AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

Trip of Multiple Cherry Gardens Lines on 24 January 2021

June 2021

Reviewable Operating Incident Report under the National Electricity Rules

INCIDENT CLASSIFICATIONS

Classification	Detail
Time and date of Incident	1643 hrs on 24 January 2021
Region of incident	South Australia
Affected regions	South Australia
Event type	Environmental – bushfire
Generation impact	75 MW of generation tripped in response to the event
Customer load impact	Temporary reduction of approximately 350 MW of customer load

ABBREVIATIONS

Abbreviation	Term
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AEST	Australian Eastern Standard Time
BOM	Bureau of Meteorology
CB	Circuit Breaker
CFS	Country Fire Service
CHG	Cherry Gardens
DNSP	Distribution network service provider
EMS	Energy Management System
INDJI	Indji Watch
kV	Kilovolt
LOR	Lack of Reserve
ms	Milliseconds
MTB	Mount Barker
MTBS	Mount Barker South
MW	Megawatt
NEM	National Electricity Market
NER	National Electricity Rules
PV	Photovoltaics
RoCoF	Rate of Change of Frequency
RERT	Reliability and Emergency Reserve Trader
RTCA	Real-Time Contingency Analysis

Abbreviation	Term
SA VDRT standard	South Australian Voltage Disturbance Ride-Through standard
SAPN	SA Power Networks
SCADA	Supervisory Control and Data Acquisition
TBE	Tailem Bend
TNSP	Transmission network service provider
TIPS	Torrens Island Power Station

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

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CONTACT

If you have any questions or comments in relation to this report, please contact AEMO at system.incident@aemo.com.au.

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1. Overview

This report relates to a reviewable operating incident[1] that occurred on 24 January 2021 in South Australia. The incident involved a bushfire near the Cherry Gardens substation, which burned under the Cherry Gardens – Mount Barker (CHG – MTB) 132 kilovolt (kV) line, the Cherry Gardens – Mount Barker South (CHB – MTBS) 275 kV line, and the Cherry Gardens – Tailem Bend (CHG – TBE) 275 kV line. The fire caused a series of phase-to-phase and phase-to-ground faults which resulted in the tripping and de-energisation of multiple Cherry Gardens lines at 1643 hrs on 24 January 2021.

The Port Stanvac generating units were operating at the time of the event and disconnected due to the voltage disturbances associated with this incident, resulting in the loss of 61 MW of generation. The two Lonsdale generating units on the 11 kV buses (circuit breaker (CB) 2200 and CB 2208) tripped while generating a total of 14 megawatts (MW). Hence, a total of 75 MW of generation was lost in response to this incident. Additionally, there was a net load drop-off of approximately 250 MW due to the voltage reduction associated with this event, which was restored within 15 minutes.

The lines were subsequently re-energised by 0945 hrs on 26 January 2021, after a full inspection was completed.

At the time of the event, AEMO was also experiencing an outage of its internal Supervisory Control and Data Acquisition (SCADA) service. Basic AEMO SCADA function was restored approximately two minutes after this incident occurred, at 1645 hrs. The AEMO SCADA failure did not contribute to or exacerbate this incident.

As this was a reviewable operating incident, AEMO is required to assess the adequacy of the provision and response of facilities and services and the appropriateness of actions taken to restore or maintain power system security[2].

AEMO has concluded that:

1. The Cherry Gardens 132 kV and 275 kV transmission lines tripped due to a bushfire adjacent to the Cherry Gardens substation.
2. Based on the information available at the time, AEMO did not reclassify the tripping of the CHG – MTB 132 kV line, the CHB – MTBS 275 kV line, and the CHG – TBE 275 kV line prior to the event at 1643 hrs. However, post-incident analysis identified that all fault locations were in the area impacted by the bushfire.
3. The fault on the CHG – MTB 132 kV line caused the maloperation of the Set X Protection at Mount Barker, and this was due to the current supervision level being set very low. ElectraNet has advised that it has corrected this issue by resetting the current supervision level back to the default value.
4. The CB 6719 status did not update in the Energy Management System (EMS) when it tripped for the CHG – TBE 275 kV line fault, due to an electrical fault in the breaker's indication circuit. This fault was found and repaired during the patrol completed on 26 January 2021 prior to the breaker being put back into service.
5. The backup overcurrent protection element of a SA Power Networks (SAPN) Bus Protection relay at Port Stanvac substation operated and initiated the inter-trip of both Lonsdale generators (CB 2200 and CB 2208). The protection operated as designed.
6. The Port Stanvac generating units were disconnected due to generator protection operating in response to the voltage disturbances associated with this incident. The performance of the Port Stanvac generators during this fault is currently being reviewed by AEMO.
7. The power system remained in a secure operating state throughout this incident.

[1] See NER clause 4.8.15(a)(1)(i), as the event relates to a non-credible contingency event; and the AEMC Reliability Panel Guidelines for Identifying Reviewable Operating Incidents.

[2] See NER clause 4.8.15(b).

This report is prepared in accordance with clause 4.8.15(c) of the National Electricity Rules (NER). It is based on information provided by ElectraNet, Snowy Hydro, SAPN, and AEMO[3].

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

2. The incident

2.1 Pre-incident conditions

Prior to this incident, the CHG – MTB 132 kV line, the CHG – MTBS 275 kV line, and the CHG – TBE 275 kV line were all in service. The Port Stanvac generating units were in service and generating a total of 61 MW, and the two Lonsdale generators were in service and generating a total of 14 MW. Total South Australia load was around 2,500 MW.

Two fires were burning concurrently near the Cherry Gardens substation:

- A smaller fire was burning to the north of the Cherry Gardens Substation near the Cherry Gardens – Torrens Island Power Station (TIPS) B, Cherry Gardens – Happy Valley, and Happy Valley – Magill 275 kV transmission lines.
- A larger fire was burning towards the Cherry Gardens – Mount Barker 132 kV, Cherry Gardens – Mount Barker South 275 kV and Cherry Gardens – Tailem Bend 275 kV lines.

Figure 5 in Appendix A2 shows the configuration at Cherry Gardens substation immediately prior to the event.

From 1545 hrs to 1645 hrs on 24 January 2021, AEMO experienced a NEM-wide SCADA outage, which is the subject of a separate incident event report[4]. Accordingly, transmission network providers (TNSPs) were requested to monitor the power system and advise AEMO of any incidents or issues. The NEM-wide outage lasted until 1645 hrs on 24 January 2021. Due to the outage, all event times and SCADA data have been obtained from or validated by ElectraNet.

2.2 The incident

At 1613 hrs on 24 January 2021, ElectraNet advised the AEMO control room that there was a grass fire moving towards the Cherry Gardens – TIPS B 275 kV lines but it was not likely to cross the easement for approximately two hours.

However, at 1643 hrs, a bushfire burning near Cherry Gardens substation caused a series of six faults which resulted in the tripping of the CHG – MTB 132 kV line, the CHG – MTBS 275 kV line, and the CHG – TBE 275 kV line.

At 1645 hrs, the two Lonsdale generating units on the 11 kV buses (CB 2200 and CB 2208) tripped while generating a total of 14 MW. The Port Stanvac generator connected to the 66 kV bus also disconnected while generating a total of 61 MW. Additionally, there was a temporary net drop off in South Australia load of 250 MW associated with the voltage reduction caused by this event.

