Trip of South Pine 275 kV No. 1 Busbar and 275/110 kV No. 5 Transformer on 26 November 2019

July 2020

Reviewable Operating Incident Report under the National Electricity Rules

INCIDENT CLASSIFICATIONS

Classification	Detail
Time and date of Incident	12:14 hours on 26th November 2019
Region of incident	Queensland
Affected regions	Queensland
Event type	Protection operation due to a high voltage fault internal to a 275 kV current transformer associated with circuit breaker 5452 at South Pine Substation
Generation impact	No generation was disconnected as a result of this incident.
Customer load impact	No customer load was disconnected as a result of this incident.
Associated reports	Nil

ABBREVIATIONS

Abbreviation	Term
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AEST	Australian Eastern Standard Time
CB	Circuit Breaker
CBF	Circuit Breaker Fail
CT	Current Transformer
HV	High voltage
kV	Kilovolt
NEM	National Electricity Market
NER	National Electricity Rules
TNSP	Transmission Network Service Provider

Important notice

PURPOSE

AEMO has prepared this report in accordance with clause 4.8.15(c) of the National Electricity Rules, using information available as at the date of publication, unless otherwise specified.

DISCLAIMER

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

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1. Overview

This report relates to a reviewable operating incident[1] that occurred at 12:14 hours on 26 November 2019 at South Pine Substation Queensland. The incident involved a high voltage fault internal to a 275 kilovolt (kV) current transformer (CT) associated with circuit breaker (CB) 5452 at South Pine Substation.

The location of the high voltage fault was within the No. 1 275 kV Busbar protection zone "blind spot/dead-zone" of CB 5452. This required the operation of the CB fail protection (CBF) of CB 5452 to successfully clear the fault.

Concurrent with this incident, there was an unexpected protection trip of the 110 kV No. 1 Capacitor Bank at West Darra Substation, which was due to the operation of the capacitor balance protection.

Although no generation or customer load was disconnected as a result of this incident there was a 300 megawatt (MW) reduction in load for approximately 20 minutes as a result of the voltage disturbance caused by the fault.

Distributed Photo Voltaic (PV) generation[2] was also observed to disconnect in response to the voltage dip; AEMO is working with stakeholders to improve performance standards for distributed resources to limit growth in this potentially problematic behaviour in future.

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[3].

AEMO has concluded that:

1. The incident involved a high voltage fault internal to a current transformer associated with 275 kV CB 5452 at South Pine Substation. All protection systems at South Pine Substation operated correctly as designed and the high voltage fault was isolated from the power system in 215.5 ms from fault inception. This time is compliant with the 250 ms CBF total fault clearance time specified in the NER[4].
2. The unexpected protection trip of the 110 kV No. 1 Capacitor Bank at West Darra Substation was due to a protection coordination issue. Powerlink will respond to AEMO by July 2020 regarding any corrective actions proposed to be taken.
3. AEMO correctly determined that reclassification as a credible contingency event was not required.
4. Regarding the 275 kV CT failure, there are potential impacts on the security of the system if further similar incidents were to occur. Therefore, AEMO has asked Powerlink to provide additional data that supports a low probability of a similar event re-occurring for this make, type, and age of CT. Powerlink is to provide a response by July 2020.
5. The power system remained in a secure operating state.

This report is prepared in accordance with clause 4.8.15(c) of the NER. It is based on information provided by Powerlink and AEMO.

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

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

[3] See NER clause 4.8.15(b).

[4] See NER clause S5.1a.8.

