West Murray Zone Power System Oscillations on 16 November 2021

February 2023

Reviewable Operating Incident Report under the National Electricity Rules

Important notice

Purpose

AEMO has prepared this report in accordance with clause 4.8.15(c) of the National Electricity Rules, using information available as at the date of publication, unless otherwise specified.

Disclaimer

To inform its review and the findings expressed in this report, AEMO has been provided with data by registered participants as to the status or response of some facilities before, during and after the reviewable incident, and has also collated information from its own observations, records and systems. Any views expressed in this report are those of AEMO unless otherwise stated, and may be based on information given to AEMO by other persons. AEMO has made reasonable efforts to ensure the quality of the information in this report but cannot guarantee its accuracy or completeness.

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Incident classifications

Classification	Detail
Time and date of Incident	0605 hrs on 16 November 2021
Region of incident	Victoria
Affected regions	Victoria and New South Wales
Event type	Other – Sub synchronous Voltage oscillations
Generation impact	Approximately 35.08 MW
Customer load impact	Nil
Associated reports	West Murray Zone Sub-Synchronous Oscillations report - https://aemo.com.au/-/media/files/electricity/nem/network_connections/west-murray/high-level-summary-of-wmz-subsynchronous-oscillations.pdf?la=en

Abbreviations

Abbreviation	Term
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AEST	Australian Eastern Standard Time
BESS	Battery Energy Storage System
DC	Direct current
DPV	Distributed photovoltaics
GPS	Global positioning system
HSM	High speed measurement
HV	High voltage
Hz	Hertz
kV	Kilovolt/s
LV	Low voltage
MW	Megawatt/s
NEM	National Electricity Market
NER	National Electricity Rules
PLL	Phase locked loop
POC	Point of connection
RCTS	Red Cliffs Terminal Station
RMS	Root mean squared
SCADA	Supervisory control and data acquisition
SF	Solar Farm
SP	Solar Park
TNSP	Transmission Network Service Provider
WETS	Wemen Terminal Station

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1 Overview

On 16 November 2021 between in Victoria and New South Wales, power system oscillations were present across the West Murray Zone[1] with a maximum peak-to-peak root mean square (RMS) voltage magnitude of 17%[2] at Bannerton Solar Park (SP) point of connection (POC) and 1.94% at the Red Cliffs Terminal Station (RCTS) 220 kilovolts (kV) bus. These oscillations persisted for approximately 37 minutes. During the incident, 35 of the 39 inverters at Wemen Solar Farm (SF) tripped, causing approximately 35 megawatts (MW) of generation to disconnect. There was no loss of customer load as a result of this incident.

AEMO considers this event to be significant to the operation of the power system (due to the size and duration of the observed power system oscillations), and consequently a *reviewable operating incident* under the National Electricity Rules (NER)[3]. For a reviewable operating incident, AEMO is required to assess and report on the adequacy of the provision and response of facilities and services and the appropriateness of actions taken to restore or maintain power system security[4].

On 6 October 2022, AEMO, with input from AusNet Services and Powercor[5], published a high-level summary on a series of West Murray Zone power system oscillations observed from 2020 through to the end of 2021[6]. On 17 February 2023, AEMO published the final report on this series of West Murray Zone oscillations[7].

In relation to the 16 November 2021 incident, AEMO has concluded that:

1. Power system oscillations were present in the West Murray Zone for around 37 minutes. The oscillations had a frequency of around 19 hertz[8] (Hz) and peak-to-peak voltage magnitude up to 1.94% was observed at the RCTS 220 kV bus. The oscillations continued despite 35 inverters tripping at Wemen SF.
2. At no point during this incident were transmission system voltages outside of relevant voltage limits.
3. No action was required by AEMO to restore or maintain power system security during the incident. The power system oscillations did not impact power system frequency and the Frequency Operating Standard was met during this incident.
4. Due to the absence of timestamped, synchronised high-speed measurement (HSM) data, no conclusions could be drawn regarding the root cause of, or individual contributions to, the oscillations. AEMO is continuing to investigate the root cause of this incident in collaboration with network service providers (NSPs) and

[1] Described in Section 2.1 of this report.

[2] 17% oscillations means that if the RMS voltage at Bannerton SP was 1.0 per unit (PU), the RMS voltage could oscillate between 1.085 PU and 0.915 PU.

[3] See NER 4.8.15(a)(3) and the AEMC Reliability Panel Guidelines for identifying reviewable operating incidents, paragraph 6(f), at https://www.aemc.gov.au/regulation/electricity-guidelines-and-standards.

[4] See NER 4.8.15(b) and (c).

[5] AusNet Services is the Declared Transmission System Operator for Victoria and Powercor is the distribution network service provider (DNSP) in Western Victoria.

[6] At https://aemo.com.au/-/media/files/electricity/nem/network_connections/west-murray/high-level-summary-of-wmz-subsynchronous-oscillations.pdf?la=en.

[7] At https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/system-operations/power-system-oscillations.

[8] The 19 Hz oscillation frequency data mentioned in this report refers to the RMS aliased frequency as measured in the phasor variables at the various measurement points. The Fast Fourier Transform (FFT) of the instantaneous three-phase voltages and currents would indicate the actual frequency components to be modulated as 50Hz ± the measured RMS frequency of 19 Hz. For more explanation please see Appendix A1 of the West Murray Zone Power System Oscillations 2020 – 2021 report found here - https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/system-operations/power-system-oscillations.

generators. In addition, the planned rollout of additional high speed monitoring improvements, outlined in Section 3 of this report, will assist AEMO with root cause analysis of future power system incidents.

5. Due to the relatively low granularity of the available data, no conclusions could be drawn regarding the performance of distributed photovoltaics (DPV) during the event.

AEMO recommends:

- As this incident occurred during a prior outage of one Wemen Terminal Station (WETS) 220/66 kV transformer, and on the evening of 17 November 2022, in response to the incident, AEMO implemented a constraint to:
  - limit the maximum number of inverters online at Wemen SF and Bannerton SP to 15 inverters at each site (that is, allowing a maximum total of 30 inverters online across the two sites); and
  - limit the total output of Wemen SF and Bannerton SP to a maximum of 70 MW,

  AEMO implement this constraint for all future WETS 220/66 kV transformer outages.
- Generator operators have procedures in place to ensure that, when generator or power system instability is identified, appropriate actions can be taken within a reasonable timeframe. These actions could include advising AEMO and NSP control rooms of the instability, investigation of the instability to determine if the generator is contributing, and, if required, disconnection of the generating facility.
- AEMO is currently consulting with industry on guidelines for how generators can best comply with NER S5.2.5.10 (protection to trip for unstable operation) for asynchronous generators[9]. AEMO will consider a strategy for engaging further with existing proponents once these guidelines are updated.
- As part of the access standards review[10], for new connections, AEMO is currently engaging with industry on the suitability of the requirements of NER S5.2.5.10 (protection to trip plant for unstable operation), with a focus on asynchronous generators. As part of this engagement, AEMO will consider amendments to the access standards for generators to:
  - Monitor for instability and alert generator operators, the NSP and AEMO.
  - Determine their contribution to system instability.
  - Trip or ramp down under critical system conditions where the system is unstable and/or where a generator identifies itself as a high contributor to the identified system instability.
- An acceptable oscillations limit is developed in conjunction with suitable operational tools and installation of adequate high-speed monitors to support control room operators in managing future oscillation events on the power system. This will enable operators to monitor and effectively manage oscillations within operational timeframes, and involves the following recommended steps:
  - AEMO, in conjunction with transmission network service providers (TNSPs), to improve high speed monitoring capabilities and implement visualisation tools providing system operators with real-time information needed to respond if automatic protection systems fail to disconnect the affected generation. For more information on this recommendation, see Section 3.1 of this report.

