Trip of Yallourn generating units 1, 3, 4 and four Macarthur Wind Farm collector groups on 11 April 2020

January 2021

An operating incident report for the National Electricity Market – information as at 13/1/2021

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.

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CONTACT

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

INCIDENT CLASSIFICATIONS

Classification	Detail
Time and date of incident	1326 hrs on 11 April 2020
Region of incident	Victoria
Affected regions	Victoria
Event type	Transmission equipment failure
Generation Impact	1021 MW
Customer Load Impact	No loss of customer load
Associated reports	Nil

ABBREVIATIONS

Abbreviation	Term
AEMO	Australian Energy Market Operator
AEST	Australian Eastern Standard Time
AGC	Automatic Generation Control
APD	Alcoa Portland
CB	Circuit breaker
DPV	Distributed photovoltaic
EA	Energy Australia
FCAS	Frequency control ancillary services
ID	Induced Draft
kV	Kilovolt
MASS	Market Ancillary Services Specification
MMS	Market Management System
Ms	Milliseconds
MW	Megawatt/s
NEM	National Electricity Market
NER	National Electricity Rules
RoCoF	Rate of Change of Frequency
TNSP	Transmission network service provider
VAC	Volts Alternating Current
VSD	Variable Speed Drive
YPS	Yallourn Power Station

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1. Overview

This report relates to a reviewable operating incident[1] that occurred on 11 April 2020 in the Victoria region where a single phase to ground fault at 13:26:41 hrs on 11 April 2020 resulted in the disconnection of three generating units at the Yallourn Power Station (YPS) and four collector groups at Macarthur Wind Farm.

This incident resulted in the loss of 1,021 megawatts (MW) of generation. This is above the maximum single generator contingency size of 750 MW and therefore insufficient frequency control ancillary services (FCAS) were enabled to cover the loss of this amount of generation.

- Yallourn Unit 3 tripped from 255 MW and 291 MW tripped from four Macarthur Wind Farm collector groups at the same time as the fault.
- Yallourn Units 1 and 4 ramped back by a further 475 MW combined over two minutes before disconnecting.

In addition to transmission generator disconnections, AEMO identified distributed photovoltaic (PV) reductions of approximately 70 MW, bringing the total equivalent contingency size to 1,091 MW.

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

This report is prepared in accordance with clause 4.8.15(c) of the National Electricity Rules (NER) and is based on information from Energy Australia (EA)[3], AGL Hydro Partnership[4], AusNet Services[5], and AEMO.

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

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

Table 1 Summary of conclusions

Finding	Actions recommended or underway
The single phase to ground fault was the result of severe weather dislodging a conductor, and all protection systems operated as expected to clear the fault.	No action required.
Following the event, multiple issues with the performance of Yallourn Power Station and Macarthur Wind Farm were identified by the respective asset owners. The issues were associated with incorrect protection settings.	Issues associated with Yallourn Units 1, 3 and 4 and Macarthur Wind Farm have been resolved.
The Frequency Operating Standard was met for this contingency event.	No action required.
Several generating units did not fully deliver their enabled FCAS requirements.	Corrective action has been implemented for the majority of these generating units. AEMO is continuing to follow up with the remaining generators to ensure future compliance.

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

[2] See NER clause 4.8.15(b).

[3] Energy Australia is the operator of the Yallourn Power Station.

[4] AGL Hydro Partnership is the operator of the Macarthur Wind Farm.

[5] AusNet Services is a transmission network service provider (TNSP) in Victoria and owner of the transmission network at Yallourn.

Finding	Actions recommended or underway
Information initially provided by Yallourn station operator EA was that further multiple unit trips were not credible. That led AEMO not to reclassify loss of multiple units as a credible event initially.	This event has highlighted that greater scrutiny is required when determining reclassification decisions. AEMO will review reclassification processes accordingly. Generators should also apply a high level of diligence when providing information on the performance of generating units.
The event highlights the need for power station protection settings to be configured to ensure that auxiliary systems which are critical to operation of the station do not inadvertently operate due to faults which the generating system is required to ride through.	Generators need to ensure there are adequate processes in place to ensure new/replacement equipment is appropriately set and tested against the agreed performance standards.

2. Incident

On 11 April 2020, a severe weather warning was issued for southern Victoria, and the Latrobe Valley experienced strong winds with recorded gusts of up to 91 km/h.

