Frequency and Time Error Monitoring – Quarter 1 2021

May 2021

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 (mainland and Tasmania) for the period January to March 2021 inclusive. AEMO has prepared this report in accordance with clause 4.8.16(b) of the National Electricity Rules, using information available as at the date of publication, unless otherwise specified.

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1. 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).

This document reports on the frequency and time error performance observed during January, February and March 2021 (Q1 2021) in all regions of the NEM as required by clause 4.8.16(b) of the NER[2]. The Queensland, New South Wales, Victoria, and South Australia regions are referred to as the 'mainland' through the report.

The *Power System Frequency and Time Deviation Monitoring Report – Reference Guide*[3] outlines the calculation procedure used by AEMO to produce the quarterly Frequency and Time Error Monitoring report. Where applicable, analysis of the delivery of slow and delayed frequency control ancillary services (FCAS) presented in this report is based on 4-second resolution SCADA information derived from AEMO's systems.

Unless otherwise noted, mainland frequency data has been 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 has been sampled at 4-second intervals using the most recent Network Operations and Control System (NOCS) frequency measurement preceding each 4-second interval.

Special note for Q1 2021: Due to a significant outage of AEMO SCADA on 24 January 2021, frequency data from a secondary source has been used throughout this report for the period between 1530 hrs and 1700 hrs. Details of the SCADA event are presented in Section 4.6.

In this report:

- Section 2 summarises frequency performance in Q1 2021.
- Section 3 assesses the lower number of FOS exceedances in Q1 compared to recent quarters in 2020, demonstrating the material improvement in power system performance.
- Section 4 examines in detail all instances where the requirements of the FOS were not met in Q1 2021.
- Section 5 details the estimates of significant rate of change of frequency (ROCOF) events for Q1 2021.
- Section 6 discusses adjustments to Automatic Generation Control (AGC) undertaken during Q1 and the results of these actions.

AEMO, with support from the industry, is continuing to progress other initiatives intended to improve frequency control in the NEM. Progress on these initiatives is discussed in Section 7 of this report.

Appendix A lists credible generation and load contingency events from Q1 2021. The inclusion of this list is intended to highlight the NEM's aggregate frequency response capability, and to affirm that frequency control during major disturbances continues to be generally satisfactory, notwithstanding any exceptions identified in this report.

Appendix B is an addendum to the final report on the power system incident that occurred on 4 January 2020 and provides further commentary on an item identified for further analysis[4].

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

[2] See https://www.aemc.gov.au/regulation/energy-rules/national-electricity-rules/current.

[3] At http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Ancillary-services/Frequency-and-time-error-monitoring.

[4] See https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2020/final-report-nsw-and-victoria-separation-event-4-jan-2020.pdf.

2. State of frequency performance

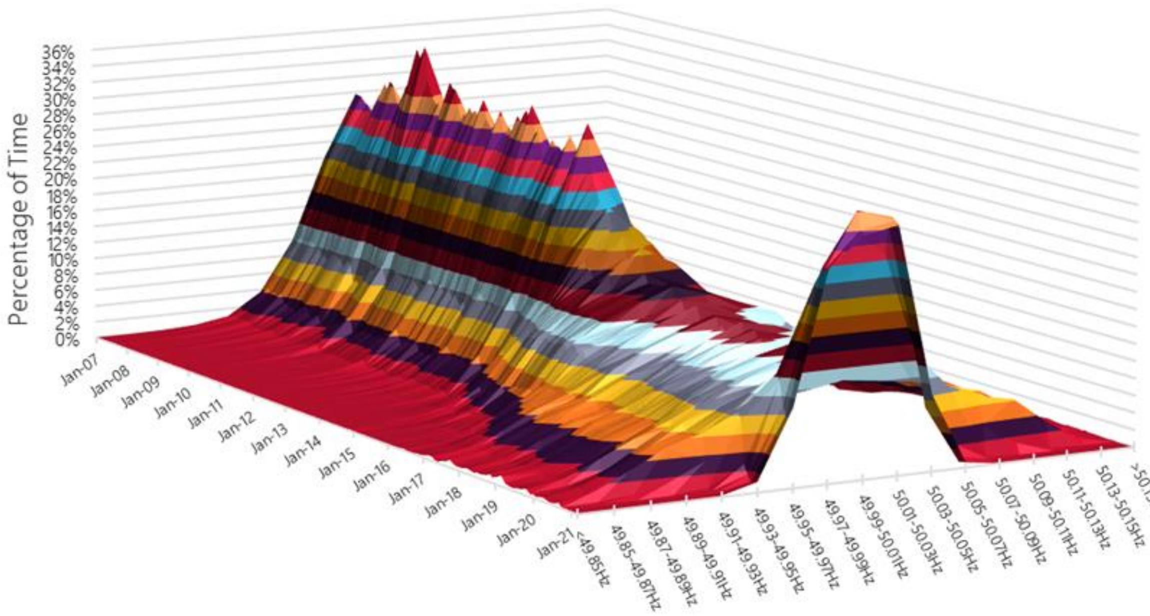
The observed improvements to key NEM frequency metrics following the implementation of widespread primary frequency response (PFR) continued throughout Q1 2021. Notable improvements in metrics include:

- Frequency remained within the Normal Operating Frequency Band (NOFB) for more than 99% of the time in Q1 2021 in both the mainland and Tasmania, for the first time since Q4 2015.
- There were no exceedances of the FOS in the mainland in Q1 2021.
- There were no occasions of frequency departing the NOFB without an identifiable cause in the mainland.
- There were no instances of time error accumulating beyond the FOS requirement of ±15 seconds (s).
- Well-contained frequency deviations and much improved recovery times following generation and load events continued to be observed.
- Time error management improved through Automatic Generation Control (AGC) tuning, resulting in a rebalance of lower and raise regulation utilisation.

As of 1 April 2021, approximately 36 gigawatts (GW) of scheduled generation have applied agreed settings in accordance with the Interim Primary Frequency Response Requirements (IPFRR). Updates regarding the rule change are available on AEMO's website[5].

A noteworthy incident in Q1 2021 was AEMO's loss of SCADA on 24 January 2021. The provision of widespread PFR from a large proportion of the NEM generation fleet helped control frequency within the FOS requirements during this period. This event is discussed in Section 4.6 to highlight a valuable demonstration of operational resilience in action.

Figure 1 Monthly frequency distribution



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

3. Achievement of the Frequency Operating Standard

AEMO's assessment of the achievement of the requirements of the FOS in Q1 2021 is summarised in Table 1.

Table 1 Frequency Operating Standard and assessment in the mainland and Tasmania

Requirement	Mainland	Tasmania	Further commentary
1 – Accumulated time error	Achieved	Achieved	
2 – No contingency/load events			
• **Within Normal Operating Frequency Excursion Band (NOFEB) at all times**	Achieved	Exceeded 25 times	See Section 0
• **Recovered in five minutes**	Achieved	Exceeded 3 times	See Section 4.2.2
• **Within NOFB 99% of the time**	Achieved	Achieved	
3 – Generation or load events			
• **Contained**	Achieved	Achieved	
• **Recovered within five minutes**	Achieved	Achieved	
4 – Network events			
• **Contained**	Achieved	Achieved	
• **Recovered within five minutes**	Achieved	Achieved	
5 – Separation events			
• **Contained**	No separation events	No separation events	
• **Managed within 10 minutes**	No separation events	No separation events	
6 – Protected events	No protected events	No protected events	
7 – Non-credible or multiple contingency events	Achieved	Achieved	
8 – Largest generation event in Tasmania	Not applicable	Achieved	

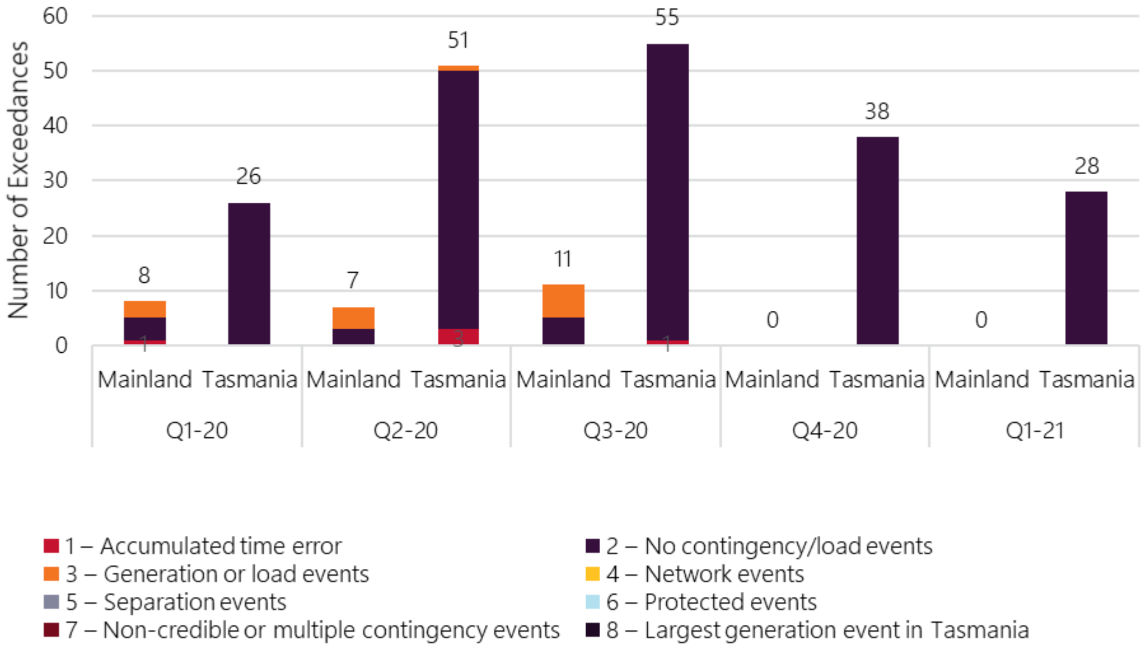
The number of exceedances of the FOS in Q1 2021 was lower than observed in the preceding quarters of 2020, before PFR was substantially implemented, as shown in Figure 2. Most identified exceedances throughout 2020 related to generation events, load events, or periods without an identified contingency.

It is apparent that implementation of the Mandatory PFR rule has contributed to reducing:

- The number of FOS exceedances following generation or load events, by increasing the available dynamic system frequency response to sudden and significant supply and demand imbalances.

- The number of FOS exceedances during periods without an identified contingency, by reducing the likelihood of frequency being near the NOFB boundaries to begin with and subsequently straying beyond the NOFB, while also increasing the available restorative response to such events should they occur.

Figure 2 FOS exceedances in the mainland and Tasmania



4. Frequency performance

Section 4 describes frequency performance in Q1 2021 against each of the key FOS requirements.

4.1 Time error

Table A.2 of the FOS (requirement 1) specifies that the accumulated time error should be maintained within the range ±15 seconds in the mainland (except for an island or during supply scarcity) and in Tasmania (except for an island or following a multiple contingency event).

The ranges of accumulated time error in the mainland and Tasmania in Q1 2021 are provided in Table 2. Time error did not exceed the FOS requirements in Q1 2021.

Table 2 Maximum and minimum time error measurements for the mainland and Tasmania

Value	Mainland	Tasmania
Highest positive time error (seconds)	4.61	4.21
Lowest negative time error (seconds)	-7.25	-12.22

Figure 3 shows the percentage of time where mainland time error was outside the ±1.5 second threshold at which accumulated time error begins to increase regulation FCAS volumes above their base values. Due to the combined impact of PFR implementation and AGC tuning completed in December 2020, time error was better balanced in Q1 2021 and generally much lower in magnitude, remaining more often within the range of ±1.5 seconds compared to the previous quarter.

