Evaluating major contingencies and conditions with the potential to cause power system disruptions

ESIG Presentation
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March 2024

We acknowledge the Traditional Owners of country throughout Australia and recognise their continuing connection to land, waters and culture.

We pay respect to Elders past and present.

Background

Luke

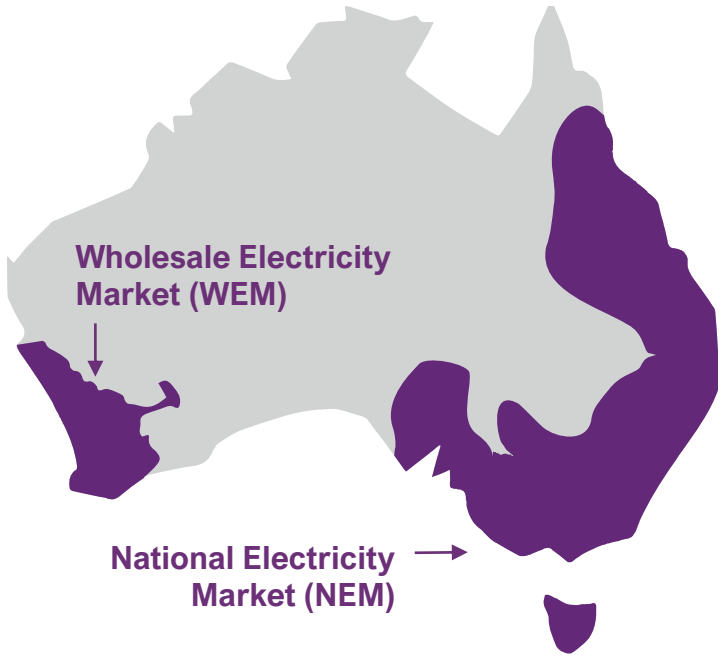
About AEMO

- AEMO is a member-based, not-for-profit organisation.
- We are the independent energy market and system operator for the National Electricity Market (NEM) and the WA Wholesale Electricity Market (WEM), and system planner for the NEM.
- We also operate retail and wholesale gas markets across south-eastern Australia and Victoria's gas pipeline grid.

AEMO SERVICES

AEMO Services is an independent subsidiary of AEMO, established in 2021 to enable the transparent provision of advisory and energy services to National Electricity Market jurisdictions.

