Final Report – South Australia and Victoria Separation Event, 16 November 2019

November 2020

A reviewable operating incident report for the National Electricity Market

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

AEMO has been provided with data by Registered Participants as to the performance of some equipment leading up to, during, and after the separation event, in accordance with clause 4.8.15 of the Rules. In addition, AEMO has collated information from its own systems.

While AEMO has made every reasonable effort to ensure the quality of the information in this report, it cannot guarantee its accuracy or completeness. The findings expressed in it may change as further information becomes available and further analysis is conducted. 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.

Accordingly, to the maximum extent permitted by law, AEMO and its officers, employees and consultants involved in the preparation of this report:

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CONTACT

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ABBREVIATIONS

Abbreviation	Term
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
AEST	Australian Eastern Standard Time
APD	Alcoa Portland (Aluminium Smelter)
ARENA	Australian Renewable Energy Agency
BESS	Battery Energy Storage System
CUO	Continuous Uninterrupted Operation
DCD	Digital Current Differential
DEIP	Distributed Energy Integration Program
FOS	Frequency Operating Standard
FCAS	Frequency Control Ancillary Service
FOS	Frequency Operating Standard
GPS	Generator Performance Standard
HPR	Hornsdale Power Reserve
HYTS	Heywood Terminal Station
Hz	Hertz (frequency)
MOPS	Mortlake Power Station
MW	Megawatt
NEM	National Electricity Market
NER and Rules	National Electricity Rules
OFGS	Over Frequency Generation Shedding
PPT CCGT	Pelican Point Combined Cycle Gas Turbine
PSSWG	Power System Security Working Group
PV	Photovoltaic Solar
RERT	Reliability and Emergency Reserve Trader
RoCoF	Rate of change of frequency
SCADA	Supervisory Control And Data Acquisition
TNSP	Transmission Network Service Provider
TRTS	Tarrone Terminal Station
UNSW	University of New South Wales
VPP	Virtual Power Plant

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1. Overview

This is AEMO's final report about a reviewable operating incident that occurred on 16 November 2019 in the Victoria region of the National Electricity Market (NEM), that resulted in the separation of the South Australia and Victoria regions.

This incident resulted in the loss of 338 megawatts (MW) of generation and 527 MW of customer load, and a reduction of approximately 761 MW of generation availability. South Australia was exporting approximately 307 MW to Victoria via the Heywood interconnector immediately prior to the event, with Murraylink interconnector out of service on a forced outage. Excess generation following the islanding of South Australia led to increased system frequency and the need for FCAS services. Refer to Appendix A1 for diagrams of the power system prior to and after the separation event.

AEMO published a Preliminary Report on 18 December 2019[1]. This final report is not intended to repeat details already covered in the Preliminary Report, but to provide further analysis based on information unavailable at the time of publication of the Preliminary Report, including:

- Root cause of the incident.
- AEMO actions to manage the incident.
- The delivery of frequency control ancillary services (FCAS) immediately after the separation event.
- The performance of conventional and distributed generating units during the disturbance created by the separation event.

This final report is prepared in accordance with clause 4.8.15(c) of the National Electricity Rules (NER) and should be read in conjunction with the Preliminary Report.

AEMO has concluded that:

- The loss of two 500 kilovolt (kV) lines that led to the separation of the South Australia region was caused by the malfunction of a communication multiplexer:
- The faulted communications equipment cards were replaced by AusNet Services[2] on 17 November 2019, and no similar events have been recorded since.
- Additional information regarding the underlying cause of the hardware malfunction and recommended remedial actions was unavailable from AusNet Services at the time of this report's publication.
- AusNet Services has indicated that additional assets may be susceptible to the same type of malfunction, however the assessed probability of failure remains low.
- AEMO actions to manage and restore the system during the incident were appropriate.
- Modifications to synchronisation check relay settings are expected to reduce issues with re-synchronising island regions.
- Factors contributing to the under-delivery of FCAS services have been identified and rectified by the appropriate parties.
- No generators were identified as non-compliant with the applicable performance standards.

[1] AEMO. Preliminary Report – Non-credible Separation Event South Australia - Victoria 16 November 2019, at https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2019/preliminary-incident-report---16-november-2019---sa---vic-separation.pdf?la=en&hash=F26C20C49BD51164AE700A30F696A511.

[2] AusNet Services disclaimer: AusNet Services is a Transmission Network Service Provider in the Victoria region. Information provided by AusNet Services has been provided on a without prejudice basis and nothing in this report is intended to constitute, or may be taken by any person as constituting, an admission of fault, liability, wrongdoing, negligence, bad faith or the like on behalf of AusNet Services (or its respective associated companies, businesses, partners, directors, officers or employees).

- Further work is required between stakeholders to develop measures to improve compliance with new and existing technical performance standards and connection requirements for distributed photovoltaic (PV) systems.

