Final Report – Trip of Torrens Island A and B West 275 kV busbars on 12 March 2021

November 2021

Reviewable Operating Incident Report under the National Electricity Rules

ABBREVIATIONS

Abbreviation	Term
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AEST	Australian Eastern Standard Time
DPV	Distributed Photovoltaics
EMT	Electromagnetic Transient
FCAS	Frequency Control Ancillary Service
LOR	Lack of Reserve
MFS	Metropolitan Fire Service
NEM	National Electricity Market
NER	National Electricity Rules
PTP	Permission to Proceed
SCADA	Supervisory Control and Data Acquisition
TNSP	Transmission Network Service Provider

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 made every reasonable effort to ensure the quality of the information in this report but cannot guarantee its accuracy or completeness. Any views expressed in this report may be based on information given to AEMO by other persons.

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1. Overview

This is AEMO's final report[1] on a reviewable operating incident[2] that occurred on 12 March 2021 in South Australia (SA). The incident involved the simultaneous trip of the Torrens A West 275 kilovolt (kV) (TORW_A) busbar and Torrens B West 275 kV (TORW_B) busbar (a non-credible contingency event[3]). The TORW_B busbar trip disconnected Barker Inlet Power station from the system, and the trip of TORW_A busbar disconnected the Torrens West 275/66 kV West transformer.

The trip of TORW_A and TORW_B busbars was caused by a failure of the Current Transformer (CT) associated with the Torrens West bus section Circuit Breaker (CB). Oil from the failed CT caught fire during the failure damaging secondary systems such as control cables, communication fibres, and the Torrens Island Power Station B (TIPSB) 275 kV CB compressed air line.

This final report is prepared in accordance with clause 4.8.15(c) of the National Electricity Rules (NER). This final report provides further analysis of the following issues that were identified in the preliminary report:

- The cause of the CT failure at Torrens 275 kV substation.
- The causes of the Torrens 275 kV substation air system, communications and control systems, and SCADA output deterioration, and the steps taken to manage/resolve this.
- The impact on system strength and the actions taken during the incident.
- The reasons for the Lack of Reserve level 1 (LOR1) and LOR2 condition notices and steps taken in response to manage reserves.
- Further assessment of system security throughout the event.
- Details of the directions AEMO issued to generators during this incident.
- Analysis of distributed photovoltaic (DPV) behaviour during this incident.

This report has been prepared using information from AEMO systems and information supplied by ElectraNet[4].

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

AEMO conclusions are summarised in Table 1 below. Each of these findings is discussed in further detail in the report.

Table 1 Summary of conclusions

Finding	Actions recommended or underway
AEMO has concluded that the outages of the busbars at Torrens 275 kV substation were caused by the failure of the CT associated with Torrens West bus section 275 kV CB.	ElectraNet is working with the CT manufacturer to identify the underlying cause of the failure. Once identified, ElectraNet should share this information with AEMO and undertake any additional remedial actions.
The power system remained in a secure operating state throughout this incident.	No action required.

[1] See Preliminary Report at https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2021/preliminary-report-torrens-island-275-kv-west-busbar-trip.pdf?la=en.

[2] 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

[3] As defined under clause 4.8.15 of the NER and the associated Reliability Panel Guidelines.

[4] ElectraNet is the Transmission Network Service Provider in South Australia

Finding	Actions recommended or underway
The Frequency Operating Standard[5] was met in relation to this incident.	No action required.
The SA system strength requirements were met throughout this incident.	No action required.
During this incident the fire at Torrens 275 kV substation resulted in increased risk of tripping of all TIPSB generating units, which AEMO therefore declared to be a credible contingency event. This impacted reserve requirements and led to forecast LOR1 conditions and actual LOR1 and LOR2 conditions in SA.	AEMO responded by informing the market of the LOR conditions throughout the event. AEMO directed additional generating units at Pelican Point Power Station to synchronise, increasing the available reserves. AEMO has assessed this reclassification and the response as appropriate in the circumstances and no action is recommended.
The CT failure led to a fire at Torrens 275 kV substation which caused a number of issues on site including: • Fire damage to equipment. • Impacts on TIPSB CB compressed air supply. • SCADA and protection communication issues at Torrens 275 kV substation. • Torrens A 66 kV substation 66/6.6 kV B house transformer trip.	Effective collaboration between AEMO, ElectraNet and AGL enabled this situation and the evolving conditions to be managed effectively, mitigating the potential severity of the event. No action recommended.
Throughout the incident a number of protection settings changes were made by ElectraNet at Torrens 275 kV substation to maintain protection system integrity. These protection settings were made prior to AEMO being informed and during the incident it was not immediately clear to AEMO how these changes would impact power system security and the requirement to reclassify contingency events.	AEMO discussed this event at the Power System Security Working Group[6] (PSSWG) on 6 August 2021. The following points were considered by the transmission network service provider (TNSP) operational representatives: • The requirement to advise AEMO before making protection changes. • The requirement to collaborate with AEMO on the impact that protection changes have on power system security. • Requirement to maintain protection knowledge across control rooms. No further action recommended.
It took approximately 9 hrs to reclassify Torrens A 66 kV circuits as a single credible contingency event following the protection settings changes made at Torrens 275 kV substation.	AEMO assessed the need for Torrens A 66 kV circuits to be reclassified when the protection setting changes had been made by ElectraNet. Initially AEMO determined it was not necessary to reclassify the affected 66 kV circuits as their simultaneous trip would have no impact on the security of the main transmission network. This was reviewed the following morning, and it was identified that the 66 kV system connected to Torrens A Station was part of AEMO's area of operational oversight. Therefore, it was determined that the simultaneous loss of these circuits should be reclassified as credible. The reclassification was effective from 0830 hrs on 13 March 2021. The delay in reclassification of the affected Torrens A 66 kV circuits had no impact on power system security. AEMO has incorporated a detailed review of this incident into internal control room training sessions. All AEMO shift teams have attended a training session covering this incident. No further action required.

[5] See https://www.aemc.gov.au/sites/default/files/2020-01/Frequency%20operating%20standard%20-%20effective%201%20January%202020%20-%20TYPO%20corrected%2019DEC2019.PDF.

[6] See Power System Security Working Group terms of reference at https://aemo.com.au/-/media/files/stakeholder_consultation/working_groups/other_meetings/nemoc/power-system-security-working-group-psswg-terms-of-reference.pdf?la=en.

Finding	Actions recommended or underway
During this incident market notice 83258 was inadvertently published with the required and available reserve numbers reversed.	AEMO has reviewed the process for the preparation and checking of market notices prior to publication. No further action required.
On 17 March 2021 site investigations identified fire damage to busbar protection circuits associated with the Torrens East 275 kV bus section CB.	ElectraNet has repaired the damaged equipment.
Due to this incident, around 70 megawatts (MW) of DPV is estimated to have disconnected in SA. This is combined with an estimated 160 MW demand drop off. These two factors resulted in a decrease in operational demand of 90 MW in response to this incident. The South Australian Government recently introduced new voltage disturbance ride-through (VDRT) standards for DPV. AEMO's analysis of this event suggests that DPV connected under the SAVDRT standard disconnected at a similar rate to DPV installed prior to this new standard.	AEMO will continue to monitor and report on DPV disconnection rates during system incidents (as appropriate). AEMO is 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.
Analysis of DPV reconnection profiles during this incident for inverters installed under the 2015 standard shows 14% of systems do not appear to be observing the applicable ramp rate limits.	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, so it can be rectified.
Due to the network constraints invoked to maintain system security during this incident, reduced generation availability and interconnector constraints, there was high price volatility in SA during the incident. This incident also led to increased 60 second frequency control ancillary services (FCAS) market prices.	High price volatility is expected during periods with challenging system conditions and where constraints are invoked on generators and transmission elements to maintain power system security following the loss of multiple transmission elements and generating units. No action required.
Initial investigation by ElectraNet indicates the failure of the CT was caused by a failure internal to the CT, and therefore unrelated to a previous CT failure event that occurred on 20 January 2020[7]. Further, the annual insulator wash cycle (undertaken on 11 March 2021) does not include the failed CT which is of polymer insulation type, therefore this does not appear to have been a factor.	ElectraNet to continue its investigation into the root cause of the CT failure and share the outcome of the investigation with AEMO. AEMO and ElectraNet to take appropriate actions in light of the investigation outcome and share details with the PSSWG as appropriate.