[9] For more information, see https://aemo.com.au/consultations/current-and-closed-consultations/ner-s52510-guideline-consultation.

[10] For more information, see https://aemo.com.au/consultations/current-and-closed-consultations/aemo-review-of-technical-requirements-for-connection.

- The Power System Security Working Group (PSSWG) to define a level of power system oscillations which may be considered acceptable for secure power system operation in the operational timeframe, which may be used to support TNSPs when providing operational limits advice.
- All TNSPs to provide AEMO with updated limit advice (where required) consistent with the acceptable level of oscillations, and identify operational actions that AEMO can take if available monitoring indicates power system oscillations exceeding the acceptable level.

- NSPs, generators, industrial load customers and AEMO continue to collaborate to identify the root cause of power system oscillation incidents in the West Murray Zone.

This report is prepared in accordance with NER 4.8.15(c) of the . It is based on information provided by the registered participants listed in Appendix A1 and AEMO.

National Electricity Market (NEM) time (Australian Eastern Standard Time [AEST]) is used in this report.

2 The incident

2.1 The West Murray Zone

The West Murray Zone[11] is an area of the NEM with low system strength, extending across parts of Victoria and New South Wales. This area has attracted significant investment in grid-scale solar and wind generation in the past three years. The scale and rapid pace of inverter-based resources (IBR) generator connections has resulted in new technical challenges, impacting grid performance and operational stability. See Appendix A2 for a single line diagram covering the West Murray Zone and the adjacent power system.

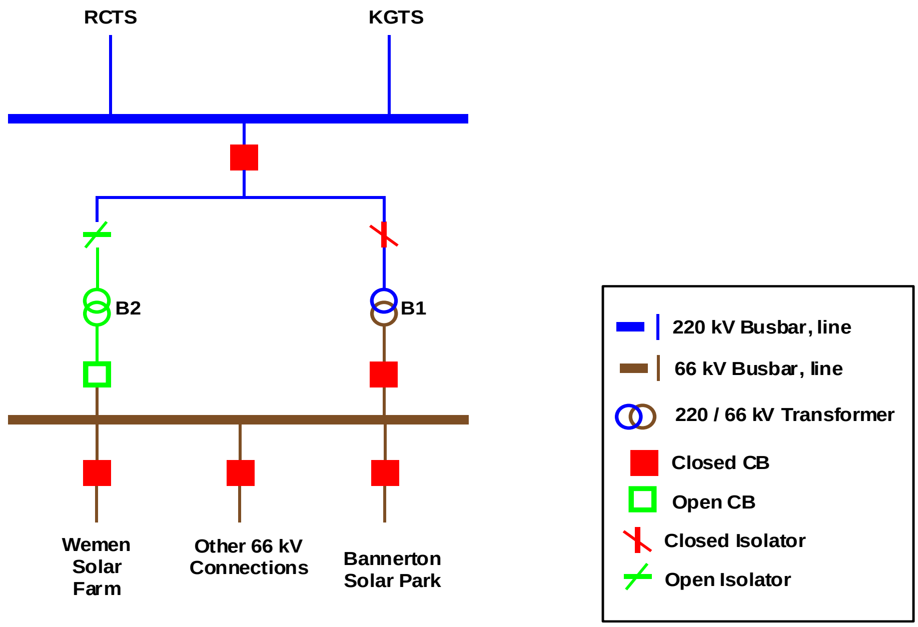
2.2 Pre-incident conditions

Prior to this incident there was a planned outage on the WETS 220/66 kV B2 transformer (see Figure 1). All other equipment around RCTS was in service. The outage of this transformer resulted in lower fault levels at Wemen SF and Bannerton SF, and the potential for low system strength[12] related stability issues to occur.

[11] For more information, see https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/participate-in-the-market/network-connections/west-murray.

[12] System strength at a given location is proportional to the fault level. The characteristics of low system strength include potential for wide area voltage and power oscillations, prolonged voltage recovery following disturbances, and instability of generator/dynamic plant control systems. For more, see AEMO, *System Strength Explained*, at https://aemo.com.au/-/media/files/electricity/nem/system-strength-explained.pdf.

Figure 1 WETS configuration during the incident



2.3 The incident

At 0605 hrs on 16 November 2021, AEMO's monitoring tool[13] identified power system oscillations in Victoria (within the West Murray Zone) at RCTS 220 kV bus. Table 1 details the following sequence of events. All of the events detailed in Table 1 occoured on 16 November 2021.

Table 1 16 November 2021 sequence of events

Time	Details
Approx. 0605 hrs	Power system oscillations in the range of 19 Hz were detected at RCTS.
Approx. 0613 hrs	35 inverters at Wemen SF tripped. Despite these inverter trips at Wemen, oscillations continue.
Between 0613 hrs and 0650 hrs	Wemen SF inverters return to service, with the entire plant operational by 0650 hrs.
Approx. 0642 hrs	Power system oscillations cease.

2.4 Analysis

AEMO systems captured the event based on the various supervisory control and data acquisition (SCADA) and HSM measurement points on the network. Figure 2 shows the power system voltage oscillations in the range of 19 Hz[14] measured at RCTS 220 kV. These voltage oscillations lasted for approximately 37 minutes, with a maximum measured peak-to-peak RMS voltage magnitude of 1.94%.

[13] After sub-synchronous oscillations were first identified in the West Murray Zone on 20 August 2020, AEMO developed a tool to monitor this phenomenon. This tool analyses data from high-speed monitors at Red Cliffs 220 kV substation and identifies any periods of sub-synchronous resonance to allow AEMO to investigate further.

[14] For more explanation of oscillation frequency please see Appendix A1 of the West Murray Zone Power System Oscillations 2020 – 2021 report found here - https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/system-operations/power-system-oscillations.

Figure 2 Red Cliffs 220 kV HSM RMS phase voltage – 16 November 2021 event 0600 hrs to 0700 hrs (AEST)

