AEMO's final report on South Australian Blackout:

Time for an Update of National Security Rules

The blackout in South Australia (SA) on 28 September 2016 offers an opportunity to explore the resilience of a wind power dominated power system against severe disturbances. Therefore, the final report on the incident was anticipated with interest.

Three previous reports from AEMO[1] and several other papers have already explained the course of events and the restoration process (see list of references with links). The final report presents 19 recommendations to be implemented to improve system security.

Fig. 1 – Electricity shortage expected in SA the next two years

This note will be limited to a few essential matters on the incident 28 September 2016:

- Production loss exceeded operating reserves
- Low system inertia prevented automatic load shedding
- Control setting of wind turbines blamed for the blackout
- AEMO predicts mid-term capacity shortage
- No security policy for non-credible contingency events
- AEMO's 19 recommendations do not address the real problems

SA is in the transition from a fossil-fuelled power system into a system based on renewable energy. This is a challenge to both operational security and security of supply. Recently the last coal-fired power plants, Playford B (240 MW) and Northern (520 MW), were closed down. Mothballing of the gas-fired Torrens A (480 MW) has been planned for 2017. The removal of traditional power plants also removes basic contributions to the operational security, such as the inertia of the turbo-generators and the reactive power control of the generators. Inverter-connected wind turbines and solar cells cannot fully replace these elements.

It is a challenge to find affordable replacements with reasonable security of both operation and supply. SA is a forerunner, and its experiences can be useful to other countries with the same ambitions.


news
.com.au
breaking news
MARCH 6, 2017 4:05PM
New blackout fears for South Australia

Fig. 2 - New interest by media after brownout.

Shortage of electricity caused a manual load shedding on 8 February 2017 [5]. The Australian media follow the development and express their concern for the electricity supply.

Production loss exceeded operating reserves

The system collapse took 91 seconds from the first fault on a 66 kV feeder to the system separation. Human intervention within that time window is impossible. The survival of the system depends on fast automatic reserves.

[1] AEMO: Australian Energy Market Operator

The SA electricity supply had three main sources prior to the events:

- 883 MW of SA wind generation.
- 330 MW of SA gas generation.
- 613 MW of electricity imports from Victoria

The available fast reserve from the Heywood interconnector was 260 MW. Was 260 MW sufficient? After six voltage dips in less than two minutes, the wind power output was reduced by 498 MW.

Table 1 shows the gas-fired capacity and production. The final report does not mention the total capacity. Therefore, it is unclear if the 840 – 330 = 510 MW were available as power reserve on 28 September.

	Output	Capacity
	MW	MW
Ladbroke Grove Unit 1	42	120
Ladbroke Grove Unit 2	40	120
Torrens Island B PS Unit 1	82	200
Torrens Island B PS Unit 3	84	200
Torrens Island B PS Unit 4	82	200
Total thermal generation	330	840

Table 1 - Thermal production before faults

However, even if they were, there would be too little time for a primary control action. The frequency was normal until less than two seconds before separation, and the import from Victoria was normal until about 10 seconds before separation.

The only option would have been to anticipate possible problems due to tough weather conditions and demand additional thermal production in order to have more fast reserve capacity available from the Heywood interconnector.

There are two links between SA and Victoria: the Heywood interconnector and Murraylink (VSC HVDC[2]). An HVDC link has the technical capability to provide fast support during disturbances. The reason for limitations could be bottlenecks in the adjoining AC-grids, but I did not find such considerations in the final report.

	Import	Capacity
	MW	MW
Heywood interconnector	500	760
Murraylink SVC HVDC	113	220
	613	980

Table 2 - Import before faults

AEMO considers the loss of the Lake Bonney wind farms (261 MW installed) to be the largest single contingency. AEMO therefore kept a 260 MW capacity reserve available on the Heywood interconnector.