Electricity



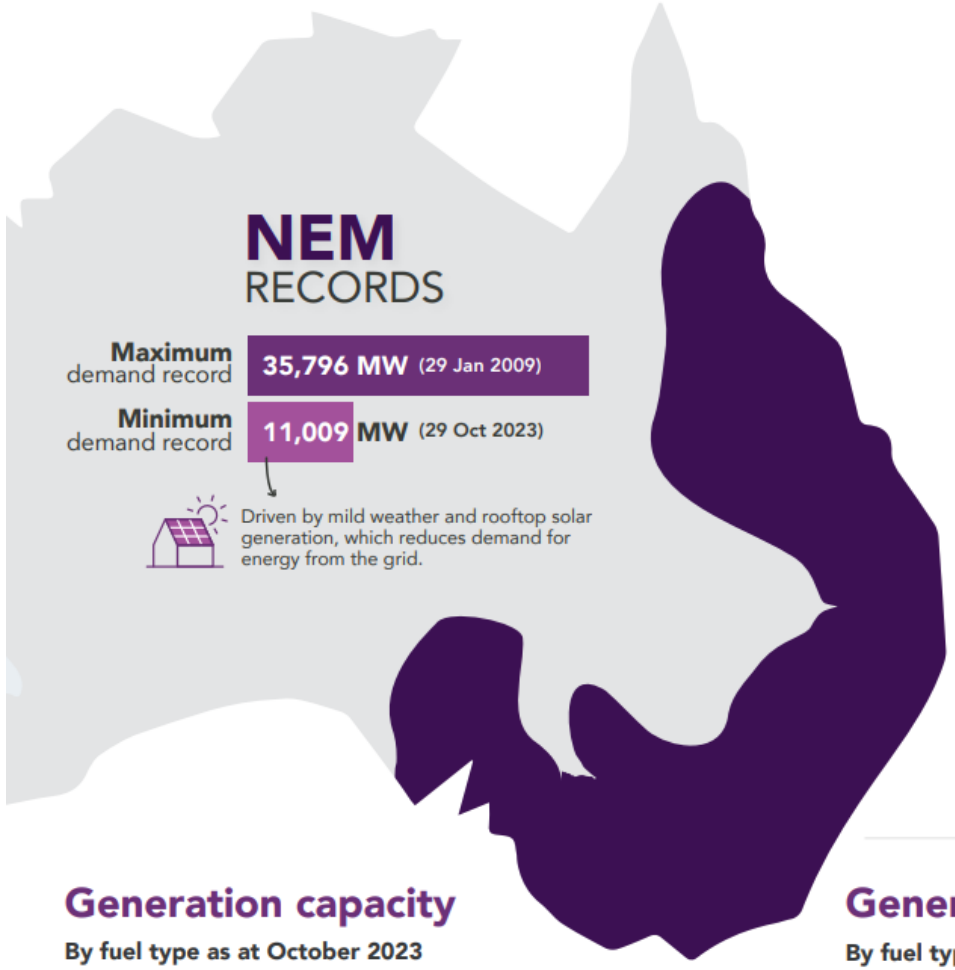
Gas

Declared Wholesale Gas Market (DWGM)

Short Term Trading Market (STTM)

and

Gas Supply Hub (GSH)



NEM RECORDS

Maximum demand record 35,796 MW (29 Jan 2009)

Minimum demand record 11,009 MW (29 Oct 2023)

Driven by mild weather and rooftop solar generation, which reduces demand for energy from the grid.

NEM Facts

Commenced as a wholesale electricity market in December 1998.

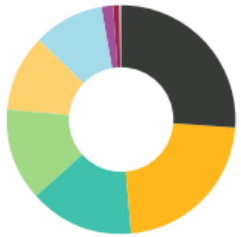
More than 570 registered participants, including generators, transmission and distribution network service providers, and market customers, including retailers.

Approx 175 terawatt hours of electricity supplied to homes and businesses a year.

$25.46 billion traded in FY22-23.

Generation capacity

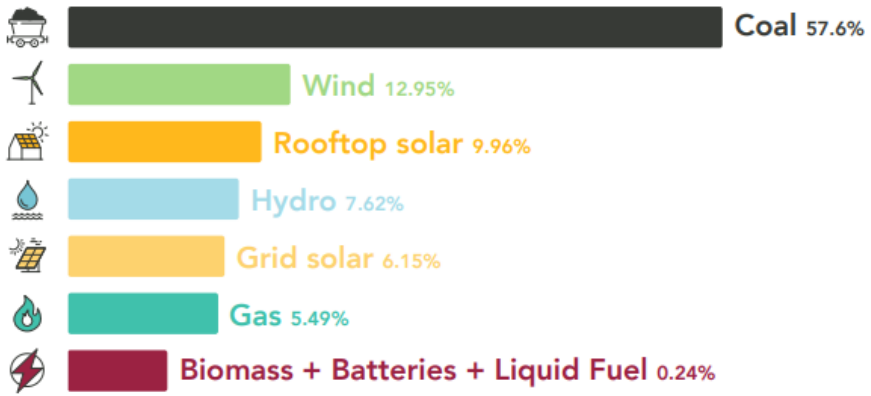
By fuel type as at October 2023



- Coal 21,255 MW
- Rooftop solar 18,000 MW
- Gas 11,924 MW
- Wind 10,582 MW
- Grid solar 8,652 MW
- Hydro 7,999 MW
- Battery storage 1,413 MW
- Biomass 542 MW
- Other 214 MW

Generation supply mix

By fuel type from 1 July 2022 – 30 June 2023



- Coal 57.6%
- Wind 12.95%
- Rooftop solar 9.96%
- Hydro 7.62%
- Grid solar 6.15%
- Gas 5.49%
- Biomass + Batteries + Liquid Fuel 0.24%

