AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

Maintaining operational demand in South Australia on 14 March 2021

November 2021

Reviewable Operating Incident Report under the National Electricity Rules

INCIDENT CLASSIFICATIONS

Classification	Detail
Time and date of Incident	1430 hrs on 14 March 2021
Region of incident	South Australia
Affected regions	South Australia
Event type	AEMO 4.8.9 instruction
Registered generation impact	Nil
Customer load impact	Nil
Associated reports	Nil

ABBREVIATIONS

Abbreviation	Term
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AEST	Australian Eastern Standard Time
APD	Alcoa Portland
ASEFS	Australian Solar Energy Forecasting System
AWEFS	Australian Wind Energy Forecasting System
BESS	Battery Energy Storage System
DPV	Distributed Photo-Voltaic
EVM	Enhanced Voltage management
FCAS	Frequency Control Ancillary Service
HYTS	Heywood Terminal Station
MLTS	Moorabool Terminal Station
MOPS	Mortlake Power Station
MW	Megawatt
NEM	National Electricity Market
NER	National Electricity Rules
PTP	Permission to Proceed
SCADA	Supervisory Control and Data Acquisition
TNSP	Transmission Network Service Provider
VDRT	Voltage Disturbance Ride-Through

KEY REPORT TERMS

Term	Explanation
[clause] 4.8.9 instruction	An instruction issued by AEMO to a registered participant under NER clause 4.8.9, other than in relation to scheduled plant or market generation. A clause 4.8.9 instruction can require a registered participant to do any act or thing if AEMO is satisfied that it is necessary to do so to maintain or re-establish the power system to a secure, satisfactory or reliable operating state. A registered participant must use reasonable endeavours to comply with a direction or clause 4.8.9 instruction.
Australian Solar Energy Forecasting System (ASEFS)	ASEFS is designed to produce solar generation forecasts for large solar power stations and small-scale DPV systems. The system includes two phases. ASEFS phase 1 (ASEFS1) involves forecast of solar generation for semi-scheduled solar farms, and any non-scheduled and unregistered solar farms that AEMO is required to model in network constraints for power system security reasons. ASEFS phase 2 (ASEFS2) provides forecasts of solar generation for DPV systems with capacity of less than 100 kW.
Australian Wind Energy Forecasting System (AWEFS)	AWEFS combines each semi-scheduled and non-scheduled wind farm's availability submission with the weather forecasts around the generating system location. From this information, generating system output is forecast. AEMO forecasts generation from all non-scheduled generation to determine what remaining demand needs to be met by scheduled and semi-scheduled generation.
Distributed photovoltaic (DPV)	This consists of distribution-connected PV installations, generating at less than 30 megawatts (MW) capacity and exempt from registration in the NEM (exempt generators). These generators cannot be dispatched by AEMO. AEMO uses data from the Distributed Energy Resources (DER) Register and the Clean Energy Regulator to monitor the size and location of new DPV installations. AEMO has access to a limited sample of actual DPV generation data from which expected DPV generation can be forecast.
Enhanced voltage management (EVM)	SA Power Networks, the electricity distributor in South Australia, uses EVM to regulate voltage levels throughout the year and, under normal circumstances, maximise the amount of energy that DPV systems can generate. When using EVM, SA Power Networks increases or decreases the voltage levels at key distribution zone substations (within safe limits). A side-benefit of EVM is that at certain higher voltage levels, a subset of DPV systems trip, disconnecting from the system. This method of disconnecting DPV can be used as a last resort when required to maintain system security.
Non-scheduled generators	Non-scheduled generating systems generally have an aggregate capacity between 5 MW and 30 MW and do not participate in the central dispatch process. Most generation less than 5 MW is not required to register with AEMO. In addition, in South Australia, there are also some wind generating systems that connected to the network prior to the introduction of the semi-scheduled generator classification. These are known as non-scheduled intermittent generating units, ranging in size between 35 MW and 91 MW, and have a total capacity of 389 MW in South Australia. The output of these wind generating systems is forecast using the Australian Wind Energy Forecasting System (AWEFS).
Operational demand	Operational demand in a region is demand that is met by local scheduled generating units, semi-scheduled generating units, non-scheduled intermittent generating units of aggregate capacity greater than or equal to 30 MW, and generation imports to the region. It excludes the demand met by non-scheduled non-intermittent generating units, non-scheduled intermittent generating units of aggregate capacity less than 30 MW, exempt generation[1], and demand of local scheduled loads. Because it excludes demand met by DPV, operational demand decreases as DPV generation increases.
SCADA controlled DPV	Larger DPV systems (with a capacity above approximately 200 kW) are required by SA Power Networks to be SCADA-controllable. These larger DPV systems can be turned off directly via SA Power Networks' SCADA system when necessary to maintain system security.
Scheduled demand	Scheduled demand in a region is demand that is met by local scheduled and semi-scheduled generation and by generation imports to the region. Scheduled demand differs from operational demand; it excludes the demand met by non-scheduled intermittent generating units of aggregate capacity greater than or equal to 30 MW, but includes the demand of local scheduled loads.

[1] Exempt generation refers to generation that is exempt from registration, under Chapter 2 of the NER and in accordance with the "Guide to NEM generator classification and exemption" issued by AEMO: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Participant_Information/New-Participants/Generator-Exemption-and-Classification-Guide.docx. Typically, this includes generation with a capacity less than 5 MW, or less than 30 MW provided it exports less than 20 GWh in any 12-month period.