At 13:26:41 hrs, there was a blue phase to earth fault and trip of the 220 kilovolt (kV)/6.6 kV Auxiliary Transformer A and the associated 220 kV transmission line at YPS. The line is only approximately 1 km long, and due to the close-in nature of the fault, it caused a large voltage disturbance at Yallourn on the faulted phase. The fault was successfully cleared by primary protection.

Immediately following the fault, Unit 3 at YPS tripped its 220 kV circuit breakers (CBs) YPS/37 & YPS/38 on negative sequence protection. This resulted in the loss of 255 MW of generation. The generating unit continued to operate and supply power station auxiliary loads of approximately 18 MW before the unit operator tripped the turbine four minutes later.

The fault also resulted in protection operations on Units 1 and 4 at YPS. At 13:26:42 hrs, the Unit 1 Induced Draft (ID) fan[6] No. 2 6.6 kV CB tripped on overload protection. The ID fan trip caused the boiler to trip (master fuel trip), which resulted in the unit ramping down from 236 MW over 1-2 minutes[7] before the unit operator tripped the unit to prevent damage.

Unit 4 at Yallourn ramped down from 239 MW due to the Mill Oil Pump Variable Speed Drive (VSD) tripping at 13:26:45 hrs. With the coupling oil pumps tripped, the mill speeds reduced, and the mills tripped on under-speed resulting in the boiler being shut down. As a result of the boiler shutting down, the turbine control valves closed as expected, then the turbine tripped. After unloading, generator 220 kV CBs YPS/40 tripped as expected, due to reverse power.

Yallourn Unit 1 returned to service at 21:27 hrs, approximately eight hours after the event. The other two units, Unit 3 and Unit 4, returned to service at 12:59 hrs and 04:57 hrs respectively the next day, 12 April 2020.

The loss of generation at Yallourn and associated system frequency disturbance resulted in the trip of collector groups 1, 2, 5 and 6 at Macarthur Wind Farm due to Rate of Change of Frequency (RoCoF) protection. The four collector groups tripped at approximately the same time as Unit 3 at Yallourn and resulted in a further loss of 291 MW of generation.

Approximately 20 minutes after the event, at 13:46 hrs, Macarthur Wind Farm indicated it was able to come back online and AEMO gave permission to proceed to return the four collector groups to service as per

[6] The ID fan is a critical component required to maintain (negative) pressure in the boiler system.

[7] By design, to prevent sudden changes in boiler pressure which can cause operation of boiler steam safety valves or damage.

standard procedure. At 20:45 hrs, after further advice by Macarthur Wind Farm into the cause of the trip (a firmware RoCoF calculation error) and a proposed solution, AEMO advised AGL Hydro Partnership that the four collector groups should be removed from service until the reason for the trip was corrected.

3. Investigation

The below is based on information provided by AusNet Services, EA, and AGL Hydro Partnership.

3.1 Initiating fault

At 13:26:41 hrs, a conductor dislodged due to a failed blue phase insulator bridging clamp on the 220 kV transmission line supplying the 220 kV/6.6 kV Auxiliary Transformer A at YPS, resulting in blue phase to earth fault and trip of the line. The line is only approximately 1 km long and due to the close-in nature of the fault, it caused a large voltage disturbance at Yallourn Power Station (to approximately 0.13 pu as recorded in the Yallourn 220 kV yard on the faulted phase). The fault was successfully cleared by the primary protection.

After the event, AusNet Services inspected all the bridging clamps on the tower and no other clamp was found to have failed, however all were replaced as a precaution. In addition, an audit on the remaining 220 kV towers at Yallourn carrying all generator circuits and 220 kV auxiliary transformer circuits was completed. Subsequently, a small number of bridging clamps were changed, although none had failed.

Following the event, non-compliance notices were issued for the three YPS units that tripped and Macarthur Wind Farm. Investigations into the cause were initiated by EA and AGL Hydro Partnership, as detailed below.

3.2 Macarthur Wind Farm

AGL Hydro Partnership's investigation into the trip of collector groups 1, 2, 5 and 6 revealed that there was a firmware error in the calculation of the RoCoF element in a specific model of protection relay that will trip the wind farm for fast frequency excursions. The phase shift associated with the fault resulted in a spurious frequency measurement, and the error in the RoCoF element caused this model of protection relay to operate. This calculation error in the protection relay is common to all collector groups Y protection relays, and if the voltage waveform as a result of the fault was slightly different it is feasible that all collector groups could have tripped.

The proposed solution to this issue was bench-tested and subsequently implemented on all collector group relays at the wind farm. A report was issued to AEMO demonstrating the root cause of the protection operation was eliminated.

The four collector groups returned to service on 17 April 2020.