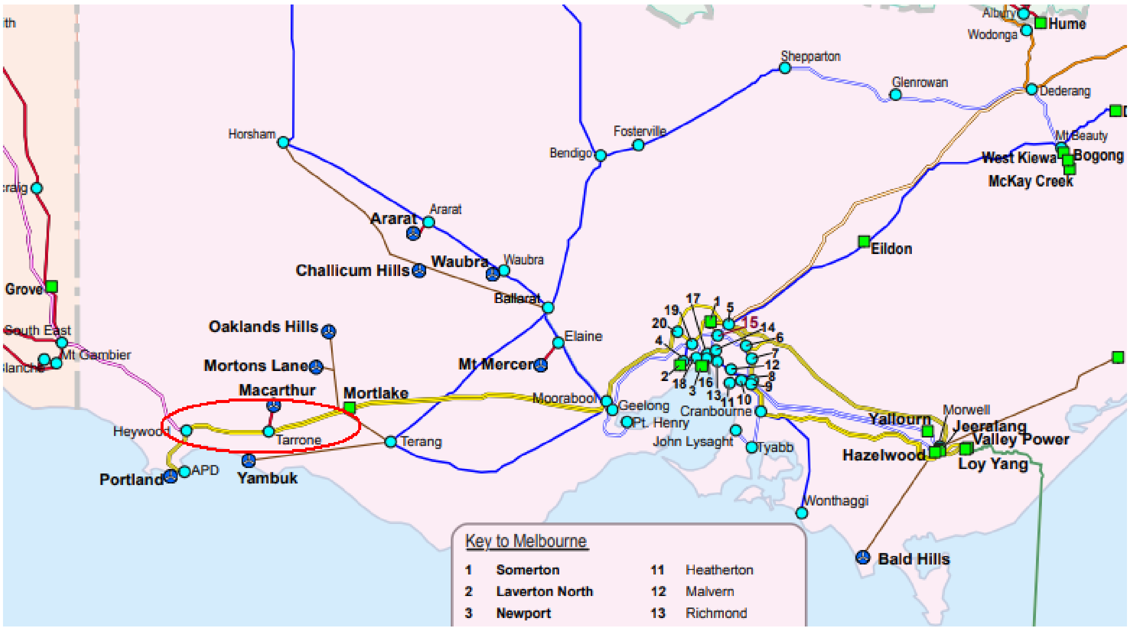
NEM time (Australian Eastern Standard Time [AEST]) is used in this report.

2. Incident overview

At 1806 hrs on 16 November 2019, two 500 kV transmission lines in Victoria were disconnected simultaneously due to malfunction of telecommunications equipment that caused operation of protection equipment on both circuits. This non-credible contingency event resulted in the disconnection of the South Australia region from the rest of the NEM power system for nearly five hours, and disconnection of electrical supply to the Alcoa Portland (APD) aluminium smelter in Victoria for nearly three hours.

Figure 1 shows the location of the affected 500 kV lines in Victoria (area circled in red).

Figure 1 Victoria transmission system



Refer to the Preliminary Report for a detailed sequence of events leading up to the separation event and diagrams of the relevant part of the power system.

Supply to APD was restored at 2156 hrs on 16 November 2019 with the interconnection between the South Australia and Victoria regions resynchronised at 2358 hrs on the same day.

This separation event had several impacts on the power system including frequency response, FCAS provision, and distributed PV performance in South Australia. These issues are discussed in this report.

3. Root cause

AusNet Services owns and operates the majority of Victoria's electricity transmission network including the lines impacted in this event. The following lines were tripped as a result of this incident:

- Heywood – Alcoa Portland – Mortlake 500 kV line (HYTS–APD-MOPS 500 kV line).
- Heywood – Alcoa Portland – Tarrone 500 kV line (HYTS–APD-TRTS 500 kV line).

Following the disconnection of the 500 kV lines, AusNet Services advised AEMO that the incident was due to malfunction of a communication multiplexer which caused the X unit protections on both of the affected transmission lines to operate and open the circuit breakers at each terminal on both lines.

AusNet Services personnel attended Heywood (HYTS), Tarrone (TRTS) and Mortlake (MOPS) sites, with APD personnel providing support at APD. Initial investigations determined that there had been no genuine fault on either of the lines. Approximately 20 seconds prior to the lines tripping event, a number of repetitive communications system alarms were received by AusNet Services from APD and HYTS. Ongoing communications alarms overwrote protection relay alarm records at both HYTS and APD, meaning no protection records are available from the relays for the time of the incident.

AusNet Services was able to determine from other records that both 500 kV lines tripped on X unit Digital Current Differential (DCD), attributed to the malfunctioning teleprotection communications equipment at APD. There was no recorded operation of the X unit distance protection or Y unit DCD or distance protection.

The communication multiplexer was isolated to enable restoration of the 500 kV lines, restoration of supply to APD and the reconnection of South Australia to the rest of the NEM. The X and Y unit distance protection and the Y unit DCD protection remained functional after the isolation of the multiplexer.

AusNet Services has reviewed associated protection functions, and modifications have been implemented at APD to interlock DCD pickup with other trip events including distance trip elements and disturbance detector elements on the X and Y protection schemes respectively. Similar changes will be implemented for a number of other AusNet Services assets with similar equipment. Further detail is provided in Section 4.

AusNet Services is continuing its investigation to determine the root cause of the simultaneous failure of both channels of the communication multiplexer, however no definitive information on the root cause of the multiplexer failure that initiated this non-credible contingency event was available from AusNet Services at the time of this report's publication.

The assessment and implementation of mitigation measures and a broader review of the implications for managing the operation and resilience of the NEM may be required once this investigation is complete. As other Transmission Network Service Providers (TNSPs) have indicated there are no similar installations with common inter-trip communication paths elsewhere in the NEM, this assessment is expected to be led by the AusNet Services. Further input may be sourced from the Power System Security Working Group (PSSWG), including AEMO and other participant members.

4. AEMO actions

Sections 4 and 5 of the Preliminary Report describe the actions taken or initiated by AEMO to return the power system to a secure operating state and maintain power system security after the event, until South Australia was reconnected to the NEM via the Heywood interconnector. This information will not be repeated in this report. This section provides additional details based on information and assessments made following the publication of the Preliminary Report.

