Frequency and Time Error Monitoring – Quarter 2 2023

August 2023

A report for the National Electricity Market

Important notice

Purpose

The purpose of this report is to provide information about the frequency and time error performance in the National Electricity Market (NEM) for the mainland and Tasmanian regions for the period April to June 2023 inclusive. AEMO has prepared this report in accordance with clause 4.8.16(b) of the National Electricity Rules (NER), using information available as at the date of publication, unless otherwise specified.

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Introduction

The Reliability Panel's Frequency Operating Standard (FOS)[1] specifies limits for power system frequency and time error for the mainland and Tasmanian regions of the National Electricity Market (NEM). AEMO must use its reasonable endeavours to control power system frequency and ensure that the FOS is achieved as required by clause 4.4.1 of the National Electricity Rules (NER).

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

The Queensland, New South Wales, Victoria, and South Australia regions are referred to as the 'mainland' throughout the report. Unless otherwise noted, mainland frequency data was sampled in New South Wales at 4-second intervals using the most recent Global Positioning System (GPS) clock frequency measurement preceding each 4-second interval. All Tasmanian frequency data was sampled at 4-second intervals using the most recent network operations and control system (NOCS) frequency measurement preceding each 4-second interval.

Abbreviations

Abbreviation	Full term
ACE	Area control error
AGC	Automatic generation control
AEMC	Australian Energy Market Commission
BESS	Battery energy storage system
FCAS	Frequency control ancillary services
FCSPS	Frequency control system protection scheme
FOS	Frequency Operating Standard
GPS	Global Positioning System
MASS	Market ancillary services specification
NEM	National Electricity Market
NER	National Electricity Rules
NOCS	Network operations and control system
NOFB	Normal operating frequency band
NOFEB	Normal operating frequency excursion band
OFTB	Operational frequency tolerance band
PFR	Primary frequency response
PFRR	Primary Frequency Response Requirements
PMU	Phasor measurement unit
RoCoF	Rate of change of frequency
TNSP	Transmission network service provider
VRE	Variable renewable energy

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

Contents

Tables

Figures

1 Actions to improve frequency control performance

1.1 Recent and in progress actions

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

- AEMO published a final determination and update to the market ancillary services specification (MASS) on 7 October 2022 and finalised a revision of a setting for Tasmanian Very Fast FCAS providers on 28 July 2023[2]. Version 8.1 of the MASS will take effect form 9 October 2023, coinciding with the commencement of the Very Fast FCAS markets.s
- Consultation on the Frequency Contribution Factors Procedure was completed, with a final report and procedure published in June 2023. Further information will be available on the Frequency Performance Payments project page[3].
- The final service commencement plan for Very Fast FCAS was published on 11 May 2023. The plan has been developed to inform stakeholders of AEMO's approach to determine the amount of Very Fast FCAS required under different power system conditions and describes how AEMO intends to transition from current contingency FCAS arrangements to the new arrangements on 9 October 2023.
- The consultation on the Primary Frequency Response Requirements (PFRR) was concluded. The final determination was published on 4 May 2023. Further information is available on AEMO's website[4].
- Draft versions of the revised MASS FCAS verification tool[5] and associated user guide[6] were published on 6 April 2023. In line with the changes made in Version 8 of the MASS which will be effective on 9 October 2023, the latest tool includes the new calculation for Very Fast FCAS and the updated calculation for Fast, Slow and Delayed FCAS. AEMO sought feedback on the draft versions and intends to publish the final versions of the tool and user guide before the Very Fast FCAS markets commence on 9 October 2023.
- The updated technical guides for the contingency FCAS registration of Battery Energy Storage Systems (BESS)[7] and intermittent generators[8] were published on 24 March 2023. The guides were developed to assist market participants intending to participate in the FCAS markets and describe the testing requirements and applicable settings of the FCAS controllers.

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[2] https://aemo.com.au/en/consultations/current-and-closed-consultations/mass-consultation---revision-of-tasmanian-settings-for-very-fast-fcas.

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

[4] See https://aemo.com.au/consultations/current-and-closed-consultations/primary-frequency-response-requirements.

[5] See https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/ancillary_services/2023/external-fcas-verification-tool-v6-for-mass-v8_draft.xlsx?la=en.

[6] See https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/ancillary_services/2023/fcas-verification-tool-user-guide-v50.pdf?la=en.

[7] See https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/ancillary_services/battery-energy-storage-system-requirements-for-contingency-fcas-registration.pdf?la=en.

[8] See https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/ancillary_services/wind-farms-and-solar-farms-testing-requirements-for-contingency-fcas-registration.pdf?la=en.

- The Reliability Panel completed a review of the Frequency Operating Standard (FOS), into which AEMO provided technical advice[9]. Key changes in the new FOS, which takes 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.
- AEMO intends to make alterations to the dynamic regulation FCAS procurement based on time error to better reflect the changes in the FOS from 9 October. Detailed information will be published ahead of changes via appropriate mechanism.
- The interim release of the Integrating Energy Storage Systems (IESS) rule change on 31 March 2023 allows small generator aggregators (SGAs) to provide contingency frequency control ancillary services (FCAS) for the first time in the National Electricity Market (NEM). Further information is available on AEMO's website[10].
- AEMO published its *Roadmap to 100% Renewables* report in December 2022[11] and recently published a follow-up called *FY2024 Priority Actions Report*[12]. These publications continue progress on a framework[13] that aims to provide a technical base to inform industry prioritisation of the steps necessary to securely, reliably and affordably transition. The framework considers frequency control and inertia, outlining the preconditions that must be satisfied for the first periods of 100% renewable penetration, and actions necessary to achieve these preconditions, as system inertia reduces and frequency response is increasingly provided by inverter-based resources (IBR).
- AEMO continues to implement the mandatory PFR requirements introduced into the National Electricity Rules (NER) in 2020[22], and made enduring in 2022. Implementation reports are on AEMO's website[23]. While implementation is complete at virtually all synchronous and BESS facilities, these reports outline the challenges remaining in completing implementation at variable renewable energy (VRE) facilities.

1.2 Impact of frequency control actions

This section illustrates the historical and latest frequency performance in the NEM, and the impact of the actions taken by AEMO and others (listed in Section 1.1) to maintain and improve power system frequency control outcomes.

Table 1 contains key metrics of frequency performance for the quarter from 1 April 2023 to 30 June 2023 (Q2 2023). The majority of long duration frequency events in the quarter, including the longest event recorded in Table 1 (25 June 2023), were caused when Basslink was in the "no-go" zone.

AEMO is encouraged by frequency performance observed over Q2 2023, especially in light of the system events that occurred over the period, such as generator trips that occurred on 7 May, 10 May and 12 June. The

[9] See https://www.aemc.gov.au/market-reviews-advice/review-frequency-operating-standard-2022.
[10] See https://aemo.com.au/initiatives/major-programs/integrating-energy-storage-systems-project.
[11] See https://aemo.com.au/-/media/files/initiatives/engineering-framework/2022/engineering-roadmap-to-100-per-cent-renewables.pdf.
[12] See https://aemo.com.au/-/media/files/initiatives/engineering-framework/2023/nem-engineering-roadmap-fy2024--priority-actions.pdf.
[13] See https://aemo.com.au/en/initiatives/major-programs/engineering-framework.
[22] See https://aemc.gov.au/rule-changes/mandatory-primary-frequency-response.
[23] See https://aemo.com.au/en/initiatives/major-programs/primary-frequency-response.

outcomes of these events indicate that, from a frequency control perspective, the system is well placed to cope with unexpected incidents.

Further details on notable events in Q2 2023 are available in Section 5.

Table 1 Key frequency statistics from the mainland and Tasmania in Q2 2023

	Mainland		Tasmania	
	Minimum	Maximum	Minimum	Maximum
Frequency (Hz)	49.8	50.1	49.0	50.6
Time error (seconds [s])	-9.24	3.70	-5.18	6.38
Longest frequency event duration (s)*	8		350	

*Frequency may return to the normal operating frequency band (NOFB) briefly during the period AEMO considers to constitute the event.

AEMO calculates daily the percentage of time that frequency remained inside the normal operating frequency band (NOFB) in the preceding 30-day window.

