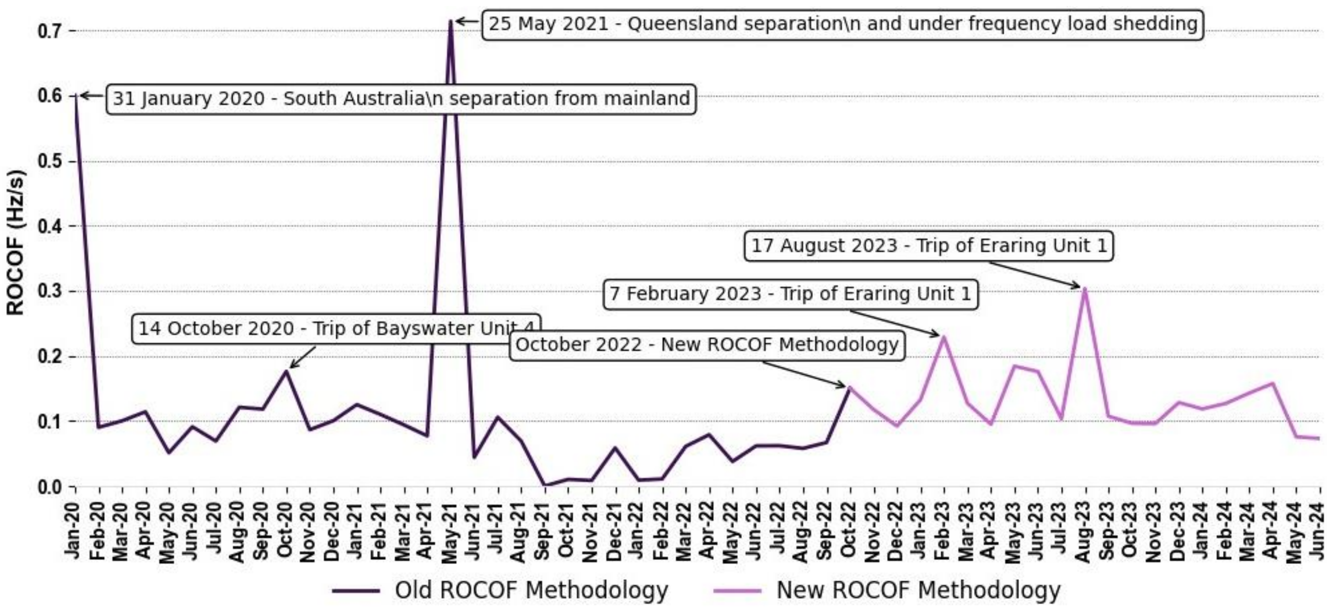
Table 7 RoCoF during frequency events in Tasmania in Q2 2024

Month	RoCoF (Hz/s)	Associated event	Event time
Apr-24	-1.43	Trip of Farrell – Sheffield No. 2 220 kilovolts (kV) line causing 532 MW of load to be lost	12/04/2024 10:49
May-24	-1.12	Unplanned outage of Loy Yang PS – Basslink Loy Yang 500 kV line causing 437 MW of load to be lost	21/05/2024 02:35
Jun-24	-0.44	Basslink flow reversal and trip of Gordon Unit 1 at 113 MW	24/06/2024 16:32

Note: Estimates of RoCoF may vary depending on data source, sampling window and calculation method. See Appendix A2.3 for further detail on the methodology used to calculate RoCoF in this report.

Figure 10 shows the maximum RoCoF recorded in the mainland NEM since Q1 2020.

Figure 10 Monthly maximum RoCoF recorded in any mainland region since 2020



Note: 31 January 2020 RoCoF as measured in South Australia and 25 May 2021 RoCoF as measured in Queensland. New ROCOF calculation methodology used as of October 2022.

Figure 11 shows the estimated level of inertia at five-minute intervals over Q2 2024 in the mainland, and Figure 12 shows the level for Tasmania. Figure 13 provides a distribution chart for the mainland and Figure 14 does the same for Tasmania. For the purposes of this report, inertia in the mainland and Tasmania at a point in time was calculated as the sum of the assumed inertia contributed by registered generators online in that region at that time.