2. The incident

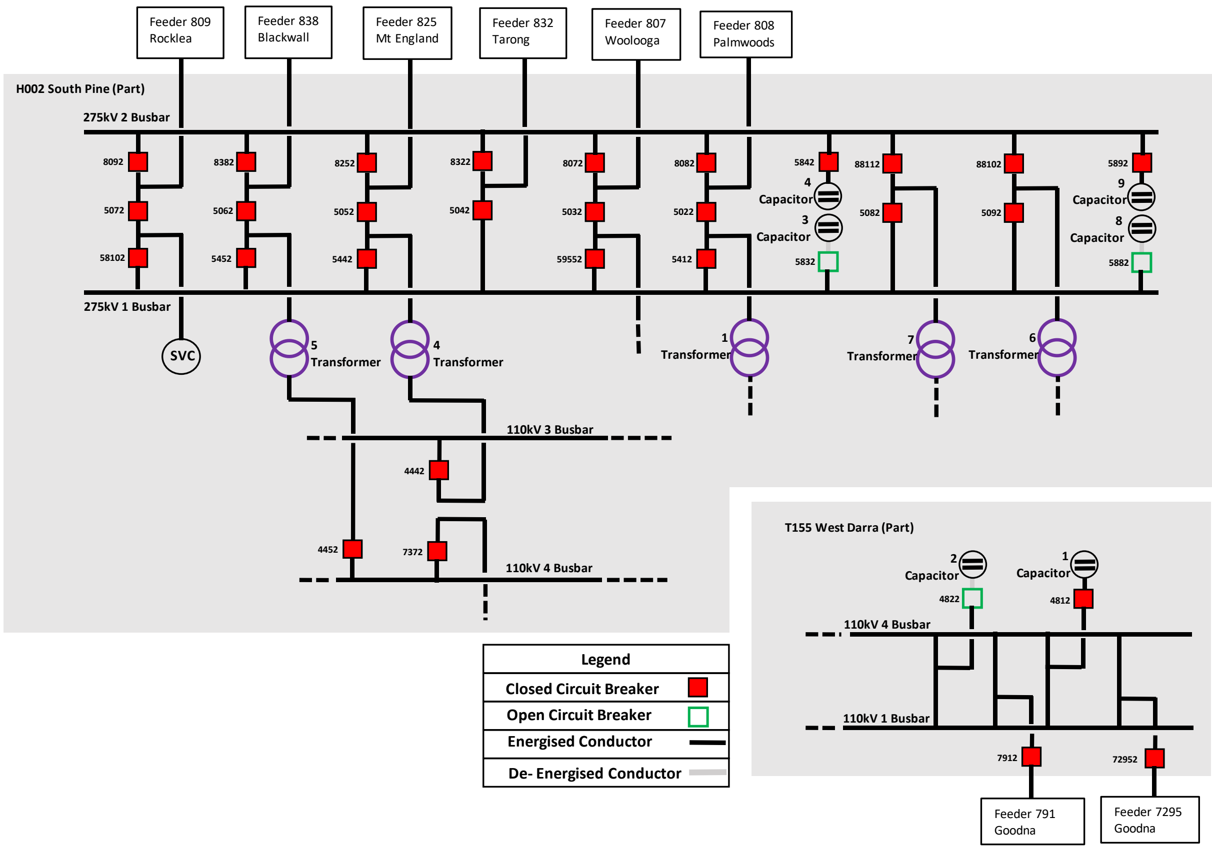
2.1 Pre-incident conditions

Immediately prior to this incident, all major transmission equipment elements – such as busbars and transmission lines – were in service, except for the following:

- The 275 kV No. 3 and No. 8 Capacitor Banks at South Pine Substation were available but not in service.
- The 110 kV No. 2 Capacitor Bank at West Darra Substation was available but not in service.

Figure 1 shows the switching configurations and statuses of the relevant power system plant at H002 South Pine Substation (Part) and T155 West Darra Substation (Part). For clarity, only plant and equipment that operated or provides connectivity between the affected items are shown.

Figure 1 Single line diagram of the relevant power system plant showing plant status prior to incident



2.2 The incident

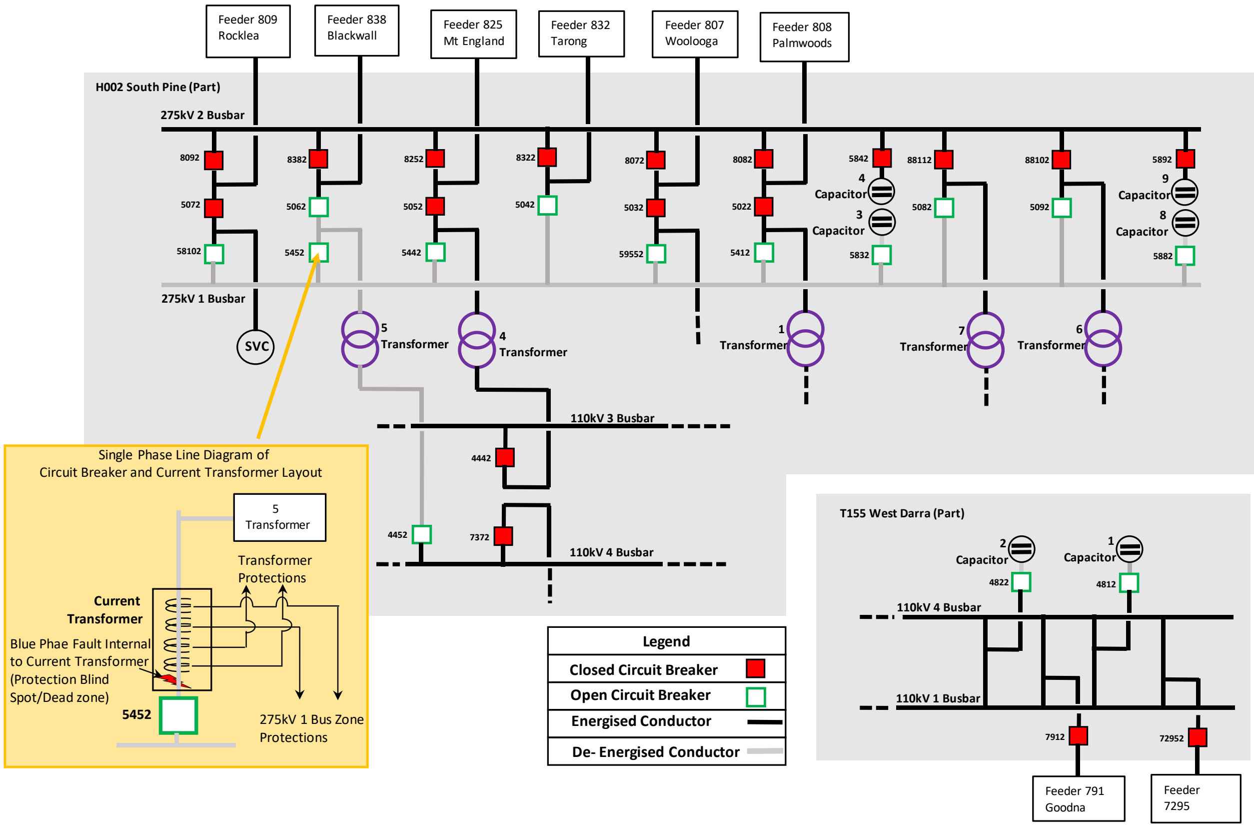
At 12:14 hours on 26 November 2019, a high voltage fault occurred internal to a 275 kV current transformer associated with CB 5452 at South Pine Substation, as shown in Figure 2.