Term	Explanation
Semi-scheduled generating systems	Since 2008, generating systems with intermittent output (such as wind or solar farms) with an aggregate name plate capacity of 30 MW or more are classified as semi-scheduled[2]. AEMO forecasts wind and solar generation and includes this in the dispatch process. AEMO can constrain semi-scheduled generation down if required for system security reasons. AEMO uses the technical properties of each semi-scheduled generating system together with real-time data to forecast the output of these systems for upcoming dispatch intervals.
Smarter Homes regulations	From 28 September 2020, DPV systems in South Australia must comply with the "smarter homes" regulations. These regulations mean customers installing or upgrading solar systems in South Australia are required to appoint a relevant agent who will be responsible for disconnecting and reconnecting the solar system during state electricity security emergencies. This capability was implemented by the South Australian Government to manage scenarios such as the one discussed in this report, where system security is at risk and the only means to mitigate this risk is via a last resort tool to actively manage DPV. When disconnection is required to maintain system security, SA Power Networks will contact the relevant agent(s) with a disconnection requirement. The relevant agents will then meet the requirement.
South Australia total generation contingency	In the context of this report, a South Australia total generation contingency is the total generation loss when a fault on the power system causes both: • The largest synchronous generating unit in South Australia to trip, and • an amount of DPV generation to trip (referred as DPV contingency which can occur due to a combination of the power system fault and prevailing system conditions).
Underlying demand	Underlying demand is actual customer electricity consumption met by local scheduled generating units, semi-scheduled generating units, non-scheduled intermittent generating units of aggregate capacity greater than or equal to 30 MW, generation imports to the region, and DPV.

[2] AEMO can also apply conditions on generators between 5 MW and 30 MW under NER clause 3.8.2(e)

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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Contents

1. Overview

This report relates to a 4.8.9 instruction issued to ElectraNet[3] on 14 March 2021 to maintain operational demand above a minimum threshold in South Australia. This resulted in SA Power Networks[4] coordinating the curtailment of 71 megawatts (MW) of distributed photovoltaic (DPV) systems. The event was significant because it was the first time AEMO had given a direction to maintain a minimum level of operational demand, resulting in DPV curtailment. Given the significance of the event and associated learnings, AEMO has prepared a reviewable operating incident report in accordance with clause 6(f) of the AEMC Reliability Panel Guidelines for identifying reviewable operating incidents[5].

On 14 March 2021, the power system was operating under the following conditions:

- The Moorabool to Mortlake (MOPS-MLTS) 500 kilovolt (kV) line in western Victoria was out of service due to a planned outage, undertaking work to install permanent replacements for the steel transmission towers that collapsed following a severe weather event in Victoria on 31 January 2020[6]. The MOPS-MLTS 500 kV line outage meant South Australia was at credible risk of synchronous separation from the rest of the NEM.
- AEMO operating advice requires operational demand to be maintained above a minimum demand threshold while South Australia is at credible risk of separation due to ensure:
    1. There is sufficient demand to maintain units online for system strength and interconnector flows within limits.
    2. System stability is maintained following a credible trip of a large generating unit and associated DPV disconnection.
- The Heywood interconnector transfer limit was reduced during the MOPS-MLTS 500 kV circuit planned outage.
- Actual operational demand was lower than the day-ahead and on-the-day forecasts due to several factors (outlined in Section 3.3.2).

The MOPS-MLTS 500 kV line restoration was commenced on 12 March 2021 and was expected to finish at 1730 hrs on 19 March 2021. Forecasts on 11 March 2021 and 12 March 2021 indicated that operational demand would remain above the minimum demand threshold throughout the duration of the outage. Therefore, at 0506 hrs on 12 March 2021, AEMO gave AusNet Services (AusNet)[7] permission to proceed (PTP) with the outage. During the outage, an event occurred at Torrens Island 275 kV substation, which is the subject of a separate incident report[8].

On 14 March 2021 at 1430 hrs, demand forecasts indicated that operational demand would fall below the minimum demand threshold of 400 MW. As such, at 1431 hrs, AEMO issued a 4.8.9 instruction to ElectraNet to maintain operational demand in South Australia above 400 MW, in order to maintain power system security.

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[3] ElectraNet is the transmission network service provider (TNSP) in South Australia.

[4] SA Power Networks is the electricity distributor in South Australia, delivering electricity from high voltage transmission network connection points operated by ElectraNet.

[5] See https://www.aemc.gov.au/sites/default/files/content/50c858eb-8f96-4164-bdad-ccf12b22827f/Final-revised-guidelines.pdf.

[6] See https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2020/final-report-vic-sa-separation-31-jan--2020.pdf?la=en.

[7] AusNet is the transmission network service provider (TNSP) in Victoria.

[8] See 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.

To comply with the 4.8.9 instruction, ElectraNet instructed SA Power Networks to maintain operational demand above 400 MW in South Australia. Over the duration of this event:

- SA Power Networks curtailed approximately 71 MW of DPV. This comprised:
  - 14 MW via Smarter Homes agents.
  - 17 MW directly through its SCADA control.
  - 40 MW using Enhanced Voltage Management (EVM).
- There was no loss of transmission or customer load.

On 14 March 2021, the 4.8.9 instruction and resulting DPV curtailment was the only action available to manage the low operational demand condition because:

- Recalling the planned outage of the MOPS-MLTS 500 kV line was not feasible due to the nature of the work being carried out on the circuit and the associated recall time,
- Curtailment of market non-scheduled wind farms in South Australia was not possible because the non-scheduled wind farms were not generating at the time, given negative market prices at the time[9].

This event is significant because it involved active management of consumer DPV. Under current market structures, this is recognised as a 'last resort' measure, to be considered only when other options to maintain power system security are not available or have been exhausted.

In this review, AEMO is assessing the adequacy of the provision and response of facilities and services, and the appropriateness of actions taken to restore or maintain power system security in connection with the event[10]. AEMO's review has concluded:

1. PTP was appropriately given on the morning of 12 March for the planned outage required for key circuit work on the MOPS-MLTS 500 kV line, given that forecasts on 11 March 2021 and 12 March 2021 indicated:
   - Operational demand in South Australia was forecast to remain above the minimum demand threshold for the duration of the outage.
   - The scheduled generators available for system strength throughout the outage were adequate.
2. Under-forecasting of DPV generation and over-forecasting of industrial load led to operational demand falling below forecast levels. In addition, variable cloud cover in South Australia made accurate forecasting of operational demand on 14 March 2021 challenging.
3. After AEMO issued the 4.8.9 instruction to ElectraNet to maintain operational demand above 400 MW at 1431 hrs on 14 March 2021, demand returned above 400 MW within 12 minutes.
4. SA Power Networks successfully delivered DPV curtailment and quickly returned operational demand above the minimum demand threshold, helping maintain power system security.
5. AEMO followed its operational procedures and took all the necessary actions to maintain power system security based on the information available.
6. AEMO has identified and implemented improvements to its operational procedures and tools since this incident. These changes, detailed in Section 6, are expected to:
   - Further minimise the likelihood of a DPV curtailment event.
   - Reduce the amount of DPV curtailment required.
   - Increase the likelihood of an instruction being issued with sufficient notice to efficiently curtail DPV.
   - Provide greater transparency to the market for any future similar incidents.
7. The power system remained in a secure operating state throughout this incident due to:

[9] Refer to an article published in WattClarity: https://wattclarity.com.au/other-resources/explanations/glossary/generators-avoiding-negative-prices/

[10] See NER clause 4.8.15(b).