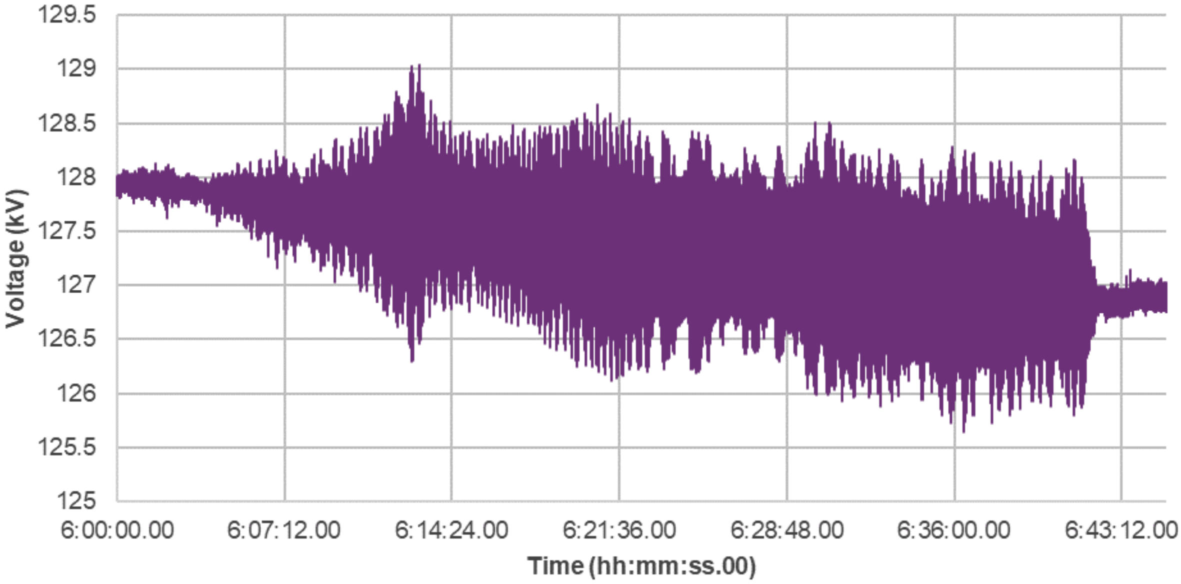


Figure 3 shows the active power output of most solar farms in the region based on SCADA data for the duration of the power system oscillations. Bannerton SP active power response varied the most throughout this event, compared to other solar farms. At approximately 0613 hrs, 35 inverters at Wemen SF tripped. The loss of these inverters is illustrated by the active power trace of Wemen SF in Figure 3. The tripped inverters at Wemen SF were subsequently automatically returned to service gradually between 0615 hrs and 0650 hrs. Post-incident investigation into two of the inverters at Wemen SF by Wirsol[15] confirmed that a number of inverters on site measured a peak terminal voltage above their voltage protection settings and tripped. This protection operation was in line with expected performance.

Figure 3 also shows that between 0615 hrs and 0650 hrs Yatpool SF's output varied between close to 0 MW and approximately 20 MW, 40 MW and 60 MW, Baywa-RE[16] has confirmed that:

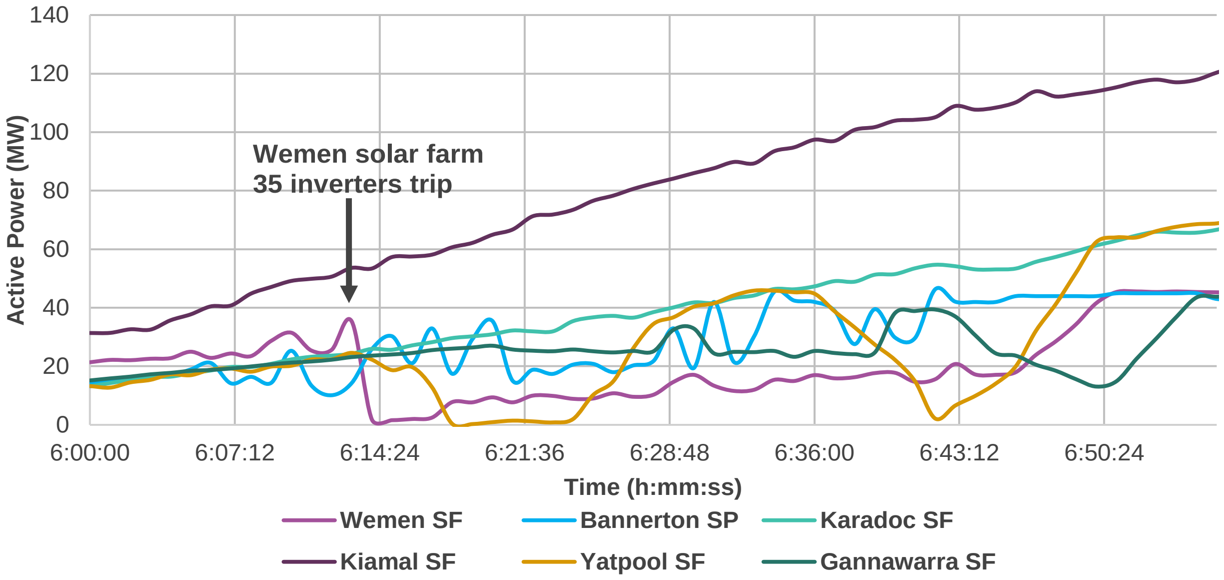
- The power system oscillations started around 10 minutes prior to the first change in Yatpool SF's output.
- All Yatpool SF's inverters appear to have remained online during the incident.
- Available solar irradiance data showed irradiance ramping constantly upwards (noting this data had a 1-minute resolution).

Considering the above information, the cause of the changes in Yatpool SF's output could not be confirmed.

[15] Wirsol is Wemen SF's owner/operator.

[16] Baywa-RE owns Yatpool SF.

Figure 3 Generator active power output during the event



To support the investigation, AEMO requested that AusNet Services and Powercor share details of any events (including switching events or load starts) that occurred within their respective networks just prior to, during, and just after the period of power system oscillations.

AEMO has analysed the data received from AusNet Services and Powercor (alongside AEMO's own high speed measurement [HSM] data). Powercor confirmed that no planned switching or unplanned outage events (faults) were recorded on the WETS network prior to or during the oscillation event. In addition, AusNet Services was not able to identify any events within its network that may have caused, or contributed to, the oscillations.

AEMO also requested and analysed HSM data from registered generators in the West Murray Zone. The data requested included (where relevant and available):

- Root mean squared (RMS) HSM data at the point of connection (POC) (both high voltage [HV] and low voltage [LV] sides).
- RMS HSM data at the inverter level.
- Data of the generator output and harmonic filter (if available).
- Direct current (DC) side voltage and current data.
- Information regarding the generator's operational protocol during night time operation, considering the time of event being early morning.
- Information regarding whether the generator had identified any alarms, planned or unplanned switching or any other activity of note in their plant or network.

Appendix A3 of this report contains a subset of the high speed measurement data received from generators in the area where the power system oscillations were identified.

A summary of the outcomes of AEMO's investigation is included in Table 2 below.

Table 2 Outcome of AEMO's analysis of 16 November 2021 oscillations event

Generator/equipment	RMS phase POC voltage (%) oscillations at POC during incident
Ararat Wind Farm (at 220 kV)	0.2
Ballarat Battery Energy Storage (at 22 kV)	0.2
Bannerton Solar Farm (at 66 kV)	17.0
Broken Hill Substation (Broken Hill Solar Plant and Silverton Wind Farm)	2.3
Bulgana Green Power Hub (at 33 kV)	1.0
Crowlands Wind Farm (at 220 kV)	0.3
Gannawarra Battery Energy Storage (at 33 kV)	3.7 (at 3 Hz)
Gannawarra Solar Farm (at 66 kV)	0.3
Karadoc Solar Farm	Insufficient data to analyse
Kiamal Solar Farm (at 220 kV)	0.9
Kiata Wind Farm (at 66 kV)	0.1
Limondale 1 Solar Farm (at 220 kV)	0.4
Limondale 2 Solar Farm (AT 22 kV)	0.1
Murra Warra Wind Farm (at 220 kV)	0.1
Sunraysia Solar Farm	Insufficient data to analyse
Waubra Wind Farm	Insufficient data to analyse
Wemen Solar Farm (at 66 kV)	9.0
Yaloak South Wind Farm (at 66 kV)	0.5
Yatpool Solar Farm (at 66 kV)	3.0

* This refers to the maximum change or variation in voltage magnitude at the POC observed during the entire duration of the oscillations and not just the peak-peak voltage magnitude within each power frequency cycle. Values are approximate, peak-to-peak in percent.