Figure 11 Time series mainland inertia in Q2 2024

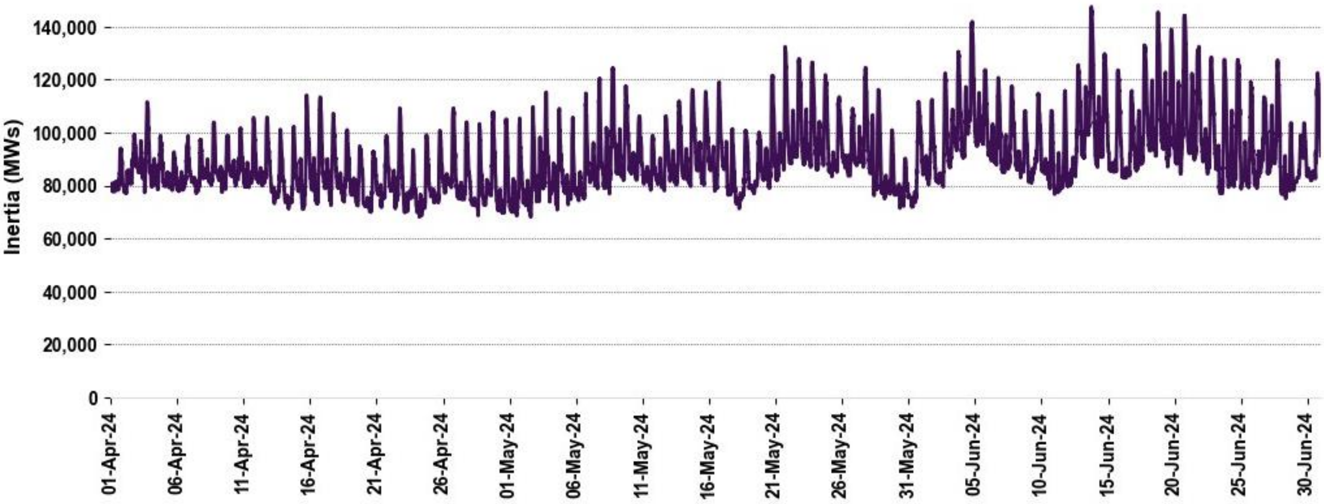


Figure 12 Time series Tasmania inertia in Q2 2024

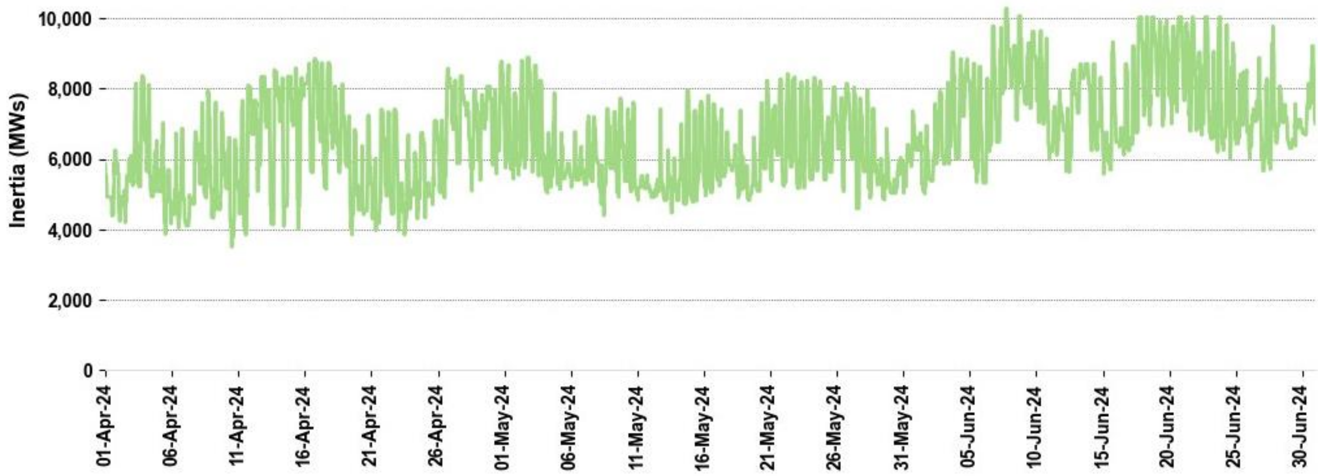


Figure 13 Distribution of mainland inertia in Q2 2024

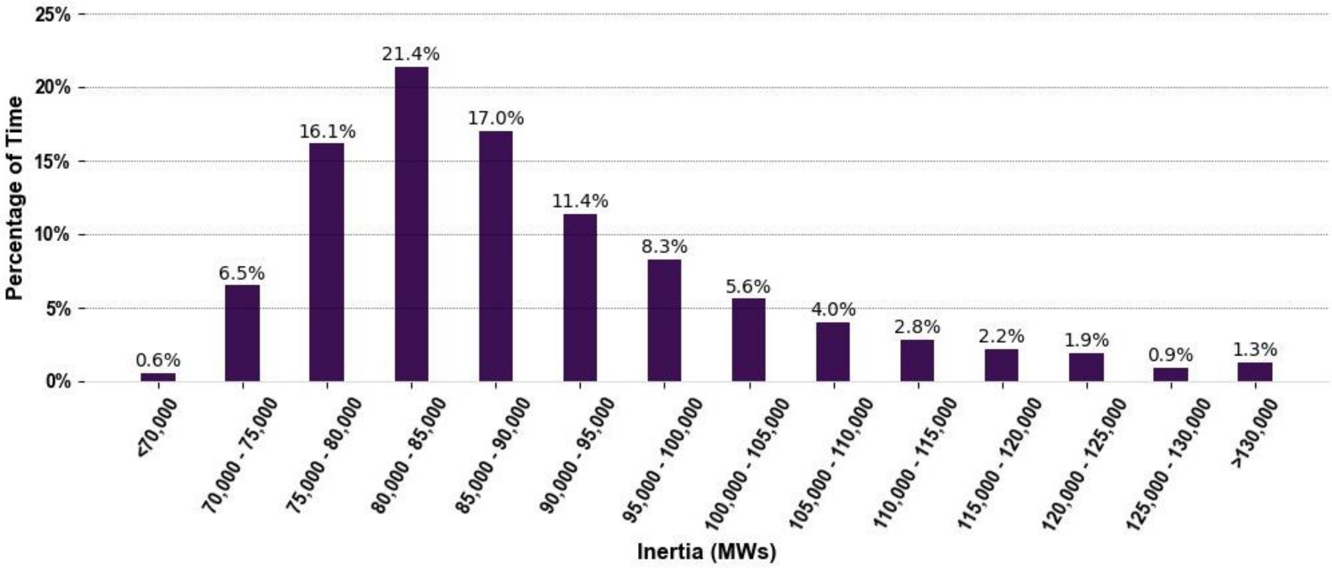
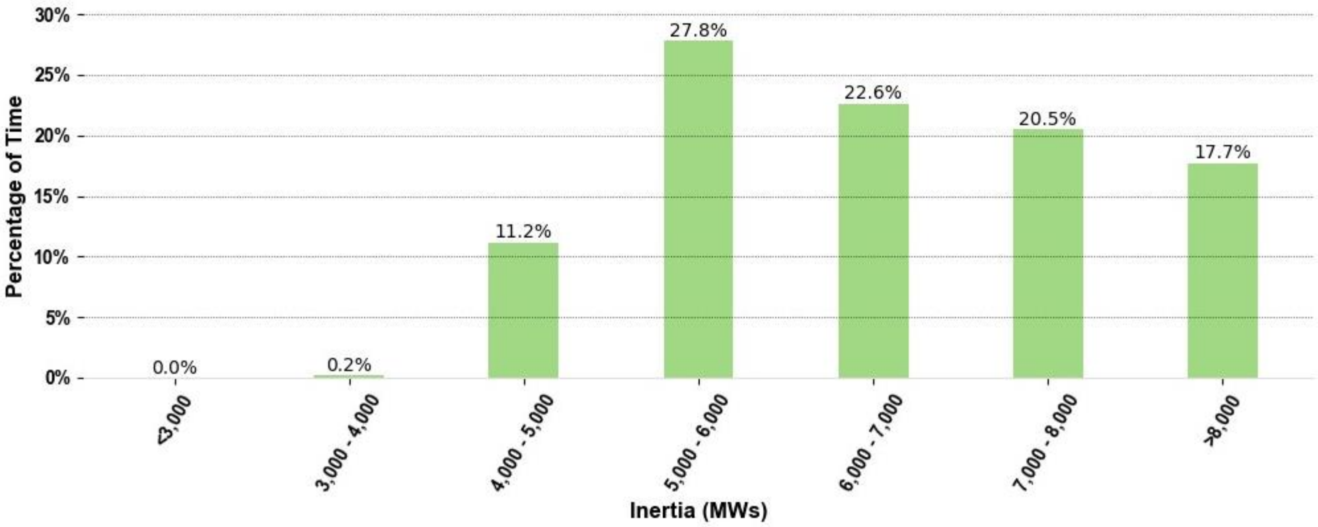


Figure 14 Distribution of Tasmania inertia in Q2 2024



4 Area control error

The calculation of ACE methodology by AEMO's AGC system is outlined in Appendix A2.4. Figure 15 and Figure 16 show the minimum and maximum ACE per half-hourly trading interval in Q2 2024 in the mainland NEM and Tasmania, respectively.