Figure 1 reports the minimum daily estimate from each month, showing the estimated time inside the NOFB, both including and excluding data during contingency events. The FOS requirement excludes periods where contingency events have occurred. Frequency in the mainland and Tasmania remained within the NOFB for more than 99% of the time in Q2 2023, indicating that the system is quite close to nominal frequency most of the time and thus would have the best capability to cope with unexpected events. Further detail on credible contingency events in Q2 2023 is available in Appendix A1.

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

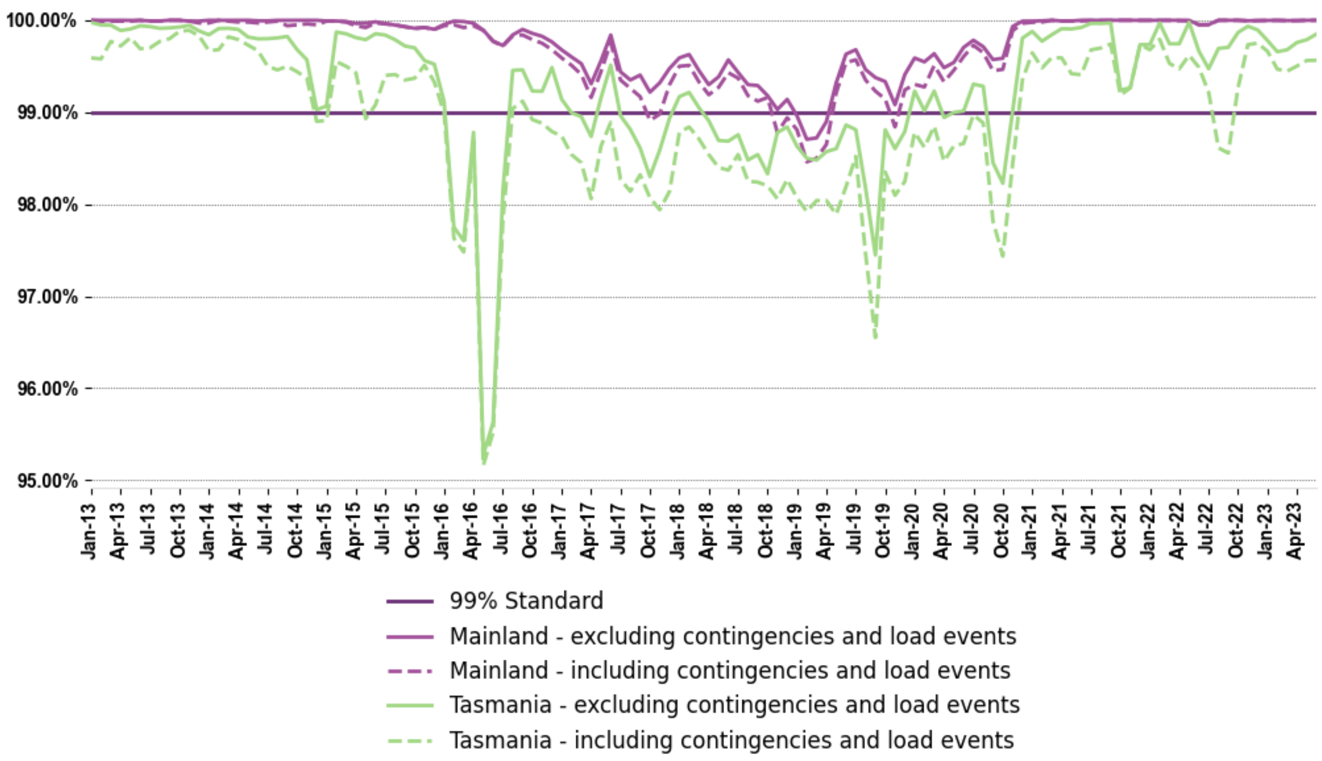


Figure 2 shows the distribution of mainland frequency within the NOFB since 2007.

Figure 2 Monthly mainland frequency distribution

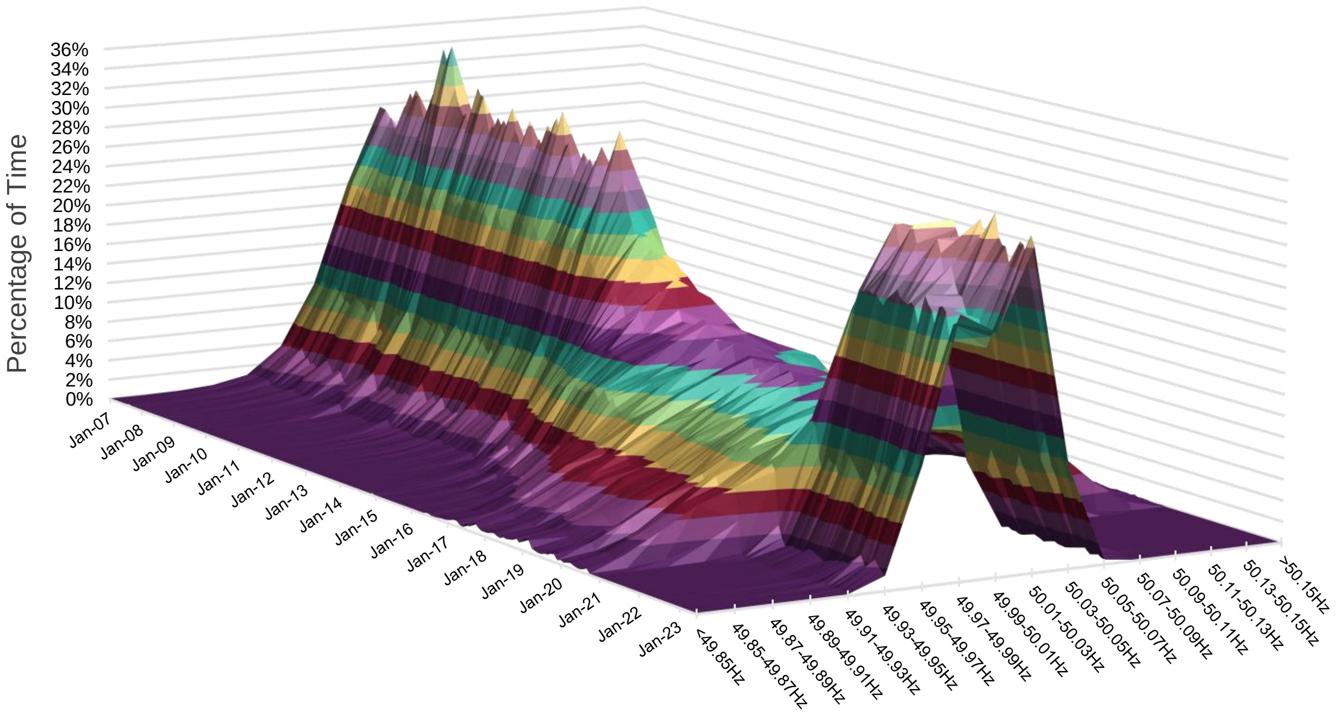
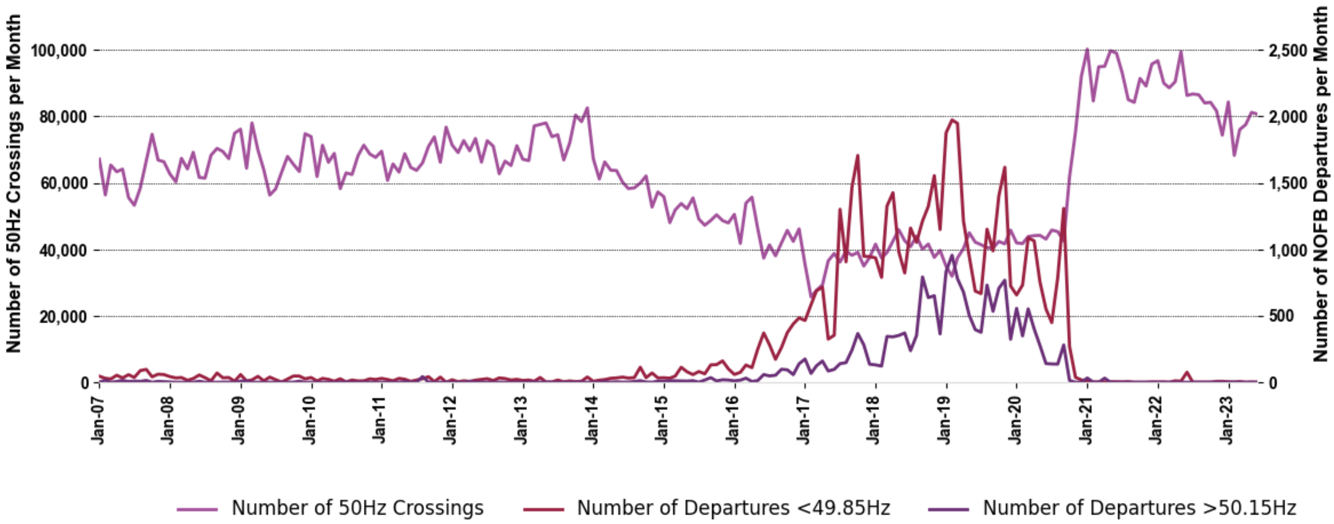


Figure 3 shows the number of times mainland frequency has crossed the nominal 50 Hz target and how often frequency has departed the NOFB since 2007.

