AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

Preliminary Report: Trip of multiple generators and lines in Queensland and associated under-frequency load shedding on 25 May 2021

June 2021

A preliminary operating incident report for the National Electricity Market – information as of 02/06/2021

ABBREVIATIONS

Abbreviation	Term
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AEST	Australian Eastern Standard Time
IBR	Inverter-based resources
NEM	National Electricity Market
NER	National Electricity Rules
RERT	Reliability and Emergency Reserve Trader
TNSP	Transmission network service provider
UFLS	Under Frequency Load Shedding

Important notice

PURPOSE

AEMO has prepared this preliminary report as part of its review of the reviewable operating incident that occurred on 25 May 2021, as a first step in reporting under clause 4.8.15(c) of the National Electricity Rules.

The observations in this report will be updated and expanded on in AEMO's final operating incident report, where new information becomes available.

DISCLAIMER

AEMO has been provided with preliminary data by Registered Participants as to the performance of some equipment leading up to, during and after the event in accordance with clause 4.8.15 of the National Electricity Rules. In addition, AEMO has collated preliminary information from its own systems. Any analysis and conclusions expressed in this document are also of a preliminary nature.

While AEMO has made every reasonable effort to ensure the quality of the information in this report, its investigations are incomplete, and any findings expressed in it may change as further information becomes available and further analysis is conducted. Any views expressed in this report are those of AEMO unless otherwise stated and may be based on information given to AEMO by other persons.

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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.

Executive summary

This preliminary report relates to a reviewable operating incident[1] that occurred on 25 May 2021 in Queensland. The incident involved the trip of multiple generators and high voltage transmission lines in Queensland, leading to a significant reduction of load and temporary synchronous separation between Queensland and New South Wales.

This preliminary report provides a summary of the known facts relating to the incident as known at the date of publication. Detailed analysis of the event, and resulting recommendations, will be released in AEMO's final incident report. Information, data and observations in this report are likely to change or be refined as new information and analysis becomes available.

A provisional sequence of events and timing is provided in Section 3 of this report.

Loss of Callide generating units

Callide Power Station (Callide) is a thermal power plant in central Queensland consisting of two 350 megawatt (MW) generating units at Callide B (B1 and B2) and 466 MW and 420 MW generating units at Callide C (C3 and C4 respectively).

Immediately prior to the event, Callide C4 was operating at 278 MW.

Initial investigations show that at 1334 hrs on 25 May 2021, Callide C4 ceased exporting active power and was observed to absorb approximately 50 MW and 300 megavolt-amperes reactive (MVAr) from the power system, with voltages at Calvale 275 kV substation remaining healthy at approximately 1.0 per unit. At 1340 hrs on 25 May 2021, CS Energy informed AEMO of a turbine hall fire at Callide C. Around four minutes later, at 1344 hrs, Callide C3 tripped from around 417 MW. A further 22 minutes later, at 1406 hrs, multiple events occurred in quick succession, negatively impacting the power system.

Separation of Queensland region

The Queensland to New South Wales Interconnector (QNI) is the main interconnection between New South Wales and Queensland, with an import capacity to Queensland of approximately 600 MW. Immediately prior to the event at 1330 hrs QNI was exporting approximately 396 MW to New South Wales.

At around 1406 hrs, approximately 3,000 MW of generation capacity tripped offline in Queensland causing QNI active power flow to rapidly increase, peaking at around 1,064 MW import to Queensland until the interconnector tripped. After QNI tripped, the Queensland frequency dropped to approximately 48.50 Hz. In response, AEMO observed a net reduction in load of approximately 2,300 MW in Queensland and 40 MW in Northern New South Wales[2]. The cause of most of this load reduction is likely to be associated with the expected operation of automatic Under Frequency Load Shedding (UFLS) relays following the observed drop in frequency, but this will need to be confirmed through analysis of relay operation.

Subsequent events

The large reduction of generation availability led to actual Lack of Reserve 1[3] (LOR1) and LOR2 conditions, and forecast LOR3 conditions in Queensland. Actual LOR1 and forecast LOR2 conditions also occurred in New South Wales.

[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] Load shed in New South Wales was being supplied by Queensland at the time.

[3] Please see Appendix A1 for details of Lack of Reserve (LOR) conditions.

As a result of the event, 15 MW of Reliability and Emergency Reserve Trader (RERT) capacity was activated in Queensland.

Forecast LOR3 conditions in Queensland were subsequently cancelled at 1923 hrs. Investigation is underway into the reasons for changes in forecast reserve conditions and will be discussed in a later report.

Next steps

AEMO is continuing its investigation into this incident. The investigation will include, as a minimum:

- A comprehensive timeline of events based on validated data.
- The impact of the event on market operation.
- AEMO's actions in response to the event.
- Generator performance:
  - Analysis of any unexpected operation (including trips) of large-scale generating units.
  - Analysis of the performance of embedded generation including distributed PV.
  - Assessment of generator frequency response performance and its impact on the event.
- System impact and performance:
  - Assessment of the performance of the transmission and distribution networks, relevant control schemes and protection equipment.
  - The cause of all transmission circuit trips associated with this incident.
  - The impact of the event on QNI and analysis of its trip and reclose operation.
  - Detailed analysis of system frequency response throughout the incident, including UFLS operation.
  - A review of reserve conditions during and immediately following the event.
- Recommendations:
  - Exploration of potential and recommended mitigation measures for future operation.
  - Where appropriate with regard to the implications of this event, recommended future work to improve the operation and resilience of the NEM power system.

Investigation of this event requires AEMO to collect and analyse data from registered participants in the NEM to assess both the cause and effects of the event, as well as the individual and combined responses of equipment within the power system, at both the transmission and distribution level. In this regard the following should be noted:

- Data and information will need to be provided by registered participants, who have (under the rules) up to 20 business days to respond to AEMO's information request. Most initial requests were issued on 27 May 2021.
- AEMO may need to request additional information from participants following initial analysis of this data.