3.3 Yallourn Power Station

3.3.1 Yallourn Unit 1

EA's investigation determined that the Unit 1 ID fan No. 2 on Auxiliary Board 5A tripped on electrical protection co-incident with the fault on the line supplying auxiliary transformer A. The event record from the auxiliary transformer overload relay showed that the ID fan motor contributed to the fault current and caused the motor protection to operate. The exact cause of the motor protection operation is unknown, as the relay was reset before the indication was recorded.

Subsequent testing on Unit 1 identified that the instantaneous overload setting on the ID fan motor protection relay was set too low or drifted. EA has stated that this has now been corrected by installing a new motor protection relay and a directional over current relay, that enable enhanced protection functions and event capture to assist in future investigations. After reviewing the test reports, AEMO is satisfied that the new relays have rectified the premature operation of motor overload protection and Unit 1 has now returned to service.

3.3.2 Yallourn Unit 3

EA's investigation determined that the fault on the 220 kV transmission line supplying the auxiliary transformer resulted in the negative sequence protection operating in response to the single-phase (unbalanced) fault. Since the transmission line fault was cleared in approximately 52 milliseconds (ms)[8] and the fault was in the protection zone for this generating unit, the protection should not have operated.

EA engaged a consultant to review the protection operation. This review revealed that the original electromechanical negative phase sequence protection relay had been replaced with a more modern electronic relay and there was an error in the transfer of the settings. Due to the differences in how the relays calculate the magnitude of the negative phase sequence imbalance, the settings as installed in the old relay were inappropriate for the newer relay.

Following the review and testing of proposed settings, the corrected settings were installed in the negative phase sequence relay and tested with secondary injection. A report was provided to AEMO outlining the investigation and subsequent rectification of the identified issues.

3.3.3 Yallourn Unit 4

EA's investigation determined that the investigation into the cause of the Mill Coupling Oil Pumps (MCOPs) VSDs tripping revealed that a voltage deviation in the 415 volt (V) unit boards due to the blue phase to earth fault resulted in the undervoltage protection operating and tripping the drive.

The Stage 2 MCOPs all have a Type A VSD, except for one MCOP, which has a Type B VSD. As the Type B models reach end of life, they are replaced with the Type A models. At the time a new VSD is installed, a number of parameters are changed from default, including a suite of parameters that pertain to power loss. Upon investigation, none of the power loss parameters had been changed from the default settings in the Type A VSDs. These default settings mean that if the supply voltage drops below 300 Volts Alternating Current (VAC) phase to phase, the VSD faults and will need to be reset and a run command must be toggled prior to returning to service.

The default 300 V bus undervoltage setting was modified to 250 V, the line loss setting was disabled and a suite of bench tests were conducted to verify the correct operation. A number of in-service tests were also conducted in a controlled manner to verify the new settings. These tests were carried out with the coupling oil pump attached and each mill running to confirm the VSD remains in operation and continues to run the mill group for a 415 VAC voltage deviation.

The new undervoltage settings were verified to prevent unwanted tripping of the MCOPs VSDs and a report was provided to AEMO detailing the investigation and resolution. Unit 3 also uses the same type of VSD for some MCOPs; it is reasonable to expect that if it had not tripped on Negative Sequence Protection, it would also have tripped due to the VSD settings. For this reason, the settings on the Unit 3 VSDs were also modified and tested to prevent this occurring again. Units 1 and 2 have a different arrangement of MCOP VSDs and EA do not deem them to be susceptible to the same problem.