Figure 3 Proportion of time mainland time error was outside of ±1.5 seconds

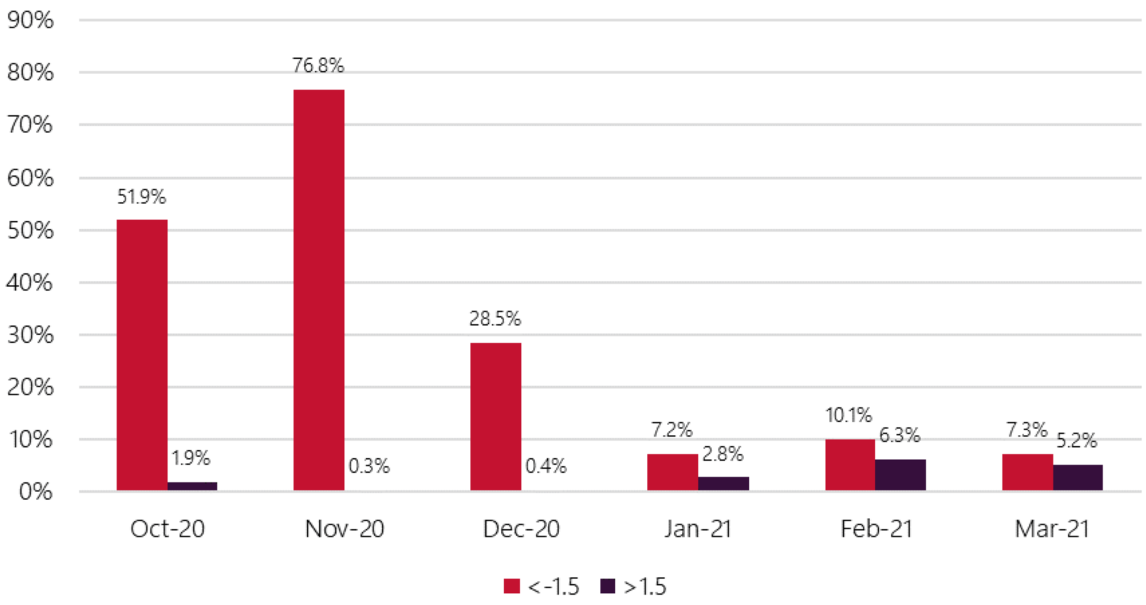
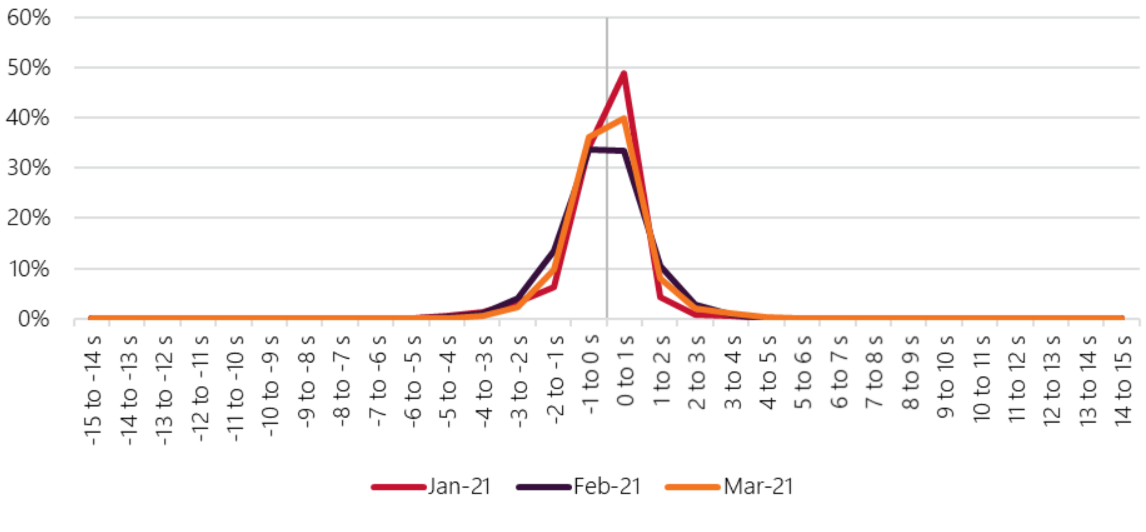


Figure 4 shows the distribution of mainland time error in the months of Q1 2021. The deterioration of time error in the negative direction evident in Q4 2020 has been reversed. AEMO will continue to monitor this aspect of system performance as the implementation of PFR continues with Tranche 2 (80 – 100 megawatts [MW]) and 3 (<80 MW) generators.

Figure 4 Mainland time error distribution



4.2 Operation during periods without contingencies or load events

When there are no associated contingency or load events in the interconnected system, table A.2 of the FOS (requirement 2) specifies that system frequency should be maintained within the applicable Normal

Operating Frequency Excursion Band (NOFEB) and not remain outside the applicable NOFB for more than five minutes on any occasion or more than 1% of the time over any 30-day period[6].

These requirements are summarised in Table 3.

Table 3 FOS requirements for no contingency or load event in an interconnected system

Region	Containment	Stabilisation	Recovery
Mainland	49.75 to 50.25 hertz (Hz) 49.85 to 50.15 Hz, 99% of the time	49.85 to 50.15 Hz within 5 minutes	
Tasmania	49.75 to 50.25 Hz 49.85 to 50.15 Hz, 99% of the time	49.85 to 50.15 Hz within 5 minutes	

4.2.1 Frequency excursions without a contingency event outside the NOFEB

Frequency excursions outside the applicable NOFEB where an associated contingency event has not been identified are shown in Table 4 for Q1 2021.

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

Event	Low/high/both frequency event	Number of events mainland	Number of events Tasmania
No contingency or load event noted	LOW	0	20
	HIGH	0	4
	BOTH	0	1

Mainland

No frequency events without an identified contingency in Q1 2021 in the mainland exceeded the NOFEB. The last such event in the mainland occurred on 28 January 2020 and was discussed in the Q1 2020 Frequency and Time Error Monitoring Report[7].

Tasmania

The 25 Tasmanian events where frequency exceeded the NOFEB in Q1 2021 without an associated contingency event are characteristic of the smaller Tasmania system. This is less than seen in recent quarters; in Q4 2020, 38 frequency events without an identified contingency exceeded the NOFEB in Tasmania.

AEMO has noted that at least 12 of the 25 instances identified in Q1 2021 are primarily due to unforecast changes in generation from Tasmania's operating wind farms – Woolnorth Wind Farm, Musselroe Wind Farm, Cattle Hill Wind Farm, and Granville Harbour Wind Farm – at times when Basslink was operating at its import limit, hence unable to provide further frequency support via its frequency controller.

The circumstances differ on each occasion, but similarities include:

- Rapid reductions in wind speed.

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

[7] See https://www.aemo.com.au/-/media/files/electricity/nem/security_and_reliability/ancillary_services/frequency-and-time-error-reports/quarterly-reports/2020/frequency-and-time-error-monitoring-quarter-1-2020.pdf.

- Turbine cut-out due to high wind speeds.
- Plant controller settings within some wind farms creating large deviations from the forecast and actual output when the Semi Dispatch Cap (SDC) is released.

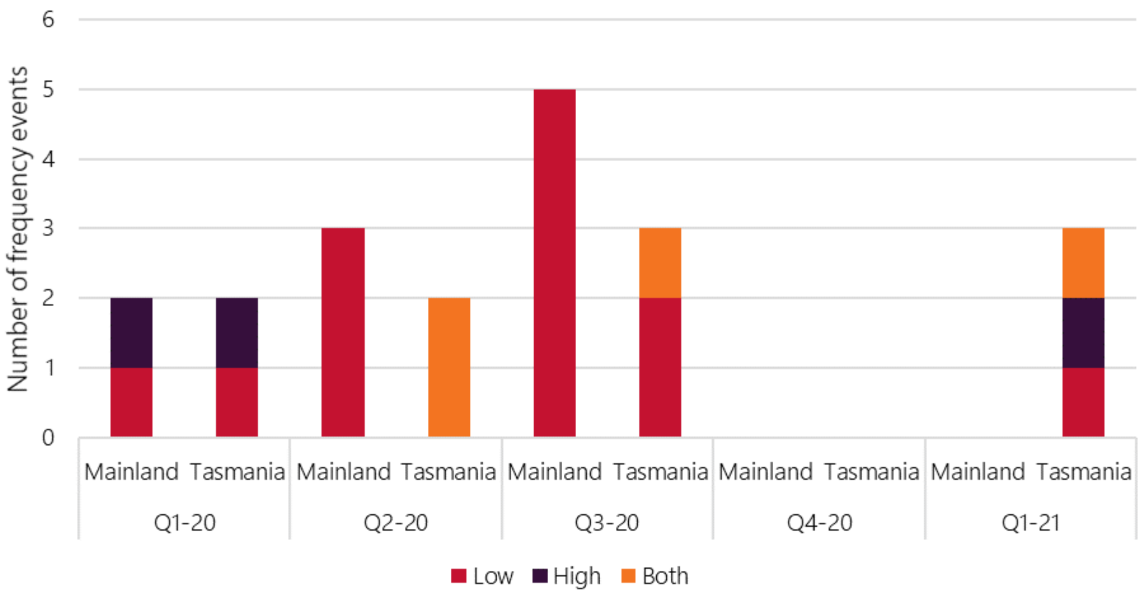
These observations provide insight into the growing challenge of maintaining effective frequency control in the mainland NEM as greater penetrations of inverter-connected generation are online alongside diminishing numbers of synchronous units.

Under system normal conditions, the FOS specifies largely the same requirements for Tasmania as it does for the mainland. However, as a much smaller system, Tasmania is more sensitive to supply/demand imbalances which manifest as larger frequency deviations. As PFR is further implemented across the NEM, including in Tasmania, AEMO will monitor and adjust control settings in Tasmania as required. In addition, AEMO has requested some of the wind farms to implement the plant controls required to reflect the true capability of the generation unit to minimise the forecast errors.

4.2.2 Frequency excursions without a contingency event outside the NOFB and not recovered in FOS timeframe

Frequency excursions outside the applicable NOFB and not recovered in the applicable FOS timeframe where an associated contingency event has not been identified are shown in Figure 5 for Q1 2021.

Figure 5 Frequency excursions without identified contingency outside the NOFB and not recovered in the FOS timeframe in the mainland and Tasmania



Mainland

In Q1 2021 there were no frequency excursions from the NOFB in the mainland without an associated contingency event that were not recovered in the FOS timeframes. This outcome is substantially improved from quarters 1-3 in 2020, as seen in Figure 5.

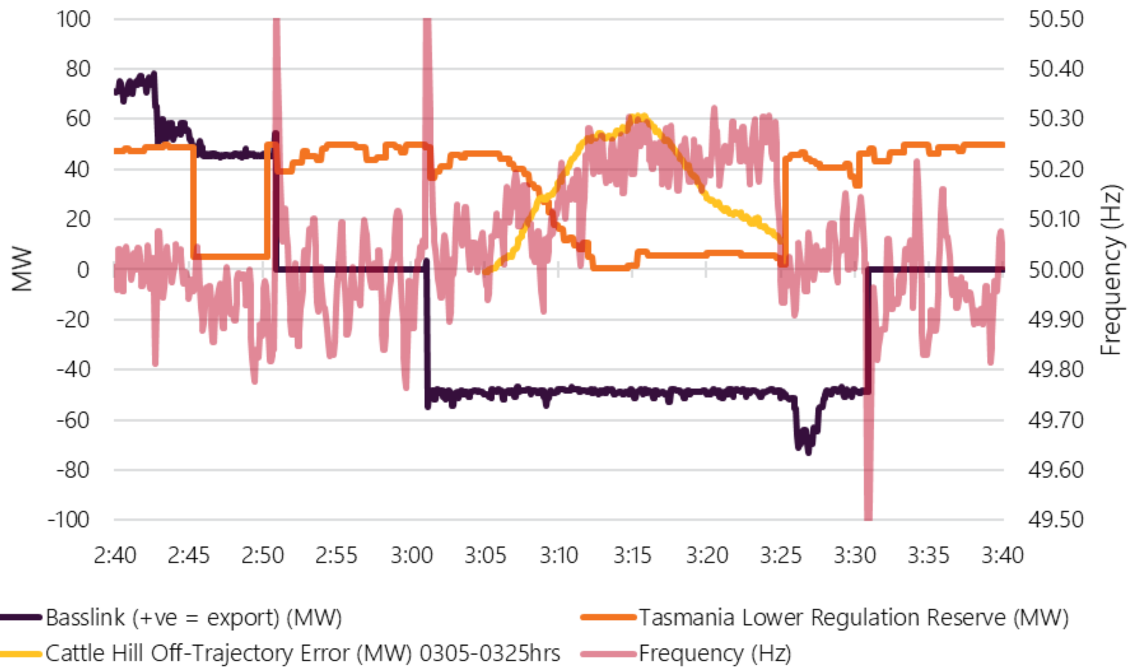
The implementation of the Mandatory PFR rule is considered to have reduced the likelihood of frequency being near the NOFB boundaries. This outcome markedly reduces the likelihood that frequency wanders beyond the NOFB, while also increasing the available restorative response to such events should they occur.

