MARKET EVENT REPORT

MT PIPER-WALLERAWANG 330 KV LINE OUTAGE 22 MAY 2014

Published: **October 2014**

AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

IMPORTANT NOTICE

Purpose

AEMO has prepared this report to advise its consideration and determination of an incident using information available as at 30 September 2014, unless otherwise specified.

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EXECUTIVE SUMMARY

This report explains an incident where a constraint did not adequately control flows on the network between Mt Piper and Wallerawang on 22 May 2014. The incident led to a price spike in New South Wales and a negative price in Queensland. Responding to stakeholder feedback, AEMO investigated the incident and found it was not due to a scheduling error.

The incident happened when AEMO took action to manage the NEM power system during an outage of the Mt Piper–Wallerawang No.71 330 kV line, at the same time as outages of the Dapto–Avon No.10, and Vales Pt–Sydney North No.22 330 kV lines.

Mt Piper Power Station and Wallerawang Power Station are located in New South Wales about 15 km from Lithgow and about 150 km west of Sydney. They are connected by three lines (No.70, No.71 330kV lines and No.94E 132 kV line). On the day in question, No.71 line was to be taken out of service for maintenance. The most critical contingency event for this outage is loss of the other 330 kV line causing a potential overload of the 132 kV line.

During the outages, AEMO's network constraint was unable to prevent an overload of the No.94E 132 kV line. The network constraint has a history of adequately managing the outages, but was insufficient on 22 May 2014. This was due to changed demand, network and generation patterns that AEMO was unable to predict or control. To rectify the situation, duty staff had to make several decisions in a very short timeframe. Despite all efforts, the event resulted in a 5-minute price spike.

AEMO was forced to use an automated constraint to manage the incident, which violated and caused the price spike in NSW and a negative price in Queensland. At around the same time, TransGrid recalled the No.71 line to service, but AEMO was unable to revoke the automated constraint in time to avoid the price outcome.

AEMO has concluded that even if the coincident No.10 and No.22 330 kV line outages in NSW had not occurred, the market outcomes would still have been the same.

AEMO and TransGrid have since identified data discrepancies affect the 132 kV networks in west NSW that have been corrected. AEMO and TransGrid have also agreed that during future outages of either of the Mt Piper–Wallerawang 330 kV lines, the parallel 132kV No.94E line will be opened.

AEMO has considered whether it should attempt to minimise the impact of automated constraints on the market with, for example, ramping constraints used for planned outages. AEMO uses automated constraints to manage existing NEM power system security issues, and concludes the benefits of ramping automated constraints do not justify the longer time to restore security.

As part of its investigation, AEMO considered whether it made a scheduling error, including:

- Whether AEMO acted consistently with its procedures in approving the three 330 kV line outages on the same day.
- Whether AEMO's constraint library had been maintained according to its procedures.
- Whether AEMO correctly applied its procedures while managing the NEM power system during the outages.

AEMO concluded that the central dispatch process was followed and AEMO could not have declared that any relevant dispatch interval contained a manifestly incorrect input, therefore no scheduling error occurred.

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1. INTRODUCTION

This report explains an incident where a constraint did not adequately control flows on the network between Mt Piper and Wallerawang on 22 May 2014. The incident led to a price spike in New South Wales and a negative price in Queensland on Thursday 22 May 2014.

The incident happened when AEMO took action to manage the NEM power system during an outage of the Mt Piper–Wallerawang No.71 330 kV line, at the same time as outages of the Dapto–Avon No.10, and Vales Pt–Sydney North No.22 330 kV transmission lines. The most critical contingency event for the No.71 330 kV line outage is loss of the parallel Mt Piper–Wallerawang No.70 330 kV line causing a potential overload of the Mt Piper–Wallerawang No.94E 132 kV line.

During the outages, AEMO's network constraint was unable to prevent a potential overload of the No.94E line. The network constraint has a history of adequately managing the outages, but was insufficient on 22 May 2014. This was due to changed demand, network and generation patterns that AEMO was unable to predict or control. To rectify the situation, duty staff had to make several decisions in a very short timeframe. Despite all efforts, the event resulted in a 5-minute price spike.

AEMO has investigated the incident with a view to determine whether it had made a scheduling error, considering the central dispatch process set out in rule 3.8 of the National Electricity Rules (NER), specifically:

- Whether AEMO acted consistently with its procedures in approving the three 330 kV outages on the same day.
- Whether AEMO's constraint library had been maintained according to its procedures.
- Whether AEMO correctly applied its procedures while managing the NEM power system during the outage.

During the investigation, AEMO also identified some data discrepancies between AEMO and TransGrid tools for the managing the NEM power system.

This report presents the findings of AEMO's investigations and subsequent actions by AEMO and TransGrid to prevent similar events occurring.