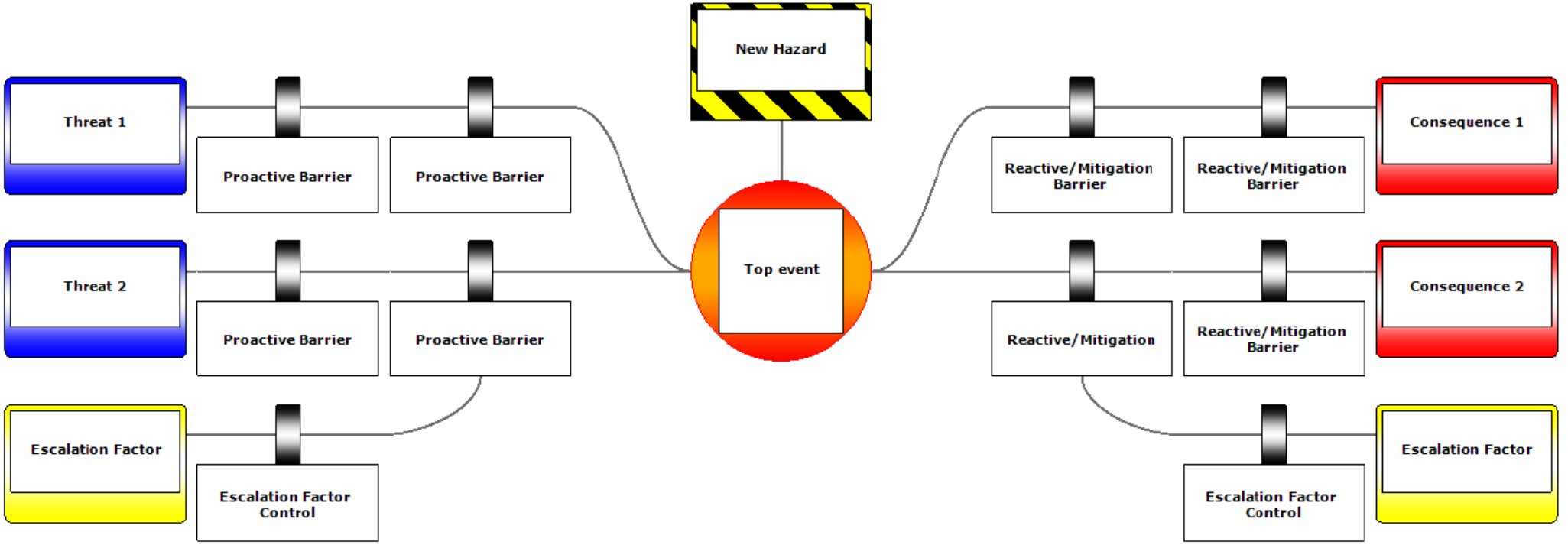
NEM context

- The NEM is supporting a once-in-a-century transformation in the way society considers and consumes energy.
- Associated with this transformation are a range of factors that influence the resilience of the NEM, such as:
  - Fewer synchronous generators online.
  - Increased power transfers through major transmission corridors.
  - Concentrated provision of contingency frequency control ancillary services (FCAS) in some regions.
  - The increase in connection of inverter-based resources (IBR) and distributed energy resources (DER) also poses challenges in maintaining grid stability, voltage and frequency control while managing evolving weather-related risks.
- These significant changes to the power system also require an increase in the number and complexity of special protection schemes (SPSs) - while SPSs can enhance the resilience of the system, they also have the potential to create additional risks in relation to maloperation of schemes.

Managing non-credible contingencies in the NEM

- Planning timeframe - e.g. Network Service Provider planning for emergency controls, General Power System Risk Review (GPSRR).
- Operational timeframe - e.g. Reclassification of non-credible contingencies, indistinct events, protected events.
- Post incident analysis and management - e.g. Reviewable incident reports.

Bow-Tie risk assessment approach

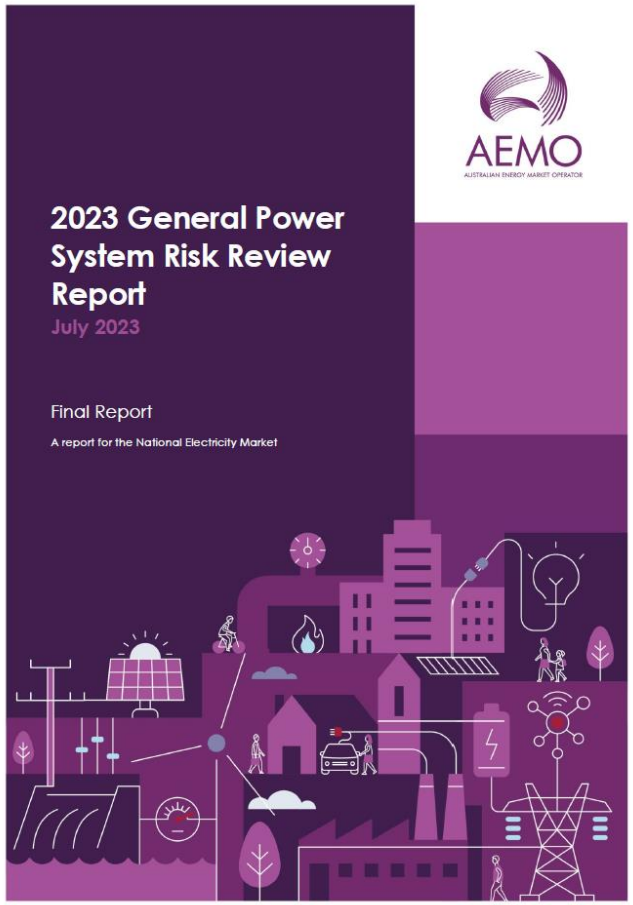


Evolution of the risk review

Luke

Evolution of the risk review

- The first Power System Frequency Risk Review (PSFRR) was undertaken in 2017 (SA) and 2018 (NEM) in response to a rule change following the 2016 South Australia black system event.
- The biennial PSFRR has expanded to include events and conditions that could lead to cascading failures or supply disruptions, with the first annual GPSRR published in 2023.
- In accordance with 5.20A of the National Electricity Rules (NER), AEMO is required to undertake a GPSRR.