Tasmania

Three events occurred in Q1 2021 where Tasmanian frequency took longer than the FOS timeframe of five minutes (300 seconds) to recover despite there being no associated contingency:

- At 0235 hrs on 5 February 2021, the significant curtailment of non-scheduled Woolnorth Wind Farm from 116 MW at a time when Basslink was near full import into Tasmania reduced Tasmanian frequency to a minimum of 49.69 Hz, and the frequency remained outside the NOFB for 405 seconds.
- From 0311 hrs to 0324 hrs on 12 February 2021 (see Figure 6), Tasmanian frequency remained elevated near 50.2 Hz outside the NOFB. This event followed a reversal of Basslink from export to import (into Tasmania) mode, which is a common occurrence. During the same period, Cattle Hill Wind Farm was up to 60 MW above target as its generation increased rapidly. The resulting increase in supply into the Tasmanian system was not able to be fully counteracted by the available 50 MW of lower regulation enabled in Tasmania. The reserve of lower regulation decreased to zero and remained low until approximately 0325 hrs, when frequency returned inside the NOFB.
- From 1200 hrs on 14 March 2021, Tasmania frequency remained below the NOFB for 348 seconds during the withdrawal of Reece 2 unit from service; this reduced generation faster than anticipated by its market target in the 1205 hrs and 1210 hrs dispatch intervals. Basslink was near full import at the time and thus was unable to provide further support via its frequency controller.

Figure 6 Tasmanian frequency event on 12 February 2021



4.2.3 Frequency within the NOFB over 30-day rolling average

AEMO calculates daily the percentage of time that frequency remained inside the NOFB in the preceding 30-day window. The minimum daily estimate from each month is reported in Figure 7 and Figure 8. The figures show 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 remained within the NOFB for more than 99% of the time in Q1 2021. Since the implementation of the Mandatory PFR rule commenced, there has been a reduction in the number and length of frequency excursions from the NOFB and a corresponding increase in time spent within the NOFB. The percentage of time that Tasmania's frequency was within the NOFB also met the FOS requirement of 99% as seen in Figure 8 which is the best quarterly performance since 2015.

There were notably no events in Q1 2021 where frequency drifted outside the NOFB where no specific contingency event was identified. When contingency events did occur, frequency was contained within the

NOFB or recovered to the NOFB faster than experienced during prior quarters for similar events. Further detail is available in Appendix A.

Figure 7 Frequency in NOFB since 2013, minimum daily time percentage in prior 30-day window

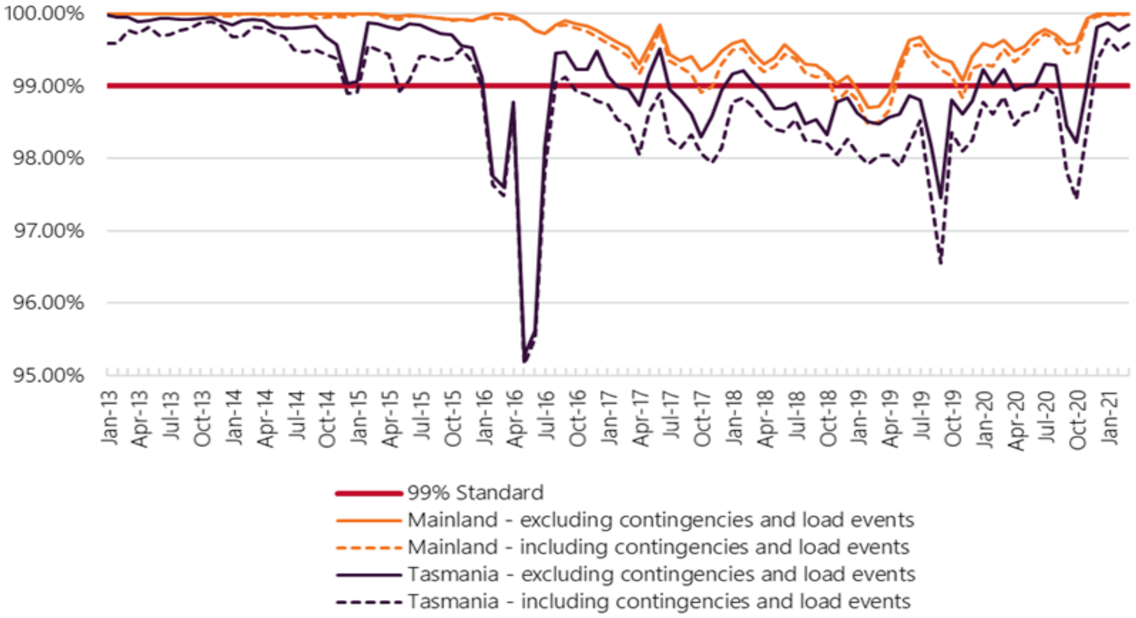
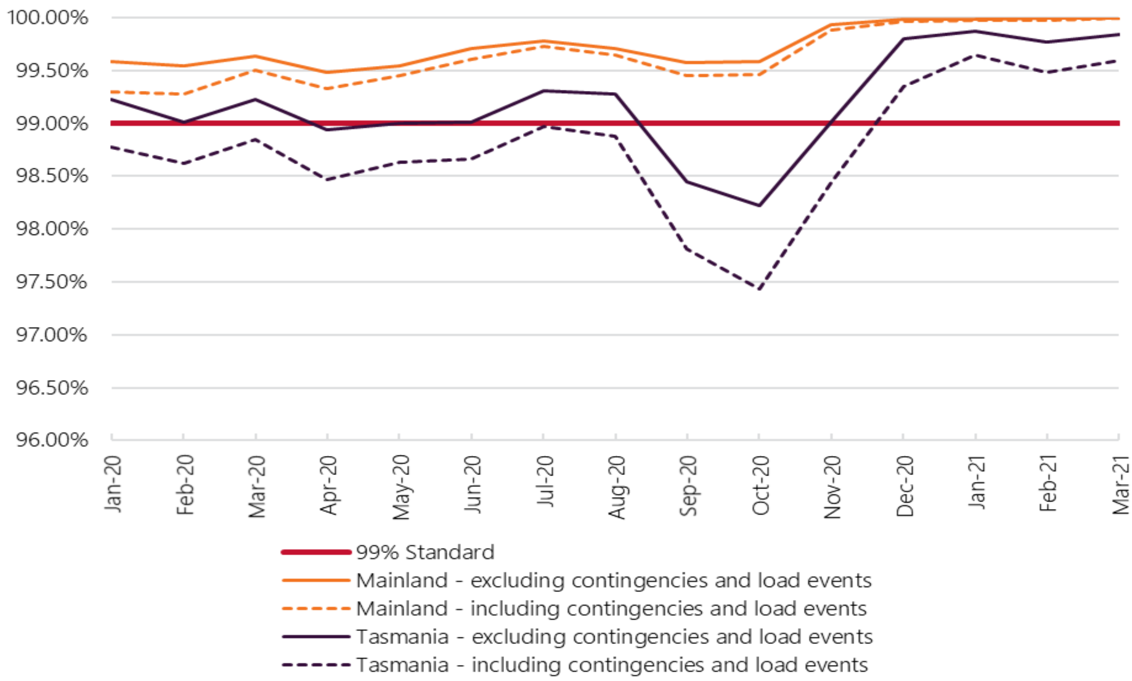


Figure 8 Frequency in NOFB since 2020, minimum daily time percentage in prior 30-day window



4.2.4 Frequency performance within the NOFB

The FOS does not include requirements for the control of frequency within the NOFB. However, frequency performance within the NOFB is important, because it demonstrates the overall tightness and stability of frequency and indicates the likelihood of frequency being close to nominal (50 Hz) when a contingency event occurs, increasing the prospects of good containment and fast recovery.

Figure 9 and Figure 10 show the frequency distribution in the mainland and Tasmania in Q1 2021, compared with data from 2010 as an example of a period where frequency control was tighter than that observed in recent years. The alignment of the frequency distribution during Q1 2021 to that observed in 2010 is one clear indicator of the significantly improved frequency control since the widespread implementation of PFR.

Figure 9 Mainland frequency distribution

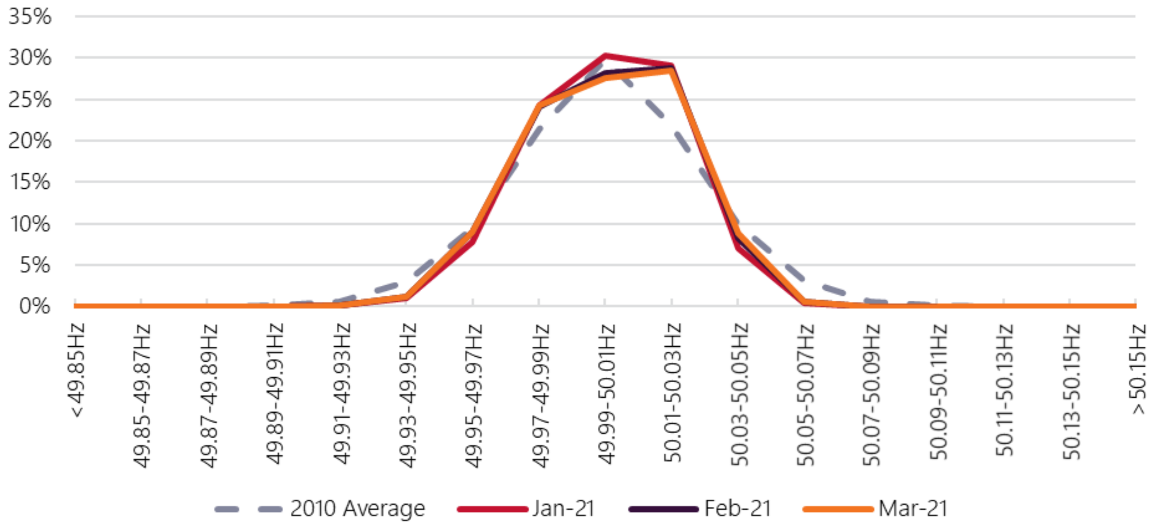


Figure 10 Tasmania frequency distribution

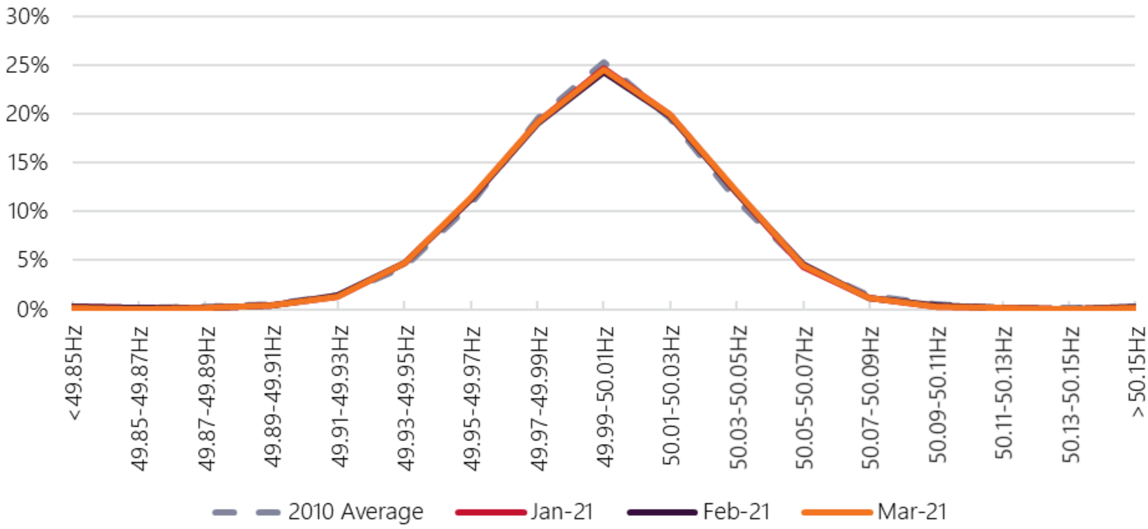
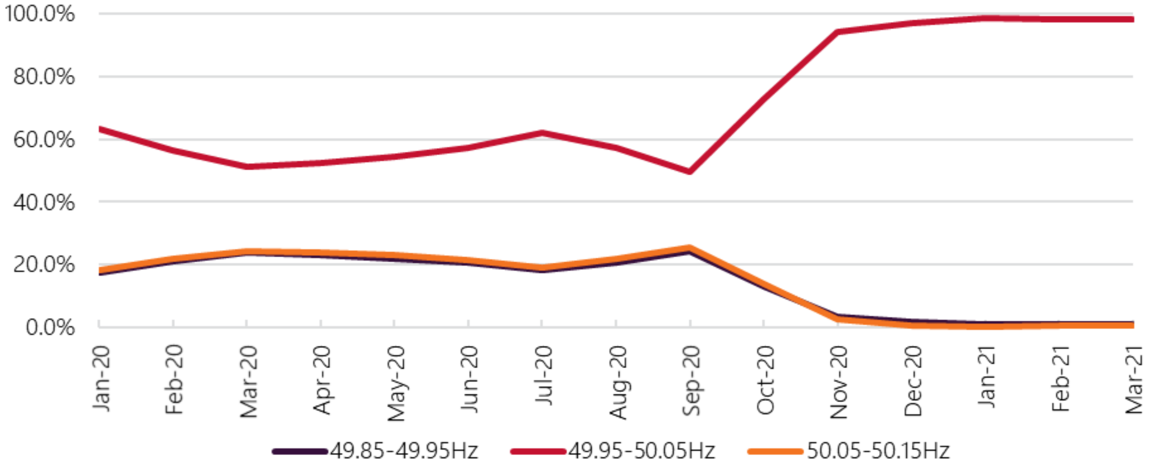


Figure 11 shows that when the frequency is within the NOFB in the mainland, the proportion of time that frequency is closer to the boundaries of the NOFB decreased sharply throughout Q4 2020 to below 10% and remained there throughout Q1 2021. Meanwhile the proportion of time that frequency remained near 50 Hz (between 49.95 Hz and 50.05 Hz) continued to be substantially above 90%.