2. Incident overview

Prior to this incident, there was a planned high impact outage of the Moorabool to Mortlake (MOPS-MLTS) No.2 500 kV line in Victoria, which started at 0506 hrs on 12 March 2021 with an expected finish time of 1730 hrs on 19 March 2021[8]. This planned outage meant that a credible single circuit fault on any transmission lines between Alcoa Portland – Heywood – Tarrone – Haunted Gully – Moorabool 500 kV substations would result in synchronous separation between Victoria and South Australia. Prior to giving permission to proceed

[7] See https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2020/tips-a-275kv-west-bus-20-jan-2020.pdf?la=en.

[8] See AEMO Market Notice 83206 for additional details on this outage.

(PTP) for this planned outage, AEMO assessed system conditions and the power system was deemed secure for the entire duration of the outage.

Immediately prior to the incident, all CBs at Torrens Island A and B 275 kV substations were closed. In addition, units 2, 3 and 4 at TIPSB and Barker Inlet Power Station were operating. Unit 1 at TIPSB and all units at Torrens Island A were not generating prior to the incident.

2.1 Event

At 1708 hrs on 12 March 2021, the CT associated with Torrens West bus section CB failed. This CT failure caused the TORW_A and TORW_B 275 kV busbars to simultaneously trip due to operation of bus zone protection. The event resulted in disconnection of Barker Inlet power station and caused the TORW_A to Torrens West 275/66 kV transformer to disconnect at the TORW_A end. Oil from the failed CT caught fire and damaged control cables, communication fibres, and the Torrens B 275kV (TIPSB) compressed air line.

See Appendix A1 for pre and post incident system diagrams.

Table 2 below summarises the key events during this incident.

Table 2 Sequence of incident events

Time	AEMO	ElectraNet/AGL
12 March 2021		
1708	Torrens Island West bus section CB CT failed causing Torrens A West 275 kV and Torrens B West 275 kV busbars to trip, disconnecting Barker Inlet Power Station from 111 MW and the Torrens West 275/66 kV West transformer.	
1709	-	ElectraNet requested first call response maintenance staff attend site.
1713	-	AGL staff on site reported to ElectraNet fire visible in vicinity of Torrens West bus section CB. ElectraNet called the Metropolitan Fire Service (MFS).
1715	-	ElectraNet advised AEMO of the situation.
1725	AEMO invoked constraint to limit Barkers Inlet output to 0 MW.	
1726	-	ElectraNet carried out switching via SCADA to make the equipment at TIPSB safe for the MFS.
1739	AEMO issued market notice 83251 advising market of non-credible contingency event in SA involving the trip of Torrens A West 275 kV and Torrens B West 275 kV busbars.	
1749	-	ElectraNet maintenance team arrived at TIPSB. ElectraNet reported there was a fire in the cable trenches on site and advised AEMO of a risk of simultaneous loss of generation at TIPSB due to the fire..
1751	-	On-site maintenance personnel confirmed the CT associated with the Torrens West bus section CB had failed due to a V phase[9] fault.

[9] ElectraNet use U, V and W as phase identifiers within their 275 kV network.

Time	AEMO	ElectraNet/AGL
1750	AEMO invoked constraints for the simultaneous loss of all TIPSB generators. This constraint limited the maximum combined generation from TIPSB to 270 MW. AEMO identified that if all TIPSB generators tripped there would be no secure system strength combinations available for dispatch.	-
1756	AEMO issued market notice 83253 to reclassify the loss of TIPS B units 1, 2, 3 and 4 as a credible contingency event until further notice.	-
1849	At Torrens A 66kV substation the 66/6.6 kV B House transformer tripped following alarm indication of Buchholz main tank trip and tripping of the associated 66 kV and 6.6 kV CBs[10].	
1849	All Torrens 275 kV and Torrens North 66 kV substation SCADA and protection communications failed.	
1850	-	Major compressed air system leak reported by field staff, requiring the shutdown of air supply to air operated circuit breakers at Torrens B substation. Without compressed air supply there was a risk that CBs would not have adequate air pressure for subsequent operations[11] once opened if the CB non return valves did not hold air . Should the affected CBs have become inoperable, all TIPSB units would become unavailable until air pressure was restored. ElectraNet requested SCADA maintenance service provider to attend Torrens 275 kV substation to repair SCADA and protection communications failure.
1906	-	ElectraNet requested telecommunications engineers to investigate communications failures at Torrens Substation.
1915	Constraints invoked to begin ramping TIPS B3 and TIPS B4 maximum output towards 0 MW.	Due to concerns about low CB air pressure, ElectraNet advised it had suggested AGL shut down TIPS B3 and TIPS B4 units.
1915-2105	AEMO closely monitored this situation throughout to ensure system security was maintained at all times.	TIPS B3 and B4 began ramping their output towards 0 MW while investigations into the compressed air systems status and the requirement for TIPS B3 and B4 to shut down continued. ElectraNet was in regular discussion with AGL and AEMO throughout this period.
1922	To improve system strength in SA, AEMO directed Pelican Point GT12 to synchronise and directed Pelican Point GT12 and ST18 to follow dispatch targets.	-
1955	AEMO requested AusNet Services (AusNet) to recall the Moorabool-Mortlake 500 kV line outage on the basis that the event at Torrens was expected to extend into the following day. Ausnet advised that work on site to recall this circuit would commence the following morning.	-

[10] This house transformer provides an auxiliary supply to the Torrens Island Power Station.

[11] Air operated CBs need a high-pressure air supply to maintain pressure in reserve for tripping. Each CB normally has a tank of stored air in its vicinity which stores enough air for a few operations. The substation's air system resupplies the air CB tanks to maintain the required high-pressure air. Should the substation air system fail, the CB tanks have a non-return valve to stop stored air leaking back out into the substation. If non-return valves fail, the CBs will become inoperable, meaning they can no longer be opened. CBs of this type are present at Torrens 275 kV substation.

Time	AEMO	ElectraNet/AGL
2010	-	ElectraNet requested staff at Torrens substation to monitor all CB air supplies to confirm they had adequate air while air system was repaired.
2027	-	Remote Fault Management Team confirmed failure of protection communications on the following lines: • New Osborne 3 – Torrens Island Power Station A 66 KV line. • New Osborne 4 – Torrens Island Power Station A 66 KV line. • Torrens A – Para 275 KV line. • Torrens A – Northfield 275 KV line. • Torrens A – Kilburn 275 KV line. • Torrens A – Torrens North 1 66 kV line. • Torrens A – Torrens North 2 66 kV line. Protection on the above circuits may not operate correctly should a fault occur.
2040	With the fire extinguished, AEMO still could not confirm the status of TIPS B protection systems due to the SCADA and protection communications issues on site. AEMO therefore retained the reclassification of all TIPS B units as a credible contingency at this time.	Site staff reported that the fire on site at Torrens B substation was extinguished but access to area was still not possible due to safety concerns.
2057	-	ElectraNet advised AEMO of impact of SCADA communication and protection signalling at Torrens 275 kV substation. ElectraNet advised AEMO that protection settings changes had been made to the following circuits: • Torrens A – Para 275 KV line. • Torrens A – Northfield 275 KV line. • Torrens A – Kilburn 275 KV line. • Torrens A – Magill 275 kV line. ElectraNet advised AEMO it would investigate whether a fault could trip the whole Torrens 275 kV substation.
2058	-	ElectraNet applied temporary protection settings to the Torrens A – Torrens North 1 66 kV and Torrens A – Torrens North 2 66kV lines.
2105	AEMO revoked the constraints which required TIPS B3 and B4 to ramp towards 0 MW output.	ElectraNet advised AEMO there was no requirement to shut down TIPS units B3 and B4 as compressed air levels in affected CBs are stable and at acceptable levels.
2107	-	ElectraNet advised AEMO that impacted protection systems at the remote end of transmission lines connected to Torrens 275 kV substation would default to distance protection and would still operate correctly. ElectraNet confirmed that protection would operate to clear any fault but may operate slower than normal. ElectraNet confirmed it was monitoring air pressure on site and would contact AEMO if air pressure goes low.
2111	-	ElectraNet applied temporary protection settings to the remote end of the remaining transmission lines impacted by protection communications issues at Torrens 275 kV substation.