Concurrent with this incident, there was an unexpected protection trip of the 110 kV 1 Capacitor Banks at West Darra Substation, which was due to the operation of the capacitor balance protection.

As a result of the incident, the following primary elements, as shown in Figure 2, were tripped following protection operations:

- H002 South Pine 275 kV No. 1 Busbar (No. 1 Busbar).
- H002 South Pine 275/110 kV No. 5 Transformer (No. 5 Transformer).
- T155 West Darra 110 kV No. 1 Capacitor Bank (No. 1 Capacitor).

Figure 2 Single line diagram of relevant power system plant including status after event



The No. 1 Busbar was returned to service at 1701 hrs on 26 November 2019[5] and the No. 1 Capacitor and No. 5 Transformer were returned to service at 1340 hrs and 1734 hrs respectively on 27 November 2019. Refer to Appendix 1 for a full sequence of events.

2.3 Analysis

2.3.1 275 kV CT fault incident analysis

The following is based on information provided by Powerlink.

The incident involved a high voltage fault internal to a 275 kV current transformer associated with CB 5452 at South Pine Substation. The location of the fault was in the "blind spot/dead-zone" of the overlapping No. 5 transformer and No. 1 Busbar protection zones of CB 5452, as shown in Figure 2.

The term "blind spot/dead-zone" is a fault location where the primary protection, in this case the 275 kV No. 1 Busbar protection, detects the fault, but does not isolate the fault, instead relying on the backup CBF protection to isolate the fault.

[5] CBs 5062 and 5452 remained open pending replacement of the faulty CT.

In summary, the primary and backup CBF protections that operated to isolate the fault were as follows:

a) At 12:14:25.575 hrs – 275 kV No. 1 Busbar protection detected the fault and correctly initiated the following:

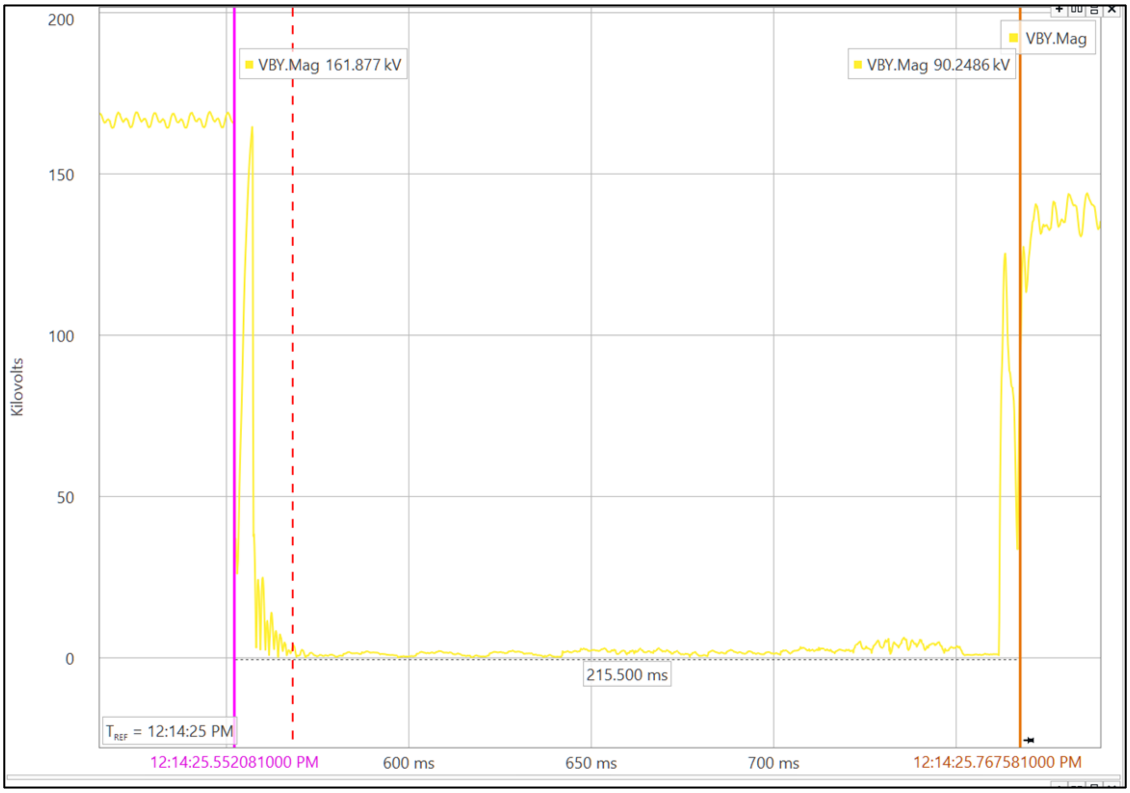
- The trip of all 275 kV No. 1 Busbar CBs, and
- Circuit breaker failure protection of all 275 kV No. 1 Busbar CBs, which included CB 5452 CBF.