- The timely and effective curtailment of DPV by SA Power Networks.
- The safety margin in the minimum demand threshold.
- More favourable power system conditions on the day than the range of possible conditions covered by the minimum demand threshold (detailed in Section 3.3.3).

Detail regarding these findings and improvements is contained in this report, along with recommendations to further improve its operational procedures and tools.

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, SA Power Networks, and AEMO.

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

2. 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 operating state as soon as practical following a contingency event in accordance with the NER[11].

In accordance with its power system security responsibilities, AEMO analysed power system operating scenarios under low load and high DPV generation conditions in South Australia, and determined that both scheduled demand and operational demand in South Australia must be maintained above a threshold which ensures:

- Sufficient demand to maintain units online for system strength and interconnector flows within limits.
- System stability is maintained following a credible trip of a large generating unit and associated DPV disconnection[12].

As of March 2021, the minimum demand level required when South Australia is at credible risk of separation was affected by several parameters:

- **System strength combination** – system strength must be maintained by one of several secure combinations of synchronous machines. Each combination results in a different minimum generation loading level[13].
- **Heywood interconnector limits –** Heywood interconnector limits are significantly reduced when South Australia is at credible risk of separation. This reduces the ability to export excess generation from South Australia to Victoria.
- **Heywood interconnector flow** – reduced flow from South Australia to Victoria over the Heywood interconnector reduces the size of the total generation contingency that can be managed without resulting in transient instability.
- **DPV contingency** – demand levels do not indicate the size of the DPV contingency, which is driven by high levels of DPV generation. For the same level of demand, a wide range of DPV generation could be online, depending on underlying demand.

[11] 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.

[12] See Appendix A1 for more information on DPV behaviour during power system disturbances.

[13] Refer to AEMO's Transfer Limits Advice – System Strength in South Australia and Victoria, at https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/congestion-information/transfer-limit-advice-system-strength.pdf. All synchronous generators have a minimum loading level. This is the minimum required generation level that each generator can operate stably. Demand levels must be sufficient to allow the generator to operate at or above this level.

- **Safety margin** – an operational safety margin to ensure the power system is not operating at the edge of the technical envelope.

At the time of the incident, AEMO was operating the South Australian power system based on a minimum demand threshold of 400 MW. This threshold was determined to ensure system security for a range of likely system conditions when South Australia was at credible risk of separation, based on the operational tools then available. AEMO has subsequently replaced this static minimum demand threshold with a dynamic demand threshold which more accurately reflects forecast conditions when South Australia is at credible risk of separation.

2.1 Procedure to maintain minimum demand

To reduce unnecessary DPV curtailment as much as possible while maintaining system security, AEMO's operating procedures at the time of the incident stated that:

- AEMO would not give PTP for any outage that left South Australia at credible risk of separation if forecast demand (both scheduled demand and operational demand) did not remain above the minimum demand threshold for the entire duration of the outage, subject to outage recall periods.
- AEMO would direct offline non-scheduled wind generation if actual scheduled demand fell below the minimum demand threshold while South Australia was at credible risk of separation.
- AEMO would instruct ElectraNet (and ElectraNet would instruct SA Power Networks)[14] to maintain operational demand above the minimum demand threshold if operational demand was forecast to fall below the minimum demand threshold within 90 minutes. At the time of the event, the trigger for AEMO's instruction was based on forecast operational demand due to the lead time required to efficiently curtail DPV.

3. The event

3.1 Pre-event conditions

On 31 January 2020, severe weather in Victoria caused several steel transmission towers to collapse on the MOPS-MLTS and Moorabool – Haunted Gully 500 kV circuits[15]. To return these circuits to service, temporary transmission towers were erected, and the circuits were transferred to temporary towers and returned to service on 3 March 2020. Ongoing works to repair the damaged transmission towers had been completed and a circuit outage was required to move the MOPS-MLTS 500 kV circuit from the temporary towers to the permanent structures. This required a planned high impact outage of the MOPS-MLTS 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. Due to the nature of the works being carried out, AusNet Services advised that this outage could not be recalled once work had commenced[16].

This planned outage meant that a credible fault on either the Alcoa Portland – Heywood – Moorabool (APD-HYTS-MOPS) 500 kV line or any transmission lines between Heywood – Tarrone – Haunted Gully – Moorabool 500 kV substations would result in synchronous separation between Victoria and South Australia.

[14] During load shedding events, it is standard practice for AEMO to instruct TNSPs, which then instruct DNSPs. This practice is maintained for DPV curtailment.

[15] See https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2020/final-report-vic-sa-separation-31-jan--2020.pdf?la=en.

[16] In other words, on 14 March 2021, the time to recall the outage would have been approximately 2.5 days to reverse works which commenced on 12 March 2021.

Prior to issuing PTP for this planned outage, AEMO performed several checks to confirm that, based on forecast conditions at the time, the power system was expected to remain secure for the entire duration of the outage.

One of those checks was that forecast operational demand in South Australia was above the minimum demand threshold of 400 MW for the duration of the planned outage. The demand forecasts completed on 11 March 2021 and 12 March 2021 before issuing PTP showed minimum operational demand was forecast to remain above 500 MW for the entire duration of the outage. This was based on forecast mild weather conditions with scattered cloud across South Australia consistent with DPV output around 880 MW (clear conditions can see DPV generation in South Australia reach approximately 1,200 MW).

