Frequency Monitoring – Quarter 1 2024

May 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 January to March 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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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 the Appendix 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 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.

Abbreviations

Abbreviation	Full term
ACE	Area Control Error
AER	Australian Energy Regulator
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
GW	Gigawatts
GWh	gigawatt hours
Hz	Hertz
Hz/s	hertz per second
L1	Very Fast Lower
MASS	Market Ancillary Services Specification
ms	Milliseconds
MW	Megawatts
MWs	megawatt seconds
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	Seconds
SCADA	supervisory control and data acquisition
TNSP	transmission network service provider
VRE	variable renewable energy
VPP	Virtual Power Plant
VF	Very Fast

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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:

- The Very Fast (VF) frequency control ancillary services (FCAS) raise and lower markets each commenced operation on 9 October 2023 with a global National Electricity Market (NEM) system normal requirement that is set at 325 megawatts (MW) for the VF Raise service and 200 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[3].
- The Australian Energy Market Commission (AEMC) has published the final rule[4] clarifying the mandatory primary frequency response (PFR) obligations for bidirectional plants. As such, AEMO is investigating options to update the PFR requirements document before Schedule 1 of this rule commences operation on 3 June 2024. Furthermore, AEMO continues to implement the mandatory PFR requirements that were introduced into the National Electricity Rules (NER) in 2020[5] and made enduring in 2022. Implementation reports are on AEMO's website[6], 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.
- The Reliability Panel completed a review of the Frequency Operating Standard (FOS), into which AEMO provided technical advice[7]. Key changes in the new FOS, which took effect from 9 October 2023, include:
  - Revised settings for normal system operation, including an explicit target frequency of 50 hertz (Hz).
  - Requirements for the rate of change of frequency (RoCoF) to be limited during contingency events.
  - Removal of limits on accumulated time error.
- In response to observed slow oscillations in Tasmanian frequency during periods when Basslink is out of operation, AEMO has reviewed the causes and impacts of the oscillations to determine if tuning of Automatic Generation Control (AGC) for the Tasmanian region or other measures are required. Subsequently, the area control gains for Tasmania were lowered as some units enabled in the regulation FCAS markets were responding in the same direction as the oscillations after receiving AGC signals. AEMO will continue to monitor frequency performance in Tasmania.

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

[4] See https://www.aemc.gov.au/rule-changes/clarifying-mandatory-primary-frequency-response-obligations-bidirectional-plant.

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

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

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

1.2 Impact of frequency control actions

The mainland frequency performance observed over the quarter from 1 January 2024 to 31 March 2024 (Q1 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 Q1 2024.

Table 1 Key frequency statistics from the mainland and Tasmania in Q1 2024

	Mainland		Tasmania	
	Minimum	Maximum	Minimum	Maximum
Frequency (Hz)	49.7	50.1	49.1	50.7
Time error (seconds [s])[A]	-23.52	11.99	-20	19.22
Longest frequency event duration (s)[B]	560		1380	

A. AEMO will continue to report time error, but there are no longer formal limits on accumulated time error in the FOS from 9 October 2023. For clarity, AEMO is reporting on the 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 13 February 2024 due to a non-credible event that occurred in Victoria. Further detail on the event is available in Section 5, and associated Preliminary Power System Incident Report[8]. For noting, AEMO will publish a reviewable operating incident report in late 2024 related to the incident involving an electrical island formed following a non-credible event at 1543 hrs on 13 February. The electrical island included the network between Jeeralang and Morwell, and generators Jeeralang power station A (JLPS A), Jeeralang power station B (JLPS B) and the Hazelwood battery energy storage system (HBESS).

As indicated in Table 1, time error increases were observed in Q1 that exceeded than historical FOS requirement of limiting accumulated time error to +/-15s. Whilst the historical performance requirement is no longer part of the FOS, time error provides a useful indication of potential unintended factors that may contribute to supply and demand imbalances. In monitoring the time error performance in Q1, AEMO identified factors contributing to supply-demand mismatches that could be corrected. Further detail is available in the associated scheduling error report[9] on 21 March 2024.

The raise regulation requirement was increased from 220 MW to 450 MW at 1200 hrs on 13 February 2024 in response to increased time error. This increase was used as a precautionary measure while AEMO investigated the cause of time error accumulation. For reference, AEMO's market notice 114561[10] was published at 1203 hrs.

[8] At the time of publication of this report, AEMO had published a Preliminary Power System Incident Report into the events of 13 February 2024 and was in the process of preparing a final report, see https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-events-and-reports/power-system-operating-incident-reports

[9] See incident number 60 https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/market_event_reports/scheduling-error-declaration.xlsx?la=en

[10] See https://www.aemo.com.au/market-notices?marketNoticeQuery=114561&marketNoticeFacets=

In addition to measures already taken in Q1, further work is intended to improve the diagnosis tools used to identify the cause of time error accumulation. AEMO will provide more information on this work, and the associated factors contributing to supply-demand mismatches as part of upcoming Ancillary Services Technical Advisory Group Meeting, and in subsequent Frequency Monitoring reports.

The frequency event of longest duration in Tasmania occurred on 11 January 2024, due to a period of repeated cycling of Tasmanian frequency in and out of the normal operating frequency band (NOFB) when Basslink was at its import limit. Further detail on the event is available in Section 2.2.2.

For clarity, AEMO considers frequency excursions outside the NOFB within a short space of time to be related and sums the cumulative time until the end of the event in these cases. AEMO defines the end of the event as the time when frequency returns to within the NOFB and remains inside the NOFB for at least five minutes.

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 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 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 Q1 2024 is available in Appendix A1.

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

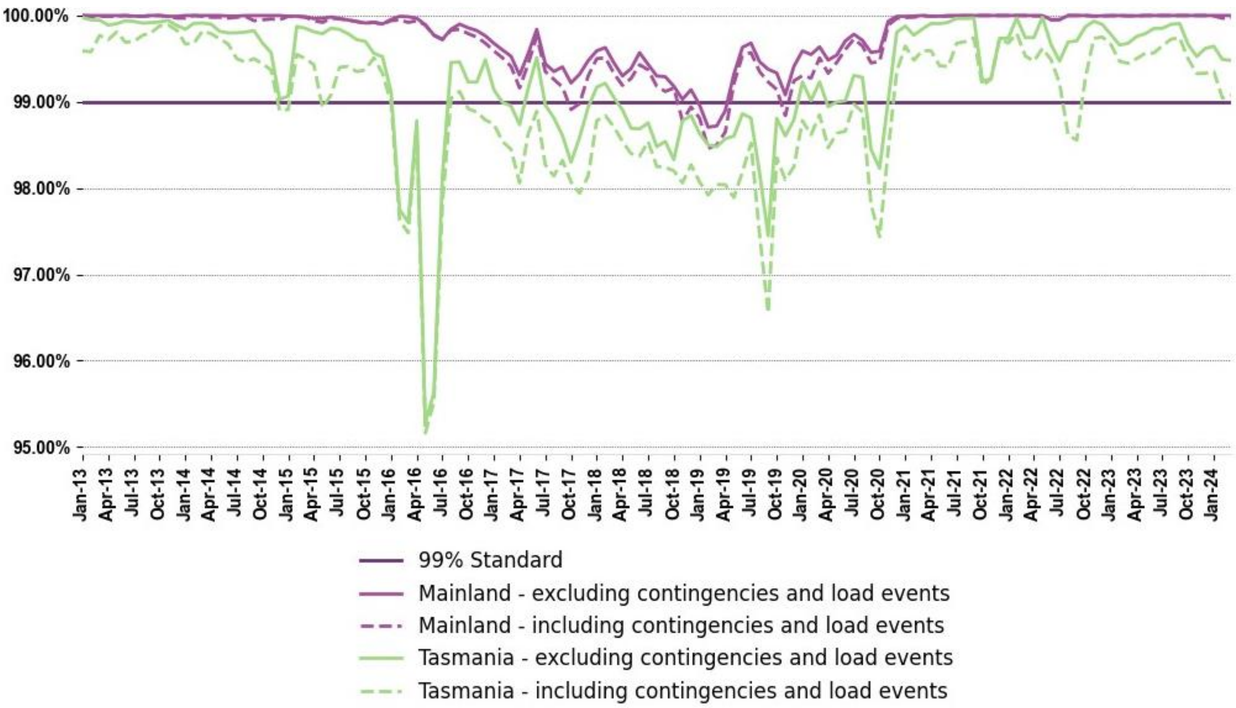


Figure 2 shows the distribution of mainland frequency within the NOFB since 2007.