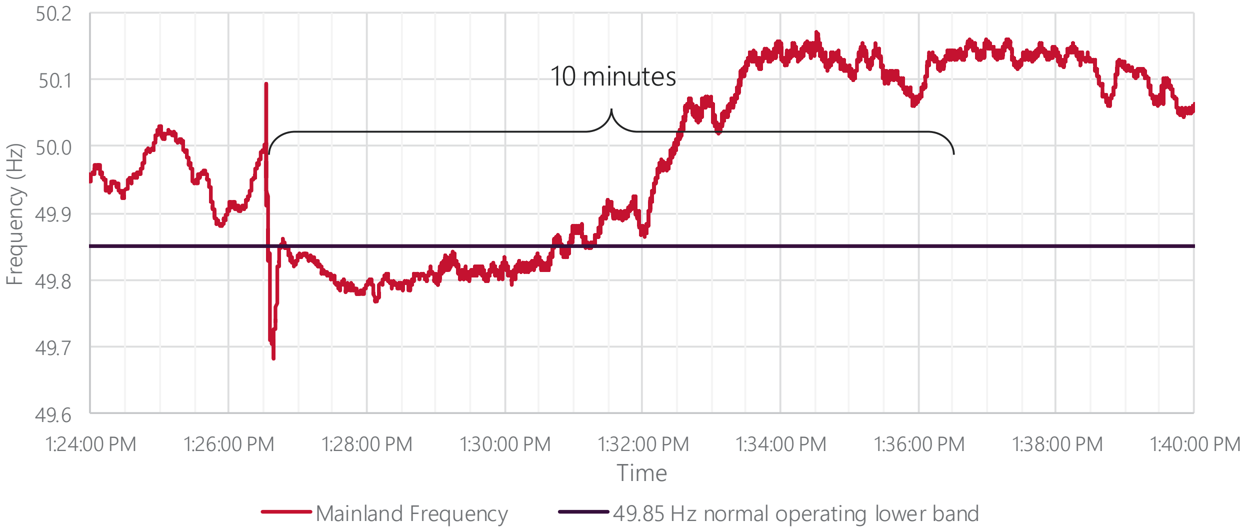
[8] The fault clearance time was within the operating time required by NER clause S5.1a.8.

4. Frequency response

As shown in Figure 1, there was a frequency excursion upon the trip of Yallourn unit 3 and Macarthur Wind Farm collector groups. These excursions remained within acceptable limits. The Frequency Operating Standard (which states that for a multiple contingency event the frequency must be contained within 47 hertz (Hz) to 52 Hz, stabilise to within 49.5 to 50.5 Hz and recover to within 49.85 to 50.15 Hz within 10 minutes) was met for the event.

Due to the unloading of Yallourn unit 1 and unit 4 before they tripped, the frequency nadir was not as low as would be expected had all 1,091 MW of generation tripped at the same time.

Figure 1 Mainland frequency during event



4.1 Delivery of frequency control ancillary services

4.1.1 FCAS analysis

AEMO reviewed the delivery of FCAS in accordance with the Market Ancillary Service Specification (MASS)[9], in response to the frequency reduction after the fault.

Table 2 shows the amount of FCAS enabled in the NEM for the dispatch interval ending 13:25 hrs on 11 April 2020, that is, just prior to the event.

[9] The current MASS is at https://www.aemo.com.au/energy-systems/electricity/national-electricity-market-nem/system-operations/ancillary-services/market-ancillary-services-specification-and-fcas-verification-tool.

Table 2 Total FCAS enablement

Service	Enabled (MW)
Fast raise	584
Slow raise	584
Delayed raise	464
Fast lower	273
Slow lower	353
Delayed lower	242

Table 3 shows the enablement and delivery of contingency raise FCAS for the dispatch interval ending 13:25 hrs on 11 April 2020[10]. It shows that a small number of generating units did not deliver the full enabled service. This is discussed further in Section 4.1.2. While some generating units did not fully deliver their enabled FCAS, the total amount of raise services delivered exceeded the amount enabled, which assisted with frequency recovery.

Table 3 Raise FCAS performance

Generating unit	Fast raise enablement	Fast raise delivered	Slow raise enablement	Slow raise delivered	Delayed raise enablement	Delayed raise delivered
Alcoa Portland (APD)	23	19.2	40	111.1	65	93
Enel X aggregated interruptible load (NSW)	31	29.8	18	48.7	14	24.8
Enel X aggregated interruptible load (QLD)	14	16.2	7	22.1	8	10.8
Enel X aggregated interruptible load (SA)	0	N/A	1	*	0	N/A
Hydro Tasmania Aggregated Load	39	^	0	N/A	0	N/A
Ballarat Battery (Gen)	10	10	25	25	20	20
Bayswater 1	10	54.5	10	44.5	5	9.1
Bayswater 2	10	38.8	10	-39.3	5	-0.6
Bayswater 3	10	74.2	10	17.5	5	5.8
Callide B2	23	33.9	35	51.6	0	N/A
Dalrymple North Battery (Gen)	30	30	30	30	30	30
Eraring 1	20	34.5	26	109.4	0	N/A
Eraring 2	6	34.3	0	N/A	0	N/A

[10] Table 3 only includes generating units enabled to provide at least one of the contingency raise FCAS. Other generating units not enabled for FCAS may also have responded to the frequency change.