4.1 Reclassification

Following the incident and the separation of the South Australia region, and prior to restoration of the lines or service to APD, AusNet Services advised that the malfunctioning communication multiplexer that initiated this non-credible contingency event had been isolated and other protection functions remained in place. Based on this information, AEMO determined that it was not necessary to reclassify the possible reocurrence of this non-credible contingency event as credible.

AusNet Services replaced the faulted communications cards on 17 November 2019. AusNet Services reinstated and validated the communications links and DCD protections, and advised AEMO that a recurrence of the fault was not likely. Based on this information, AEMO considered that the reoccurrence of the event was not reasonably possible and the reclassification of the non-credible contingency event was not necessary.

AEMO was kept informed of the ongoing AusNet Services investigation into the malfunction of the multiplexer both directly and via the PSSWG. As part of these discussions, AusNet Services confirmed that replacement of the communications cards had been identified at the time as clearing the issue, and that the installation was compliant with the NER and AusNet Services' own design standards. Separate inter-trip communication paths are not explicitly required in either.

Other TNSPs, in their capacity as members of the PSSWG, indicated that no other instances had been identified elsewhere in the NEM where common inter-trip communications equipment could trip parallel lines.

AusNet Services advised that a repeat of the same fault was not likely, and on that basis AEMO determined that the ongoing classification of the loss of the HYTS–APD-MOPS and HYTS–APD–MRTS 500 kV lines as non-credible remained appropriate.

AusNet Services has since advised that the common communications carrier vulnerability does exist at several other locations and that the DCD protection interlock modifications detailed in Section 3 are yet to be implemented at all impacted sites. AusNet Services informed AEMO that this incident is the only recorded failure of its type across all AusNet Services assets with similar architectures, and that the likelihood of failure is considered very low. AEMO has therefore not reclassified the loss of any of these lines as credible contingency events.

4.2 Restoration

The Preliminary Report highlighted ongoing frequency alignment issues experienced when attempting to resynchronise Victoria and South Australia at HYTS.

AEMO had identified the frequency and phase angle settings in the synchronisation check relay at HYTS were very narrow and contributed to the delays in resynchronising the South Australia and Victoria regions. AusNet Services has since modified the synchronisation check relay settings at HYTS at AEMO's request to increase these tolerances. This is expected to reduce the time required to resynchronise South Australia and Victoria under similar circumstances.

5. Frequency response

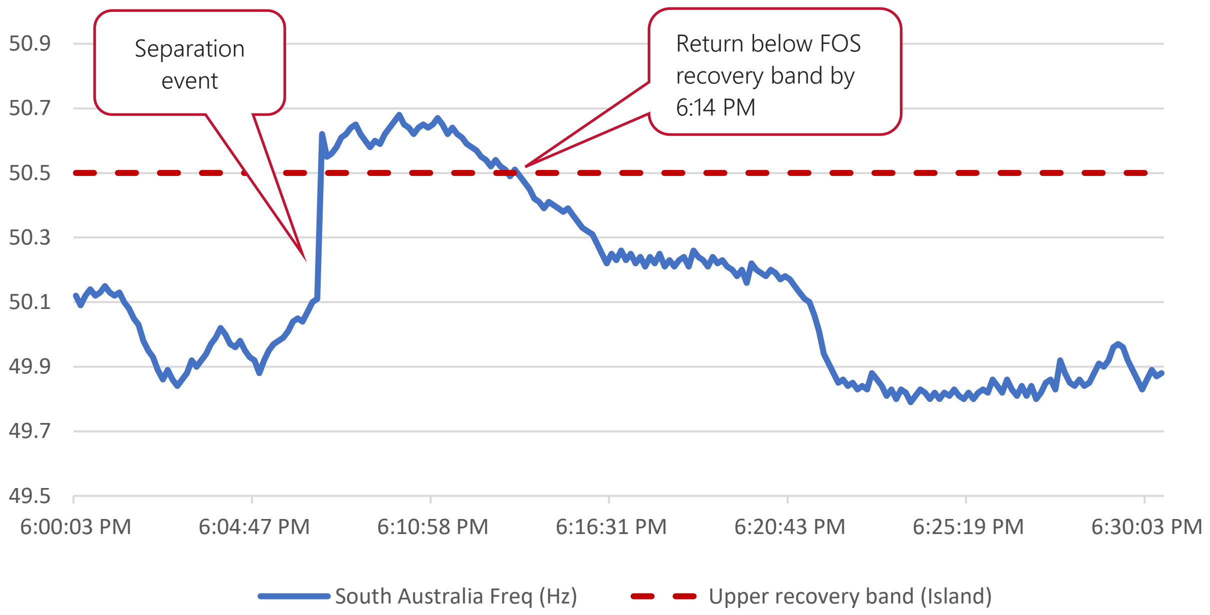
AEMO conducted a review of the system frequency response and delivery of FCAS across the NEM in response to the separation event.

The Frequency Operating Standard (FOS)[3] defines a separation event as a *credible* contingency event affecting a transmission element that results in an island. As this event is a result of a non-credible contingency event, the FOS requirements for a multiple contingency event apply.

The FOS for an island system in a multiple contingency event allows for reasonable endeavours to bring the frequency below a maximum of 52 hertz (Hz) (containment), with reasonable endeavours to bring the frequency lower than 51.0 Hz (stabilisation) within two minutes and to below 50.5 Hz (recovery) within 10 minutes[4]. South Australia operates an over frequency generation shedding (OFGS) scheme between 51 Hz and 52 Hz to assist in limiting frequency rise to 52 Hz.