Figure 2 Monthly mainland frequency distribution

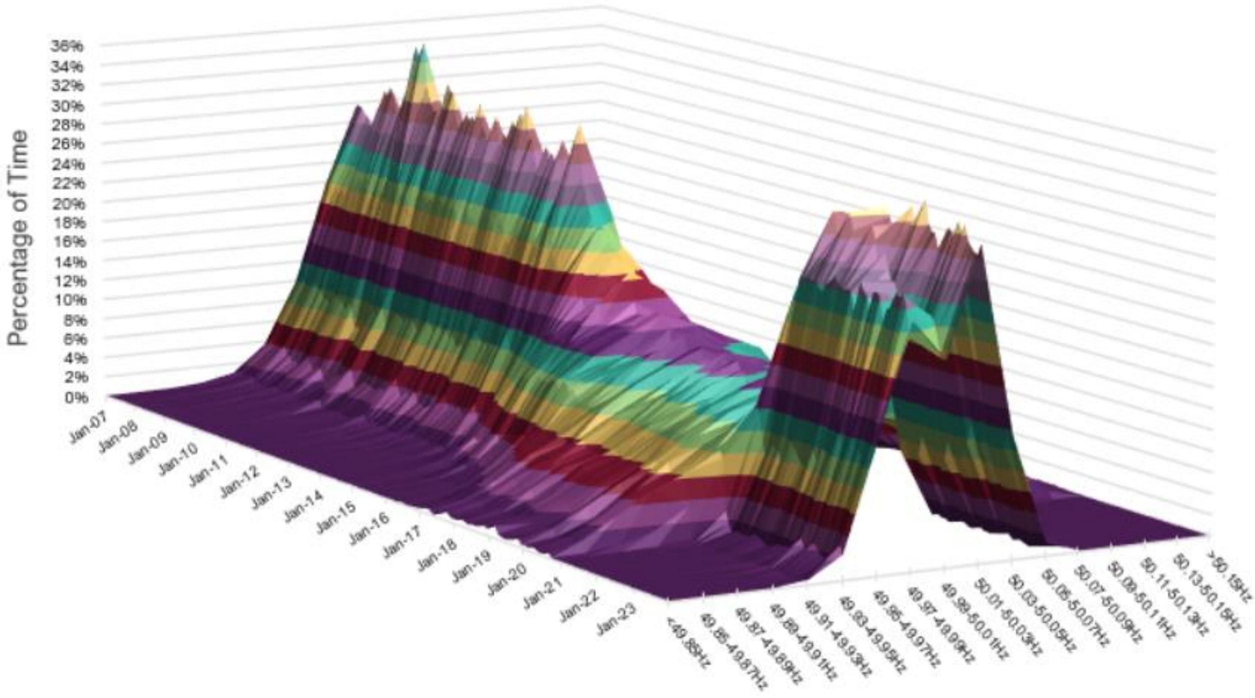
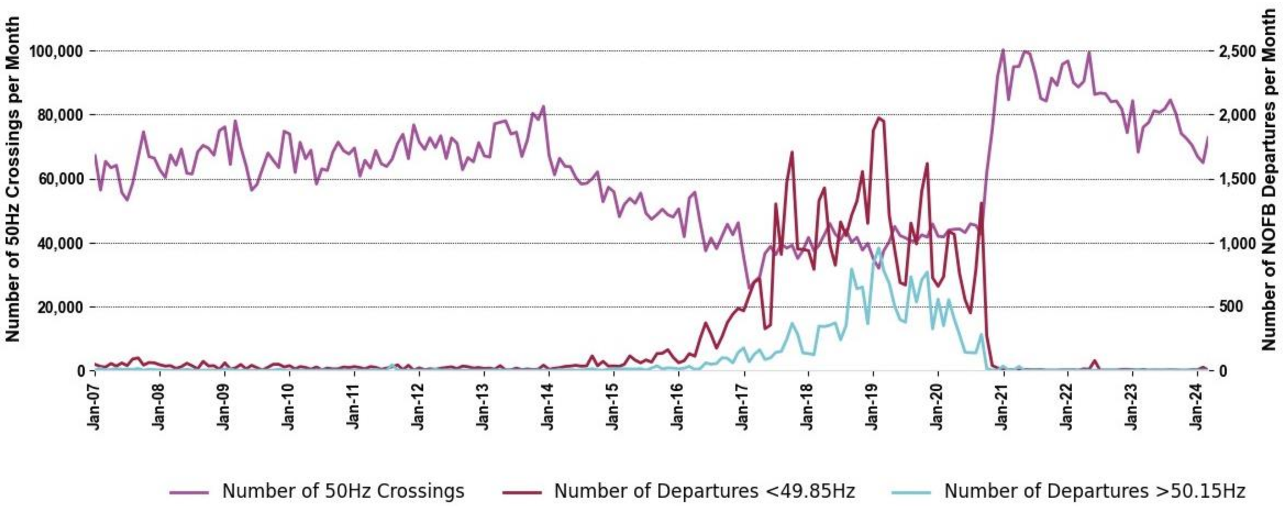


Figure 3 shows the number of times mainland frequency has crossed the nominal 50 Hz target and how often frequency has departed the NOFB since 2007.

Figure 3 Monthly mainland frequency crossings

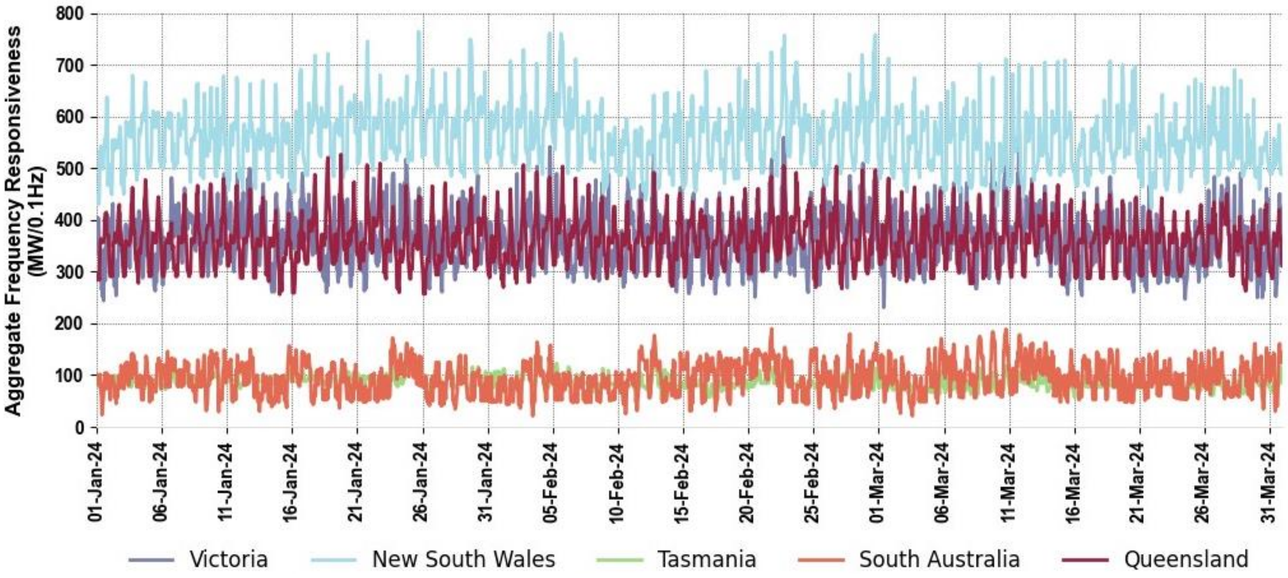


1.3 Aggregate frequency responsiveness

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



1.4 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 MASS[11].

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[12], naming[13] and implementation[14] of FCAS constraints is available on AEMO's website.

[11] 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.