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

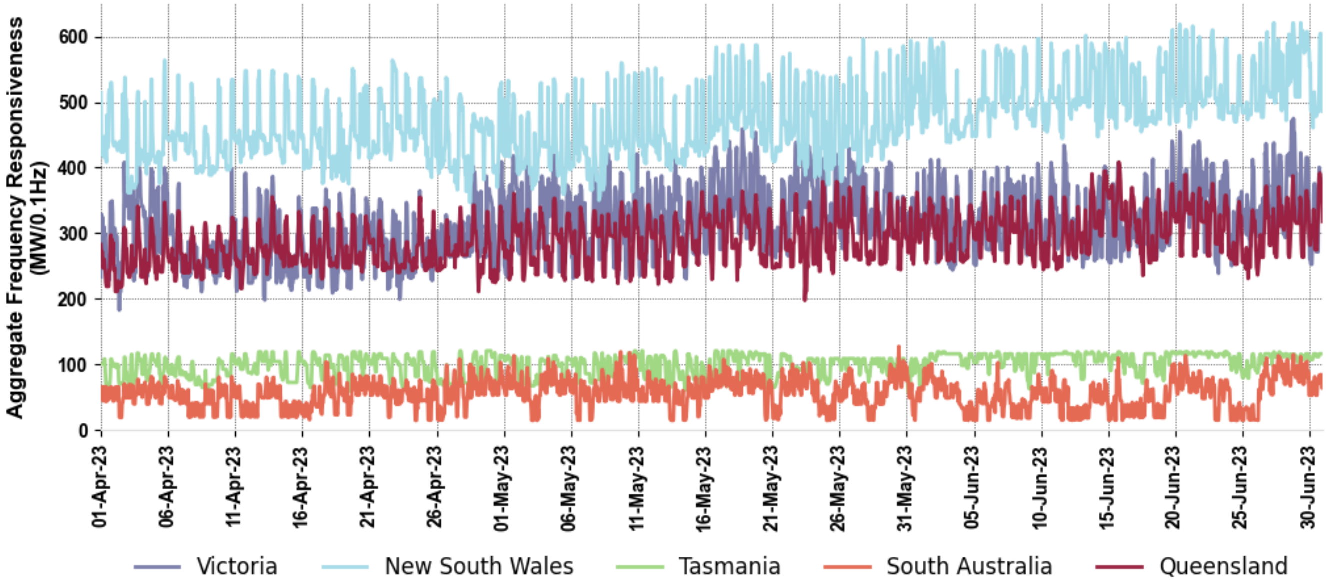


1.3 Aggregate frequency responsiveness

This section reports a measure that was included for the first time in the Q3 2022 quarterly report to fulfill the new reporting obligation introduced in clause 4.8.16(b)(1A) of the NER.

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

Figure 4 Estimated aggregate frequency responsiveness in NEM regions



2 Achievement of the Frequency Operating Standard

2.1 Overview

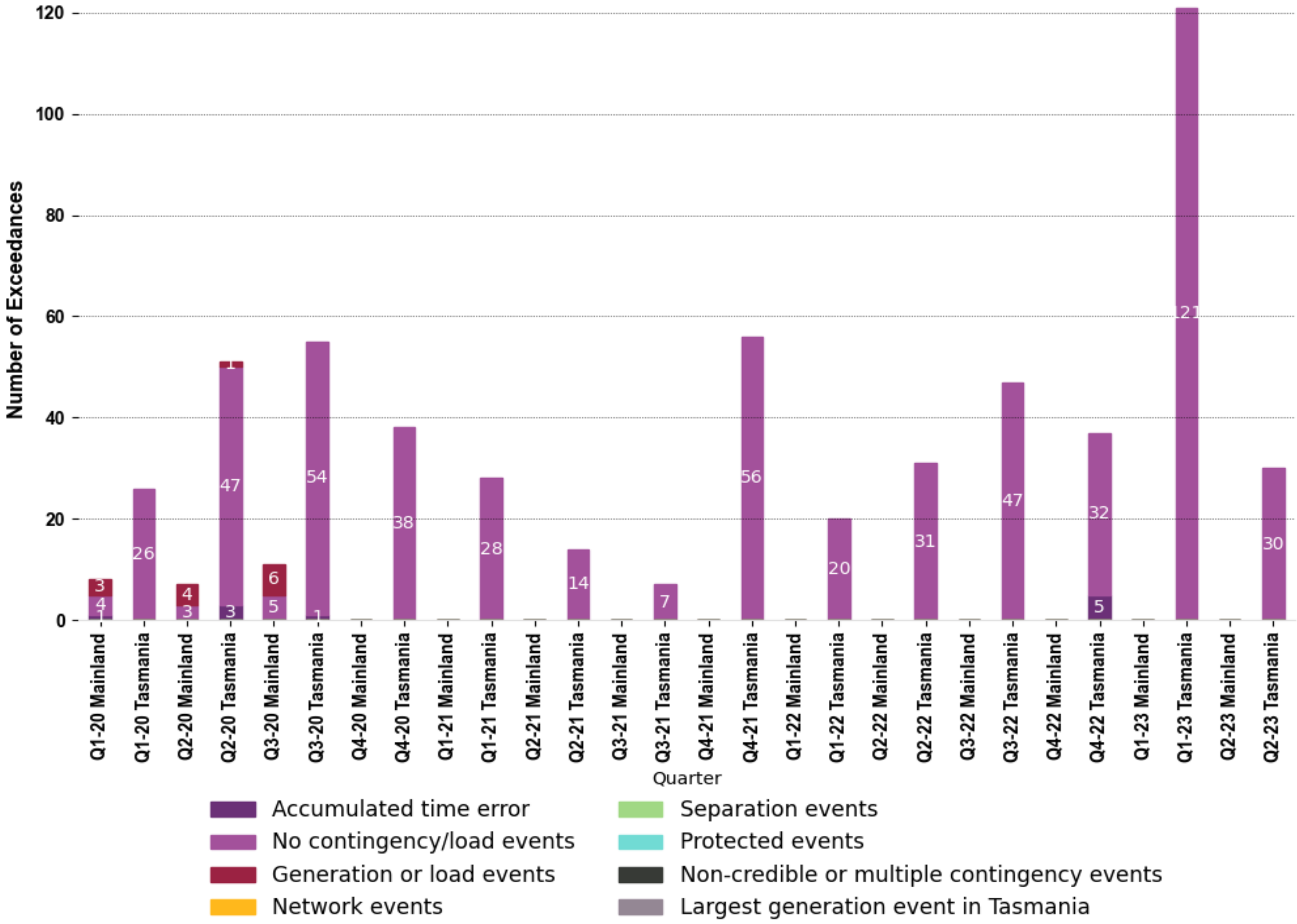
AEMO's assessment of the achievement of the requirements of the FOS in Q2 2023 is summarised in Table 2, and further information on the FOS exceedances is in Section 2.2. Additionally, Figure 5 shows the FOS exceedances since 2020.

As noted in Section 1.1, the Reliability Panel completed a review of the FOS in April 2023. The revised FOS introduces new requirements that will apply from 9 October 2023.