Figure 2 shows the frequency response in the South Australia island prior to and after the separation event.

Figure 2 Frequency in the South Australia island



For this event, the maximum frequency reached in the South Australia island was 50.7 Hz and did not exceed the FOS containment or stabilisation boundaries. Despite under-delivery of delayed lower FCAS from some FCAS-enabled facilities (refer to Section 5.2) the frequency in the South Australia island recovered to below 50.5 Hz within approximately five minutes. In the South Australia island the FOS was met but the frequency remained at approximately 50.15 Hz for a further 10 minutes. Refer to Section 0 for more information.

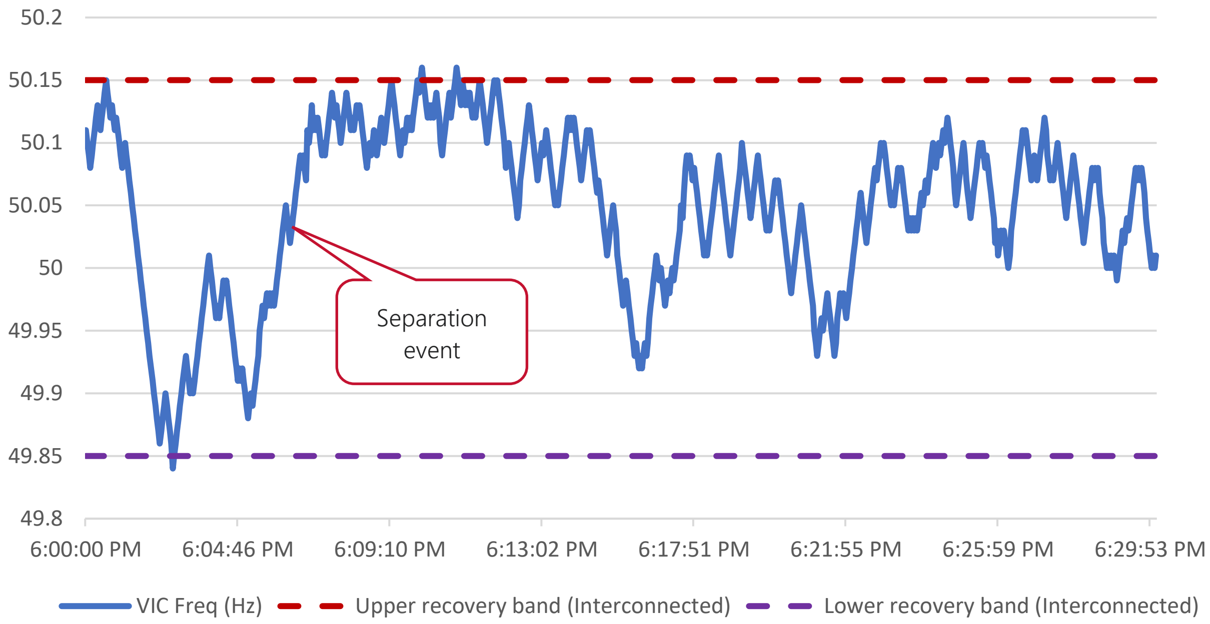
As the frequency did not exceed 51 Hz, there was no shedding of generation load as a result of OFGS operation.

[3] Frequency Operating Standard, effective 1 January 2020, available at https://www.aemc.gov.au/media/87484.

[4] Refer Table A.1.2 of Frequency Operating Standard, at https://www.aemc.gov.au/sites/default/files/content/c2716a96-e099-441d-9e46-8ac05d36f5a7/REL0065-The-Frequency-Operating-Standard-stage-one-final-for-publi.pdf.

Figure 3 shows the frequency response in the other mainland regions prior to and after the separation event. The FOS for a separation event allows the frequency to range between 49 Hz and 51 Hz (containment) but the frequency must return to between 49.5 Hz and 50.5 Hz (stabilisation) within two minutes and to between 49.85 Hz and 50.15 Hz (recovery) within 10 minutes.

Figure 3 Frequency in the remainder of the mainland NEM



For this event, the frequency briefly exceeded the FOS upper recovery limit in the minutes following the separation of South Australia, with the loss of the APD load exceeding the reduced generation capacity from South Australia. A maximum frequency of 50.17 Hz was recorded in the mainland regions excluding South Australia. This is only marginally outside the FOS recovery limit and returned within the FOS limits within the 10-minute window. As such, an FCAS assessment was not conducted for units outside of South Australia.

5.1 Potential for regional FCAS

In its report[5] on the separation of the Queensland and South Australia regions from the rest of the NEM on 25 August 2018, AEMO reviewed the potential for FCAS to be enabled on a regional basis under certain circumstances. While AEMO can and does implement regional FCAS to address credible contingency scenarios, further work would be required to justify specific FCAS dispatch requirements for non-credible events. AEMO will continue to review FCAS dispatch requirements, including through the 2020 Power System Frequency Risk Review and implementation of the Frequency Control Work Plan.

5.2 Delivery of FCAS

The maximum frequency recorded in South Australia reached 50.7 Hz and required FCAS delivery of ancillary service facilities in South Australia.