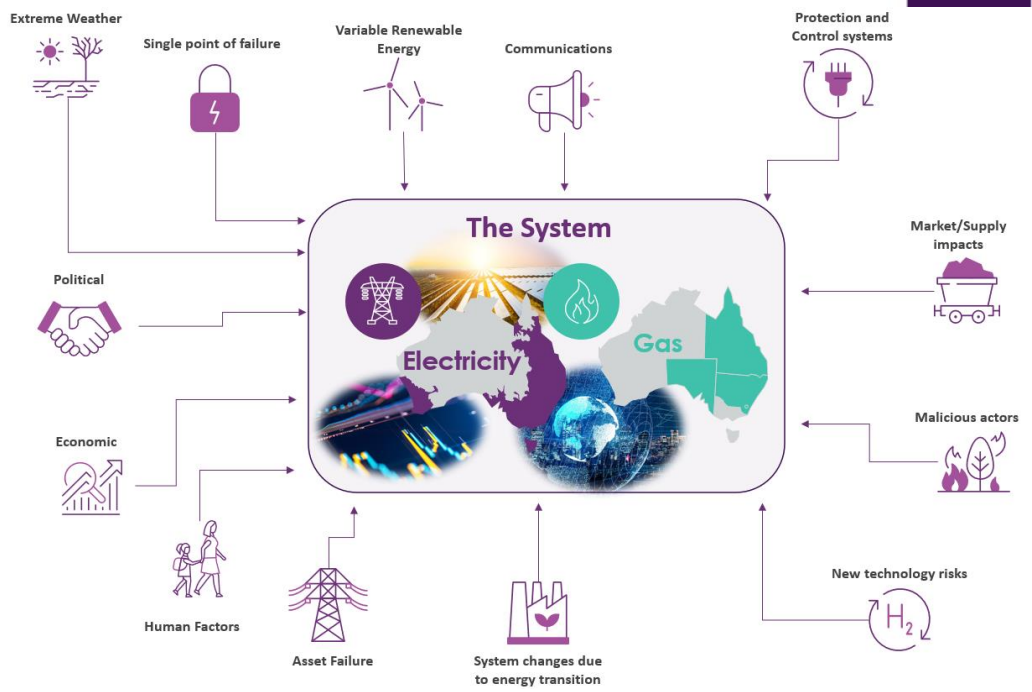


GPSRR

- The purpose of the GPSRR to review:
  - A prioritised set of risks comprising contingency events and other events and conditions that could lead to cascading outages or major supply disruptions.
  - The current arrangements for managing the identified priority risks and options for their future management.
  - The arrangements for management of existing protected events and consideration of any changes or revocation.
  - The performance of existing emergency frequency control schemes and the need for any modifications.

The GPSRR achieves this by:

- Exploring the risks and consequences of non-credible contingencies, and other system events and conditions that could lead to cascading outages or major supply disruptions.
- Considering how these risks evolve over a five-year planning horizon, taking into account potential changes in power system risks within that period.
- Building on and complementing other work undertaken by AEMO, such as the Integrated System Plan (ISP), Engineering Roadmap to 100% Renewables, and AEMO risk management initiatives.



Identifying priority risks

Luke

GPSRR approach

Key activities required for the 2024 GPSRR are listed below.

- Review recent power system events and operational challenges, for example:
  - Nov 2023 challenges managing minimum synchronous generator operation in NSW
  - Feb 2024 500kV double circuit trip in Victoria
- Engagement with AEMO internal teams and Network Service Providers (NSPs) to finalise the scope of 2024 GPSRR
  - Review known risks and controls through extensive engagement with NSPs
  - Cross-departmental brainstorming sessions
  - Risk evaluation and calibration sessions

Event details	Likelihood	Consequence	Mitigations (current / planned)

GPSRR approach (cont.)

- Write up of proposed GPSRR draft approach paper including:
  - Proposed risks
  - Risk assessment process
  - Modelling approach
  - Consultation approach
- Industry consultation on the 2024 GPSRR draft approach paper
  - 20 day consultation period and industry Q&A session
- Publication of the 2024 GPSRR final approach paper
  - Taking on board feedback from industry
- Undertake the GPSRR including:
  - Completion of studies on the agreed priority risks
  - Propose mitigation solutions, such as operational constraints, emergency control schemes, protected events or other
  - Share draft report and findings with industry for consultation
- Publication of the final 2024 GPSRR report.

