ANALYSIS OF THE SOUTH AUSTRALIAN BLACKOUT

October 2017

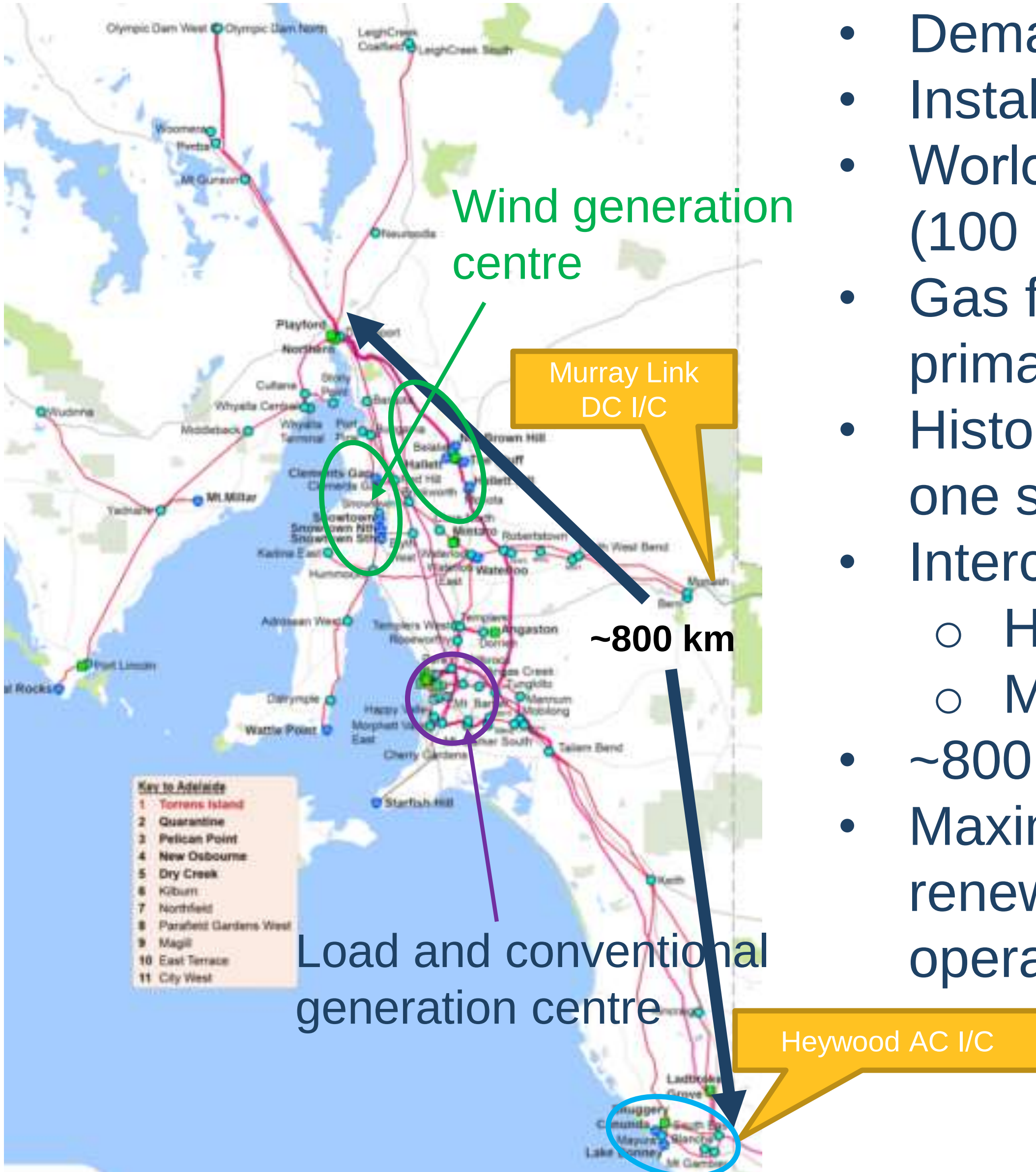
PRESENTED BY BABAK BADRZADEH

AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

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

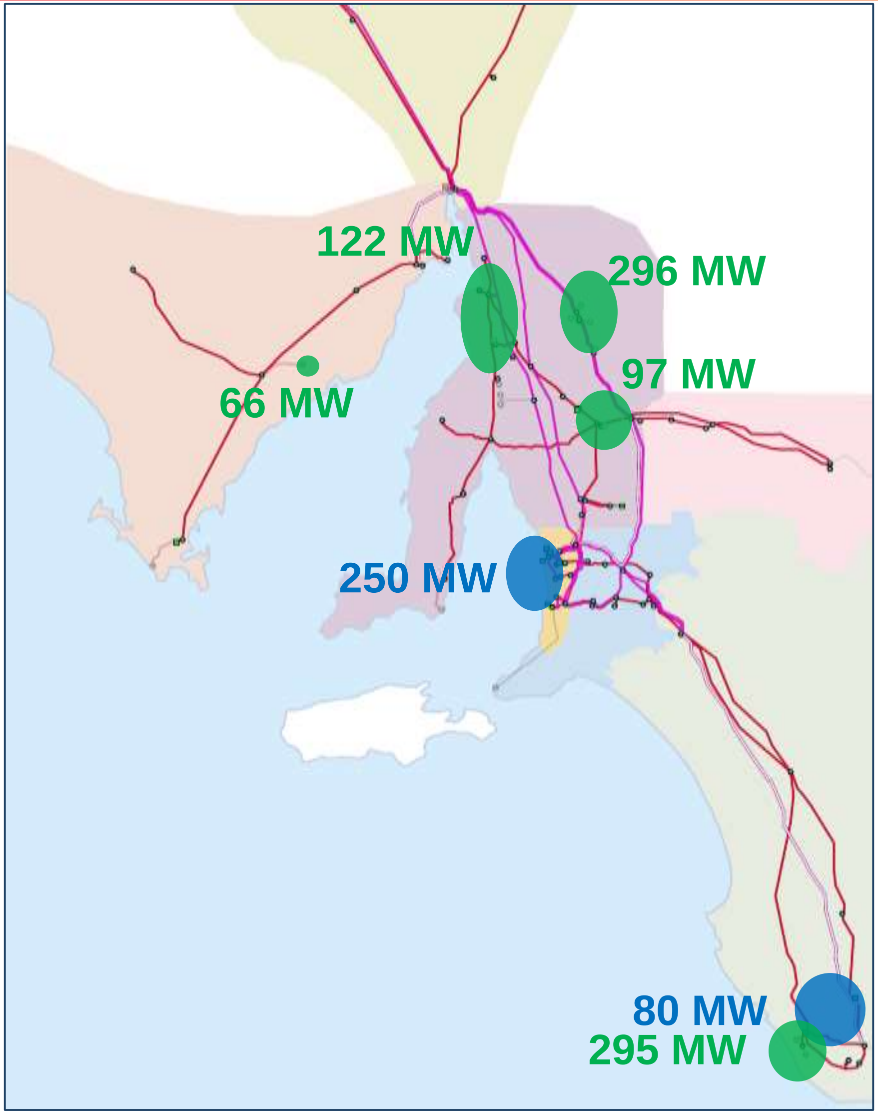
SOUTH AUSTRALIA



- 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

GENERATION MIX PRIOR TO THE EVENT

Synchronous Generation Distribution



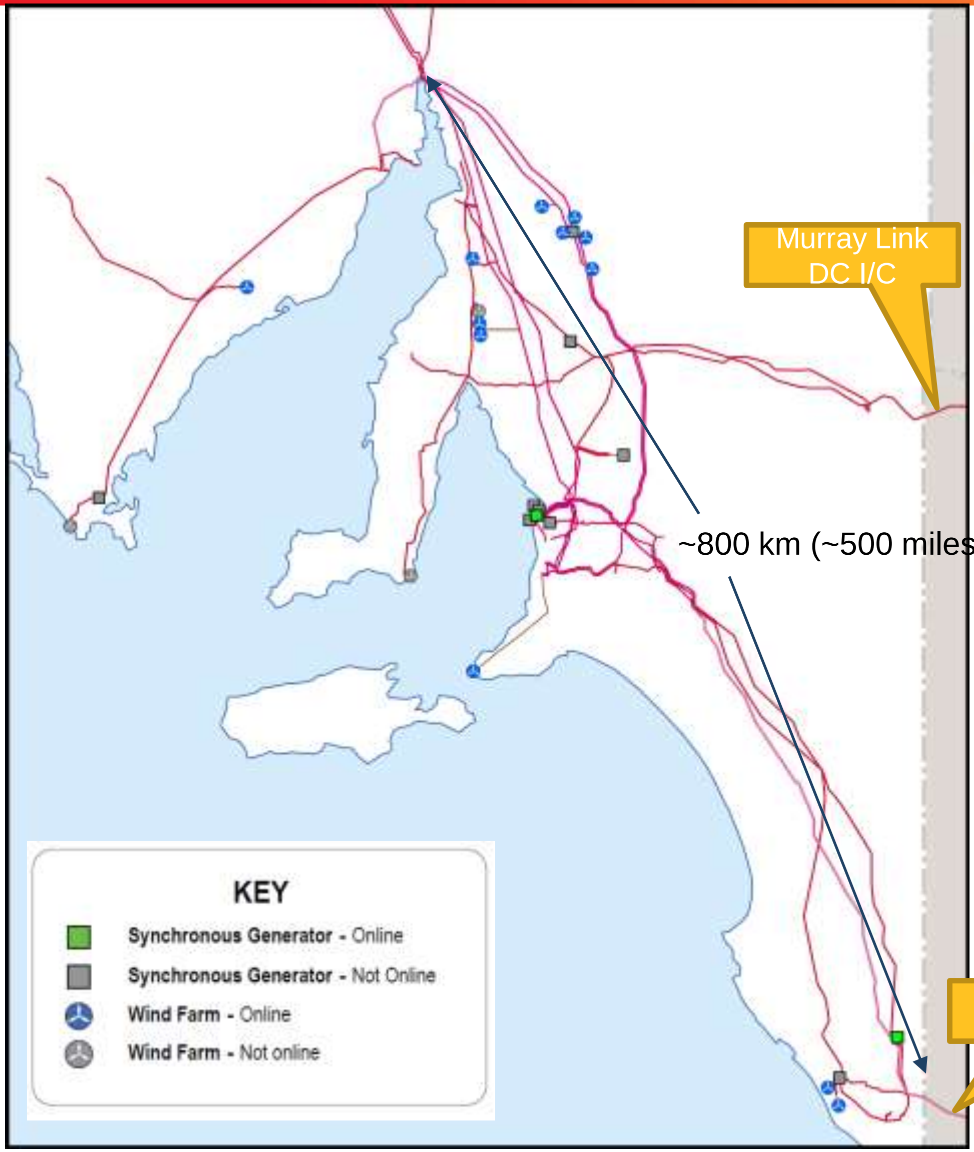
Wind Generation Distribution

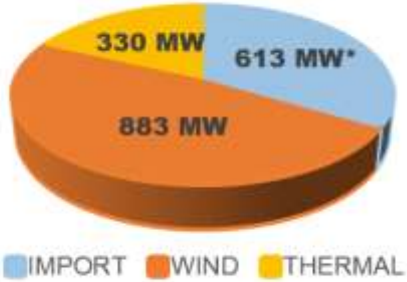
The ratio of non-synchronous/synchronous generation is not considered excessive

CAUSATION CHAIN RESULTING IN SOUTH AUSTRALIA BLACK SYSTEM EVENT ON 28 SEPTEMBER 2016

WHAT HAPPENED?