Time	AEMO	ElectraNet/AGL
2253	-	ElectraNet advised AEMO that there was no longer a risk of all TIPSB units tripping for a single system fault.
2310	AEMO requested information from ElectraNet regarding the impact of temporary protection settings on protection operations at Torrens A 275 kV and 66 kV substations	ElectraNet advised that the following four 275 kV lines could potentially trip simultaneously: • Torrens Island A – Magill 275 kV line. • Torrens Island A – Para 275 kV line. • Torrens Island A – Northfield 275 kV line. • Torrens Island A – Kilburn 275 kV line. ElectraNet also advised that the following 66 kV lines could trip simultaneously: • Torrens Island – Port Adelaide North 66 kV line. • Torrens Island – Kilburn 66 kV line. • Torrens Island – New Osborne No 3 66 kV line. • Torrens Island – New Osborne No 4 66 kV line. • Torrens – Torrens North No 1 66 kV line. • Torrens – Torrens North No 2 66 kV line.
2356	-	Site staff at Torrens substation advised ElectraNet that smoke from failed CT was increasing. To assess the risk the fire may re-ignite, ElectraNet requested MFS attendance on site. MFS attended site and confirmed the fire was extinguished.
2358	AEMO issued market notice 83276 to advise that the cause of the non-credible contingency had been identified. The reclassification for loss of all TIPS B station units as a credible contingency was cancelled from 2340 hrs.	-
13 March 2021		
0036	AEMO issued market notice 83278 to reclassify the loss of: • Torrens Island A – Magill 275 kV line, • Torrens Island A – Para 275 kV line, • Torrens Island A – Northfield 275 kV line, and • Torrens Island A – Kilburn 275 kV line as a credible contingency until further notice.	-
Approximately 0300	Additional system strength combinations were identified by AEMO staff which did not rely on TIPS generation.	-
0337	-	Site staff reported to ElectraNet that temporary repair had been completed on the TIPSB compressed air system and it was no longer leaking.
0407	AEMO advised AusNet that the recall of the Moorabool-Mortlake 500 kV line outage was not required.	-

Time	AEMO	ElectraNet/AGL
0903	AEMO issued market notice 83281 to reclassify • Torrens Island – Port Adelaide North 66 kV line, • Torrens Island – Kilburn 66 kV line, • Torrens Island – New Osborne No 3 66 kV line, • Torrens Island – New Osborne No 4 66 kV line, • Torrens – Torrens North No 1 66 kV line, and • Torrens – Torrens North No 2 66 kV line as a credible contingency from 0830 hrs on 13 March 2021 until further notice.	-
0930	-	All protection signalling and ElectraNet SCADA switching control for Torrens 275 kV substation restored.
1112	AEMO issued market notice 83283 to cancel the reclassification of: • Torrens Island A – Magill 275 kV line, • Torrens Island A – Para 275 kV line, • Torrens Island A – Northfield 275 kV line, and • Torrens Island A – Kilburn 275 kV line as a credible contingency.	-
1117	AEMO issued market notice 83282 to advise of the reclassification of the trip of Torrens Island Power Station – Magill 275 kV line and either: • Torrens Island A – Para 275 kV line, or • Torrens Island A – Northfield 275 kV line, or • Torrens Island A – Kilburn 275 kV line as a credible contingency	-
1151	AEMO issued market notice 83285 to advise that the reclassification of Torrens Island A – Magill 275 kV line and either: • Torrens Island A – Para 275 kV line, or • Torrens Island A – Northfield 275 kV line, or • Torrens Island A – Kilburn 275 kV line as a credible contingency had been cancelled.	-
1524	All Torrens 275 kV substation AEMO SCADA indications returned to normal (except for the Torrens Island 275 kV West bus coupler circuit breaker).	-
2208	Torrens B West 275 kV busbar returned to service.	

Time	AEMO	ElectraNet/AGL
14 March 2021		
0922	Torrens A West 275 kV busbar returned to service.	
1952	AEMO issued market notice 83355 to cancel the reclassification of the: • Torrens Island – Port Adelaide North 66 kV line, • Torrens Island – Kilburn 66 kV line, Torrens Island – New Osborne No 3 66 kV line, • Torrens Island – New Osborne No 4 66 kV line, • Torrens – Torrens North No 1 66 kV line, and • Torrens – Torrens North No 2 66 kV line as a credible contingency.	-

2.2 Analysis of events and response at Torrens 275 kV substation

Throughout this incident the CT failure and subsequent fire in the Torrens 275 kV substation caused multiple issues on site. Analysis of the cause and response to each of these different issues is provided below.

2.2.1 CT failure

Post incident investigation has confirmed that the V phase[12] of the CT associated with Torrens West bus section 275 kV CB failed. The CT failure caused the bus bar protection on both the TORW_A and TORW_B busbars to operate. ElectraNet was first notified of the fire on site at 1713 hrs, around 5 minutes after the initial CT fault. ElectraNet immediately called the MFS to attend the site and notified AEMO. The fire on site was caused because oil from the CT phase caught fire during the CT failure. This fire continued to burn for several hours after the initial CT failure, affecting other equipment on site. ElectraNet carried out switching at the substation ahead of the MFS's arrival to allow them safe access to control the fire. In addition, AEMO updated system constraints and issued market notices throughout the incident. Regular communication was maintained between AEMO and ElectraNet throughout the incident as the fire affected different parts of the substation and its secondary systems.

ElectraNet's initial investigation indicates that the CT failure on 12 March 2021 was caused by a fault internal to the CT. Based on ElectraNet's investigation there does not appear to be a common cause or link to an earlier CT failure at Torrens 275 kV substation that occurred on 20 January 2020[13]. The investigation into the root cause of this previous CT failure concluded that an external flashover was likely to have occurred due to build-up of pollution from bushfire smoke in the air which may have settled on the CT. ElectraNet also advised that the annual insulator wash cycle (undertaken on 11 March 2021) does not include the failed CT which is of polymer insulation type, therefore this does not appear to have been a factor in this event.

[12] ElectraNet uses U, V and W as phase identifiers within its 275 kV network.

[13] 20 January 2020 CT failure incident report can be found here https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2020/tips-a-275kv-west-bus-20-jan-2020.pdf?la=en.

2.2.2 Torrens B compressed air system leak

At 1850 hrs on 12 March 2021, ElectraNet site staff identified a major air leak affecting the TIPSB air system. The CT failure or subsequent fire appears to have damaged the high-pressure air lines close to the failed CT. This air leak affected the CBs associated with TIPS units B3 and B4[14].

Due to the risk of air operated CBs losing air and becoming stuck in the closed position, ElectraNet requested that AGL shut down TIPS B3 and B4. AEMO invoked constraints at ElectraNet's request to ramp TIPS B3 and B4 output towards 0 MW at 1915 hrs. During this time ElectraNet was still investigating this issue to confirm whether TIPS B3 and B4 needed to shut down. In addition, while working to repair the air system ElectraNet staff monitored CB air pressures regularly to ensure they remained at acceptable levels. Due to the ongoing investigation, TIPS B3 and B4 ramped down gradually but did not reach 0 MW. At 2105 hrs on 12 March 2021 ElectraNet staff were satisfied that CB air pressures were holding and were sufficient for correct CB operation and that there was no requirement for TIPS B3 and B4 to shut down. AEMO subsequently adjusted constraints to require TIPS B3 and B4 unit generation to be at or above 40 MW.

ElectraNet site staff managed to affect a temporary repair to the air system at 0337 hrs on 13 March 2021, reinstating air supply to the affected CBs. ElectraNet informed AEMO of the air system repair at 0349 hrs. During this incident, at no point did CB air pressure drop below the levels required for CB operation and AEMO and ElectraNet responded promptly and appropriately to the evolving air system issues.

2.2.3 SCADA and protection communication failures

At 1849 hrs on 12 March 2021, EMS SCADA communications and protection signalling for transmission lines at Torrens 275 kV and Torrens North 66 kV substations failed. Due to the signalling and communication issues, ElectraNet could not confirm that the protection would operate correctly should a fault occur on site. In response to this situation, ElectraNet informed AEMO that it had applied temporary protection settings at 2057 hrs to maintain protection integrity via functioning backup systems. These settings changes extended the reach of remote end line protection to ensure that any fault in Torrens substation would be disconnected promptly from the system.