Figure 11 Mainland frequency time percentage spent within selected bands within the NOFB



4.3 Operation during generation or load contingency events

When there is an associated generation or load event in an interconnected system, table A.2 of the FOS (requirement 3) specifies that system frequency should be maintained within the applicable Generation and Load Change Band (GLCB) and not remain outside the applicable NOFB for more than five minutes in the mainland or more than 10 minutes in Tasmania, as described in Table 5.

Table 5 FOS requirements for a generation or load event in an interconnected system

Region	Containment	Stabilisation	Recovery
Mainland	49.5 to 50.5 Hz	49.85 to 50.15 Hz within five minutes	
Tasmania	48.0 to 52.0 Hz	49.85 to 50.15 Hz within 10 minutes	

4.3.1 Frequency excursions following a generation or load event outside the Generation and Load Change Band

In Q1 2021, there were no frequency excursions following a generation or load event where frequency exceeded the GLCB.

4.3.2 Frequency excursions following a generation or load event not recovering to the NOFB within the FOS timeframe

In Q1 2021 there were no frequency excursions following a generation or load event where frequency was not recovered to the NOFB within the applicable FOS timeframe (five minutes in the mainland and 10 minutes in Tasmania).

This outcome is a substantial improvement on previous quarters in 2020 where several credible generator contingency events resulted in protracted recoveries of frequency. In Q3 2020 there were six such frequency excursions following a generation event that did not recover to the NOFB within the FOS timeframe.

4.3.3 Frequency performance following generation or load events

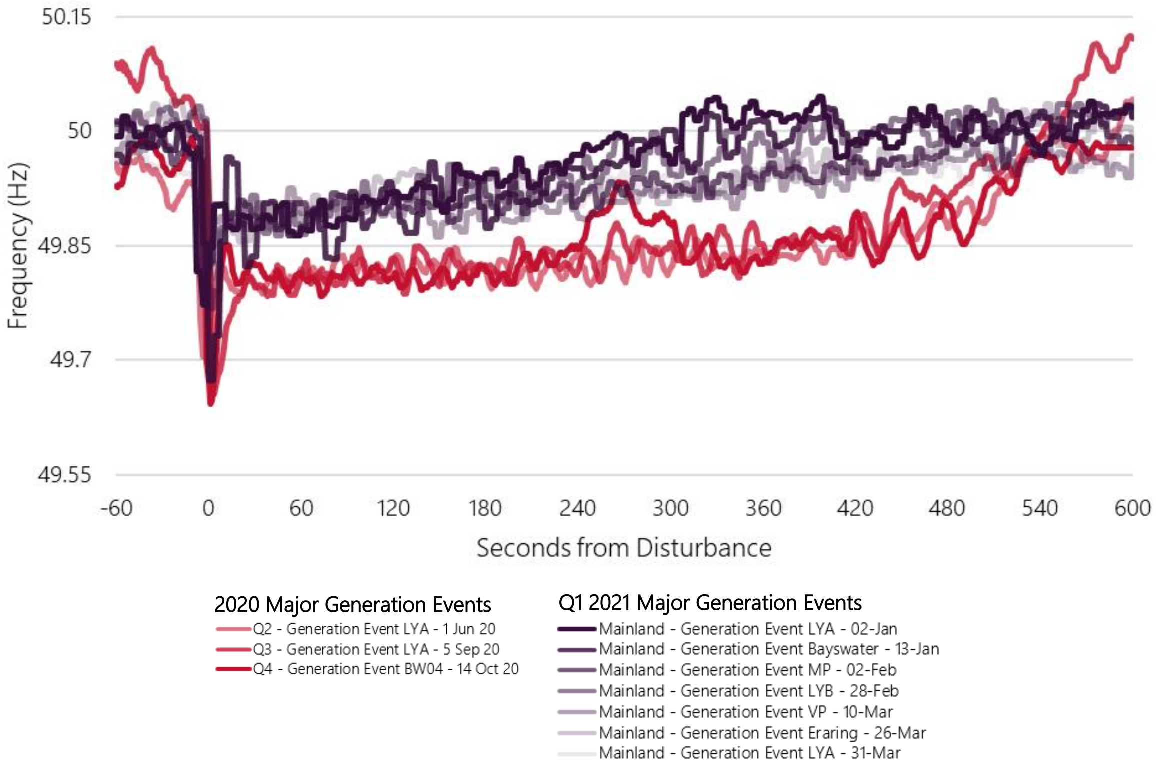
AEMO assesses frequency performance over time with metrics that complement the requirements of the FOS. Several generation and load events occurred in Q1 2021 which demonstrate the frequency response characteristic of the NEM system, despite these events remaining within the boundaries of the FOS.

Events AEMO considers particularly notable and interesting are described in this section. Appendix A has detailed information about frequency outcomes following other selected generation and load contingency events.

Generation events in Q1 2021

Figure 12 shows the frequency outcomes for ten events across 2020 and Q1 2021 where a major NEM generator tripped. The contingency sizes below range from 506 MW to 666 MW. There is evident improvement in the frequency recoveries in Q1 2021 following these significant imbalances in NEM supply and demand. Frequency was continually contained within the required GLCB and recovered to within the NOFB within 300 seconds as required by the FOS.

Figure 12 Selected generation events in Q1 2021 and 2020



4.4 Operation during separation contingency events

When there is a separation event, table A.2 of the FOS (requirement 5) sets out expectations for the initial frequency containment, recovery, and revised requirements for further contingency events in the islanded region. AEMO is required to maintain system frequency within the applicable containment band and should recover frequency in the NOFB within the FOS timeframe.

No separation events occurred during Q1 2021 in the mainland or Tasmania, noting that a trip of Basslink is conventionally considered a network event and not a separation event.

4.5 Operation during network, protected, non-credible, or multiple contingency events

When there is a network contingency, protected event, non-credible contingency, or multiple contingency event in an interconnected system, table A.2 of the FOS (requirements 4 to 7) specifies that frequency should be maintained within the applicable containment band and recover to the NOFB in the FOS timeframe.

4.5.1 Frequency excursions following network, protected, non-credible or multiple contingency events not within the FOS

There were no instances in Q1 2021 in the mainland or Tasmania where a frequency excursion following a network event, protected event, non-credible event, or multiple contingency event was not contained within the applicable containment band and/or not recovered to the NOFB within the FOS timeframe.

4.5.2 Frequency performance following network and non-credible events

AEMO assesses frequency performance over time with metrics that complement the requirements of the FOS. Several network and non-credible events occurred in Q1 2021 which demonstrate the frequency response characteristics of the NEM system, despite these events remaining within the boundaries of the FOS.

Trips of Basslink in Q1 2021

There were three trips of Basslink in Q1 2021, and each demonstrated a satisfactory frequency outcome in both Tasmania and the mainland. Frequency in Tasmania was contained within ±0.6 Hz through a combination of control scheme actions and frequency response from generators in the islanded power system. Figure 13 to Figure 15 detail the frequency outcomes observed during these three events.

Figure 13 Tasmanian and mainland frequency during outage of Basslink on 12 January 2021

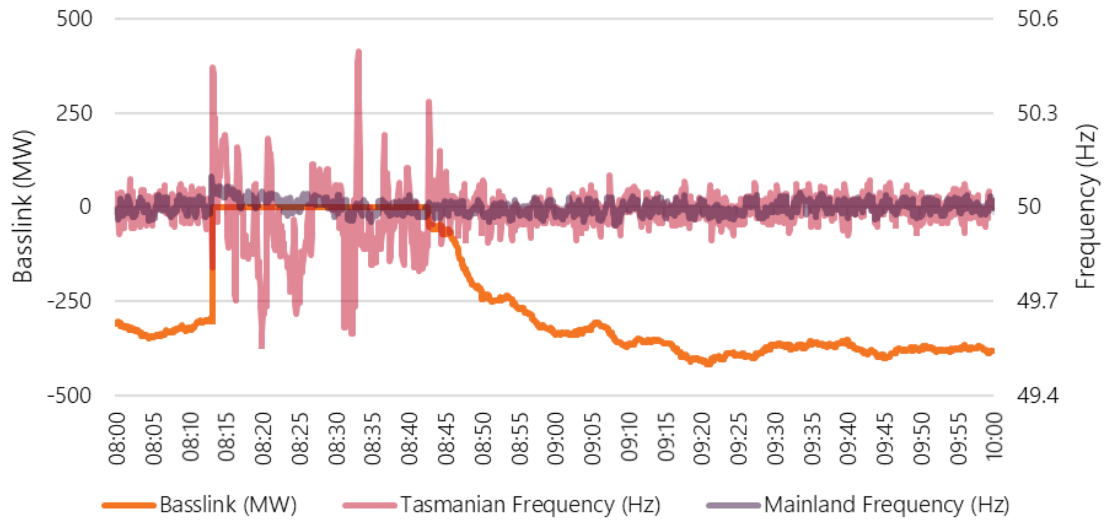


Figure 14 Tasmanian and mainland frequency during outage of Basslink on 9 February 2021

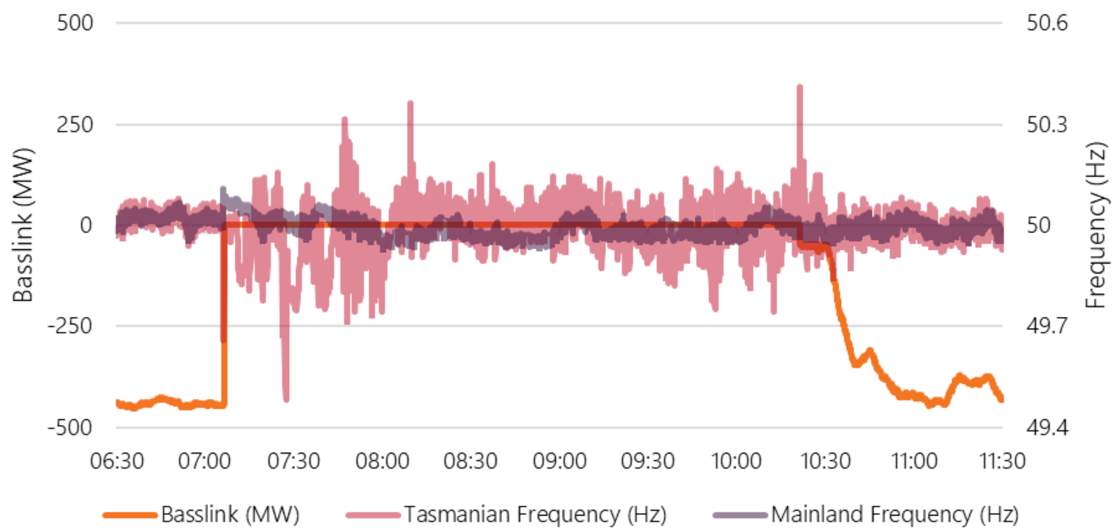
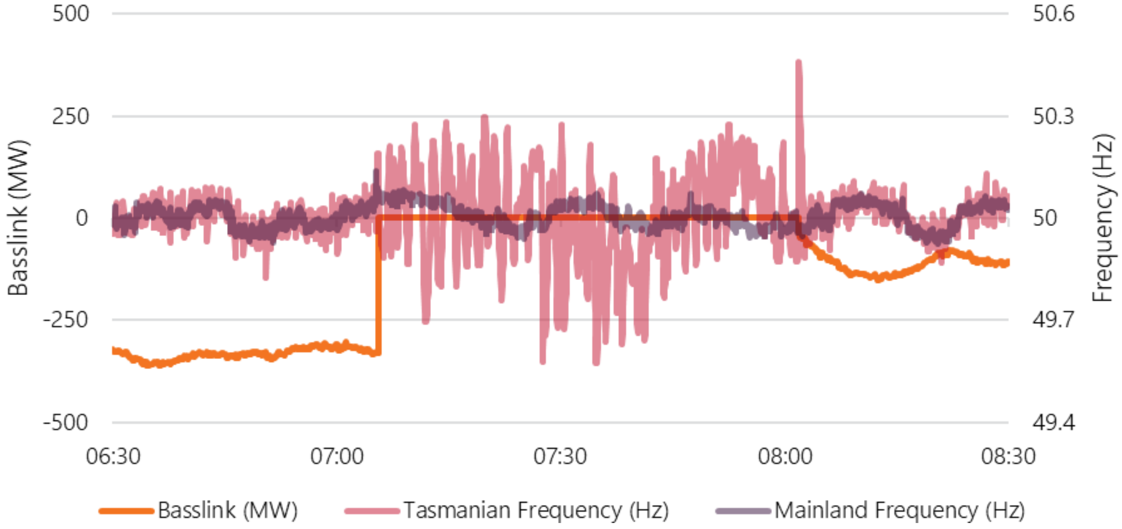