Load returned to pre-event levels within approximately 15 minutes.

[3] ElectraNet is the transmission network service provider (TNSP) in South Australia, Snowy Hydro is the owner of the Port Stanvac Power Station, and SAPN is the distribution network service provider (DNSP).

[4] AEMO, Preliminary Report, Total Loss of NEM SCADA Data Preliminary Report 24 January 2021, published 16 February 2021, at https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2021/preliminary-report-total-loss-of-nem-scada-data.pdf.

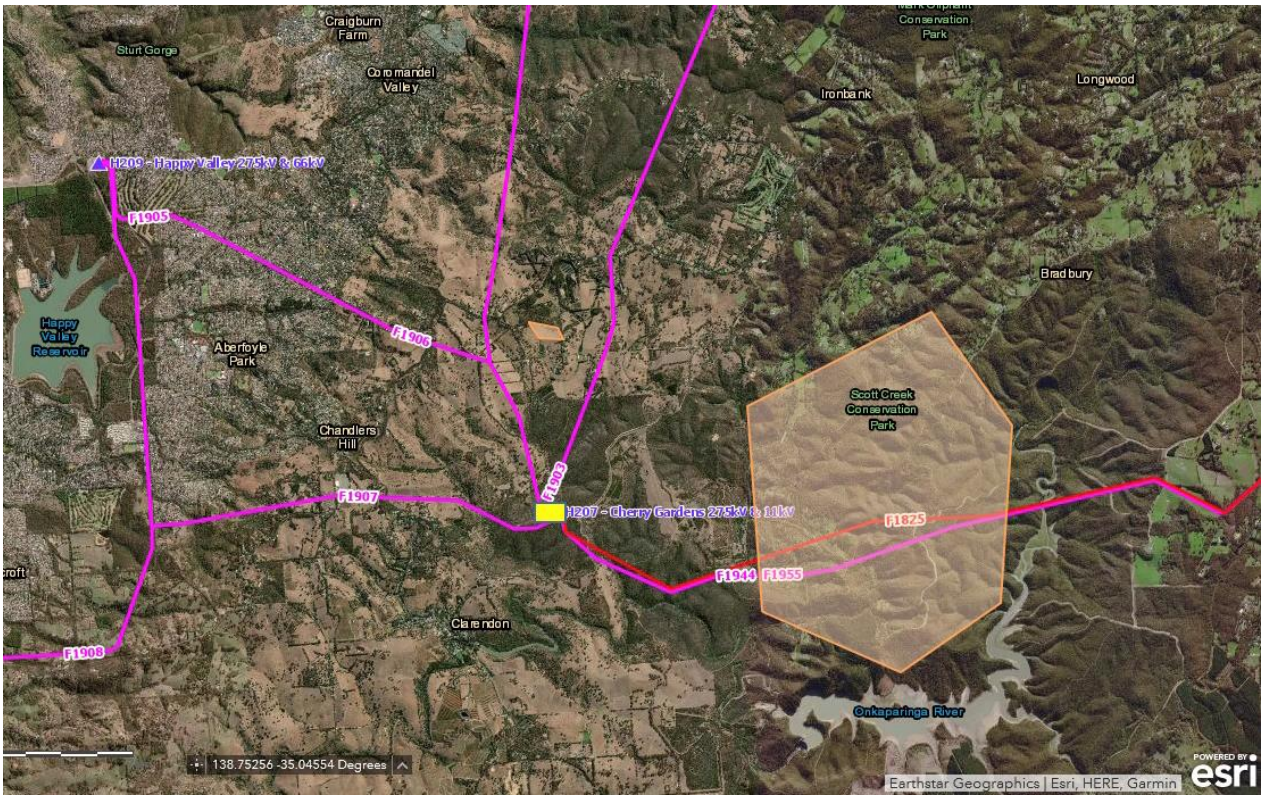
2.3 Analysis

The detailed sequence of events is available in Appendix A1 of this report. The following analysis is based on information provided by ElectraNet.

At 1613 hrs, ElectraNet notified AEMO that there was a fire burning north of the Cherry Gardens Substation that was expected to burn towards the Cherry Gardens – TIPS B 275 kV lines. ElectraNet advised AEMO that the fire was not classed as a major risk at that time, and this was supported by live data from the INDJI[5] system used by AEMO. At 1632 hrs, ElectraNet notified AEMO that the fire was expected to cross the line between 1930 hrs and 2030 hrs.

At 1643 hrs, ElectraNet was advised by the Country Fire Service (CFS) that seven separate spot fires had been reported. Moments later, one of these newly reported fires burned under the CHG – MTB 132 kV, CHG – MTBS 275 kV, and CHG – TBE 275 kV lines, causing multiple line faults. Due to the speed of the changes in fire location and status, no new notifications were received from INDJI prior to the event.

Figure 1 Bushfire location in relation to the transmission network



At 1643 hrs, the bushfire caused an 'R-T'[6] phase-to-phase fault on the CHG – MTB 132 kV line. Both Set X and Set Y[7] distance protection detected the fault and tripped CB 6031 at Cherry Gardens and CB 6083, CB 6084 at Mount Barker to de-energise the CHG – MTB 132 kV line.

[5] Indji Watch (INDJI) is a system that monitors live information feeds on hazards such as bushfires and displays their positions relative to the locations of transmission assets and is used by AEMO to track lightning and bushfires. For bushfire monitoring, it shows fire type, location and CFS status based on live data from the CFS, the Bureau of Meteorology (BOM) and satellite signals. The satellites can fail to detect fires due to a number of reasons, including cloud cover, dense canopy or low intensity of the fire at the time the satellite passed overhead.

[6] R-S-T and U-V-W phase sequences are equivalent to A-B-C, R-W-B, or R-Y-B phase sequence. R-S-T are used to denote the phases of 132 kV lines, and U-V-W are used to denote the phases of 275 kV lines.

[7] Many elements of transmission equipment have two sets of primary protection systems to provide redundancy. Both these protection systems monitor the protected equipment and both systems will attempt to trip the equipment should a monitored (or in zone) fault occur. To differentiate between one primary protection system and another, ElectraNet refers to one system as the X protection and the other as the Y protection.

Set X distance protection operated the Zone 1 phase element from Cherry Gardens and the Zone 1 ground element at Mount Barker, which initiated auto-reclose[8] at Mount Barker.

Set Y distance protection operated Zone 1 phase element at Cherry Gardens and the Zone 2 phase element initiating 'fast Zone 2 trip' at Mount Barker.

Auto-reclose of the line was incorrectly initiated due to the Set X protection at Mount Barker misidentifying the fault as a phase-to-ground fault rather than a phase-to-phase fault. ElectraNet has advised that the settings for the associated relay were reviewed and it was found that the current supervision level had been set to a very low value, allowing the earth fault element to operate for phase-to-phase faults. In consultation with the relay manufacturer, ElectraNet has since reset the current supervision level to the default value. ElectraNet is currently reviewing the settings of other devices in the network and will update settings as required.

Distance protection on the CHG – MTB 132 kV line is designed not to auto-reclose on phase-to-phase faults, however as a result of the Set X protection misidentifying the fault as phase-to-ground, five seconds after the CHG – MTB 132 kV line tripped the CB 6084 at Mount Barker automatically re-closed. Almost immediately following this, an 'R-S' phase-to-phase fault was detected by the Set X and Set Y line protection systems at Mount Barker. The Set Y blocking scheme and Switch onto Fault element operated to trip CB 6084. This locked out auto-reclose of this line, and the line remained out of service.