There were five dispatchable units enabled for lower contingency services in South Australia for the dispatch interval ending at 1810 hrs on 16 November 2019. Table 1 summarises the amount of FCAS enabled by the

[5] Available on the AEMO website, at https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2018/qld---sa-separation-25-august-2018-incident-report.pdf?la=en&hash=49B5296CF683E6748DD8D05E012E901C.

market systems for lower contingency services, and the FCAS delivery of the ancillary service facilities in South Australia.

The Preliminary Report also identified Enel X and Pelican Point Combined Cycle Gas Turbine (PPT CCGT) as enabled for FCAS services during the same dispatch interval. Both were enabled for raise contingency services only at the time and did not contribute towards the lower contingency in this instance.

Table 1 shows the FCAS response from the Torrens B3, B4 and Dalrymple Battery Energy Storage System (BESS) facilities was more than or equal to the enabled lower contingency services by the market systems, with under-delivery by Hornsdale Power Reserve (HPR) and the Energy Locals Virtual Power Plant (VPP[6]). This is discussed further in Section 0. The total service delivered exceeded the enabled requirements in the South Australia island, which remained within the FOS frequency boundaries for an islanded system[7].

Table 1 South Australian FCAS enablement

Dispatchable Unit	MW enabled			MW delivered		
	Fast Lower	Slow Lower	Delayed Lower	Fast Lower	Slow Lower	Delayed Lower
Torrens B3	0.0	10.0	0.0	50.8	55.7	75.2
Torrens B4	0.0	10.0	0.0	71.9	85.0	71.0
Dalrymple BESS	1.0	1.0	1.0	6.5	8.2	3.6
HPR BESS	40.0	18.5	40.0	50.5	15.4	32.9
Energy Locals VPP	1.0	1.0	1.0	0.8	0.8	0.8
Total	**42.0**	**40.5**	**42.0**	**180.5**	**165.0**	**183.5**

5.2.1 Analysis of non-compliant enabled FCAS providers

HPR exceeded the required enablement amount for fast lower contingency service. However, the slow and delayed FCAS response was lower than the enabled amount, due to an incorrect setting used by HPR to calculate the lower FCAS response required. AEMO has discussed this with the operator of HPR, and the FCAS offers for HPR have been adjusted to reflect the actual capability. A similar observation was made after the 4 January 2020 and 31 January 2020 events, however this was not identified and adjusted until after the 31 January 2020 incident.

Due to a frequency dead-band setting issue on some home battery systems, the FCAS delivery from the Energy Locals VPP was approximately 20% below the minimum requirement. AEMO has followed its FCAS non-compliance process and dead-band settings have been corrected by Energy Locals and Tesla.

[6] A virtual power plant (VPP) broadly refers to an aggregation of resources (such as decentralised generation, storage and controllable loads) coordinated to deliver services for power system operations and electricity markets. AEMO is collaborating with the Australian Renewable Energy Agency (ARENA), the AEMC, the Australian Energy Regulator (AER), and members of the Distributed Energy Integration Program (DEIP) to establish VPP demonstrations to inform changes to regulatory frameworks and operational processes so distributed energy resources can be effectively integrated into the NEM.

[7] Refer Table A.1.2 of FOS, at https://www.aemc.gov.au/sites/default/files/content/c2716a96-e099-441d-9e46-8ac05d36f5a7/REL0065-The-Frequency-Operating-Standard-stage-one-final-for-publi.pdf.

6. Response of generating units

AEMO reviewed the response of generating units to the frequency change due to the separation event. The majority of generating units performed as expected, with no generators identified as non-compliant with their Generator Performance Standards (GPS).

7. Response of distributed photovoltaic generation

Distributed rooftop PV generation is now a significant component of the power system, and as such its aggregated behaviour can affect outcomes during system incidents. AEMO has traditionally had limited visibility of distributed PV behaviour.

For analysis of the behaviour of distributed PV during this event, Solar Analytics provided data from approximately 4,000 individual distributed PV systems in South Australia under a joint Australian Renewable Energy Agency (ARENA) funded project[8], with anonymisation to ensure system owner and addresses could not be identified.

Immediately prior to the separation event, distributed PV was contributing around 200 MW of generation in South Australia.

7.1 Disconnections

The observed disconnection behaviour of distributed PV inverters in South Australia is summarised in Table 2, with a benchmarking comparison to a previous similar separation event on 25 August 2018.

Table 2 Disconnection of distributed PV inverters, compared with findings on 25 August 2018[A]

		16 November 2019 event	25 August 2018 event[B]	
		South Australia	South Australia	Queensland
Inverters that dropped to zero/ disconnected	2005 standard[C]	17% (9-27%)	*11% (5-21%)*	*10% (5-16%)*
	2015 standard	11% (10-12%)	*6% (5-7%)*	*4% (3-5%)*
Maximum frequency (Hz)		50.83 Hz	*50.46 Hz*	*50.88 Hz*
Maximum rate of change of frequency (RoCoF) over first 10 cycles (0.2 seconds)		1.2 Hz/s	*1.25 Hz/s*	*0.64 Hz/s*
Maximum RoCoF over first second		0.6 Hz/s	*0.7 Hz/s*	*0.5 Hz/s*

A. Uncertainty estimates are based on a 95% confidence interval for the population, based on sample sizes.
B. Final Incident Report available at https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2018/qld---sa-separation-25-august-2018-incident-report.pdf?la=en&hash=49B5296CF683E6748DD8D05E012E901C.
C. The 2005 standard refers to AS/NZS4777.3:2005. The 2015 standard refers to AS/NZS4777.2:2015.