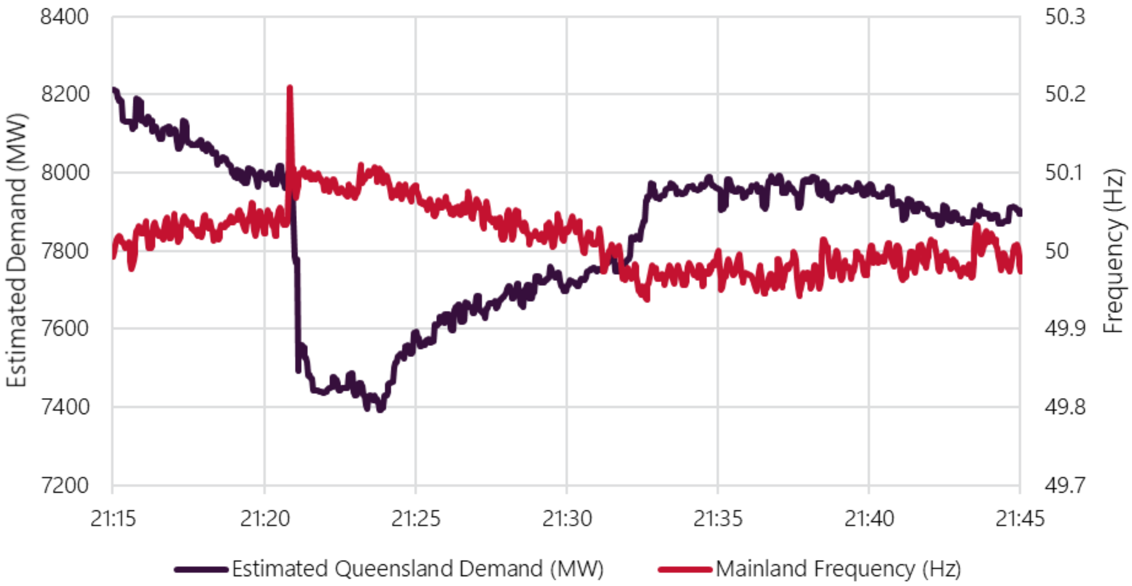
Figure 15 Tasmanian and mainland frequency during outage of Basslink on 13 March 2021



22 February 2021

A non-credible trip of the South Pine SVC and the Mount England – Wivenhoe Power Station No 824 275 kV line occurred at 2121 hrs on 22 February 2021. The full details of this event will be published in an AEMO power system incident report[8]. Mainland frequency increased to 50.21 Hz following the trip due to an estimated load reduction of 500 MW in south-east Queensland (load often disconnects following a major power system fault due to large, transient, decreases in power system voltage). Most load affected during this event was reconnected by 2135 hrsFigure 16.

Figure 16 Frequency and estimated Qld demand during non-credible event on 22 February 2021



[8] See https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-events-and-reports/power-system-operating-incident-reports.

4.6 Reviewable operating incidents

AEMO is required to review power system incidents that meet the criteria in the NER and Reliability Panel guidelines for identifying reviewable operating incidents[9]. Mainland frequency exceeding the Operational Frequency Tolerance Band (OFTB) is the existing guideline for identifying a reviewable operating incident which affected power system frequency and is one basis for any inclusions below. Other reviewable operating incidents are included here at AEMO's discretion.

24 January 2021

A significant failure of AEMO's SCADA system occurred between approximately 1546 hrs and 1656 hrs on 24 January 2021. During this period:

- AEMO lost operational visibility of power system conditions and could not use SCADA for dispatch of generation or for centralised secondary frequency control.
- AEMO's AGC was unable to ramp generation between market dispatch points, or control units enabled for regulation FCAS.

However, frequency remained within the requirements of the FOS throughout the incident, and frequency did not depart the NOFB.

A preliminary incident report on the events of 24 January 2021 has been published[10] and a final incident report will be available following the completion of AEMO's investigation. The following information should be considered subject to change pending further investigation, but is current as of the date of publication.

The data used to analyse this event in this Q1 2021 Frequency and Time Error Monitoring report has been obtained from non-SCADA sources, including the transmission network service providers (TNSPs), and from AEMO's high-speed monitoring network.

Of great benefit to the ongoing control of NEM frequency throughout the event was the action of PFR, which has been increased by implementation of the Mandatory PFR rule from late 2020. The estimated aggregate PFR response is provided below in Figure 17. AEMO estimates that up to 1,157 MW of PFR (in the form of reduced generation) was provided across the power system, which was able to hold frequency within the NOFB. In the absence of this widespread PFR, the frequency deviation would almost certainly have been much larger.

It is also notable that the aggregate frequency response was much greater than the contingency FCAS volumes procured immediately prior to and during the period of the SCADA outage, in particular the lower services as provided in Table 6, while regulation FCAS reserves were of no value as they could not be controlled.

In the absence of the Mandatory PFR rule, the system may have exceeded the ±0.5 Hz contingency event range, as indicated by the magnitude of the PFR action which is a proxy for the supply-demand imbalance. However, interventions such as manual re-dispatch may have countered this.

Table 6 Average FCAS procured during SCADA outage (MW)

	Fast	Slow	Delayed	Regulation
Raise	602	604	475	250
Lower	238	322	289	154

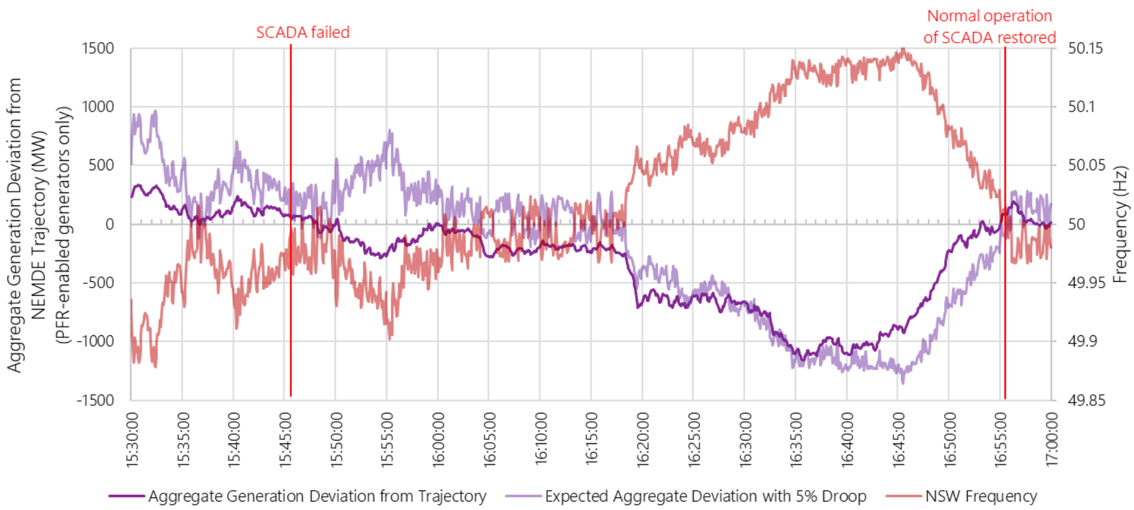
[9] See https://www.aemc.gov.au/sites/default/files/2018-02/Final-revised-guidelines.pdf.

[10] AEMO, Preliminary Report: Total Loss of NEM SCADA Data, published 16 February 2021, at https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-events-and-reports/power-system-operating-incident-reports.

The availability of primary frequency response across a large proportion of the NEM generation fleet at the time was a demonstration of operational resilience in action, during an unusual and strenuous system event. Widespread PFR is able to continuously act in a co-ordinated manner to provide supply-demand balancing and frequency control, as it responds to the universal property of system frequency, rather than relying on centralised communication and control processes via SCADA.

AEMO emphasises that the ability of highly distributed and consistently applied frequency response settings to minimise the impact of unusual and unplanned for power system events should be a key consideration in all future reforms of the NEM's frequency control framework.

Figure 17 Mainland frequency during SCADA outage of 24 January 2021 and estimated aggregate primary frequency response



5. Rate of change of frequency

5.1 ROCOF methodology

The rate of change of frequency following a frequency event is an indicator of the evolving system response to frequency disturbances. Measuring a system variable such as ROCOF is influenced by several assumptions concerning the available data and measurement methodology. This ROCOF methodology uses snapshots of measured frequency from the AEMO/TNSP Phasor Measurement Unit (PMU) system at 1-second intervals. This is a higher resolution than is available from the GPS clock system and is therefore more appropriate for assessing ROCOF.

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

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

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

$$else\ no\ measurement\ attempted$$

where:

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

5.2 ROCOF during frequency events

The maximum ROCOF recorded in the mainland each month in Q1 2021, and any other ROCOF exceeding the standard frequency ramp rate for the mainland (as specified in the market ancillary services specification [MASS]) of 0.125 Hz/s, is provided in Table 7.

Table 7 ROCOF during frequency events in the mainland

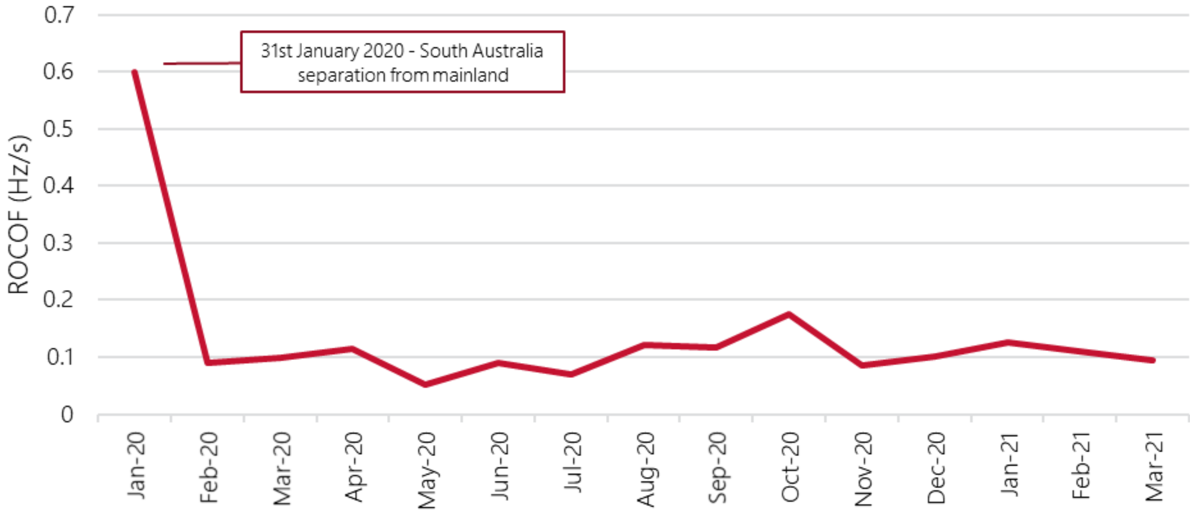
Month	ROCOF (Hz/s)	Associated event	Event time
January	-0.125	Trip of Loy Yang A1 unit	2/1/2021 18:38
February	-0.110	Trip of Loy Yang B1 unit	28/2/2021 00:47
March	-0.094	Trip of Loy Yang A2 unit	31/3/2021 10:25

Note: Estimates of ROCOF may vary depending on data source, sampling window and calculation method.