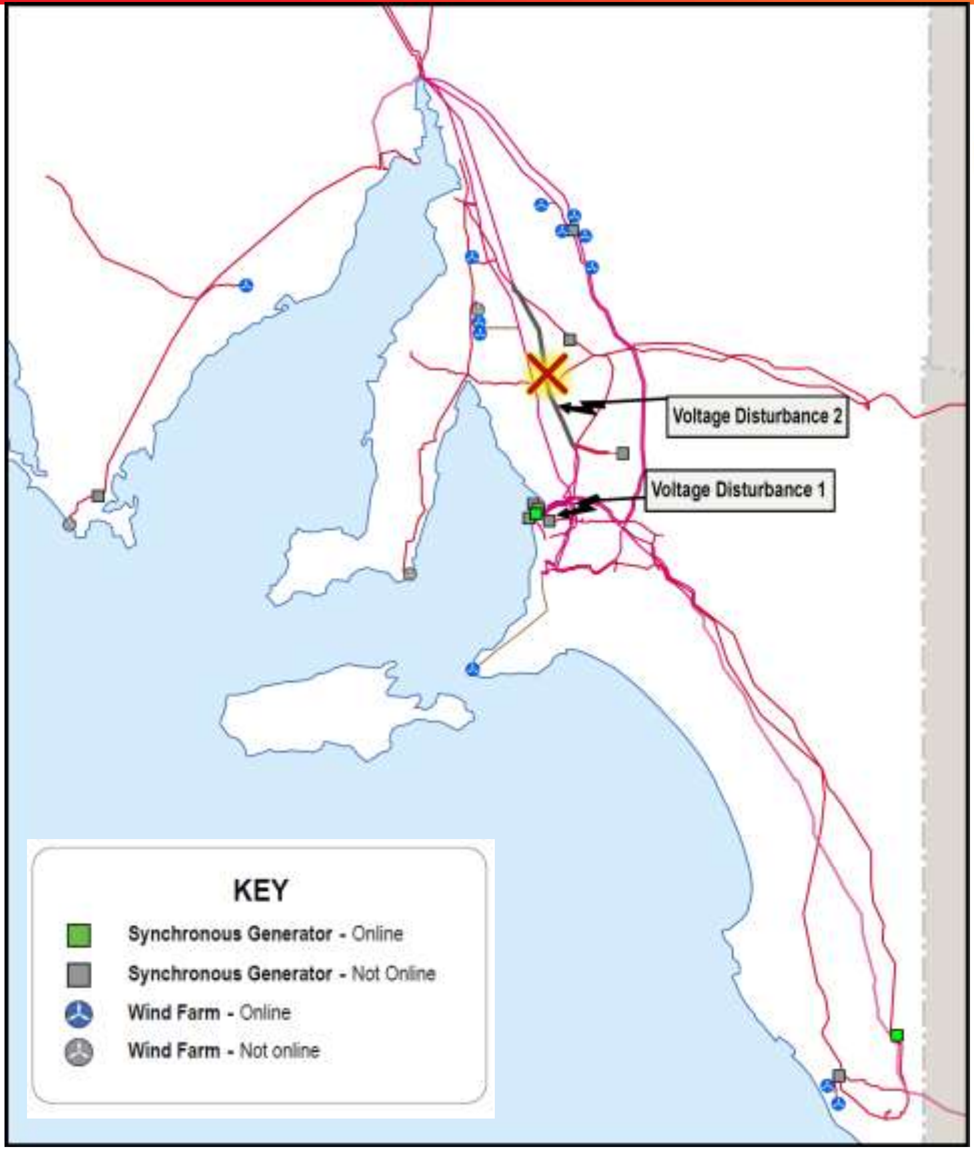
Before incident

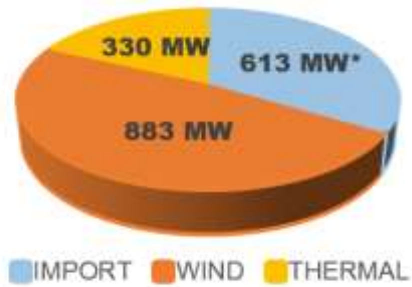




*Includes Heywood & Murray Link Interconnectors

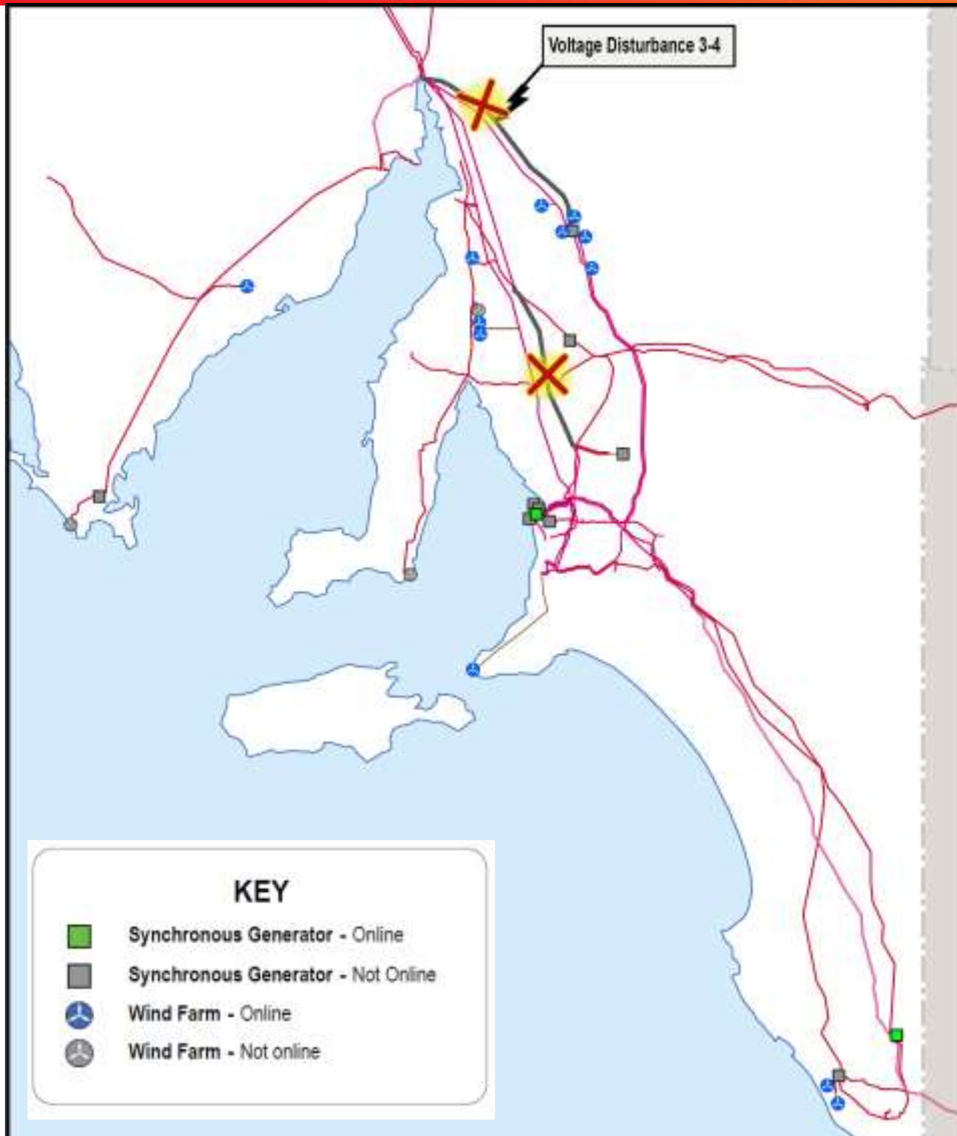
WHAT HAPPENED?

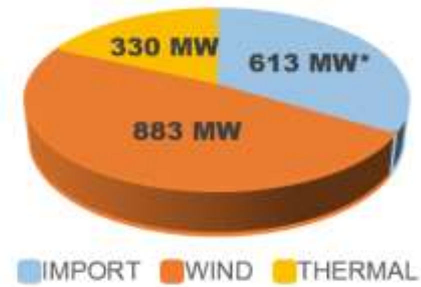




*Includes Heywood & Murray Link Interconnectors

WHAT HAPPENED?