Inverters installed prior to October 2015 (on the 2005 standard) may have frequency trip settings anywhere in the range 50-55 Hz, according to AS/NZ4777.3:2005. AEMO's survey of frequency trip settings[9] conducted in 2015 did not identify any manufacturers with over-frequency trip settings below 50.98 Hz, although only around half the installed capacity in South Australia was surveyed. This event shows that some manufacturers may have frequency trip settings below this level, echoing findings from the 25 August 2018 event.

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[8] Collaboration on ARENA funded project "Enhanced Reliability through Short Time Resolution Data" with further details at https://arena.gov.au/projects/enhanced-reliability-through-short-time-resolution-data-around-voltage-disturbances/

[9] AEMO (April 2016) Response of existing PV inverters to frequency disturbances. Available at: https://aemo.com.au/-/media/Files/PDF/Response-of-Existing-PV-Inverters-to-Frequency-Disturbances-V20.pdf

Disconnection behaviour may also be related to rate of change of frequency (RoCoF). Laboratory bench testing of inverters by the University of New South Wales (UNSW) has identified at least one 2005 standard inverter that disconnects for RoCoF exceeding 1 Hz/s[10]. This does not alone explain the field observations, but may be a contributing factor.

Inverters installed after October 2016, under AS/NZ4777.2:2015, should not disconnect until frequency moves outside the range of 47-52 Hz. The disconnection/drop to zero of 11% (10-12%) of these inverters during this event does not align with the requirements specified in this standard. Similar levels of disconnection/drop to zero behaviour were also observed during the 25 August 2018 separation event[11], as summarised in Table 2. UNSW's laboratory testing has identified at least one 2015 standard inverter that disconnects for RoCoF exceeding 0.4 Hz/s, and there may be others that have not yet been tested that demonstrate similar behaviour. Alternatively (or perhaps in addition), disconnection behaviour may be indicative of distributed PV systems that have not been installed with the correct standards applied.

7.1.1 Possible manufacturer-specific issue

Approximately 55% of all disconnections of systems on the 2015 standard in South Australia in this event appear to have been PV systems attributable to a single manufacturer. 86% of the inverters from this manufacturer in South Australia installed under the 2015 standard were observed to disconnect during this event. In contrast, only 7% of the inverters installed under the 2015 standard in South Australia from other manufacturers were observed to disconnect. Disconnection behaviour in response to frequency disturbances can become problematic for system security when a large capacity of generation is involved. AEMO is exploring these findings further with the relevant manufacturer.

7.2 Over-frequency droop response

The 2015 standard requires that if an over-frequency event occurs, inverters should remain connected until frequency reaches 52 Hz for at least one second. They should also provide an over-frequency droop response; when frequency exceeds 50.25 Hz, the inverter should reduce power output linearly as a function of frequency, until 52 Hz. Output power should then remain at or below the lowest power level reached until frequency recovers to 50.15 Hz or below for at least sixty seconds, to provide hysteresis. This controlled reduction in output power is designed to assist with stabilising power system frequency.

Responses of inverters on the 2015 standard were analysed to determine whether they were providing this response as specified; 43% of the sampled systems were assessed to be providing the over-frequency droop as specified in the standard, with a further 2% partially responding. However, 35% of systems did not respond according to the specified requirement, and a further 11% of systems appear to have disconnected (also inconsistent with behaviour specified in the standard). Figure 4 shows the normalised response of inverters in these categories. The black dotted line indicates the "specified response", based upon the maximum frequency reached in South Australia during this event (50.8 Hz).

The distributed PV behaviours demonstrated were not problematic in aggregate in this particular event, since the total aggregate response is close to the specified requirement. However, the fact that 35% of sampled systems did not provide the specified over-frequency droop, and a further 11% of systems disconnected, is evidence that a large proportion of inverters may not be behaving according to the standard. This reinforces and echoes earlier evidence from the separation event on 25 August 2018[12].