Figure 18 shows the maximum ROCOF recorded in the mainland since Q1 2020. AEMO employs a value called the 'standard frequency ramp rate' in the MASS as a standardised way of assessing FCAS capability. In real events, and in islanded systems, the ROCOF can be quite different. Under substantially different ROCOF conditions, FCAS capability for some plant would be different.

Based on the data above (and previous quarters), the MASS's value of 0.125 Hz/s for a credible contingency appears to remain fit for purpose, as the maximum ROCOF in most months has been near 0.125 Hz/s. The notable exception in Figure 18 occurred on 31 January 2020 when South Australia separated from the mainland NEM, however this was a non-credible event.

Figure 18 Monthly maximum ROCOF recorded in the mainland in 2020 and 2021



6. Automatic Generation Control

6.1 Area Control Error (ACE) methodology

As per the Regulation FCAS Contribution Factors Procedure[11], AEMO calculates an ACE representing the MW equivalent size of the current frequency deviation and accumulated frequency deviation (time error) of the NEM system. ACE may be considered to represent a rough proxy for the required regulation FCAS volume.

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

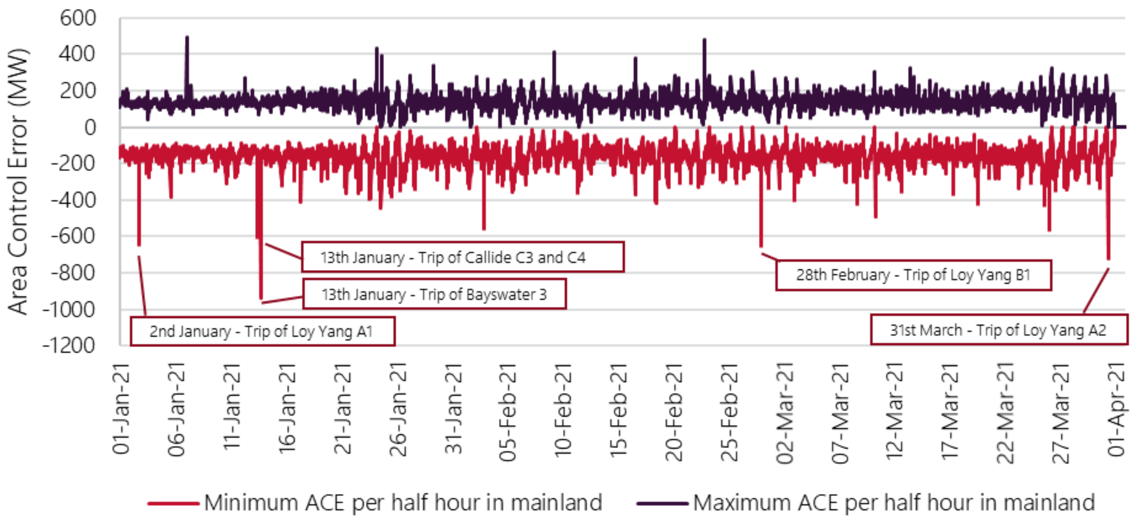
where:

- **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.

6.2 ACE reporting

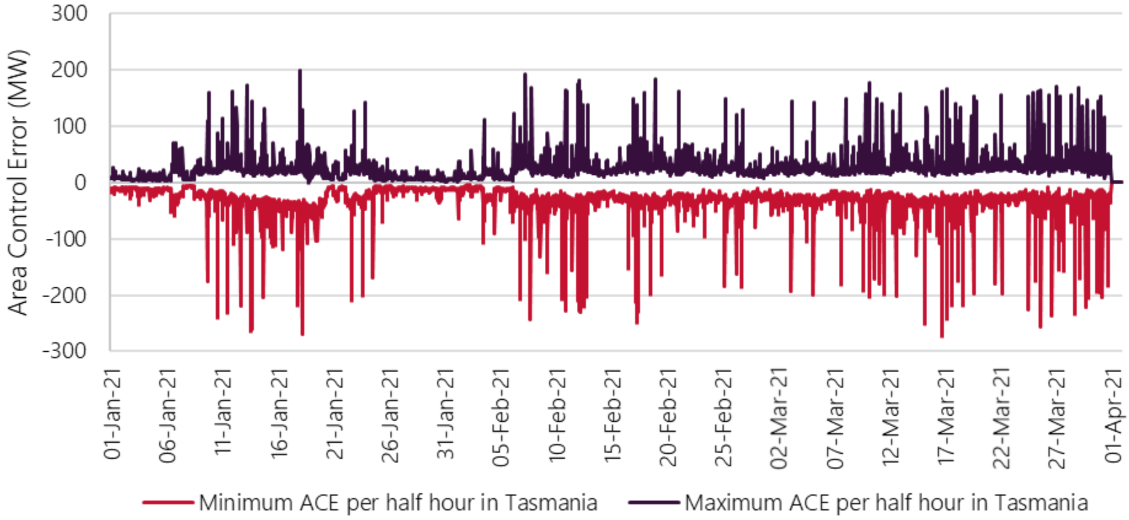
Figure 19 and Figure 20 show the minimum and maximum ACE per half-hourly trading interval in Q1 2021. Relatively balanced positive and negative ACE values have been observed throughout Q1 2021.

Figure 19 Minimum and maximum ACE per half-hour in mainland



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

Figure 20 Minimum and maximum ACE per half-hour in Tasmania



The observable broadening of ACE commencing from around 18 January 2021 is associated with the disablement of 'basepoint adjustment' – an AGC feature AEMO had enabled in December 2020 which resulted in the need to exclude data from the relevant Causer Pays run[12]. On Monday 18 January 2021, AEMO reverted changes to the basepoint adjustment AGC parameter to address this Causer Pays issue until such time as an appropriate fix can be developed. AEMO is still assessing the case for undertaking the changes that would be necessary to accommodate this feature.

6 January 2021

No FCAS regulation service was dispatched in the NEM for two dispatch intervals on 6 January 2021, at 1255 hrs and 1300 hrs. This occurred during an unplanned failover of AEMO's EMS system. The status of AGC units was flagged as suspect following the failover, which led to no regulation being dispatched. The data quality issue was rectified following an automatic restart of the failed server. Mainland frequency remained within the NOFB during this incident. AEMO has implemented several actions to reduce the risk of failover and enhance recovery in these circumstances.

7. Actions to improve frequency control performance

The long general decline in frequency control performance under normal conditions in the NEM over the period of approximately 2010 to 2020 has been well documented and is the subject of many inter-related

[12] 'Basepoint Adjustment' seeks to identify how facilities have moved away from their basepoint (in particular for frequency response reasons) and add this to the Regulation FCAS workload.

areas of work. In this report, AEMO publishes a range of metrics intended to document aspects of frequency control that are not related to requirements in the FOS but are important indicators of frequency stability.

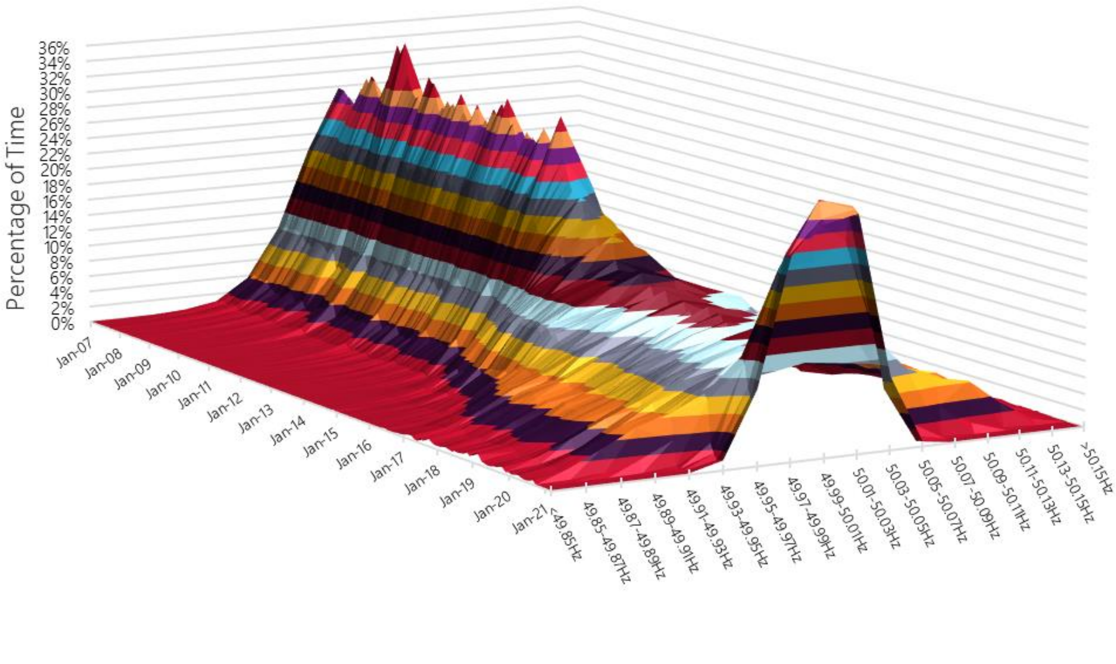
These also form a basis for assessing the impacts of current actions, such as the implementation of the Mandatory PFR rule. This rule came into effect from 4 June 2020, but implementation at generators commenced from the end of Q3 2020, and it is therefore a significant feature of this Q1 2021 report.

7.1 Measure 1 – distribution of frequency within NOFB

This measure examines the distribution of frequency within the NOFB. As Figure 21 shows, a flattening of the frequency distribution within the NOFB has been observed over time, and particularly since 2014-15, so frequency has spent more time out towards the edges of the NOFB than it used to. Among other things, this means that when a contingency event occurs, the resulting frequency change is more likely to deviate significantly away from 50 Hz.

A large improvement was observed in Q4 2020 and this continued throughout Q1 2021, which can be attributed to industry efforts to implement the Mandatory PFR rule throughout the reporting period. The sharp improvement in the distribution of system frequency has returned performance to levels not seen since approximately 2014.

Figure 21 Monthly frequency distribution



7.2 Measures 2 and 3 – number of frequency crossings and NOFB excursions

These measures examine the number of times frequency crosses the nominal 50 Hz target and how often frequency departs the NOFB. Over the last few years, there was a dramatic increase in the number of instances where frequency departs the NOFB, as shown in Figure 22 and Figure 23. Interestingly, there was also a significant decline in the number of 50 Hz crossings, which relates to the fact that frequency tended to spend much more time away from 50 Hz, and therefore did not have as much 'opportunity' to cross.

Since the implementation of mandatory PFR, there has been a clear return of the metrics monitored below to levels previously seen prior to 2015. AEMO considers these results to indicate a material improvement in frequency control within the NEM has been achieved.