Generating unit	Fast raise enablement	Fast raise delivered	Slow raise enablement	Slow raise delivered	Delayed raise enablement	Delayed raise delivered
Eraring 3	20	34.3	10.5	108.4	0	N/A
Gordon	35	^	85.9	^	41	^
Gladstone 2	5	80.6	5	85	0	N/A
Gladstone 3	5	69.2	5	80.6	0	N/A
Gladstone 4	5	62.2	5	89.9	0	N/A
Gladstone 5	5	79.1	5	80.4	0	N/A
Gladstone 6	5	50.8	5	74.9	0	N/A
Hornsdale Power Reserve	63	63	19	19	41	41
Lake Bonney Battery	15	15	4	4	10	10
Liddell 3	10	80.7	10	47.7	0	N/A
Liddell 4	10	55.4	10	31.8	0	N/A
Loy Yang B1	13	81.3	23	120	7	43.8
Loy Yang B2	8	76.3	15	96.7	7	35.4
Loy Yang A1	20	25.8	20	59.5	20	39.7
Loy Yang A2	20	90.5	20	112.1	20	52.1
Loy Yang A4	20	41	20	45.8	20	33.4
Mackay Gas Turbine	0	N/A	0	N/A	13	7.6
Poatina 220	0	N/A	7	^	0	N/A
Wivenhoe Pump 2	0	N/A	0	N/A	83	367
Snowy Hydro Jindabyne Pump	50	51.6	70	66.2	35	33.0
Stanwell 1	5	16.4	5	11.4	0	N/A
Tarong 1	10	-3.2	5	-2.2	0	N/A
Tarong 2	10	-3.1	5	0	5	^
Enel X aggregated interruptible load (VIC)	22	28.5	16	46.8	8	28.5
Energy Locals VPP (SA)	2	3.5	2	3.5	2	3.5
Totals	584	1371	584	1598	464	884

^ Switched provider that was not triggered.
* No assessment completed for 1 MW.

4.1.2 Frequency control ancillary services performance

Fast FCAS response from Alcoa Portland (APD) was limited due to an unusual configuration of its switchyard due to the ongoing recovery of the APD potlines after the major system events on 16 November 2019 and

31 January 2020. In future, FCAS offers from APD will be recalibrated during potline outages to ensure this issue does not re-occur.

At the time of the frequency event, Bayswater 2 was reducing generation in order to follow its Automatic Generation Control (AGC) setpoint. AGL has informed AEMO that following an adequate R6 response, Bayswater 2 resumed responding to its AGC setpoint rather than the system frequency as would be expected of an R60 provider. Bayswater 2 ceased offering FCAS while investigations took place. The investigation resulted in a setting change to the governing system and as a result, AEMO is satisfied that it may resume bidding into the FCAS market.

The Mackay Gas Turbine begins a start-up sequence when triggered on under-frequency to deliver R5. The time required to synchronise is variable and, on this occasion, synchronisation took longer than expected. Previous events have shown that the turbine has been able to meet and exceed its enablement. This is understood to be a variable factor in normal operation of the turbine and not due to any incorrect settings.

The Snowy Hydro Jindabyne Pumps were importing 67 MW (approximately 33.5 MW on each pump) immediately prior to the power system incident. Each of the two pumps is rated at 35 MW and can normally deliver up to 70 MW of slow raise FCAS by tripping the pump. A 35 MW pump can deliver 70 MW of the slow raise service because twice the time average of the raise response is used when calculating the amount of slow raise FCAS that is delivered. At the time of the incident, Snowy Hydro had bid 70 MW of slow raise FCAS as available across the Jindabyne pumps, on the basis that tripping one pump would deliver the required service. However, each pump was only operating at approximately 33.5 MW at the time of the incident, resulting in the under-delivery of the service. Snowy Hydro has subsequently revised its FCAS bids in relation to the Jindabyne pumps.

FCAS delivery from Tarong 1 and Tarong 2 is partly dependent on the number of mills in operation. At the time of the event, a configuration in the control system caused a misalignment between the offer trapezium and the control system trapezium. Although the FCAS offer was able to be physically delivered for the number of mills in operation at the time, the control system configuration prevented the units from doing so. This configuration has been corrected.

A number of units significantly over-delivered FCAS, which averted possible load shedding that could have resulted from this event. As seen in Table 2, only 580 MW of fast raise FCAS was dispatched, which is much less than the total equivalent contingency size of 1,091 MW including the distributed PV response. The total fast raise delivered by FCAS enabled generators was 1,371 MW, which assisted in arresting the frequency decline and resulted in a frequency nadir of only 49.68 Hz.

5. Power system security

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

The power system was in a secure operating state throughout this incident. No action was required by AEMO to restore or maintain power system security.