2. BACKGROUND

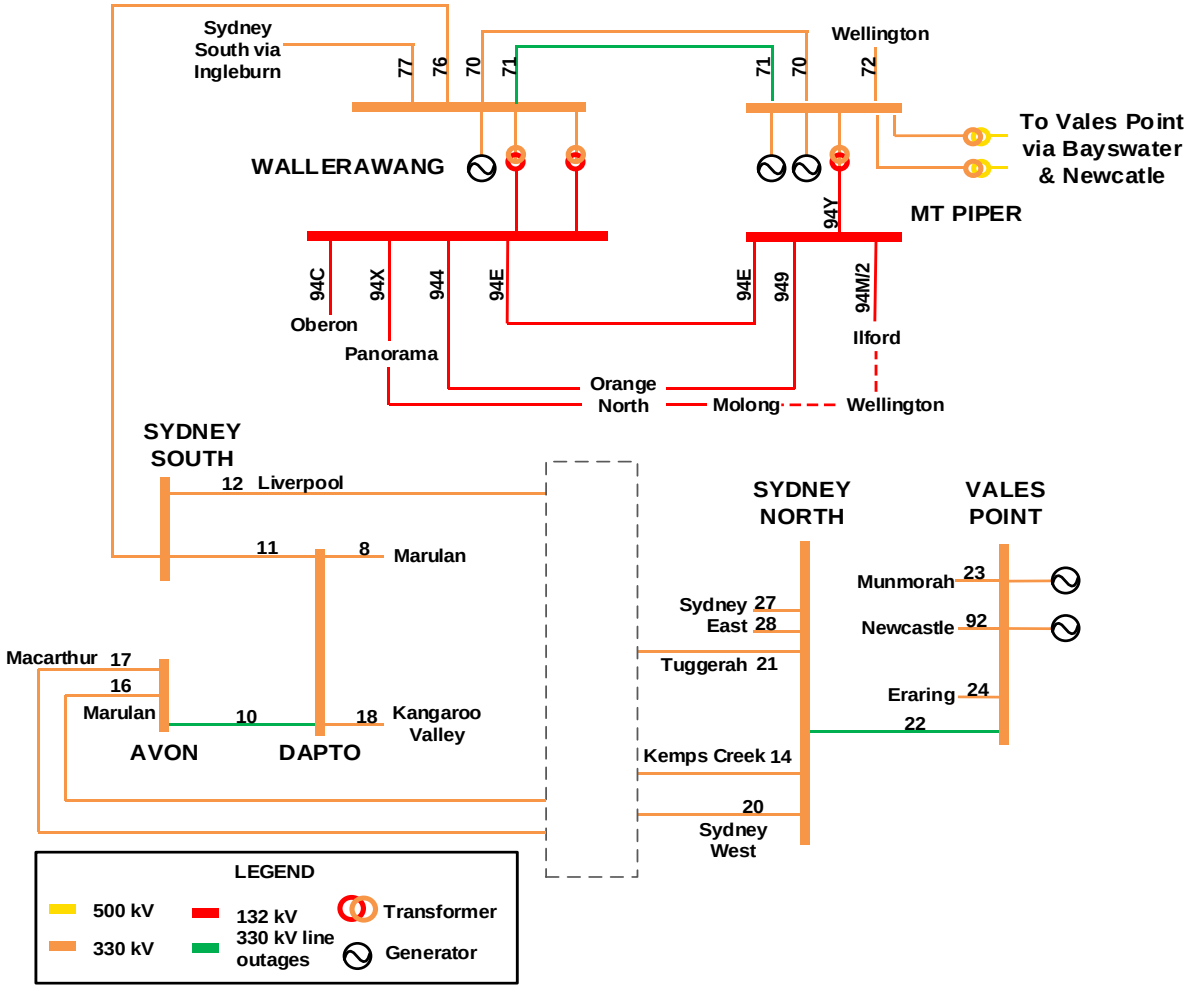
2.1 NEM Power System

Mt Piper Power Station and Wallerawang Power Station are located in New South Wales about 15 km from Lithgow and about 150 km west of Sydney. They are connected by three lines (Mt Piper–Wallerawang No.70 and No.71 330kV lines and Mt Piper–Wallerawang No.94E 132 kV line). On 22 May 2014, No.71 line was to be taken out of service for maintenance. The most critical contingency for this prior outage is loss of the other 330 kV line causing a potential overload of the 132 kV line.

On the same day, there were concurrent outages of the Dapto–Avon No.10 330 kV line south of Sydney and the Vale Pt–Sydney North No.22 330 kV line north of Sydney. These lines are owned and operated by TransGrid, which advises that these outages can proceed at the same time without affecting each other or NEM power system security.

These outages are shown in Figure 1.

Figure 1 Simplified system diagram for the 330 kV lines out of service



2.2 Processes for Managing Network Outages

AEMO maintains a number of procedures and guidelines that implement the requirements of the NER. The relevant AEMO documents for this outage are:

- SO_OP_3718 Outage Assessment, which describes procedures for submitting and assessing outage requests.
- SO_OP_3715 Power System Security Guidelines, which describes procedures for preparing for outages and granting permission to proceed.
- Constraint formulation guidelines[1], which among other things include the processes by which AEMO will identify or be advised of the requirement to create or modify a constraint and to be used by AEMO for applying, invoking and revoking a constraint.

2.3 Scheduling Errors in the NEM

A scheduling error is any one of the following circumstances[2]:

- AEMO declares, or the dispute resolution panel determines, that AEMO has failed to follow the central dispatch process set out in rule 3.8 of the NER; or
- AEMO determines under clause 3.9.2B(d) that a dispatch interval contained a manifestly incorrect input.

Failure to follow the central dispatch process

The relevant parts of rule 3.8 are:

- Clause 3.8.1(b) paragraphs (4) and (5), which require that central dispatch is subject to power system security requirements and network constraints.
- Clause 3.8.10, which requires AEMO to develop and comply with the network constraint formulation guidelines.[3]

Manifestly incorrect inputs

The procedures for manifestly incorrect inputs require that a dispatch interval (DI) must be identified as subject to review by the automated procedure referred to in clause 3.9.2B(h) before it can be considered a scheduling error.

[1] Refer clause 3.8.10 of the NER.
[2] Refer clause 3.8.24 of the NER.
[3] AEMO. *Constraint Formulation Guidelines*. 6 July 2010. http://www.aemo.com.au/Electricity/Market-Operations/Ancillary-Services/Guides-and-Descriptions/Constraint-Formulation-Guidelines

3. EVENT DETAILS

3.1 Prior to the Event

On 2 May 2014, TransGrid requested the No.71 line outage through the Network Outage Scheduler and was approved as follows:

- AEMO completed medium term outage assessment and provided “Medium Term Likely to Proceed” approval on 14 May 2014. This assessment included assessment of concurrent outages of No.71 line, No.10 and No.22 330kV lines. AEMO concluded the interaction of these three outages were minimal and that it was appropriate to use individual outage constraints for each outage. This was confirmed with TransGrid.
- AEMO completed short term outage assessment and provided “Short Term Likely to Proceed” approval on 15 May 2014.
- AEMO studied the outage on 21 May 2014 and identified that flow on No.94E line following loss of No.70 line may exceed the line’s rating without a network constraint to manage the flow. Constraint equations were invoked to manage the outage.