Figure 22 Monthly frequency crossings – under 49.85 Hz, across 50 Hz, beyond 50.15 Hz

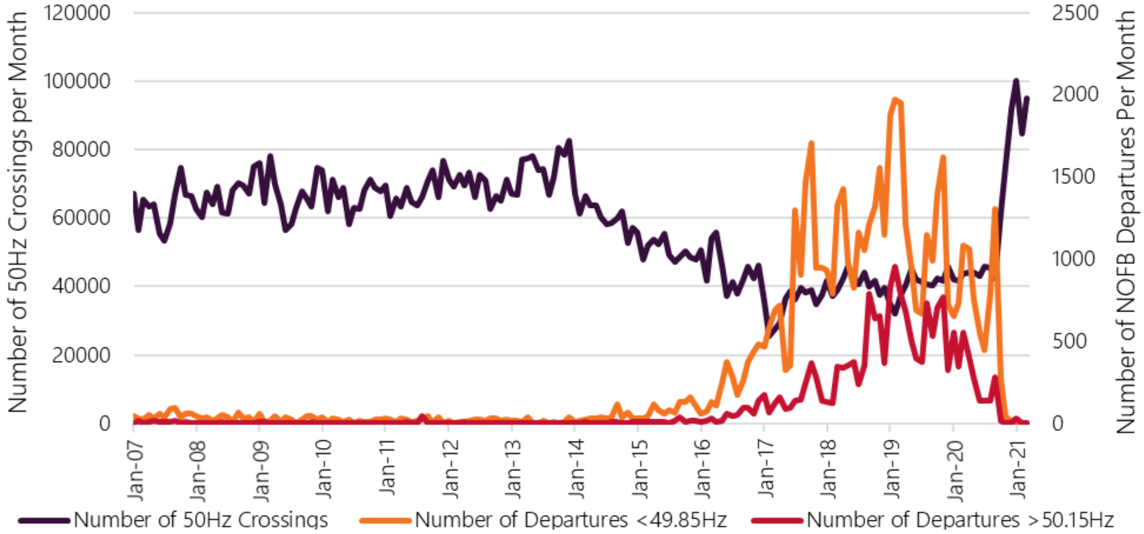
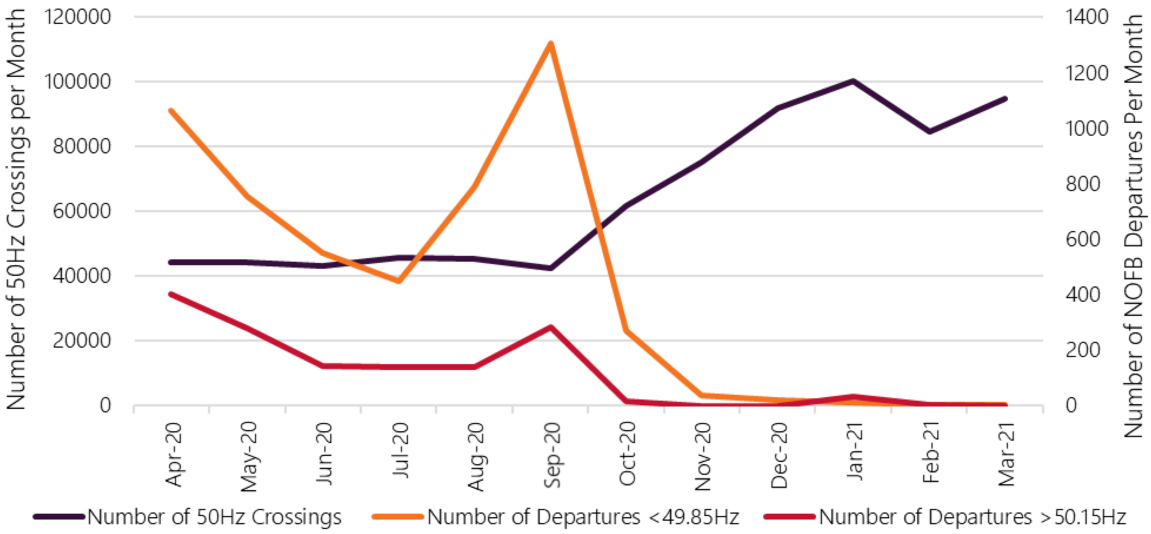


Figure 23 Monthly frequency crossings for recent 12 months



7.3 Measure 4 – frequency "mileage"

This measure examines the total amount of change in frequency over time. It is a metric that may be used as an indication of how stable frequency is; that is, more stable frequency will see a lower mileage. Table 8 provides a simple demonstration of the calculation method. The final estimate of mileage is dependent on the selection of the length of time interval. The measurements below are derived from 4-second intervals.

Table 8 Example frequency mileage calculation for a series of 4-second intervals

Sample	0s	4s	8s	12s	Mileage sum
NSW frequency (Hz)	50	50.5	49.5	50	
Mileage (Hz)		ABS(50.5-50)=0.5	ABS(49.5-50.5)=1.0	ABS(50-49.5)=0.5	0.5+1.0+0.5 = 2.0Hz

Interestingly, frequency mileage has remained reasonably consistent, with a recent small decline seeming to emerge over the past two quarters; however, the change is not nearly as dramatic as the change in frequency performance. That is, frequency mileage does not seem to be significantly reduced by the widespread provision of PFR. This may mean that frequency mileage is a better indicator of underlying load behaviour than frequency performance itself.

Figure 24 Monthly frequency mileage

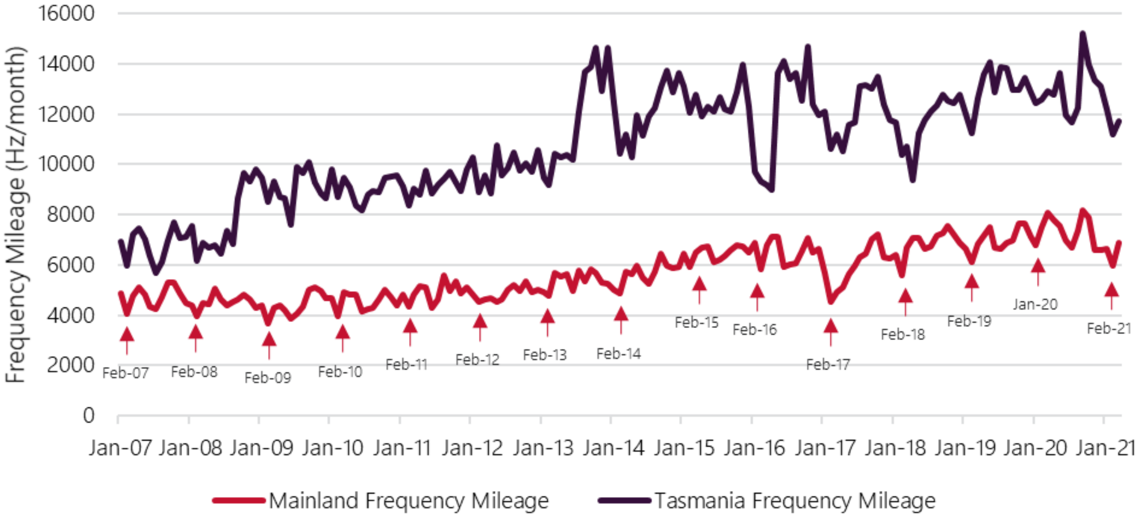
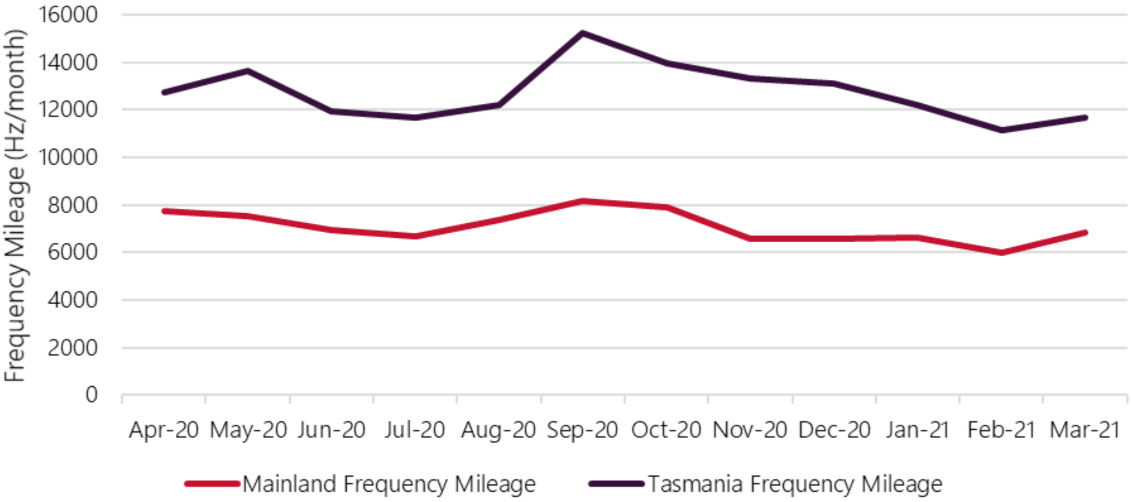


Figure 25 Monthly frequency mileage for recent 12 months



7.4 Progress on primary frequency response initiative

The implementation of the Mandatory PFR rule is a major work program currently underway involving AEMO and all affected generators in the NEM. The Australian Energy Market Commission (AEMC, or Commission) summarised the rule as follows[13]:

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

On 26 March 2020, the Commission made a final rule to require all scheduled and semi-scheduled generators in the NEM to support the secure operation of the power system by responding automatically to changes in power system frequency.

The final rule is designed to address the immediate need to improve frequency control as identified by AEMO and the other rule change proponent Dr Peter Sokolowski. The substantive elements of the final rule commence on 4 June 2020 and sunset after 3 years on 4 June 2023.

Key aspects of the final rule include:

- *All scheduled and semi-scheduled generators, who have received a dispatch instruction to generate to a volume greater than 0 MW, must operate their plant in accordance with the performance parameters set out in the Primary frequency response requirements (PFRR) as applicable to that plant.*
- *AEMO must consult on and publish the PFRR, which will specify the required performance criteria for generator frequency response, which may vary by plant type.*

Generators may request and AEMO may approve variations or exemptions to the PFRR for individual generating plant.

While the Mandatory PFR rule commenced from 4 June 2020, actual physical changes to generating plant controls (and therefore frequency performance) are subject to a staged implementation strategy based on generator size.

Actual physical implementation of IPFRR agreed settings at generators commenced in the final few days of Q3 2020. Tranche 1, which affects generators 200 MW or greater, was largely completed by the end of Q4 2020 and has been an instrumental factor in the major improvements to frequency performance observed in this report. Implementation of Tranche 2, affecting generators in the range 80-200 MW along with some remaining plant from Tranche 1, was substantially progressed in Q1 of 2021. At the time of writing, PFR assessments for Tranche 3 generators (<80 MW) were also progressing, with around 28% of Tranche 3 installed capacity having commenced or completed setting changes as at 13 April 2021.

AEMO maintains an area on its website for information and documentation relating to the implementation of the Mandatory PFR rule, including periodic updates on the rollout of the Mandatory PFR rule including listings of all generation that has applied agreed PFR settings, along with any variations or exemptions that have been agreed[14].

7.5 Other recent and upcoming actions

Other notable recent and upcoming actions in the area of frequency control include:

- In March 2021 AEMO published an update to the frequency control workplan[15] to help promote visibility, coordination, and prioritisation of frequency-related tasks.
- The Engineering Framework March 2021 Report[16] was published to summarise work underway, in frequency control among other operational areas, to inform and invite further stakeholder input.
- From 9-17 December 2020, AEMO undertook tuning of the AGC system in the mainland regions to better cater for the changes to frequency conditions that have occurred over the last few months. Changes involved altering AGC's behaviour to better utilise available regulation FCAS resources, and included:
  - Revision of AGC internal deadbands and minor adjustments to gains.
  - Changes to make AGC integral action more persistent.

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

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

[16] See https://aemo.com.au/-/media/files/initiatives/engineering-framework/2021/nem-engineering-framework-march-2021-report.pdf?la=en&hash=3B1283D31B542115CC56E0ECCDFB3D69.

  - Enablement of basepoint adjustment for distribution of required energy not accounted for by energy market targets among regulating units. The distributed total basepoint adjustment includes additional energy from PFR enabled and regulating units, and calculated load frequency response.
    - The basepoint adjustment changes were reverted on 18 January 2021, due to an issue related to data gathering processes in the Causer Pays process. AEMO is reviewing basepoint adjustment with a view to resolving the Causer Pays issue and re-enabling basepoint adjustment if justified. Any further plans to undertake adjustment to area level AGC tuning will be flagged ahead of time through Market Notices and other suitable channels.
- AEMO commenced a consultation on the MASS in January 2021[17]. This review proposes:
  - Improvements to MASS readability and usability and clarification of FOS references.
  - Adjustments to response ranges to improve utilisation of FCAS from frequency responsive and non-frequency responsive controllers.
  - Clarification and enhancement of requirements to improve the co-ordination of local (contingency FCAS and PFR) controls with remote (regulation FCAS/AGC) controls.
  - Clarification of the characteristics and requirements for the provision of regulation FCAS.
  - Clarification of the requirements of delayed FCAS.
  - Setting the ongoing measurement arrangements for distributed energy resources (DER) to participate in the contingency FCAS markets

  As a result of the number of submissions and the complexity involved, the first stage submission review has been extended by 25 business days, with a new planned date of 17 May 2021 for the draft determination. This extension was to allow sufficient time to properly consider the breadth of feedback from stakeholders.
- Following assessment and subsequent adjustment of mainland load relief, AEMO commenced work with TNSP TasNetworks to undertake a review of load relief in the Tasmanian region. Tasmanian load relief is being progressively adjusted from 1.0% to 0.0% (zero) in fortnightly increments of 0.1%, beginning from 9 December 2020. As of 28 April 2021, the load relief has been reduced to 0.2%.
- AEMO is supporting the AEMC's work on a range of significant rule changes affecting frequency control frameworks including Fast Frequency Response (FFR) and PFR. This set of rule changes is collectively referred to by the AEMC as the "System Services rule changes"[18].