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

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

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

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 RoCoF Risk. Notes: • Peak RoCoF Risk = 25 x Highest NEM generation unit output / NEM inertia. • Different linear equations are used for different containment bands[15], 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. Notes: • Peak RoCoF Risk = 25 x Highest NEM generation unit output / 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.	L1 increases in volume as inertia decreases. See Figure 6 below.
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 Q1 2024, and the potential variation due to prevailing contingency size. For the given contingency sizes, it is assumed that load relief is 118 MW, which represents the load relief (0.5%) for an average NEM load quantity of 23,687 MW as observed in Q1 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 fortnightly basis to determine

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

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 Q1 2024

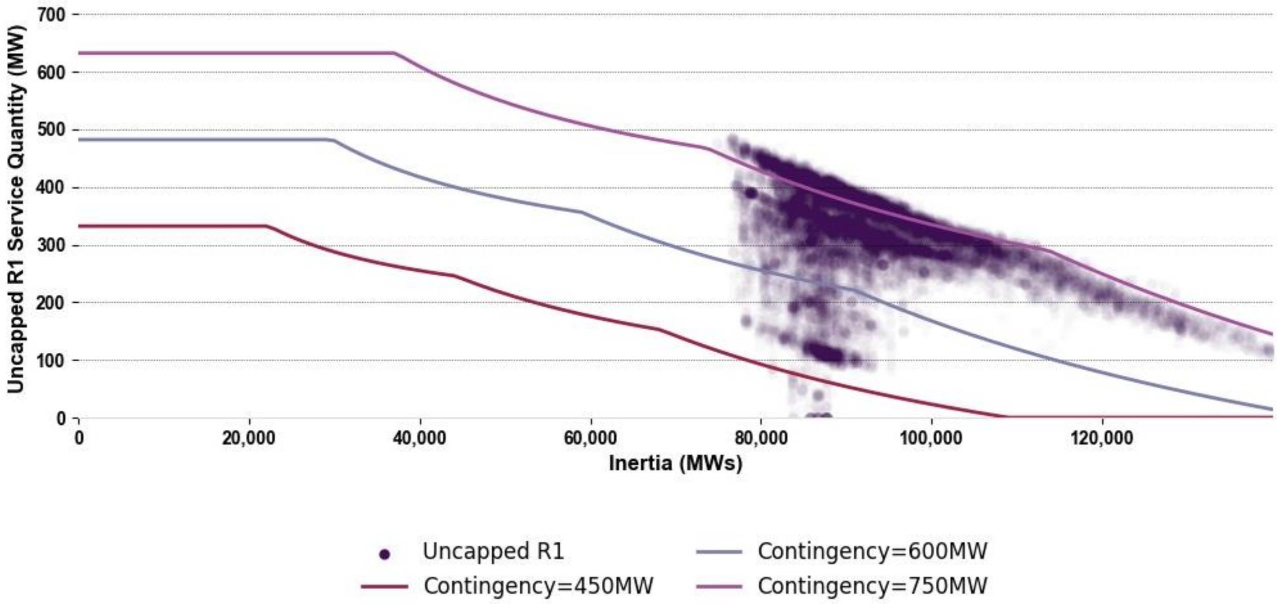
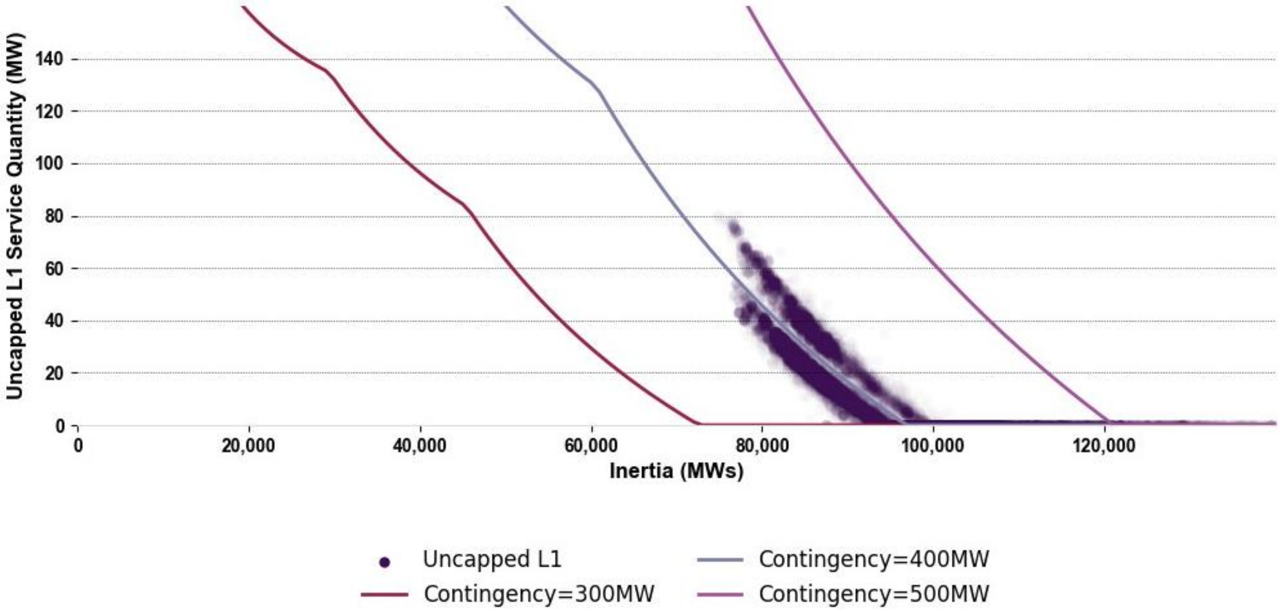


Figure 6 Relationship of uncapped L1 service quantities to inertia in Q1 2024



2 Achievement of the Frequency Operating Standard

2.1 Overview

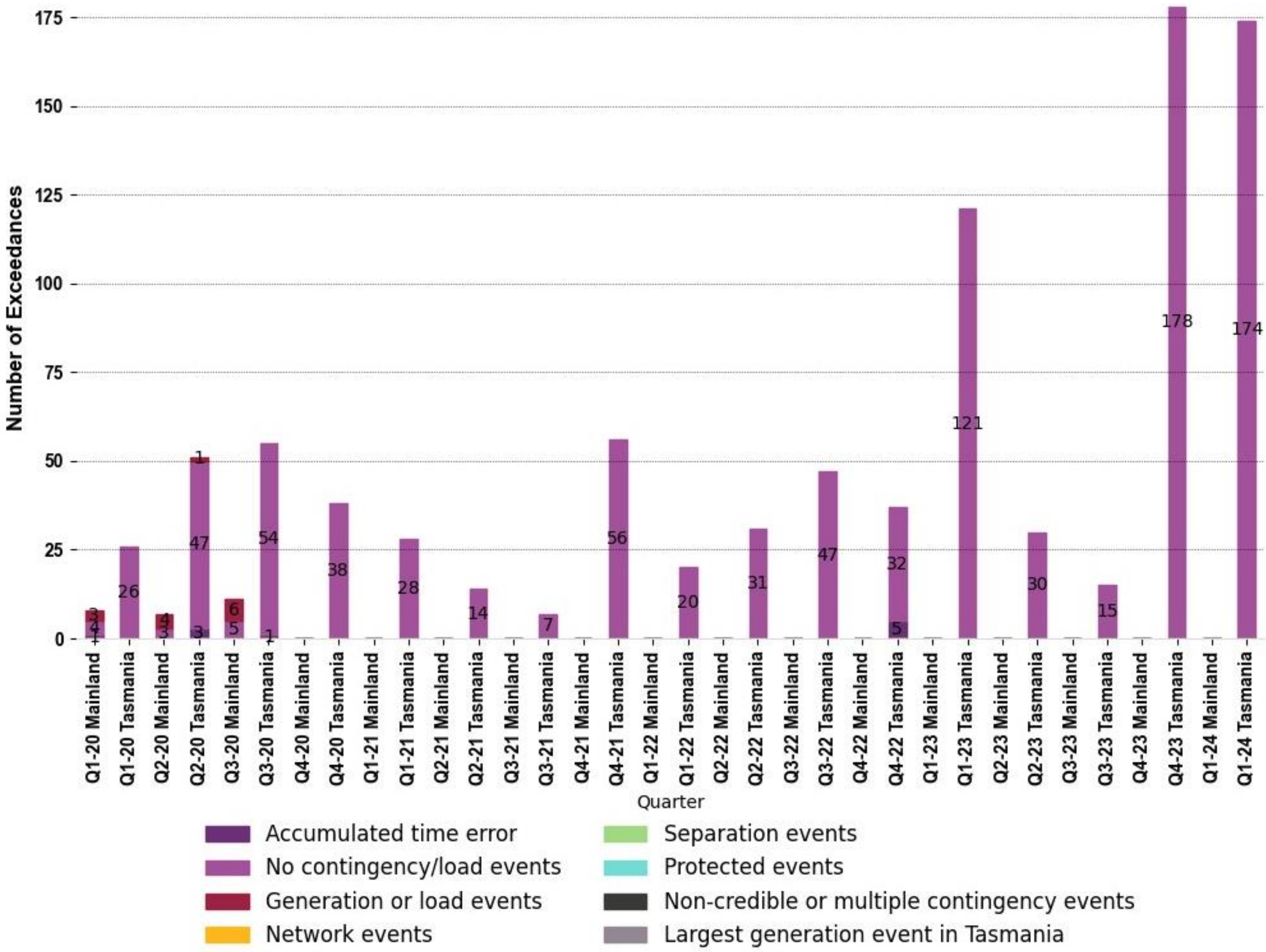
As noted in Section 1.1, the Reliability Panel completed a review of the FOS in April 2023 and new requirements for limiting RoCoF following an event were introduced from 9 October 2023.