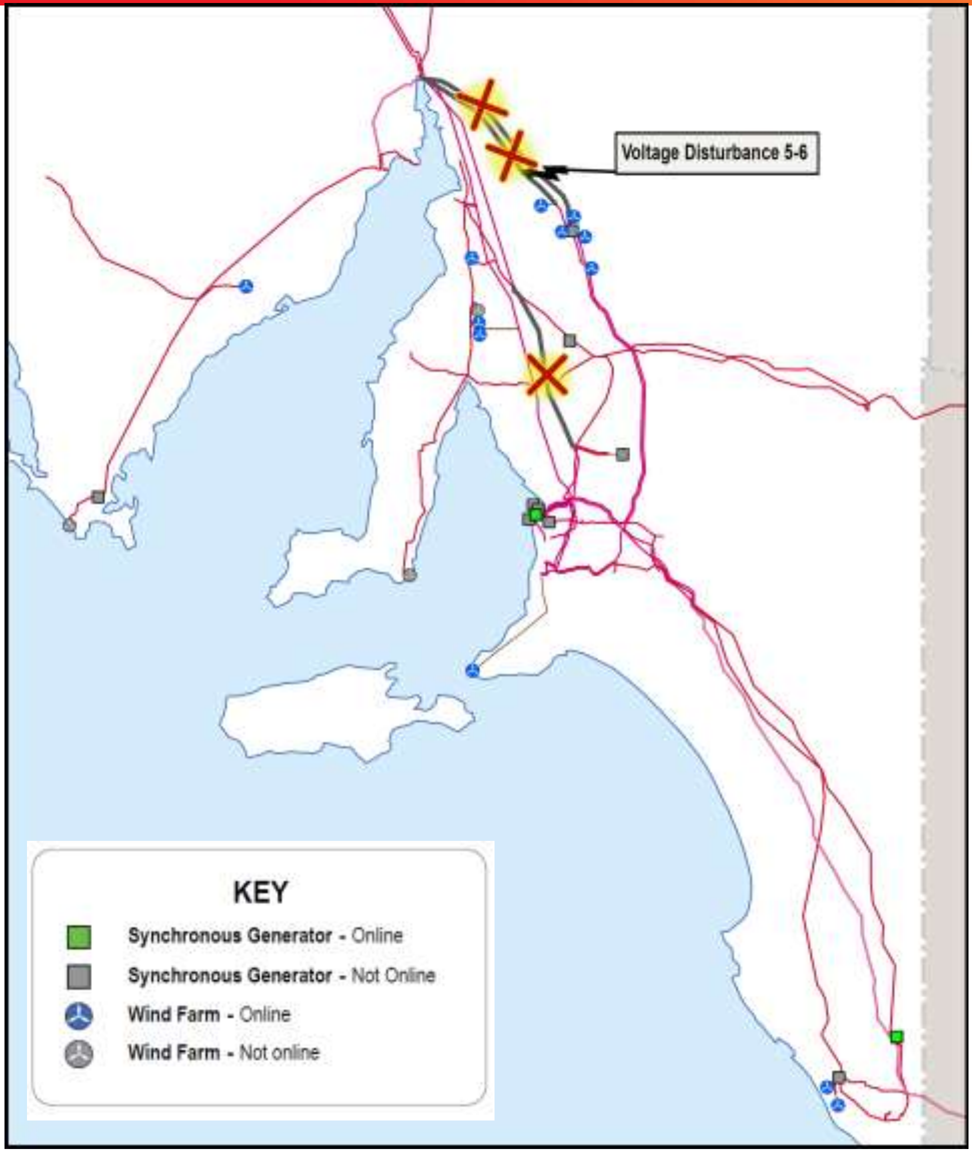


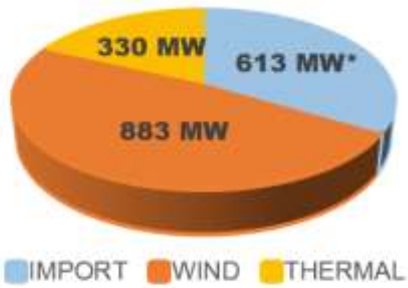
*Includes Heywood & Murray Link Interconnectors

WHAT HAPPENED?

Loss of three transmission lines

Multiple faults





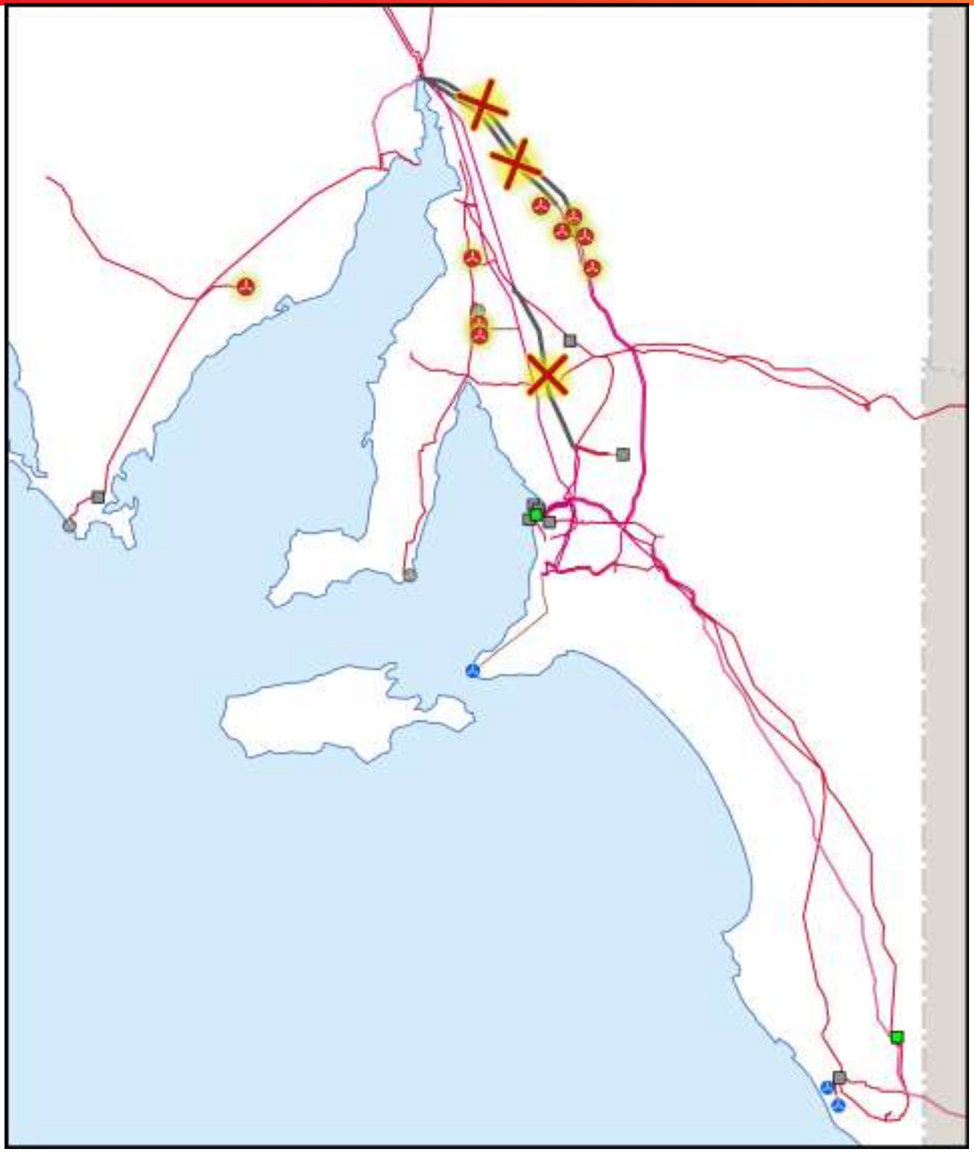
*Includes Heywood & Murray Link Interconnectors

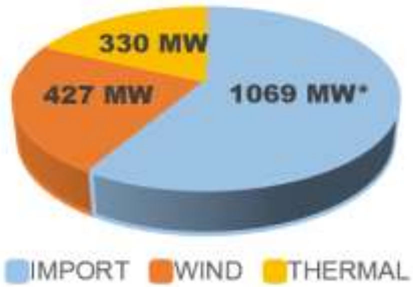
WHAT HAPPENED?

Loss of three transmission lines

Multiple faults

Wind farm protection triggered

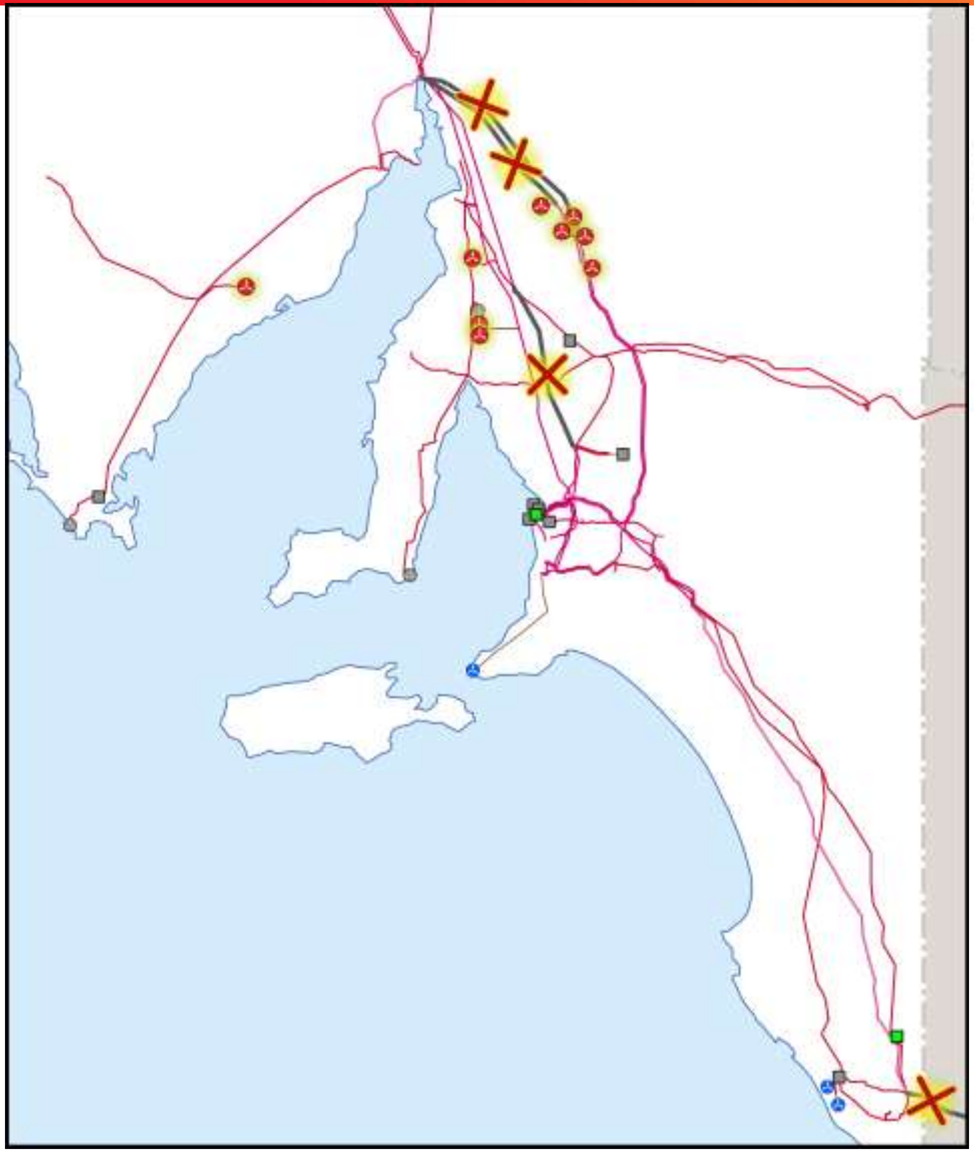


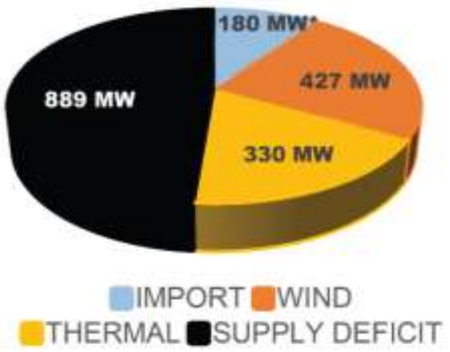


*Includes Heywood & Murray Link Interconnectors

WHAT HAPPENED?