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

[18] See https://www.aemc.gov.au/news-centre/media-releases/new-timeframes-set-system-services-arrangements.

Appendix A

This Appendix provides information on credible generation and load events in 2020-21 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 greater between successive 4-second SCADA scan intervals.

This list is not intended to be a comprehensive list of all credible contingency events which 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 to form a reasonable understanding of the ongoing success or otherwise of the NEM's aggregate ability to control frequency during major disturbances.

Unrepresented events 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 over a timespan longer than 4 seconds.
- Network events.
- Separation events.
- Non-credible events.
- Multiple contingency events.
- Protected events.

Table 9 and Table 10 demonstrate that both generation and load events in Q1 2021 tended to have an average frequency nadir nearer to 50 Hz and average recovery time shorter than seen in Q1-Q3 2020, which is a strong indicator of generally better frequency response following contingencies.

Table 11 is a list of identified contingencies from Q1 2021.

Table 9 Credible generation events in 2020-21

Quarter	Number of events	Average contingency size (MW)	Average frequency nadir (Hz)	Average recovery time (s)
Q1 2021	20	392	49.84	21
Q4 2020	38	315	49.84	45
Q1-Q3 2020	65	385	49.79	111

Table 10 Credible load events in 2020-21

Quarter	Number of events	Average contingency size (MW)	Average frequency nadir (Hz)	Average recovery time (s)
Q1 2021	8	289	50.08	0
Q4 2020	17	268	50.11	0
Q1-Q3 2020	33	279	50.17	30

Table 11 Credible generation and load events in Q1 2021

Event time	Unit	Contingency size (MW)	Frequency nadir (Hz)	Recovery to NOFB (s)	FOS compliant
02-Jan-21 18:39:04	LYA1	544	49.77	16	Yes
13-Jan-21 10:58:00	CPP_3	422	49.79	160	Yes
13-Jan-21 10:58:00	CPP_4	406	49.79	160	Yes
13-Jan-21 18:19:04	BW03	666	49.67	16	Yes
17-Jan-21 08:23:04	YWPS3	375	49.89	0	Yes
17-Jan-21 09:51:20	LYA3	420	49.84	8	Yes
18-Jan-21 07:34:00	APD1	270	50.06	0	Yes
21-Jan-21 12:54:16	TARONG#1	228	49.88	0	Yes
24-Jan-21 05:56:48	TOMAGO4	318	50.12	0	Yes
29-Jan-21 09:44:08	TOMAGO1	305	50.12	0	Yes
29-Jan-21 13:36:40	APD1	281	50.04	0	Yes
02-Feb-21 23:20:00	MP1	553	49.87	0	Yes
03-Feb-21 07:30:16	APD1	277	50.09	0	Yes
06-Feb-21 04:30:40	MUWAWF1	206	49.93	0	Yes
14-Feb-21 15:50:16	LD02	284	49.92	0	Yes
20-Feb-21 04:55:12	APD1	282	50.08	0	Yes
24-Feb-21 17:01:44	STAN-1	286	49.90	0	Yes
26-Feb-21 11:59:12	VP6	281	49.90	0	Yes
28-Feb-21 00:47:20	LOYYB1	580	49.76	16	Yes
05-Mar-21 09:48:24	APD1	260	50.05	0	Yes
08-Mar-21 17:29:04	GSTONE1	256	49.85	0	Yes
10-Mar-21 08:51:28	VP5	552	49.81	16	Yes
13-Mar-21 19:54:40	TOMAGO3	317	50.10	0	Yes
17-Mar-21 10:19:20	CALL_B_1	303	49.87	0	Yes
21-Mar-21 04:06:40	ER04	243	49.90	0	Yes
25-Mar-21 15:55:44	MUWAWF1	208	49.93	0	Yes
26-Mar-21 02:15:36	ER03	506	49.79	16	Yes
31-Mar-21 10:26:08	LYA2	511	49.74	16	Yes

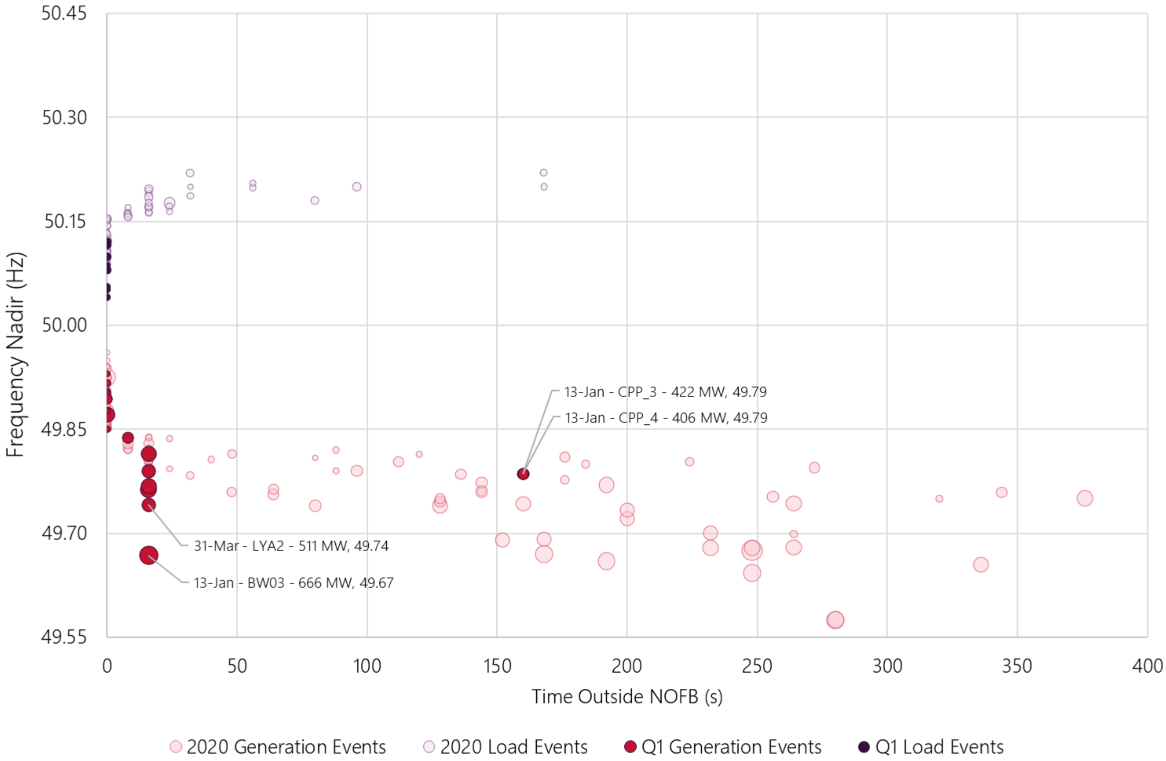
Note: TOMAGO1-4 & BOYNE1-3 are not registered dispatchable unit identifiers (DUIDs) but are included here to identify potlines of major NEM smelters.

Figure 26 displays each event from Table 11 to illustrate the distribution of frequency outcomes following credible contingency events in Q1 2021, in comparison to 2020.

Generation events in Q1 2021 were contained inside the GLCB and recovered within the FOS timeframe of five minutes. In Q1 2021, average frequency nadir was nearer 50 Hz and average recovery time was shorter than in Q1-Q3 2020.

Load events in Q1 2021 continued to be frequently contained within the NOFB, which represents a notable shift compared to 2020, when such events would frequently cause short (and sometimes long) frequency excursions outside the NOFB.

Figure 26 Frequency outcomes of identified credible generation and load events



Size of contingency events is represented by bubble size.

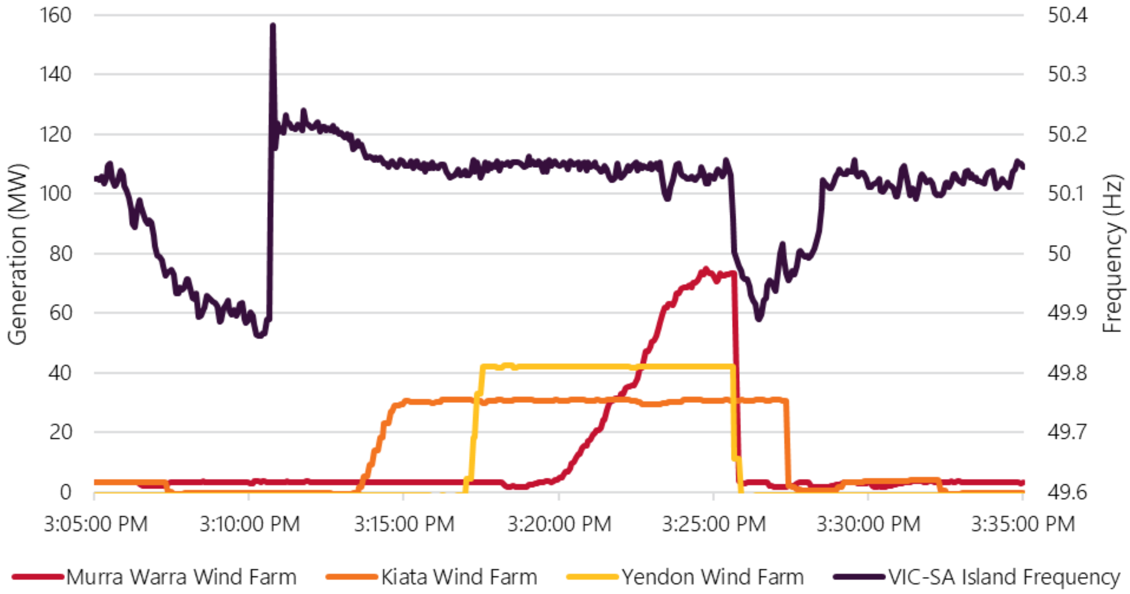
Appendix B

AEMO is providing further analysis in this Appendix to resolve an outstanding question raised in the final power system incident report into the events of 4 January 2020[19].

Following the separation of Victoria from New South Wales at 1510 hrs, frequency in the Victoria – South Australia – Tasmania island remained high, near 50.15 Hz, until 1526 hrs. At 1526 hrs, a significant drop in frequency to 49.87Hz occurred; this was to be the subject of further investigation by AEMO.

The frequency deviation within the NOFB observed at 1526 hrs in the Victoria – South Australia island shortly after the separation event on 4 January 2020 was largely due to the rapid curtailment of three generating units in Victoria – Murra Warra Wind Farm, Yendon Wind Farm and Kiata Wind Farm – in response to their new dispatch targets delivered at 1525 hrs. The three units were generating 73 MW, 42 MW, and 31 MW respectively before commencing curtailment.

Figure 27 Frequency in Victoria – South Australia island following 4 January 2020 separation event



In the NEM Dispatch Engine (NEMDE) dispatch process, it is assumed that units ramp linearly between their market targets. When generating units do not follow these linear trajectories, the ensuing supply-demand imbalance is indicated through changing system frequency. Semi-scheduled units have been observed to have the ability to curtail generation almost instantaneously, and frequently do so.

Frequency in the Victoria – South Australia island reduced from 50.15 Hz to 49.87 Hz between 1525 hrs and 1526 hrs. Frequency remained well within the applicable NOFB for an island on the mainland at the time (49.5-50.5 Hz). The 146 MW of curtailed generation is considered large for the electrical island and such a generation event would be expected to affect frequency substantially.

It is important to note that there was relatively little frequency response within the NOFB available to counteract frequency changes of any origin at the time of the islanding, and the FOS does not set any

[19] AEMO, Final Report: New South Wales and Victoria Separation Incident, published 25 September 2020, at https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-events-and-reports/power-system-operating-incident-reports.

particular standards for control of frequency within the NOFB. Similar large movements in frequency within the NOFB were observed repeatedly until resynchronisation at 2156 hrs.

The implementation of PFR in late 2020 has substantially increased AEMO's ability to maintain system frequency within the NOFB during similar islanding events. The semi-scheduled generator dispatch obligations rule change[20], which came into effect 12 April 2021, is expected to further discourage similar rapid curtailment responses from semi-scheduled generators in future events in favour of linearly ramping between targets.

[20] See https://www.aemc.gov.au/rule-changes/semi-scheduled-generator-dispatch-obligations.