Figure 15 Minimum and maximum ACE per half-hour in mainland NEM in Q2 2024

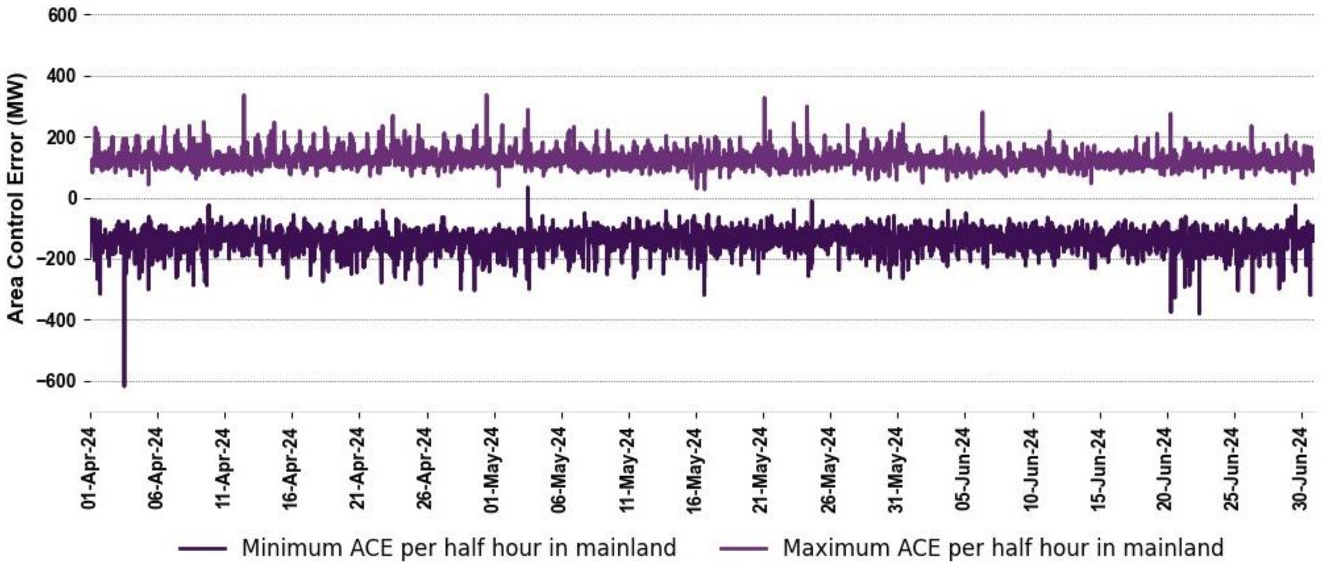
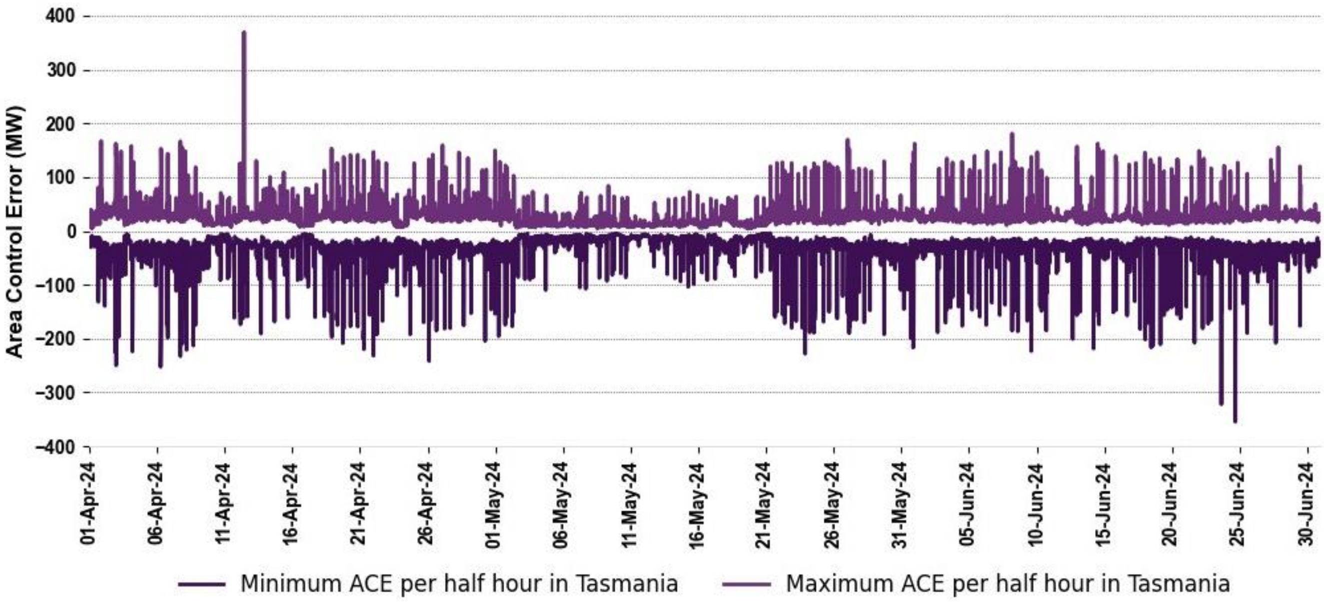


Figure 16 Minimum and maximum ACE per half-hour in Tasmania in Q2 2024



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[14].

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 2024 relating to frequency exceeding the OFTB.