At 2310 hrs on 12 March 2021, AEMO requested information from ElectraNet regarding the impact of temporary protection settings on protection operations at Torrens A 275 kV and 66 kV substations. ElectraNet confirmed that protection settings changes meant several 275 kV and 66 kV lines at Torrens A substation were at risk of simultaneously tripping for certain faults. AEMO control room staff performed analysis to assess the impact of these protection changes and associated multiple trips.

At 0036 hrs on 13 March 2021, AEMO issued a market notice 83278 advising that the 275 kV lines identified by ElectraNet as at risk of simultaneous trip had been reclassified as a credible contingency from 2340 hrs on 12 March 2021. AEMO also considered reclassifying the 66 kV lines identified by ElectraNet at this time. However, the affected 66 kV lines included:

- Connection assets for Quarantine Power Station (Quarantine Power station was only operating No. 1 Unit at approximately 26 MW).
- Connection to New Osborne substation, which has alternate connections to the transmission system (in addition, Osborne Power Station was out of service).
- Connections to distribution substations Kilburn 66 kV and Port Adelaide North 66 kV, both of which have alternate connections to the transmission system.

Given the above information, AEMO assessed that the loss of these 66 kV lines had no material impact on the security of the main transmission network and it was not considered necessary to reclassify the 66 kV lines as a credible contingency.

During AEMO control room shift handover on the morning of 13 March 2021, it was noted that the 66 kV system connecting Torrens A Station was part of AEMO's area of operational oversight, and it was agreed it

[14] Other generators at TIPSB do not use air operated CBs and as such were not impacted by the air system leak

would be appropriate to reclassify the affected 66 kV lines as a credible contingency. AEMO issued market notice 83281 at 0903 hrs reclassifying the simultaneous loss of the affected 66 kV lines as a credible contingency from 0830 hrs on 13 March 2021. Reclassification did not impact power system security and the power system remained secure during the period where there was no reclassification.

At 0930 hrs on 13 March 2021, ElectraNet restored the affected protection signalling and ElectraNet SCADA. At 1524 hrs on 13 March 2021, ElectraNet restored AEMO SCADA for the Torrens A 275 kV substation.

Throughout this incident AEMO liaised with ElectraNet to assess the status of protection systems on site. During this incident, ElectraNet made some protection changes prior to notifying AEMO and there was a subsequent delay in identifying how protection settings changes could impact protection operation and therefore power system security. This was addressed through discussion between AEMO and ElectraNet. A recommendation has been included in Table 1 of this report to clarify the appropriate process to follow when making protection changes. Post incident analysis has confirmed this reclassification delay had no adverse impact on system security during the incident.

Post incident investigation has confirmed the SCADA and protection communication failures were caused by direct fire damage to communication fibres in the vicinity of the failed CT.

2.2.4 Torrens A 66 kV substation 66/6.6 kV B house transformer trip

At 1919 hrs on 12 March 2021, the Torrens A 66kV substation 66/6.6 kV B house transformer[15] tripped after alarm indication of the main tank Buchholz relay. The associated 66 kV CBs 6W6 and 6C6 and the associated 6.6 kV CB tripped, disconnecting the transformer. Post incident investigation has confirmed that this trip was caused by fire damage to control cables. This damage caused a short circuit on inputs to the protection system, resulting in protection operation. No action was required by AEMO or ElectraNet in response to this trip.

2.2.5 Post incident site investigation

On 17 March 2021, site investigations identified fire damage to busbar protection circuits associated with the Torrens East 275 kV bus section CB. ElectraNet took this CB out of service at 1402 hrs on 17 March 2021 to implement repairs. After ElectraNet replaced damaged cables and completed protection testing, the CB was returned to service at 2104 hrs on 19 March 2021.

3. Power system security

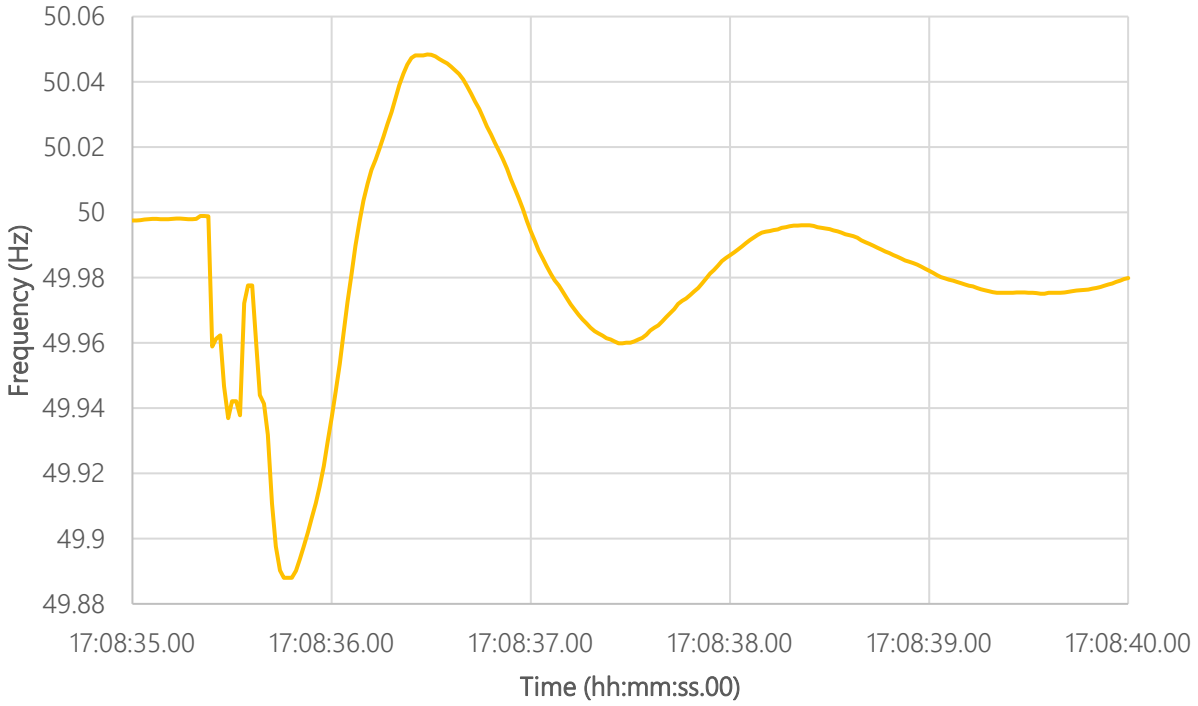
Post incident analysis has confirmed that the power system remained in a secure operating state throughout this incident. An analysis of power system performance is included in this section.

3.1 Frequency performance

As shown below in Figure 1, as result of the non-credible contingency at 1708 hrs the system frequency reached a maximum of 50.048 hertz (Hz) and a minimum 49.89 Hz. The frequency did not leave the normal operating frequency band throughout the incident. The Frequency Operating Standard was met in relation to this incident.

[15] This house transformer provides an auxiliary supply to the Torrens Island Power Station.

Figure 1 Power system frequency 12 March 2021



3.2 SA system strength

Due to the fire impacting equipment at Torrens B West 275 kV substation, the simultaneous loss of all TIPSB generators was reclassified as a credible contingency from 1750 hrs to 2340 hrs on 12 March 2021. During this time, if all TIPSB generators had tripped there would have been no secure system strength combinations available for dispatch. However, TIPS B2, B3 and B4 remained in service and post incident analysis has confirmed that throughout this incident the combination of synchronous generators online at any one time was sufficient to maintain SA system strength. In addition, in the evening of 12 March 2021 AEMO undertook offline analysis using EMT simulation software to identify additional system strength generator combinations. These additional generator combinations allowed greater flexibility, giving AEMO combinations of generation in SA which did not require TIPSB units to be online.

3.3 SA reserve conditions

During this incident LOR1 and LOR2 conditions were declared due to a tightening of electricity supply reserves in SA[16]. Table 3 below outlines how reserve capacity requirements and capacity availability changed during the incident, and how AEMO responded to this and updated the market.