Given these considerations, a timeline for publication of AEMO's final detailed operating incident report is yet to be determined.

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1. Report objective

This is AEMO's preliminary operating incident report into the trip of multiple generators and lines in Queensland and associated under-frequency load shedding on 25 May 2021. It is intended to provide an initial overview of the known facts relating to the incident as known at the date of publication. This report sets out the key next steps for finalising AEMO's incident reporting under clause 4.8.15 of the National Electricity Rules (NER).

This report is based on preliminary analysis of data obtained from AEMO systems and initial information provided by transmission network service providers (TNSPs). While these sources are considered reliable, the data does not comprise all of the power system information necessary to complete AEMO's investigation of the event.

AEMO requires high speed monitoring data from devices in the field, within TNSP systems and from generating plant, to complete a thorough analysis to support conclusive findings and recommendations. This data is in the process of being obtained and (in accordance with NER timeframes for the provision of information by registered participants) is expected to be provided to AEMO by late June 2021. AEMO notes that the analysis of that data may identify additional aspects of the event that require investigation before the review can be completed.

References to times in this report, unless otherwise specified, are to Australian Eastern Standard Time.

2. Pre-event conditions

A summary of generation online at 1330 hrs on 25 May 2021, just prior to the first generator trip of this incident, is shown in Table 1.

Table 1 Regional demand and generation at 1330 hrs, 25 May 2021

Region	Operational demand [A] (MW)	Scheduled and semi-scheduled generation [B] (MW)
Queensland	5310	6088
New South Wales	7043	6514
Victoria	5538	5287
South Australia	1148	1342
Tasmania	1304	862

A. Based on 30-minute average of preceding six 5-minute operational demands.
B. Based on 30-minute trading interval average.

A detailed list of all scheduled and semi-scheduled generation online in Queensland prior to the event is listed in Table 2, along with the generation dispatch at 1330 hrs on 25 May 2021[4].

[4] Dispatch at 1330 hrs corresponds to dispatch instructions issued for the 1335 dispatch interval.

Table 2 Queensland generation dispatch at 1330 hrs, 25 May 2021

Unit name	Dispatched generation (MW)	Unit name	Dispatched generation (MW)
Barron Gorge Power Station Unit 2	15	Kidston Solar Project	27
Callide Power Station Unit B2	350	Lilyvale Solar Farm	47
Childers Solar Farm	24	Longreach Solar Farm	11
Clare Solar Farm	45	Maryrorough Solar Farm	24
Clermont Solar Farm	56	Moranbah North Waste Coal Mine Gas Power Station	40
Callide C Nett Off Unit 3	424	Mount Emerald Wind Farm	86
Callide C Nett Off Unit 4	280	Middlemount Solar Farm	4
Collinsville Solar PV Power Station	14	Millmerran Power Plant Unit 1	420
Daydream Solar Farm	29	Oakey 1 Solar Farm	7
Darling Downs Solar Farm, Units 1-44	80	Oakey 2 Solar Farm	18
Emerald Solar Park	21	Ross River Solar Farm, Units 1-64	103
German Creek Power Station	32	Rugby Run Solar Farm	16
Gladstone Power Station Unit 2	150	Susan River Solar Farm	32
Gladstone Power Station Unit 3	150	Stanwell Power Station Unit 1	365
Gladstone Power Station Unit 4	150	Stanwell Power Station Unit 3	365
Gladstone Power Station Unit 5	165	Stanwell Power Station Unit 4	365
Gladstone Power Station Unit 6	150	Tarong Power Station Unit 2	330
Hamilton Solar Farm	20	Tarong Power Station Unit 3	280
Haughton Solar Farm Stage 1	65	Tarong Power Station Unit 4	330
Hayman Solar Farm	12	Tarong North Power Station	443
Hughenden Solar Farm	9	Warwick Solar Farm 1	5
Kareeya Power Station Unit 1	22	Whitsunday Solar Farm	19
Kareeya Power Station Unit 2	22	Townsville Gas Turbine	83
Kareeya Power Station Unit 3	22	Yarranlea Solar Farm	52
Kareeya Power Station Unit 4	22	Yarwun Power Station	115
Kogan Creek Power Station	190		

Prior to the incident, there were no high impact transmission outages in Queensland and all three converters at Directlink were in service. However, in Northern New South Wales there was a Lismore 330 kilovolt (kV) bus outage which also required the Armidale–Lismore 89 330 kV line to be out of service.

Table 3 lists transmission outages in Queensland and New South Wales that were ongoing at the time of the event and required constraints invoked resulting reduced capacity on interconnectors between New South Wales and Queensland.

Table 3 Outages in Queensland and New South Wales affecting interconnectors to Queensland

Region	Element	Start	Finish	Constraint invoked
Queensland	Halys – Braemar 8814 275 kV line	25/05/2021 10:02	03/06/2021 17:00	Q-BRHA
New South Wales	Lismore No.1 330 kV Bus	25/05/2021 06:01	25/05/2021 16:15	N-CHLS_89 N-DLETS_OS

Table 4 shows all NEM interconnector flows prior to the incident.