Simulation study methodology

Dan

Factors considered to determine modelling approaches for GPSRR studies

Current risks

RMS studies

Simplified model

Future risks

EMT studies

Full NEM model

Full NEM model for current studies

- Full NEM model as downloaded from AEMO Operations and Planning Data Management System (OPDMS), based on historical timestamps of the system
- Additional dynamic models are added:
  - CMLD (composite load model)/DER (distributed energy resources) models
  - Updated governor settings and generic governor models for hydro, gas, steam
  - UFLS (under frequency load shedding)/OFGS (over frequency generator shedding)
  - System protection schemes

AEMO CMLD/DER models

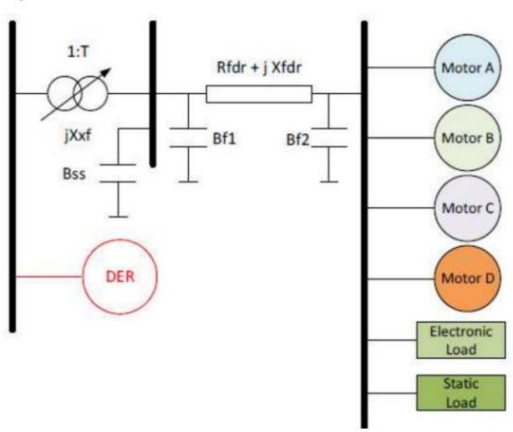
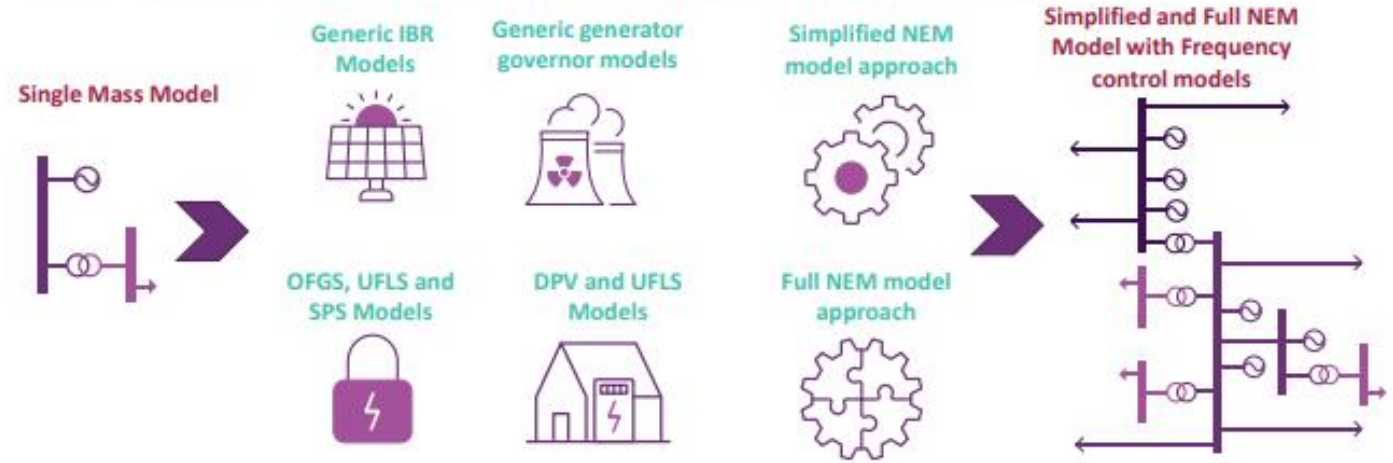


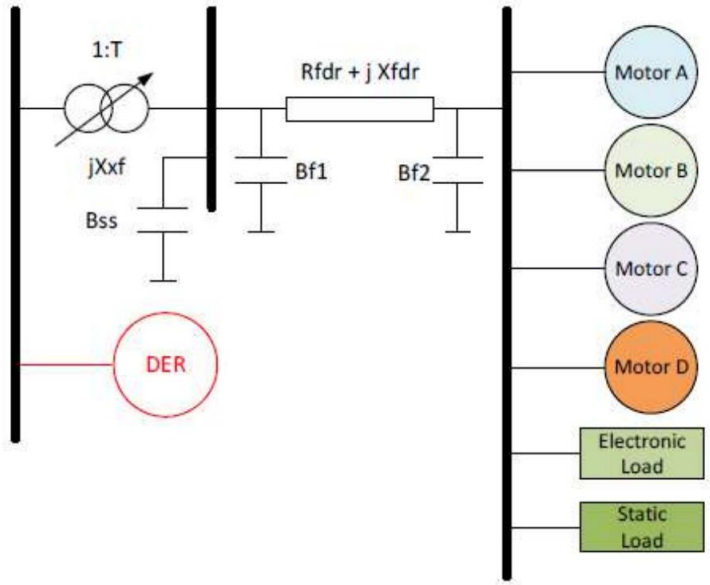
Figure 3 PSFRR study model improvements in full OPDMS and in NEM simplified models since 2017