3.2 The event

On 14 March 2021, the operational demand forecast completed at 0930 hrs indicated that the operational demand would fall below 400 MW at 1300 hrs, after 210 minutes which was not within 90 minutes.

On the same day, actual operational demand fell below 400 MW from approximately 1343 hrs and remained below 400 MW, but operational demand forecasts did not indicate this until 1430 hrs, for the period commencing at 1500 hrs. The forecast completed at 1430 hrs indicated that operational demand would fall below 400 MW at 1500 hrs[17]. One minute later, at 1431 hrs on 14 March 2021, AEMO issued a 4.8.9 instruction to ElectraNet to maintain operational demand above the minimum demand threshold of 400 MW.

At 1434 hrs, ElectraNet instructed SA Power Networks to maintain operational demand above 400 MW.

Over the duration of this event, SA Power Networks curtailed an estimated:

- 14 MW of DPV via Smarter Homes agents.
- 17 MW of DPV directly through SCADA control.
- 40 MW of DPV using EVM mechanism.

The operational demand increased from 370 MW at 1431 hrs to above 400 MW from 1443 hrs onwards, 12 minutes after AEMO issued the 4.8.9 instruction.

The actual operational demand recovered back to above 400 MW from around 1443 hrs, 12 minutes after the issue of the 4.8.9 Instruction.

The 4.8.9 instruction to ElectraNet was cancelled at 1555 hrs on 14 March 2021.

Table 1 presents the actual operational demand for key intervals on 14 March 2021. As shown, actual operational demand was below 400 MW from approximately 1343 hrs. Analysis of the operational demand forecasts are provided in Section 3.3.2.

3.3 Analysis

Analysis of this event is split into three sections:

- Section 3.3.1 outlines a timeline of events on 14 March 2021 and analyses the response to, and impact of the 4.8.9 Instruction.
- Section 3.3.2 analyses the demand forecasts and aggregated real-time data available to AEMO prior to the incident, and the timing of the 4.8.9 instruction.
- Section 3.3.3 discusses power system security.

3.3.1 Timeline of events and response to 4.8.9 instruction

Table 1 below provides a timeline of key events on 14 March 2021.

[17] Note that this is within 30 mins, as compared to the desired notification time of 90 mins noted in section 2.1 of this report.

Table 1 14 March 2021 timeline of events

Time	Actual operational demand in South Australia (MW)	AEMO	Network service provider actions
0730 hrs	1,089	The pre-dispatch forecast completed at 0730 hrs indicates scheduled demand would fall below the threshold at 1300 hrs.	-
0817 hrs	976	AEMO issues Market Notice 83319 advising that scheduled demand is forecast to fall below 400 MW.	-
0837 hrs	909	AEMO advises ElectraNet that scheduled demand is forecast to fall below 400 MW and that operational demand is close to falling below 400 MW.	-
0930 hrs	717	The pre-dispatch forecast completed at 0930 hrs indicates operational demand would fall below the threshold at 1300 hrs.	-
0939 hrs	710	AEMO informs ElectraNet that operational demand is forecast to fall below 400 MW, and an instruction to manage operational demand may be given.	-
1200 hrs	524	-	ElectraNet advises SA Power Networks that AEMO may issue an instruction to maintain operational demand above 400 MW.
1330 hrs	434	AEMO forecasts completed at 1330 hrs indicate that operational demand will reach a minimum of 456 MW at 1400 hrs before increasing above 480 MW by 1430 hrs.	-
1335 hrs	425	-	
1339 hrs	405	Actual operational demand falls to 398.5 MW but after a few seconds has increased above 400 MW. Actual operational demand moves between 397 MW and 406 MW until around 1343 hrs.	
1340 hrs	406	-	
1343 hrs	393	Actual operational demand falls below 400 MW and remains below 400 MW. AEMO's operational demand forecasts did not predict that operational demand would fall below 400 MW within 90 minutes until the forecast available at 1430 hrs.	
1345 hrs	385	First 5-minute dispatch interval where operational demand falls below 400 MW.	
1350 hrs	383	-	
1355hrs	374	-	
1400 hrs	365	AEMO forecasts completed at 1400 hrs indicate that operational demand will reach a minimum of 406 MW at 1430 hrs before increasing to above 470 MW by 1500 hrs. Whilst actual demand was below 400 MW, forecasts indicated that operational demand would not remain below the threshold in subsequent trading intervals.	-

Time	Actual operational demand in South Australia (MW)	AEMO	Network service provider actions
1405 hrs	347	-	
1410 hrs	363	-	
1415 hrs	349	-	
1420 hrs	350	-	ElectraNet advises SA Power Networks to prepare to curtail 10 - 20 MW of DPV. SA Power Networks curtails approximately 14 MW of DPV via Smarter Homes agents. Note SA Power Networks activated the following relevant agents during this incident: • SA Power Networks (acting in its capacity as a relevant agent) • Intellihub.
1425 hrs	363	-	
1430 hrs	372	AEMO forecasts completed at 1430 hrs indicate operational demand will reach a minimum of 389 MW at 1500 hrs. AEMO demand forecast alerts control room to low operational demand condition in the next dispatch interval (from 1500 hrs to 1530 hrs). AEMO instructs ElectraNet to maintain operational demand above 400 MW.	- -
1431 hrs	370	AEMO issues Participant Notice to ElectraNet. This is a clause 4.8.9 instruction to instruct ElectraNet and ElectraNet to instruct SA Power Networks to keep operational demand above 400 MW.	-
1434 hrs	370	-	ElectraNet instructs SA Power Networks to maintain operational demand above 400 MW.
1435 hrs	372	-	
14:38 hrs onwards	380	-	SA Power Networks curtails approximately 17 MW of DPV directly via SCADA control and a further 40 MW through EVM.
1440 hrs	375	-	
1443 hrs	403	Actual operational demand exceeds 400 MW and remains above 400 MW.	
1445 hrs	429	-	
1450 hrs	426	-	
1530 hrs	524	-	SA Power Networks deactivates EVM, operational demand is above 500 MW.
1555 hrs	600	AEMO issues Participant Notice to ElectraNet cancelling the 4.8.9 instruction to ElectraNet.	-

Time	Actual operational demand in South Australia (MW)	AEMO	Network service provider actions
1558 hrs	610	-	ElectraNet cancels instruction to SA Power Networks.
1615 hrs	675	-	SA Power Networks rescinds curtailment requirement for all DPV and Smarter Homes.
1645 hrs	825	-	All DPV is restored.