AEMO notes the following events which caused the frequency to go outside the NOFB:

- On 3 April at 1321 hrs, the minimum mainland frequency reached 49.78 Hz due to a trip of Eraring Units 1 and 2. The frequency recovered within the NOFB after 16.7 seconds and an analysis was conducted for all participants enabled for Very Fast Raise (R1) and Fast Raise (R6)
  - AEMO has confirmed an adequate response from 39 providers and is still investigating the performance of one FCAS facility. Additionally, AEMO identified two providers who failed to meet their FCAS requirements, and causes of these issues are listed below.
  - Three sites from a facility did not provide any raise FCAS response as they were not armed at the time of the event. Additionally, forecast errors from two other sites contributed further to the under delivery of raise FCAS.
  - A facility did not provide any raise FCAS response due to maintenance activities on site.
  - The relevant participants have worked with AEMO to correct the non-compliances.
- On 23 June at 1531 hrs, the minimum frequency in Tasmania reached 48.73 Hz due to a trip of Gordon Unit 1. The frequency recovered within the NOFB after 12 seconds and an analysis was conducted for all participants enabled for R1 and R6 in Tasmania. The response of FCAS providers during this incident is being investigated.
- At the time of publishing the Q1 2024 Frequency Monitoring report, AEMO was still investigating the performance of one FCAS provider from the 18 January 2024 frequency event and six providers from the 13 February 2024 frequency event.
  - One additional non-compliance was identified following the publication of the Q1 2024 Frequency Monitoring report that was under investigation in both the 18 January 2024 event and the 13 February 2024 event; during both events, the facility's droop curve was scaled based on the available power and number of inverters online, however, the FCAS availability of the facility was not being updated in the bids. This led to an under delivery of the raise services. The relevant participant has worked with AEMO to correct the non-compliance.

No further issues were identified with the response of the remaining five providers for the 13 February 2024 event.

[14] 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 since 2020 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 8-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 eight seconds.
- Network events, separation events, non-credible events, multiple contingency events, and protected events.

Table 8 and Table 9 demonstrate that both generation and load events in Q2 2024 tended to have an average frequency nadir nearer to 50 Hz and average recovery time much shorter than seen in 2020, which is a strong indicator of better frequency response following contingency events.

Table 10 is a list of contingencies from Q2 2024 meeting the criteria noted above.

Table 8 Credible generation events since 2020

Quarter	Number of events	Average contingency size (MW)	Average frequency nadir (Hz)	Average recovery time (s)
Q2 2024	11	274	49.92	0
Q1 2024	20	379	49.88	4
2023	56	364	49.88	4
2022	76	347	49.88	5
2021	72	365	49.86	9
2020	96	362	49.80	93

Table 9 Credible load events since 2020

Quarter	Number of events	Average contingency size (MW)	Average frequency nadir (Hz)	Average recovery time (s)
Q2 2024	16	291	50.07	0
Q1 2024	18	292	50.09	0
2023	76	278	50.08	0
2022	102	278	50.09	0
2021	58	261	50.09	N/A
2020	50	275	50.15	20

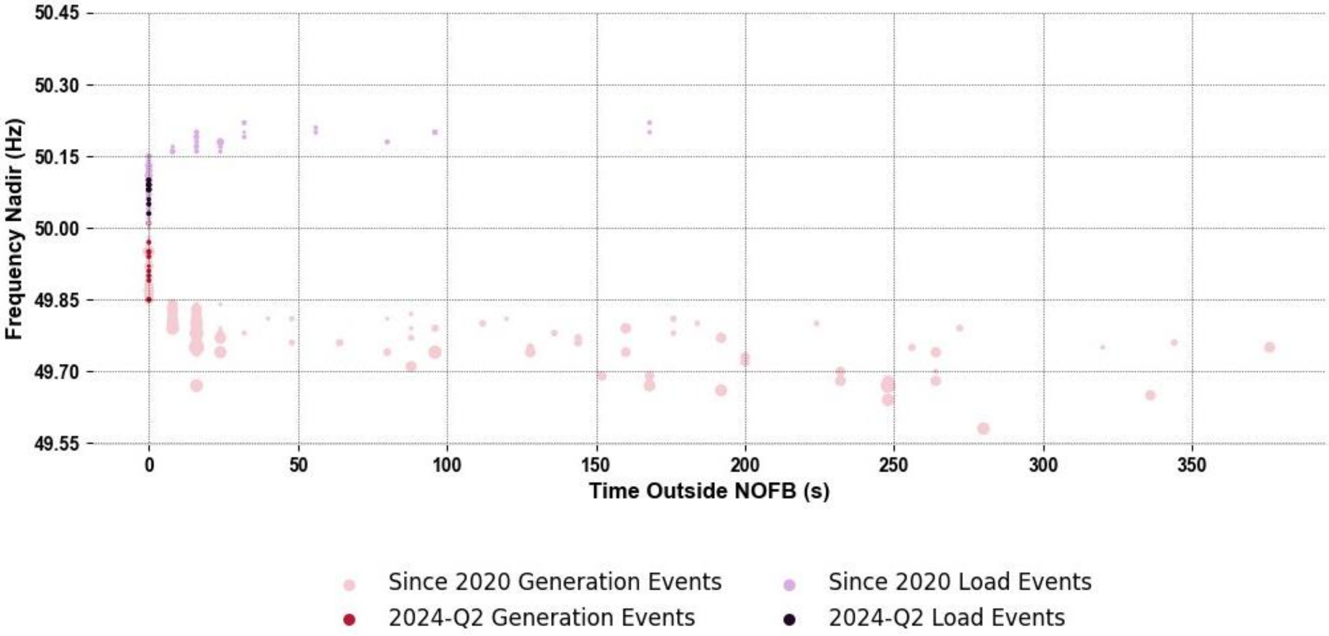
Table 10 Credible generation and load events in Q2 2024