Table 4 Interconnector flows at 1330 hrs, 25 May 2021

Interconnector	Target flow [A] (MW)
Queensland to New South Wales Interconnector (QNI) (negative is flow into New South Wales)	-389
Terranora (negative is flow into New South Wales)	-55
Victoria – New South Wales (positive is flow into New South Wales)	173
Heywood (negative is flow into Victoria)	-351
Murraylink (negative is flow into Victoria)	-45
Basslink (Negative is flow into Tasmania)	-383

A. Based on 30-minute trading interval average.

2.1 Weather conditions in Queensland on 25 May 2021

A ridge of high pressure over Queensland and North-Eastern New South Wales was maintaining settled conditions throughout Tuesday 25 May 2021. This resulted in:

- A mostly sunny day with a maximum temperature of 24°C forecast at Archerfield in Brisbane, resulting in moderate demand forecasts, with operational demand in Queensland expected to peak at 7,430 megawatts (MW) at 1800 hrs, as per the day-ahead (1230 hrs pre-dispatch) forecast.
- Moderate wind generation expected to drop to low levels during the evening.
- Some patchy cloud present along the Queensland and New South Wales coastlines creating some limited variability in both the large-scale and rooftop solar generation throughout the day.

3. Event

The below description of this event is based on AEMO's initial review and preliminary information available at the time of preparing this report.

Immediately prior to the event, Callide Power Station (Callide) C4 was operating at 278 MW. At 1334 hrs on 25 May 2021, Callide C4 stopped generating but did not disconnect from the power system. At 1340 hrs, CS

Energy[5] informed AEMO of a possible turbine hall fire at Callide C. Around four minutes later, at 1344 hrs, Callide C3 tripped from approximately 417 MW. SCADA data provided through AEMO's Energy Management System (EMS) indicated that Callide C4 started absorbing around 50 MW and 300 MVArs, with Calvale 275 kV substation voltage remaining healthy at approximately 1.0 per unit. A further 22 minutes later, at 1406 hrs, multiple events (listed below) occurred in quick succession. The exact chronological order of these events will need to be confirmed following careful analysis of high speed data, so the below list may not be in order:

- Callide C4 disconnected from the power system[6].
- Callide B2 tripped from around 347 MW.
- All 275 kV lines out of Calvale 275 kV substation tripped at one end only.
- Stanwell Power Station units 1, 3 and 4 tripped to house load.
- Gladstone Power Station units 2, 3 and 4 tripped.
- Yarwun Power Station tripped.
- Townsville Gas Turbine ramped down to 0 MW.
- Queensland to New South Wales Interconnector (QNI) flow rapidly increased, peaking at around 1,064 MW, then tripped.

After QNI tripped, resulting in synchronous separation between Queensland and the rest of the NEM, the frequency in Queensland dropped to approximately 48.50 hertz (Hz). As would be expected, consistent with pre-determined settings, this low frequency caused Under Frequency Load Shedding (UFLS) relays to operate automatically, disconnecting load in Queensland to arrest the frequency decline.

The observed net power system load reduction was approximately 2,300 MW in Queensland and 40 MW in Northern New South Wales (noting that part of far north New South Wales remained synchronously connected to Queensland following the trip of QNI). While the cause of most of this load reduction is likely to be associated with UFLS relay operation, this will need to be confirmed through further analysis.

By around 1407 hrs, the Queensland frequency had recovered to approximately 50 Hz and QNI reclosed automatically. At the time of the QNI trip, frequency in the rest of the NEM dropped to around 49.68 Hz then increased to around 50.2 Hz, then returned to around 50 Hz a few seconds later.

Table 5 below provides a preliminary summary of events from the incident on 25 May 2021. A comprehensive list of events will be provided in AEMO's detailed operating incident report after completion of the review.

Table 5 Preliminary sequence of events

Event sequence	Description	Notes	Cumulative generation loss
25/5/2021			
1334 hrs	Callide C4 stops generating while remaining connected to the power system	Approximately 278 MW of Generation lost.	278 MW
1344 hrs	Callide C3 trips	Approximately 417 MW of Generation lost.	695 MW
1406 hrs	Callide C4 disconnects from the power system	-	
	Callide B2 trips	Loss of approximately 347 MW of generation.	1,042 MW

[5] CS Energy is a generator owner/operator in the NEM and operates Callide C and B power stations.

[6] The Calvale 275 kV substation was disconnected from the power system, disconnecting Callide C4 from the system.

Event sequence	Description	Notes	Cumulative generation loss
	All 275 kV lines out of Calvale substation trip: • Calvale-Halys 8810 275 kV line • Calvale-Halys 8811 275 kV line • Calvale-Stanwell 855 275 kV line • Calvale-Stanwell 8873 275 kV line • Calvale-Stanwell 8874 275 kV line • Calvale-Wurdong 871 275 kV line	The trip of all lines was single ended with circuit breakers only opening at the remote end of each circuit. The Calvale – Halys line reactor tripped, which is at the Calvale end of the line. Due to prior outages in the 132 kV network at the time of the event, the local 132 kV network was supplied radially from Calvale 275 kV substation. Therefore, this 132 kV network was also disconnected from the wider power system as a result of these 275 kV circuit trips.	
	Stanwell units 1, 3 and 4 trip to house load (TTHL), disconnecting from power system but remain generating.	Approximately 1095 MW of generation lost.	2,137 MW
	Gladstone units 2, 3 and 4 trip and disconnect from power system	Approximately 705 MW of generation lost Gladstone units 5 and 6 remain online and generating through the incident	2,842 MW
	Yarwun Power Station trips and disconnects from power system	Approximately 115 MW of generation lost	2,957 MW
	Townsville Gas Turbine ramps down to 0 MW but remains connected to the power system	Approximately 88 MW of generation lost	3,045 MW
	QNI flow peaks at approximately 1064 MW from NSW to QLD QNI trips through circuit breakers on Armidale-Dumaresq 8C 330 kV Line and Armidale-Sapphire Wind Farm 8E 330 kV Line opening	Loss of around 2350 MW of generation within 1-minute drives sharp increase in QNI imports to QLD Nominal QNI rating is around 600 MW for import to QLD Following QNI trip, no synchronous connection between QLD and the balance of the NEM	
	Frequency in QLD drops to around 48.5 Hz and load disconnects	Approximately 2,300 MW of load disconnected in QLD and 40 MW in NSW, most of this expected to be the result of planned operation of UFLS relays	
	Strathmore No.1 Static VAr Compensator (SVC) trips	-	
	Lismore No.1 SVC trips.	-	
14:06:57	QLD frequency recovered to approximately 50 Hz	-	
14:06:57	Armidale-Dumaresq 8C 330 kV Line and Armidale-Sapphire Wind Farm 8E 330 kV Line automatically reclose.	Restoring synchronous connection between QLD and NSW	
1410 hrs	AEMO gives permission to start restoration of UFLS-tripped load	-	
1414 hrs	AEMO gives permission to restore Boyne Island load	Tripped as part of the UFLS operation	