As shown in Table 1, AEMO issued the 4.8.9 instruction to ElectraNet at 1431 hrs to maintain operational demand above 400 MW. ElectraNet instructed SA Power Networks at 1434 hrs, three minutes later. SA Power Networks had successfully restored operational demand above 400 MW at 1443 hrs, nine minutes later.

SA Power Networks increased operational demand by curtailing DPV in the following order, with the Smarter Homes mechanism initiated prior to issue of AEMO's 4.8.9 instruction:

- 14 MW of DPV via Smarter Homes agents.
- 17 MW of DPV directly through SCADA control.
- 40 MW of DPV using EVM mechanism.

The DPV MW value curtailed via Smarter Homes was calculated based on nameplate capacity of DPV which was successfully disconnected as reported by Relevant Agents on the day. At present and based on further operational experience and as a reflection of the increased capacity of DPV on Smarter Homes, SA Power Networks derates the nameplate capacity by a factor of 0.73 to reflect the estimated DPV generation during minimum demand periods. To enable aggregate near real-time visibility of DPV at statistically valid samples, it is recommended to update Relevant Smarter Homes framework by the South Australian Government to require separation of new DPV connections by relevant agents at the meter.

To estimate the DPV MW value curtailed via EVM, SA Power Networks estimate DPV generation during minimum demand (nameplate capacity x 0.73) and then use estimated percentage of DPV disconnected (derived from field trials).

AEMO had collaborated closely with SA Power Networks in the months prior the incident and had advised SA Power Networks of the minimum demand threshold of 400 MW. AEMO had advised that an instruction to maintain operational demand above this threshold would be issued to prevent demand falling below 400 MW. On observing actual operational demand already below the secure demand threshold, SA Power Networks concluded that an instruction to manage operational demand would be imminent. Considering the lead time required to curtail DPV, SA Power Networks acted proactively to return operational demand above the minimum demand threshold and activated the Smarter Homes mechanism at approximately 1420 hrs, which was prior to AEMO's 4.8.9 instruction at 1431 hrs. Even though actual operational demand felt below the demand threshold, the power system remained secure as the demand threshold was a trigger to take actions to keep power system security. Refer to Section 3.3.3 which discusses power system security.

AEMO's procedures were intended to avoid operational demand falling below the minimum demand threshold. Due to the lead time required to efficiently curtail DPV, AEMO's instruction to manage operational demand was triggered based on forecast operational demand falling below the minimum demand threshold within a window of 90 minutes, corresponding to the latest time to intervene to deliver an efficient and coordinated DPV curtailment response. When the procedures were established, it was not anticipated that actual operational demand would fall and remain below the threshold without being forecast. This resulted in the 4.8.9 instruction being issued by AEMO later than the ideal time.

SA Power Networks' proactive action helped maintain power system security while demand was below the minimum demand threshold. AEMO has since updated its procedure and tools to include an instruction trigger based on real-time operational demand, in addition to forecast operational demand.

During the incident, SA Power Networks curtailed DPV in the following order:

1. Smarter Homes mechanism.
2. SCADA control of DPV systems equal to and greater than 200 kW.
3. EVM.

The Smarter Homes mechanism had not been utilised previously, meaning there was no operational experience to confirm its effectiveness or timeliness. SA Power Networks initiated this mechanism first, ensuring that the other mechanisms (of which there was more operational experience) could be used should the Smarter Homes mechanism not deliver the expected level of DPV curtailment. The Smarter Homes mechanism delivered DPV curtailment successfully.

SA Power Networks has advised that DPV will be curtailed in the following order when responding to future 4.8.9 instructions from AEMO:

1. SCADA control of DPV systems equal to and greater than 200 kW.
2. Smarter Homes mechanism.
3. EVM.

3.3.2 Demand forecasting and real-time demand during the event

AEMO carries out same-day operational demand and scheduled demand forecasts, which include forecasting of DPV every 30 minutes as part of its normal processes. The actions in AEMO's operational procedure (at the time of the incident) relating to these demand forecasts, and the actions taken during the incident are summarised in Table 2.

Table 2 AEMO actions relating to operational and scheduled demand forecasts

Condition	Action	Reason	On 14 March 2021
Forecast scheduled demand is below 400 MW	Issue Market Notice advising of potential need for AEMO to curtail non-scheduled wind generation and DPV.	Advises the market that AEMO action or intervention may be required.	• The pre-dispatch forecast completed at 0730 hrs indicates scheduled demand would fall below the threshold at 1300 hrs. • AEMO issued Market Notice 83319 at 0817 hrs.
Forecast operational demand is below 400 MW, in more than 90 minutes time	Advise ElectraNet (ElectraNet to advise SA Power Networks) that an instruction to manage operational demand may be given.	This indicates that the curtailment of non-scheduled wind could be insufficient to manage system security and that DPV curtailment may be required. This is advance notice allowing SA Power Networks to appropriately prepare for subsequent instructions.	• The pre-dispatch forecast completed at 0930 hrs indicates operational demand would fall below the threshold at 1300 hrs. • AEMO advises ElectraNet at 0939 hrs that an instruction to manage operational demand may be given.
Forecast operational demand is below 400 MW, within 90 minutes time	Instruct ElectraNet (ElectraNet to instruct SA Power Networks) to maintain operational demand above 400 MW.	Operational demand is forecast to fall below the minimum demand threshold within the lead time required to efficiently curtail DPV.	• The pre-dispatch forecast issued at 1430 hrs is the first forecast to indicate operational demand would fall below the threshold within 90 minutes (at 1500 hrs). • AEMO issues 4.8.9 instruction to ElectraNet at 1431 hrs.