Event time	Unit	Contingency size (MW)	Frequency nadir/peak (Hz)	Recovery to NOFB (s)	FOS compliant?
4/04/2024 10:30	Alcoa Portland Unit 2	290	50.1	0	YES
7/04/2024 9:53	Kogan Creek Power Station	290	49.9	0	YES
22/04/2024 18:00	Alcoa Portland Unit 2	287	50.08	0	YES
29/04/2024 17:45	Alcoa Portland Unit 2	283	50.09	0	YES
3/05/2024 7:10	Alcoa Portland Unit 2	284	50.08	0	YES
6/05/2024 13:52	Rye Park Renewable Energy	285	49.94	0	YES
6/05/2024 21:49	Rye Park Renewable Energy	302	50.01	0	YES
6/05/2024 23:21	Rye Park Renewable Energy	285	49.97	0	YES
8/05/2024 1:28	Vales Point "B" Power Station Unit 5	245	49.91	0	YES
11/05/2024 9:05	Rye Park Renewable Energy	323	49.95	0	YES
11/05/2024 10:06	Rye Park Renewable Energy	223	49.91	0	YES
23/05/2024 6:59	Alcoa Portland Unit 2	288	50.08	0	YES
24/05/2024 7:00	Alcoa Portland Unit 2	294	50.1	0	YES
27/05/2024 7:14	Alcoa Portland Unit 2	290	50.09	0	YES
28/05/2024 7:14	Alcoa Portland Unit 2	295	50.08	0	YES
31/05/2024 18:48	Gladstone Power Station Unit 1	240	49.91	0	YES
6/06/2024 7:44	Alcoa Portland Unit 2	299	50.05	0	YES
10/06/2024 11:32	Millmerran Power Plant Unit 2	214	49.92	0	YES
11/06/2024 7:00	Tomago 2	304	50.08	0	YES
17/06/2024 18:05	Alcoa Portland Unit 2	261	50.06	0	YES
19/06/2024 6:50	Alcoa Portland Unit 2	303	50.09	0	YES
20/06/2024 7:23	Alcoa Portland Unit 2	302	50.03	0	YES
20/06/2024 7:31	Kogan Creek Power Station	326	49.85	0	YES
26/06/2024 7:20	Alcoa Portland Unit 2	299	50.09	0	YES
28/06/2024 8:50	Callide Power Station B Unit 2	279	49.89	0	YES
28/06/2024 21:57	Alcoa Portland Unit 2	291	50.09	0	YES

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

Figure 17 displays each event from Table 10 to illustrate the distribution of frequency outcomes following credible contingency events in Q2 2024, in comparison to events since 2020.

Figure 17 Frequency outcomes of identified credible generation and load events in Q2 2024, and compared to events since 2020



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

A2. Methodology

A2.1 Guidelines for assessing frequency events

The purpose of identifying frequency events is to review the state of frequency control in the NEM and the achievement or otherwise of the FOS throughout the reporting period under evaluation. The FOS categorises power system contingency events and the limits within which system frequency must remain during these events.

AEMO's method of assessing the achievement of the FOS is provided below:

- AEMO reviews 4-second frequency data every week and quarter to identify all times when system frequency was outside the NOFB in the mainland or Tasmania.
- For each identified event, the following key event statistics are recorded:
  - Frequency event location (mainland or Tasmania).
    - Location of data recorder.
  - Frequency event start time.
    - Time of last measurement of system frequency inside the NOFB.
  - Frequency event duration.
    - Total cumulative time system frequency was outside the NOFB.
    - The end time of an event is the last measurement before system frequency returns to the NOFB. AEMO will use its discretion to determine the end time of a frequency event when there are multiple excursions, but typically will select the last measurement system frequency returns to the NOFB and stays within the NOFB for at least five minutes. Detailed worked examples are available below.
  - Frequency event deviation magnitude in Hz.
    - Maximum and minimum system frequency during frequency event.
  - If relevant, frequency event RoCoF in Hz/s.
    - The highest RoCoF observed during the event, using a rolling window of 500 milliseconds (ms) in the mainland or 250 ms in Tasmania.
    - AEMO only calculates the estimated RoCoF using AEMO/ transmission network system provider (TNSP) PMU data for the most significant frequency events in the reporting period, as defined by size of generation or load loss.
- Each frequency event is categorised as per the FOS definitions. When required, AEMO will use its discretion to make the most suitable assessment of each frequency event.
  - AEMO reviews large generators and major loads for evidence of 50 MW change in output or consumption over 30 seconds in the mainland, or 20 MW in Tasmania, at the time of the start of the frequency event, in

accordance with the FOS definitions. If a generator or load is identified based on its change in active power which caused the frequency, then the event is categorised as a generation event or load event.