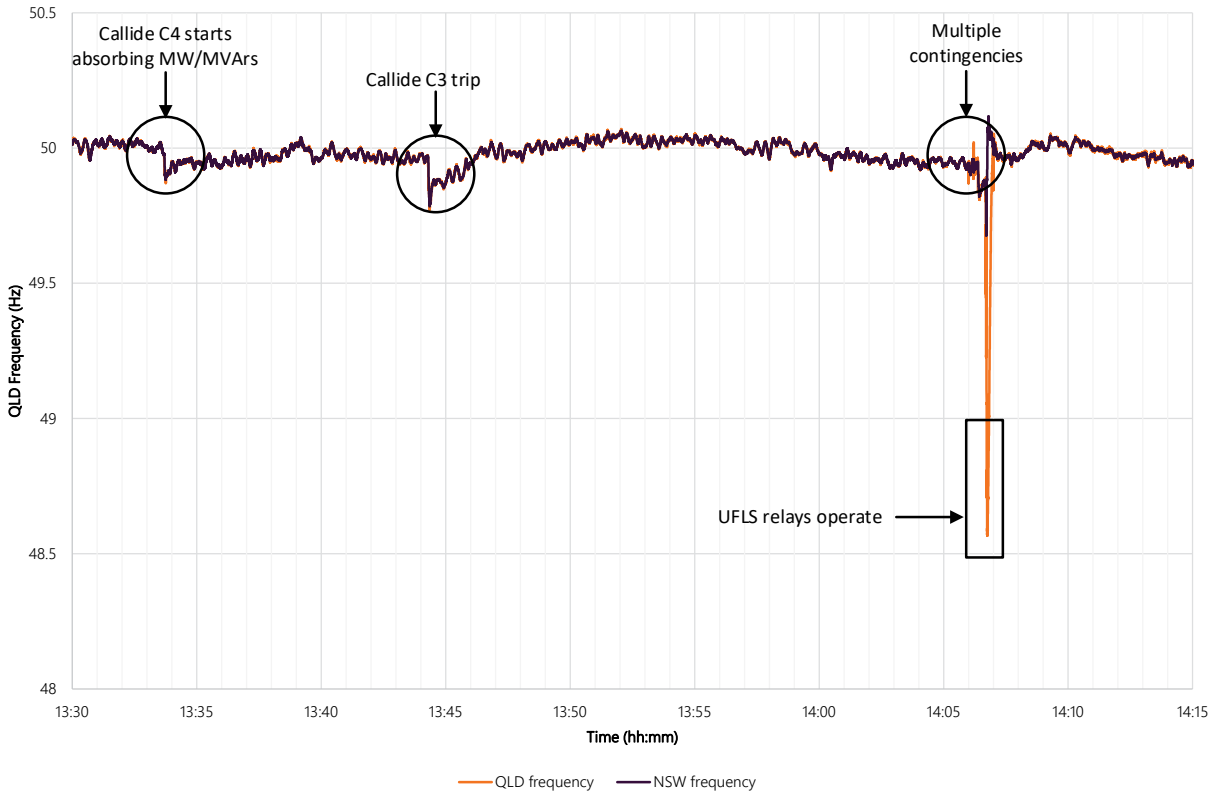
Event sequence	Description	Notes	Cumulative generation loss
1417 hrs	AEMO gives permission to restore load in northern NSW	Tripped as part of the UFLS operation	
1418 hrs	AEMO gives permission to restore Queensland Alumina Limited load	Tripped as part of the UFLS operation	
1422 hrs	Lismore No.1 SVC returned to service	-	
1428 hrs	Permission given for Yarwun generating unit 1 to synchronise and follow market targets	-	
1430 hrs	AEMO invoked constraint sets Q-HACL and Q-X_HACL_HACL	Constraint set invoked to manage loss of all lines from Calvale 275 kV bus	
1431 hrs	Permission given to Stanwell to synchronise the TTHL units and follow market targets	Units to be synchronised in sequentially	
1445 hrs	Stanwell generating unit 4 synchronised	-	
1446 hrs	Strathmore No.1 SVC returned to service.	-	
1452 hrs	Permission given to CS Energy to synchronise the Gladstone tripped units and follow market targets	Units to be synchronised in sequentially, as they become available to sync	
1503 hrs	Stanwell generating unit 3 synchronised	-	
1504 hrs	Calvale-Stanwell 855 275 kV line returned to service	-	
1521 hrs	Stanwell generating unit 1 synchronised	-	
1529 hrs	Calvale-Halys 8810 and Calvale-Stanwell 855 275 kV Lines returned to service		
1534 hrs	Calvale-Halys 8811 275kV Line returned to service	-	
1535 hrs	AEMO invoked constraint set Q-CLWU	Constraint invoked as Calvale-Halys and Calvale-Stanwell lines have been returned to service but Calvale-Wurdong lines remain out of service	
1538 hrs	Calvale-Stanwell 8873 275kV Line returned to service	-	
1539 hrs	Calvale-Stanwell 8874 275kV Line returned to service	-	
1540 hrs	AEMO revoked constraint sets Q-HACL and Q-X_HACL_HACL	Constraint set no longer needed as Calvale-Halys and Calvale-Stanwell lines have been returned to service	
1540 hrs	Calvale-Wurdong 871 275 kV line returned to service	-	
1540 hrs	All 275kV lines out of Calvale substation returned to service	-	
1545 hrs	AEMO revoked constraint set Q-CLWU	Constraint set no longer needed as Calvale-Wurdong lines have been returned to service	
1604 hrs	AEMO gives permission given to restore all remaining load	-	

