AEMO's third report on South Australian Blackout:

Wind Generation did not Survive Multiple Voltage Dips

In December 2016, the Australian Energy Market Operator (AEMO) published its third report on the South Australian blackout on 28 September 2016. The 160 pages report includes a large amount of supplementary information. A fourth and final report is due to be published in March 2017.

AEMO states: *"The particular event was initiated by the loss of three transmission lines involving a sequence of faults in quick succession tripping generators offline. Such extreme events occur rarely and are classified as 'non-credible' in the National Electricity Market (NEM)."*

A disturbance of the power supply in South Australia (SA) could not be avoided. The question is, if reasonable precautions could have cushioned the consequences.

Operating reserves

On the morning of Wednesday 28 September 2016, weather warnings were received by AEMO's NEM Control Room, stating a severe storm with heavy lightning and damaging winds across SA was approaching. Based on an assessment of information available at 0830 hrs, it was determined that there was no action to be taken by AEMO to reclassify lines as a result of the weather warnings.

AEMO manages the power system to an N-1 standard, meaning that any single element (generator, transmission line, etc.) can be suddenly lost without violation of critical limits. Events beyond the N-1 standard, such as the coincident loss of multiple generating units or transmission lines, are termed non-credible contingency events. AEMO can reclassify non-credible contingency events as credible contingency events if circumstances increase the risk of their occurrence.

The Heywood Interconnector to Victoria would remain stable for the loss of 260 MW of generation within SA.

456 MW wind generation lost

From AEMO's third report:

"Immediately prior to the event, Supervisory Control and Data Acquisition (SCADA) data showed that the 1,826 MW of electricity demand of SA's 850,000 electricity customers was being collectively supplied by:

- *883 MW of SA wind generation.*
- *330 MW of SA gas generation.*
- *613 MW of electricity imports via the two interconnections with Victoria.*

The total amount of domestic solar photovoltaic (PV) was estimated to be approximately 50 MW.
Extreme weather conditions resulted in five system faults on the SA transmission system in the 87 seconds between 16:16:46 and 16:18:13, with three transmission lines ultimately brought down.
In response to these faults32, and the resulting six voltage disturbances, there was a sustained reduction of 456 MW of wind generation to the north of Adelaide. Analysis of high speed monitoring data has shown a further 42 MW of transient wind power reduction. This transient response is the normal expected response of wind farms riding through the voltage disturbances."

These are the facts, which should be combined with the following circumstances:

- Weather conditions were much worse than predicted in the weather forecasts.
- AEMO did not know that wind turbines have protective features that result in a significant power reduction if they experience more than a pre-set number of voltage dips within a two-minute period.

Weather conditions

At 0830 hrs on 28 September 2016, Bureau of Meteorology weather reports included wind speed forecasts of up to 120 km/h (gusts). The forecasts received by AEMO did not include any warnings regarding the possibility of tornadoes.

Later reports indicate the occurrence of a few tornados with wind speeds in the range of 190–260 km/h.

During the period of the event, two tornadoes almost simultaneously damaged a single circuit 275 kV transmission line and a double circuit 275 kV transmission line, some 170 km apart.

Wind power performance

Five transmission line faults, resulting in six voltage disturbances on the network, occurred within the 88 seconds from 16:16:46 to 16:18:14.

Wind turbine control systems are set to go in "fault ride-through mode" when voltage dips to below 80% to 90% of normal voltage, but keep the unit connected if the voltage remains within a FRT-profile[1].

A typical fault ride-through profile could have a minimum voltage at 5% for 0.3 seconds. Each of the six voltage dips are well within the fault ride-through profile, but many wind farms have a protection feature that takes action if the number of ride-through events in a specific period exceeds a pre-set limit.

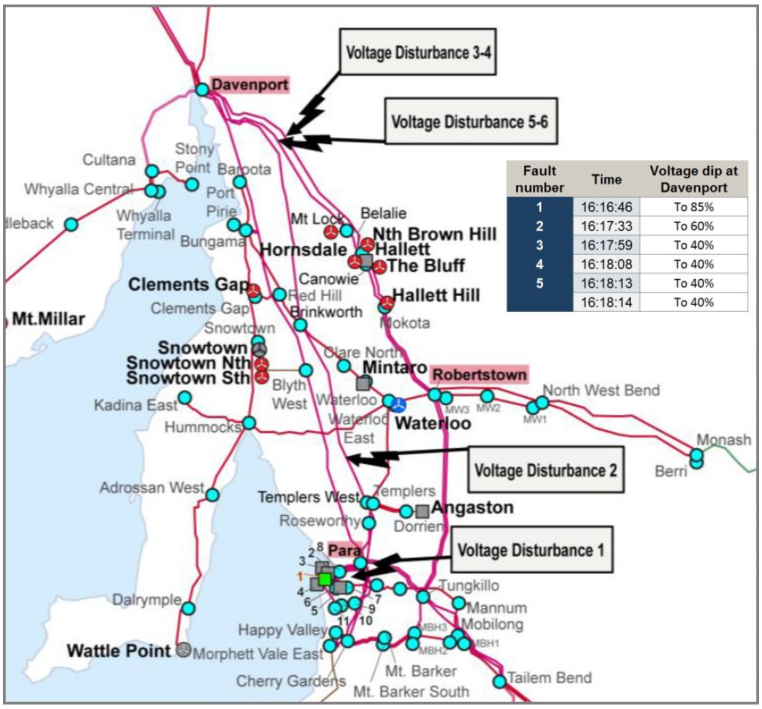

Fig. 1 - Disturbance 1 occurred in the urban Adelaide area.