Approximately 0.5 seconds after CB 6084 tripped following auto-reclose, CB 6083 at Mount Barker auto-reclosed successfully and re-energised the CHG – MTB 132 kV line from the Mount Barker Side. CB 6031 at Cherry Gardens remained open.

At 1645 hrs, Set X differential and Set Y distance protection systems detected a 'U-V'[6] phase-to-phase fault on the CHG – MTBS 275 kV line, initiating three-phase tripping of all line CBs.

At 1646 hrs, the CHG – TBE 275 kV line tripped on a 'W' phase-to-ground fault. Set X differential and Set Y distance protection initiated single-phase tripping of CB 6536, CB 6535 at Tailem Bend, and CB 6719 at Cherry Gardens, and three-phase tripping of CB 6718 at Cherry Gardens. Auto-reclose of the associated single-phase tripped circuit breakers was initiated following fault clearance. During the auto-reclose deadtime, and while the line was energised on the remaining two phases, a 'U-V' phase-to-phase fault was detected by Set X differential protection and Set Y distance protection, which resulted in the three-phase tripping of the line breakers and the lockout of auto-reclose. This occurred approximately 580 milliseconds (ms) after the clearance of the 'W' phase-to-ground fault and before auto-reclose of the 'W' phase CBs. The indication for CB 6719 did not update on EMS after opening – the correct status had to be confirmed from fault recordings. ElectraNet has advised that this was due to a loose wire in the breaker's indication circuit, which was found and repaired during the patrol completed on 26 January 2021 prior to the breaker being put back into service.

At 1647 hrs, the CHG – MTB 132 kV line (CB 6083 at Mount Barker), which had successfully auto-reclosed at 1643 hrs, tripped on an 'S-T' phase-to-phase fault. Set X and Set Y distance protection systems detected the fault and tripped CB 6083 at Mount Barker to de-energise the CHG – MTB 132 kV line.

Figure 6 in Appendix A2 shows the final system configuration following the six faults caused by the bushfire. Table 1 in Appendix A1 summarises the sequence of events.

The locations of all the above faults were determined to be within the area impacted by the bushfire. All lines were kept de-energised until a patrol could be arranged as directed by the CFS. This was completed on Tuesday, 26 January 2021 and confirmed that none of the lines were significantly damaged. All lines were successfully re-energised by 0945 hrs on 26 January 2021.

[8] Transmission system circuit breakers are typically capable of single-phase or three-phase auto-reclose. The auto-reclose function means that after a fault is detected, the breaker will open (either a single phase or all three phases), clearing the fault, and then attempt to reclose again after a specified deadtime/delay. If the fault is still present, the breaker will lockout auto-reclose and remain open. Transient, single-phase faults constitute the majority of faults on high voltage transmission lines. It is therefore common practice to employ single-phase trip and auto-reclose functionality on high voltage transmission lines to minimise the impact of these faults on power system security. The dead time for auto-reclose, in this case, is approximately five seconds for 132 kV CBs and 1 second for 275kV.

2.4 Port Stanvac and Lonsdale generators

Concurrent with the Cherry Gardens – Mount Barker South 275 kV line fault, the backup overcurrent protection element of a SAPN Bus Protection relay at Port Stanvac substation operated and initiated the inter-trip of both Lonsdale generators (CB 2200 and CB 2208). No inter-trip was sent to the to the 66 kV breakers for the Port Stanvac generator (CB Q102B and CB Q202B), as this condition is subject to a 100 ms time delay which was not satisfied.

SAPN has advised that the protection operated as designed. The CB 2200 and CB 2208 breakers successfully reclosed at 1800 hrs.

Snowy Hydro has also confirmed that all 36 Port Stanvac generating units disconnected at 1645 hrs while generating a total of 61 MW, meaning a total of 75 MW of generation was lost in response to this incident. Both the 11 kV and 66 kV breakers remained closed. Several of the units were tripped by negative sequence overcurrent generator protection. The remaining units subsequently tripped due to the generator's environmental shutdown function. This function trips units due to the requirement to maintain a minimum number of units online per each generator bank to maintain the exhaust temperature above the minimum allowable temperature.

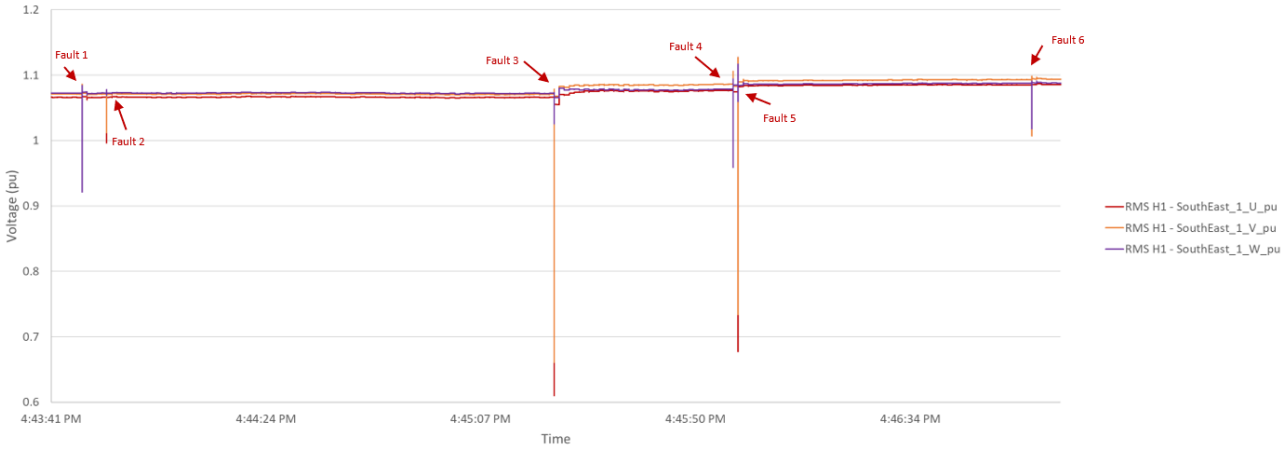
The generating units came back online by 1744 hrs. The performance of the Port Stanvac generators during this fault is currently being reviewed by AEMO.

2.5 Voltage disturbances

High speed monitoring at Tailem Bend recorded the voltage disturbances associated with the six faults caused by the bushfire, as shown in Figure 2.