3.2 Sequence of the Events on the Day

Table 1 Sequence of Events – 22 May 2014

Time	Events/Comments
07:30	Ramping constraints for the planned outage commenced.
08:00	Outage constraint set N-MPWW_ONE commenced from dispatch interval ending 08:05 hrs.
08:02	Mt Piper–Wallerawang No.71 330 kV line outage commenced.
08:05	Contingency violations flagged by AEMO’s contingency analysis software, indicating the potential for an overload of the Mt Piper–Wallerawang No. 94E 132 kV line following a trip of the Mt Piper–Wallerawang No.70 330 kV line. The estimated potential overload was in the order of 9 MVA above the continuous rating of 229 MVA.
08:29	AEMO agreed a contingency plan with TransGrid to open the No.94E line if the No.70 line trips. TransGrid accepted a short overload on the line until the line would be opened.
08:50	The potential overload increased to the extent that TransGrid requested the contingency plan cease and that AEMO manage the outage with constraint equation. From this time the power system was no longer in a secure operating state.
08:51	AEMO invoked auto constraint set CA_SPS_428FB629 to commence from dispatch interval ending 09:00 hrs.
08:54	TransGrid advised No.71 line is being recalled and that the auto constraint was no longer required. As the auto constraint had already been processed for dispatch interval ending 09:00, the auto-constraint was revoked from dispatch interval ending 09:05 hrs.
08:55	Dispatch for the dispatch interval ending 09:00 hrs published. Equation CA_SPS_428FB629_01 violated, over-constrained dispatch rerun and manifestly incorrect input processes triggered. AEMO determined there was no manifestly incorrect input and prices confirmed. NSW dispatch price $13,100/MWh and Queensland dispatch price -$1,000/MWh
08:56	TransGrid permission to restore No.71 line.
08:57	Mt Piper–Wallerawang No. 71 330 kV transmission line returned to service
08:59	Outage constraint modified based on coefficients used in the automated constraint.
09:00	Dispatch for the DI ending 0905 hrs published and prices were in the normal range. The outage constraint set N-MPWW_ONE revoked at 09:00:36.
09:25	Spot prices for TI ending 09:00 hrs published. NSW $2,224.54/MWh, Queensland -$124.56/MWh. Other region prices were between $39/MWh and $55/MWh

3.3 NEM Power System Outcomes

During the No.71 line outage, no lines exceeded their ratings and the NEM power system was operated in a satisfactory operating state.

Despite indications of a potential overload from 08:00 hrs, the NEM power system was also operated in a secure operating state while the contingency plan agreed between TransGrid and AEMO was in place. However, from 08:50 hrs TransGrid determined the contingency plan was no longer sufficient and the NEM power system was no longer being operating in a secure operating state. At this time, AEMO took steps to invoke an automated constraint to return the power system to a secure operating state as soon as practical.[4]

AEMO has determined the NEM power system was not in a secure operating state from 08:50 hrs until 08:57 hrs, when the No.71 line was returned to service.

3.4 Market Outcomes

Spot prices in New South Wales and Queensland were $2,224.54/MWh and -$124.56/MWh respectively for the trading interval (TI) ending 09:00 hrs. This was a result of the 5-minute dispatch prices in New South Wales and Queensland being the market price cap of $13,100/MWh and the market floor price of -$1,000/MWh respectively for DI ending 0900 hrs. This was caused by the violation of the automated constraint.

The automated constraint violated for DI ending 0900 hrs when the desired generation changes could not be achieved within the dispatch interval. This was because a number of generators in NSW were either fully dispatched, limited by their FCAS profile or ramp rates, or were fast start units requiring more than 5-minute to synchronise.

The automatic over-constrained dispatch process triggered for DI ending 0900 hrs. When a dispatch solution is not feasible (or “over-constrained”), the price determined by AEMO may include the value of constraint violation penalty factors designed to allow constraints to be violated in a priority order and a dispatch solution to be determined. The over-constrained dispatch process is run automatically to determine a price based on market bids and offers without any influence from those factors.

The automatic process for identifying prices subject to review due to a potential manifestly incorrect input was triggered for DIs ending 0900 hrs and 0905 hrs. AEMO determined that there were no incorrect inputs and the prices were confirmed. Market Notices No. 45750 and 45751 were issued at 0904 hrs to inform participants.

The incident has been discussed at the National Electricity Market Wholesale Consultative Forum meetings. In those meetings, AEMO advised it would undertake a review of the incident with a view to determining whether it had made a scheduling error.

[4] Refer general principles for maintaining power system security in clause 4.2.6 of the NER.

4. ISSUES

4.1 Simultaneous outages

Stakeholders raised concerns that the outage should not have been scheduled at the same time

Post event power system analysis carried by AEMO has verified that the simultaneous outages of the No.71, No.10 and No.22 330 kV lines had minimum impact on the post-contingent flow of the No.94E 132 kV line in the event of a trip of the No.70 330 kV line. A separate analysis by TransGrid also confirmed that the outages had no impact on the incident.