Table 3 Lack of reserve conditions in SA 12 March 2021

Time	Market notice	Details	LOR time period	Reserve requirement	Reserve available
12 March 2021					
1756	83253	Simultaneous trip of all TIPSB units declared as a credible contingency.	Until further notice	N/A	N/A

[16] Refer to Appendix A2.1 for an explanation of LOR conditions and notices.

Time	Market notice	Details	LOR time period	Reserve requirement	Reserve available
1839	83254	Forecast LOR1 condition in SA. Capacity requirement was increased due to constraints on TIPSB associated with the reclassification of simultaneous trip all TIPSB units as a credible contingency.	From 1900 hrs to 1930 hrs on 12/03/2021	439 MW (LOR1 reserve requirement)	433 MW
1845	83255	Actual LOR1 condition in SA.	From 1835 hrs to 1930 hrs on 12/03/2021	439 MW (LOR1 reserve requirement)	432 MW
1922	N/A	Participant notice 83265 - AEMO issued a direction for Pelican Point Power Station GT12 to connect to the power system and directed Pelican Point GT12 and ST18 to follow dispatch targets[17]. AEMO took this action to improve system strength in the region.	From 1905 hrs on 12/03/2021	N/A	N/A
1925	83258	Update to actual LOR1 condition in SA.	From 1835 hrs to 2030 hrs on 12/03/2021	420 MW[18] (LOR1 reserve requirement)	296 MW
1947	83263	Actual LOR2 condition in SA.	From 1930 hrs to 2030 hrs on 12/03/2021	228 MW (LOR2 reserve requirement)	97 MW
1952	83265	Update to actual LOR1 condition in SA.	Until 2100 hrs on 12/03/2021	420 MW (LOR1 reserve requirement)	97 MW
2004	83262	AEMO informed the market of a direction to a participant in SA.	N/A	N/A	N/A
2012	Second gas turbine at Pelican Point synchronised to the power system				
2033	83268	Cancellation of actual LOR2 condition in SA.	Cancelled from 2030 hrs on 12/03/2021	N/A	N/A

[17] Pelican Point Power Station ST18 was already synchronised and generating prior to this participant notice. However, participant notice 83256 was issued directing both Pelican Point GT12 and ST18 to synchronise and follow dispatch targets. As ST18 was already synchronised, the part of the direction for ST18 to synchronise was not required.

[18] In market notice 83258, the capacity requirement and capacity available was inadvertently recorded the wrong way round. A recommendation is included in this report relating to this.

Time	Market notice	Details	LOR time period	Reserve requirement	Reserve available
2042	83269	Update to actual LOR1 condition in SA.	Until 2110 hrs on 12/03/2021	420 MW (LOR1 reserve requirement)	380 MW
2110	83273	Cancellation of actual LOR1 condition in SA.	Cancelled from 2110 hrs on 12/03/2021	N/A	N/A

As shown above, at 1756 hrs on 12 March 2021 the simultaneous loss of all TIPSB units was reclassified as a credible contingency until further notice. This meant that if all TIPSB units had tripped there would have been no secure system strength combinations available for dispatch. In addition, constraints placed on TIPSB to limit the generators maximum output reduced reserve levels in SA. From this time onwards, reserve levels decreased, leading to forecast LOR1 conditions and then actual LOR1 and LOR2 conditions in SA.

To improve system strength in the region, AEMO directed a second gas turbine at Pelican Point to synchronise to the system at 1922 hrs on 12 March 2021. The second Pelican Point generator successfully connected to the power system at around 2012 hrs on 12 March 2021. The connection of this additional generator improved SA system strength and had the additional benefit of improving reserve conditions. From 2012 hrs onwards reserve levels improved, allowing the actual LOR2 condition in SA to be cancelled from 2030 hrs on 12 March 2021. This also led to the cancellation of the actual LOR1 condition in SA from 2110 hrs on 12 March 2021.

3.4 Moorabool to Mortlake (MOPS-MLTS) No. 2 500 kV line planned outage

As discussed in Section 2, prior to this incident there was a planned outage of the Moorabool to Mortlake (MOPS-MLTS) 500 kV line in Victoria, which commenced at 0506 hrs on 12 March 2021 with an expected return to service of 1730 hrs on 19 March 2021[19]. This planned outage meant that a credible single circuit fault on any transmission lines between Alcoa Portland – Heywood – Tarrone – Haunted Gully – Moorabool 500 kV substations would result in synchronous separation between Victoria and SA.

When SA is at credible risk of separation, system strength requirements in SA are increased and interconnector flows in both directions are also restricted, compared to system normal conditions.

At 1922 hrs on 12 March 2021, the situation at Torrens 275 kV substation appeared to be worsening with LOR conditions in SA, SCADA issues, protection issues, possible system strength shortfalls, and the ongoing fire and air system issues onsite. Given these facts, AEMO requested a recall of the MOPS-MLTS line. AusNet[20] advised that recall was possible because the majority of work planned for the outage had not yet started, but it would take around 12 hours to return the circuit to service. In addition, AusNet advised that this work could only be carried out in daylight hours and therefore AusNet staff would commence the process on the morning of 13 March 2021.

By 0349 hrs on 13 March 2021 the situation at Torrens 275 kV substation was stable and improving, the fire had been extinguished, the air system had been repaired, no LOR conditions were forecast, and there was sufficient system strength in SA as a result of additional system strength combinations identified by AEMO. Given this situation, at 0407 hrs on 13 March 2021 AEMO advised AusNet that there was no longer a requirement to recall the MOPS-MLTS 500 kV line outage.

[19] See AEMO market notice 83206 for additional details on this outage.

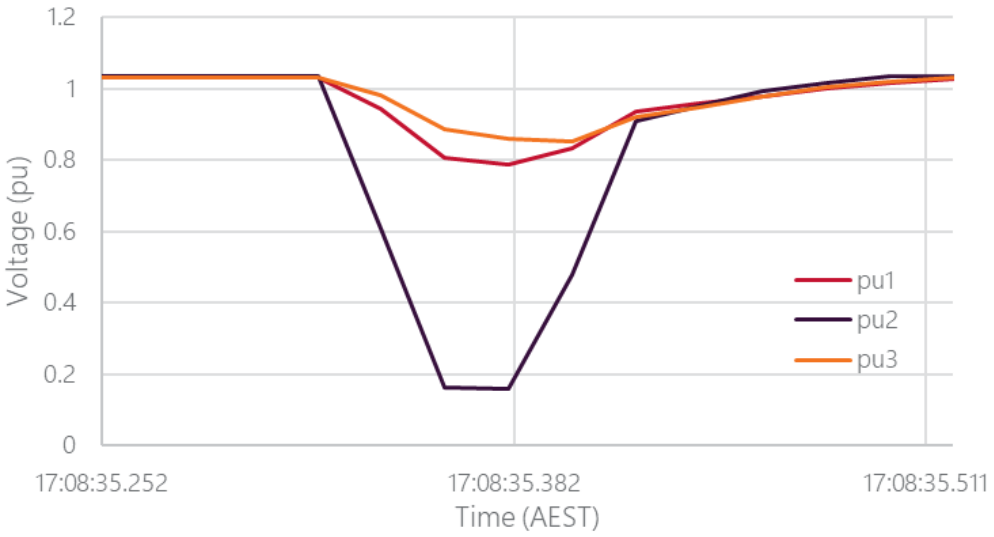
[20] AusNet (the transmission network service provider in Victoria) was carrying out the work on this line.

4. Distributed PV behaviour

4.1 Voltage disturbances

High speed monitoring at Magill recorded a minimum voltage of 0.16 pu on a single phase (and a minimum of 0.60 pu positive sequence) during the fault, as shown in Figure 2. Voltage disturbances of this depth on previous occasions have been observed to result in more than 20% of DPV in SA disconnecting, and significant load disconnection, as discussed further in Appendix A3.