Event sequence	Description	Notes	Cumulative generation loss
1756 hrs	Gladstone generating unit 4 synchronised	-	
1832 hrs	Swanbank E generating unit synchronised	-	
1845 hrs	Gladstone generating unit 2 synchronised	-	
2208 hrs	Auxiliary supplies restored to Callide power station	-	
26/5/2021			
0100 hrs	Gladstone generating unit 3 synchronised	-	

3.1 Frequency

AEMO's initial investigation shows that Queensland system frequency dropped slightly and recovered when Callide C4 ceased generating at 1333 hrs. The frequency also dropped and recovered from the Callide C3 trip at 1344 hrs. However, as shown below, the multiple contingency events that occurred at 1406 hrs led to a large frequency drop to around 48.50 Hz in Queensland. In response to this frequency drop, a net load reduction of around 2,340 MW of load was observed and Queensland returned to approximately 50 Hz. Figure 1 shows Queensland and New South Wales system frequencies on 25 May 2021, illustrating that New South Wales (and the rest of the mainland NEM) frequency dropped to around 49.68 Hz before recovering.

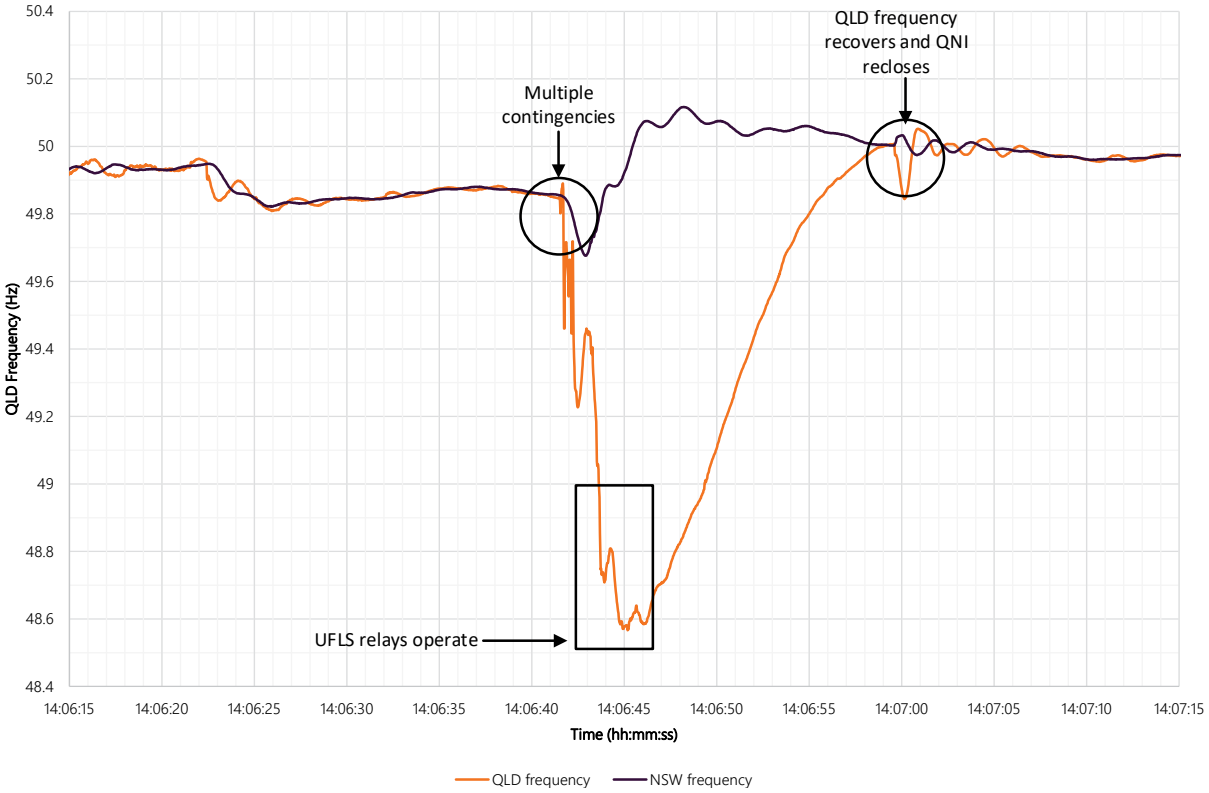
Figure 1 Queensland[A] and New South Wales[B] frequency, 25 May 2021



A. Measured at Stanwell 275 kV substation Phase Monitoring Unit.
B. Measured at Sydney West 330 kV substation Phase Monitoring Unit.

Figure 2 presents the same Queensland and New South Wales system frequency, focused around the multiple contingency events at 1406 hrs on 25 May 2021.