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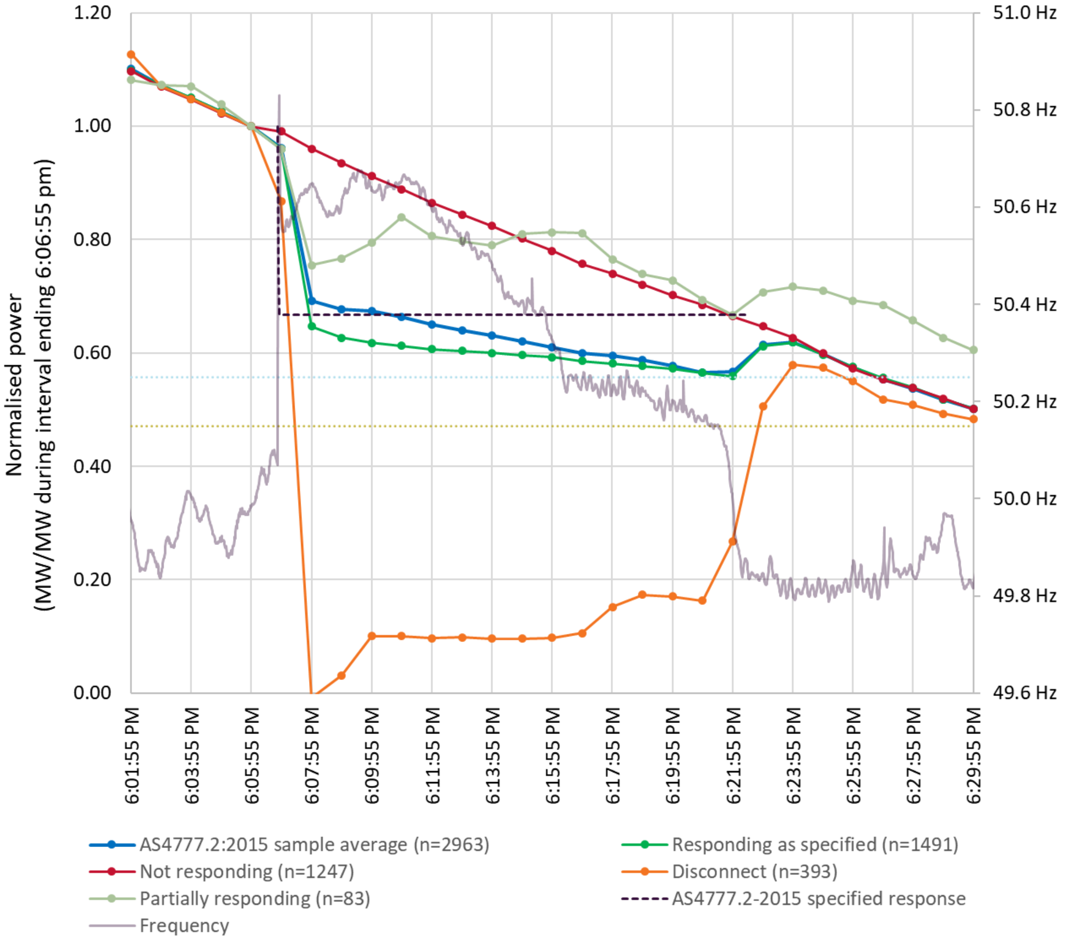
[10] Collaboration involving UNSW, ElectraNet and TasNetworks on ARENA funded project "Addressing Barriers to Efficient Renewable Integration" with further details at https://arena.gov.au/projects/addressing-barriers-efficient-renewable-integration/.

[11] AEMO (10 January 2019) Final Report – Queensland and South Australia system separation on 25 August 2018, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Market_Notices_and_Events/Power_System_Incident_Reports/2018/Qld---SA-Separation-25-August-2018-Incident-Report.pdf.

[12] AEMO (10 January 2019) Final Report – Queensland and South Australia system separation on 25 August 2018, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Market_Notices_and_Events/Power_System_Incident_Reports/2018/Qld---SA-Separation-25-August-2018-Incident-Report.pdf. AEMO's earlier assessment indicated that at least 15% of inverters in Queensland and at least 30% of inverters installed in South Australia post October 2016 did not provide the over-frequency droop response as specified. AEMO has further interrogated these datasets with the improved algorithms developed for the assessment outlined here, finding that 32% of inverters in Queensland and 41% of inverters in South Australia did not provide the specified over-frequency droop.

UNSW's bench testing[13] of 16 inverters on the 2015 standard (representing around 66 MW, or 8%, of the installed capacity of distributed PV in South Australia) found that all inverters tested delivered the over-frequency droop response[14]. This suggests that the 35% of systems not delivering the over-frequency droop response in the field is more likely to be related to installer error than to manufacturer settings and design.

Figure 4 Categorised average responses of inverters installed after October 2016 in South Australia



7.2.1 Possible standard compliance issue

The finding that 35-45% of distributed PV inverters are not behaving according to the standard is indicative of a growing system security concern. Further auditing and establishment of methods for monitoring and improving compliance are required. AEMO is working with stakeholders including the Clean Energy Regulator, distributed PV suppliers and distribution network businesses to develop measures to improve compliance with new and existing technical performance standards and connection requirements for distributed PV systems[15].

[13] Collaboration on ARENA-funded project "Addressing Barriers to Efficient Renewable Integration", with further details at https://arena.gov.au/projects/addressing-barriers-efficient-renewable-integration/.

[14] Three inverters responded slowly (taking at least 5-10 seconds to ramp), which is strictly compliant with AS/NZ4777.2:2015, but not fast enough to assist with the initial arrest of a frequency rise in the timescales of an extreme over-frequency event (although it will assist with frequency stabilisation in the subsequent period). The Solar Analytics dataset would likely show these inverters as responding as specified, given the sixty second resolution of data.

[15] AEMO (April 2020) Renewable Integration Study Stage 1 – Appendix A: High Penetrations of Distributed Solar PV, at https://aemo.com.au/-/media/files/major-publications/ris/2020/ris-stage-1-appendix-a.pdf?la=en.

7.3 Upscaled response

This analysis suggests an overall reduction in distributed PV of around 44 MW in response to the over-frequency event in South Australia and other causes as below. This represents around a 20-25% reduction in distributed PV generation from the 200 MW operating in South Australia prior to the event.

This aligns with the estimated load observations from AEMO supervisory control and data acquisition (SCADA) trends for the South Australia region (which indicated around a 60 MW increase in scheduled demand).

Of this distributed PV reduction, around a quarter (23%/10 MW) is estimated to be related to the controlled over-frequency droop response of distributed PV, and half (50%/22 MW) related to erroneous disconnection behaviour of distributed PV. The remaining quarter is attributed to a mild reduction response from some 2005 systems and normal ramping down as the sun sets.

8. Conclusions and remedial actions

AEMO has assessed this incident in accordance with clause 4.8.15(b) of the NER. 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.