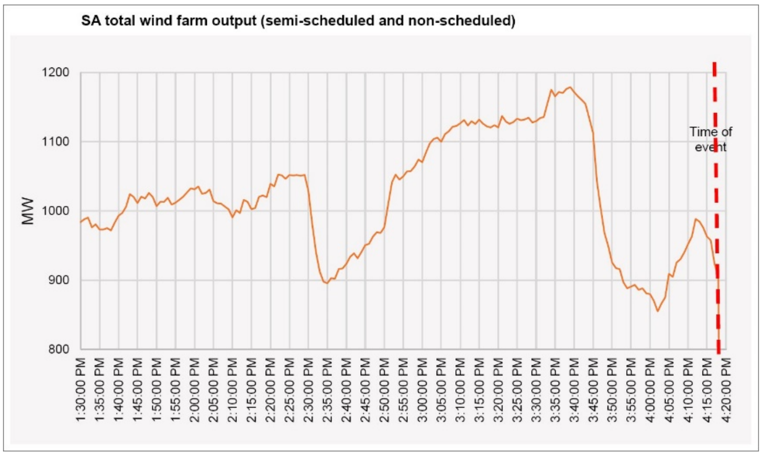

Fig. 3 - Wind farm output four hours prior to faults

This is just following a rule. Would common sense lead to the same result? Can the 510 MW thermal rotating reserve catch a maximum drop of wind? If weather conditions cause the damage of a tower on the Heywood interconnector, both circuits would be lost. This is not a credible contingency event,

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[2] VSC HVDC: Voltage-Source Converter High Voltage Direct Current

but it is possible, and it could delay a restoration process considerably. The Murraylink cannot be used for reviving a black grid, because it would depend on AC supply from both sides (page 71).

Low system inertia prevented automatic load shedding

The sudden loss of production or import to a power system causes a drop of frequency. The SA power system has like most other power systems automatic load shedding in order to restore the balance between generation and consumption and to prevent a total blackout.

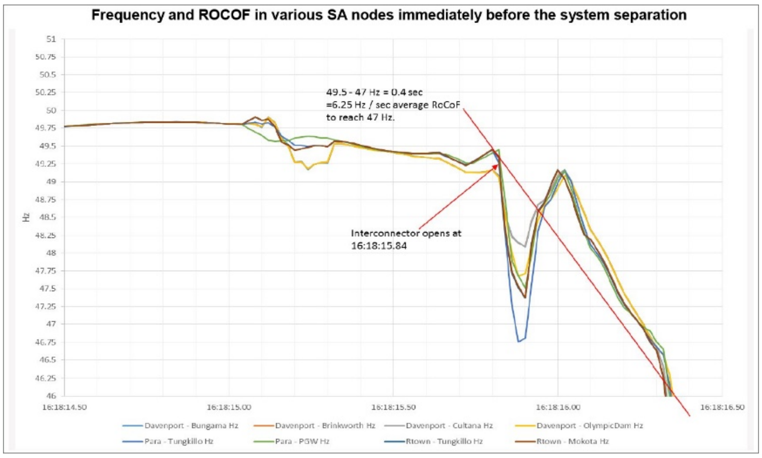

Fig. 4 - The frequency collapse

After the separation on 28 September 2016, the rate of change of frequency (RoCoF) was so high that that load shedding would come too late. The average RoCoF was 6.25 Hz/s (fig. 4). A successful automatic load shedding would require a RoCoF not exceeding about 2 Hz/s.

RoCoF depends on the power deficit and on the rotating mass of the synchronous generators (the inertia).

After the loss of both 456 MW wind power and the Heywood link only 757 MW were available to cover 1826 MW demand. The system inertia was 3,000 MW.s (megawatt-seconds). In three previous cases of islanding, the system inertia was between 7,600 and 11,100 MW.s (table 11 of the final report).

A further expansion of inverter connected production and the corresponding reduction of synchronous generation will make the SA power system even more vulnerable in case of islanding.

It may be necessary to install new sources of inertia such as synchronous condensers, but islanding would still be a risky event depending on the possible deficit of power and the remaining system inertia.

New interconnections to Victoria and New South Wales could be another measure for preventing blackouts.

Control setting of wind turbines blamed for the blackout

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.