AEMO's assessment of the achievement of the requirements of the FOS in Q1 2024 is summarised in Table 3, and further information on the FOS exceedances is in Section 2.2. Additionally, Table 3 shows the number of FOS exceedances since 2020.

Table 3 FOS assessment in the mainland and Tasmania

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**	Achieved	Exceeded 173 times	See Section 2.2.1
• **Recovered in five minutes**	Achieved	Exceeded 1 time	See Section 2.2.2
• **Within NOFB 99% of the time**	Achieved	Achieved	
3 – Generation or load events			
• **Contained**	Achieved	Achieved	RoCoF Limits:
• **Recovered within five minutes**	Achieved	Achieved	M - ±1 hertz per second (Hz/s) over 500 milliseconds (ms)
• **Less than RoCoF limit**	Achieved	Achieved	T - ±3 Hz/s over 250 ms
4 – Network events			
• **Contained**	Achieved	Achieved	RoCoF Limits:
• **Recovered within five minutes**	Achieved	Achieved	M - ±1 Hz/s over 500 ms
• **Less than RoCoF limit**	Achieved	Achieved	T - ±3 Hz/s over 250 ms
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			
• **Contained**	Achieved	Achieved	
• **Recovered within five minutes**	Achieved	Achieved	RoCoF Limits:
• **Less than RoCoF limit**	Achieved	Achieved	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



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 Q1 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.

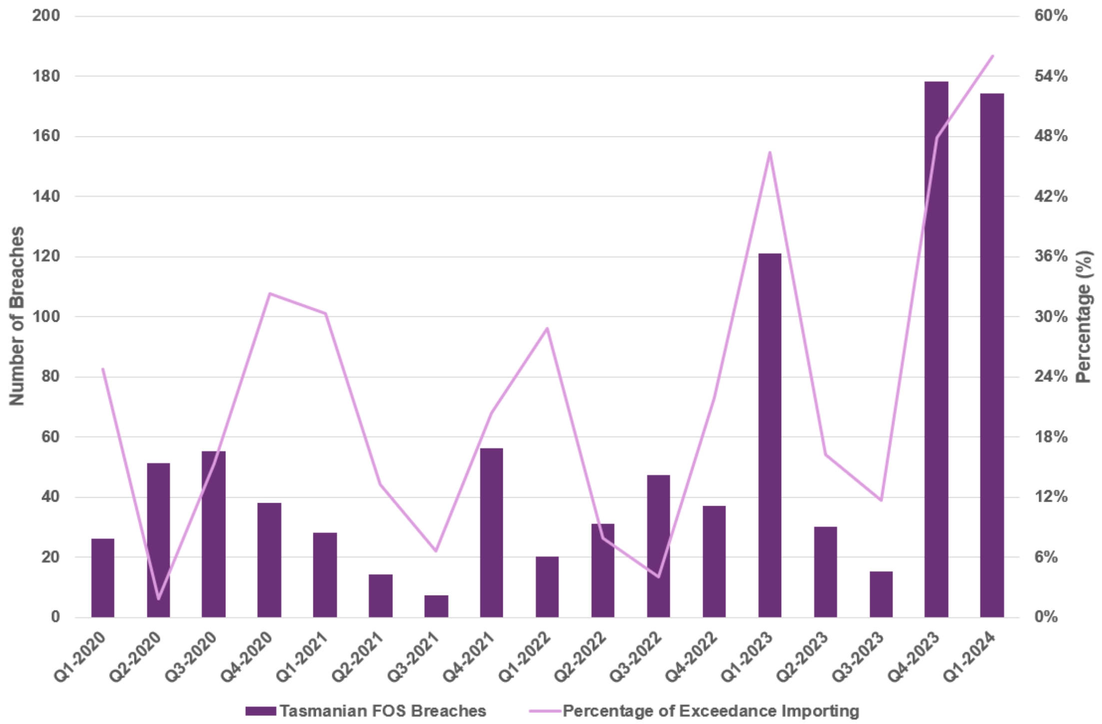
Table 4 Number of frequency excursions without identified contingency outside the NOFEB in Q1 2024

Event	Low/high/both frequency event	Number of events Mainland	Number of events Tasmania
No contingency or load event noted	LOW	0	173
	HIGH	0	0
	BOTH	0	0

Tasmania had a substantial number of events where frequency departed the NOFEB without an associated contingency event, totalling 173 events in Q1 2024.

Similar to Q4 2023, the increased number of frequency excursions outside the NOFEB in Tasmania in Q1 2024 is due to an observed increase in the percentage of time where Basslink was operating close to its maximum import capacity, along with a significant increase in total energy imported into Tasmania. Figure 8 suggests that the functionality of Basslink's frequency controller would often have been limited since it cannot modulate its output higher than its maximum import limit to aid frequency control, and this was the main contributing factor to the 173 excursions observed during the quarter.

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



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

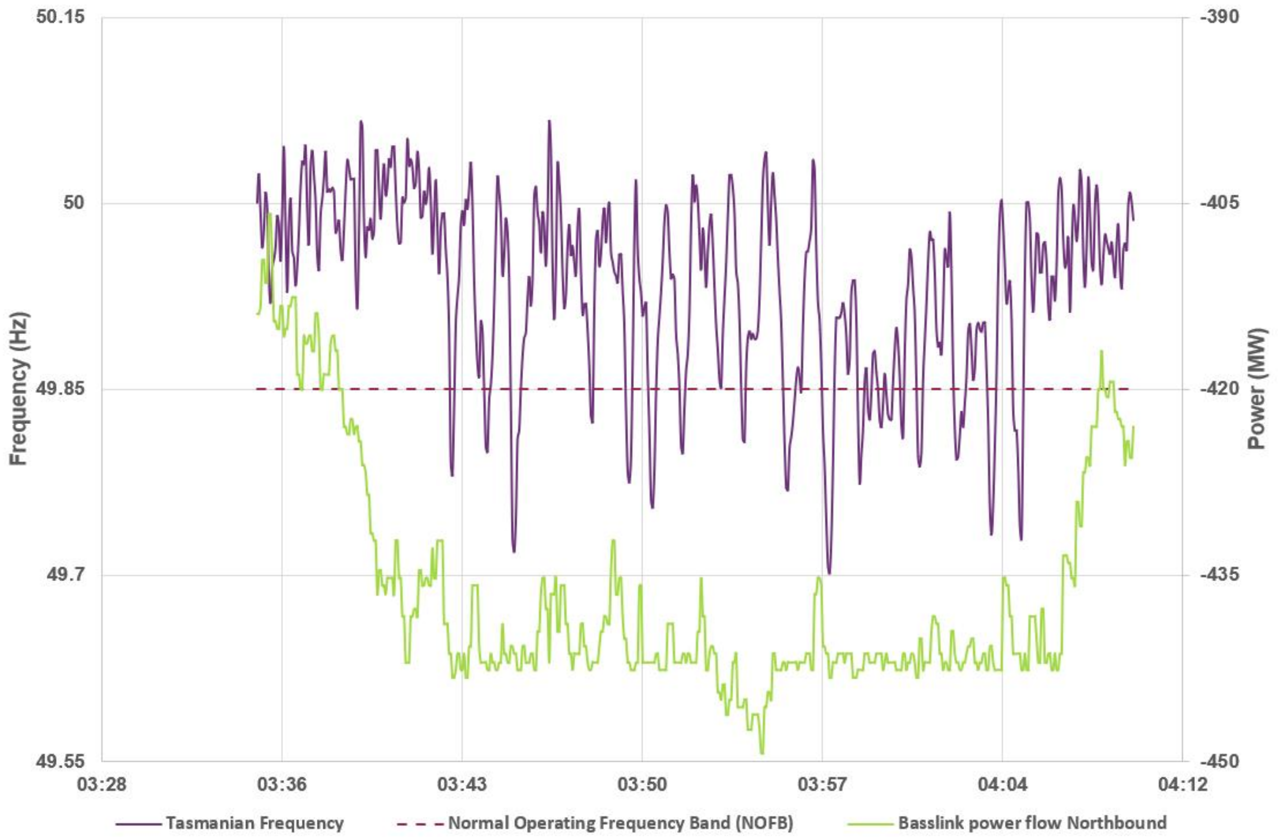
Table 5 shows frequency excursions in Q1 2024 outside the applicable normal operating frequency band (NOFB, 49.85 Hz to 50.15 Hz) for more than 5 minutes on one occasion where an associated contingency event has not been identified.