AEMO has concluded that:

- The loss of two 500 kV lines that led to the separation of the South Australia region was caused by the malfuncion of a communication multiplexer:
- The faulted communications equipment cards were replaced by AusNet Services on 17 November 2019 and no similar events have been recorded since.
- Additional information regarding the underlying cause of the hardware malfuntion and recommended remedial actions was unavailable from AusNet Services at the time of this report's publication.
- AusNet Services has indicated that additional assets may be susceptible to the same type of malfunction, however the assessed probability of failure remains very low.
- AEMO actions to manage and restore the system during the incident were appropriate.
- Modifications to synchronisation check relay settings are expected to reduce issues with re-synchronising island regions.
- Factors contributing to the underdelivery of FCAS services have been identified and rectified by the appropriate parties.
- No generators were identified as non-compliant with the applicable performance standards.
- Further work is required between stakeholders to develop measures to improve compliance with new and existing technical performance standards and connection requirements for distributed PV systems.

Table 3 provides a summary of the remedial actions identified as a result of this incident.

Table 3 Remedial actions

	Task	Responsible	Status
1	Confirmation of root cause of communications multiplexer malfunction at APD.	AusNet Services	Open
2	Review of mitigation measures for NEM security, pending resolution of Item 1.	AusNet Services	Open
3	Assess risk to NEM from common communication carriers with legacy DCD protection logic and determine if reclassification of assets required.	AEMO	Complete
4	Modify synchronisation check relay settings at HYTS to increase likelihood of successful resynchronisation between South Australia and Victoria.	AusNet Services	Complete
5	Hornsdale Power Reserve FCAS offers to be revised to prevent underdelivery of slow and delayed FCAS response.	HPR Operator	Complete
6	Correction of frequency dead-band settings on home battery systems.	Energy Locals/Tesla	Complete
7	Auditing and establishment of methods for monitoring and improving compliance of distributed PV systems.	AEMO/Stakeholder s	Open

A1. Status of major transmission circuits prior to and after separation

Figure 5 and Figure 6 below show the status of the circuits of the transmission network between South Australia and Victoria immediately prior to and immediately after separation. The transmission circuits are shown as follows:

- Solid purple lines represent in-service 275 kV transmission circuits.
- Solid yellow lines represent in service 500 kV transmission circuits.
- Solid blue lines indicate Inservice 220 kV transmission circuits.
- Solid green lines represent deenergised 500 kV circuits.
- The dotted blue line represents the boundary between the South Australia and Victoria regions.

Figure 5 Status of major transmission circuits prior to separation

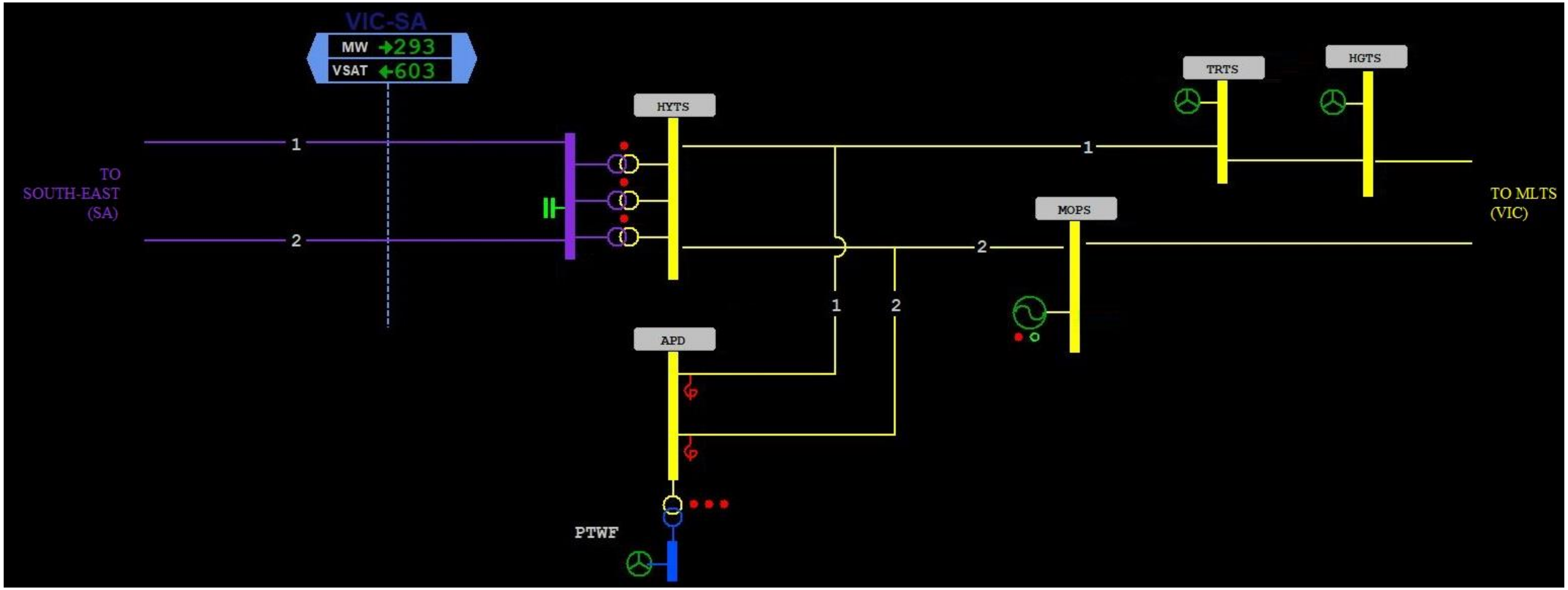


Figure 6 Status of major transmission circuits immediately after separation