5.1 Reclassification

AEMO issued Market Notice 75304 at 14:07 hrs on 11 April 2020, 41 minutes after the event, to advise of the non-credible contingency event. Based on the investigation by EA, AEMO issued an update to the initial market notice on 12 April at 13:39 hrs, stating AEMO was satisfied that the event was unlikely to reoccur under the current circumstances and therefore did not reclassify this event as a credible contingency event.

After further investigation and analysis by EA and AEMO, it was identified that there was a credible risk of losing the three Yallourn units (1, 3 and 4) simultaneously for a phase to earth fault close to the station auxiliary transformer. The simultaneous loss of Yallourn W1, W3 and W4 generating units was declared credible at 19:00 hrs on 3 July 2020 and the constraint set V-YWPS_134_N-2 was invoked.

On 13 July 2020, AEMO issued an update to the previous market notice to advise that the issue affecting unit 4 at YPS had been rectified. A new market notice was issued to cover the credible simultaneous loss of units 1 and 3 at YPS.

On 4 August 2020, AEMO issued an update to the previous market notice to advise that the issue affecting unit 3 at YPS was rectified.

5.2 Distributed PV behaviour

Distributed PV[11] generation is now a significant component of the power system, and as such its aggregated behaviour can affect outcomes during system incidents. AEMO has traditionally had limited visibility of distributed PV behaviour.

The fault on the line supplying the auxiliary transformer resulted in a large voltage dip which propagated throughout the network. This may cause distributed PV generation to trip or reduce output in response to the magnitude and location of the voltage disturbance. The extent to which this incident affected the distributed PV is detailed in Appendix A1.

The analysis showed that distributed PV in both Victoria and South Australia reduced output by approximately 4%, which resulted in an increase in the contingency size of 70 MW. This is minor compared to the other generation shed by the event, and the over-delivery of the FCAS response meant that this did not impact whether load shedding was to occur or not.

6. Market advice

For this incident, AEMO informed the market on the following matters in accordance with the following requirements:

1. A non-credible contingency event – notify within two hours of the event.
   - AEMO issued Market Notice 75304 at 14:07 hrs on 11 April 2020, 41 minutes after the event, to advise of the non-credible contingency event.
2. Reclassification, details, and cancellation of a non-credible contingency – notify as soon as practical.
   - Market Notice 75327 was issued on 12 April 2020, stating that AEMO was satisfied that another occurrence of this event was unlikely under the current circumstances.
   - AEMO issued Market Notice 76173 at 19:00 hrs on 3 July 2020, declaring the simultaneous loss of Yallourn W1, W3 and W4 generating units as credible.
   - AEMO issued Market Notice 76289 and 76290 on 13 July 2020, to advise that the issue affecting unit 4 at YPS was rectified and therefore the previous reclassification was revoked (76290). The simultaneous loss of units 1 and 3 at Yallourn however was still credible.

[11] Distributed PV refers to any PV system connected to the distribution network. This includes rooftop PV, as well as small solar farms and commercial PV systems on buildings.

– AEMO issued Market Notice 76535 on 4 August 2020, to advise that the issue affecting unit 3 at YPS was rectified and therefore the previous reclassification was revoked (76289).

Further details of the market notices can be obtained from the AEMO website[12].

7. Conclusion

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

AEMO has concluded that:

1. The single phase to ground fault was the result of severe weather dislodging a conductor, and all protection systems operated as expected to clear the fault.
2. The event highlighted a number of issues with the performance of YPS and Macarthur Wind Farm due to errors in protection settings.
3. All non-compliances have now been rectified.
4. The Frequency Operating Standard was met for this event, due to the frequency response of a number of stations which supported frequency recovery.
5. The power system remained in a secure operating state throughout this incident.

[12] See https://www.aemo.com.au/Market-Notices.

A1. Distributed PV behaviour

Just prior to the incident, distributed PV was contributing an estimated 5.0 gigawatts (GW) of generation in the mainland NEM. The analysis below explores the behaviour of distributed PV in response to the non-credible contingency trip at 13:26 hrs.

Solar Analytics[13] provided AEMO with data from approximately 13,000 individual distributed PV systems in the NEM under a joint Australian Renewable Energy Agency (ARENA) funded project[14], with anonymisation to ensure system owners and addresses could not be identified. Due to a small sample size, Tasmania has been excluded from this analysis.

Figure 2 shows the minimum voltages measured across the Victorian transmission network at the time of the event, as context for interpreting distributed PV responses. The locations of YPS and Macarthur Wind Farm are indicated (Event location). The zones indicated in red and white concentric circles were used to analyse distributed PV responses by proximity to the fault that occurred at YPS.