In summary, Table 2 indicates that the highest magnitude of peak-to-peak voltage oscillations recorded were at the Bannerton SP and Wemen SF POCs, measured at approximately 17% and 9% magnitude respectively. The next largest peak-to-peak oscillations recorded were at Gannawarra Battery Energy Storage System (BESS) and Yatpool SF POCs, with around 3.7% and 3% magnitude respectively, followed by Broken Hill Solar Plant and Silverton Wind Farm (each 2.3%), Bulgana Green Power Hub (1%), and Kiamal SF (0.9%). The recorded oscillation levels at the POCs of other West Murray Zone generators were in the range of 0.1% to 0.5%.

However, the analysis performed on information provided by generators and NSPs did not enable any conclusions to be drawn regarding the root cause of the oscillations during this event. Some of the factors that made identification of the root cause of these oscillations challenging were:

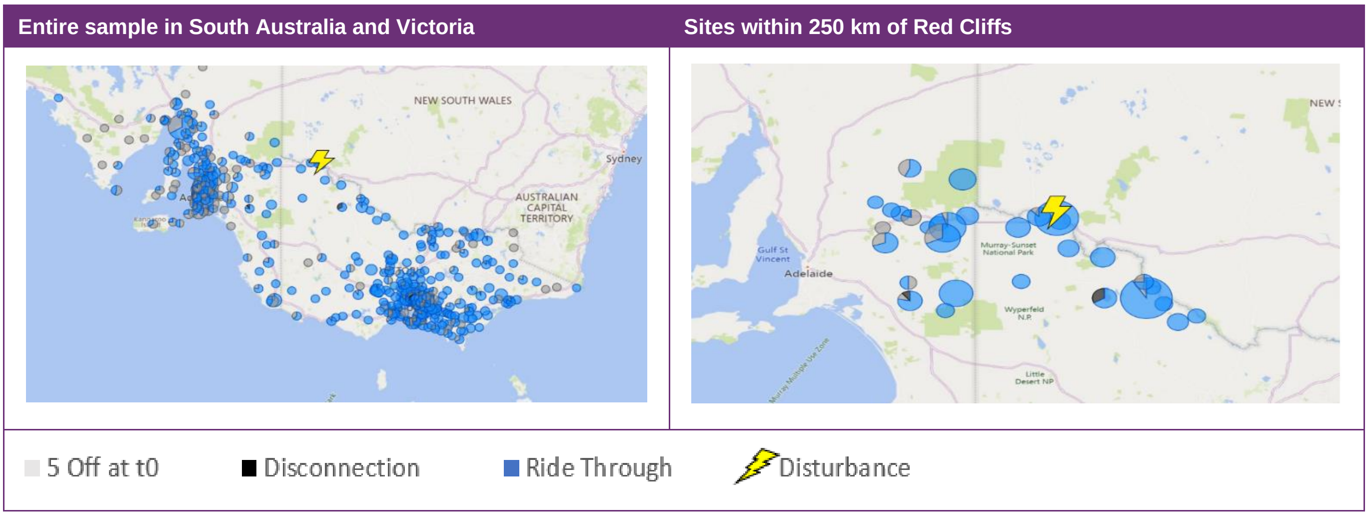
- Not all the HSM data received from registered generators was global positioning system (GPS) synchronised. This made it difficult to confirm which plant starts oscillating first, and which generator(s) contributed to or reacted to the oscillations.
- HSM data is not available for loads in the West Murray Zone, meaning the potential contribution of nearby load to the onset of the oscillations cannot be adequately analysed.
- Some data requested from generators – such as active and reactive power reference signals, voltage reference signal at inverter/turbine terminals, DC side voltage and current data, recorded direct and quadrature axis currents, recorded direct and quadrature axis current references, and high-speed recorded output of the phase locked loop (PLL) – was not available and therefore was not provided by the generators for the time of the event.

2.5 Response of distributed photovoltaics

Between 0600 hrs and 0640 hrs, DPV inverters were estimated to be generating approximately 6 MW to 60 MW in South Australia and 100 MW to 300 MW in Victoria. To determine whether there was any response by DPV generators to the disturbance, AEMO procured anonymised 60-second and 5-second resolution generation data from Solar Analytics for a sample of 8,611 DPV circuits (all systems < 100 kilowatts [kW]) in South Australia and Victoria.

Figure 4Figure 4 shows the locations of DPV inverters sampled, and the categorisation of responses observed. The size of the circle indicates the number of inverters in the sample in the postcode, while the colours indicate the proportion of inverters in that postcode categorised with a particular type of response. The majority of inverters are shown in blue, indicating no discernible response to the disturbance (ride-through behaviour). Very few inverters were observed to disconnect from the power system during this disturbance. This suggests no notable response from DPV during this disturbance. However, the resolution of the dataset available (60 second/5 second sample rate) does not allow observation of complex sub-second behaviours.

Figure 4 Behaviours observed from sample of DPV



3 Power system security

AEMO is responsible for power system security in the NEM. This means AEMO is required to operate the power system in a secure operating state to the extent practicable and take all reasonable actions to return the power system to a secure state following a contingency event in accordance with the NER[17].

AEMO has analysed the impact of this incident on power system security and has concluded that:

- At no point during this incident were transmission system voltages outside of relevant voltage limits defined in the NER, or specified by NSPs in their limits advice to AEMO (to confirm, the phase voltage at RCTS 220 kV bus oscillated between 125.5 kV and 129.1 kV during the incident).
- The current flows on all transmission lines remained within operating limits throughout the incident.

[17] Refer to AEMO's functions in section 49 of the National Electricity Law and the power system security principles and definitions in NER 4.2.

- Other than the 35 inverters at Wemen SF, no other generators were observed to have disconnected due to this incident.
- No load was observed to have been impacted by these oscillations.
- There was no notable response from DPV in response to this incident.
- Power system frequency was not impacted by these sub-synchronous oscillations and the Frequency Operating Standard[18] was met during this incident.
- Power system oscillations persisted for 37 minutes with a maximum measured peak-peak voltage magnitude of 1.94% at RCTS 220 kV bus.

It is likely these oscillations were not 'adequately damped' in line with the criteria set out in NER S5.1.8, although currently there is no defined operational limit which can be used to identify the level of background power system oscillation that is acceptable. It is realistic to expect some level of ongoing background system oscillation in power systems with significant amounts of operating grid following IBR and low system strength, however given the magnitude of oscillations that occurred in this event, it is likely that they would exceed any threshold that is subsequently defined.

3.1 High-speed monitors and operational tools

At present, AEMO has no automated reporting or alarming capabilities to monitor power system stability issues arising from control interactions between IBR. AEMO is working with TNSPs to improve high speed monitoring capabilities and implement tools to provide operators with visibility in real time. The project is being co-ordinated as part of AEMO's Operations Technology Roadmap[19] to uplift operational capability and help manage system security in the context of a power system increasingly dominated by IBR.