Table 5 Number of frequency excursions without identified contingency outside the NOFB for more than five minutes in Q1 2024

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

Figure 10 shows the Tasmanian FOS exceedance that occurred when Basslink was at its import limit on 11 January 2024. Tasmanian frequency cycled in and out of the NOFB for more than five minutes due to Basslink not being able to provide any frequency control. For clarity, frequency did not remain outside the NOFB for more than five minutes in any single excursion or exceed the Normal Operating Frequency Tolerance Band (NOFTB).

Figure 9 Tasmanian frequency excursion on 11 January



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 Q1 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 Q1 2024.

Table 6 RoCoF during frequency events in the mainland

Month	RoCoF (Hz/s)	Associated event	Event time
Jan-24	-0.12	Trip of Loy Yang A Power Station Unit 4 at 550 MW	8/01/2024 9:13
Feb-24	-0.13	Trip of Bayswater Power Station Unit 3 at 558 MW	8/02/2024 17:36
Mar-24	-0.14	Trip of Bayswater Power Station Unit 1 at 660 MW	21/03/2024 18:00

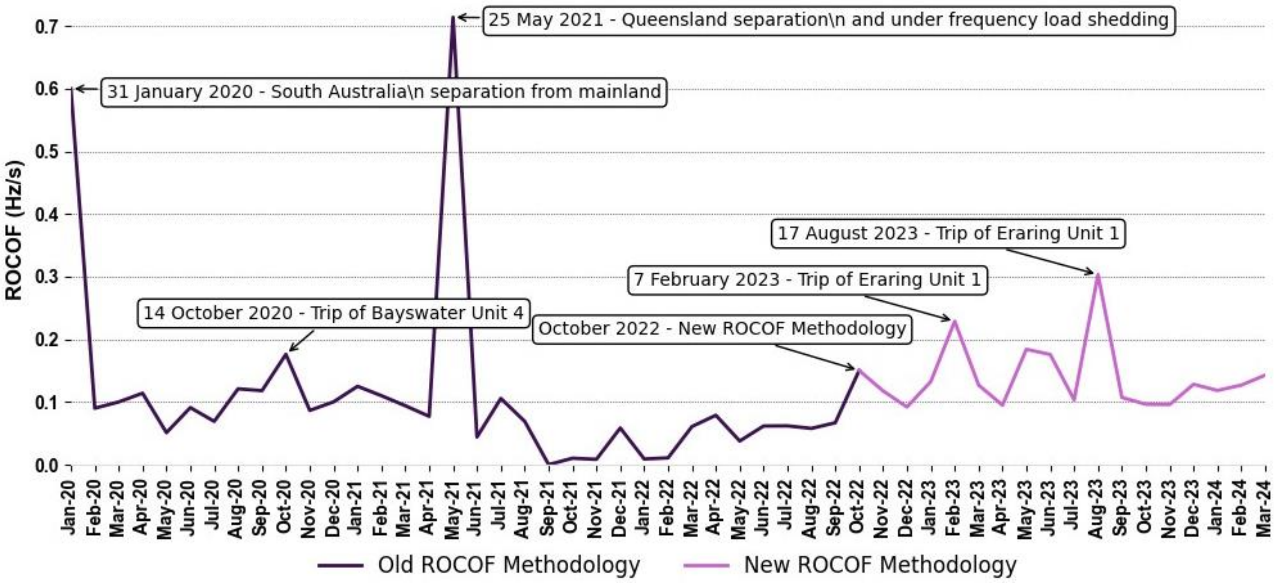
Table 7 RoCoF during frequency events in Tasmania

Month	RoCoF (Hz/s)	Associated event	Event time
Jan-24	-0.25	Basslink Load Reversal	17/01/2024 20:15
Feb-24	0.33	Trip of Temco at 88 MW	14/02/2024 02:28
Mar-24	0.46	Trip of Comalco at 114 MW	06/03/2024 08:07

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.

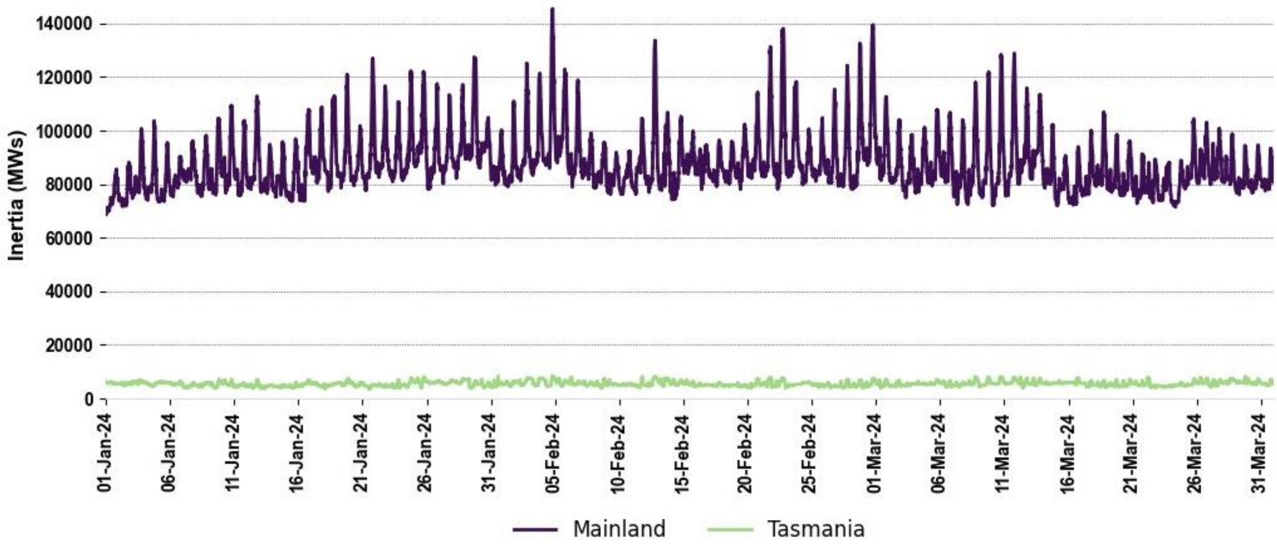
Figure 10 Monthly maximum RoCoF recorded in any mainland region in 2020-24



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.

The estimated level of inertia in the mainland and Tasmania at five-minute intervals over Q1 2024 is shown in Figure 11, and a distribution chart for the mainland is provided in Figure 12 and for Tasmania in Figure 13. For the purposes of this report, inertia in the mainland and Tasmania at a point in time is calculated as the sum of the assumed inertia contributed by registered generators online in that region at that time.