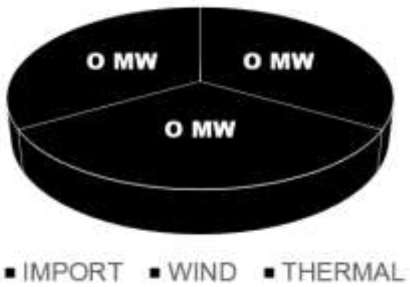
Operation of loss of synchronism protection





*Includes Heywood & Murray Link Interconnectors

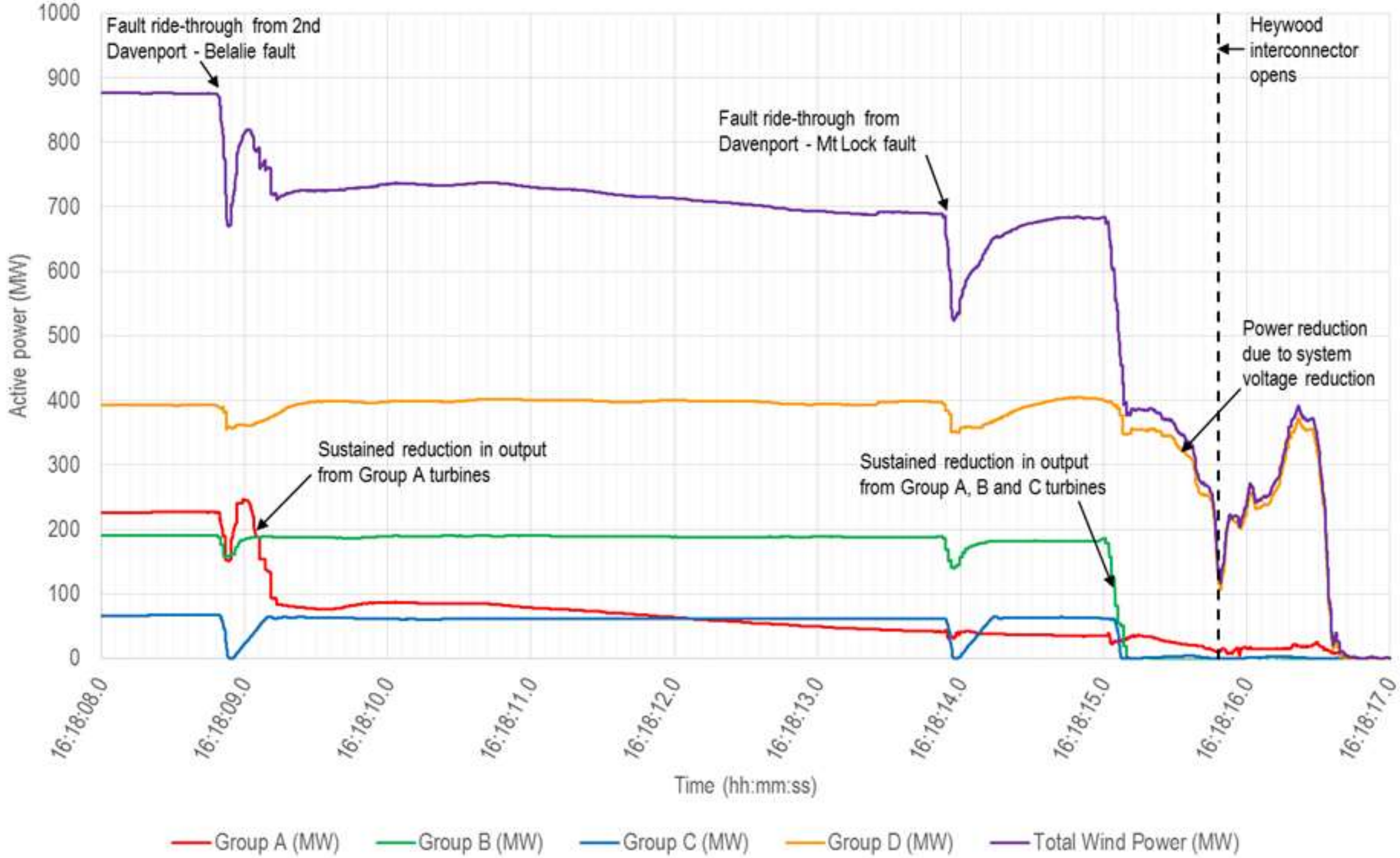
WHAT HAPPENED?



VOLTAGE DISTURBANCES AT A SUBSTATION CLOSE TO WIND GENERATION CONCENTRATION

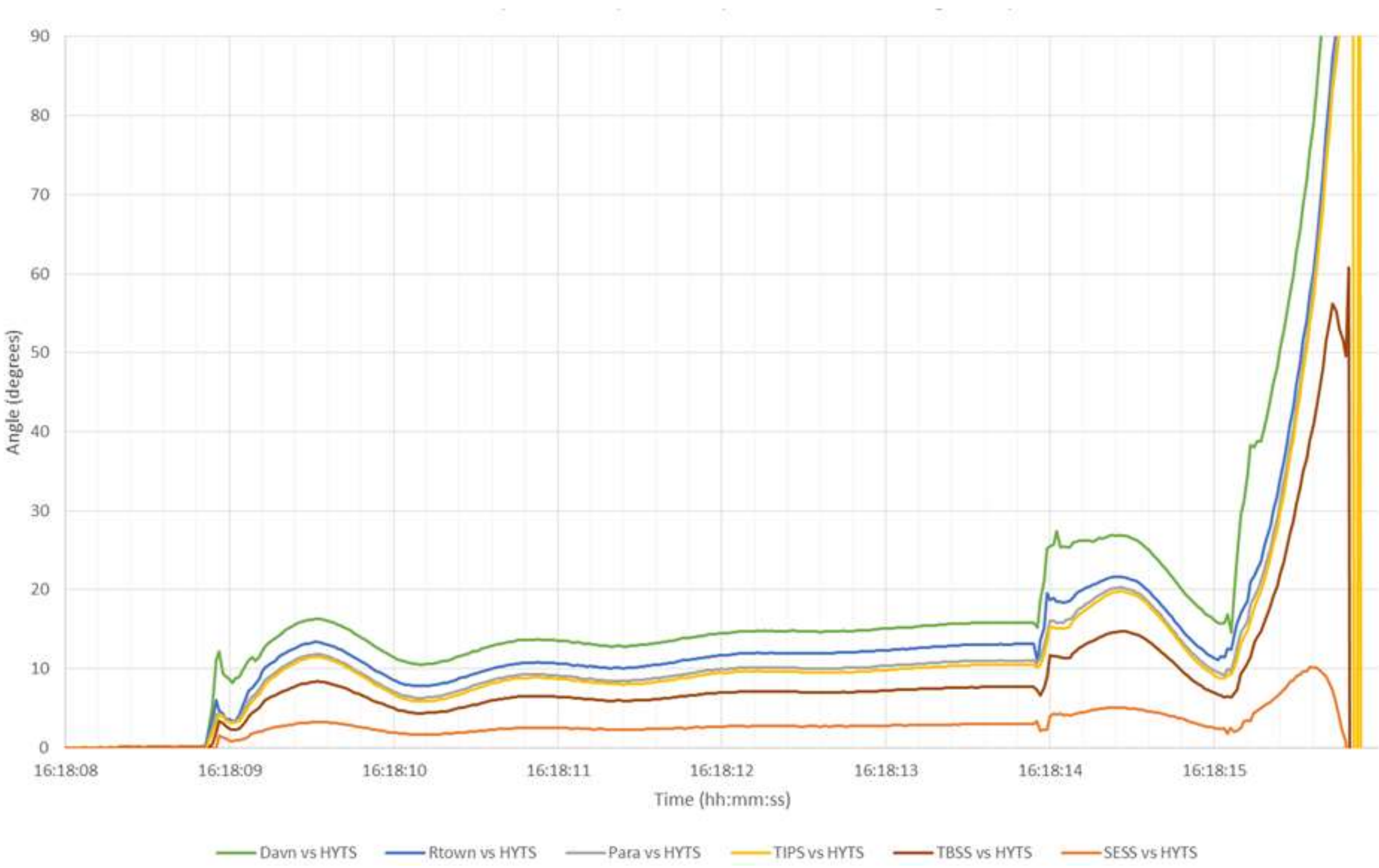
Short duration (less than 100 ms clearance), unbalanced (mostly LG) voltage disturbances well within LVRT withstand capability of wind turbines