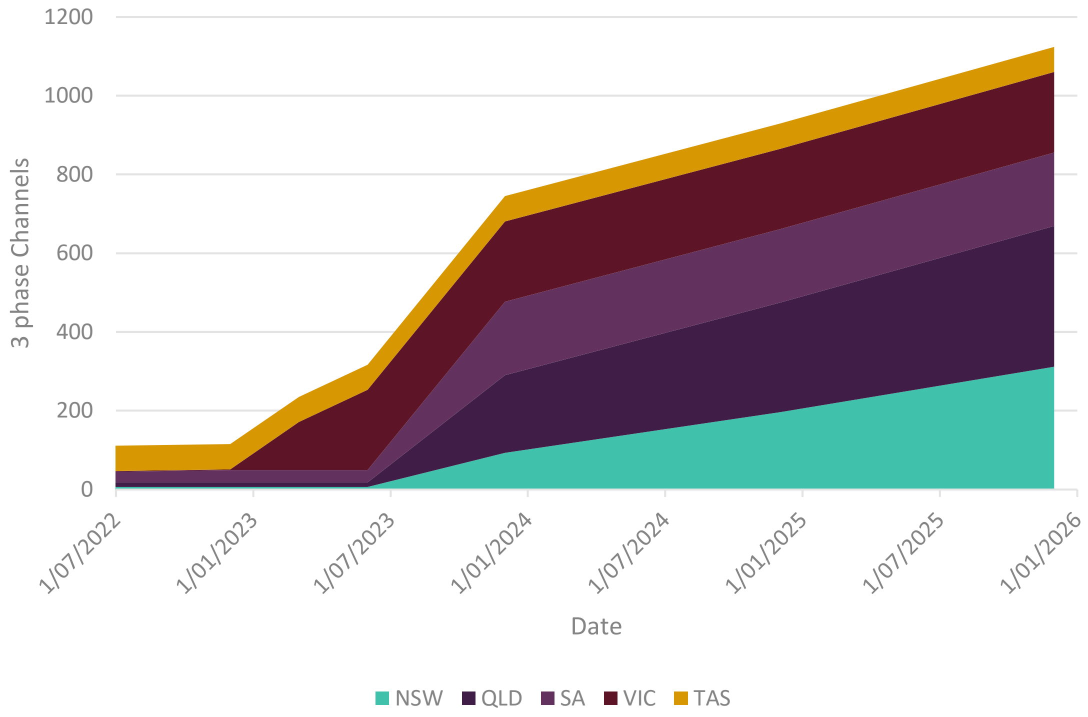
Figure 5 presents the total number of high-speed monitor channels[20] planned for installation as part of this project, and when these additional channels are expected to become available.

[18] See https://www.aemc.gov.au/sites/default/files/2020-01/Frequency%20operating%20standard%20-%20effective%201%20January%2020 20%20-%20TYPO%20corrected%2019DEC2019.PDF.

[19] For more details of the Operations Technology Roadmap, see https://aemo.com.au/-/media/files/initiatives/operations-technology-roadmap/executive-summary-report-for-the-otr.pdf?la=en.

[20] Many high speed monitors include multiple measurement "channels" or measurements from which AEMO will be able to review data.

Figure 5 Planned NEM HSM monitor installations



As part of the same project, there are plans to develop operational tools (including alarms and dashboards) to improve operator visibility of system oscillations. These tools will help operators identify the source of oscillations and take appropriate actions[21], which may include disconnection of unstable generator(s) as a last resort where automatic protection systems fail to disconnect the affected generator(s).

AEMO recommends that an acceptable oscillations limit is developed in conjunction with:

- suitable operational tools; and
- the installation of a suitable number of high-speed monitors,

to enable AEMO to monitor and effectively manage oscillations within operational timescales.

3.2 Action taken by AEMO in response to incident

From the evening of 17 November 2021, AEMO instructed operators at Wemen SF and Bannerton SP to operate a maximum of 15 inverters each for the duration of the WETS 220/66 kV transformer outages. AEMO took this action to help reduce the risk of potentially unacceptable power system oscillations recurring while there was low fault level/system strength at WETS (due to the ongoing transformer outages) and while the root cause of oscillations was initially under investigation.

The planned WETS transformer outages concluded on 25 November 2021, and both Wemen SF and Bannerton SP returned to full capacity.

[21] Multiple monitors need to be available within a network area to allow operational tools and operators to locate the approximate source of any oscillations and identify a suitable response.

During future WETS 220/66 kV transformer outages, AEMO will implement a constraint to:

- limit the maximum number of inverters online at Wemen SF and Bannerton SP to 15 inverters; and
- limit the total output of Wemen SF and Bannerton SP to a maximum of 70 MW.

3.3 Reclassification

AEMO assessed whether to reclassify this incident as a credible contingency event[22]. This incident did not include any non-credible contingency events, therefore AEMO was not required to put any reclassifications in place.

4 Market information

AEMO is required by the NER and operating procedures to inform the market about certain incidents as they progress[23].

AEMO was not required to and did not issue any market notices during the course of this incident.

5 Conclusions

AEMO has assessed this incident in accordance with NER 4.8.15(b). In particular, AEMO has assessed the adequacy of the provision and response of facilities or services, and the appropriateness of actions taken to restore or maintain power system security.

In relation to the 16 November 2021 incident, AEMO has concluded that:

1. Power system oscillations were present in the West Murray Zone for around 37 minutes. The oscillations had a frequency of around 19 Hz[24] and peak-to-peak voltage magnitude up to 1.94% was observed at the RCTS 220 kV bus. The oscillations continued despite 35 inverters tripping at Wemen SF.
2. At no point during this incident were transmission system voltages outside of relevant voltage limits
3. No action was required by AEMO to restore or maintain power system security during the incident. The power system oscillations did not impact power system frequency and the Frequency Operating Standard was met during this incident.
4. Due to the absence of timestamped, synchronised HSM data, no conclusions could be drawn regarding the root cause of, or individual contributions to, the oscillations. AEMO is continuing to investigate the root cause of this incident in collaboration with NSPs and generators. In addition, the planned rollout of additional HSM improvements, outlined in Section 3 of this report, will assist AEMO with root cause analysis of future power system incidents.

[22] AEMO is required to assess whether or not to reclassify a non-credible contingency event as a credible contingency event – NER 4.2.3A(c) – and to report how the reclassification criteria were applied – NER 4.8.15(ca).

[23] AEMO generally informs the market about operating incidents as they progress by issuing Market Notices – see https://www.aemo.com.au/Market-Notices.

[24] For more explanation please see Appendix A1 of the West Murray Zone Power System Oscillations 2020 – 2021 report found here - https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/system-operations/power-system-oscillations.

5. Due to the relatively low granularity of the available data, no conclusions could be drawn regarding the performance of DPV during the event.

Recommendations

AEMO recommends:

- As this incident occurred during a prior outage of one Wemen Terminal Station (WETS) 220/66 kV transformer, and on the evening of 17 November 2022, in response to the incident, AEMO implemented a constraint to:
  - limit the maximum number of inverters online at Wemen SF and Bannerton SP to 15 inverters at each site (that is, allowing a maximum total of 30 inverters online across the two sites); and
  - limit the total output of Wemen SF and Bannerton SP to a maximum of 70 MW,

  AEMO implement this constraint for all future WETS 220/66 kV transformer outages.
- Generator operators have procedures in place to ensure that, when generator or power system instability is identified, appropriate actions can be taken within a reasonable timeframe. These actions could include advising AEMO and NSP control rooms of the instability, investigation of the instability to determine if the generator is contributing and if required, disconnection of the generating facility.
- AEMO is currently consulting with industry on guidelines for how generators can best comply with NERS5.2.5.10 (protection to trip for unstable operation) for asynchronous generators[25]. AEMO will consider a strategy for engaging further with existing proponents once these guidelines are updated.
- As part of the access standards review[26], for new connections, AEMO is currently engaging with the industry on the suitability of the requirements of NER S5.2.5.10 (protection to trip plant for unstable operation), with a focus on asynchronous generators. As part of this engagement, AEMO will consider amendments to the access standards for generators to:
  - Monitor for instability and alert generator operators, the NSP and AEMO.
  - Determine their contribution to system instability.
  - Trip or ramp down under critical system conditions where the system is unstable and/or where a generator identifies itself as a high contributor to the identified system instability.
- An acceptable oscillations limit is developed in conjunction with suitable operational tools and installation of adequate high-speed monitors to support control room operators in managing future oscillation events on the power system. This will enable operators to monitor and effectively manage oscillations within operational timeframes, and involves the following recommended steps:
  - AEMO, in conjunction with TNSPs, to improve HSM capabilities and implement visualisation tools providing system operators with real-time information needed to respond if automatic protection systems fail to disconnect the affected generation. For more information on this recommendation, see Section 3.1 of this report.