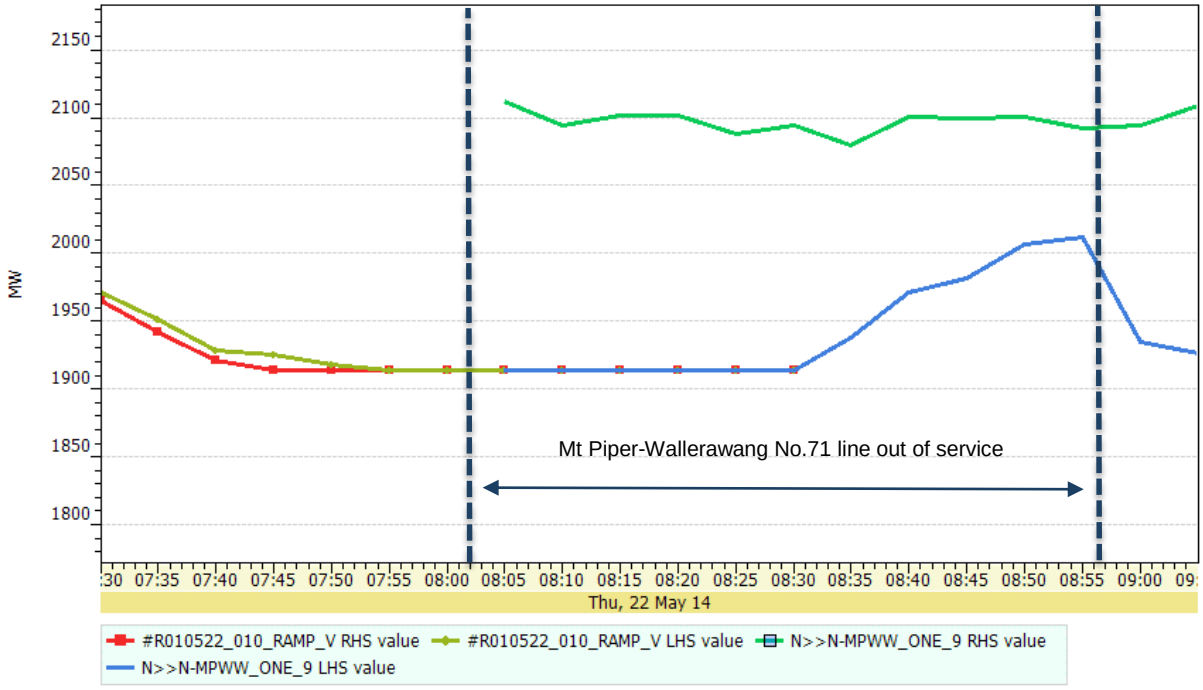
4.2 Outage constraint equations

Constraint set N-MPWW_ONE was invoked to commence from 0800 hrs for DI ending 0805 hrs when the No.71 line was removed from service. This constraint set manages the post-contingent flows on several lines during the outage of the No.71 line for the trip of the parallel No.70 line. The most critical contingency event for this outage is loss of the other 330 kV line causing a potential overload of the No.94E 132 kV line, which is managed by the constraint equation N>>N-MPWW_ONE_9. The coefficients used on the left-hand-side (LHS) and right-hand-side (RHS) of this constraint are shown in Appendix A.1.

This constraint equation had been invoked twice prior to this event – 10 October 2013 from DIs ending 0705 hrs to 1525 hrs, and from 7 January 2014 DI 0705 hrs to 8 January 2014 DI 1620 hrs. The constraint equation N>>N-MPWW_ONE_9 did not bind during those periods and no contingency violation was flagged in AEMO's real time contingency analysis (RTCA) application. The same version of the constraint equation was invoked for the outage on the 22 May 2014.

On 22 May 2014, the constraint equation also did not bind. The differences between the left and right hand side values ranged between 80 MW to 199 MW (as shown in Figure 2) even though contingency violations were flagged by AEMO's real time contingency analysis application. Recent augmentations of the 132 kV network around Orange, Molong, Wallerawang and the Manildra areas shifted area demands and changed the line flows on the network.

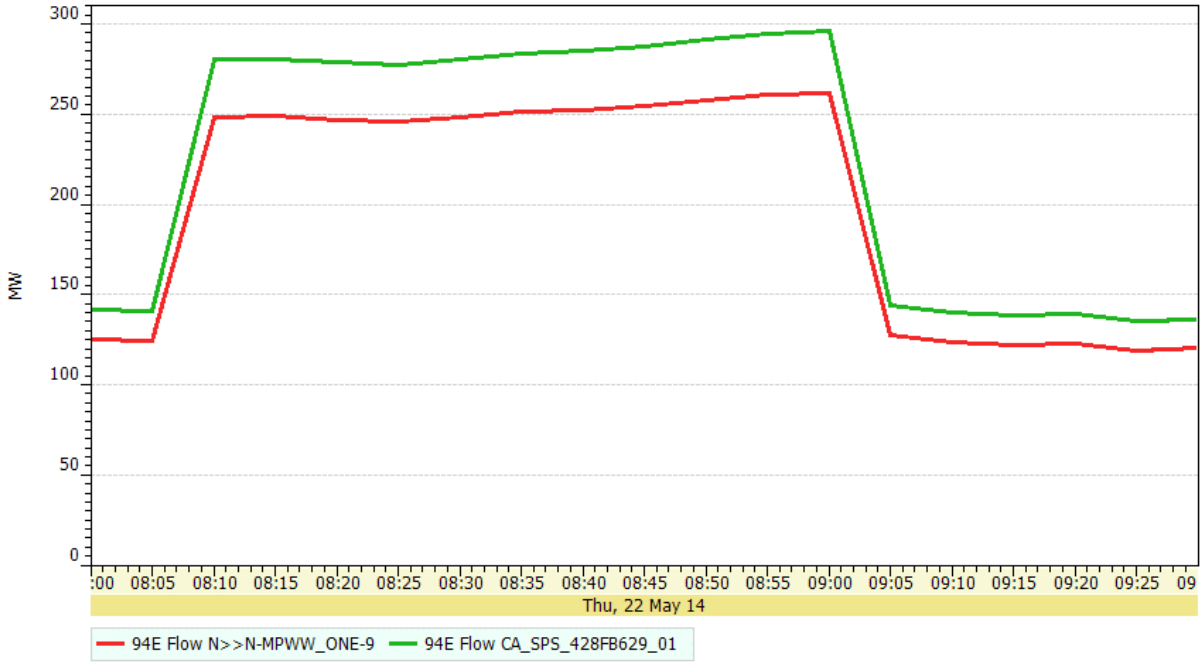
Figure 2 LHS and RHS values of constraint equations



Automated constraint equation CA_SPS_428FB629_01 was invoked in DI ending 0900 hrs (see the constraint description in Appendix A.2) and violated by 39.42 MW. Automated constraints are generated ad hoc using the most recently available network model and demand data. AEMO reviewed the performance of the constraint equation N>>N-MPWW_ONE_9 and determined that it should have been binding. The factors were adjusted at 0959hrs to take into account the 132 kV subsystem changes between Mt Piper and Wallerawang. In particular the post-contingent flow RHS terms were changed to reflect a higher contribution from the tripping of the No.70 transmission line.