  – If the frequency event was due to a network event, separation event, protected event, non-credible event or multiple contingency event, then the event is noted in market notices or other logged records and is categorised as such in the quarterly Frequency Monitoring reports.
  – AEMO considers frequency events that remain uncategorised to meet the FOS definition of 'no continency or load event'.

- AEMO assesses whether each frequency event was within the limits required by the FOS for the event category.

The following worked examples illustrate how AEMO may determine the end of a frequency event in various cases.

Figure 18 is a case of a single NOFB excursion. The frequency event start time is determined as the last measurement of system frequency inside the NOFB, and the frequency event end time is determined as the first measurement of system frequency back within the NOFB.

Figure 18 Frequency event with a single NOFB excursion – worked example

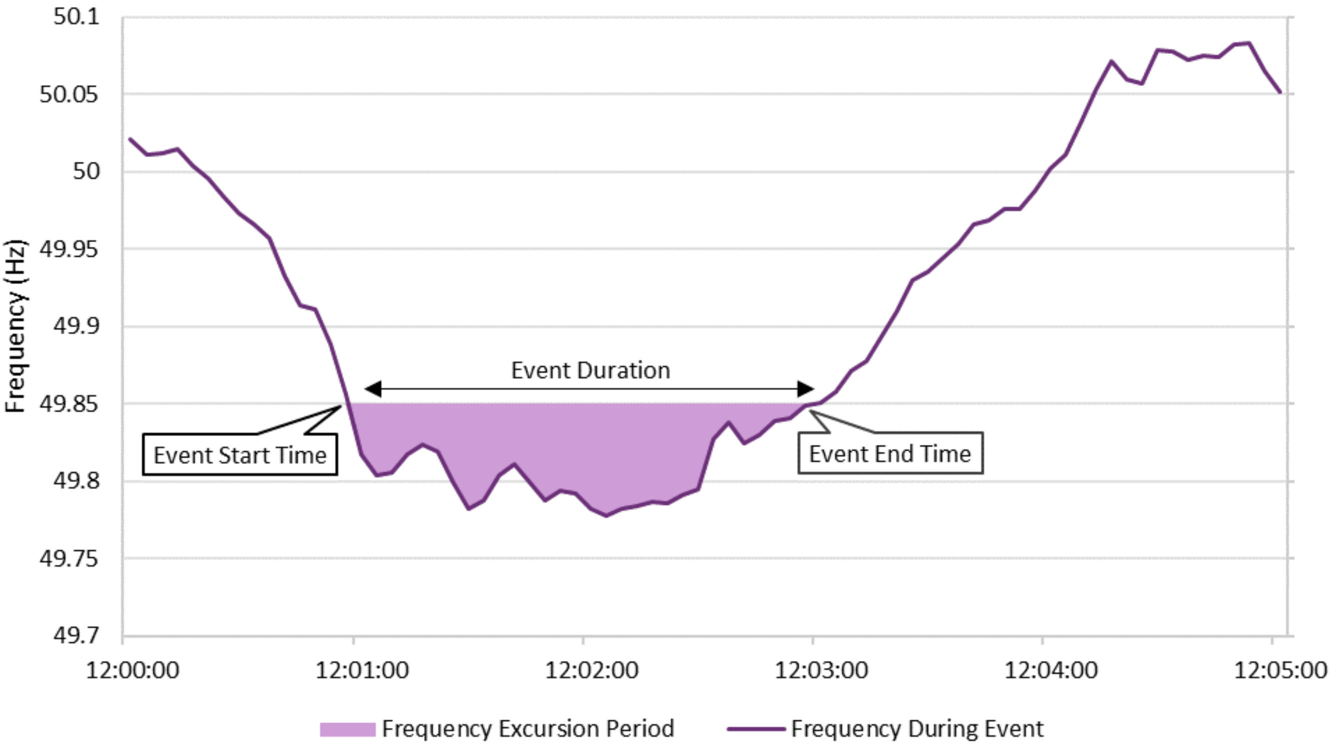
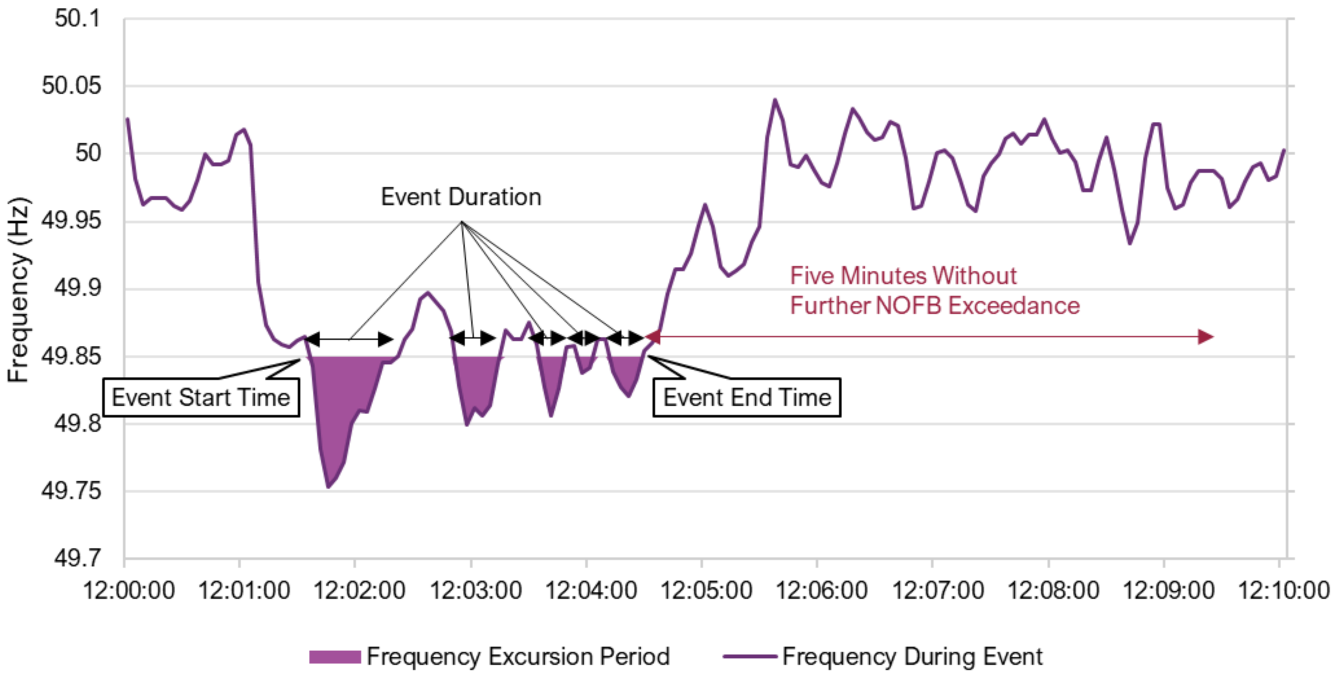