Figure 11 Time series mainland and Tasmania inertia in Q1 2024



MWs: megawatt seconds

Figure 12 Distribution of mainland inertia in Q1 2024

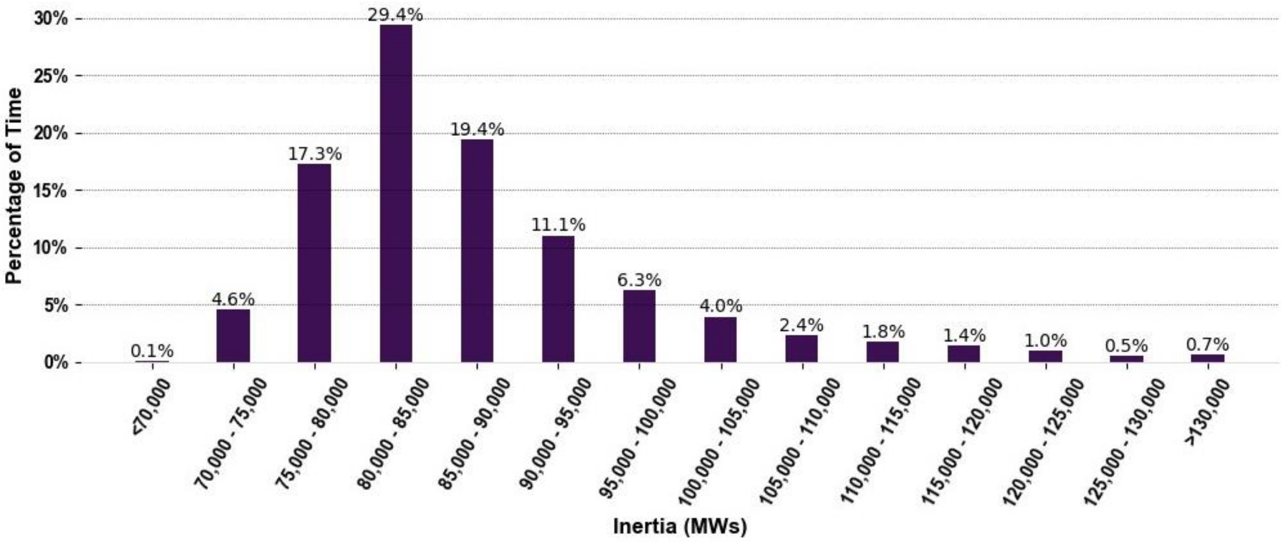
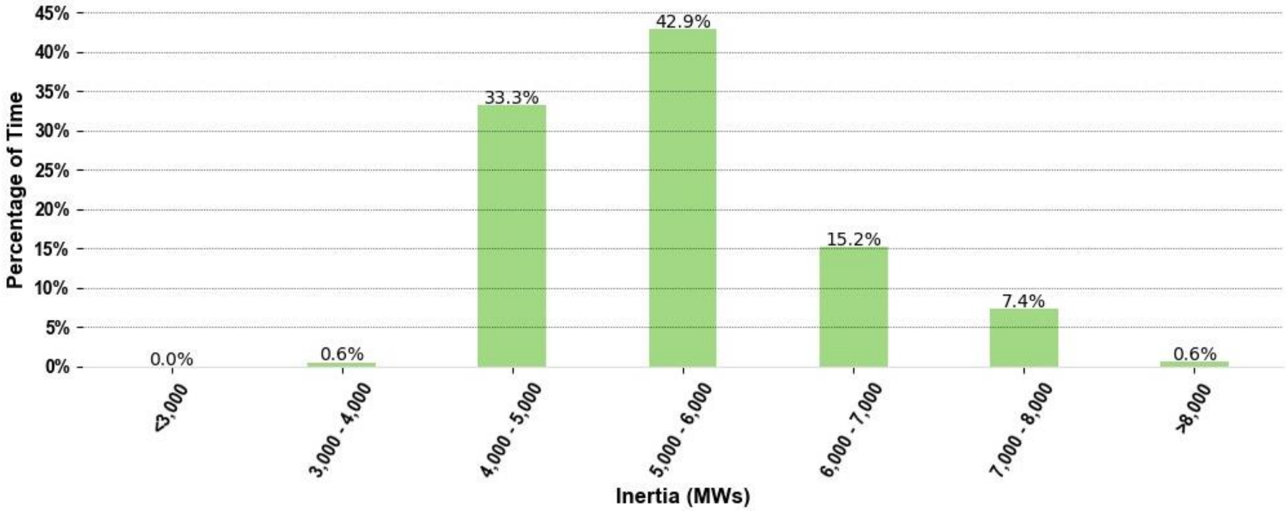


Figure 13 Distribution of Tasmania inertia in Q1 2024



4 Area control error

The calculation of ACE methodology by AEMO's AGC system is outlined in Appendix A2.4. Figure 14 and Figure 15 show the minimum and maximum ACE per half-hourly trading interval in Q1 2024 in the mainland NEM and Tasmania, respectively.

Figure 14 Minimum and maximum ACE per half-hour in mainland NEM

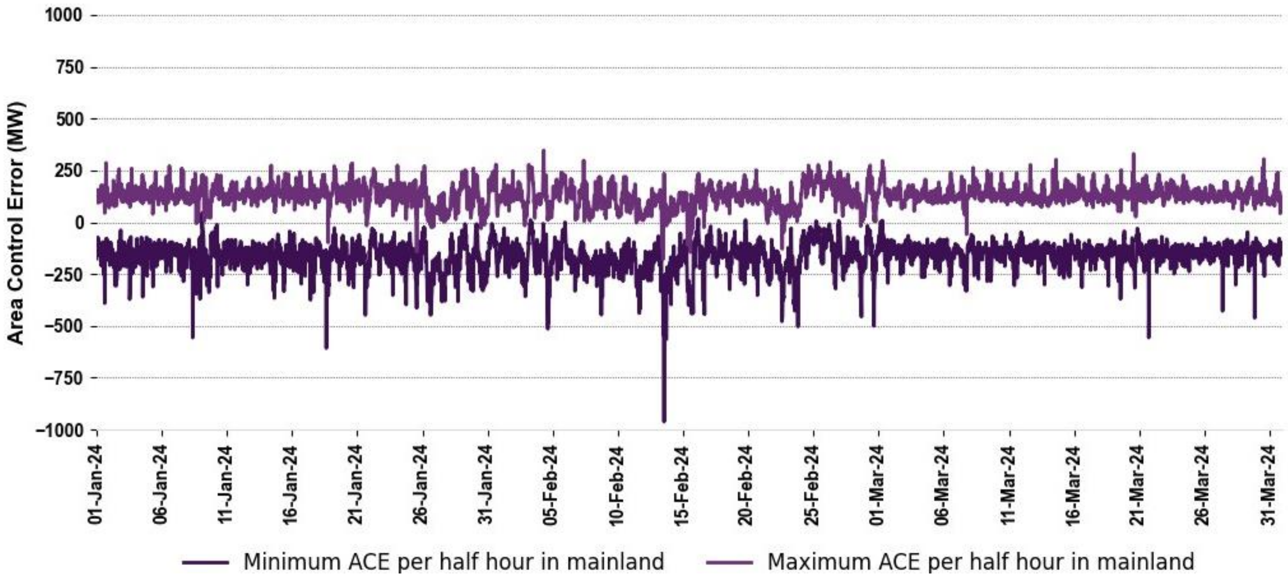
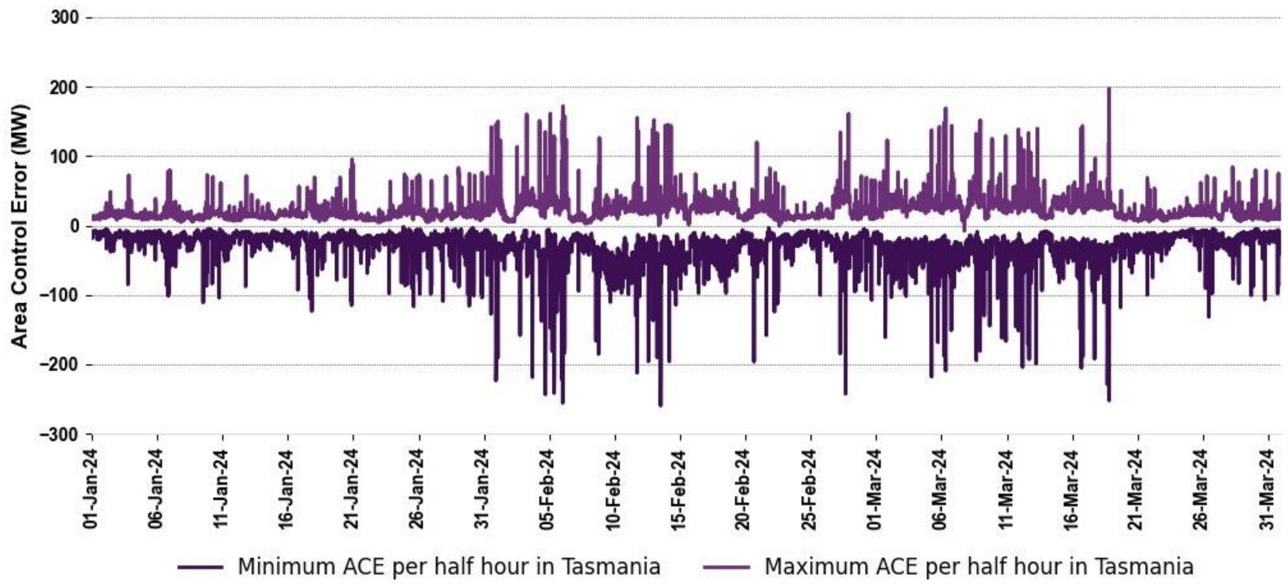


Figure 15 Minimum and maximum ACE per half-hour in Tasmania



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[16].