Figure 2 Queensland[A] and New South Wales[B] frequency during multiple contingencies, 25 May 2021



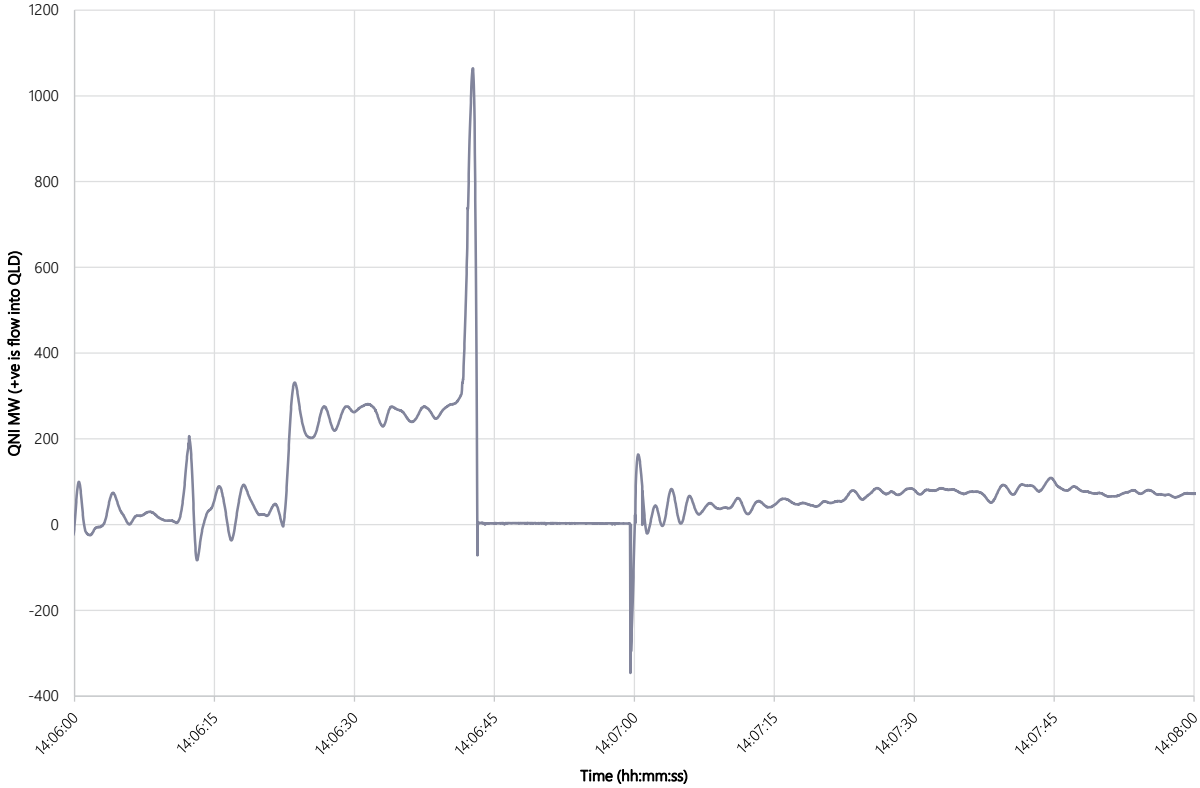
A. Measured at Stanwell 275 kV substation Phase Monitoring Unit.
B. Measured at Sydney West 330 kV substation Phase Monitoring Unit.

3.2 QNI flow

As outlined above, during this incident QNI flow rapidly increased to a maximum of around 1,064 MW import into Queensland (well above its nominal maximum rating of around 600 MW for imports to Queensland) and QNI tripped. QNI reclosed a short time later, with its flow stabilising at around 50 MW import to Queensland.

Figure 3 presents QNI flow during the incident.

Figure 3 QNI flow[A] during 25 May 2021 incident



A. Measured at Bulli Creek substation High Speed Monitoring (HSM).

4. Reclassification

No reclassifications were made during this incident as failed equipment was not returned to service.

5. Constraints

From 1410 hrs on 25 May 2021, the system strength constraints listed below acted reduce the output of inverter-based generation (IBR) in north and central Queensland. These constraints are part of the Queensland NIL outage constraint set and are always invoked. The data below only relates to 25 May 2021.

Constraint Name	IBR limited	Binding DIs on 25/05/21	Notes
Q_NIL_STRGTH_CLRSF	Clare Solar Farm	1415 to 2355 on 25/05/21	-
Q_NIL_STRGTH_COLSF	Collinsville Solar Farm	1415 to 2355 on 25/05/21	-

Constraint Name	IBR limited	Binding DIs on 25/05/21	Notes
Q_NIL_STRGTH_DAYSF	Daydream Solar Farm	1420 to 2355 on 25/05/21	Daydream Solar Farm's generation for the 1415 DI was below the limit at which the constraint binds.
Q_NIL_STRGTH_HAMSF	Hamilton Solar Farm	1415 to 2355 on 25/05/21	-
Q_NIL_STRGTH_HAUSF	Haughton Solar Farm	1415 to 2355 on 25/05/21	-
Q_NIL_STRGTH_HAYSF	Hayman Solar Farm	1415 to 2355 on 25/05/21	-
Q_NIL_STRGTH_KIDSF	Kidston Solar Farm	1415 to 2355 on 25/05/21	-
Q_NIL_STRGTH_MEWF	Mount Emerald Wind Farm	1415 to 1725 on 25/05/21	Limitations on Mt Emerald to run in absence of other IBR with only five central QLD units in service was confirmed via analysis following the incident. Constraint Q_NIL_STRGTH_MEWF was blocked from operation at 1725
Q_NIL_STRGTH_RGBSF	Rugby Run Solar Farm	1415 to 2355 on 25/05/21	-
Q_NIL_STRGTH_RRSF	Ross River Solar Farm	1415 to 2355 on 25/05/21	-
Q_NIL_STRGTH_SMSF	Sun Metals Solar Farm	1415 to 2355 on 25/05/21	-
Q_NIL_STRGTH_WHTSF	Whitsunday Solar Farm	1415 to 2355 on 25/05/21	-

At 1430 hrs on 25 May 2021, AEMO invoked constraint sets Q-HACL and Q-X_HACL_HACL to reflect the loss of all 275 kV transmission lines out of Calvale substation. The constraints in these sets limit power flow between Central Queensland and South Queensland, and Central Queensland and North Queensland, due to the reduced capacity of the network. These constraint sets were revoked at 1540 hrs on 25 May 2021.