OPDMS: AEMO's Operational Data Management System

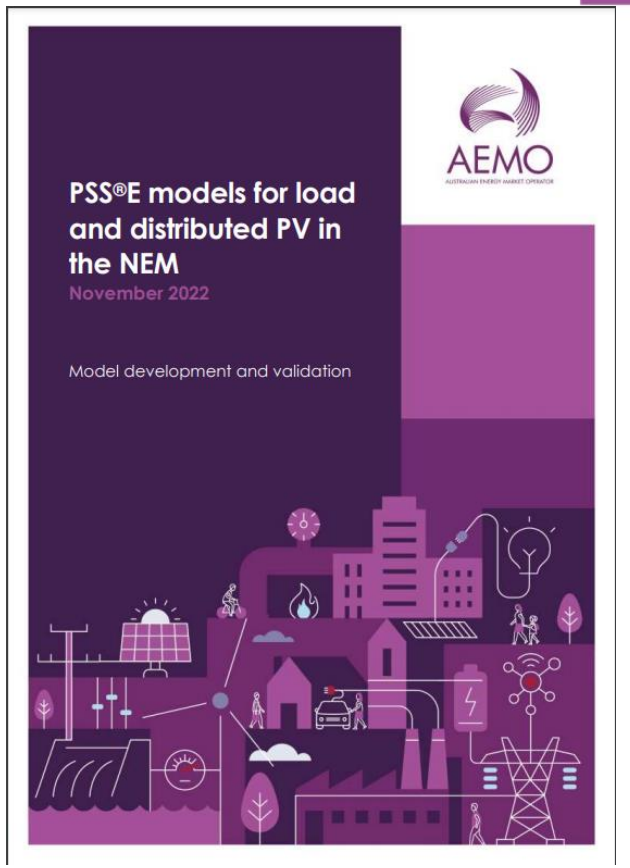
Load models: CMLD

- AEMO composite load model (CMLD) was used to model load response in all GPSRR studies,
- Captures load shake off in response to large disturbances
- The composite load model consists of six load components
- It includes:
  - three three-phase (3P) induction motor models (Motor A, B and C)
  - a single-phase (1P) capacitor-start motor performance model (Motor D)
  - static load components (constant current and constant impedance)
  - a power electronic load model (constant active and reactive power)



DER models: DERAEMO1

- DERAEMO1 model used to represent DER in risk review studies
- Based on DER_A model developed by WECC (Western Electricity Coordinating Council)
- Additional to the DER_A model, the DERAEMO1 model features:
  - Partial power reduction following an under-frequency or over-frequency event
  - Partial power reduction following a low or high RoCoF (Rate of Change of Frequency)
  - Asymmetric reactive power-voltage control
  - Flexible voltage reference