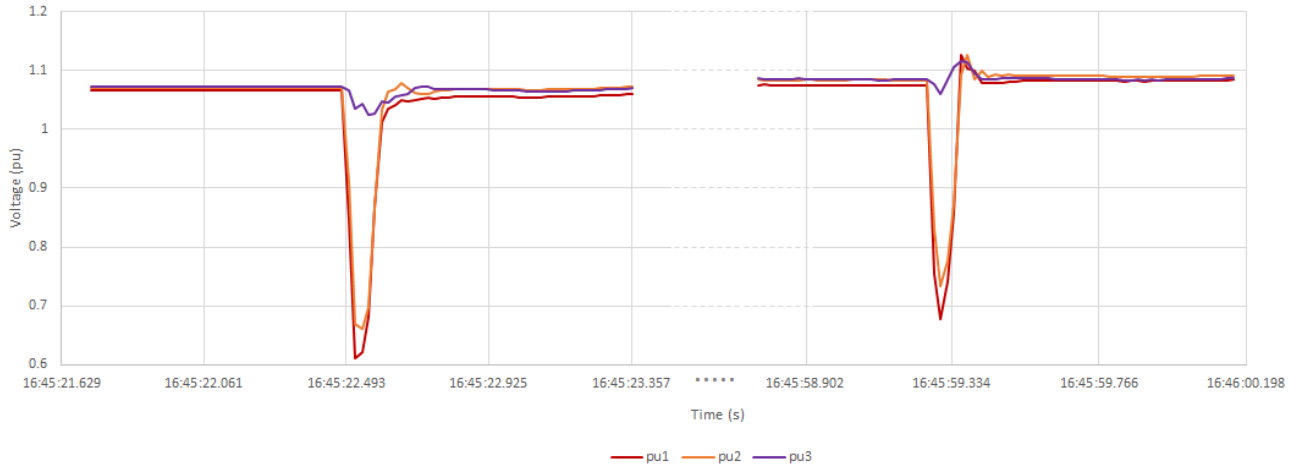
Figure 3 shows a voltage minimum of just above 0.6 pu on a single phase (and a minimum of 0.77 pu positive sequence) following the third fault[9]. Voltage disturbances of this depth on previous occasions have been observed to result in more than 10% of distributed photovoltaics (PV) disconnecting, and significant load disconnection, as discussed further in Appendix A3.

Figure 2 Tailem Bend 275 kV line fault recorder data



[9] As of 2018, Schedule 5.2.5.5 of the NER specifies that, for minimum access, generating units must remain in continuous uninterrupted operation for a series of up to six disturbances within any five-minute period subject to a number of conditions, including that up to three of the disturbances cause the voltage at the connection point to drop below 50% of normal voltage. Hence, for this event, generating units being assessed against S5.2.5.5 of the NER would be required to remain in operation. Refer to S5.2.5.5 of the NER for more information.

Figure 3 Tailem Bend 275 kV line fault recording data of 275 kV for faults 3 and 5

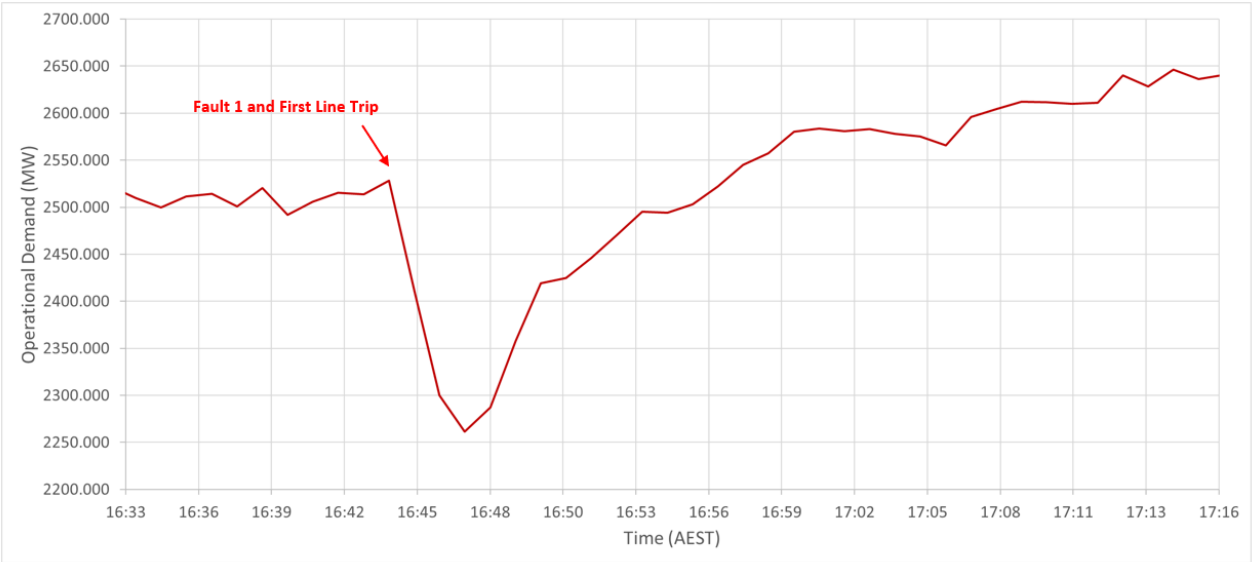


2.6 Load response

Prior to the event, total operational demand in South Australia was estimated at 2,510 MW. As a result of the voltage disturbance caused by this incident, there was an approximate 250 MW temporary net reduction in load, as shown in Figure 4. The load returned to pre-fault levels within approximately 15 minutes.

Distributed PV was estimated to be generating a total of 576 MW in South Australia immediately prior to the disturbance. It is estimated that approximately 100 MW of distributed PV disconnected in response to the voltage disturbance, as discussed further in Appendix A3. Since distributed PV disconnection offsets load disconnection, it is estimated that a total of approximately 350 MW of underlying load disconnected in response to this event.

Figure 4 South Australia regional load at the time of event



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[10].

The power system remained in a secure operating state during this incident and no action was required from AEMO apart from invoking the following constraints.

- At 1655 hrs on 24 January 2021, constraint set S-CGTB1 was invoked due to the CHG – TBE 275 kV line being out of service.
- An auto constraint set CA-BRIS-4F1FE461_1 was invoked at 2120 hrs on 24 January 2021, while the Cherry Gardens elements were still out of service, as the Real-Time Contingency Analysis (RTCA) tool indicated that the loss of the Tungkillo – Tailem Bend 275 kV line would overload the Mobilong – Tailem Bend 132 kV line. This constraint was revoked at 0920 hrs on 25 January 2021.
- At 0920 hrs on 25 January 2021, a discretionary constraint I-SV_100 was then invoked to limit the transfer across the South Australia – Victoria interconnector to 100 MW to manage the overloading of the Mobilong – Tailem Bend 132 kV line. This constraint was revoked at 1200 hrs on 25 January 2021.
- The S-CGTB1 constraint was revoked at 0955 hrs on 26 January 2021, after the CHG – TBE 275 kV line was put back into service.

Table 1 in Appendix A1 details the sequence of events including the invoking of constraints.

From 1545 hrs to 1645 hrs on 24 January 2021, there was also a NEM-wide loss of all SCADA event, which is the subject of a separate incident event report[11].

3.1 Reclassification

AEMO assessed whether to reclassify this incident as a credible contingency event[12].

Based on the information AEMO had prior to this event, there was no reason to reclassify the loss of the transmission elements as credible. The advice from ElectraNet received by the control room was that the fire may only affect the Cherry Gardens – TIPS B 275 kV line, and not for approximately two hours. No further notifications were received from INDJI[5] indicating otherwise, prior to the event.

The patrol completed after the event confirmed that none of the transmission elements that tripped were significantly damaged and ElectraNet indicated to AEMO that there were no additional risks that could cause the event to reoccur. As such, AEMO correctly determined that reclassification as a credible contingency event was not required.

[10] Refer to AEMO's functions in section 49 of the National Electricity Law and the power system security principles in clause 4.2.6 of the NER.

[11] AEMO, Preliminary Report, Total Loss of NEM SCADA Data Preliminary Report 24 January 2021, published 16 February 2021, at https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2021/preliminary-report-total-loss-of-nem-scada-data.pdf.