Figure 3 shows the difference between the calculated post-contingency flows on the No.94E line for the outage constraint and the automated constraint, showing a difference of around 30 MW.

Figure 3 Post contingent flows on No.94E line based on different factors



4.3 Model differences between AEMO and TransGrid

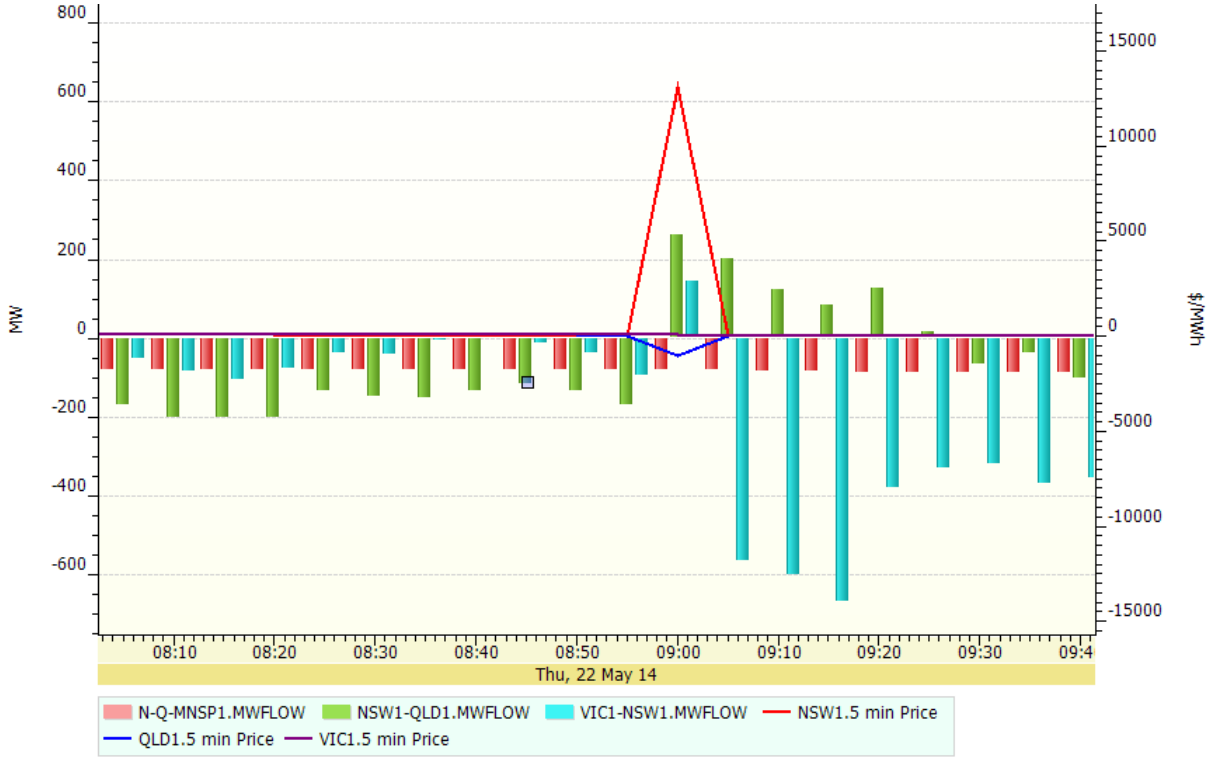
The automated constraint CA_SPS_428FB629_01 was invoked at TransGrid's request as the potential overload on the No.94E line increased. According to TransGrid's analysis, by 0850 hrs the post-contingency loading had exceeded the short term rating of the No.94E line. However, AEMO's RTCA indicated approximately 65 MVA lower in the post-contingency loading. AEMO will generally use the higher estimate of an overload where differences between models are found when making operational decisions. The difference was found to be due to incorrect line impedances entered for the No.94E line in TransGrid's systems.

Following this incident, AEMO and TransGrid have agreed that for future outages of either Mt Piper–Wallerawang No.70 or No.71 330 kV lines, the No.94E 132 kV line will be opened. This will overcome potential issues with needing to constrain generation in the NEM without compromising NEM power system security.

4.4 Market impact

There were large changes in the flows on the VIC-NSW and QNI interconnectors, as shown in Figure 4. Target flow on QNI reversed from exporting 163 MW towards New South Wales to importing 264 MW to Queensland. This reduced the generation targets of Queensland units by approximately 360 MW. The dispatch price in Queensland reduced from $49.53/MWh to -$1,000/MWh due to the excess generation in Queensland. The target flow on the VIC-NSW interconnector changed direction, from exporting 91 MW to Victoria to importing 144 MW to New South Wales. The dispatch prices in Victoria increased from $51.00/MWh to $61.94/MWh.

Figure 4 5-Minute dispatch prices and interconnector target flows for selected regions and interconnectors



AEMO has examined whether a correctly functioning constraint would have violated, shifting the price spike to the start of the outage. AEMO re-ran the dispatch algorithm substituting the outage constraint N>>N-MPWW_ONE_9 with the automated constraint CA_SPS_428FB629_01 at the start of the outage. This indicates what may have happened had the constraint issue been identified and corrected before the outage. Table 2 compares the two constraints for DI ending 0810 hrs.

Table 2 Comparison of market outcomes for DI 0810 hrs

	Published result	Re-run result
New South Wales RRP ($/MWh)	53.48	53.48
NSW to Queensland target (MW)	-198	-164
Gladstone Units 1-4 targets (MW)	186.80	178.37
Mt Piper 1 -2 target	532.86	516.8
Vales Pt 5 -6 target	507.46	540.59
CA_SPS_428FB629_01 RHS (MW)	N/A	1832.73
CA_SPS_428FB629_01 Marginal value ($)	N/A	-6.52

The analysis confirms a correctly functioning constraint would not have violated. AEMO concludes the price spike in DI ending 0900 hrs would not have occurred had the automated constraint been invoked at the start of the outage instead of 0900 hrs.