At this stage, the fault was not isolated because the fault location was in "blind-spot/dead-zone".

b) At 12:14:25.717 hrs – as fault current was still flowing through the faulted CT to the "blind-spot/dead-zone" location, the CB 5452 CBF backup protection operated correctly 142 ms following the operation of the 275 kV No. 1 Busbar protection and initiated the trip of 275 kV CB 5062 and No. 5 Transformer 110 kV CB 4452 to isolate the fault.

Resulting from the fault, a disturbance recording (see Figure 3) was taken of the South Pine 275 kV B phase voltage magnitude, as measured from a voltage transformer on an unimpacted element at South Pine Substation. This recording clearly shows that the total fault clearance time was 215.5 ms.

Figure 3 Disturbance recording of the South Pine 275 kV B phase voltage



All protection systems at South Pine Substation operated correctly as designed and the high voltage fault was isolated from the power system in 215.5 ms from fault inception, as shown in Figure 3. This time is compliant with the 250 ms CBF total fault clearance time specified in the NER[6].

Regarding the 275 kV CT failure, there are potential impacts on the security of the system if further similar incidents were to occur. Therefore, AEMO has asked Powerlink to provide additional data that would support the low probability of a similar event reoccurring for this make, type, and age of CT. Powerlink is to provide a response to AEMO by July 2020.

[6] See NER clause S5.1a.8.

2.3.2 Protection trip of 110 kV No. 1 Capacitor Bank at West Darra

Concurrent with the fault at South Pine Substation, there was an unexpected protection trip of the 110 kV No. 1 Capacitor Bank at West Darra Substation, which was due to the operation of the capacitor balance protection.

Powerlink has subsequently advised:

- This event has identified a potential coordination issue between:
  - The preferred capacitor bank balance protection settings applicable to credible single-phase faults, and
  - Close-by high current single-phase faults present on the power system for CBF non-credible clearance time events (as was the case for the South Pines incident), which would require less sensitive settings.
- The capacitor bank configuration that tripped at West Darra is not overly common in the Powerlink network, but Powerlink has others of similar design.
- Powerlink has referred the operation of the capacitor bank balance protection relay to the relay manufacturer for comment and will review their feedback and update AEMO by July 2020.

3. Power system security

AEMO is responsible for power system security in the NEM. This means AEMO is required to operate the power system in a secure operating state to the extent practicable and take all reasonable actions to return the power system to a secure state following a contingency event in accordance with the NER[7].