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

4. Reserve

At 1655 hrs on 24 January 2021, the S-CGBT1 constraint set was invoked due to the outage of the CHG – TBE 275 kV line. One of the constraint equations in this set, S>>CGTB1_TBTU_TBMO, was binding from 1655 hrs until 2120 hrs. This constraint equation constrains import flows to South Australia from Victoria and the output of several South Australian generators. Additionally, following the incident, operational demand in South Australia grew to a peak of approximately 2,650 MW at 1900 hrs.

At 1840 hrs on 24 January 2021, AEMO declared an actual Lack of Reserve (LOR) level 2 condition in South Australia, forecasted to exist until 1900 hrs. The LOR 2 condition was cancelled at 1910 hrs on 24 January, after which the demand in South Australia began to reduce. The Reliability and Emergency Reserve Trader (RERT) that was available in South Australia at this time requires more than 30 minutes to be brought online. Therefore, due to the LOR 2 condition not being forecast until after 1830 hrs, and only lasting until 1910 hrs, AEMO did not dispatch any RERT in response to this condition, as there was not adequate time to contract the RERT available on the Short Notice RERT Panel.

Since the S>>CGTB1_TBTU_TBMO constraint reduced the availability of generation in South Australia, the outage of the CHG – TBE 275 kV line that was caused by this incident directly contributed to the LOR conditions experienced in South Australia on 24 January.

5. Market information

AEMO is required by the NER and operating procedures to inform the market about incidents as they progress. This section assesses how AEMO informed the market[13] over the course of this incident.

For this incident, AEMO informed the market on the following matters:

1. A non-credible contingency event – notify within two hours of the event[14].
   - AEMO issued Market Notice 82348 at 1829 hrs on 24 January 2021, 106 minutes after the event occurred, to advise of the non-credible contingency event, and to advise that the cause of this non-credible contingency event had been identified.
2. Reclassification, details, and cancellation of a non-credible contingency – notify as soon as practical[15].
   - AEMO issued Market Notice Update 82383 at 0955 hrs on 26 January 2021 to advise that all lines impacted had been returned to service, and to advise that the cause of this non-credible contingency event had been identified and AEMO was satisfied that another occurrence of this event was unlikely under the circumstances.
3. Constraints invoked with interconnector terms on left hand side (LHS)[16].

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

[14] AEMO is required to notify the market of a non-credible contingency event within two hours of the event – AEMO, Power System Security Guidelines, Section 7.3.

[15] AEMO is required to notify the market of a reclassification – NER clause 4.2.3(g), details of the reclassification – 4.2.3(c), and when AEMO cancels the reclassification – 4.2.3(h).

[16] For short notice outages, AEMO is required to notify the Market of variances to interconnector transfer limits as per section 22 of AEMO's Power System Security Guidelines.

- AEMO issued Market Notice 82355 at 2128 hrs on 24 January 2021 to advise it invoked constraint set CA_BRIS_4F1FE461_1 from 2120 hrs. This constraint set contains constraint equations with Victoria – South Australia interconnector terms on the LHS.
- AEMO issued Market Notice Update 82358 at 0920 hrs on 25 January 2021 to advice it revoked constraint set CA_BRIS_4F1FE461_1 at 0920 hrs and invoked constraint set I-SV_100 from 0920 hrs until further notice. This constraint set contains constraint equations with Victoria – South Australia interconnector terms on the LHS.
- AEMO issued Market Notice Update 82363 at 1209 hrs on 25 January 2021 to advice it revoked constraint set I-SV_100 at 1200 hrs and extended constraint set S-CGTB1 until 0400 hrs on 27 January 2021. This constraint set contains constraint equations with Victoria – South Australia interconnector terms on the LHS.
- AEMO issued Market Notice Update 82363 at 1209 hrs on 25 January 2021 to advise it revoked constraint set I-SV_100 at 1200 hrs and extended constraint set S-CGTB1 until 0400 hrs on 27 January 2021. These constraint sets contain constraint equations with interconnector terms on the LHS.

4. Declaration of actual LOR conditions in South Australia.
   - AEMO issued Market Notice 82347 at 1744 hrs on 24 January 2021 to declare an Actual LOR 1 in the South Australia region from 1740 hrs, forecast to exist until 2000 hrs. The capacity reserve requirement was 420 MW, and the minimum capacity reserve available was 240 MW.
   - AEMO issued Market Notice 82349 at 1844 hrs on 24 January 2021 to declare an Actual LOR 2 condition in the South Australia region from 1840 hrs, forecast to exist until 1900 hrs. The capacity reserve requirement was 222 MW, and the minimum capacity reserve available was 213 MW.
   - AEMO issued Market Notice 82351 at 1914 hrs on 24 January 2021 to advice of the cancellation of the Actual LOR 2 condition in the South Australia region at 1910 hrs.
   - AEMO issued Market Notice 82354 at 2016 hrs on 24 January 2021 to advice of the cancellation of the Actual LOR 1 condition in the South Australia region at 2010 hrs.

6. Conclusions

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:

1. The Cherry Gardens 132 kV and 275 kV transmission lines tripped due to a bushfire adjacent to the Cherry Gardens substation.
2. Based upon the information available at the time, AEMO did not reclassify the tripping of the CHG – MTB 132 kV line, the CHB – MTBS 275 kV line, and the CHG – TBE 275 kV line prior to the event at 1643 hrs. However, post-incident analysis identified that all fault locations were in the area impacted by the bushfire.
3. The fault on the CHG – MTB 132 kV line caused the maloperation of the Set 1 Protection at Mount Barker, and this was due to the current supervision level being set very low. ElectraNet has advised that it has corrected this issue by resetting the current supervision level back to the default value.
4. The CB 6719 status did not update in EMS when it tripped for the CHG – TBE 275 kV line fault, due to an electrical fault in the breaker's indication circuit. This fault was found and repaired during the patrol completed on 26 January 2021 prior to the breaker being put back into service.

5. The backup overcurrent protection element of a SAPN Bus Protection relay at Port Stanvac substation operated and initiated the inter-trip of both Lonsdale generators (CB2200 and CB2208). The protection operated as designed.
6. The Port Stanvac generating units were disconnected due to generator protection operating in response to the voltage disturbances associated with this incident. The performance of the Port Stanvac generators during this fault is currently being reviewed by AEMO.
7. The power system remained in a secure operating state throughout this incident.