5. SCHEDULING ERROR ASSESSMENT

A scheduling error occurs where AEMO has failed to follow the central dispatch process set out in rule 3.8 of the NER or where AEMO determines that a dispatch interval contained a manifestly incorrect input[5].

This section describes AEMO's consideration of whether it had failed to follow the central dispatch process in terms of the following:

- Whether AEMO acted consistently with its procedures in approving the three 330 kV outages on the same day.
- Whether AEMO's constraint library had been maintained according to its procedures.
- Whether AEMO correctly applied its procedures while managing the NEM power system during the outage.

5.1 Approval of concurrent outages of three 330 kV lines

AEMO's processes followed prior to the event are described in section 3.1 above. The approval steps taken are consistent with the requirements of AEMO's outage assessment procedures and AEMO concludes there was no failure to follow this procedure.

5.2 Constraint library maintenance

AEMO maintains a large set of constraints in AEMO's constraint library to ensure that any constraint equations invoked are up-to-date. The constraints within the library are reviewed on a regular basis and also when required, such as when transmission network service providers provide new limit advices.

Over the last three years, the outage constraint equation that was invoked N>>N-MPWW_ONE_9 had been revised three times prior to the last version that was invoked (revised date of 4 October 2013). A summary of the changes is available from Table 3.

Table 3 Constraint equation N>>N-MPWW_ONE_9 modifications

Revised data	Modifications
12 May 2011	Added Gunning and Woodlawn wind farms
14 May 2013	Change in operating margin as per limit advise
21 August 2013	Updated CVP to the new value
4 October 2013	Added Gullen Range wind farm and Yass-Gullen Range No.3J 330 kV line

The same version of the constraint set that was invoked on 22 May 2014 was invoked twice in the system prior to the event – on 10 October 2013 from DIs ending 0705 hrs to 1525 hrs, and from 7 January 2014 DI 0705 hrs to 8 January 2014 DI 1620 hrs. The constraint equation N>>N-MPWW_ONE_9 did not bind during those periods and no contingency violations were flagged.

AEMO concludes its procedures for maintaining the constraint library were followed. Further, AEMO considers it had no information to indicate the constraint would not correctly manage the outage.

5.3 Management of the outage

AEMO endeavoured to apply its procedures while liaising with TransGrid to ensure that the NEM power system remains secure during the outage of No.71 line. As per AEMO's operating procedure[6], in the event a network constraint is ineffective, AEMO manages power system security in the following order of preference:

[5] Clause 3.8.24(a) of the NER.
[6] AEMO. 29 July 2014. *Power System Security Guidelines SO_OP3715.* Available: http://www.aemo.com.au/Electricity/Policies-and-Procedures/System-Operating-Procedures/Power-System-Security-Guidelines-SO_OP3715

- Reconfigure the transmission network
- Direction or clause 4.8.9 instruction
- Involuntary load shedding post-contingency
- Involuntary load shedding pre-contingency (applicable in cases of unplanned transmission outages)

The procedure requires that any contingency plan will need to be agreed with parties involved in the execution of the plan. In this event, TransGrid was regularly consulted and contingency plans were agreed upon by both AEMO and TransGrid prior to implementation.

When AEMO's RTCA application indicated the potential for thermal overload of the No.94E line following a trip of the No.70 line, AEMO and TransGrid agreed a contingency plan involving opening the No.94E line if the No.70 line trips.

However, once the post-contingency overload on the No.94E line was observed to increase, TransGrid requested AEMO to use constraint equation(s) to manage power system security instead of the agreed contingency plan. As stated in AEMO's procedure[6], in most cases network constraints will be used to manage the power system. With the invoked outage constraint set, N-MPWW_ONE, being too relaxed an auto constraint set CA_SPS_428FB629 was invoked. It was revoked once TransGrid advised that it had recalled the No.71 line.

When the automated constraint set was invoked, it initially violated because of the high post-contingency load on the No.94E line. The price spike in NSW and the negative price in Queensland was caused by the violation of the automated constraint. AEMO uses ramping techniques to reduce the impact of network constraints that may violate during preparations for transmission outages. While similar techniques are feasible for automated constraints, there are some practical difficulties with the current process that make this impractical to apply at this stage:

- It requires a predispatch run to determine the parameters for the ramping constraints.
- Ramping occurs over a period of 30 minutes, which would not be consistent with AEMO's obligations for managing NEM power system security.
- Automated constraints are usually used to rectify existing power system security issues, where AEMO needs to act as quickly as possible.

AEMO concludes it correctly followed its procedures in managing the outage.

5.4 Manifestly incorrect input

As indicated in section 2.3, a DI cannot be considered to be affected by a manifestly incorrect input (and therefore a scheduling error) unless AEMO rejects the price of a dispatch interval that has been identified as subject to review. For this incident:

- Dispatch intervals ending 08:05 to 09:00 hrs used the outage constraint, which should have bound. Because the constraint did not bind, there was no trigger and so these DIs were not marked as subject to review.
- Dispatch interval ending 09:05 hrs used the automated constraint, which violated and caused the price spike. The price spike triggered the automated procedure and the interval was marked as subject to review.

Although DIs ending 08:05 to 09:00 hrs could be argued as being affected by an incorrect input (the outage constraint), it was not a manifestly incorrect input because the dispatch interval was not automatically marked as subject to review.

Conversely, although DI ending 09:05 hrs was automatically marked as subject to review, the automated constraint was correct and AEMO correctly accepted the prices because there was no incorrect input.

AEMO could not have declared that any of these DIs contained a manifestly incorrect input.

6. CONCLUSIONS AND RECOMMENDATIONS

The incident was the result of an outage constraint that did not adequately control flow on the network between Mt Piper and Wallerawang on 22 May 2014. This led to a price spike in New South Wales and a negative price in Queensland. Responding to stakeholder feedback, AEMO investigated the incident and found it was not due to a scheduling error.

The incident happened when AEMO took action to manage the NEM power system during an outage of the Mt Piper–Wallerawang No.71 330 kV line, at the same time as outages of the Dapto–Avon No.10, and Vales Pt–Sydney North No.22 330 kV lines. The most critical contingency for the No.71 line outage is loss of the Mt Piper–Wallerawang No.70 330 kV line causing a potential overload of the Mt Piper–Wallerawang No.94E 132 kV line.