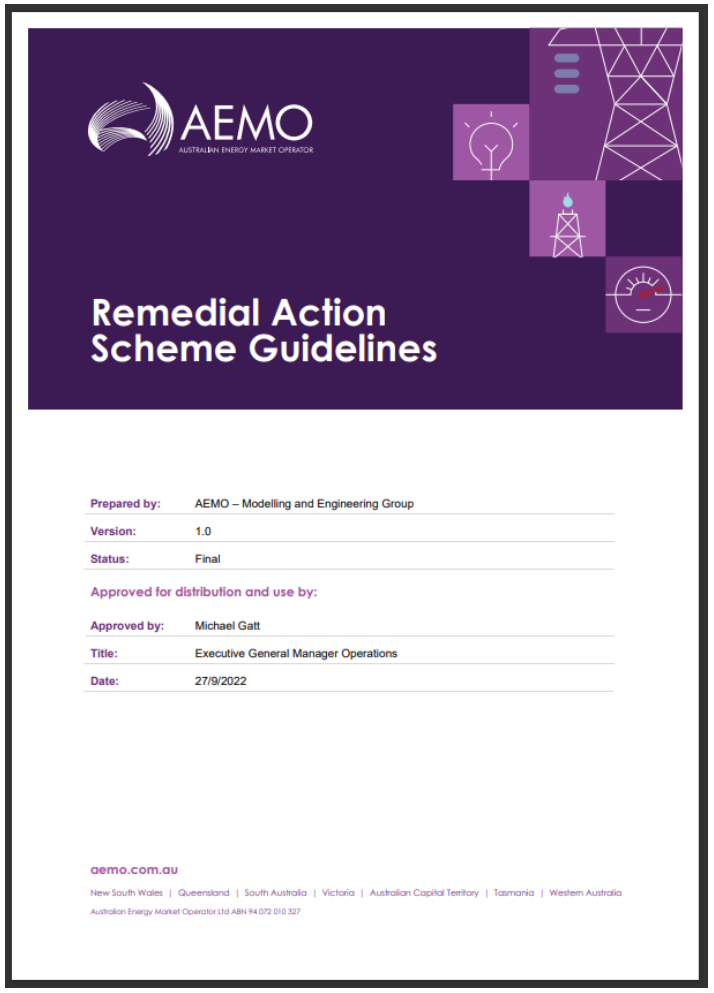


https://aemo.com.au/-/media/files/initiatives/der/2022/psse-models-for-load-and-distributed-pv-in-the-nem.pdf?la=en

Governor models

- Proponent-provided models with site-specific settings including mandatory primary frequency response (PFR) settings
- Where site specific settings were not available, AEMO developed generic governor models with PFR settings for steam, gas and hydro units
- Droop at connection point set less than or equal to 5%
- PFR deadband no wider than +/- 0.015 Hz
- Generic models based on:
  - Steam turbines: IEEEG1SDU
  - Gas turbines: GGOVDU
  - Hydro turbines: HYGOVDU

Remedial Action Scheme (RAS) Guidelines

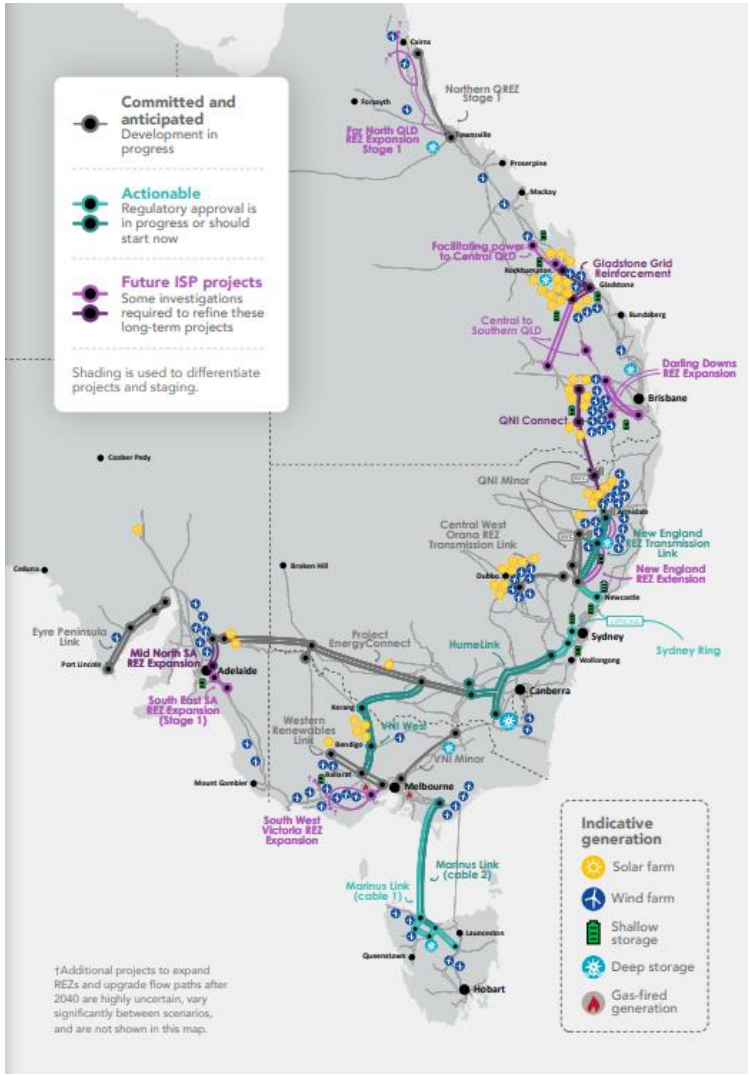


- Relevant RASs considered in risk review studies
- Guidelines developed by AEMO in consultation with industry
- Provides reference of good industry practice for development of RASs in the NEM
- Summarises RAS related rules obligations for NSPs, AEMO and participants
- Includes assessment criteria to evaluate proposed or modified RASs in the NEM