A1. Sequence of events

Table 1 Sequence of events

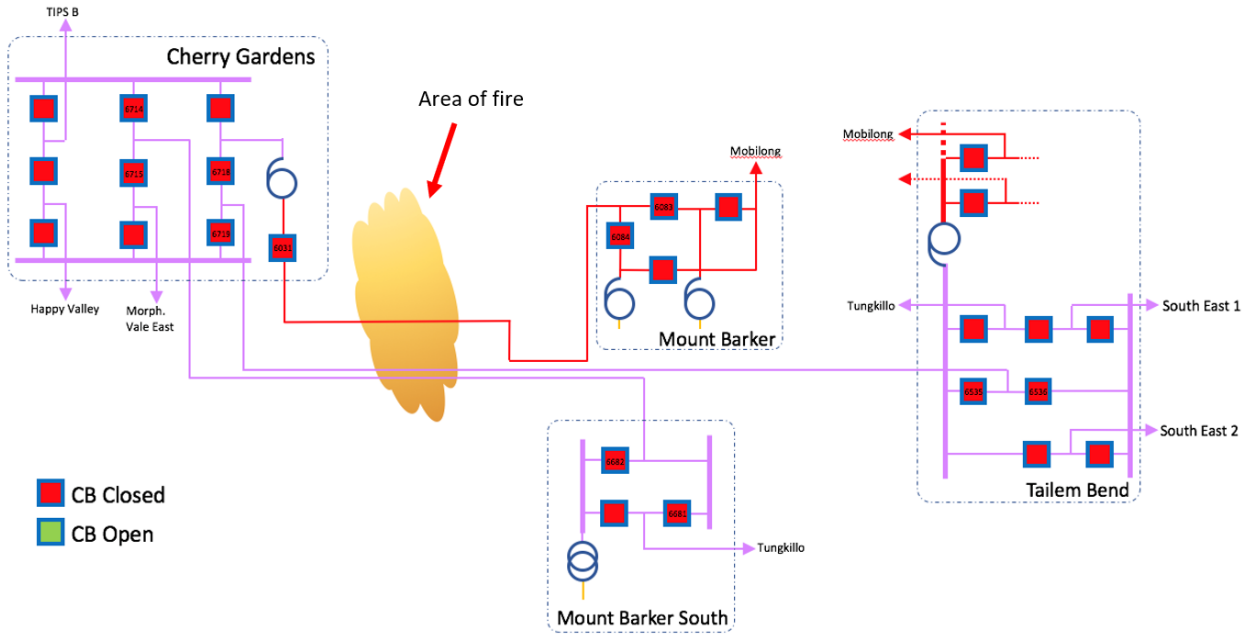
Date	Time	Event Type	Event
24/1/2021	1613	Other	ElectraNet advised the AEMO Control Room that there was a grass fire burning near the Cherry Gardens – TIPS B 275 kV line but would not cross the line for approx. 2 hours.
24/1/2021	1643.47	Transmission	Cherry Gardens – Mount Barker 132 kV line: • CB6031 at Cherry Gardens, C6083 and CB6084 at Mount Barker tripped on 'R-T' phase-to-phase fault with clearance time of 71 ms. Auto-reclose initiated for CB6083, CB6084 at Mount Barker.
24/1/2021	1643.52	Transmission	Cherry Gardens – Mount Barker 132 kV line: • CB6084 at Mount Barker reclosed onto 'R-S' phase-to-phase fault and tripped with a clearance time of 61 ms. Approx. 0.5 s after CB6084 tripped, CB6083 successfully reclosed.
24/1/2021	1645.22	Transmission	Cherry Gardens – Mount Barker South 275 kV line: • Three-phase tripping of all CBs due to a 'U-V' phase-to-phase fault with a clearance time of 85 ms.
24/1/2021	1645.30	Generator	Circuit breakers for Lonsdale generators (CB 2208 and CB 2000) tripped. The Port Stanvac generating units disconnected.
24/1/2021	1645.58	Transmission	Cherry Gardens – Tailem Bend 275 kV line: • 'W' phase-to-ground fault caused single-phase tripping of CB6536, CB6535 at Tailem Bend, CB6719 at Cherry Gardens and three-phase trip of CB6718 at Cherry Gardens with a clearance time of 86 ms. Auto-reclose initiated on single-phase tripped CBs.
24/1/2021	1645.59	Transmission	Cherry Gardens – Tailem Bend 275 kV line: • 'U-V' phase-to-phase fault caused three-phase tripping of CB6536, CB6536 and CB6719 and locking out of auto-reclose with a clearance time of 71 ms. Occurred before auto-reclose of W pole CBs.
24/1/2021	1646.58	Transmission	Cherry Gardens – Mount Barker 132 kV line: • 'S-T' phase-to-phase fault causes CB6083 at Mount Barker to trip with a clearance time of 89 ms, de-energising the line.
24/1/2021	1655	Constraint	Constraint set S-CGTB1 invoked.
24/1/2021	1744	Notice	MN 82347 issued Actual LOR 1 in South Australia region from 1740 hrs.
24/1/2021	1829	Notice	MN 82348 issued Non-credible contingency event – South Australia region – 24/1/2021 (note within two-hour requirement).
24/1/2021	1844	Notice	MN 82349 issued Actual LOR 2 in South Australia region from 1840 hrs.
24/1/2021	1914	Notice	MN 82351 issued Actual LOR 2 in South Australia region cancelled.
24/1/2021	2016	Notice	MN 82354 issued Actual LOR 1 in South Australia region cancelled.
24/1/2021	2120	Constraint	RTCA indicated that the trip of Tungkillo – Tailem Bend 275 kV line resulted in overload of Mobilong – Tailem Bend 132 kV Line. Constraint Set CA _BRIS_4F1FE461_1 invoked from 2120 hrs until further notice.

Date	Time	Event Type	Event
24/1/2021	2128	Notice	MN 82355 issued Inter-regional transfer limit variation – South Australia region - 24/1/2021.
25/1/2021	0920	Constraint	Constraint set CA _BRIS_4F1FE461_1 revoked.
25/1/2021	0920	Notice	MN 82358 issued Update – Inter-regional transfer limit variation – South Australia region – 25/1/2021.
25/1/2021	1200	Constraint	Constraint set I-SV_100 revoked. Constraint set S-CGTB1 extended until 0400 hrs 27/1/2021.
25/1/2021	1209	Notice	MN 82363 issued. Update – Inter-regional transfer limit variation – South Australia region – 25/1/2021.
26/1/2021	0945	Transmission	All lines returned to service following patrol.
26/1/2021	0955	Notice	MN 82383 Update – Non-credible contingency event – South Australia region – 24/1/2021. All lines returned to service.
26/1/2021	0955	Constraint	Constraint Set S-CGTB1 revoked.

A2. System diagrams

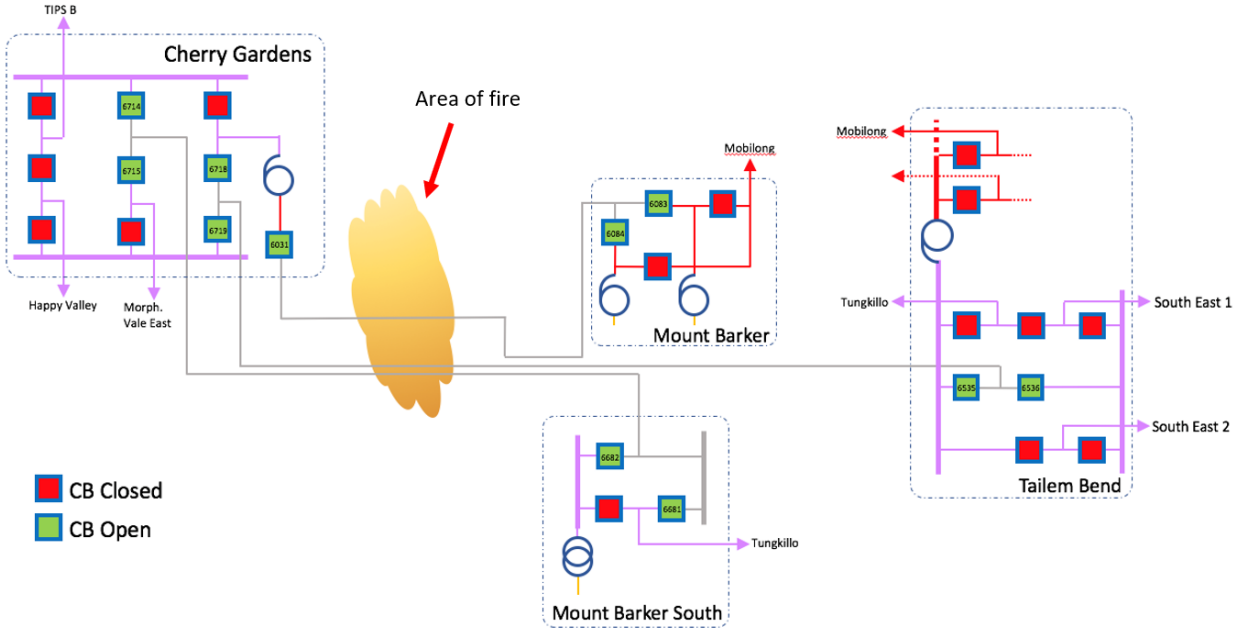
The diagram below provides an overview of part of the power system immediately before the incident.