AEMO and TransGrid took appropriate actions during the planning and operational stages of the outage to ensure power system security. These actions included initially agreeing a contingency plan to manage the most critical contingency event. TransGrid subsequently considered the contingency plan was no longer adequate and requested AEMO use a constraint equation to remedy the situation. AEMO used an automated constraint to do this, which violated and caused a high price in NSW and a negative price in Queensland. TransGrid decided to recall the No.71 line to service, but AEMO was unable to revoke the automated constraint in time to avoid the price outcome.

AEMO has concluded that even if the coincident No.10 and No.22 line outages in NSW had not occurred, the market outcomes would still have been the same.

AEMO and TransGrid have since identified data discrepancies affect the 132 kV networks in west NSW that have been corrected. AEMO and TransGrid have also agreed that during future outages of either of the Mt Piper–Wallerawang 330 kV lines, the parallel 132kV No.94E line will be opened.

AEMO has considered whether it should attempt to minimise the impact of automated constraints on the market with, for example, ramping constraints used for planned outages. AEMO uses automated constraints to manage existing NEM power system security issues, and concludes the benefits of ramping automated constraints do not justify the longer time to restore security.

AEMO concludes it has not made a scheduling error because:

- AEMO acted consistently with its procedures in approving the three 330 kV line outages on the same day.
- AEMO's constraint library had been maintained according to its procedures and the failure of the outage constraint was due to circumstances outside AEMO's knowledge or control.
- AEMO correctly applied its procedures while managing the NEM power system during the incident. The automated constraints used by AEMO to restore loading on the NEM power system acted correctly.

AEMO concludes that because the central dispatch process was followed and AEMO could not have declared that any relevant dispatch interval contained a manifestly incorrect input, no scheduling error occurred.

APPENDIX A. CONSTRAINT EQUATIONS

A.1 N>>N-MPWW_ONE_9

Constraint type: LHS<=RHS

Effective date: 04/10/2013

Version No: 1

Weight: 30

Constraint active in: Dispatch and DS PASA, Predispatch and PD PASA, ST PASA

5 Min Predispatch RHS: Predispatch

Active in PASA for: LRC & LOR

Constraint description: Out = Mt. Piper to Wallerawang(70 or 71), avoid Mt Piper to Wallerawang(94E) O/L on MtPiper-Wallerawang(71 or 70) trip; Feedback

LHS=

0.237 x Bayswater unit 1 (ENERGY)

0.237 x Bayswater unit 2 (ENERGY)

0.343 x Bayswater unit 3 (ENERGY)

0.343 x Bayswater unit 4 (ENERGY)

0.205 x Blowering hydro (3 aggregated units) (ENERGY)

0.154 x Woodlawn wind farm (ENERGY)

0.23 x Gullen Range WF (ENERGY)

0.189 x Guthega hydro (2 aggregated units) (ENERGY)

0.199 x Hume (NSW) hydro (ENERGY)

0.228 x Hunter GT (2 aggregated units) (ENERGY)

0.228 x Liddell unit 1 (ENERGY)

0.228 x Liddell unit 2 (ENERGY)

0.228 x Liddell unit 3 (ENERGY)

0.228 x Liddell unit 4 (ENERGY)

-0.197 x Lower Tumut pumps (3 aggregated pumps) (ENERGY)

0.197 x Lower Tumut hydro (6 aggregated units) (ENERGY)

0.227 x Redbank unit 1 (ENERGY)

0.778 x Mt Piper unit 1 (ENERGY)

0.778 x Mt Piper unit 2 (ENERGY)

0.079 x Shoalhaven hydro (aggregated Bendeela and Kangaroo Valley units) (ENERGY)

-0.079 x Shoalhaven pumps (2 aggregated pumps) (ENERGY)

0.2 x Uranquinty GT unit 1 (ENERGY)

0.2 x Uranquinty GT unit 2 (ENERGY)

0.2 x Uranquinty GT unit 3 (ENERGY)

0.2 x Uranquinty GT unit 4 (ENERGY)

0.197 x Upper Tumut hydro (8 aggregated units) (ENERGY)

- Wallerawang unit 7 (ENERGY)

- Wallerawang unit 8 (ENERGY)

0.211 x Gunning Wind Farm (ENERGY)

-0.212 x MW flow north on the Terranora Interconnector

-0.218 x MW flow north on the QNI AC Interconnector

0.198 x MW flow north on the Vic to NSW AC Interconnector

RHS

Default RHS value= 3000

Dispatch RHS=

6.824 x (NSW: 94E Mt.Piper - Wallerawang 132kV Sustained Emergency Rating

- MW flow on 94E 132kV line at Mt Piper

- 0.261 x [MW flow on 70 330kV line at Mt Piper, Line end switched MW]

- 0.261 x [MW flow on 71 330kV line at Mt Piper, Line end switched MW]

- 10 {Margin})

+ 0.198 x [MW flow north on the Vic to NSW AC Interconnector]

- 0.218 x [MW flow north on the QNI AC Interconnector]

- 0.212 x [MW flow north on the Terranora Interconnector]

+ 0.237 x [Bayswater unit 1]

+ 0.237 x [Bayswater unit 2]

+ 0.343 x [Bayswater unit 3]

+ 0.343 x [Bayswater unit 4]

+ 0.228 x [Liddell unit 1]

+ 0.228 x [Liddell unit 2]

+ 0.228 x [Liddell unit 3]

+ 0.228 x [Liddell unit 4]

+ 0.778 x [Mt Piper unit 1]

+ 0.778 x [Mt Piper unit 2]

- Wallerawang unit 7

- Wallerawang unit 8

+ 0.079 x [Shoalhaven hydro (aggregated Bendeela and Kangaroo Valley units)]

- 0.079 x [Shoalhaven pumps (2 aggregated pumps)]

+ 0.205 x [Blowering hydro (3 aggregated units)]

+ 0.227 x [Redbank unit 1]

+ 0.199 x [Hume (NSW) hydro]