WIND GENERATION FAULT RIDE-THROUGH RESPONSE



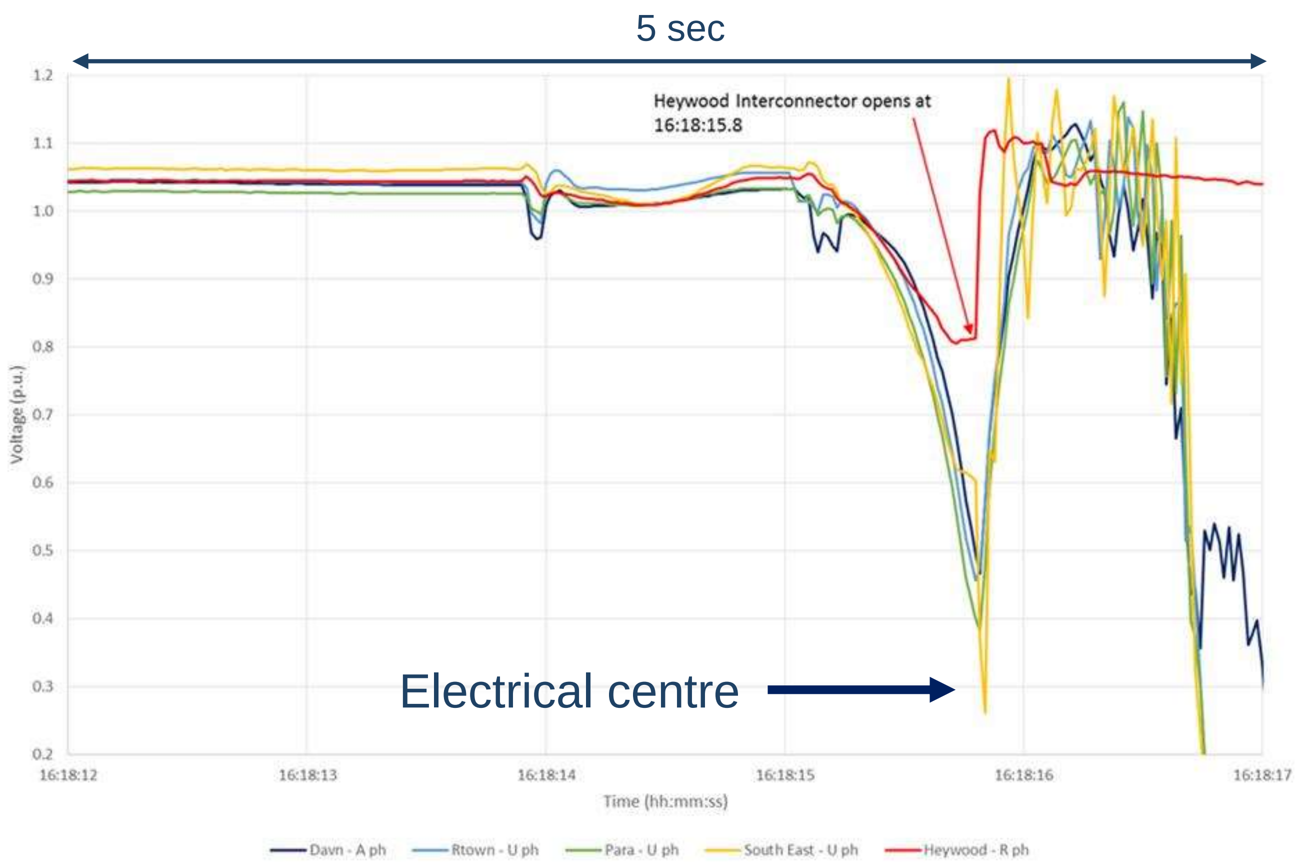
Wind turbine group	Multiple ride-through capability on 28 September 2016	Actions taken for improved ride-through capability
Group A1	2 within 2 minutes	6 within 2 minutes
Group A2	2 within 2 minutes	15–19 within 2 minutes
Group B	5 within 30 minutes (also 5 within 2 minutes)	Changed to 20 within 120 minutes (also 20 within 2 minutes)

VOLTAGE ANGLE DIFFERENCE BETWEEN VARIOUS SA NODES AND HEYWOOD SUBSTATION



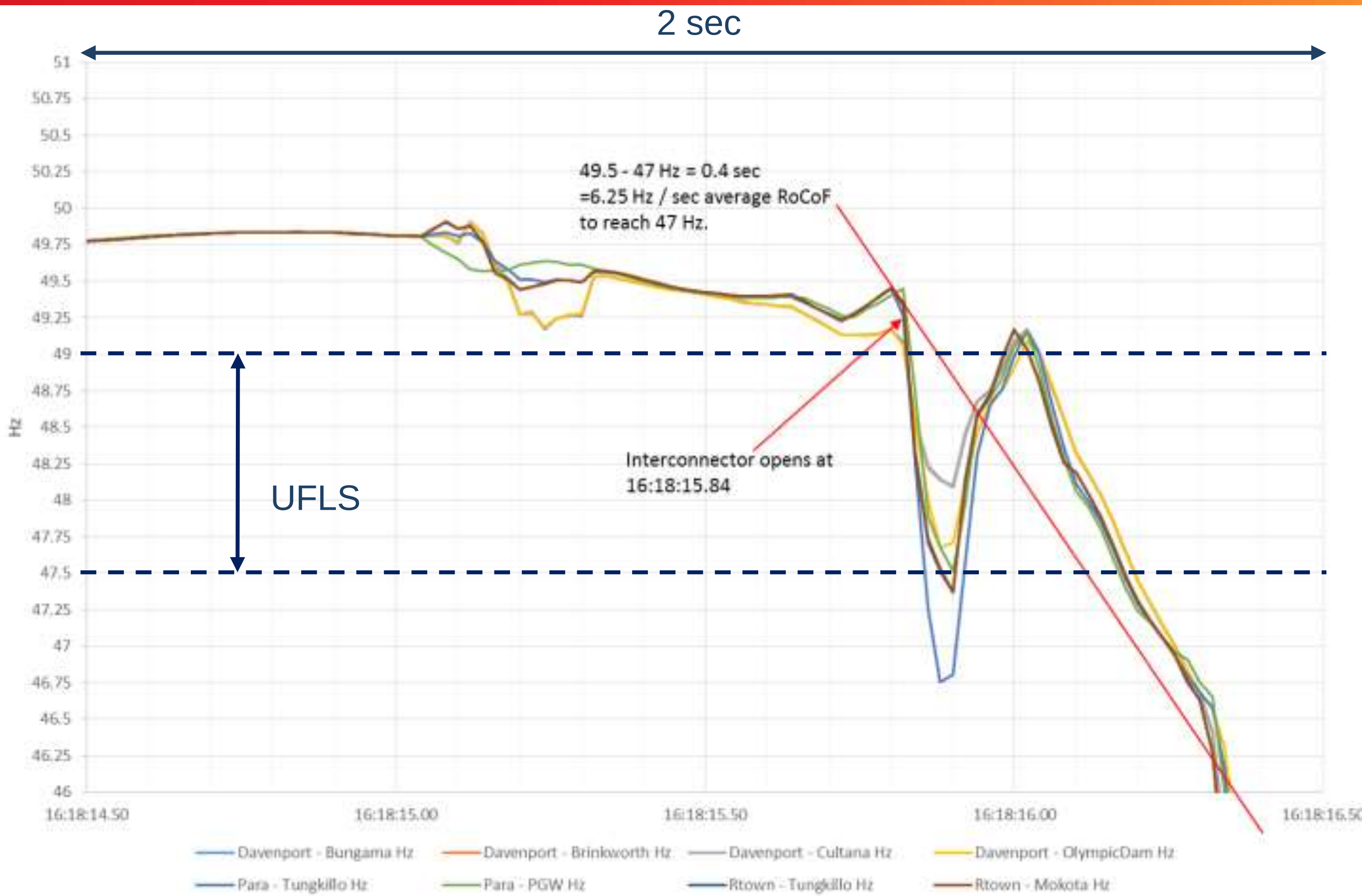
Relative phase angles started to diverge immediately after the sixth voltage disturbance due to loss of significant amount of active power resulting in loss of synchronism conditions.

SYSTEM VOLTAGE RESPONSE



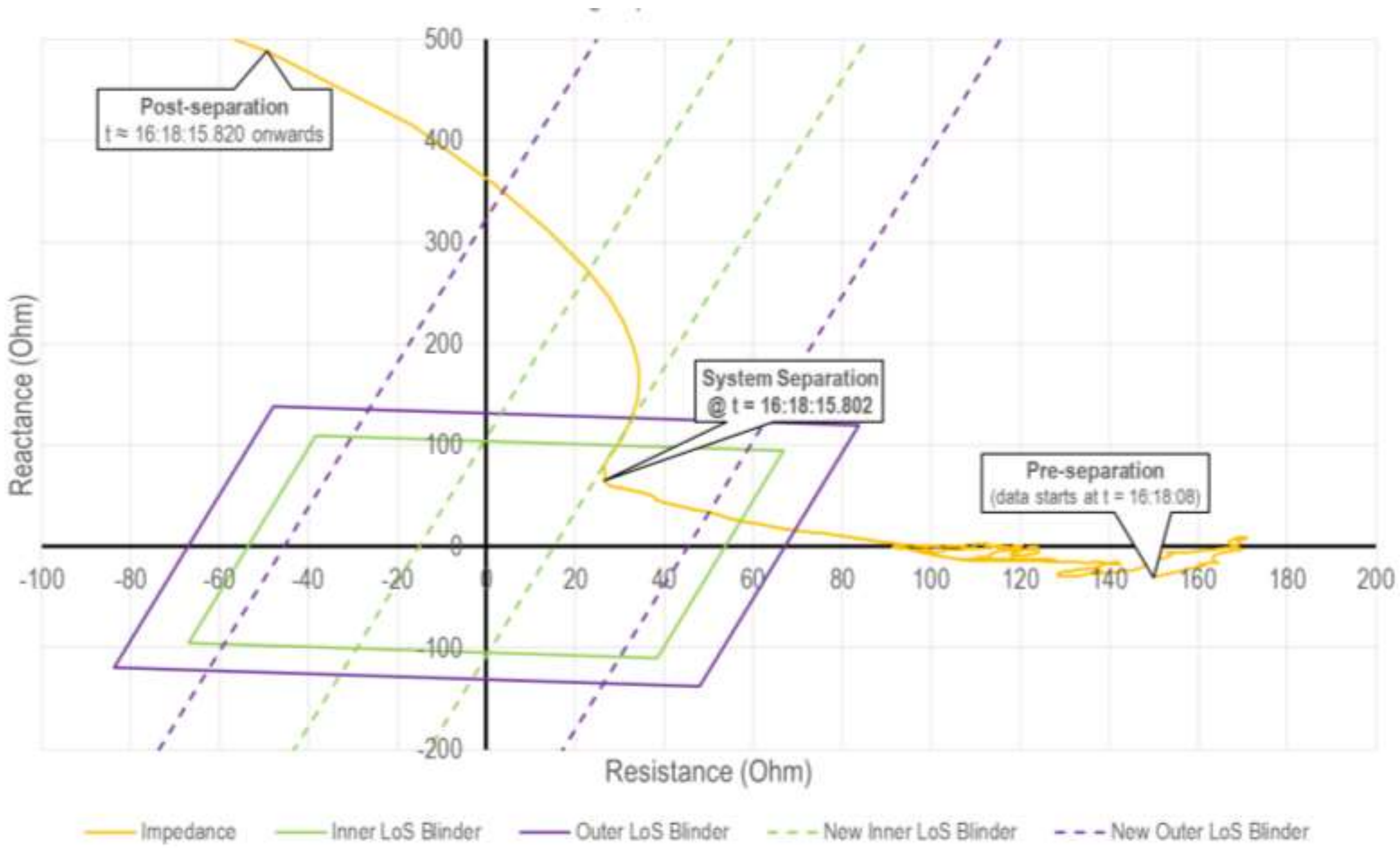
- System voltages started to decline globally until they collapse down to 0.2 pu within 600 ms
- Dynamic voltage collapse is a symptom of loss of synchronism conditions