Table 2 FOS assessment in the mainland and Tasmania

Requirement	Mainland	Tasmania	Further commentary
1 – Accumulated time error	Achieved	Achieved	
2 – No contingency/load events • **Within normal operating frequency excursion band (NOFEB) at all times** • **Recovered in five minutes** • **Within NOFB 99% of the time**	 Achieved Achieved Achieved	 Exceeded 30 times Achieved Achieved	 See Section 2.2.2
3 – Generation or load events • **Contained** • **Recovered within five minutes**	 Achieved Achieved	 Achieved Achieved	
4 – Network events • **Contained** • **Recovered within five minutes**	 Achieved Achieved	 Achieved Achieved	
5 – Separation events • **Contained** • **Managed within 10 minutes**	 No separation events No separation events	 No separation events No separation events	
6 – Protected events	No protected events	No protected events	
7 – Non-credible or multiple contingency events	Achieved	Achieved	
8 – Largest generation event in Tasmania	Not applicable	Achieved	

Figure 5 FOS exceedances in the mainland and Tasmania



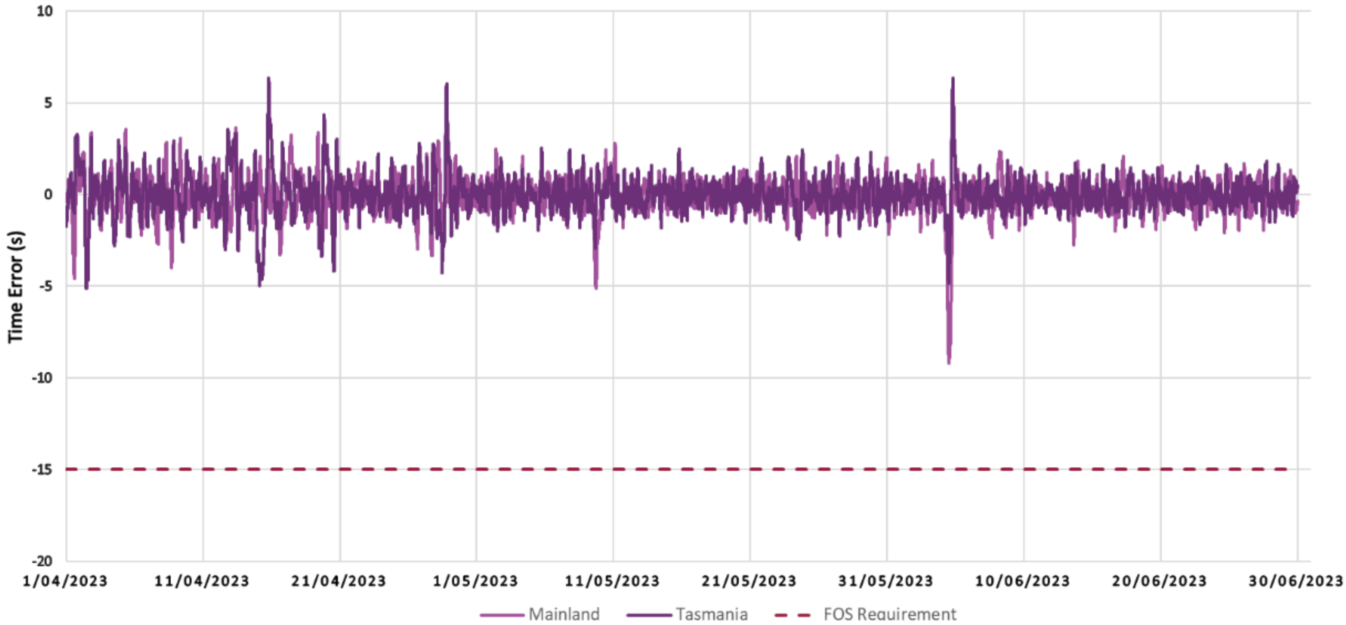
2.2 Operation during identified FOS exceedances

This section provides further detail on the exceedances of the FOS listed in Table 2.

2.2.1 Time error exceedances

Figure 6 shows that there were no time error exceedances in Q2 2023.

Figure 6 Time error in the mainland and Tasmania in Q2 2023



2.2.2 Frequency excursions without a contingency event outside the NOFEB

Table 3 shows, for Q2 2023, frequency excursions outside the applicable normal operating frequency excursion band (NOFEB) where an associated contingency event has not been identified.

Table 3 Number of frequency excursions without identified contingency outside the NOFEB in Q2 2023

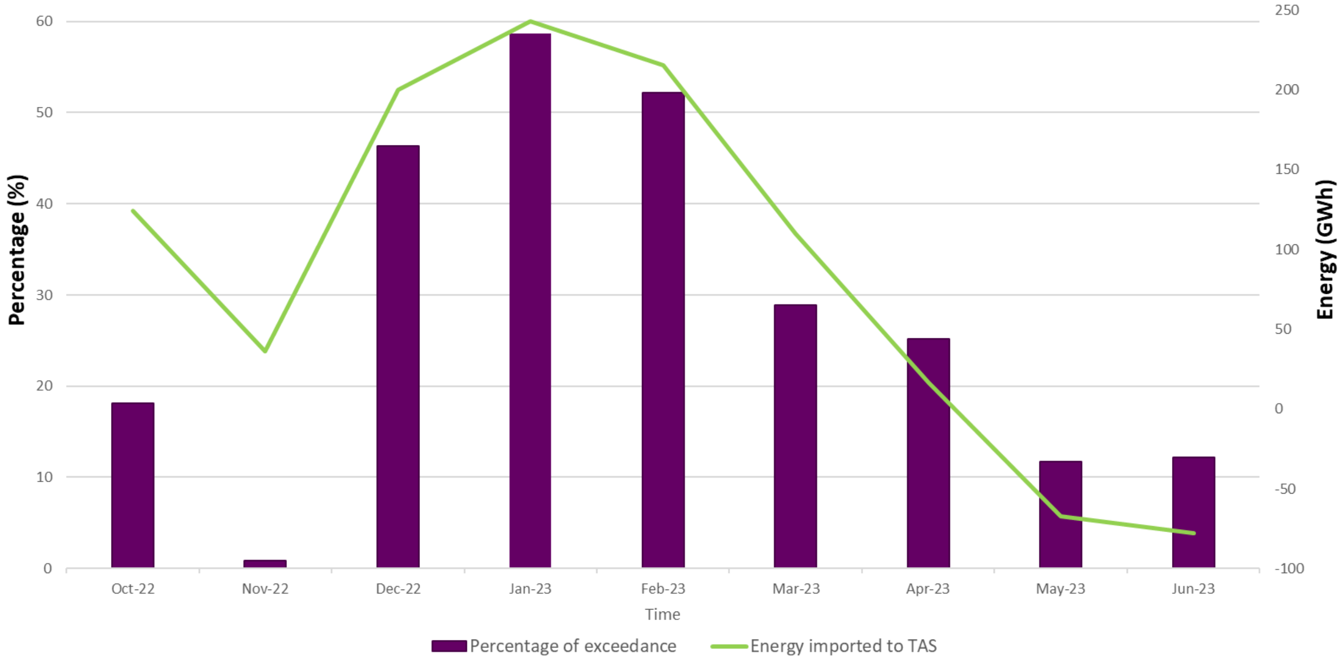
Event	Low/high/both frequency event	Number of events Mainland	Number of events Tasmania
No contingency or load event noted	LOW	0	28
	HIGH	0	2
	BOTH	0	0

Tasmania had significantly fewer events this quarter where frequency exceeded the NOFEB without an associated contingency event compared to Q1 2023; 121 events occurred in Q1 2023 compared to 30 events in Q2 2023.

All 30 instances identified in Q2 2023 occurred during times when the Basslink high voltage direct current (HVDC) interconnector was at its import limit, undergoing a reversal, or out of service. The frequency in Tasmania observed during these periods was characteristic of the smaller Tasmanian system when it lacks the support generally provided by the Basslink frequency controller.

The decline in number of exceedances outside the NOFEB can be explained by the fact that Basslink was not required to operate at high import capacity as often in Q2 2023 compared to Q1 2023, and in part by the decrease of energy imported to Tasmania during Q2 2023. Therefore, the functionality of Basslink's frequency controller would not have been limited as often in Q2 2023 compared to Q1 2023. This is shown in Figure 7.

Figure 7 Percentage of time where import to Tasmania exceeded 400 megawatts (MW) and energy imported to Tasmania



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 A2.2.

Table 4 shows the maximum RoCoF recorded in the mainland in each month in Q2 2023, 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).