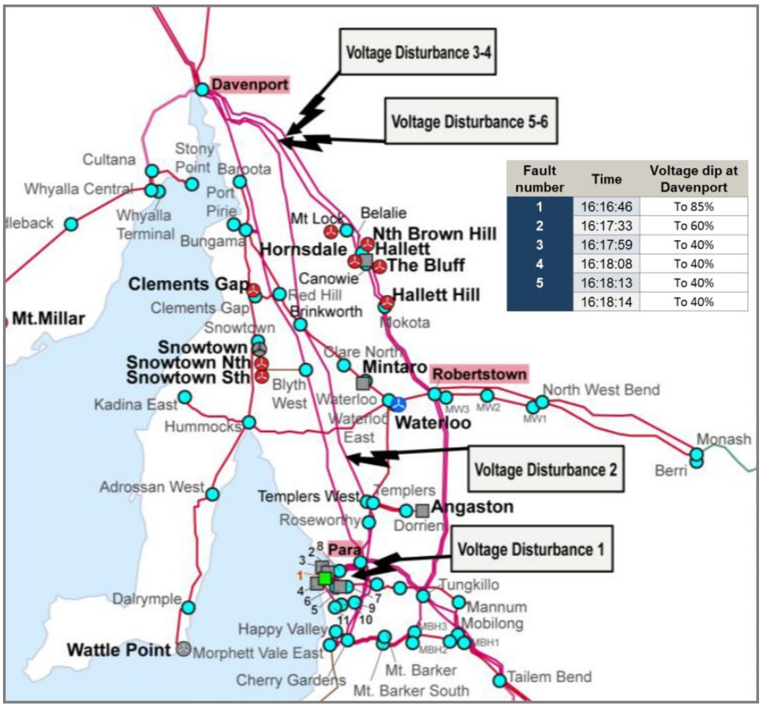

Fig. 5 - Disturbance 1 occurred in the urban Adelaide area.

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[3].

A typical FRT 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.

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

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 wind farms after activation of FRT mode. Thus, the total loss of generation was 498.3 MW.

[3] FRT: fault ride-through

		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 3 - Wind power performance after grid disturbances

AEMO states in the final report:

> *Wind turbines successfully rode through grid disturbances. It was the action of a control setting responding to multiple disturbances that led to the Black System. Changes made to turbine control settings shortly after the event has removed the risk of recurrence given the same number of disturbances.*

Thus, AEMO puts a main responsibility for the blackout on the setting of the wind farm protections. AEMO adds:

> *Had the generation deficit not occurred, AEMO's modelling indicates SA would have remained connected to Victoria and the Black System would have been avoided. AEMO cannot rule out the possibility that later events could have caused a black system, but is not aware of any system damage that would have done this.*

The important lesson for power systems, dominated by new technology:

> *Access to correct technical information about grid-connected equipment is critical for system security.*

AEMO predicts mid-term capacity shortage

Since the blackout 28 September 2016, there has been some attention on the capacity problems in SA. Wind and solar energy displace electricity from fossil fuels. The last coal-fired power stations have closed down in 2015 and 2016. Mothballing of the gas-fired Torrens A was decided for 2017, but is now being reconsidered.

The electricity consumption has peaks both summer and winter, but the summer peak (in February and March) is higher than the winter peak.

Fig. 6 - Summer can be very hot in SA

The reserves were stretched to the very limit in 2017. On 8 February it was necessary to shed 100 MW load in SA for 27 minutes [5]. On 10 February it was necessary to disconnect 290 MW load in New South Wales for 60 minutes.