+ 0.228 x [Hunter GT (2 aggregated units)]

+ 0.197 x [Upper Tumut hydro (8 aggregated units)]

+ 0.197 x [Lower Tumut hydro (6 aggregated units)]

- 0.197 x [Lower Tumut pumps (3 aggregated pumps)]

+ 0.189 x [Guthega hydro (2 aggregated units)]

+ 0.2 x [Uranquinty GT unit 1]

+ 0.2 x [Uranquinty GT unit 2]

+ 0.2 x [Uranquinty GT unit 3]

+ 0.2 x [Uranquinty GT unit 4]

+ 0.211 x [Gunning Wind Farm]

+ 0.154 x [Woodlawn wind farm]

+ 0.23 x [Gullen Range WF]

A.2 CA_SPS_428FB629_01

Constraint type: LHS<=RHS

Effective date: 22/05/2014

Version No: 1

Weight: 30

Constraint active in: Dispatch and DS PASA, Predispatch and PD PASA, ST PASA

5 Min Predispatch RHS: Dispatch

Active in PASA for: LRC & LOR

Constraint description: Constraint Automation, O/L 94E @MT_PIPER for CTG LNWT on trip of MT_PIPER-WWANG 70 330KV LINE. Generated by STNET[NORFL] Host NOREEMP4(SP)

Source: Constraint Automation

LHS=

0.2348 x Bayswater unit 1 (ENERGY)

0.2348 x Bayswater unit 2 (ENERGY)

0.3364 x Bayswater unit 3 (ENERGY)

0.3364 x Bayswater unit 4 (ENERGY)

0.1967 x Blowering hydro (3 aggregated units) (ENERGY)

0.1381 x Woodlawn wind farm (ENERGY)

0.2168 x Gullen Range WF (ENERGY)

0.1846 x Guthega hydro (2 aggregated units) (ENERGY)

0.1864 x Hume (NSW) hydro (ENERGY)

0.2268 x Hunter GT (2 aggregated units) (ENERGY)

0.2268 x Liddell unit 1 (ENERGY)

0.2268 x Liddell unit 2 (ENERGY)

0.2268 x Liddell unit 3 (ENERGY)

0.2268 x Liddell unit 4 (ENERGY)

-0.1845 x Lower Tumut pumps (3 aggregated pumps) (ENERGY)

0.1845 x Lower Tumut hydro (6 aggregated units) (ENERGY)

0.2262 x Redbank unit 1 (ENERGY)

0.7479 x Mt Piper unit 1 (ENERGY)

0.7479 x Mt Piper unit 2 (ENERGY)

0.1884 x Uranquinty GT unit 1 (ENERGY)

0.1884 x Uranquinty GT unit 2 (ENERGY)

0.1884 x Uranquinty GT unit 3 (ENERGY)

0.1884 x Uranquinty GT unit 4 (ENERGY)

0.1841 x Upper Tumut hydro (8 aggregated units) (ENERGY)

- Wallerawang unit 7 (ENERGY)

- Wallerawang unit 8 (ENERGY)

0.2051 x Gunning Wind Farm (ENERGY)

-0.2122 x MW flow north on the Terranora Interconnector

-0.2177 x MW flow north on the QNI AC Interconnector

0.1853 x MW flow north on the Vic to NSW AC Interconnector

RHS

Default RHS value= 10000

Dispatch RHS=

5.5709 x (-1 x [MW flow on 94E 132kV line at Mt Piper]

- 0.2972 x [MW flow on 70 330kV line at Mt Piper, Line end switched MW]

+ NSW: 94E Mt.Piper - Wallerawang 132kV Sustained Emergency Rating

- 10 {Margin})

+ 0.2348 x [Bayswater unit 1]

+ 0.2348 x [Bayswater unit 2]

+ 0.3364 x [Bayswater unit 3]

+ 0.3364 x [Bayswater unit 4]

+ 0.2268 x [Liddell unit 1]

+ 0.2268 x [Liddell unit 2]

+ 0.2268 x [Liddell unit 3]

+ 0.2268 x [Liddell unit 4]

+ 0.2262 x [Redbank unit 1]

+ 0.7479 x [Mt Piper unit 1]

+ 0.7479 x [Mt Piper unit 2]

- Wallerawang unit 7

- Wallerawang unit 8

+ 0.1381 x [Woodlawn wind farm]

+ 0.2051 x [Gunning Wind Farm]

+ 0.1884 x [Uranquinty GT unit 1]

+ 0.1884 x [Uranquinty GT unit 2]

+ 0.1884 x [Uranquinty GT unit 3]

+ 0.1884 x [Uranquinty GT unit 4]

- 0.2122 x [MW flow north on the Terranora Interconnector]

+ 0.1864 x [Hume (NSW) hydro]

+ 0.1967 x [Blowering hydro (3 aggregated units)]

+ 0.1853 x [MW flow north on the Vic to NSW AC Interconnector]

- 0.2177 x [MW flow north on the QNI AC Interconnector]

+ 0.2268 x [Hunter GT (2 aggregated units)]

+ 0.2168 x [Gullen Range WF]

+ 0.1841 x [Upper Tumut hydro (8 aggregated units)]

+ 0.1845 x [Lower Tumut hydro (6 aggregated units)]

+ 0.1846 x [Guthega hydro (2 aggregated units)]

- 0.1845 x [Lower Tumut pumps (3 aggregated pumps)]

GLOSSARY

Abbreviations	Term
AEMO	Australian Energy Market Operator Ltd
EMS	Energy Management System
CVP	Constraint Violation Penalty
DI	Dispatch Interval
kV	kilo Volt
LHS	Left-Hand-Side
MII	Manifestly Incorrect Input
NEM	National Electricity Market
NEMDE	NEM Dispatch Engine
NER	National Electricity Rules
NOS	Network Outage Scheduler
OCD	Over-Constrained Dispatch
PTR	Permission to Restore
QNI	Queensland - New South Wales 330kV interconnector
RTCA	Real Time Contingency Analysis
RHS	Right-Hand-Side
SCADA	Supervisory Control and Data Acquisition
TI	Trading Interval