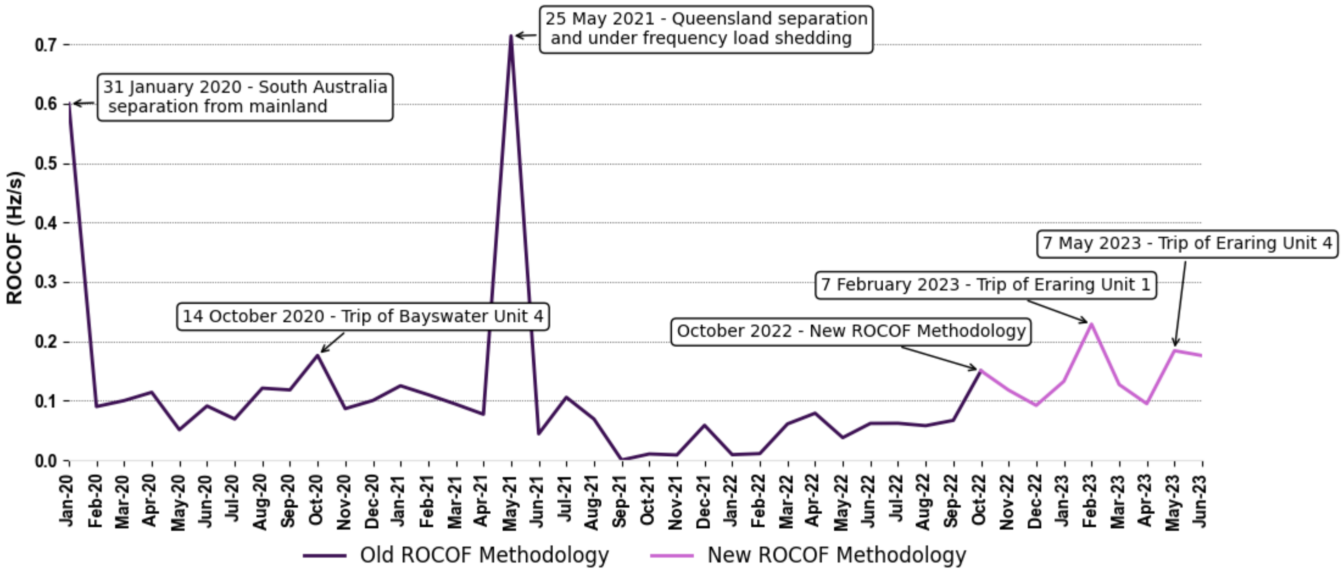
Table 4 RoCoF during frequency events in the mainland

Month	RoCoF (Hz/s)	Associated event	Event time
Apr-23	-0.09	Trip of STAN-4 at 292 MW	27/04/2023 10:33
May-23	-0.18	Trip of Eraring Power Station Unit 4 at 601 MW	7/05/2023 4:20
May-23	-0.13	Trip of Vales Point Power Station Unit 6 at 574 MW	10/05/2023 13:16
Jun-23	-0.18	Trip of Kogan Creek Power Station Unit 1 at 759 MW	12/06/2023 12:33

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

Figure 8 shows the maximum RoCoF recorded in the mainland NEM since Q1 2020.

Figure 8 Monthly maximum RoCoF recorded in any mainland region in 2020-23 (HZ/s)



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 Q2 2023 is shown in Figure 9, and a distribution chart for the mainland is provided in Figure 1010 and for Tasmania in Figure 11. 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 9 Time series mainland and Tasmania inertia in Q2 2023 (megawatt seconds (MWs))

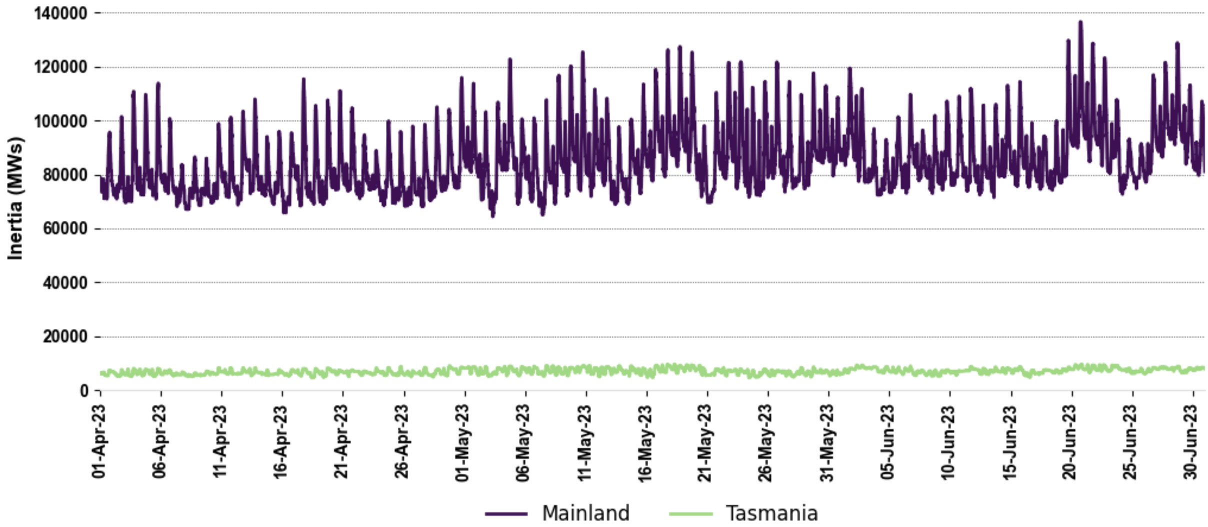


Figure 10 Distribution of mainland inertia in Q2 2023

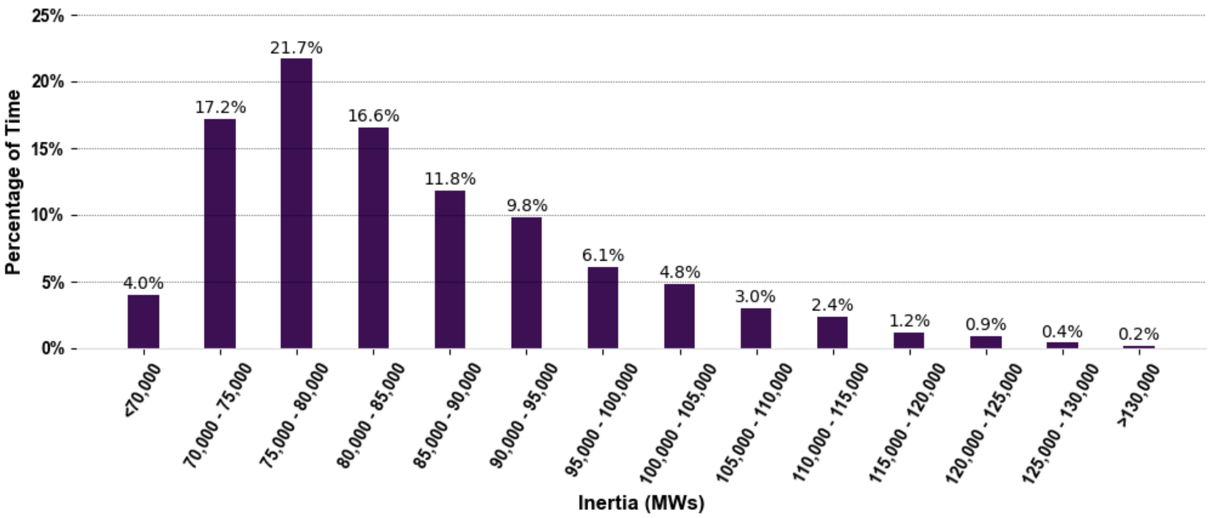
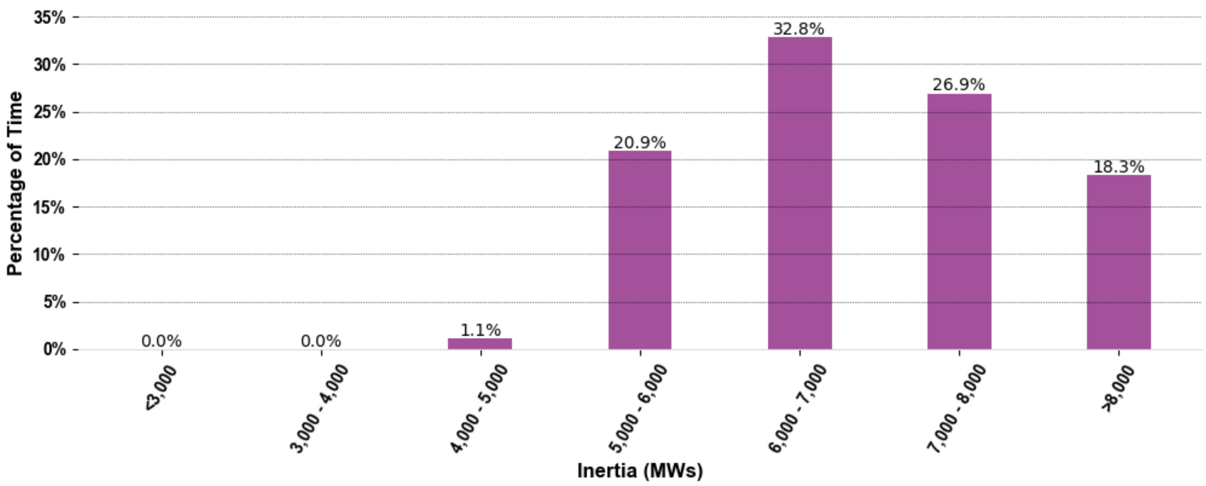