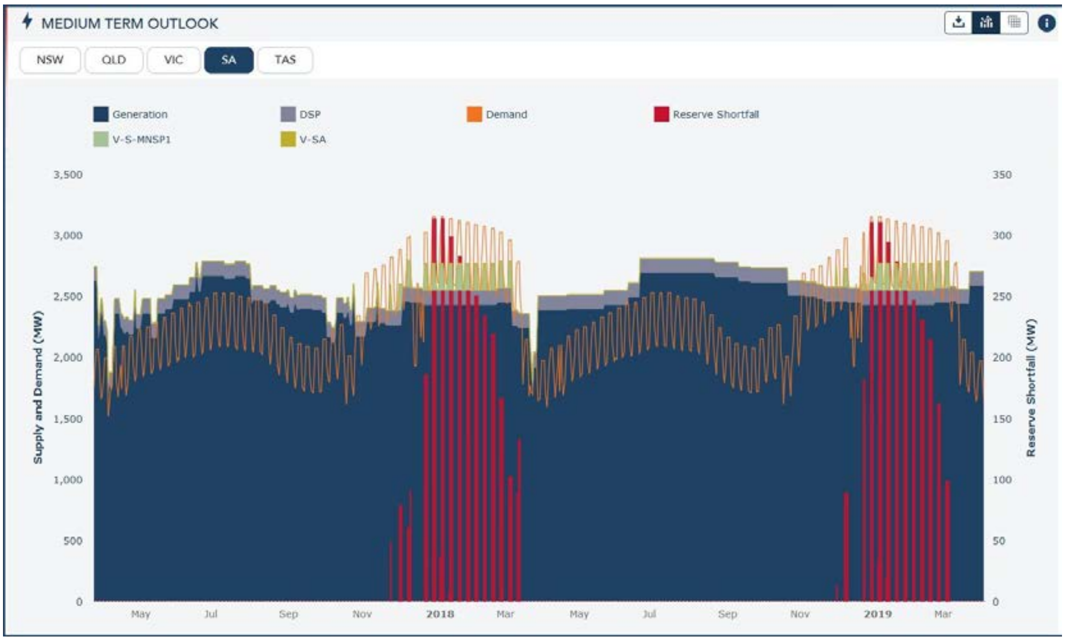

Fig. 7 - Medium term outlook. Source: https://www.aemo.com.au/

AEMO also expects supply problems for SA in 2018 and 2019 (fig. 7). A maximum demand at about 3,000 MW with a reserve shortfall of 300 MW has been forecasted. The red columns in fig. 7 show the shortfall (scale on right axis). Future decisions on operating reserves and load shedding can be a balance on a knife-edge, because maintaining supply of all demand can be at the cost of operational security.

No security policy for non-credible contingency events

The security of the electricity supply system is based on National Electricity Rules (NER), chapter 4 on *power system security* (78 pages [6]). The purpose is to keep the power system in a *secure operating state* (clause 4.2.4). Disturbing events can be *credible contingencies* or *non-credible contingencies* (clause 4.2.3).

In a secure operating state, the system must return to a *satisfactory operating state* after a credible contingency event. The rules are comprehensive, but not very specific. The definition of a credible contingency event is essential. According to clause 4.2.3, it can be the unexpected reduction in capacity of **one** operating generating unit or **one** major item of transmission plant *(other than as a result of a three phase electrical fault anywhere on the power system)*.

The final report says (appendix F.9): *"Only credible contingency events are considered when assessing whether the system is in a secure operating state."* The text suggests that events that are more serious are not considered or analysed in the operational planning.

The distinction between credible and non-credible contingency events makes the security planning more rigid than it should be. There is a possibility to reclassify contingency events (appendix F.10), but it is probably not a daily routine.

More differentiated security strategies have “defence lines”. Frequent and single disturbances must be absorbed without any consequences to consumers. Less frequent and combined disturbances can cause disconnection of some consumers, but without loss of control of the system. The normal reserves must be restored within specified time limits. A restoration plan must be ready for the very seldom combination of circumstances and events, which can cause a full blackout.

Traditional power plants will not survive the implementation of SA’s energy policy. New production patterns will introduce new combinations of disturbing events. The infrastructure and the market should be redesigned. A robust power system must include flexible response to both credible and non-credible contingency events.

AEMO’s 19 recommendations do not address the real problems

The recommendations are shown in annex 1 of this note. Most of these recommendations are minor precautions to be “proposed”, “assessed”, “considered” or “reviewed”.

I did not find any steps towards new and stronger interconnections from SA to Victoria and New South Wales among the recommendations.

Chapter 4 on *power system security* in the National Electricity Rules (NER) was written for a power system of the past. Therefore, the rewriting of chapter 4 of NER could have been a natural part of the recommendation. The blackout has demonstrated that there is a need to develop an affordable infrastructure for a future energy market based on sustainable energy sources. It will require new system planning procedures including flexible rules for the balance between security of supply and operational security.