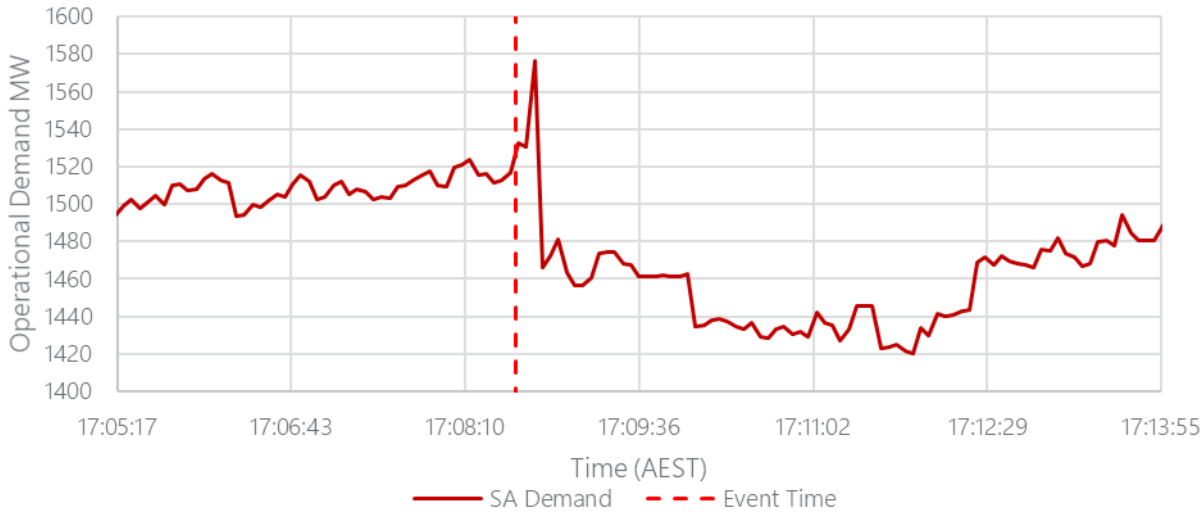
Figure 2 Three phase voltage measured at Magill



4.2 Load and distributed PV response

Prior to the event, total operational demand in South Australia was estimated at 1,520 MW. Following the event, demand reduced to less than 1,430 MW (as shown in Figure 3), a net load reduction of approximately 90 MW. It is estimated that approximately 70 MW of DPV disconnected in response to the voltage disturbance, as discussed further in Appendix A3. This level of DPV disconnection is somewhat lower than observed in previous similar disturbances. The causes for this remain under investigation. Since DPV disconnection offsets load disconnection, it is estimated that a total of approximately 160 MW of underlying load disconnected in response to this event.

Figure 3 South Australia load response



5. Market impacts

This incident resulted in significant volatility in the South Australian energy price and contributed to high prices for the SA 60 Second Lower frequency control ancillary services (FCAS) service on 12 March 2021.

5.1 Volatility in the South Australian energy price

Between 1800 hrs and 0000 hrs on 12 March 2021, the SA energy price was volatile. For eight dispatch intervals (DIs) over this period the South Australian price hit the Market Price Cap of $15,000/megawatt hour (MWh).

Some especially notable price outcomes in SA during this period are detailed below:

- An initial price spike of $15,000/MWh was observed for DI ending 1805 hrs.
- Prices remained above $11,000/MWh between DI ending 1925 hrs and 2010 hrs.
- There was a period of prolonged high prices from DI ending 2235 hrs.

Price outcomes in this period were affected by several different factors that led to low generation availability. These are outlined below:

- The incident resulted in the immediate disconnection of Barker Inlet Power Station (210 MW of capacity)[21].
- At 1756 hrs, AEMO reclassified the loss of TIPSB units 1, 2, 3 and 4 as a credible contingency event. A constraint was invoked to limit the combined output of these units to less than 270 MW.[22]
- At 1915 hrs, quick constraints were invoked to reduce output at TIPS B3 and B4 down towards zero with the units possibly needing to be taken offline.

[21] At the time Barker Inlet Power Station was disconnected, it was generating 111 MW.

[22] TIPSB has a rated capacity of 840 MW (4 x 210 MW units). Unit 1 at TIPSB was not operating at time of the incident.

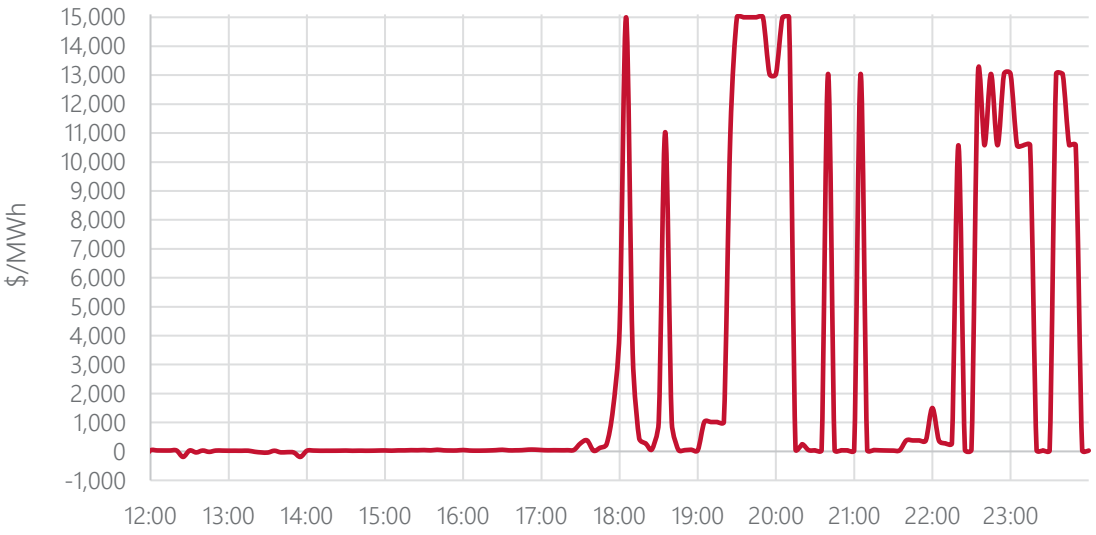
- At 2105 hrs, ElectraNet advised that the shutdown of TIPS B3 and B4 was no longer required, and constraints were revised so that these units were maintained at or above 40 MW[23].
- From 1830 hrs, total output from South Australian wind farms was less than 150 MW and dropped to as low as 20 MW[24].
- Solar generation output also reduced as daylight hours waned.

SA price outcomes were also impacted by constraints affecting the Heywood interconnector. These impacts are detailed below:

- As a result of the planned outage of the MOPS-MLTS line, there was a credible risk of SA separating from the rest of the NEM. This meant several constraints had to be invoked to maintain power system security[25]. These constraints limited flows on the Heywood interconnector. During the planned MOPS-MLTS outage the maximum flow from Victoria into South Australia was restricted to 249 MW, whereas under normal conditions transfers of up to 600 MW into South Australia are permissible.
- Mortlake Power Station Unit 12 had bid its entire capacity at the market price cap from 2205 hrs. As Unit 12 came offline (because it was not economically dispatched), this reduced headroom on constraints affecting the Heywood interconnector, heavily constraining the interconnector with negligible power transfer possible from Victoria into South Australia. This caused another period of high prices[26].

The daily average trading price (30-minute basis) for 12 March 2021 was $1,335/MWh. Figure 4 below presents the 5-minute dispatch price outcomes on 12 March 2021.

Figure 4 SA 5-minute dispatch price from 12:00 hrs on 12 March 2021 to 00:00 on 13 March 2021



[23] NEMDE was unable to solve prices for six intervals (between 19:20 hrs and 20:10 hrs) leading to Over Constrained Dispatch (OCD). OCD was triggered due to violation of these quick constraints invoked in relation to the Torrens Island B units. These DIs were manually reviewed on Monday 15 March 2021 and prices were unchanged.

[24] From DI ending 22:30 hrs, the constraint V_MLMO_VS_LB_CAN_50 was also limiting output from Lake Bonney 2, Lake Bonney 3, and Canunda windfarms.