Operational demand forecasts completed on 14 March 2021 are summarised in Table 3. On mild-sunny days such as 14 March 2021, the minimum level of demand forecast in South Australia is highly dependent on the expected level of DPV generation. On 14 March 2021, there was some scattered cloud expected across Adelaide throughout the day. Scattered cloud increases the uncertainty associated with DPV forecasts, as small movements or positional changes in the expected cloud cover can have a material impact of the DPV generation.

While operational demand had fallen below the minimum demand threshold by 1400 hrs, the forecast available at the time indicated that operational demand would not remain below the threshold in subsequent trading intervals, so a 4.8.9 instruction was not issued. The forecast issued at 1430 hrs was the first forecast to indicate operational demand would be below the minimum demand threshold within 90 minutes, and on that basis AEMO issued a 4.8.9 instruction to ElectraNet at 1431 hrs to maintain operational demand above the minimum demand threshold.

Table 3 Operational demand forecasts for South Australia from 14 March 2021

	Forecast available at (hrs)													Actual operational demand (MW)
Forecast for interval (hrs)*	0900	0930	1000	1030	1100	1130	1200	1230	1300	1330	1400	1430	1500	
1200	508	478	475	484	502	567								524
1230	460	435	432	432	451	514	524							495
1300	426	408	406	407	414	434	480	484						460
1330	407	**393**	**391**	**391**	**397**	400	440	482	466					434
1400	408	**397**	**396**	**397**	400	405	428	474	481	456				**365**
1430	447	438	436	437	439	443	461	493	505	483	406			**372**
1500	491	485	484	485	487	490	505	530	539	526	471	**389**		461
1530	552	548	548	549	550	552	563	583	588	578	562	482	491	524

* AEMO's forecast is run every 30 minutes.
In this table, values in **bold** are below the 14 March 2021 minimum demand threshold (400 MW). Yellow cells highlight the forecast demand interval at least 90 minutes after that particular forecast first became available (that is, for the forecast available at 1030 hrs, the demand intervals from 1200 hrs onwards are shown in yellow)

Post-incident analyses show that day ahead demand forecasts were over-forecasting for the following reasons:

- DPV output was under-forecast by around 150 MW; this is associated with the cloud expectations of global weather models that were revised on the morning of 14 March.
- Industrial loads in South Australia were under-forecast by around 45 MW. As these loads are not scheduled, intra-day variations at this magnitude are not unusual.
- Inputs to the forecast model (such as temporal forecast of temperature, humidity, and DPV output) varied between the time of forecast and actual time, which resulted in a further 90 MW of day-ahead forecast deviation.

Further, on the day of 14 March 2021, operational demand forecasts deviated from actual operational demand for the following reasons:

- Variable cloud cover over Adelaide caused a reduction in DPV generation output at around 1300 hrs. This cloud started to dissipate at around 1330 hrs, causing a fast increase in DPV output and a reduction in operational demand. This variable cloud cover is a typical challenge of DPV forecasting, which directly translates to the uncertainty associated with demand forecasting.
- The "forecast" produced by AEMO serves as a market signal that projects the most likely scenario of outcomes. Participants and asset owners can then decide how to respond to this market signal. Outcomes such as the level of demand or generation can quickly change after a forecast is produced, as a direct result of response to the forecast conditions.
- An example of this response occurred on 14 March 2021, when up to an estimated 60 MW of non-scheduled wind generation was switched off due to market prices. This caused a corresponding deviation in the scheduled demand forecast.
- Other embedded generation and price responsive load may have been switched in response to the low and negative prices in South Australia throughout the day, this generation and load switching is not visible to AEMO and as such materialises as forecast deviations.
- The causes and magnitude of the forecast deviations on 14 March 2021 are not unusual. They reflect the uncertainty that is associated with the forecasting of very high penetrations of DPV generation, particularly at times of low demand. In addition, very low demands such as experienced on 14 March 2021 are becoming increasingly difficult to forecast due to price-responsive load and embedded generation as low demand conditions are often occurring during negative pricing.
- The measured real-time five-minute operational demand from 14 March 2021 is shown in Table 1. This table shows that actual operational demand first dropped (and remained) below 400 MW from approximately 1343 hrs on 14 March 2021. The table also shows that operational demand remained below 400 MW in each dispatch interval between 1345 hrs and around 1440 hrs.
- A number of factors on 14 March 2021 made accurately forecasting operational demand challenging. AEMO has updated its procedures to better account for forecast uncertainty when managing low demand conditions. A continuous program of work is also ongoing to adapt and improve demand forecasting and DPV models, including:
  - A 'Nowcasting' trial in South Australia to investigate potential improvements to on-the-day forecasting[18].
  - Continued investigation into use of the Smarter Homes data to aid AEMO's operational visibility, and to increase visibility of DPV that may be required to be actively controlled to maintain power system security.