The AEMO report divides the wind farms into four groups, A to D:

A. 5 wind farms set to allow maximum 2 FRT-events in 120 seconds
B. 3 wind farms set to allow maximum 5 FRT-events in 30 minutes
C. One wind farm going temporarily into zero power mode with a slow recovery of generation
D. 5 wind farms set to allow maximum 10 FRT events in 30 minutes

[1] FRT: fault ride-through

The groups A to C lost nearly all generation after the voltage dips. The total loss was 456.5 MW. Group D was able to maintain generation with a sustained reduction of about 10%. This is a natural response of those remaining wind farms, which activated their FRT mode. Thus, the total loss of generation was 498.3 MW.

		Pre-set max number of FRT-events within 120 seconds	Number of FRT-activations	Output at 16:18:08 (pre-event) MW	Output at 16:18:15.4 MW	Sustained reduction MW
A	5 wind farms	2	3	226.1	28.2	197.9
B	3 wind farms	5	6	190.8	-3.1	193.9
C	1 wind farm	n.a.	5	66.6	1.9	64.7
D	5 wind farms	10	0-6	392.6	350.8	41.8
				876.1	377.8	498.3

Table 1 - Wind power performance after grid disturbances

AEMO is negotiating with wind farm owners and manufacturers on changed settings of multiple FRT capacity with the following results for the four groups so far:

A. Proposed change from 2 to 4 events in 120 seconds
B. Changed to 20 events in up to 120 minutes
C. The possibilities of modifications are being investigated
D. No changes proposed

Low system inertia prevented automatic load shedding

The automatic under-frequency load shedding (UFLS) is supposed to reduce load and restore the balance between demand and supply if the generation is insufficient. In this case, the rate of change of frequency (RoCoF) was too high. A contributory factor was a modest capacity of synchronous generators connected to the SA grid.

Table 10 of the report is an interesting comparison with previous SA system separations.

Date	Time	Cause of interconnector trip	Supply interrupted in SA	Duration of separation	Sufficient load was shed by UFLS prior to separation	System inertia (MW.s)	Peak Heywood flow (MW)	Frequency started to drift until system separation
2 12 1999	13:11	Trip of both units at Northern Power Station	1,130 MW	26 minutes	Yes	10693	950	2.8 seconds
8 03 2004	11:28	Runback of both units at Northern Power Station	650 MW	43 minutes	Yes	7617	825	1.7 seconds
14 03 2005	06:39	Runback of both units at Northern Power Station	580 MW	22 minutes	Yes	11127	900	2 seconds
28 September 2016	16:18	Extreme weather event caused loss of three transmission lines and loss of 456 MW of generation from nine wind farms.	1,895 MW Black System	65 minutes	No	3000	890	0.6 seconds

Table 2 - Previous events – complete loss of the Heywood Interconnector due to generation disconnection in SA

The purpose of the load reduction is to maintain system control at a lower supply level and to make the restoration process simpler and faster.

The inertia of traditional power systems delays a frequency drop after a credible loss of generation a few seconds. The SA UFLS systems are designed to operate with RoCoF up to 3 Hz per second, but due to the low inertia, the RoCoF was rather 6 Hz per second.

Restoration

The restoration process began immediately in accordance with a system restart plan, which involved the use of restart capability from one of the two contracted SA system restart ancillary service (SRAS) generating units and restoration of supply from the Victoria region via the Heywood Interconnector.

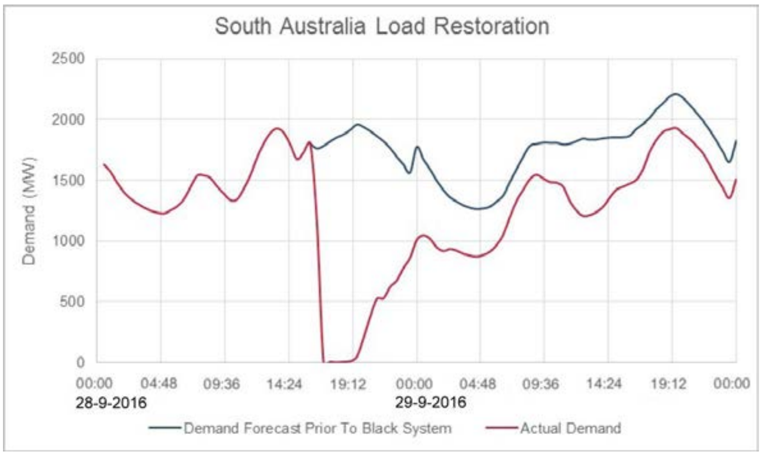

Fig. 2 - The course of restoration

The relevant generating unit successfully started, but was unable to supply power at the level required to restart a major generating unit. Restoration therefore proceeded only via the Heywood Interconnector.

By 2030 hrs, about 40% of the load in SA capable of being restored had been restored. By midnight, 80 to 90 % of the load that could be restored had been restored.

AEMO claims that the time to restore the majority of the load was in line with restoration times experienced in other recent power system restorations. On the other hand, the restoration was not complete until 10 October because it depended on the repair of transmission lines.