Figure 2 Minimum voltages recorded (pu minimum on a single phase) at the time of fault (13:26 hrs)

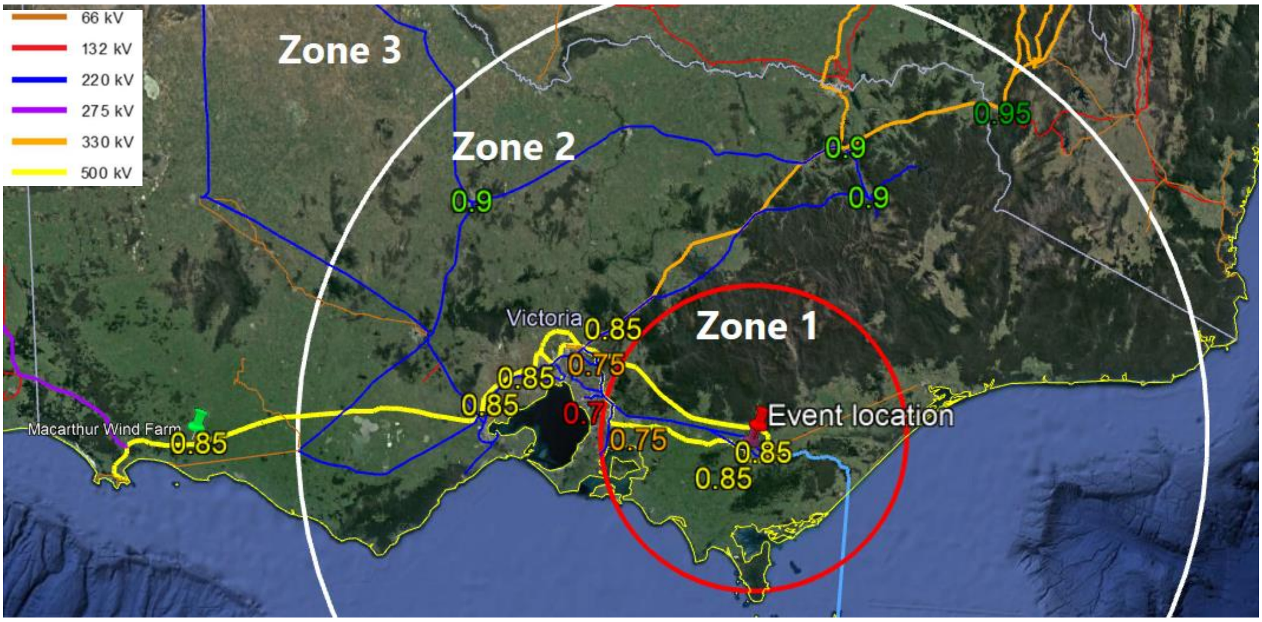


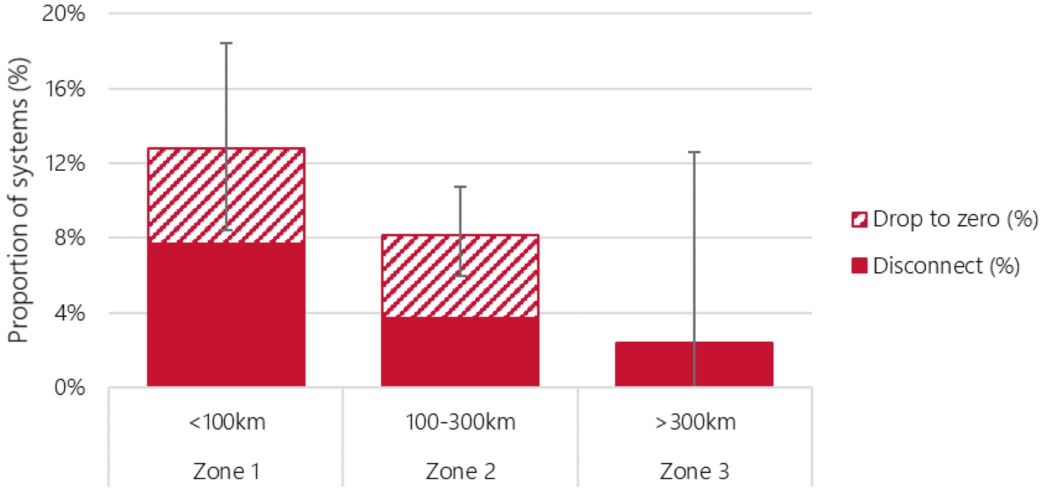
Figure 3 shows the disconnection of distributed PV observed in each of the zones illustrated in Figure 2.