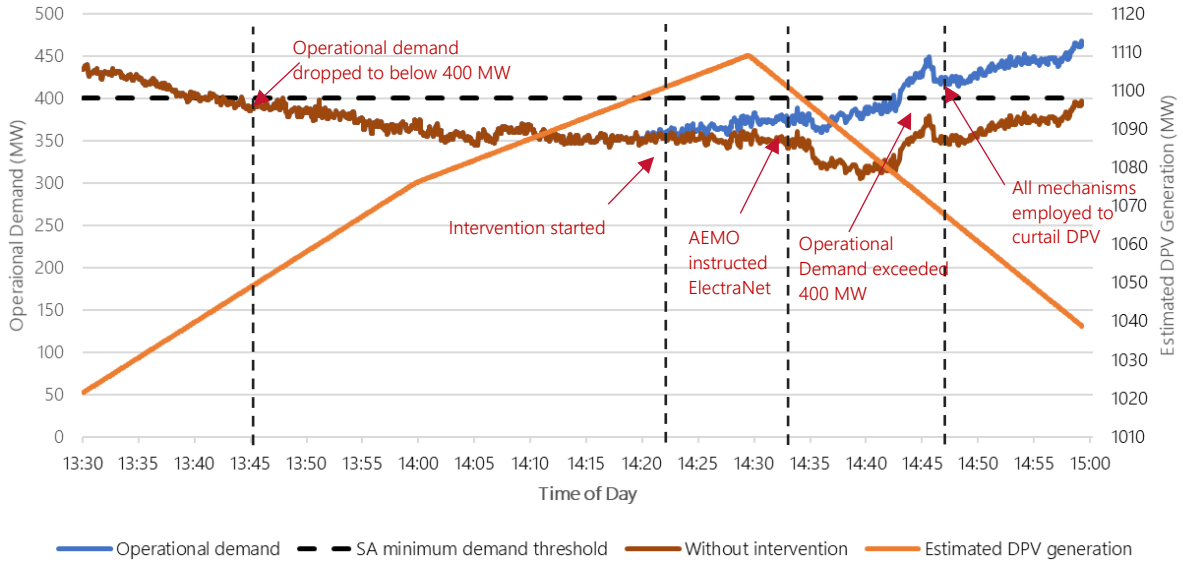
3.3.3 Power system security analysis

As Figure 1 shows, actual operational demand in South Australia fell below the minimum demand threshold of 400 MW from 1343 hrs to 1443 hrs. This demand drop coincided with an increase in DPV generation from around 1,030 MW to over 1,109 MW from 1330 hrs to 1430 hrs.

Estimated actual DPV peaked at around 1,109 MW at 1430 hrs. Around this time of peak DPV output, actual operational demand dropped to a low of 347 MW.

[18] For further information on the ARENA funded Nowcasting project, refer to: https://arena.gov.au/projects/gridded-renewables-nowcasting-demonstration-over-south-australia/.

Figure 1 14 March 2021 South Australia actual operational demand and estimated DPV generation



Post-incident analysis shows that when operational demand dropped below 400 MW, the power system was still in a secure operating state during this incident. The power system remained secure due to more favourable power system conditions on the day than the range of possible conditions that had been planned for in developing the minimum demand threshold:

- Heywood interconnector flow remained low and moved between small imports/exports to/from South Australia throughout this period.
- The South Australia synchronous generation combinations required to provide system strength at sufficient level remained online throughout the day.
- Underlying demand was estimated to be above 1,450 MW throughout the incident. This meant a sizeable amount of demand was expected to trip simultaneously should a (generation) contingency have occurred, reducing the net size of the contingency.
- The minimum demand threshold included a prudent safety margin to prevent the power system from operating at the edge of the technical envelope.
- AEMO issued the 4.8.9 instruction at 1431 hrs, and SA Power Networks started to respond within three minutes. This prevented operational demand falling further. Without intervention, it is estimated that South Australia demand would have fallen to around 300 MW, as shown in Figure 1.
- It should be noted that on 14 March 2021, AEMO did not yet have the operational tools to optimise the minimum demand threshold. The minimum demand threshold of 400 MW had been implemented to maintain power system security for a range of likely power system conditions while South Australia was at credible risk of separation. AEMO has since implemented a dynamic demand threshold for when South Australia is at credible risk of separation, which more accurately reflects forecast conditions.

3.4 Alternative options to maintain power system security

As discussed in Section 2, the minimum operational demand threshold ensures the following requirements are satisfied:

a. There is sufficient demand to operate synchronous generating units required for system strength and frequency response.

b. The maximum total generation contingency would not trigger the separation of South Australia from the rest of the NEM.

On 14 March 2021, DPV curtailment mechanisms were employed to increase operational demand and mitigate the system security risks associated with the low demand conditions. This was the only action available to manage the low operational demand condition, because:

- Recalling the planned outage of the MOPS-MLTS 500 kV line was not feasible due to the nature of the work being carried out on the circuit.
- Curtailment of non-scheduled wind farms in South Australia was not possible, because the non-scheduled wind farms were not generating at the time.

4. Market information

AEMO is required by the NER and operating procedures to inform the market about certain conditions or anticipated circumstances as they progress. AEMO generally does this by issuing market notices.

- For this incident, following the 0730 hrs pre-dispatch forecast of scheduled demand below the 400 MW threshold (with more than 90 minutes lead time), AEMO issued Market Notice 83319 at 0817 hrs on 14 March 2021. The notice informed participants that forecasts indicated there was insufficient scheduled demand to maintain a secure operating state in the South Australian region from 1300 hrs to 1430 hrs. It indicated the possibility that AEMO may need to issue directions or instructions to maintain power system security in South Australia, which could result in actions such as the curtailment of non-scheduled wind and DPV.
- No further market notices were issued before AEMO issued the 4.8.9 instruction to ElectraNet at 1431 hrs, one minute after the demand forecast completed at 1430 hrs indicated that forecast operational demand would fall below the 400 MW threshold at 1500 hrs. AEMO cancelled the 4.8.9 instruction by a further notice to ElectraNet at 1555 hrs on 14 March 2021[19].
- A clause 4.8.9 instruction is not an 'AEMO intervention event' under the NER, and there is no requirement for AEMO to inform the market of a foreseeable instruction that is unrelated to low reserve or lack of reserve conditions, or after an instruction has been issued.
- AEMO is, however, committed to providing greater transparency surrounding conditions involving the actual or potential curtailment of DPV.

5. Conclusions

AEMO has assessed its instruction to maintain operational demand, leading to the curtailment of DPV in South Australia on 14 March 2021, 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:

[19] The cancellation time is one hour after operational demand was forecast to exceed the minimum threshold demand. The buffer in the cancellation time is to insure against forecast uncertainty. A later cancellation time should not result in unnecessary DPV curtailment, as SA Power Networks can still satisfy the instruction and progressively wind back DPV curtailment before the cancellation time if demand increases.

1. PTP was appropriately given on the morning of 12 March for the planned outage required for key circuit work on the MOPS-MLTS 500 kV line given that forecasts on 11 March 2021 and 12 March 2021 indicated:
   - Operational demand in South Australia was forecast to remain above the minimum demand threshold for the duration of the outage.
   - The scheduled generators available for system strength throughout the outage were sufficient for requirements.
2. Under-forecasting of DPV generation and over-forecasting of industrial load led to operational demand falling below forecast levels. In addition, variable cloud cover in South Australia made accurate forecasting of operational demand on 14 March 2021 challenging.
3. After AEMO issued the NER Cl. 4.8.9 instruction to ElectraNet to maintain operational demand above 400 MW at 1431 hrs on 14 March 2021, demand returned above 400 MW within 12 minutes.
4. SA Power Networks successfully delivered DPV curtailment and quickly returned operational demand above the minimum demand threshold, helping maintain power system security.
5. AEMO followed its operational procedures and took all the necessary actions to maintain power system security based on the information available on 14 March 2021.
6. The power system remained in a secure operating state throughout this incident due to:
   - The timely and effective curtailment of DPV by SA Power Networks.
   - The safety margin in the minimum demand threshold.
   - More favourable power system conditions on the day than the range of possible conditions covered by the minimum demand threshold (detailed in Section 3.3.3).