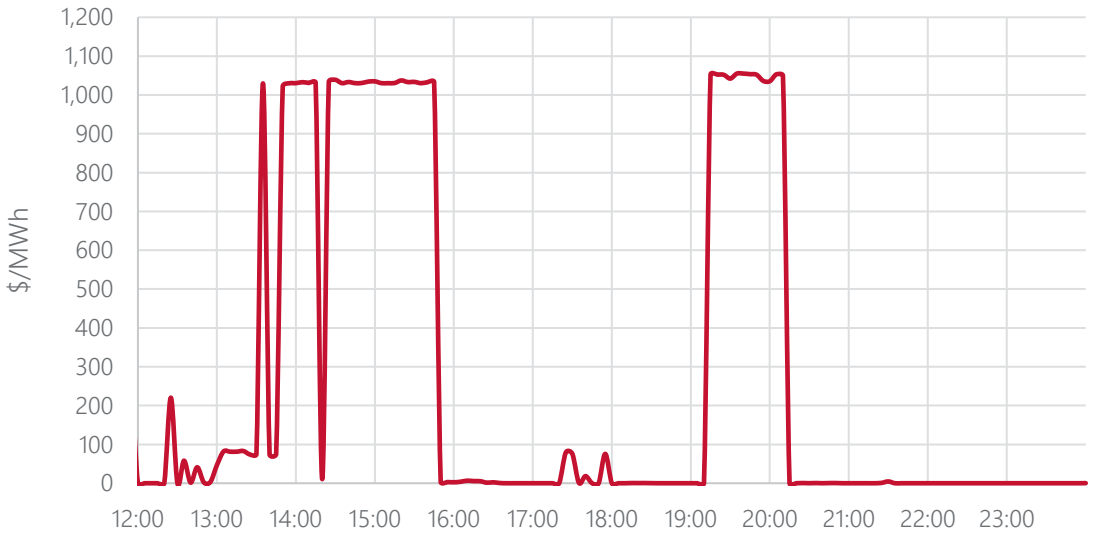
[25] Among other things, these constraints are used to manage the size of any potential contingency, ensure there are sufficient local FCAS providers, and limit the rate of change of frequency.

[26] The constraints that limited the interconnector manage requirements relating to system strength (V_MLMO_VS_LB_CAN_50) and the provision of lower contingency FCAS services across New South Wales, Victoria and Queensland (F_ESTN++MLMO_L6, F_ESTN++MLMO_L60, F_QNV++MLMO_L6 and F_QNV+MLMO_L60), At points these constraints forced power into Victoria from SA.

5.2 High prices in Lower 60 Second FCAS market in South Australia

As shown in Figure 5, between 1915 hrs and 2010 hrs on 12 March 2021 the price for the South Australian 60 Second Lower FCAS service remained above $1,000/MWh, peaking at $1,055/MWh. High prices over this period were largely due to limited Lower 60 Second FCAS supply from Torrens Island Power Station due to the incident. High prices had also been observed earlier in the day as the MOPS-MLTS outage necessitated local South Australian Lower FCAS requirements[27]. Figure 5 shows the Lower 60 Second FCAS price outcomes from on 12 March 2021.

Figure 5 SA Lower 60 Second FCAS price from 12:00 hrs on 12 March 2021 to 00:00 on 13 March 2021



[27] In other words, the credible risk of separation of SA from the rest of the NEM meant FCAS requirements for the SA region had to be met by plant within SAtralia.

A1. System diagrams

Figure 6 Pre fault system diagram

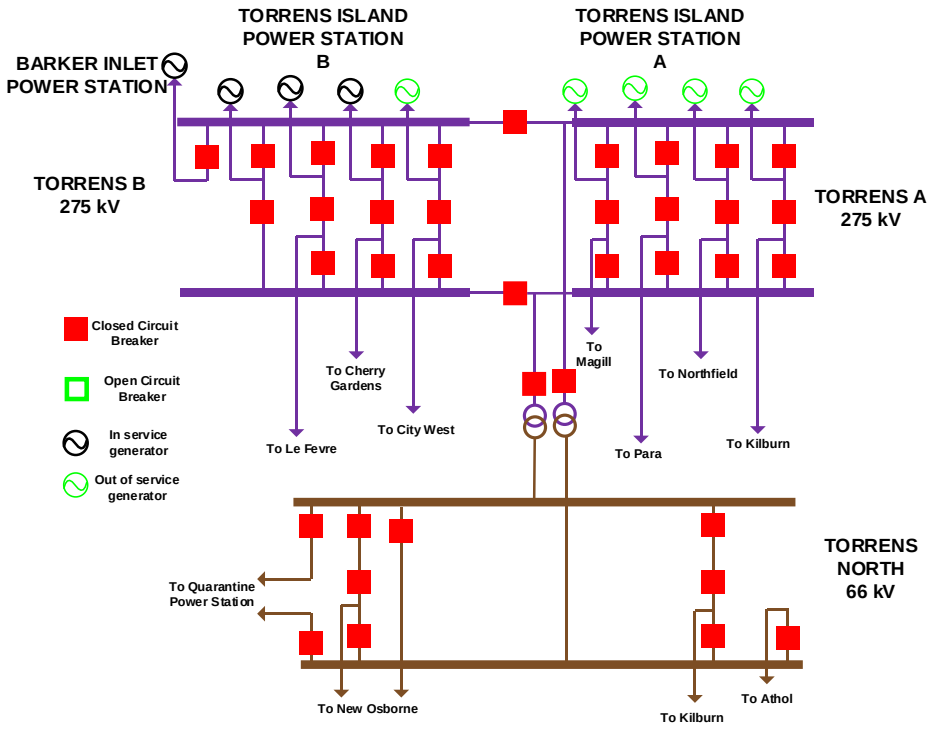
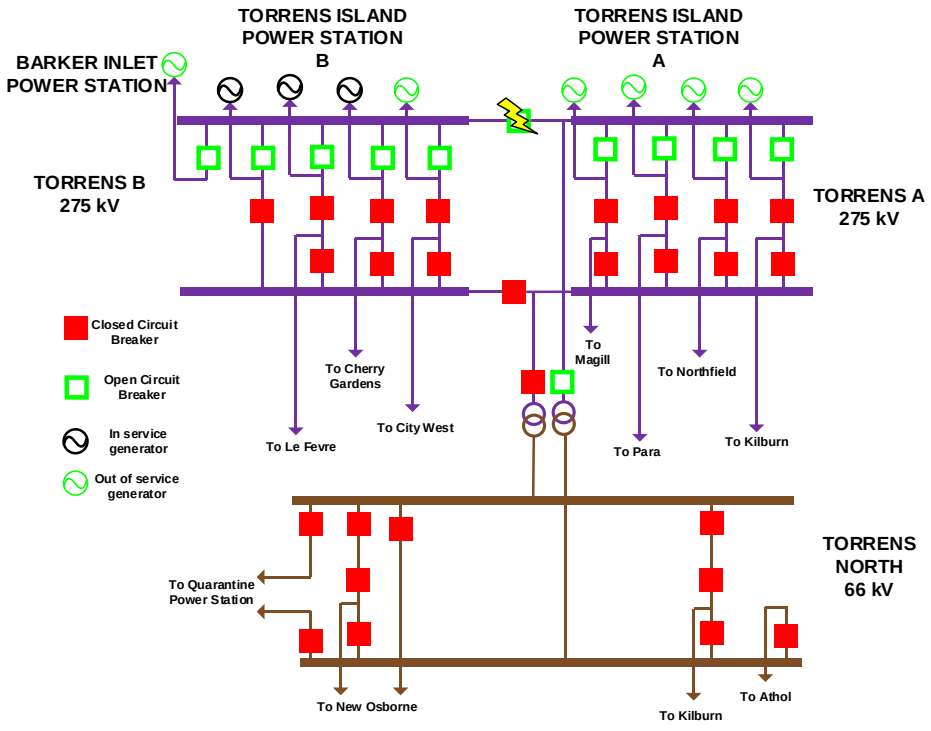


Figure 7 Post fault system diagram



A2. Lack of reserve notices

In the NEM, the level of energy reserves available to maintain power system supply to energy consumers is continually assessed. Pre-determined reserves refer to the level of 'spare' capacity to provide this buffer, over and above the level of electricity demand that is forecast at any given time. AEMO have a number of processes and arrangements in place to mitigate risk to energy supply when the system is affected by Lack Of Reserve (LOR) conditions.

A2.1 LOR level 1 notice

A LOR1 notice is given to the market by AEMO to indicate that reserve levels are lower than the two largest supply resources in a state. This notice can be forecast (AEMO is forecasting this situation will arise in the future) or actual (this is the case in the current market interval). LOR1 signals a reduction in pre-determined electricity reserve levels, encouraging generators to offer more supply, or large industrial or commercial consumers to reduce their demand. At this stage, there is no impact to power system security or reliability and AEMO continues to monitor reserve levels to maintain adequate supply.