Figure 11 Distribution of Tasmania inertia in Q2 2023



4 Area control error

The calculation of area control error (ACE) methodology by AEMO's automatic generation control (AGC) system is outlined in Appendix A2.3. Figure 12 and Figure 13 show the minimum and maximum ACE per half-hourly trading interval in Q2 2023 in the mainland NEM and Tasmania, respectively.

Figure 12 Minimum and maximum ACE per half-hour in mainland NEM

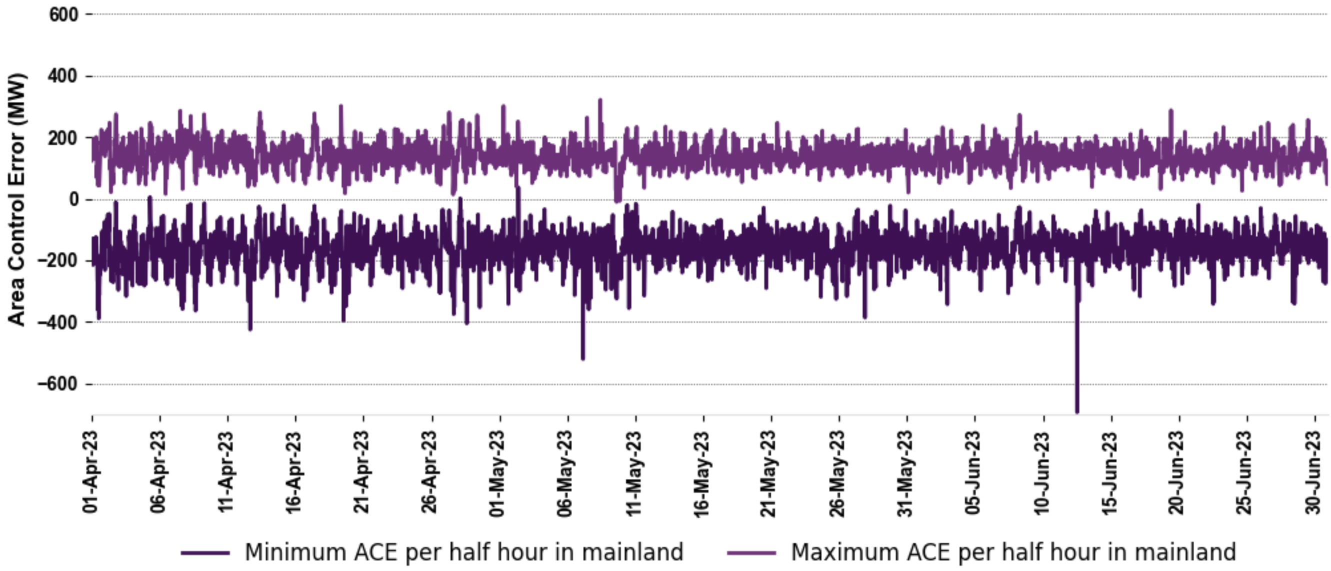
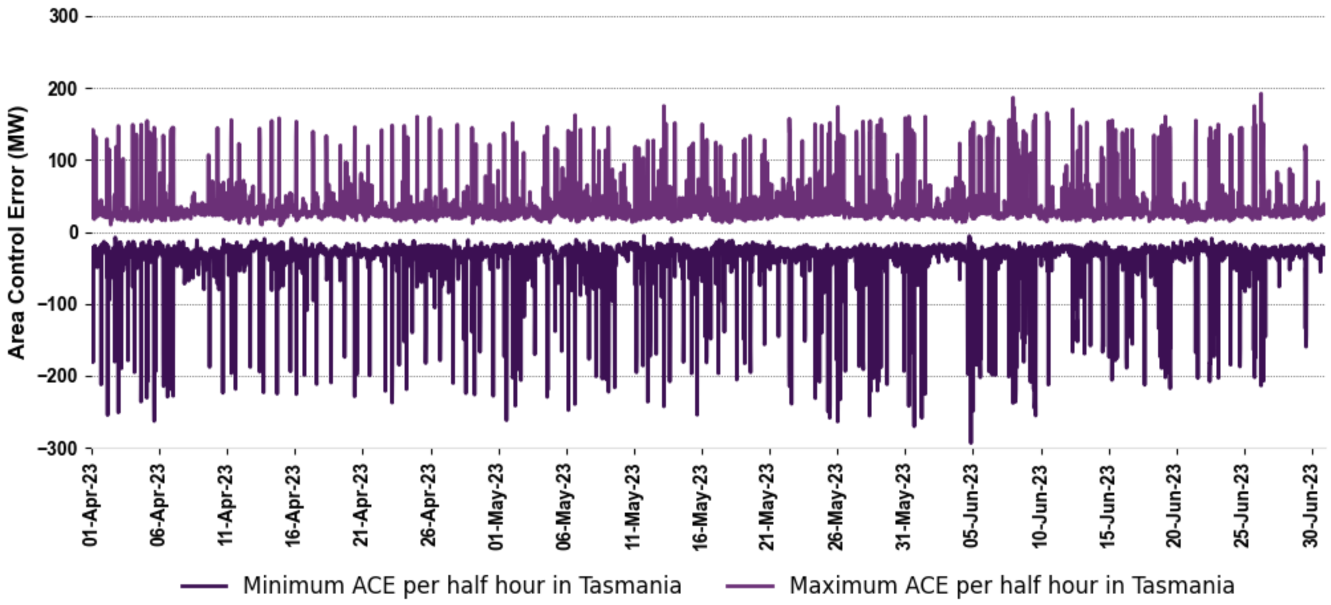


Figure 13 Minimum and maximum ACE per half-hour in Tasmania



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[24].

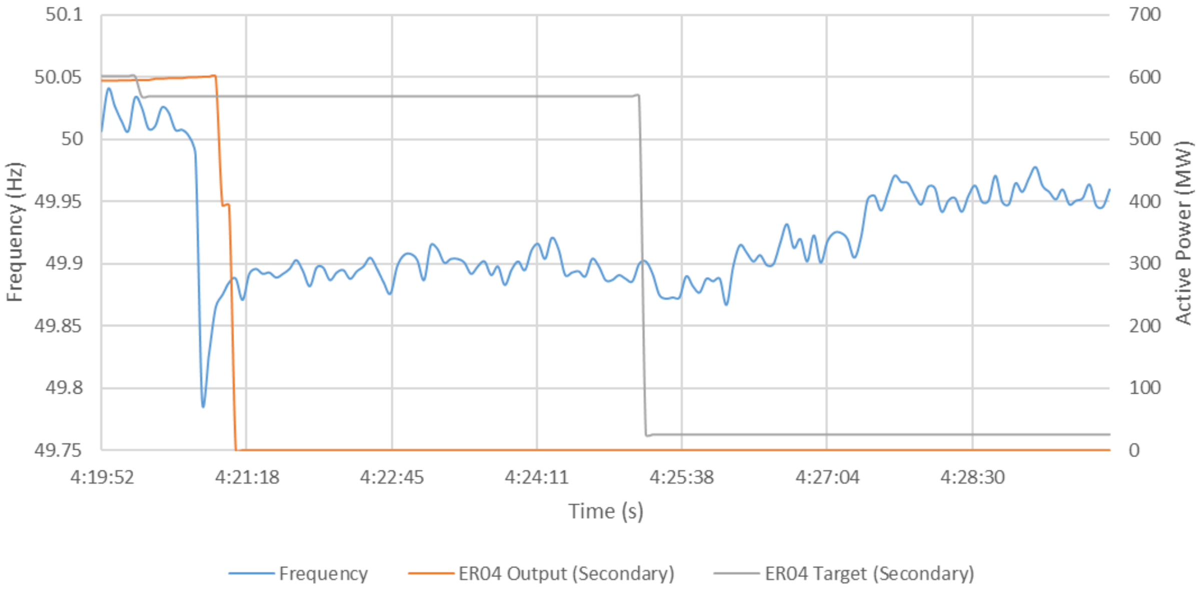
Mainland frequency exceeding the operational frequency tolerance band (OFTB) is the existing guideline for identifying a reviewable operating incident which affected power system frequency and is one basis for inclusion in this section. Other reviewable operating incidents may be included here at AEMO's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