6. Improvement actions and recommendations

This section summarises recommended actions which have either been implemented or are underway.

DPV curtailment

- AEMO recommends the South Australian Government consider update to the Smarter Home framework to require separation of new DPV connections at the meter to enable aggregate near real-time visibility of DPV at statistically valid samples.
- AEMO also recommends other governments consider how DPV curtailment will be managed in their networks during low operational demand conditions.

Minimum demand threshold

- AEMO has replaced the static 400 MW minimum demand threshold with a dynamic demand threshold calculated on forecast conditions in the pre-dispatch timeframe. This dynamic demand threshold manages both the risks of insufficient demand for minimum combinations of scheduled synchronous units and the DPV contingency exceeding secure limits. Depending on the forecast conditions, the dynamic demand threshold may be lower or higher than the previous threshold of 400 MW. It is expected to reduce unnecessary DPV curtailment while maintaining power system security in scenarios where a 400 MW threshold would not be sufficient.

- AEMO continues to improve understanding of DPV disconnection rates in South Australia. AEMO will use this improved understanding to inform future secure minimum demand level calculations and constraints.

Permission to proceed (PTP)

- AEMO has added a 100 MW forecast uncertainty buffer to the calculated minimum demand threshold required for planned outages to proceed. Forecast scheduled demand and forecast operational demand must remain above this new threshold for the entire duration of the planned outage for it to proceed (accounting for early recall times if applicable).
- AEMO has also added a requirement for forecast Australian Solar Energy Forecasting System (ASEFS) 2 generation to remain below a calculated threshold for the entire duration of a planned outage for it to proceed. This ASEFS2 threshold is the level at which the DPV contingency is forecast to exceed secure limits based on forecast conditions, and also includes a 100 MW forecast uncertainty buffer.
- These updates reduce the likelihood of South Australia operating at credible risk of separation while demand is below the minimum demand threshold, and therefore reduces the likelihood of DPV curtailment being required.

Forecast uncertainty

- AEMO has added a 100 MW forecast uncertainty buffer to the demand threshold to create an *instruction threshold*. AEMO will issue a 4.8.9 instruction to maintain demand above the minimum demand threshold if operational demand is forecast to fall below the instruction threshold within 90 minutes. This buffer does not increase the minimum demand threshold, but triggers the issue of an instruction at an earlier stage. In some cases, when demand is forecast to be very close to but remain above the minimum demand threshold, an instruction might be issued when it otherwise would not. However, this will allow for uncertainties in the forecast and provide sufficient time to allow SA Power Networks to be ready and able to immediately respond if operational demand approaches the minimum demand threshold and prevent it from being breached.

Monitoring of real-time operational demand

- AEMO has updated its procedures and monitoring systems to trigger an instruction to manage operational demand if real-time operational demand falls below the instruction threshold. This will prevent a situation in which real-time operational demand remains below the minimum demand threshold but an instruction is not issued because forecast operational demand remains above the instruction threshold.

Market communication

- AEMO has updated its market notice and operating framework. Following consultation with stakeholders, AEMO has implemented a new market notice and operating framework to keep the market better informed about DPV curtailment. This framework defines levels that will trigger market notices when the risk of DPV curtailment is forecast, when DPV curtailment occurs, and when an instruction to manage the low operational demand condition has been cancelled. The market notice framework is summarised below in Table 4. Refer to AEMO's website for more information[20].
- In addition, AEMO will report publicly on all future DPV curtailment events, and through reviewable operating incident reporting where required under NER 4.8.15.

[20] Refer to AEMO's new market signal to improve transparency and system security at: https://www.aemo.com.au/newsroom/media-release/aemos-new-market-signal-to-improve-transparency-and-system-security and factsheet at: https://www.aemo.com.au/-/media/files/electricity/nem/security_and_reliability/power_system_ops/consumer-fact-sheet.pdf.

Table 4 Market notice framework for low demand and DPV contingency events

Market notice	Description
Level 1	Indication that a risk of low demand and/or DPV contingency compromising power system security is forecast in the pre-dispatch horizon and AEMO action or intervention may be required in the absence of market response. At this stage, AEMO assesses available options to avoid or minimise DPV curtailment as much as possible, for example: • Recall of a planned outage of transmission equipment • Direction of registered generation A cancellation of a Level 1 notice will indicate that the forecast risk has been cleared in the forecast horizon without AEMO action or intervention.
Level 2	Confirmation that AEMO has taken or initiated action to manage power system security, for example by recalling outages or directing large-scale generation. An instruction to manage the low operational demand condition may subsequently be issued in the event that other response was unavailable or not sufficient to maintain power system security. A cancellation of a Level 2 notice will indicate that the action or intervention has been cancelled because the system security risk is no longer present.
Level 3	Confirmation that DPV curtailment is occurring to maintain power system security. A cancellation of a Level 3 notice will indicate that the instruction to manage DPV generation levels has been cancelled.

A1. Distributed PV behaviour

To assess distributed PV response to disturbances, AEMO analyses generation data procured from Solar Analytics[21] for a subset of individual distributed PV systems (<100 kilowatts [kW]) in South Australia. Data is provided at a mixture of five-second and 60-second measurement intervals. Systems are categorised based on when they were installed:

1. Systems installed prior to October 2015 were installed under AS/NZS4777.3:2005 ("the 2005 standard").
2. Systems installed after October 2016 were installed under AS/NZS4777.2:2015 ("the 2015 standard").
3. 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")[22] introduced by the Office of the Technical Regulator[23].

[21] 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.

[22] 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.

[23] 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.