SYSTEM FREQUENCY RESPONSE



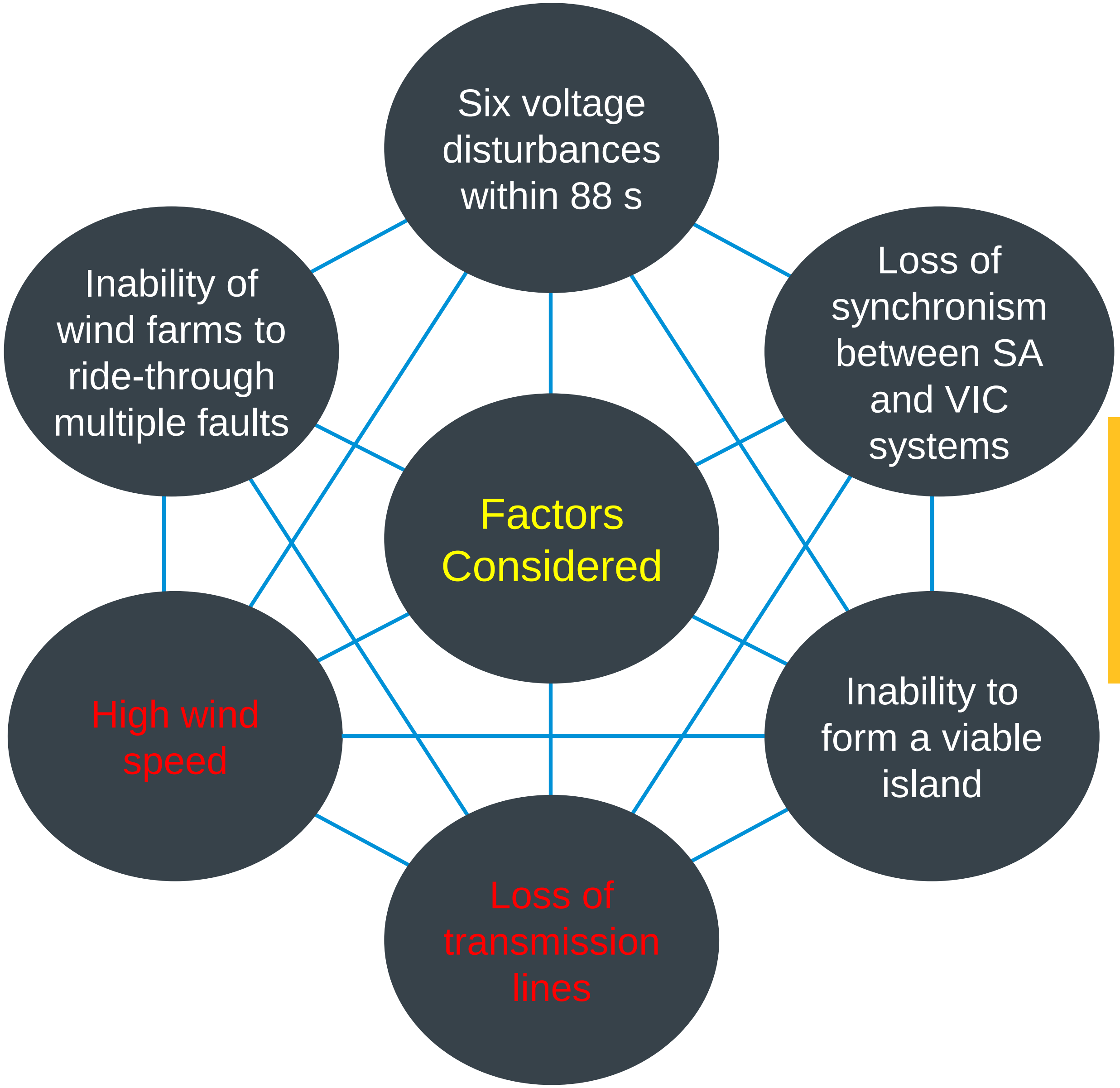
- Prior to system separation system frequency did not drop sufficiently to initiate UFLS or governor response (the latter would have been insignificant anyway).
- Post separation frequency collapsed very rapidly where UFLS did not have sufficient time to respond.

RESPONSE OF HEYWOOD INTERCONNECTOR LOSS OF SYNCHRONISM RELAY



Correct and intended operation of loss of synchronism relays which resulted in disconnection of SA power system from rest of the NEM

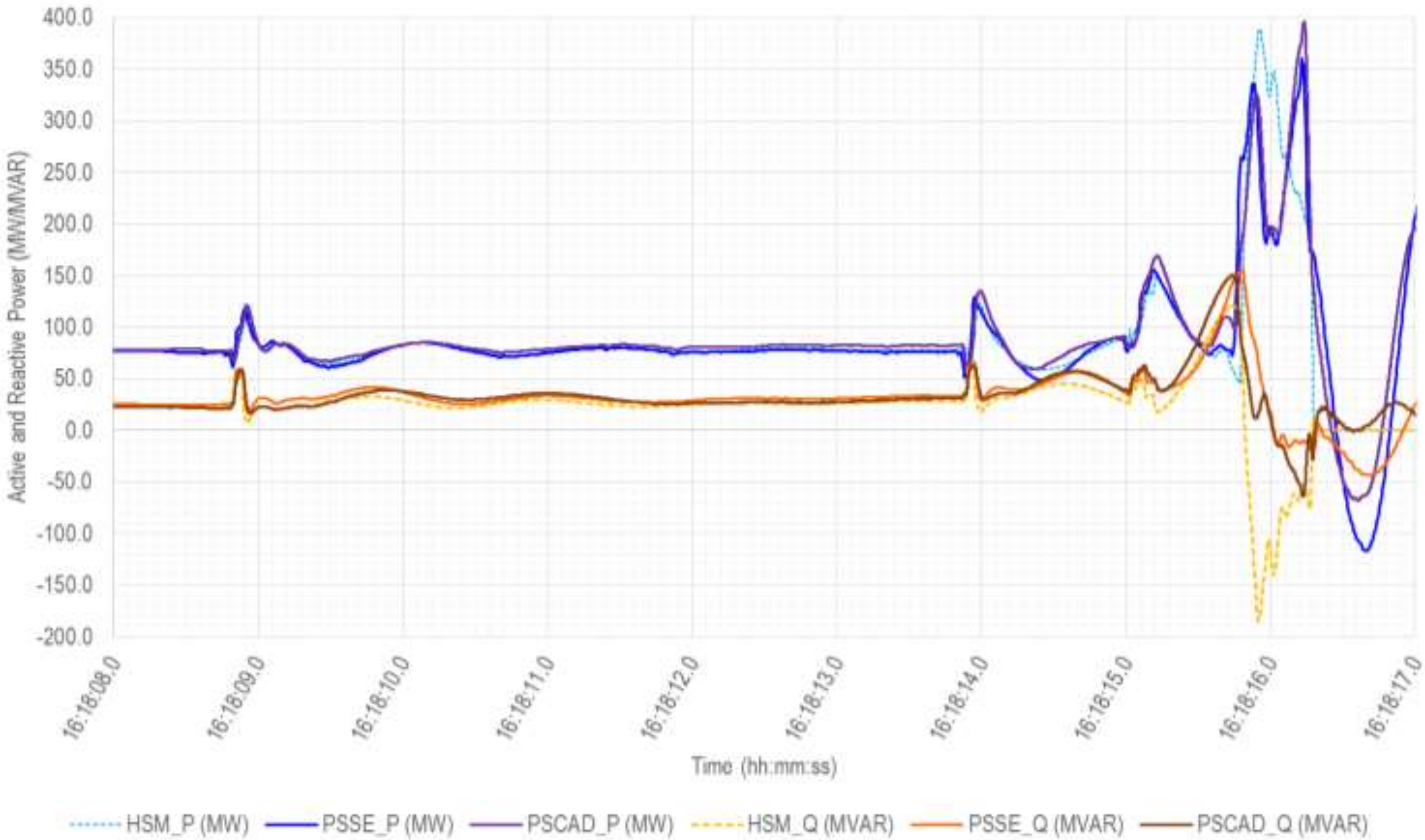
KEY CONTRIBUTORS TO THE BLACK SYSTEM



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

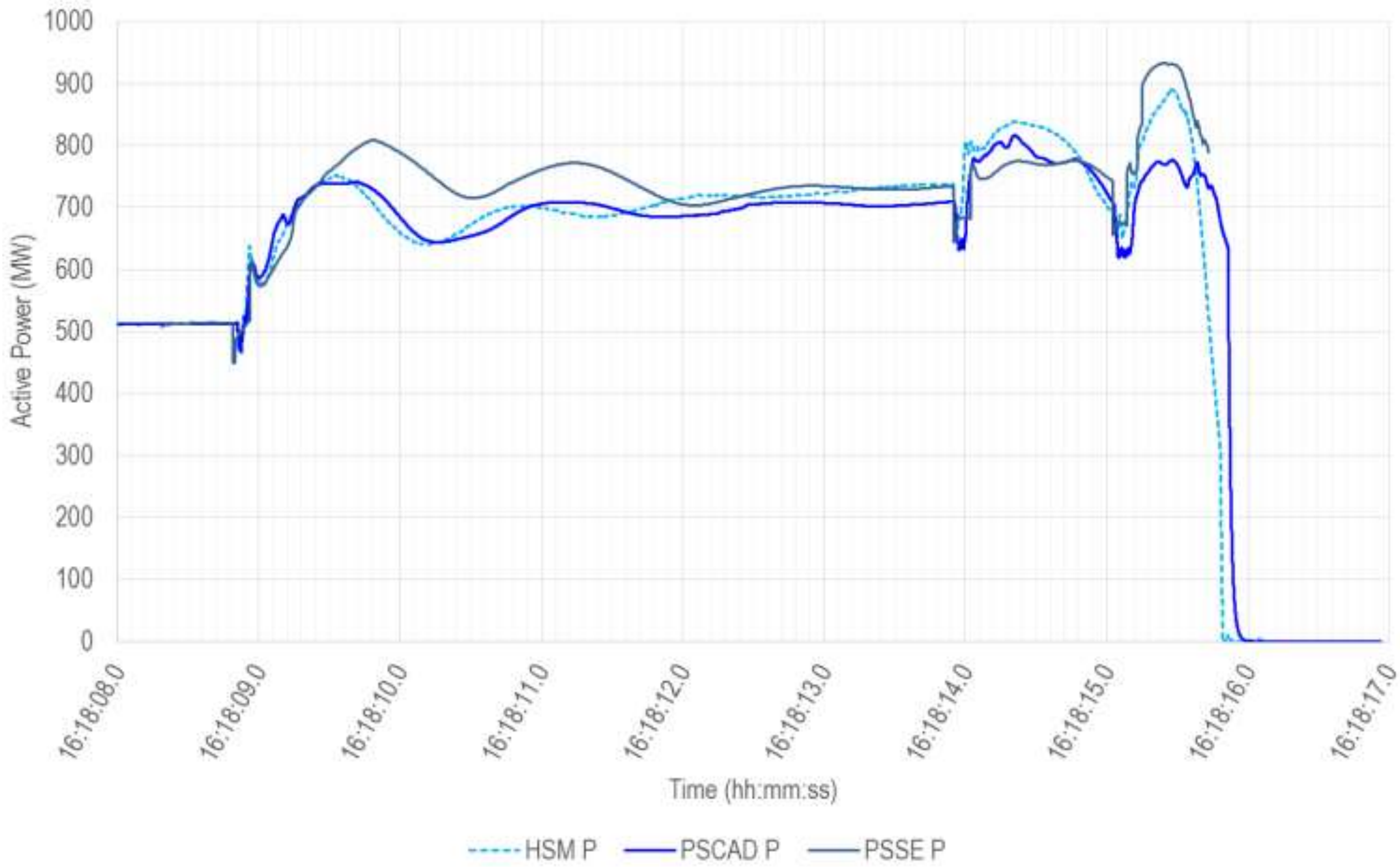
MODELLING AND SIMULATION OF CAUSATION CHAIN