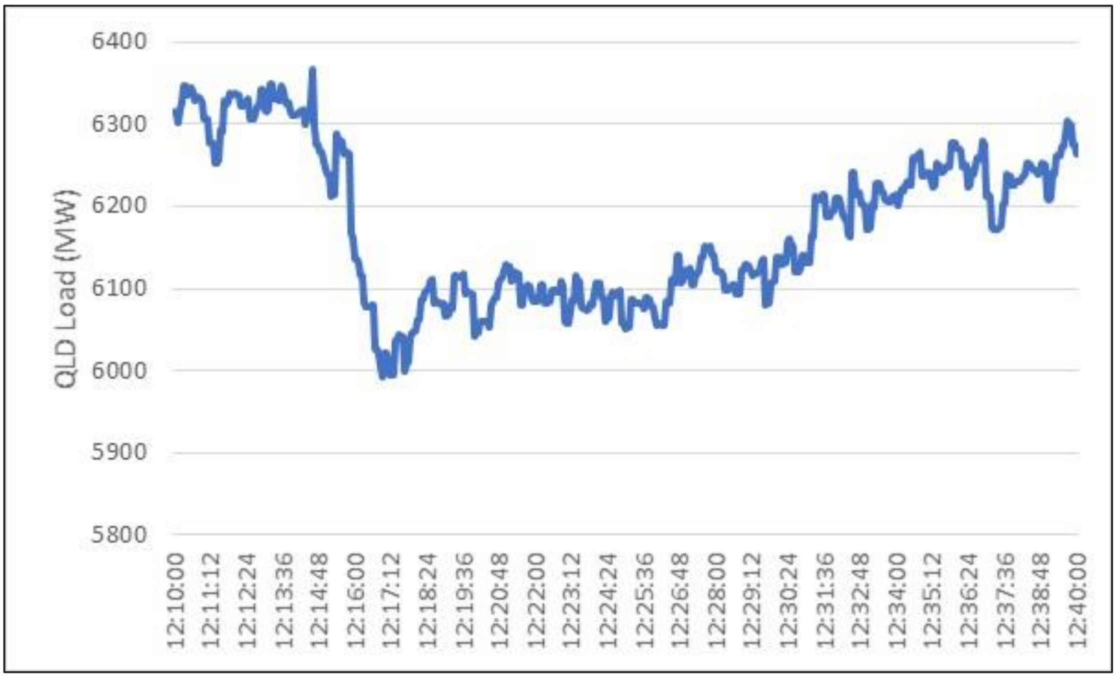
The power system was in a secure operating state prior to this incident and remained in a secure operating state for the duration of the incident. No action was required by AEMO in relation to power system security.

3.1 Load response

As a result of the voltage disturbance caused by this incident, there was an approximate 300 MW temporary reduction in customer load[8] as shown in Figure 4 The load returned to pre-fault levels within approximately 20 minutes.

[7] 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.

Figure 4 Queensland Load in response to fault



Further analysis of the Queensland load in response to the voltage disturbance shows the change comprises two major components:

- A reduction in load of approximately 490-620 MW, and
- A reduction in distributed PV generation in the South East Queensland area in the range of 180-310 MW,

resulting in a net reduction in load of approximately 310 MW.

The disconnection of distributed PV generation in this particular event was not problematic, since it acted to reduce the size of the contingency by netting from the load disconnection. The resulting reduction in load was less than what would have been seen if distributed PV generation did not disconnect, and consequently the frequency disturbance was smaller.

However, if a similar event were to occur in a period with a larger amount of distributed PV generation operating, the loss of distributed PV generation could exceed the loss in load and potentially exacerbate the impact of generation trip events.

The response of the distributed PV generation is discussed further in Appendix A2.

4. Reclassification

AEMO is required to assess whether to reclassify this incident as a credible contingency event[9].

Based on the information provided by Powerlink, AEMO has determined that this incident is unlikely to reoccur, and reclassification is not required.

5. Market information

AEMO is required by the NER and operating procedures to inform the market about incidents as they progress. This section assesses how AEMO informed the market[10] over the course of this incident.

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

1. A non-credible contingency event – notify within two hours of the event[11].

    AEMO issued Market Notice 71402 at 12:44 hrs on 26 November 2019, 30 minutes after the event, to advise of the non-credible contingency event and that reclassification as a credible contingency event was not required.

6. Conclusions

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

AEMO has concluded that:

1. The incident involved a high voltage fault internal to a current transformer associated with 275 kV CB 5452 at South Pine Substation. All protection systems at South Pine Substation operated correctly as designed and the high voltage fault was isolated from the power system in 215.5 ms from fault inception. This time is compliant with the 250 ms CBF total fault clearance time specified in the NER[12].
2. The unexpected protection trip of the 110 kV No. 1 Capacitor Bank at West Darra Substation was due to a protection coordination issue. Powerlink will respond to AEMO by July 2020 regarding any corrective actions proposed to be taken.
3. AEMO correctly determined that reclassification as a credible contingency event was not required.

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[9] AEMO is required to assess whether to reclassify a non-credible contingency event as a credible contingency event – NER clause 4.2.3A(c) – and to report how the reclassification criteria were applied – NER clause 4.8.15(ca).

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

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

[12] See NER clause S5.1a.8.

4. Regarding the 275 kV CT failure, there are potential impacts on the security of the system if further similar incidents were to occur. Therefore, AEMO has asked Powerlink to provide additional data that supports a low probability of a similar event re-occurring for this make, type, and age of CT. Powerlink is to provide a response by July 2020.
5. The power system remained in a secure operating state.