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 2024 relating to frequency exceeding the OFTB.

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

- On 18 January at 1517 hrs, the minimum mainland frequency reached 49.80 Hz when there was delay of approximately two minutes before a large generator started to ramp up to its dispatch target. The frequency recovered within the NOFB after 2 minutes 21 seconds, and an analysis was conducted for all participants enabled for R1, Fast Raise (R6), and Slow Raise (R60) during this event.
  - AEMO has confirmed an adequate response from 38 providers and is still investigating the performance of one FCAS facility. Additionally, AEMO identified another provider who failed to meet their Fast FCAS requirements due to a delay close to 6 seconds before their facility responded. AEMO is working with this provider to confirm the non-compliance period, as the site may not have been able to meet its Fast FCAS requirements during other trading intervals, and to ensure that appropriate measures have been taken by the provider to prevent a re-occurrence.
- The minimum mainland frequency reached 49.69 Hz on 13 February at 1310 hrs following a non-credible event in Victoria. The frequency recovered within the NOFB after 8 minutes 20 seconds and an analysis was conducted for all participants enabled for all raise FCAS services. Further information on this event has been provided in AEMO's Market Notice 114577[17] and in AEMO's preliminary operating incident report[18].
  - AEMO has confirmed adequate response from 41 providers and is still assessing the performance of six providers. Additionally, five non-compliances were identified and their causes are listed below:
    a. A facility was responding to the energy price signals from its bidding optimisation platform. However, the energy price signals opposed the raise FCAS response during the event and this led to an under-delivery of raise FCAS.
    b. A facility was offline at the time of the frequency event and should not have been offered into the FCAS markets.
    c. A facility had disabled its FCAS controller minutes before the event due to an operational issue on site. The site was only non-compliant for one trading interval, and following this, the site was bid out of the FCAS markets.

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

[17] See https://aemo.com.au/en/market-notices?marketNoticeQuery=114577&marketNoticeFacets.

[18] See https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2024/preliminary-report---loss-of-moorabool---sydenham-500-kv-lines-on-13-feb-2024.pdf?la=en

d. A facility did not provide any raise FCAS response at the time of the event due to its state of charge being too low. The participant continued to offer the BESS into the raise FCAS markets despite the BESS not maintaining adequate headroom to meet its FCAS requirements.

e. A facility did not respond to the frequency disturbance as its output was intentionally limited due to planned works on site. This restricted the unit's FCAS capability but was not reflected in the facility's FCAS offer until approximately five weeks later.

– AEMO is working with these providers to ensure that measures have been implemented to prevent a re-occurrence and has also informed the Australian Energy Regulator (AER) of the non-compliances.

At the time of publishing the Q4 Frequency and Time Error Monitoring report, AEMO was still investigating the performance of participants enabled for R1 and R6 FCAS following the trip of Bayswater Unit 1 on 31 December 2023. AEMO has confirmed adequate response from 35 providers and has identified two non-compliances.

The FCAS response from one FCAS facility was considered as marginally non-compliant due to a small delay in responding to the frequency disturbance, and AEMO will continue to monitor the FCAS facility closely. Another FCAS provider had scaled its droop curve based on the available power and number of inverters online, however, the FCAS availability of the BESS was not properly updated in the bids which resulted in an under-delivery of the raise services. This FCAS provider is now bidding conservatively until a permanent solution is implemented.

A1. Credible generation and load events

This appendix identifies credible generation and load events since 2020 meeting the following criteria:

- Supervisory control and data acquisition (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 8 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 Q1 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 Q1 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)
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)
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 Q1 2024

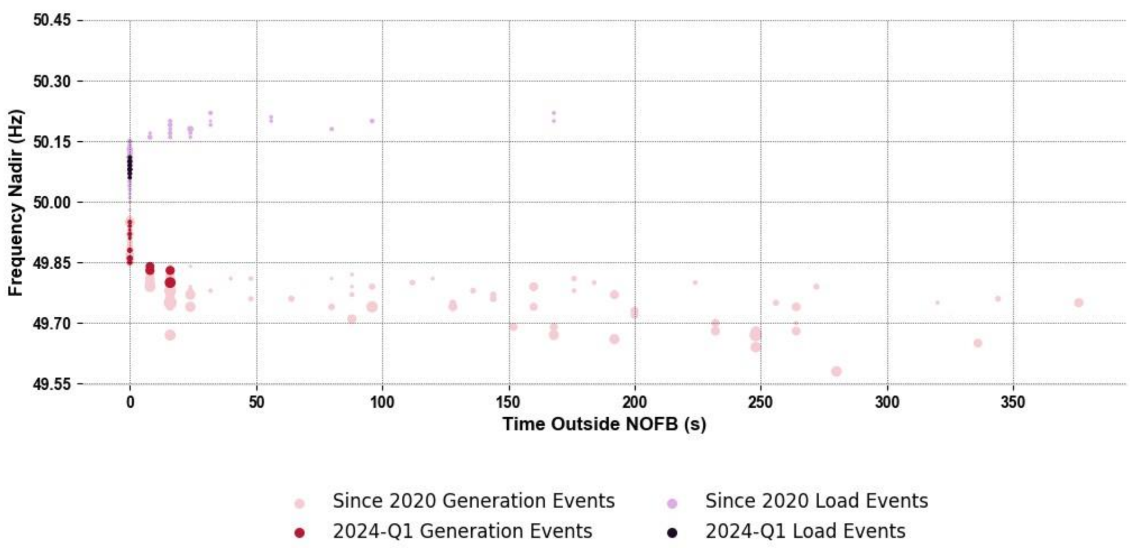
Event time	Unit	Contingency size (MW)	Frequency nadir/peak (Hz)	Recovery to NOFB (s)	FOS compliant?
3/01/2024 13:25	Bayswater Power Station Unit 2	352	49.85	0	YES
8/01/2024 9:14	Loy Yang A Power Station Unit 4	550	49.8	16	YES
8/01/2024 22:50	Loy Yang A Power Station Unit 4	547	49.83	8	YES
9/01/2024 10:01	Alcoa Portland Unit 2	277	50.06	0	YES
9/01/2024 11:06	Loy Yang A Power Station Unit 4	351	49.88	0	YES
14/01/2024 14:10	Loy Yang A Power Station Unit 1	307	49.88	0	YES
14/01/2024 15:30	Kogan Creek Power Station	326	49.88	0	YES
16/01/2024 2:44	Vales Point "B" Power Station Unit 6	226	49.91	0	YES
17/01/2024 10:21	Vales Point "B" Power Station Unit 6	422	49.86	0	YES
18/01/2024 8:35	Tomago 1	303	50.1	0	YES
18/01/2024 11:00	Alcoa Portland Unit 2	284	50.08	0	YES
19/01/2024 5:31	Tomago 2	309	50.08	0	YES
23/01/2024 10:31	Tarong Power Station Unit 4	293	49.92	0	YES
26/01/2024 12:53	Tomago 1	298	50.07	0	YES
26/01/2024 17:52	Tomago 2	311	50.08	0	YES
29/01/2024 22:25	Tomago 1	298	50.1	0	YES
1/02/2024 22:33	Tomago 1	302	50.09	0	YES
4/02/2024 19:30	Alcoa Portland Unit 2	279	50.08	0	YES
7/02/2024 9:26	Tomago 2	307	50.1	0	YES
8/02/2024 17:36	Bayswater Power Station Unit 3	559	49.83	8	YES
13/02/2024 12:27	Stockyard Hill Wind Farm	243	49.88	0	YES
13/02/2024 15:00	Alcoa Portland Unit 2	292	50.08	0	YES
21/02/2024 18:50	Alcoa Portland Unit 2	275	50.08	0	YES
22/02/2024 15:45	Alcoa Portland Unit 2	283	50.07	0	YES
23/02/2024 19:53	Loy Yang A Power Station Unit 3	556	49.84	8	YES
5/03/2024 22:05	Eraring Power Station Unit 1	209	49.93	0	YES
6/03/2024 10:40	Stanwell Power Station Unit 1	294	49.92	0	YES
8/03/2024 6:25	Alcoa Portland Unit 2	287	50.1	0	YES
9/03/2024 7:28	Vales Point "B" Power Station Unit 6	284	49.94	0	YES
9/03/2024 8:39	Tomago 4	309	50.09	0	YES
12/03/2024 22:04	Tomago 4	296	50.08	0	YES
14/03/2024 15:22	Tomago 4	296	50.11	0	YES
21/03/2024 18:00	Bayswater Power Station Unit 1	660	49.8	16	YES
22/03/2024 12:01	Wivenhoe Pump 1	243	50.08	0	YES
23/03/2024 16:48	Mt Piper Power Station Unit 2	202	49.91	0	YES
27/03/2024 9:30	Tallawarra Power Station B	315	49.86	0	YES
27/03/2024 12:40	Tallawarra Power Station B	314	49.95	0	YES