At 1535 hrs on 25 May 2021, AEMO invoked constraint set Q-CLWU to reflect thermal limits with Calvale–Wurdong line 871 out of service. This constraint set was revoked at 1545 hrs on 25 May 2021.

6. Lack of Reserve conditions and RERT dispatch

As a result of the loss of Callide C and the subsequent trip of generating units at Callide B, Gladstone, Stanwell, and Yarwun, actual and forecast Lack of Reserve (LOR) conditions in New South Wales and Queensland were declared. In response to these LOR conditions, AEMO activated its Reliability and Emergency Reserve Trader (RERT) functions. Details of the market notices and capacity shortfalls and RERT notices are outlined below.

Table 6 LOR conditions and RERT dispatch

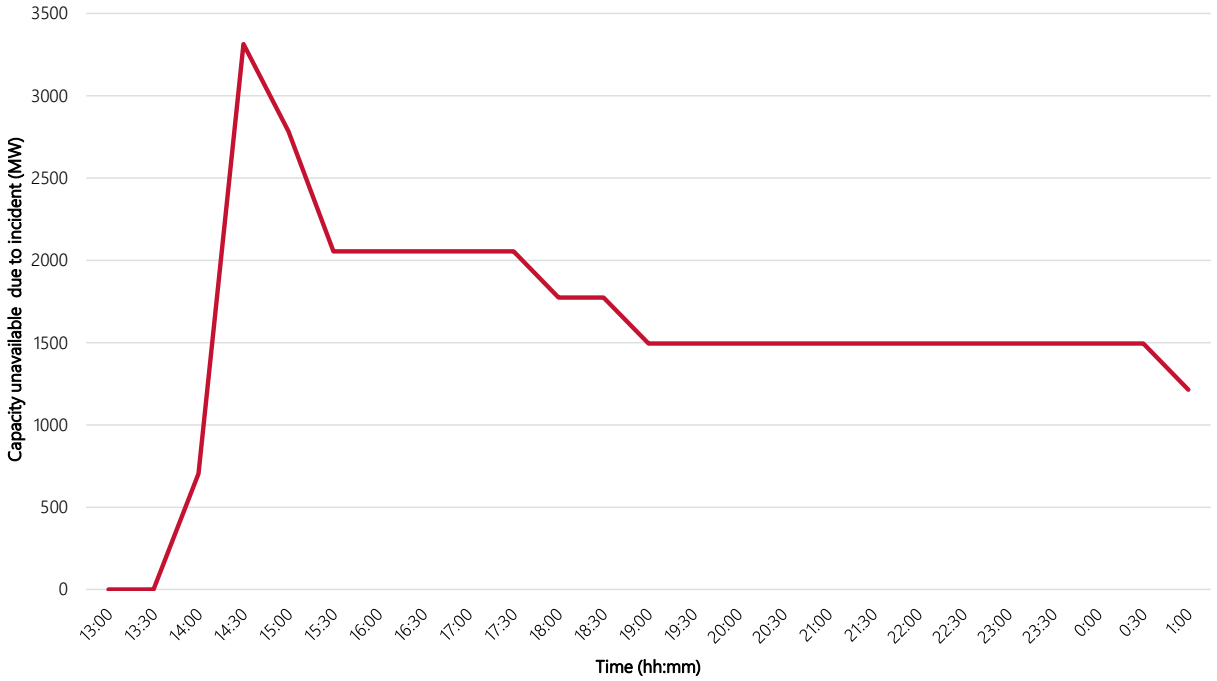
Time	Market Notice	Details	LOR time period	Capacity requirement	Capacity available
25 May 2021					
1512 hrs	85949	Forecast LOR1 in NSW	1730 hrs 25/05/2021 to 1930 hrs 25/05/2021	1,430 MW	965 MW
1521 hrs	85952	Forecast LOR2 in QLD	1730 hrs 25/05/2021 to 1900 hrs 25/05/2021	443 MW	367 MW
1529 hrs	85955	Forecast LOR 1 in QLD	1530 hrs 25/05/2021 to 2130 hrs 25/05/2021	863 MW	367 MW
1548 hrs	85965	Forecast LOR2 in NSW	1730 hrs 25/05/2021 to 1830 hrs 25/05/2021	730 MW	705 MW
1507 hrs	85990	Forecast LOR3 in QLD	1700 hrs 25/05/2021 to 2100 hrs 25/05/2021	1,043 MW forecast shortfall	N/A
1613 hrs	85976	Intention to commence RERT contract negotiations in QLD[A]	Requests for tender for period - 1730 hrs to 2000 hrs 25/05/2021		
1644 hrs	85992	Actual LOR2 in QLD	1640 hrs 25/05/2021 to 2130 hrs 25/05/2021	863 MW	-1,043 MW
1700 hrs	N/A	15 MW RERT activated in QLD[B]			
1721 hrs	86006	Cancel forecast LOR2 in NSW	Cancelled at 1715 hrs on 25/05/2021	N/A	N/A
1739 hrs	86007	Notice of intervention event - RERT	Reserve contracts activated from 1700 hrs 25/05/2021, expected to remain activated until 2130 hrs on 25/05/2021		
1813 hrs	86028	Actual LOR1 in NSW	1800 hrs 25/05/2021 to 2000 hrs 25/05/2021	1400 MW	759 MW
1841 hrs	86033	Cancel actual LOR1 condition in NSW	Cancelled at 1840 hrs on 25/05/2021	N/A	N/A
1849 hrs	86035	Cancel forecast LOR1 in NSW	Cancelled from 1845 hrs on 25/05/2021	N/A	N/A
1913 hrs	86029	Cancel actual LOR2 condition in QLD	Cancelled at 1910 hrs on 25/05/2021	N/A	N/A
1923 hrs	86038	Cancel forecast LOR3 condition in QLD	Cancelled at 1910 hrs on 25/05/2021	N/A	N/A
1924 hrs	86039	Cancel forecast LOR1 condition in QLD	Cancelled at 1910 hrs on 25/05/2021	N/A	N/A
1926 hrs	86037	End of RERT dispatch in QLD	Ended from 1930 hrs on 25/05/2021	N/A	N/A
1955 hrs	86040	Forecast LOR1 in QLD	1700 hrs 26/05/2021 to 1900 hrs on 26/05/2021	868 MW	575 MW