[25] For more information on this consultation, see https://aemo.com.au/consultations/current-and-closed-consultations/ner-s52510-guideline-consultation.

[26] For more information on the access standards review, see https://aemo.com.au/consultations/current-and-closed-consultations/aemo-review-of-technical-requirements-for-connection.

  - The PSSWG to define a level of power system oscillations which may be considered acceptable for satisfactory power system operation in the operational timeframe, which may be used to support TNSPs when providing operational limits advice.
  - All TNSPs to provide AEMO with updated limit advice (where required) consistent with the acceptable level of oscillations, and identify operational actions that AEMO can take if available monitoring indicates power system oscillations exceeding the acceptable level.
- NSPs, generators, industrial load customers and AEMO continue to collaborate to identify the root cause of power system oscillation incidents in the West Murray Zone.

A1. Participants who provided data

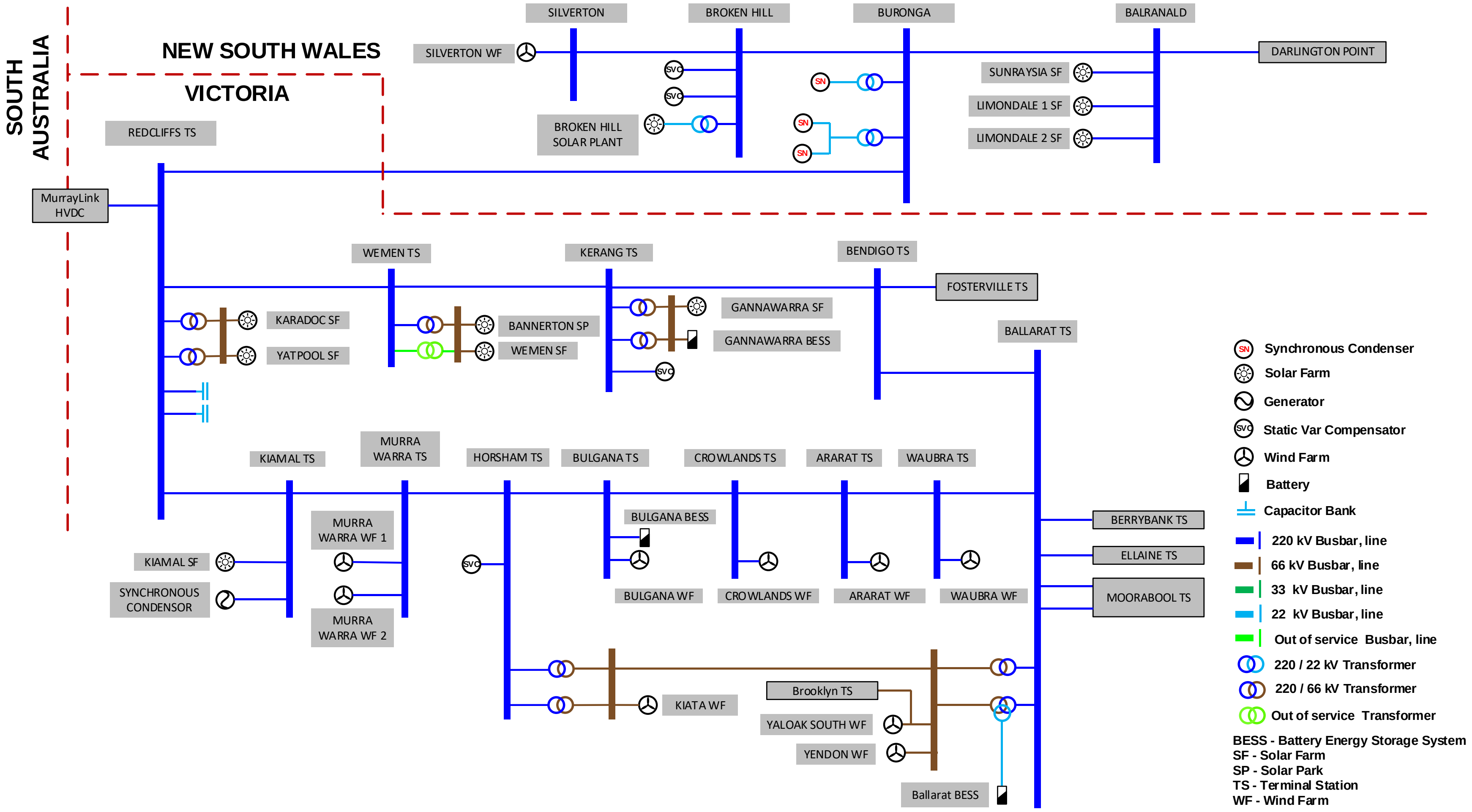
Table 3 Registered participants who provided data for AEMO's investigation

Participant	Station name
AusNet Transmission Group Pty Ltd	The Victorian Transmission Network
Powercor Australia Ltd	The Victorian Distribution Network
Ararat Wind Farm Pty Ltd	Ararat Wind Farm
Alinta Energy Retail Sales Pty Ltd	Bannerton Solar Park
EnergyAustralia Pty Ltd	Ballarat Battery Energy Storage System
AGL Hydro Partnership	Broken Hill Solar Plant
Bulgana Wind Farm Pty Ltd	Bulgana Green Power Hub - Battery Units 1-40
	Bulgana Green Power Hub - Wind Units 1-56
Pacific Hydro Crowlands Pty Ltd	Crowlands Wind Farm
EnergyAustralia Pty Ltd	Gannawarra Energy Storage System
Gannawarra Solar Farm Pty Ltd	Gannawarra Solar Farm
Iraak Sun Farm Pty Ltd	Karadoc Solar Farm
KSF Project Nominees Pty Ltd as Trustee for the KSF Project Trust	Kiamal Solar Farm
Kiata ProjectCo Pty Ltd as trustee for Kiata Project Trust	Kiata Wind Farm
Limondale Sun Farm Pty Ltd	Limondale Solar Farm 1
	Limondale Solar Farm 2
Telstra Energy (Generation) Pty Ltd	Murra Warra Wind Farm
Murra Warra II Project Co Pty Ltd asTrustee for The Murra Warra II Project Trust	Murra Warra Wind Farm Stage 2
AGL PARF NSW Pty Ltd	Silverton Wind Farm
Sunraysia Solar Project Pty Ltd as trustee for the Sunraysia Solar Project Trust	Sunraysia Solar Farm
Pyrenees Wind Energy Development Pty Ltd	Waubra Wind Farm
Wemen Asset Co Pty Ltd ATF Wemen Solar Unit Trust	Wemen Solar Farm, Units 1-39
Pacific Hydro Yaloak South Pty Ltd	Yaloak South Wind Farm
Yatpool Sun Farm Pty Ltd	Yatpool Solar Farm

A2. System diagram

The diagram below provides an overview of part of the power system immediately after the incident.

