ANALYSIS OF THE SOUTH AUSTRALIAN BLACKOUT

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AGENDA SLIDE

1. South Australian electrical system
2. Overview of 28 September 2016 SA blackout event
3. Root cause investigation of the event
4. Use of power system modelling and analysis
5. Development of operating procedures and technical requirements to manage power system security
SOUTH AUSTRALIA

- Demand: 500–3400 MW
- Installed Wind: 1800 MW
- World’s largest battery storage (100 MW) to connect in 4 weeks
- Gas fired synchronous generators primarily
- Historically operated with down to one synchronous generator only
- Interconnector capacity
  - Heywood: +/- 600 MW
  - Murraylink: +/- 220 MW
- ~800 MW of rooftop PV
- Maximum ~170% instantaneous renewable penetration to operational demand
The ratio of non-synchronous/synchronous generation is not considered excessive.
CAUSATION CHAIN RESULTING IN SOUTH AUSTRALIA BLACK SYSTEM EVENT ON 28 SEPTEMBER 2016
WHAT HAPPENED?

Before incident

*Includes Heywood & Murray Link Interconnectors

~800 km (~500 miles)

Heywood AC I/C

Murray Link DC I/C

330 MW

613 MW*

883 MW

IMPORT WIND THERMAL
WHAT HAPPENED?

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- Loss of three transmission lines
- Multiple faults

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- Loss of three transmission lines
- Multiple faults
- Wind farm protection triggered

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WHAT HAPPENED?

Operation of loss of synchronism protection

*Includes Heywood & Murray Link Interconnectors
Short duration (less than 100 ms clearance), unbalanced (mostly LG) voltage disturbances well within LVRT withstand capability of wind turbines
WIND GENERATION FAULT RIDE-THROUGH RESPONSE

Wind turbine group | Multiple ride-through capability on 28 September 2016 | Actions taken for improved ride-through capability
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Group A1 | 2 within 2 minutes | 6 within 2 minutes
Group A2 | 2 within 2 minutes | 15–19 within 2 minutes
Group B | 5 within 30 minutes (also 5 within 2 minutes) | Changed to 20 within 120 minutes (also 20 within 2 minutes)
Relative phase angles started to diverge immediately after the sixth voltage disturbance due to loss of significant amount of active power resulting in loss of synchronism conditions.
- System voltages started to decline globally until they collapse down to 0.2 pu within 600 ms
- Dynamic voltage collapse is a symptom of loss of synchronism conditions
Prior to system separation system frequency did not drop sufficiently to initiate UFLS or governor response (the latter would have been insignificant anyway).

Post separation frequency collapsed very rapidly where UFLS did not have sufficient time to respond.
Correct and intended operation of loss of synchronism relays which resulted in disconnection of SA power system from rest of the NEM.
KEY CONTRIBUTORS TO THE BLACK SYSTEM

Factors Considered

- Inability of wind farms to ride-through multiple faults
- Loss of synchronism between SA and VIC systems
- Inability to form a viable island
- Loss of transmission lines
- Six voltage disturbances within 88 s

Legend
White: confirmed as contributing factors
Red: factors ruled out following investigations

High wind speed
MODELLING AND SIMULATION OF CAUSATION CHAIN
All individual generator models were benchmarked against the actual measurements using both PSS/E and PSCAD/EMTDC simulations.
HEYWOOD INTERCONNECTOR ACTIVE POWER FLOW

PSCAD model replicates precisely the overall system response
Accurate replication of impedance trajectory seen by loss of synchronism relays

 Crossing green line = Heywood IC opens
Accurate simulation of voltage phase angles which are the key indicator of loss of synchronism conditions.
SA SYSTEM SECURITY IMPROVEMENTS
SYSTEM SECURITY TRILEMA

Supply-demand balance

- Generation and load disturbance ride-through
- Active power control
- Load shedding
- RoCoF

System strength

Temporary over-voltages

- Adequacy of synchronous machines and protection systems
- Withstand capability of non-synchronous generation

High-voltage disturbance ride-through
LEARNING FROM SYSTEM BLACK EVENT

**Critical issues**

- Pre-set protection settings on the number of voltage disturbances in quick succession.

**Opportunities for improvement**

- Unexpected reactive power response of some wind farms during some of the voltage disturbances, i.e. no reactive current injection.
- Ability to shed loads before system separates, and while system frequency is still healthy.

**Emerging issues not relevant to the actual event**

- Transient power reduction of non-synchronous generation during a successful ride-through event.
- Over-voltage withstand capability of wind farms and synchronous generators.
- Management of adequate system strength accounting for the response of both generating systems and protection functions.
- Lack of observability/predictability/controllability of DER
RISK MITIGATION METHODS TO MANAGE SA SYSTEM SECURITY

- Increased technical performance requirements on generating systems including DER.

- The need for a minimum quantity of synchronous characteristics (currently in place operationally at all times).
  - Likely to be replaced by large-scale synchronous condensers in mid-term.

- Detailed modelling of both primary and secondary power system components with appropriate simulation tools.

- Consideration of both credible and non-credible events, and developing control and protection schemes to account for non-credible events:
  - E.g. pre-emptive load shedding before SA becomes islanded.
Both transmission and distribution systems have been historically exposed to a large number of faults.

Non-credible events had occurred in the past, and can happen again.
OTHER MECHANISMS CAUSING MULTIPLE VOLTAGE DISTURBANCES

LVRT control action especially in weaker parts of the network can be counted as multiple faults in quick succession by the wind turbine protection counter.
MULTIPLE LOW VOLTAGE DISTURBANCE RIDE-THROUGH

• Requirements on the number of faults would under-utilise the capability of generating units.

• Requirement for withstanding multiple voltage disturbances
  o Up to 15 voltage disturbances each resulting in up to 100% voltage drop at the connection point with the total disturbance duration limited to 1500 ms, and
  o A single worst-case long-duration shallow voltage disturbance, causing the voltage at the connection point to drop to 70-80 percent of the normal voltage for a total duration of 2000 ms.

• The majority of wind turbine and solar inverter manufacturers meet the proposed requirements.
  o Generally no limitations on solar inverters other than UPS rating