7. Pending actions

There are two pending actions for Powerlink as a result of this incident:

- The 275 kV CT failure – given the potential impacts on the security of the system if further similar incidents were to occur, AEMO has asked Powerlink to provide additional data that supports a low probability of a similar event re-occurring for this make, model, and age of CT. Powerlink is to provide a response by July 2020.
- The 110 kV No. 1 Capacitor Bank at West Darra Substation – Powerlink has referred the unexpected operation of the capacitor bank balance protection relay to the relay manufacturer for comment. Powerlink will review its feedback when received and respond to AEMO by July 2020 regarding any proposed corrective actions.

AEMO will review the Powerlink responses when these are received. An updated report will not be published unless significant new information is received.

A1. Sequence of events

Table 1 Sequence of events, 26-27 November 2019

Date/time (hh:mm:ss.ms)	Time from initial event (ms)	Site	Event	Remarks
26/11/2019				
12:14:25.575	0	H002 South Pine	275 kV 1 Busbar protection trip	275 kV 1 Busbar protection detected fault and initiated the trip of all CBs associated with 1 Busbar
12:14:25.623	48	H002 South Pine	CB 5412 OPEN	
12:14:25.624	49	H002 South Pine	CB 5092 OPEN	
12:14:25.626	51	H002 South Pine	CB 5442 OPEN	
12:14:25.626	51	H002 South Pine	CB 5082 OPEN	
12:14:25.627	52	H002 South Pine	CB 58102 OPEN	
12:14:25.627	52	H002 South Pine	CB 5042 OPEN	
12:14:25.627	52	H002 South Pine	CB 5452 OPEN	CB associated with faulted CT
12:14:25.628	53	H002 South Pine	CB 59552 OPEN	
12:14:25.690	115	T155 West Darra	CB 4812 OPEN	Unexpected operation of 110 kV 1 Capacitor balance protection, due to potential protection grading issue
12:14:25.717	142	H002 South Pine	CB 5452 Blind Spot / Circuit Breaker Fail protection trip	CB 5452 CBF protection operated and initiated trip of 5 Transformer CBs 4452 and 5062
12:14:25.762	187	H002 South Pine	CB 4452 OPEN	
12:14:25.774	199	H002 South Pine	CB 5062 OPEN	Faulted isolated from system
16:50:07		H002 South Pine		Faulty current transformer isolated from power system
17:01:02		H002 South Pine		275 kV 1 Busbar returned to service
27/11/2019				
13:40:48		T155 West Darra		110 kV 1 Capacitor returned to service
17:34:30		H002 South Pine		275/110 kV 5 Transformer returned to service

A2. Distributed PV response

A2.1 Distributed PV behaviour

At 12:14:25 hrs, prior to the event, demand in Queensland was estimated at 6,330 MW. By 12:17 hrs, this had fallen to around 6,015 MW, a net drop of 312 MW. This indicates load disconnection in response to the voltage disturbance. Positive sequence voltage recorded by high speed monitoring equipment at Mudgeeraba substation on the Gold Coast in south east Queensland reached a minimum of just below 0.7 p.u, with similar measurements recorded at three other high speed monitors nearby. Distributed PV was estimated to be generating a total of 1,910 MW in Queensland immediately prior to the disturbance.

Solar Analytics[13] supplied data from individual distributed PV systems in Queensland under a joint ARENA funded project[14]. Systems are categorised based on when they were installed, because different performance standards were applied at different times. Systems installed prior to October 2015 were installed under AS/NZS4777.3:2005 ("the 2005 standard"), and systems installed after October 2016 were installed under AS/NZS4777.2:2015 ("the 2015 standard"). Systems installed between these dates could meet either standard, and are not analysed here.

A2.1.1 Disconnection behaviour

Around 11% (6-17%) of systems installed in Queensland prior to October 2015 (under the 2005 standard) were observed to disconnect or drop to zero[15], and 16% (14-18%) of systems installed in Queensland after October 2016 (under the 2015 standard) were observed to disconnect or drop to zero. This is consistent with AEMO's analysis of distributed PV behaviour during previous voltage disturbances[16].

For systems on the 2015 standard, disconnections were higher for larger systems, with 26% (22-30%) of systems in the size category 30-100kW disconnecting or dropping to zero, compared with 14% (12-15%) of systems in the <30kW category. Similar findings were observed for 13 other voltage disturbances, occurring in various geographic locations within New South Wales, Victoria, and Queensland, representing a range of different voltage disturbance depths. AEMO will adjust its modelling accordingly.

Inverters installed prior to October 2015 may have under-voltage protection settings at any voltage between the range of 200-230 V. Some level of distributed PV disconnection is therefore anticipated during events where the minimum voltage falls below ~0.8pu (as it did during this disturbance).

Inverters installed after October 2016 should be compliant with the 2015 standard, which indicates that inverters should not disconnect until voltage falls below 180 V (~0.8pu) for at least one second. The duration of the voltage dip was much shorter than one second in this disturbance. However, laboratory bench testing of individual single-phase distributed PV inverters, conducted by the University of New South Wales (UNSW)

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[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. Data was supplied with anonymisation to ensure system owner and address could not be identified.