A higher disconnection rate is observed closer to the event location, consistent with the depth and geographic extent of voltage measurements recorded. Minimal distributed PV disconnections were observed in locations further than 300 km from the separation location (where there was minimal voltage disturbance), suggesting that the primary cause of distributed PV disconnections in this area was the voltage disturbance.

[13] 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.

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

Figure 3 Distributed PV disconnections in Victoria by distance from Yallourn Power Station



Uncertainty estimates are based on sample sizes and observed number of disconnections, calculated at a 95% confidence level.

Table 4 summarises the behaviour of distributed PV in response to the disturbance, with observations as follows:

- Distributed PV generation in Victoria reduced by approximately 34 MW (4%). This is thought to be primarily in response to the voltage disturbance in Victoria, as discussed above. Transmission voltages reached a minimum of 0.7 pu east of Melbourne at Rowville Terminal Station (measured on a single phase). Laboratory bench testing has shown that many inverters disconnect in response to voltage disturbances[15]. AEMO worked with stakeholders to improve disturbance ride-through behaviour through changes to AS/NZS4777.2:2015 (the 2015 standard) which resulted in the updated standard AS/NZS4777.2:2020 (the 2020 standard)[16].
- Minimal distributed PV disconnections were observed in New South Wales and Queensland. In these regions there was no observed voltage disturbance, and frequency reached a minimum of 49.68 Hz. This indicates that frequency in this range does not lead to significant distributed PV disconnection.
- A relatively high rate of disconnections was observed in South Australia, despite there being no significant voltage disturbance recorded in this region, and frequency being the same as other regions where minimal disconnections were observed. AEMO is investigating this further.
- In both Victoria and South Australia, the rate of disconnections observed was higher for larger systems (30-100 kilowatts [kW]) compared with smaller systems (<30 kW). This has also been observed in other events, and other NEM regions[17]. This may be related to distribution network protection systems applied for larger connections, and AEMO is investigating this possibility with distribution network service providers.

[15] UNSW ARENA project, "Addressing Barriers to Efficient Renewable Integration", at https://research.unsw.edu.au/projects/addressing-barriers-efficient-renewable-integration and testing results at http://pvinverters.ee.unsw.edu.au/.

[16] AS.NZS 4777.2:2020 Grid connection of energy systems via inverters, Part 2: Inverter requirements, at https://www.techstreet.com/sa/standards/as-nzs-4777-2-2020?product_id=2202786.

[17] AEMO (July 2020) Trip of South Pine 275 kV No. 1 Busbar and 275/110 kV No. 5 Transformer on 26 November 2019, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2019/incident-report-south-pine-incident-on-26-nov-19.pdf?la=en&hash=0DF7B519D37BF3CCA1FCF9CF4A4C0CE7.

Table 4 Observed behaviour of distributed PV in response to the disturbance

	Distributed PV generation prior to the disturbance (MW)	Distributed PV reduction in response to the disturbance	% of DPV systems disconnecting / dropping to zero [C]			
			2005 standard [A]		2015 standard [B]	
			<30 kW	30-100 kW	<30 kW	30-100 kW
Victoria	1,000	34 MW (4%)	4% (0.4%-15%)	10% (2%-27%)	6% (4%-9%)	19% (13%-26%)
South Australia	750	37 MW (4%)	2% (0%-12%)	No data	5% (4%-5.6%)	20% (15%-25%)
New South Wales	1,500	No noticeable change	3% (1% - 6%)	0.0% (0% - 16%)	1% (0.6% - 1.5%)	0% (0% - 1%)
Queensland	1,750	No noticeable change	0% (0% - 5%)	No data	0.5% (0.1% - 1%)	1.1% (0.2% - 3%)

[A] 2005 standard refers to AS/NZS4777.3:2005, applicable for distributed PV installed prior to October 2015.
[B] 2015 standard refers to AS/NZS4777.2:2015, applicable for distributed PV installed after October 2016.
[C] Values shown illustrates the proportion of distributed PV systems observed to reduce power to close to zero for at least two measurement intervals (termed "disconnection") and distributed PV systems observed to reduce power to close to zero for one measurement interval (termed "drop to zero"). Uncertainty estimates are based on sample sizes and observed number of disconnections, calculated at a 95% confidence level.

AEMO is continuing to use events such as this one to calibrate and improve power system models representing the behaviour of distributed PV and load in disturbances.