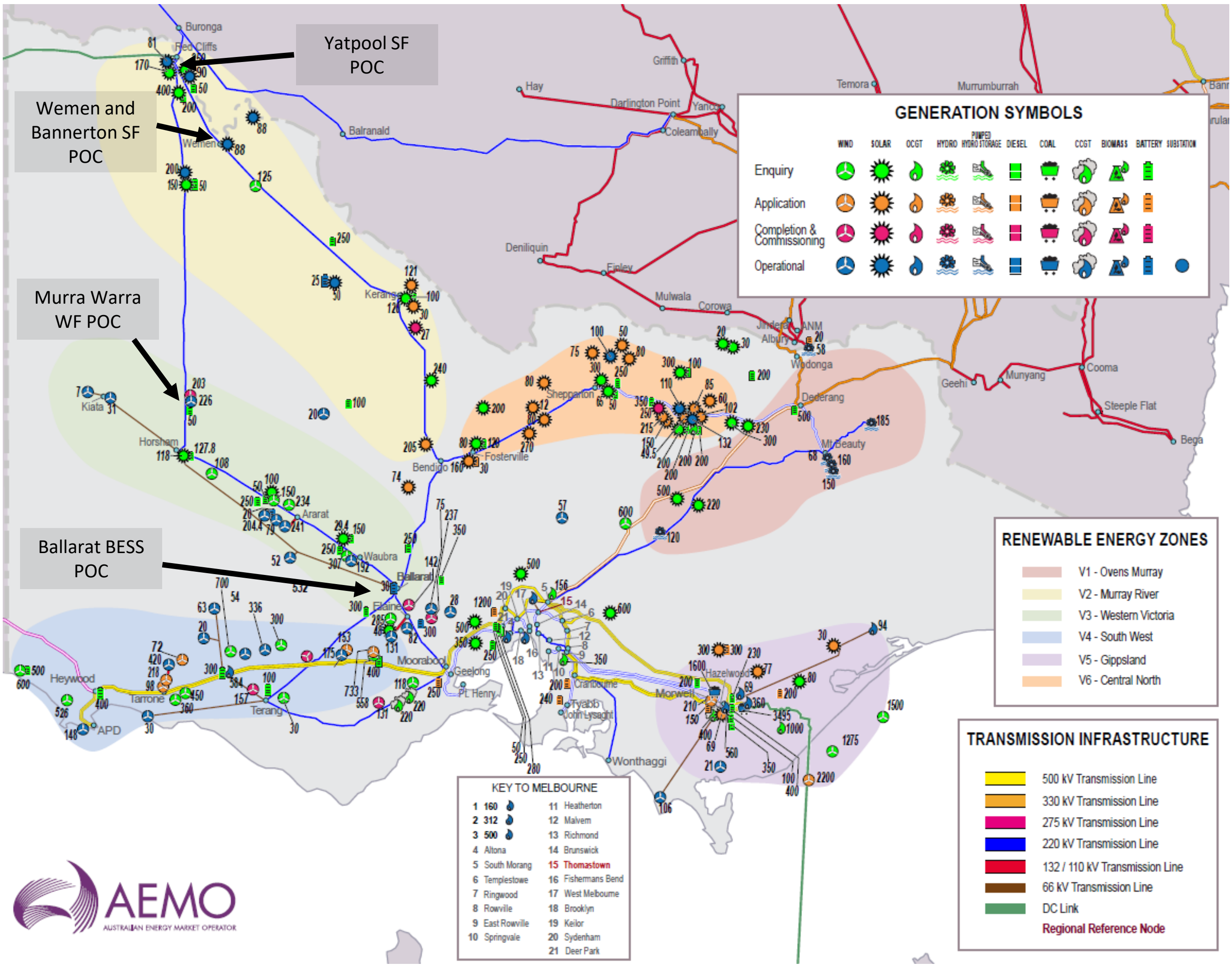
Figure 6 Overview of West Murray Zone



A3. Point of connection RMS oscillations

This appendix contains high speed measurement data from a subset of generator connection points in the area where the power system oscillations on 16 November 2021 were identified. Figure 7 outlines the measurement location for the high speed measurement data included in this appendix.

Figure 7 Geographic location of point of connection (POC) high speed monitoring (HSM) measurements included in Appendix A3



The following figures show the measured RMS voltage at the different IBR generators' POCs. The data covers the period from 0555 hrs to 0650 hrs AEST on 16 November 2021, but due to each high speed monitors' settings, the recorded/displayed data timestamps may vary.