MODEL BENCHMARKING



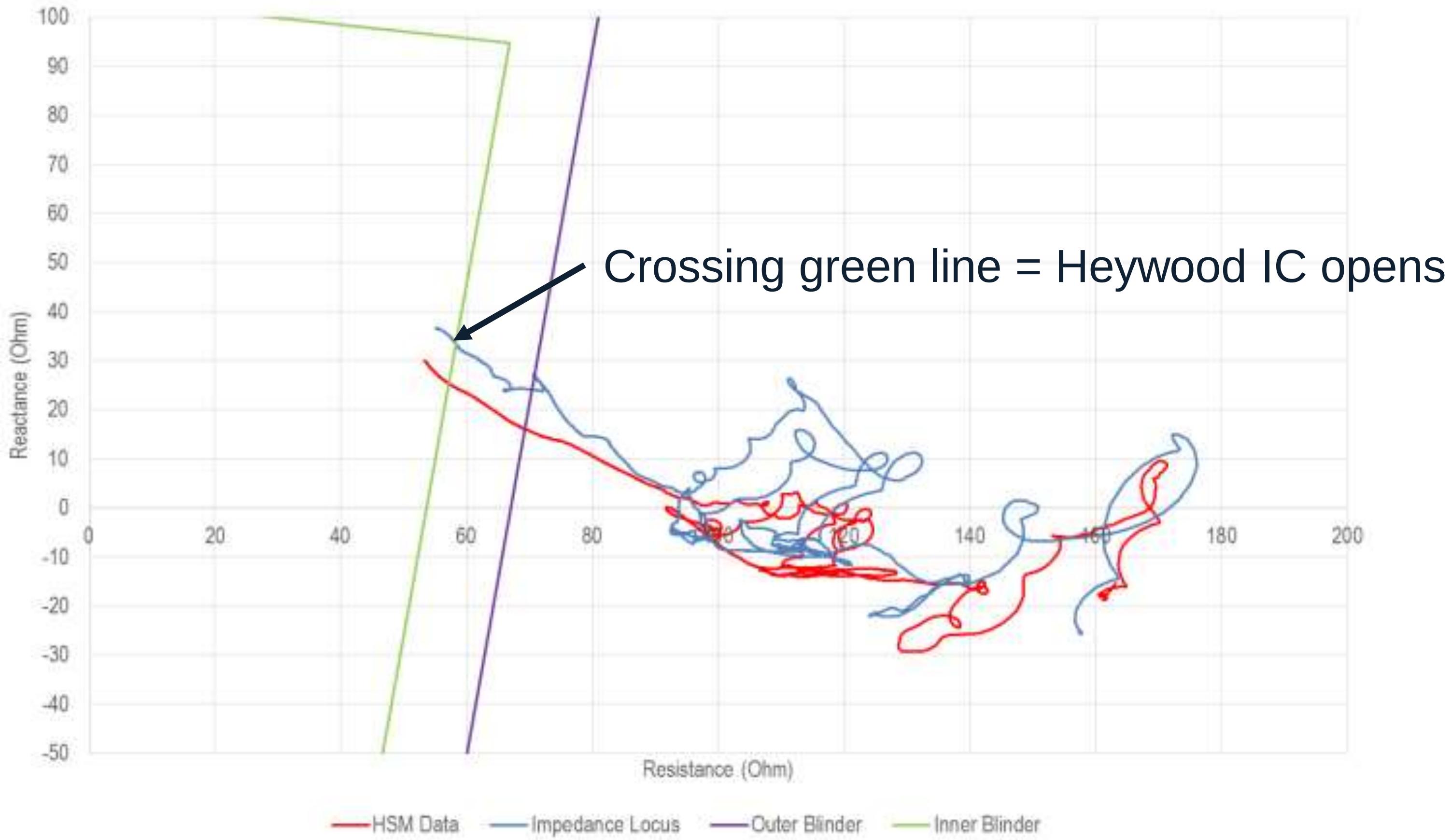
All individual generator models were benchmarked against the actual measurements using both PSS/E and PSCAD/EMTDC simulations

HEYWOOD INTERCONNECTOR ACTIVE POWER FLOW



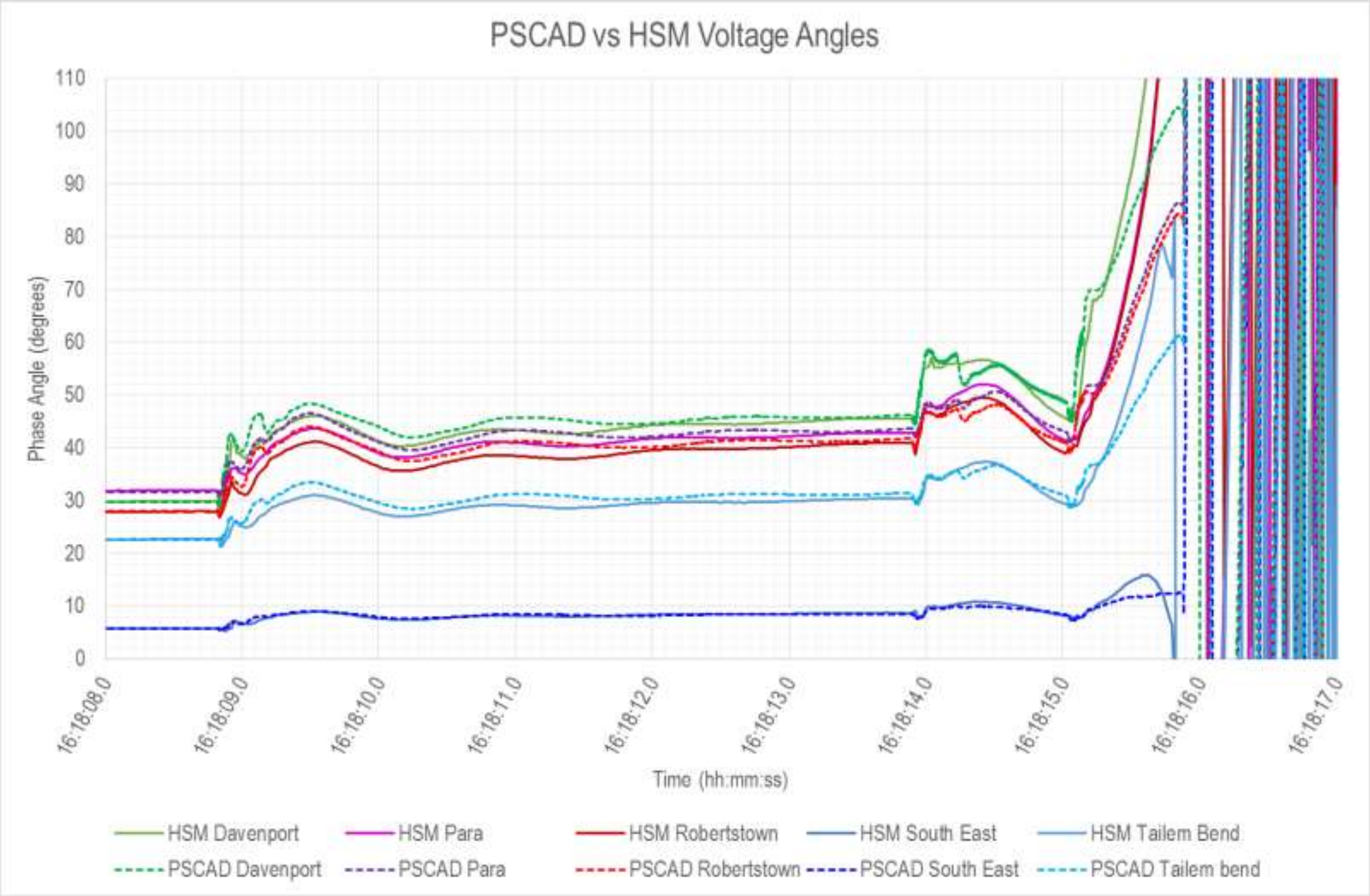
PSCAD model replicates precisely the overall system response