Event time	Unit	Contingency size (MW)	Frequency nadir/peak (Hz)	Recovery to NOFB (s)	FOS compliant?
29/03/2024 20:50	Loy Yang B Power Station Unit 1	573	49.83	16	YES

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

Figure 16 displays each event from Table 10 to illustrate the distribution of frequency outcomes following credible contingency events in Q1 2024, in comparison to events since 2020.

Figure 16 Frequency outcomes of identified credible generation and load events



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 Normal Operating Frequency Band (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/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 17 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 17 Frequency event with a single NOFB excursion

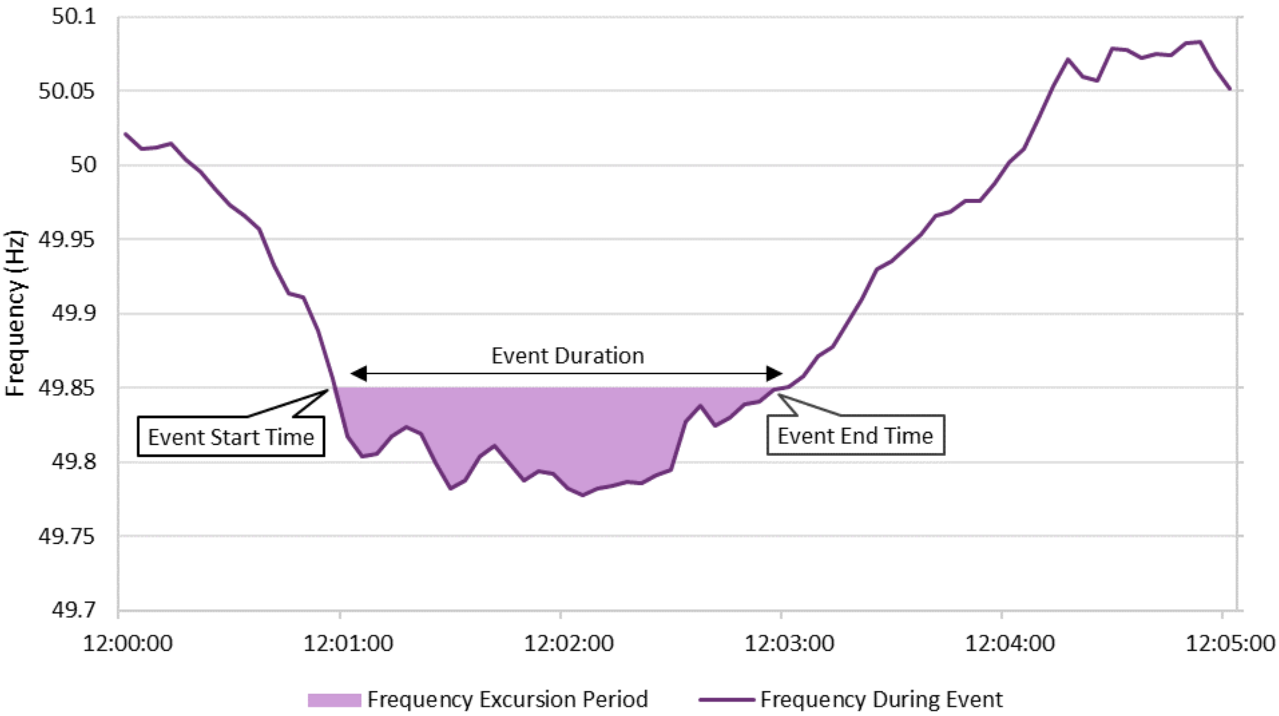
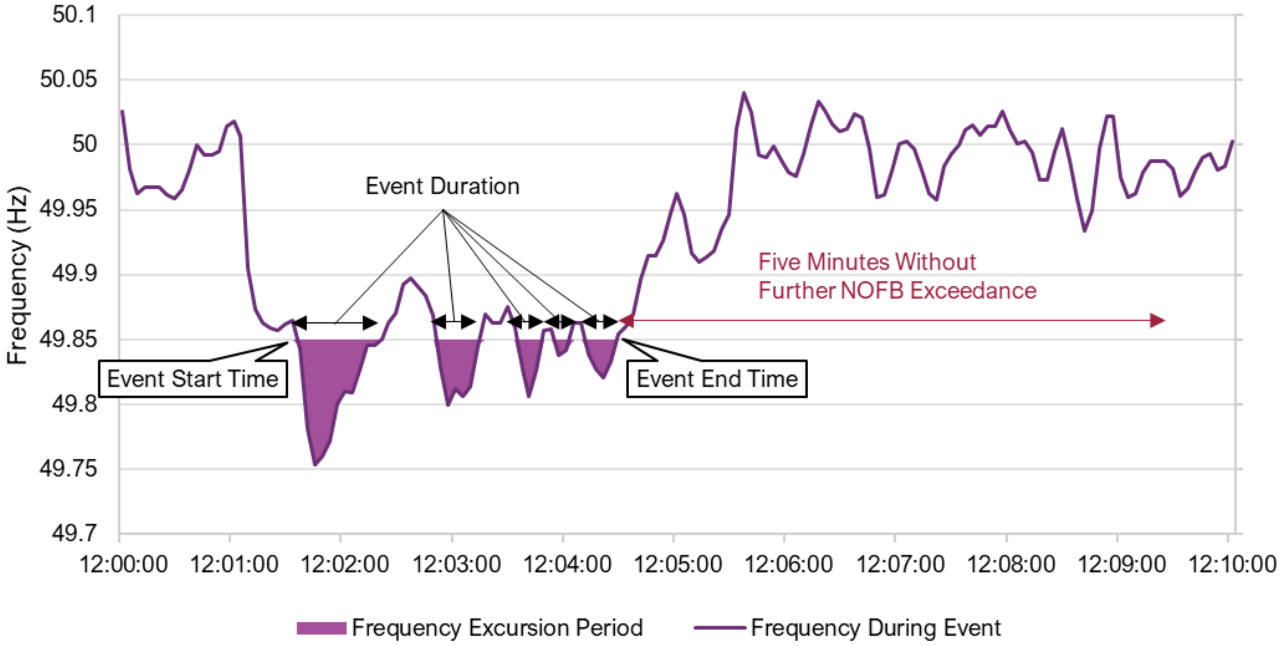


Figure 18 is a case of multiple NOFB excursion in a short space of time, The frequency event start time is determined as before, and the frequency event end time is determined as the last measurement before system frequency returns to the NOFB and stays within the NOFB for at least five minutes.

Figure 18 Frequency event with multiple NOFB excursions



A2.2 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.

A2.3 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 are taken from a PMU in Sydney, while Tasmanian data are taken from a PMU in Tungatinah.

Method 1: From Q1 2020 to Q3 2022

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 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.

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[19], 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.

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

- **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.