Figure 19 is a case of multiple NOFB excursion in a short space of time. The frequency event start time is determined as before, and the frequency event end time is determined as the last measurement before system frequency returns to the NOFB and stays within the NOFB for at least five minutes.

Figure 19 Frequency event with multiple NOFB excursions – worked example



A2.2 Aggregate frequency responsiveness methodology

Estimated available aggregate frequency responsiveness in this quarterly report was 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 was estimated in MW/0.1 Hz 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 was estimated for each hour interval in MW/0.1 Hz 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 included:

- Unit frequency response was calculated using the *Maximum Capacity* from AEMO registration information.
- Units were 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 were not included in the calculation.
- The calculation ignored 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, were not modelled.
- Primary Frequency Response Requirements (PFRR) variations agreed with AEMO were not modelled in the calculation.
- Frequency response was not included from distributed energy resources, nor from units which provide FCAS but not energy.
- Load relief was not included.

A2.3 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.

RoCoF as reported in this report has been calculated using two different methods for the periods from Q1 2020 to Q3 2022 and from Q4 2022 onwards.

Mainland frequency data used for calculation were taken from a PMU in Sydney, while Tasmanian data were taken from a PMU in Tungatinah.

Method 1: From Q1 2020 to Q3 2022

This RoCoF methodology used snapshots of measured frequency from the AEMO/TNSP PMU system at 1-second intervals. This is a higher resolution than was available from the Global Positioning System (GPS) clock system and was therefore more appropriate for assessing RoCoF.

For the purposes of frequency monitoring reports:

- RoCoF was 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 was not available. RoCoF assessment was not attempted for periods longer than two seconds without data.
- The maximum RoCoF recorded between five seconds prior and 30 seconds after each frequency event was the RoCoF associated with that event.

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

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

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

where:

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

Method 2: From Q4 2022 onwards

This RoCoF methodology uses a rolling 500 ms window of frequency, measured at a sampling rate of 20 ms from the AEMO/TNSP PMU system, to calculate the change in frequency over each 500 ms interval. This value is then doubled to convert to Hz/s. For the purposes of this report, the estimation of RoCoF in the 500 ms window with greatest change in frequency recorded between five seconds prior and 30 seconds after each frequency event, with t=0s defined as being the time when frequency exits the NOFB, is the RoCoF associated with that event.

$$\boldsymbol{If}\ 20ms\ data\ available\ \boldsymbol{then}\ RoCoF\ _t = MAX\left(ABS\left(\frac{f_{t+250ms}-f_{t-250ms}}{t_{t+250ms}-t_{t-250ms}}\right)\right)\ \forall\ t$$

where:

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

A2.4 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.

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

[15] See https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/ancillary_services/regulation-fcas-contribution-factors-procedure-final.pdf?la=en.

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.