A2.2 LOR level 2 notice

A LOR2 notice is given to the market by AEMO to indicate that reserve levels are lower than the single largest supply resource in a state. This notice can be forecast (AEMO is forecasting this situation will arise in the future) or actual (this is the case in the current market interval). At this level, there is no impact to the power system, but supply could be disrupted if a large incident occurred. Once a forecast LOR2 condition is declared, AEMO has the power to direct generators or activate the Reliability and Emergency Reserve Trader (RERT) mechanism to improve the supply-demand balance.

A2.3 LOR level 3 notice

A LOR3 notice is given to the market by AEMO to indicate a deficit in the supply/demand balance. This condition exists when the available electricity supply is equal to or less than the operational demand. This means there are no reserve supplies available. Controlled load shedding may be required as a last resort to protect system security and avoid damage to system infrastructure.

A3. Distributed PV behaviour further information

To assess DPV response to the disturbance, AEMO procured generation data from Solar Analytics[28] for 4,295 individual DPV systems (<100 kilowatts [kW]) in South Australia. Data was provided at a mixture of 5-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 in South Australia after 28 September 2020 are required to meet additional voltage ride-through requirements (the South Australian Voltage Disturbance Ride-Through [VDRT] standard, or "the SA VDRT standard")[29] introduced by the Office of the Technical Regulator[30]. This is discussed further in Section A3.1.1.

A3.1 Unintended disconnection of distributed PV

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

- Approximately 11% (4-23%)[31] of DPV systems installed under the 2005 standard disconnected[32] (based on a sample of 101 systems).
- Approximately 19% (15-24%) of DPV systems installed under the 2015 standard disconnected (based on a sample of 4,062 systems).
- Approximately 20% (12-31%) of DPV systems installed under the SA VDRT standard disconnected (based on a sample of 132 systems). This is discussed further in Section A3.1.1.

These disconnection estimates have been scaled to correct bias in the representation of certain manufacturers in the Solar Analytics sample[33]. These 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 DPV systems were observed to disconnect at a higher rate than smaller DPV systems, with 37% (32-41%) of 30-100 kW systems on the 2015 standard disconnecting, compared with 19% (18-21%) of <30 kW systems on the 2015 standard disconnecting.

[28] 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.

[29] 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.

[30] 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.

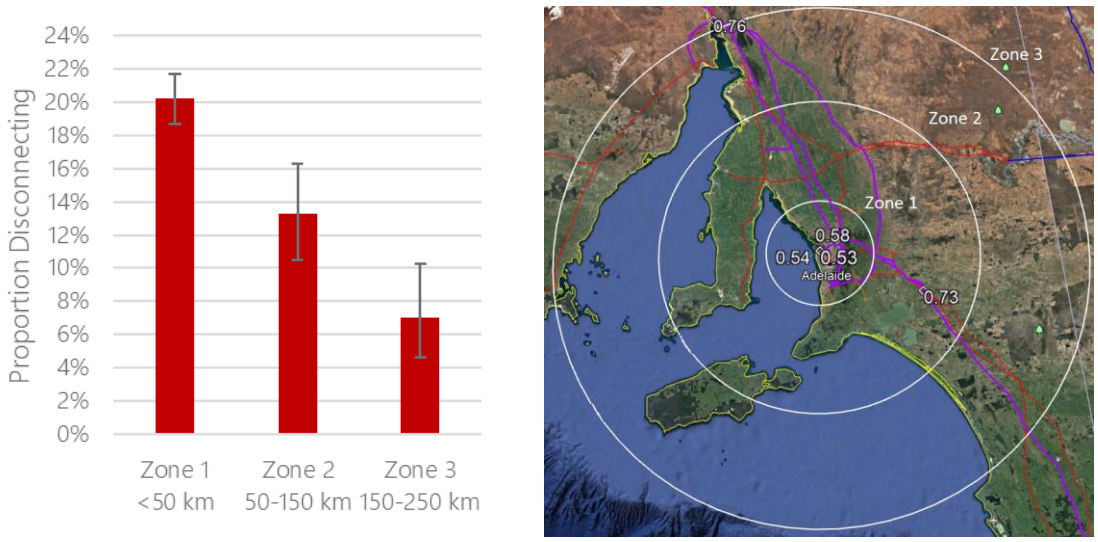
[31] Uncertainty ranges (shown in brackets) are based on the sample size, with a 95% confidence interval. The uncertainty range for systems under the 2005 standard is wider than the range for the 2015 systems due to the smaller sample size.

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

[33] 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 fewer than 30 systems represented in the sample were used to define the disconnection rate of the remaining installed capacity in South Australia.

Figure 8 shows that DPV disconnections were highest close to the fault location and reduced at more distant locations, as expected based on the high-speed voltage measurements recorded at each location.

Figure 8 Distributed PV disconnections by proximity to the fault (systems under the 2015 standard)



Map illustrates minimum recorded positive sequence per unit voltages in the 275kV network.

A3.1.1 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 VDRT requirement, in addition to the requirements specified in the 2015 standard (AS/NZS4777.2:2015). 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 previous 2015 standard.

There are a range of known reasons why inverters may disconnect, which are not covered by the SA VDRT standard. These include phase angle jumps, and Rate of Change of Frequency (RoCoF), and multiple faults in close succession. This means that severe disturbances, which often demonstrate these phenomena in addition to a voltage dip, can lead to unintended disconnection via maloperation of inverter protection systems. The 2020 standard (AS/NZS4777.2:2020[34]) 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 unintended disconnection may be occurring.

Observed behaviour

The Solar Analytics sample provided generation data for 132 DPV circuits at 67 unique sites that were installed in SA after 28 September 2020. Of these, 22 circuits at 14 unique sites were observed to reduce power to close to zero immediately following the voltage dips. Most of these sites remained at close to zero generation for approximately one minute, then ramped back up to close to pre-event 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 20% (12-31%) which is similar to the disconnection rate for inverters installed prior to the SA VDRT standard being introduced, suggesting the event may have also triggered other power system effects.

[34] 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.

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.

A3.2 Estimate of total distributed PV disconnection

DPV was estimated to be generating a total of 460 MW in South Australia immediately prior to the disturbance. At the time of the disturbance, the total installed capacity of DPV in South Australia is estimated to be 47% (640 MW) installed under the 2005 standard, 41% (558 MW) installed under the 2015 standard, 5% (68 MW) installed in the transitional period between standards, and 8% (106 MW) installed after 28 September 2020 under the SA VDRT test.

Based on weighting the disconnection rates outlined above for each category with the installed capacity for each, AEMO estimates that DPV reduced by approximately 70 MW following this disturbance due to unintended disconnection.

As outlined in Section 4, net load was observed to reduce by approximately 90 MW. The total loss of underlying load is therefore estimated at around 160 MW, partially offset by unintended disconnection of approximately 70 MW of DPV.

A3.3 Reconnection behaviour

The reconnection behaviour of DPV 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 eight DPV systems under the 2005 standard that disconnected. Most of these were observed to remain at close to zero generation for one to two minutes following disconnection, and then rapidly recommenced generation at close to pre-event 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, 458 systems were observed to disconnect. The aggregate normalised[35] generation profile from these systems is shown in Figure 9. The aggregate profile remained close to zero for approximately 1.5 minutes, then ramped up somewhat faster than the response trajectory specified in the 2015 standard (which requires a six-minute ramp rate limitation).

Analysis of individual reconnection profiles for inverters installed under the 2015 standard shows 14% of systems do not appear to be observing the six-minute ramp rate limitation, ramping at a sustained average ramp rate exceeding 50% of rated power per minute[36]. This is consistent with AEMO's findings in previous disturbances and suggests that some DPV inverters are not behaving consistently with the defined standards. AEMO is continuing collaboration with industry to assess possible causes of this behaviour, so it can be rectified.

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

[36] 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, and 2) previously, compliance had been assessed using mainly 60-second resolution data, and by taking the maximum ramp rate. However, compliance is now assessed also using 5-second resolution data, which does not contain the same degree of implicit averaging. To account for this and prevent the compliance status being affected by small fluctuation in the power output, the methodology has been adjusted to use the average ramp rate that was sustained by the inverter over the majority of the reconnection ramp.

Figure 9 Normalised aggregate generation profile for distributed PV systems under the 2015 standard that disconnected