Figure 8 Yatpool Solar Farm POC measured single phase RMS voltage

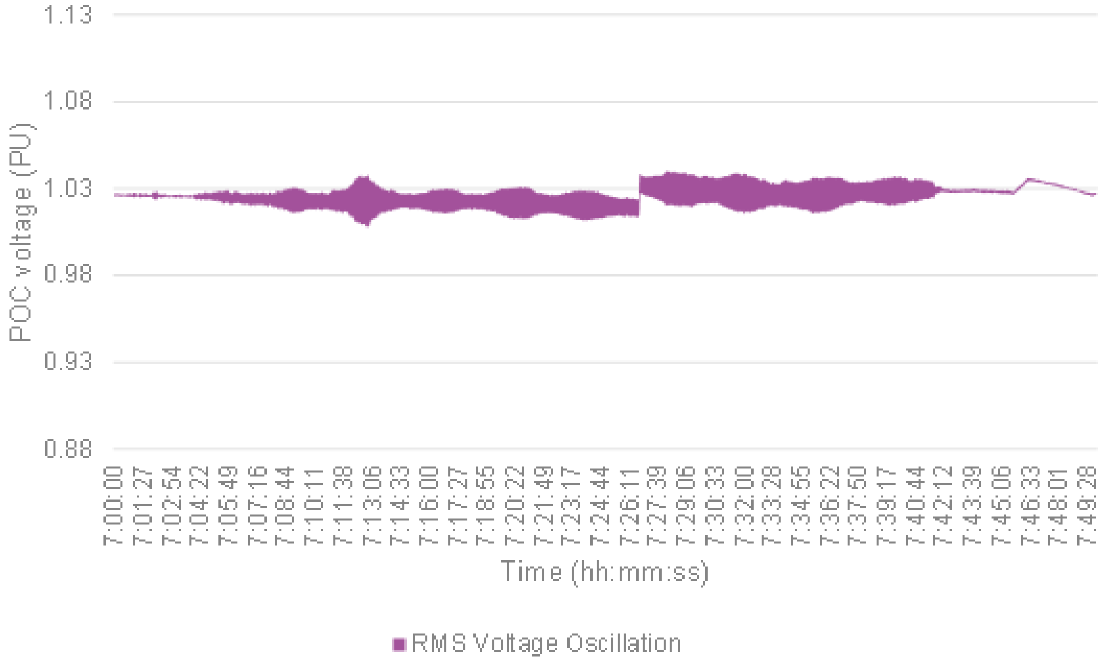


Figure 9 Wemen Solar Farm POC measured single phase RMS voltage

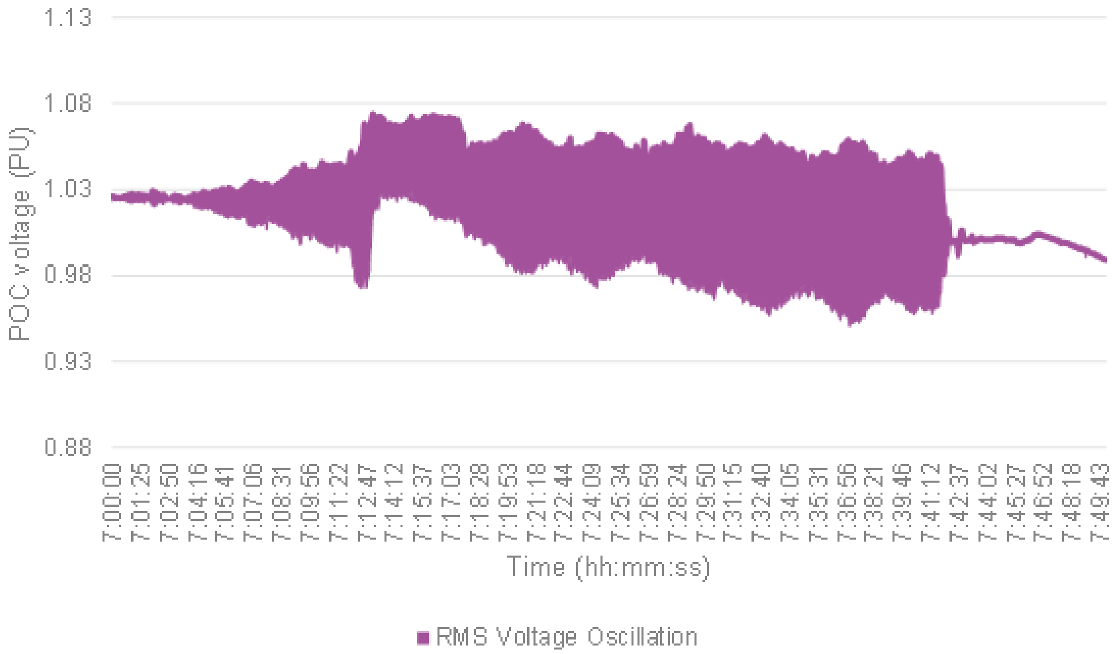


Figure 10 Bannerton Solar Park POC measured single phase RMS voltage

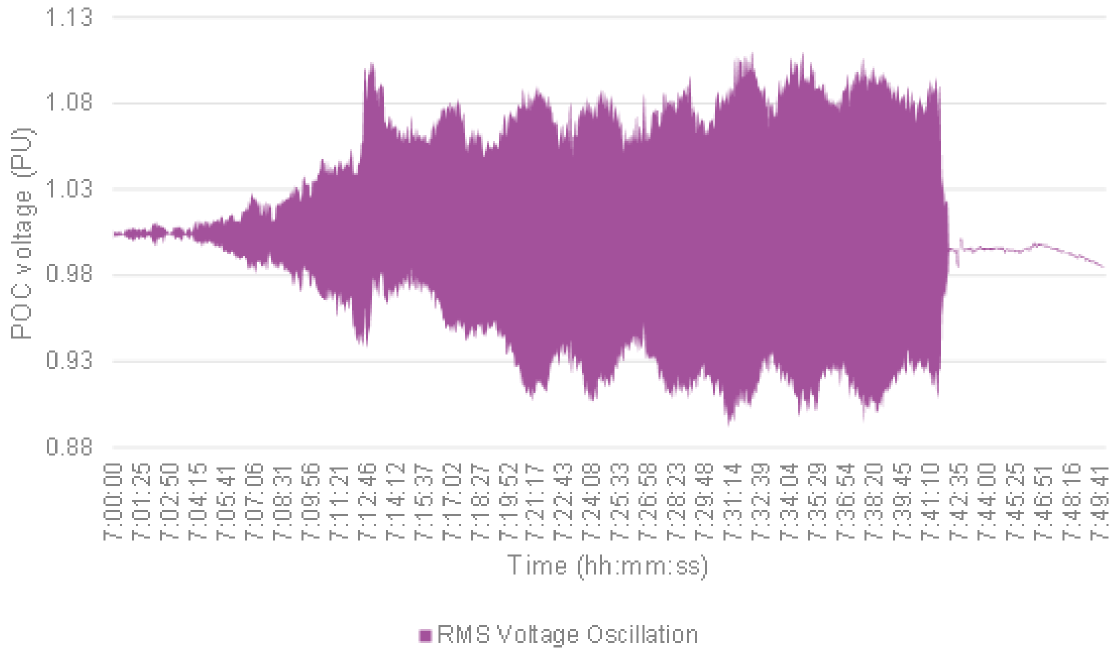


Figure 11 Murra Warra Wind Farm POC measured single phase RMS voltage

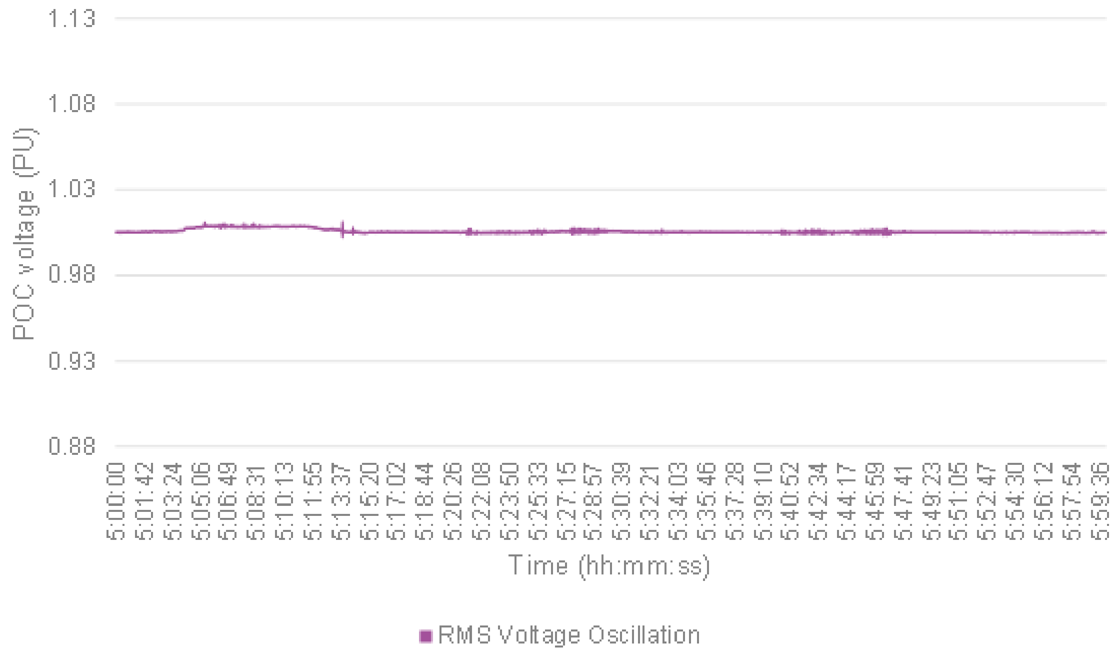


Figure 12 Ballarat Battery Energy Storage System POC measured single phase RMS voltage