Figure 5 Initial network configuration prior to the event



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

Figure 6 Final network configuration after the event



A3. Distributed PV behaviour

The behaviour of load and embedded generation during disturbances is material to the operational strategies used to maintain power system security. The emergence of distributed PV as a significant embedded generating resource is leading to greater need for understanding and insight into its aggregate behaviour during the range of disturbances that occur across the power system.

To assess distributed PV response to the disturbance, AEMO procured data from Solar Analytics[17] for 4,250 individual distributed (<100 kilowatts [Kw]) PV systems in South Australia. Data was provided at a mixture of five-second and 60-second measurement intervals. Systems were categorised based on when they were installed:

- Systems installed prior to October 2015 were installed under AS/NZS4777.3:2005 ("the 2005 standard").
- Systems installed after October 2016 were installed under AS/NZS4777.2:2015 ("the 2015 standard").
- Systems installed after 28 September 2020 are required to meet additional voltage ride-through requirements (termed the South Australian Voltage Disturbance Ride-Through standard, or the "SA VDRT standard")[18] introduced by the Office of the Technical Regulator[19]. This is discussed further in Section A3.2.1.

A3.1 Estimate of total distributed PV disconnection

Distributed PV was estimated to be generating a total of 576 MW in South Australia immediately prior to the disturbance. The total installed capacity of distributed PV in South Australia at the date of the incident is estimated to be 1,340 MW, with 48% (640 MW) installed under the 2005 standard, 42% (558 MW) installed under the 2015 standard, 5% (68 MW) installed in the transitional period between the 2005 and 2015 standards, and 6% (78 MW) installed after 28 September 2020 under the SA VDRT test requirements.

Based on weighting the disconnection rates outlined above for each category with the installed capacity for each, AEMO estimates that distributed PV reduced by approximately 100 MW following this disturbance due to unintended disconnection.

As outlined in Section 2.6, operational demand in South Australia was observed to reduce by approximately 250 MW. The total loss of underlying load is therefore estimated at around 350 MW, partially offset by unintended disconnection of approximately 100 MW of distributed PV.

A3.2 Unintended disconnection of distributed PV

Based on the sample of data provided by Solar Analytics, it is estimated that:

[17] Solar Analytics Pty Ltd is a software company that designs, develops and supplies solar and energy monitoring and management services to consumers and solar fleet managers. Data was supplied with anonymisation to ensure system owner and address could not be identified.

[18] AEMO, Short Duration Undervoltage Disturbance Ride-Through Test Procedure, at https://aemo.com.au/en/initiatives/major-programs/nem-distributed-energy-resources-der-program/standards-and-connections/vdrt-test-procedure.

[19] Government of South Australia, Voltage Ride Through, at https://www.energymining.sa.gov.au/energy_and_technical_regulation/energy_resources_and_supply/regulatory_changes_for_smarter_homes/voltage_ride_through.

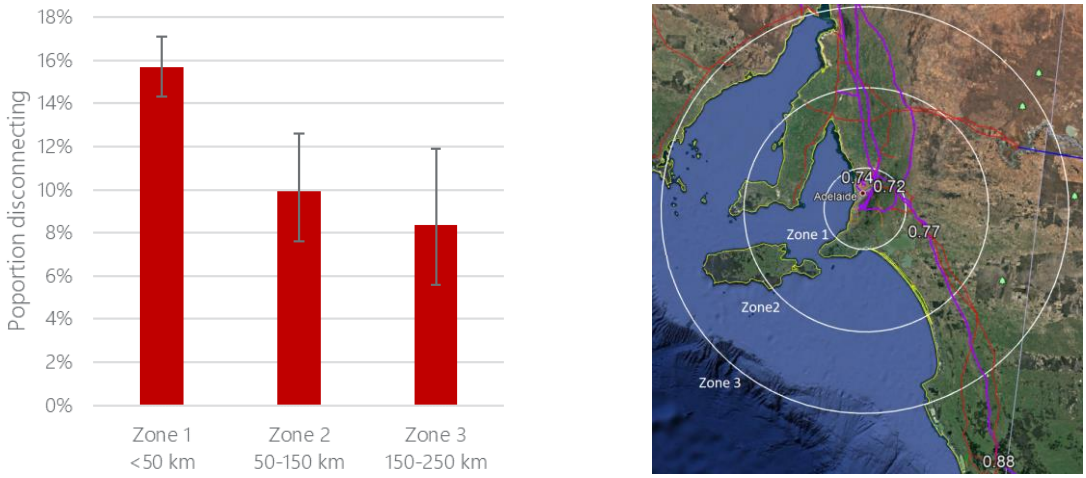
- Approximately 13% (6-24%)[20] of distributed PV systems installed under the 2005 standard disconnected[21] (based on a sample of 101 systems).
- Approximately 20% (16-24%) of distributed PV systems installed under the 2015 standard disconnected (based on a sample of 4,091 systems).
- Approximately 24% (15-37%) of distributed PV systems installed under the SA VDRT standard disconnected (based on a sample of 114 systems). This is discussed further in Section A3.2.1.

These disconnection estimates have been scaled to correct bias in the representation of certain manufacturers in the Solar Analytics sample[22]. The estimated disconnection rates for inverters under the 2005 and 2015 standards are consistent with AEMO's observations in previous similar disturbances.

Also consistent with observations from previous similar disturbances, larger distributed PV systems were observed to disconnect at a higher rate than smaller distributed PV systems. In this event, 33% (29-37%) of 30-100 kW systems on the 2015 standard disconnected, compared with 11% (10-12%) of <30 kW systems on the 2015 standard (excluding systems installed since September 2020 under the SA VDRT standard).

Figure 7 shows that distributed PV disconnections were highest close to the fault locations and reduced at more distant locations, as expected based on the high-speed voltage measurements recorded at each location.

Figure 7 Distributed PV disconnections by proximity to the fault (systems under the 2015 standard, excluding SA VDRT inverters)



Map illustrates minimum positive sequence per unit voltages recorded in the transmission network.

A3.2.1 Disconnection of inverters under the SA VDRT standard

Background

The South Australian Government recently introduced a new technical standard requiring that distributed inverters meet a new test requirement for voltage disturbance ride-through (VDRT), in addition to the tests specified in the 2015 standard (AS/NZS4777.2:2015[23]).