In March 2017, the government of South Australia has introduced a new energy plan [7]: South Australian power for South Australians. The headline on the front-page says “Its’ time to take charge of our energy future”. The published plan is not very specific, but it has some interesting intentions, such as building government-owned gas-fired backup units and supporting analyses of new interconnectors.

References

AEMO reports:

1. Preliminary Report – Black System Event in South Australia on 28 September 2016
2. Update Report – Black System Event in South Australia on 28 September 2016
3. Third Preliminary Report - Black System South Australia 28 September 2016
4. Final Report - Black System South Australia 28 September 2016
5. System Event Report South Australia, 8 February 2017

Other Australian sources:

6. Power System Security – Chapter 4
7. South Australian Power for South Australians

Comments:

8. Blackout in South Australia on 28 September 2016 - Preliminary overview - PFB
9. Wind Generation did not Survive Multiple Voltage Dips - PFB

Annex 1

AEMO's 19 recommendations

1	AEMO to propose to ESCOSA changes to generator licensing conditions, and also to request similar changes to the NER, to address deficiencies in performance standards identified through this investigation.
2	AEMO to put in place more rigorous processes to monitor weather warnings for changes to forecasts, to trigger reassessment of reclassification decisions where relevant.
3	AEMO to review and implement, following consultation, a more structured process for reclassification decisions when faced with power system risks due to extreme wind speeds.
4	AEMO to assess options for improved forecasting of when wind speeds will exceed protection settings on wind turbines, which would lead to 'over-speed cut-outs'.
5	AEMO to consider development of a new generator reclassification process to manage generator 'type' risks5, including how information about potential risks will be sought, and the most appropriate methods to manage power system security during such a generator reclassification.
6	AEMO to modify operational procedures for SA island operation to: * Take into account the fact that, under islanded conditions, system strength may fall to a level where some wind farms might not be able to ride through credible voltage disturbances. * Ensure that maintenance of adequate system strength is incorporated into the transmission planning process in a more systematic manner.
7	AEMO to modify existing transfer limits on the Heywood Interconnector to take into account the fact that the largest credible generator contingency under conditions of high wind generation is greater than previously assumed.
8	AEMO to modify operational procedures for SA island operation to: * Take into account the fact that, under islanded conditions, system strength may fall to a level where some wind farms might not be able to ride through credible voltage disturbances. * Ensure that maintenance of adequate system strength is incorporated into the transmission planning process in a more systematic manner.
9	AEMO to support ElectraNet to identify and address any specific risks to the operation of protection systems due to the low levels of system strength that may be experienced if SA is islanded.
10	AEMO to support ElectraNet in reassessing control strategies to achieve very rapid switching of reactive plant to manage the risk of severe over voltages in SA that might occur due to large levels of under frequency load shedding following separation.
11	AEMO to review its reclassification procedures to address any remaining material risk due to multiple voltage disturbances, and to approach relevant Generators to review the feasibility of increasing plant limits for the maximum number of multiple voltage disturbances that can be tolerated over a 30-minute period.
12	AEMO, together with the South Australian System Restart Working Group, to review the system restart process in detail to determine efficiencies and to implement relevant recommendations from the Reliability Panel. These learnings will be shared across all Australian jurisdictions
13	Any differences between SRAS test plans and the restart process set out in a system restart plan and associated local black system procedures to be identified and explained by AEMO, to ensure the test simulates, as far as practicable, the conditions that will be encountered in a real restart situation
14	Similarly, where the restart procedure depends initially on starting a low voltage generator, the start of this generator alone to be tested on a regular basis, in addition to the annual test of the entire SRAS source
15	AEMO to develop detailed procedures for in power system operations during periods of market suspension, and identify if any NER changes are desirable to improve the process
16	AEMO to investigate a better approach to ensuring that the minimum stable operating levels of generating units are taken into account in the dispatch process
17	AEMO to review market processes and systems, in collaboration with participants, to identify improvements and any associated NER or procedure changes that may be necessary to implement those improvements
18	AEMO to develop a more structured process in consultation with participants to source and capture data after a major event in a timely manner and to co-ordinate data requests.
19	AEMO to investigate with participants the possibility of introducing a process to synchronise all high speed recorders to a common time standard.