There were no reviewable operating incidents in Q2 2023 relating to frequency exceeding the OFTB. However, AEMO notes the following events which caused the frequency to go outside the NOFB:

- Eraring Unit 4 tripped on 7 May 2023, which resulted in a loss of 600 megawatts (MW). As shown in Figure 14, minimum frequency observed in the mainland was 49.79 Hz, which is well within FOS requirements for a single generation event. The frequency recovered to within NOFB after 8 seconds.

  An analysis was conducted for all participants enabled for Fast Raise FCAS (R6) during this event and concluded that all providers enabled for the event met their R6 requirements, which contributed to the rapid recovery of frequency.

Figure 14 Frequency disturbance following Eraring Unit 4 generator trip

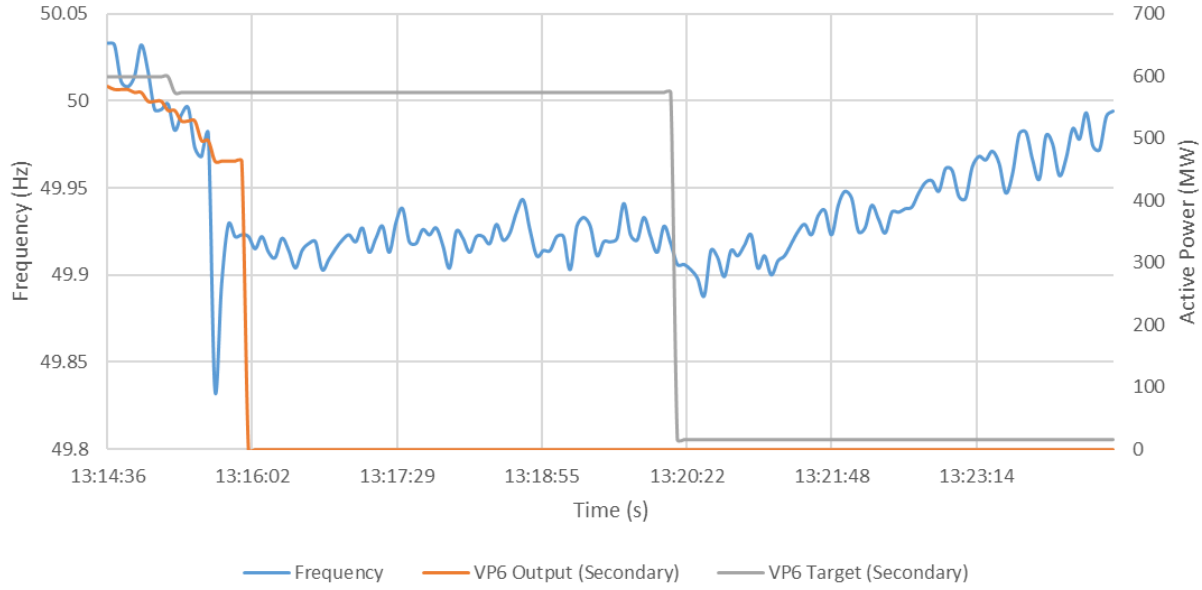


- Vales Point Unit 6 tripped on 10 May 2023, which resulted in a loss of 600 MW. As shown in Figure 14, the minimum frequency observed in the mainland was 49.83 Hz, which was also well within FOS requirements for a single generation event. The frequency recovered to within NOFB after 2 seconds.

  The response of FCAS providers during this incident is being investigated. AEMO has confirmed adequate response from six providers and is continuing to analyse the response of two providers.

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

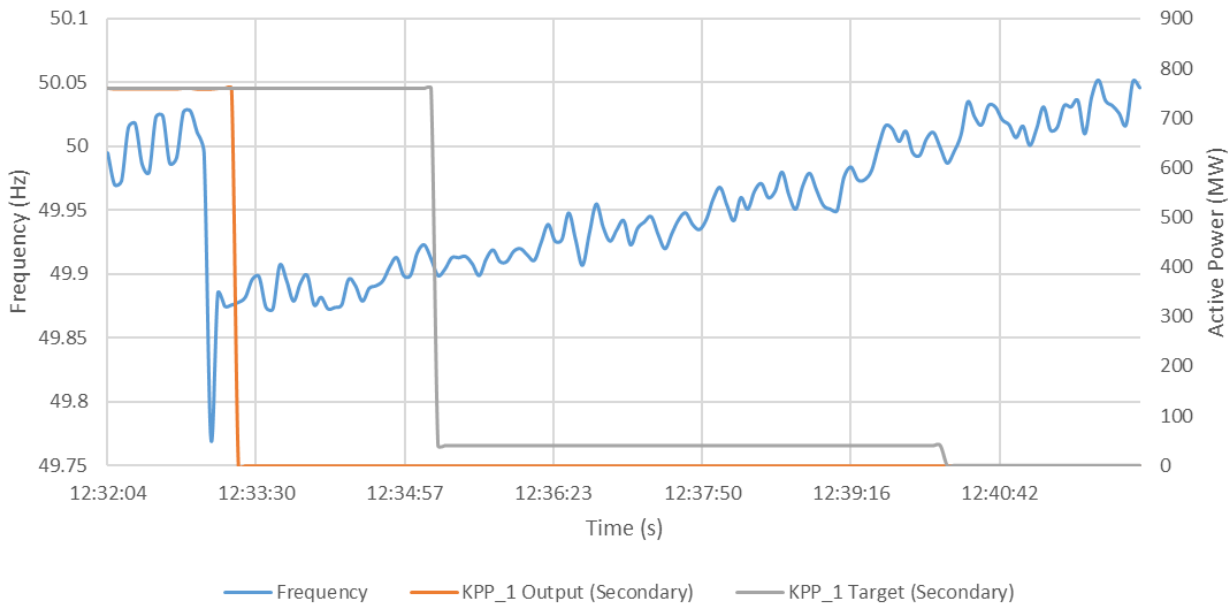
Figure 15 Frequency disturbance following VP06 generator trip



- Kogan Creek tripped on 12 June 2023, which resulted in a loss of 760 MW. This event is of particular relevance to frequency performance, as this is generally considered the 'design event' for Raise Contingency FCAS, since this is around the maximum contingency size under typical circumstances. As shown in Figure 14, the minimum frequency observed in the mainland was 49.72 Hz, which is well within the FOS requirements and is particularly encouraging for the strength of the system. The frequency also recovered quickly, returning to the within normal operating frequency band (NOFB) after 6 seconds.

  The response of FCAS providers during this incident is being investigated. AEMO has confirmed adequate response from 31 providers and is continuing to analyse the response of 12 providers.

Figure 16 Frequency disturbance following KPP_1 generator trip



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 4-second SCADA scan intervals.

This is not intended to be a comprehensive list of all credible contingency events that affected power system frequency, as some thresholds must be selected to reasonably limit the number of events included. However, AEMO intends to include enough events of system significance to form a reasonable understanding of the ongoing success or otherwise of the NEM's aggregate ability to control frequency during major disturbances.