[20] Uncertainty ranges are based on the sample size, with a 95% confidence interval. The uncertainty range for systems under the 2005 standard is wider than the range for the 2015 systems due to the smaller sample size.

[21] Systems were assessed to have disconnected if their measured generation was observed to drop to close to zero for at least 1 measurement interval.

[22] Scaling of the disconnection rates was based on the capacity associated with each manufacturer installed in South Australia, for any manufacturer with more than 30 systems represented in the Solar Analytics sample. Remaining systems with less than 30 systems represented in the sample were used to define the disconnection rate of the remaining installed capacity in South Australia.

[23] AEMO, AS/NZS4777.2 – Inverter Requirements Standard, at https://aemo.com.au/en/initiatives/major-programs/nem-distributed-energy-resources-der-program/standards-and-connections/as-nzs-4777-2-inverter-requirements-standard.

The VDRT test procedure was specifically designed to assess the ride-through capability for short duration under voltage events, which was not included in the original AS/NZS4777.2 standard.

There are a range of known reasons why inverters may disconnect, which are not covered by the SA VDRT standard. These include withstand against phase angle jumps, Rate of Change of Frequency (RoCoF), and multiple faults in close succession (all of which occurred during this incident). These types of disturbances can lead to maloperation of inverter protection systems.

The 2020 standard (AS/NZS4777.2:2020[24]) published on 18 December 2020 and becoming mandatory from 18 December 2021 has been designed with a suite of additional specifications and tests intended to address these broader reasons that may result in unintended inverter disconnection.

Observed behaviour

The Solar Analytics sample provided generation data for 114 distributed PV circuits at 65 unique sites that were installed in South Australia after 28 September 2020. Of these, 24 circuits at 14 unique sites were observed to reduce power to close to zero immediately following the voltage dips. All of these sites remained at close to zero generation for approximately one minute, then ramped back up to close to pre-incident power over the subsequent few minutes (consistent with reconnection requirements specified in the 2015 standard). The sample size is small, but this suggests a disconnection rate of 24% (15-37%), which is similar to the disconnection rate for inverters installed prior to the SA VDRT standard being introduced, suggesting that the incident may have also triggered other power system effects.

Due to the small size of the sample in this analysis, AEMO will continue to analyse any further disturbances and seek complementary sources of data to better understand these findings. AEMO is also engaging with the Clean Energy Regulator, the Clean Energy Council, the Office of the Technical Regulator, the manufacturers involved, and other relevant stakeholders on these findings, to explore why inverters may be disconnecting, and to determine whether there may be further measures that could improve ride-through performance.

A3.3 Reconnection behaviour

The reconnection behaviour of distributed PV is important to understand to allow appropriate enablement of contingency reserves for management of frequency recovery following disturbances.

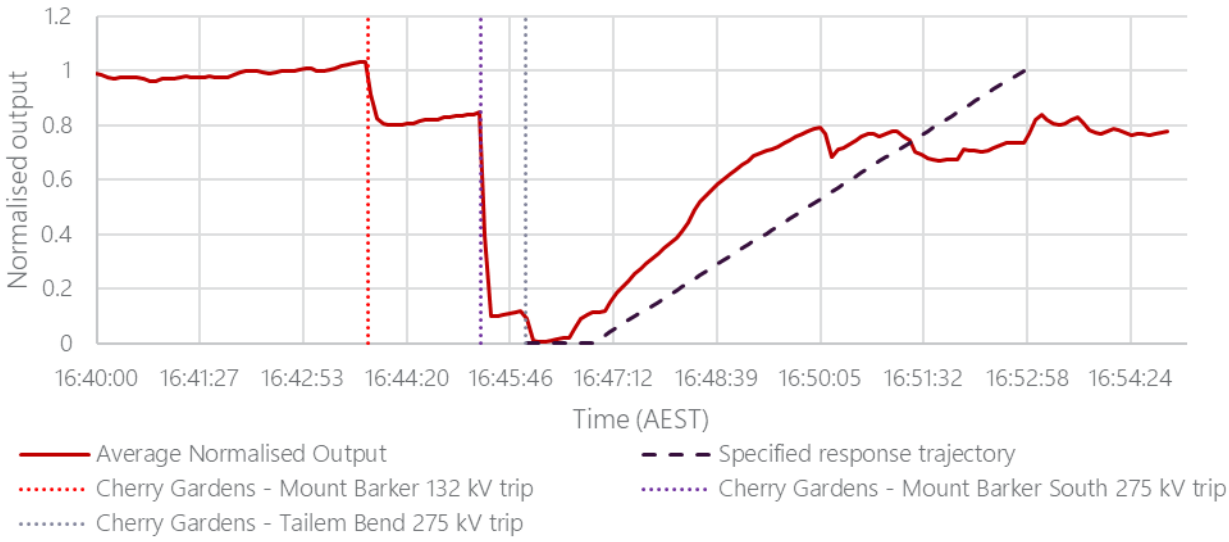
In the Solar Analytics sample of five-second resolution data, there were four distributed PV systems under the 2005 standard that disconnected. All of these were observed to remain at close to zero generation for one to two minutes following disconnection, then immediately recommenced generation at close to pre-incident levels. This is consistent with expectations based on specifications in the 2005 standard.

For inverters installed under the 2015 standard in the Solar Analytics sample of five-second resolution data, 252 systems (out of 1,351 samples) were observed to disconnect during the event window associated with the disturbances. The aggregate normalised[25] generation profile from these systems is shown in Figure 8. Systems disconnected in several tranches, following each of the faults, with the maximum number of systems disconnected following the third fault. The aggregate profile remained close to zero for approximately 30 seconds, then ramped up somewhat faster than the response trajectory specified in the 2015 standard (which requires a six-minute ramp rate limitation).

[24] Government of South Australia, Voltage Ride Through, at https://www.energymining.sa.gov.au/energy_and_technical_regulation/energy_resources_and_supply/regulatory_changes_for_smarter_homes/voltage_ride_through.

[25] Systems are normalised so that their peak output through the disturbance event window is 1.

Figure 8 Normalised aggregate generation profile for distributed PV systems under the 2015 standard that disconnected



Analysis of individual reconnection profiles for inverters installed under the 2015 standard shows:

- Most systems (97%) that disconnected remained at close to zero generation for each least one minute or longer.
- 24% of systems do not appear to be observing the six-minute ramp rate limitation, ramping at a sustained average ramp rate exceeding 33.3% of rated power per minute[26].

This is consistent with AEMO's findings in previous disturbances, and suggests that some distributed PV inverters are not behaving consistently with the defined standards. AEMO is continuing collaboration with industry to assess possible causes of this behaviour.

[26] The reconnection analysis methodology used differs from previous events in two ways: 1) the inverter rated output was estimated based off the maximum output during the event day, rather than the pre-event interval; 2) previously, compliance has been assessed using a range of 60-second, 30-second, and five-second resolution data and by taking the maximum ramp rate. However, compliance is now assessed using five-second resolution data, which does not contain the implicit averaging that is present in 60-second and 30-second resolution data. To account for this, the total ramp is calculated as a percentage of estimated rated capacity. If the total ramp of more than 25% of the estimated rated capacity occurs at a rate faster than 33.3% per minute, then the circuit is categorised as non-compliant.