[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/.

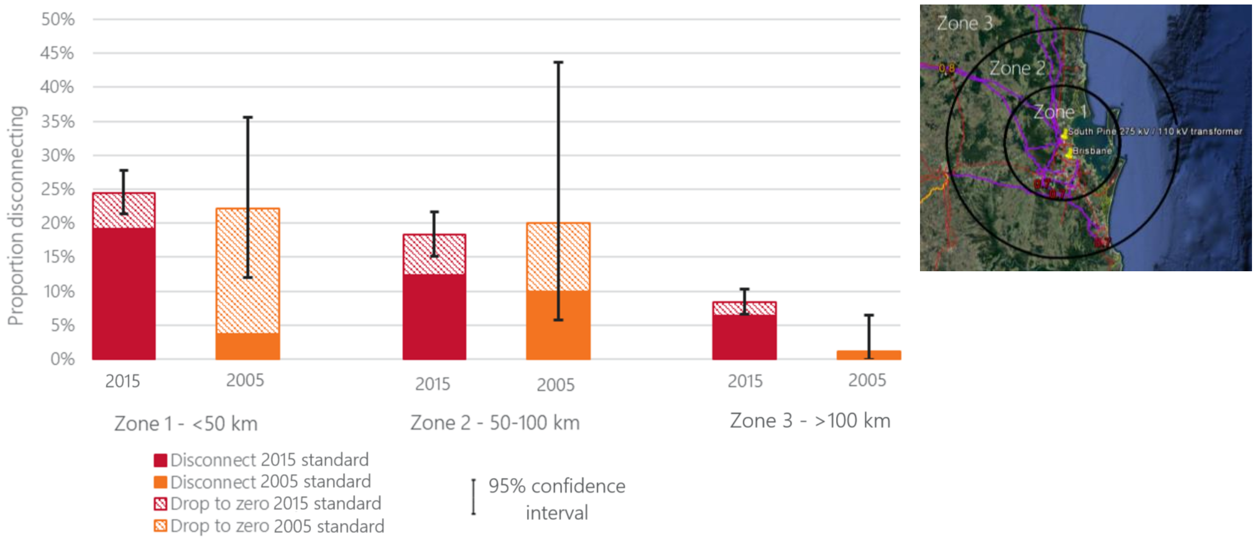
[15] Systems were assumed to have disconnected if generation reduced to close to zero for at least two measurement intervals following the disturbance. Some systems also showed a "drop to zero" response, reducing generation to close to zero for one measurement interval. These may also represent a disconnection response (with slightly lower confidence).

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

as part of an ARENA-funded collaboration with AEMO, ElectraNet and TasNetworks[17], shows that many distributed PV inverters do disconnect in response to short duration voltage dips. These laboratory tests found that around one third of the 17 inverters tested on the 2015 standard do not have the ability to ride through short duration voltage sags, of the type that might occur in typical transmission faults[18]. The analysis of field behaviour in this disturbance is consistent with this finding.

Figure 5 shows that distributed PV disconnections were highest close to the fault location and reduced at more distant locations.

Figure 5 Distributed PV disconnections by distance from fault location in Queensland



A2.1.2 Reconnection behaviour

For inverters installed under the 2005 standard, Solar Analytics provided anonymised data at a five second resolution for five distributed PV systems that were observed to disconnect or drop to zero. All 2005 systems observed remain at close to zero generation for a full minute following disconnection. This is consistent with the 2005 standard, which specifies that the inverter should not reconnect until voltage and frequency are within the required ranges for at least one minute. Following the first minute, four of the five systems observed appear to almost instantaneously increase power to close to pre-event levels. This behaviour is consistent with expectations based on the 2005 standard.

For inverters on the 2015 standard, Solar Analytics provided anonymised data at a five second resolution for 135 distributed PV systems that were observed to disconnect. The average normalised[19] generation from each of these systems is shown in Figure 6. The following observations can be made:

- The aggregate profile remains close to zero for one full minute. This is consistent with the 2015 standard, which specifies that the inverter should not reconnect until voltage and frequency are within the required ranges for at least one minute. All but one inverter demonstrated this behaviour.
- Following the first minute, the aggregate generation profile increases gradually, reaching close to pre-event power over around 10 minutes.
- The aggregate rate of increase is faster in the first two minutes.