Time	Market Notice	Details	LOR time period	Capacity requirement	Capacity available
1956 hrs	86041	Forecast LOR 2 in QLD	1730 hrs 26/05/2021 to 1830 hrs 26/05/2021 and 1930 hrs 26/05/2021 to 2000 hrs 26/05/2021	696 MW 592 MW	575 MW 584 MW
2219 hrs	86060	Update to forecast LOR1 in QLD	1700 hrs 26/05/2021 to 2000 hrs 26/05/2021	868 MW	579 MW
2220 hrs	86061	Cancel forecast LOR2 in QLD	Cancelled from 2215 hrs on 26/05/2021	N/A	N/A
26 May 2021					
0742 hrs	86068	Update to forecast LOR1 in QLD	1700 hrs 26/05/2021 to 2130 hrs 26/05/2021	878 MW	462 MW
1011 hrs	86070	Update forecast LOR1 in QLD	1700 hrs 26/05/2021 to 1930 hrs 26/05/2021	878 MW	793 MW

A. AEMO originally issued this Market Notice stating New South Wales; this was corrected at 1845 hrs on 25/5/2021 with MN 86034.
B. AEMO's published RERT report relating to this event is at https://aemo.com.au/en/energy-systems/electricity/emergency-management/reliability-and-emergency-reserve-trader-rert/rert-reporting.

Figure 4 shows how the availability of generation capacity in Queensland changed during the event, due to generation tripping and returning to service. As shown below, at 1430 hrs on 25 May 2021, 3,314 MW of generation[7] was unavailable for dispatch. From 1430 hrs onwards, generation impacted by the event started to return to service. The impact of constraints on generation availability is not accounted for in Figure 4.

Figure 4 Changes in max available bid generation capacity unavailable due to incident in Queensland 25 May 2021 from generators tripped during the incident



[7] The generation capacity unavailable is based on the maximum availability bid from each of the affected generators in the period from 1300 hrs on 25 May 2021 to 0100 hrs on 26 May 2021.

7. Market notices

In addition to Market Notices associated with reserve conditions described in Section 6, the following Market Notices were issued in relation to power system security:

- At 1410 hrs on 25 May 2021, AEMO issued MN 85926 to advise of a non-credible contingency event involving tripping of Callide C3 and C4.
- At 1421 hrs on 25 May 2021, AEMO issued MN 85928 to advise of a non-credible contingency event involving tripping of multiple 275 kV circuits out of Calvale substation.
- At 1616 hrs on 25 May 2021, AEMO issued MN 85978 to update the market on the non-credible contingency event, advising the market of approximate MW of load interrupted.
- At 1952 hrs on 25 May 2021, AEMO issued MN 86042 to update the market on the non-credible contingency event and update the market that all forecast and actual LOR conditions for 25 May 2021 had been cancelled.
- At 0952 hrs on 26 May 2021, AEMO issued MN 86069 to provide the final update on the non-credible contingency event.
- At 1401 hrs on 26 May 2021, AEMO issued MN 86076 advising the market of updated system strength combinations for North Queensland.
- In addition, during the incident there were a number of market notices informing the market of price intervals under review[8].

8. Next steps

AEMO is continuing its investigation into this incident.

The investigation will include, as a minimum:

- A comprehensive timeline of events based on validated data.
- The impact of the event on market operation.
- AEMO's actions in response to the event.
- Generator performance:
  - Analysis of any unexpected operation (including trips) of large-scale generating units.
  - Analysis of the performance of embedded generation including distributed photovoltaics (PV).
  - Assessment of generator frequency response performance and its impact on the event.
- System impact and performance:
  - Assessment of the performance of the transmission and distribution networks, relevant control schemes, and protection equipment.
  - The cause of all transmission circuit trips associated with this incident.

[8] All market notices can be found at https://aemo.com.au/en/market-notices.

  - The impact of the event on QNI and analysis of its trip and reclose operation.
  - Detailed analysis of system frequency response throughout the incident, including UFLS operation.
  - A review of reserve conditions during and immediately following the event.
- Recommendations:
  - Exploration of potential and recommended mitigation measures for future operation.
  - Where appropriate with regard to the implications of this event, recommended future work to improve the operation and resilience of the NEM power system.

Investigation of this event requires AEMO to collect and analyse data from registered participants in the NEM to assess both the cause and effects of the event, as well as the individual and combined responses of equipment within the power system, at both the transmission and distribution level. In this regard, the following should be noted:

- Data and information will need to be provided by registered participants, who have (under the rules) up to 20 business days to respond to AEMO's information request. Most initial requests were issued on 27 May 2021.
- AEMO may need to request additional information from participants following initial analysis of this data.

Given these considerations, a timeline for publication of AEMO's final detailed operating incident report is yet to be determined.

A1. Lack of reserve notices

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

A1.1 LOR level 1 notice

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

A1.2 LOR level 2 notice

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

A1.3 LOR level 3 notice

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