Events not featured below may include, but are not limited to:

- Generation and load events where the abrupt change of generation or consumption was less than 200 MW or was over a timespan longer than 4 seconds.
- Network events, separation events, non-credible events, multiple contingency events, and protected events.

Table 5 and Table 6 demonstrate that both generation and load events in Q2 2023 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 7 is a list of contingencies from Q2 2023 meeting the criteria noted above.

Table 5 Credible generation events since 2020

Quarter	Number of events	Average contingency size (MW)	Average frequency nadir (Hz)	Average recovery time (s)
Q2 2023	9	407	49.86	4
Q1 2023	23	338	49.90	3
2022	77	347	49.88	5
2021	72	365	49.86	9
2020	96	362	49.80	93

Table 6 Credible load events since 2020

Quarter	Number of events	Average contingency size (MW)	Average frequency nadir (Hz)	Average recovery time (s)
Q2 2023	13	257	50.07	0
Q1 2023	23	286	50.09	0
2022	18	278	50.09	0
2021	58	261	50.09	N/A
2020	50	275	50.15	20

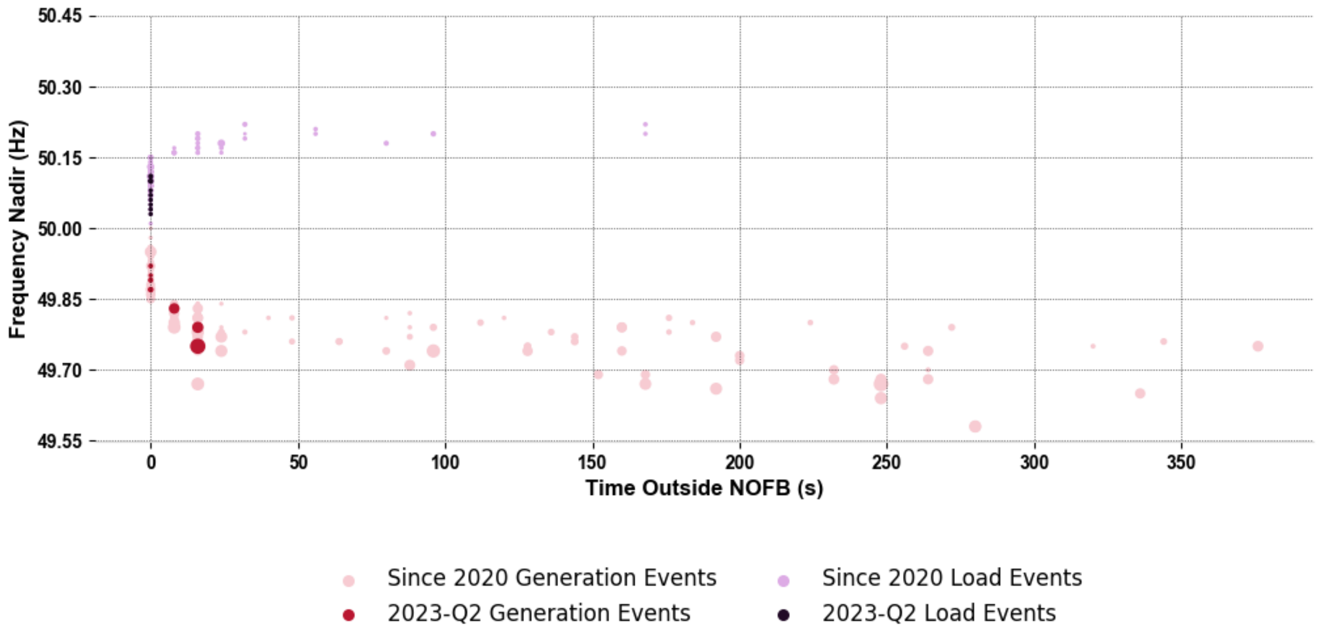
Table 7 Credible generation and load events in Q2 2023

Event time	Unit	Contingency size (MW)	Frequency nadir/peak (Hz)	Recovery to NOFB (s)	FOS compliant?
7/04/2023 20:13	APD2	232	50.06	0	YES
12/04/2023 13:53	TOMAGO3	285	50.1	0	YES
27/04/2023 10:33	STAN-4	292	49.87	0	YES
1/05/2023 7:45	APD2	235	50.05	0	YES
7/05/2023 4:21	ER04	601	49.79	16	YES
8/05/2023 10:52	TOMAGO4	320	50.1	0	YES
8/05/2023 13:24	TOMAGO1	304	50.11	0	YES
9/05/2023 10:02	TARONG#3	292	49.92	0	YES
10/05/2023 6:43	APD2	239	50.06	0	YES
10/05/2023 13:16	VP6	574	49.83	8	YES
12/05/2023 6:45	APD2	231	50.07	0	YES
13/05/2023 5:55	APD2	238	50.04	0	YES
18/05/2023 7:21	APD2	241	50.05	0	YES
22/05/2023 6:41	APD2	251	50.04	0	YES
25/05/2023 14:29	APD2	255	50.07	0	YES
26/05/2023 17:45	APD2	251	50.08	0	YES
12/06/2023 10:44	YWPS4	252	49.9	0	YES
12/06/2023 12:33	KPP_1	759	49.75	16	YES
12/06/2023 16:00	MPP_2	273	49.89	0	YES
17/06/2023 3:39	MPP_2	330	49.87	0	YES
19/06/2023 10:44	APD2	262	50.03	0	YES
20/06/2023 10:32	STAN-2	292	49.89	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 7 to illustrate the distribution of frequency outcomes following credible contingency events in Q2 2023, in comparison to events since 2020.

Figure 17 Frequency outcomes of identified credible generation and load events



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

A2. Methodology

A2.1 Aggregate frequency responsiveness methodology

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

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

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

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

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

where:

- **D** is unit percentage droop, and zero [0] represents that no droop is implemented.
- **N** is unit N.
- **MW** is unit initial MW in trading interval.
- **T** is trading interval, ending on the hour.
- **EFR** is unit estimated frequency response.
- **C** is unit maximum capacity.

Estimated available aggregate frequency responsiveness is estimated for each hour interval in MW/0.1Hz using the following equation:

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

where:

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

Further assumptions in the calculation of aggregate frequency responsiveness include:

- Unit frequency response is calculated using the *Maximum Capacity* from AEMO registration information.
- Units are assumed to provide frequency response in accordance with their implemented droop setting as confirmed by AEMO when implementing the mandatory PFR changes.
- Units that have not implemented PFR settings are not included in the calculation.

- The calculation ignores frequency response deadband. This is equivalent to assuming no deadband.
- Internal unit limits to providing frequency response, such as ramp rates, delays or minimum and maximum operating levels, are not modelled.
- Primary Frequency Response Requirements (PFRR) variations agreed with AEMO are not modelled in the calculation.
- Frequency response is not included from distributed energy resources and units which provide FCAS but not energy.
- Load relief is not included.

A2.2 Rate of change of frequency (RoCoF) methodology

The RoCoF following a frequency event is an indicator of the evolving system response to frequency disturbances. Measuring a system variable such as RoCoF is influenced by several assumptions concerning the available data and measurement methodology.

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/transmission network service provider (TNSP) PMU system at 1-second intervals. This is a higher resolution than is available from the Global Positioning System (GPS) clock system and is therefore more appropriate for assessing RoCoF.

For the purposes of this report, RoCoF has been assessed as the recorded change in frequency per second over an interval of one second, or over an interval of two seconds when a measurement is not available. RoCoF assessment has not been attempted for periods longer than two seconds without data. For the purposes of this report, the maximum RoCoF recorded between five seconds prior and 30 seconds after each frequency event is considered to be the RoCoF associated with that event.

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

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

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

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 milliseconds (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 considered to be 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.

A2.3 Area Control Error (ACE) methodology

As per the Regulation FCAS Contribution Factors Procedure[25], AEMO calculates an ACE representing the MW equivalent size of the current frequency deviation and accumulated frequency deviation (time error) of the NEM system. ACE may be considered to represent a rough proxy for the required Regulation FCAS volume.

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

where:

- **Bias** is the area frequency bias and is a tuned value that represents the conversion ratio between MW and 0.1 Hz of frequency deviation.
- **F** is the current measured system frequency.
- **FS** is the scheduled frequency (50.0 Hz).
- **FO** is a frequency offset representing accumulated frequency deviation, that is, time error.

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