[17] Addressing barriers to efficient renewable integration, at https://research.unsw.edu.au/projects/addressing-barriers-efficient-renewable-integration. Bench testing results can be viewed at http://pvinverters.ee.unsw.edu.au/

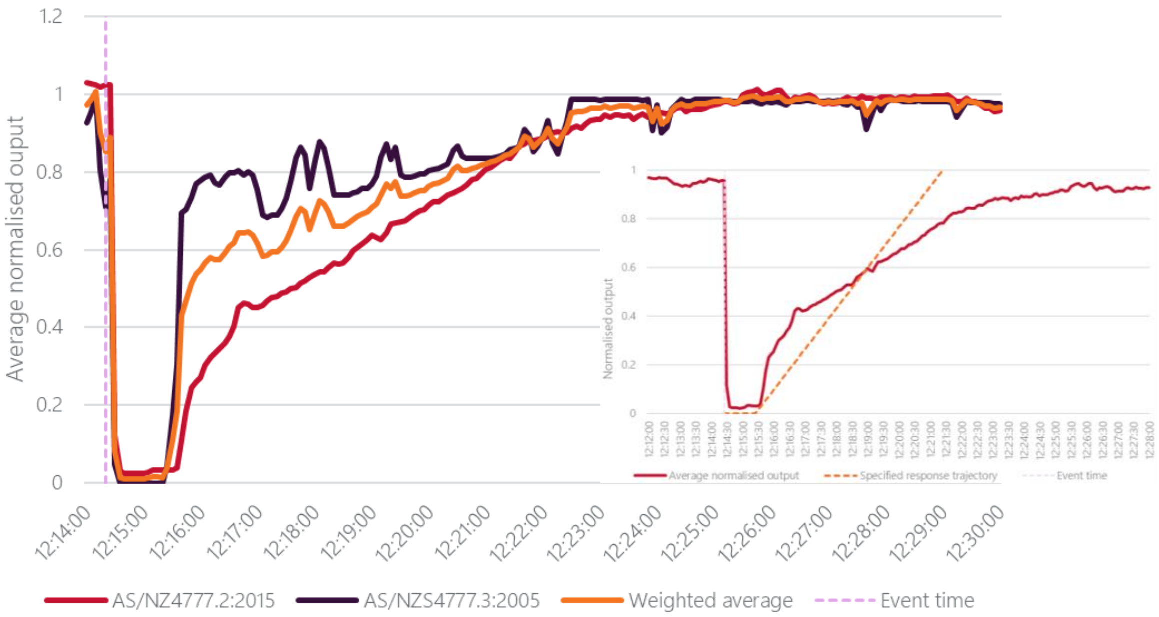
[18] UNSW Sydney, Addressing Barriers to Efficient Renewable Integration – Inverter Bench Testing Results, at http://pvinverters.ee.unsw.edu.au/.

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

Analysis of the reconnection behaviour indicates that 30-40% of systems do not appear to be observing the six-minute ramp rate limitation specified in the 2015 standard, ramping up in two minutes or less[20]. This provides evidence that up to 40% of distributed PV inverters are not behaving consistently with defined standards and is consistent with previous findings exploring compliance with over-frequency droop response[21]. AEMO is engaging with stakeholders across the industry to develop a program of work to improve monitoring and enforcement of standards compliance.

Figure 6 shows the average normalised output for systems under the 2005 and 2015 standards that disconnected after the event, with an average normalised output weighted by the proportion of systems in Queensland installed under each standard[22].

Figure 6 Average normalised reconnection profile for in Queensland (inset with 2015 inverter response)



Bench testing of individual distributed PV inverters[23] shows that most inverters on the 2015 standard do observe the six minute ramp rate limitation. The field measurements above suggesting 30-40% of inverters do not observe this limitation therefore suggests issues related to inverter settings at the time of installation. AEMO is working with stakeholders to implement improved processes around compliance with standards.

A2.1.3 Upscaled estimate of distributed PV response

Accounting for the relative proportions of inverters under each standard and the confidence intervals around disconnections in each category, this dataset suggests that 12% (9-16%) of all distributed PV in Queensland disconnected in response to this event. Based upon the estimate of 1910 MW distributed PV generation prior to the event, it is estimated that distributed PV in Queensland reduced by around 240 MW (180-310 MW) in response to this disturbance.

[20] Trends with system size were also explored. Of the 135 systems analysed, 12 had capacity in the range of 30-100 kW, and the remaining 123 systems had capacity less than 30 kW. Of the 12 larger systems, 25% returned to close to pre-event power within 1.5 minutes of their disconnection, and a total of 75% of systems returned to close to pre-event power within 3 minutes of their disconnection. Accounting for small sample sizes, this is consistent with the proportions identified above for all reconnecting systems on the 2015 standard. This suggests there are not significant differences between the size categories with regards to reconnection behaviour.

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

[22] "Transition" inverters installed between October 2015 and October 2016 have been assumed to be split evenly, with half behaving as observed for 2005 inverters, and half behaving as observed for 2015 inverters.

[23] Conducted by UNSW as part of an ARENA-funded collaboration with AEMO, ElectraNet and TasNetworks: Addressing barriers to efficient renewable integration, at https://research.unsw.edu.au/projects/addressing-barriers-efficient-renewable-integration. Bench testing results can be viewed at http://pvinverters.ee.unsw.edu.au/.