IMPEDANCE TRAJECTORY SEEN BY LOSS OF SYNCHRONISM PROTECTION



Accurate replication of impedance trajectory seen by loss of synchronism relays

RELATIVE VOLTAGE PHASE ANGLES AT KEY SA 275 KV SUBSTATIONS

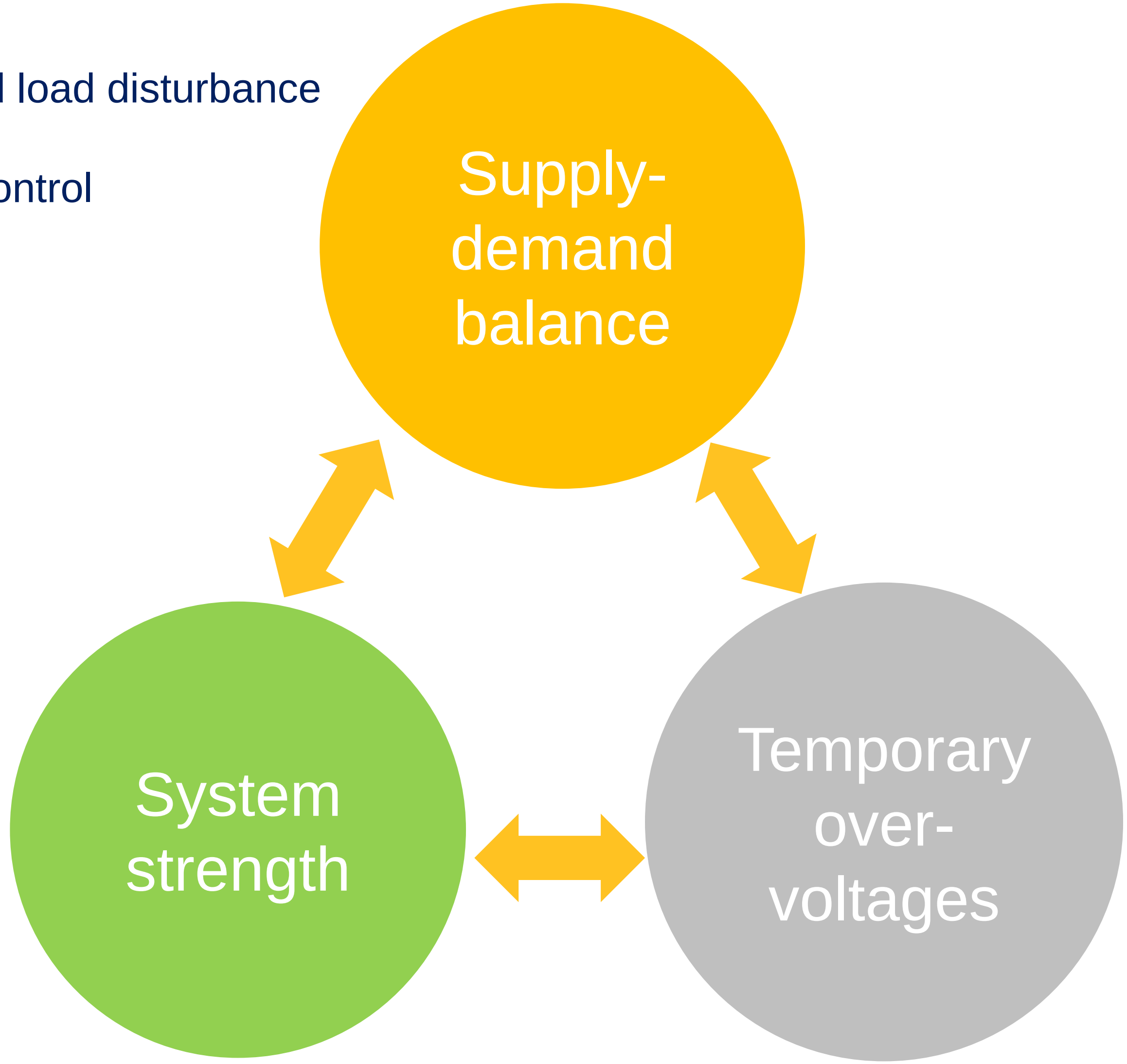


Accurate simulation of voltage phase angles which are the key indicator of loss of synchronism conditions

SA SYSTEM SECURITY IMPROVEMENTS

SYSTEM SECURITY TRILEMA

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



- 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

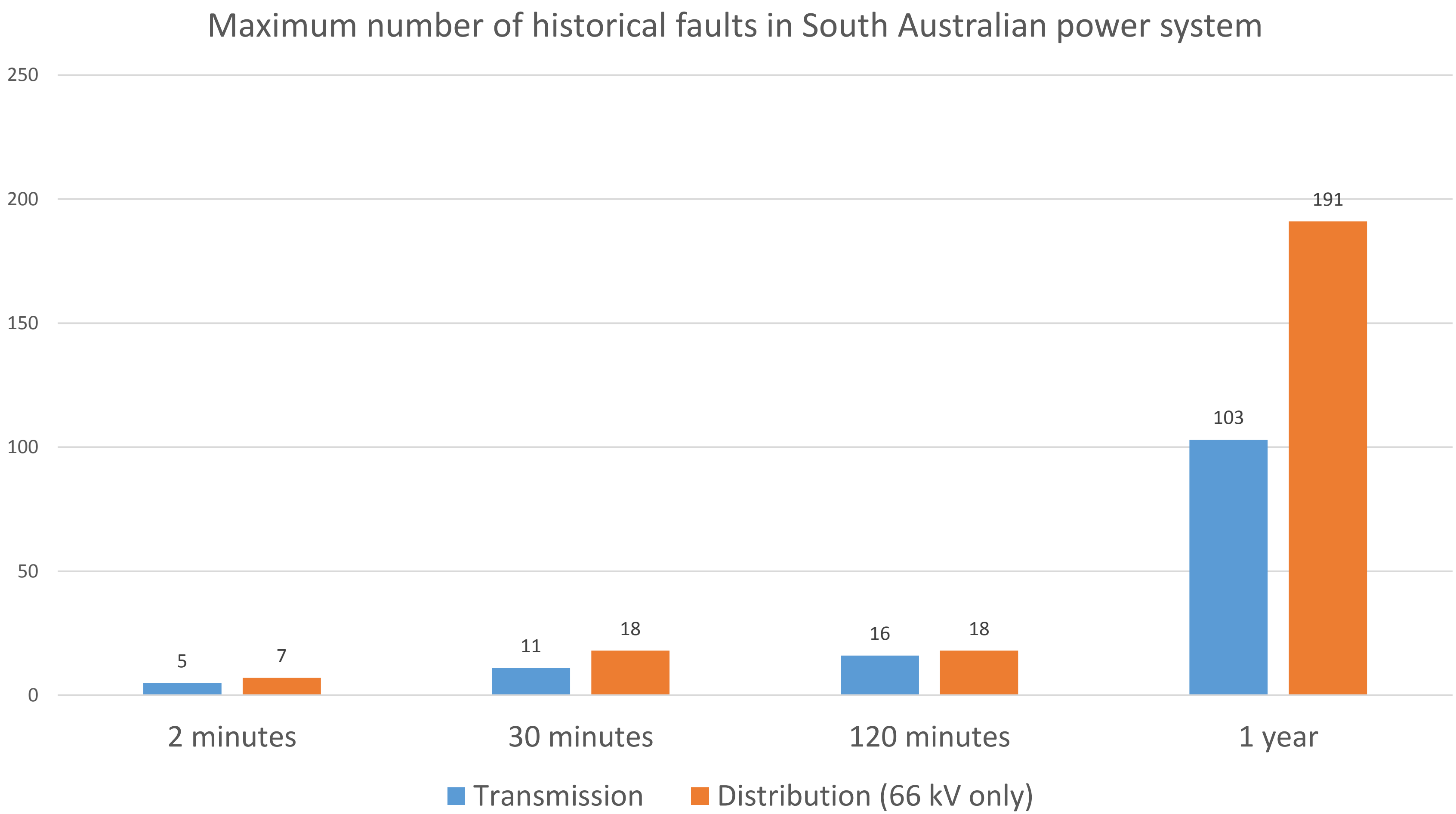
- Increased technical performance requirements on generating systems including DER.

- 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.

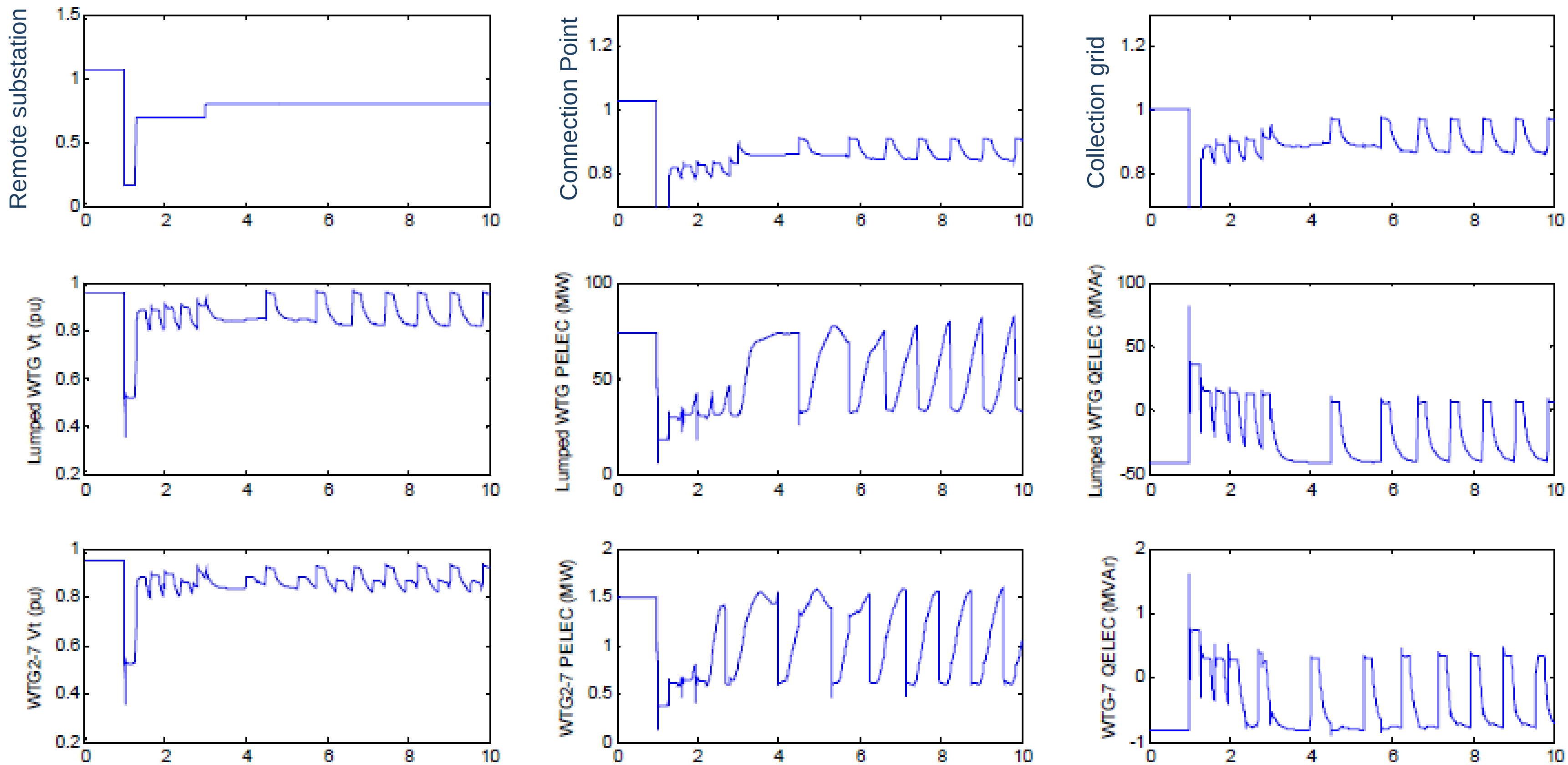
- Consideration of both credible and non-credible events, and developing control and protection schemes to account for non-credible events:
  - E.g. pre-emptive load shedding before SA becomes islanded.

MAXIMUM NUMBER OF HISTORICAL FAULTS IN SOUTH AUSTRALIA



- 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
  - 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
  - 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.
  - Generally no limitations on solar inverters other than UPS rating

DISCUSSION