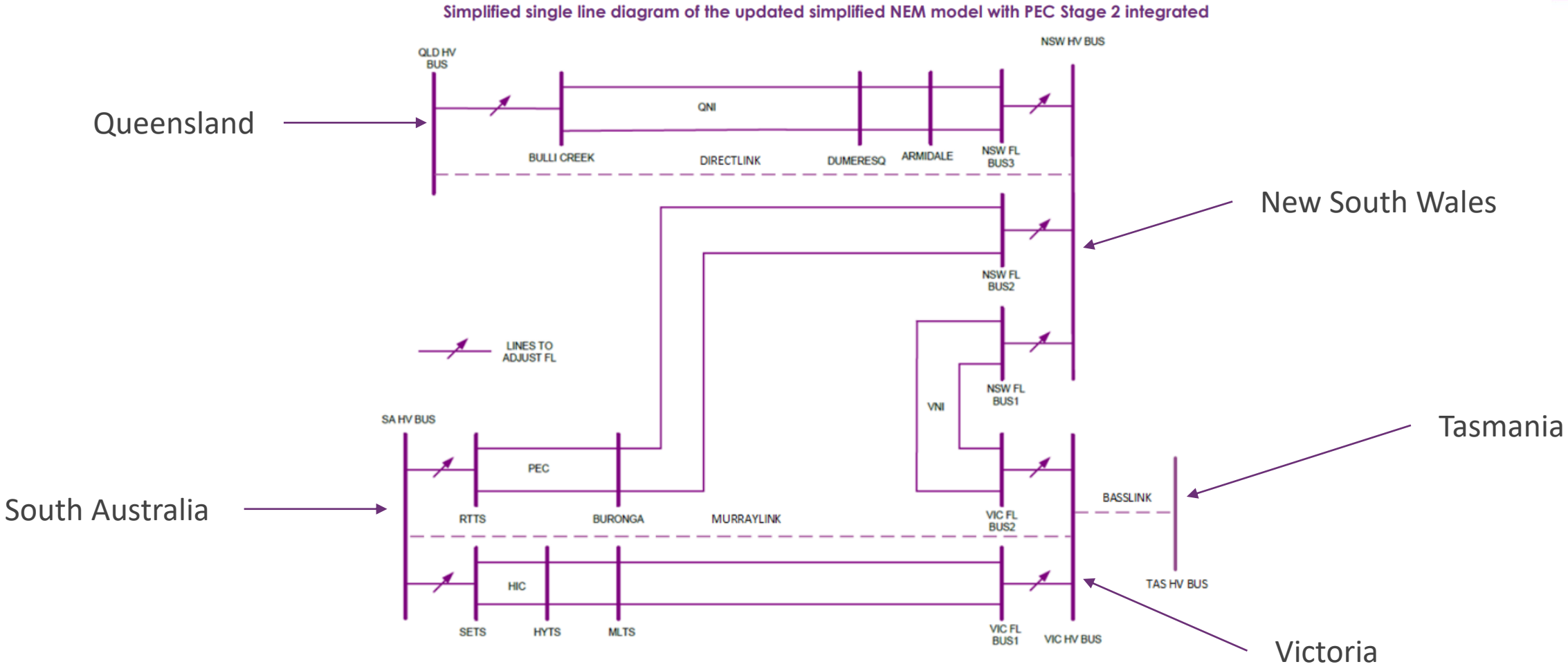
See: https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/system-operations/remedial-action-scheme-guidelines

Full NEM model: future studies

- Similar approach to the current risk studies with a few key differences:
  - Can't rely on OPDMS snapshots
  - Dispatch is now based on latest Integrated System Plan (ISP) forecast data rather than historical data
  - New augmentations and committed generation need to be added in to the model
    - Interconnectors
    - Committed generation
    - Renewable energy zones



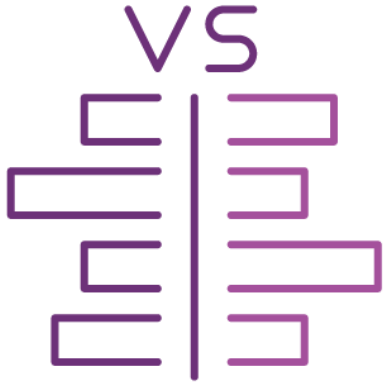
Simplified model



Simplified model benefits and limitations

Benefits:

- Reasonably accurate frequency response
- Balances the time it takes to prepare models with accuracy, while enabling the assessment of a wider range of future dispatch scenarios and contingencies
- Full NEM model can still be used to benchmark the simplified model.

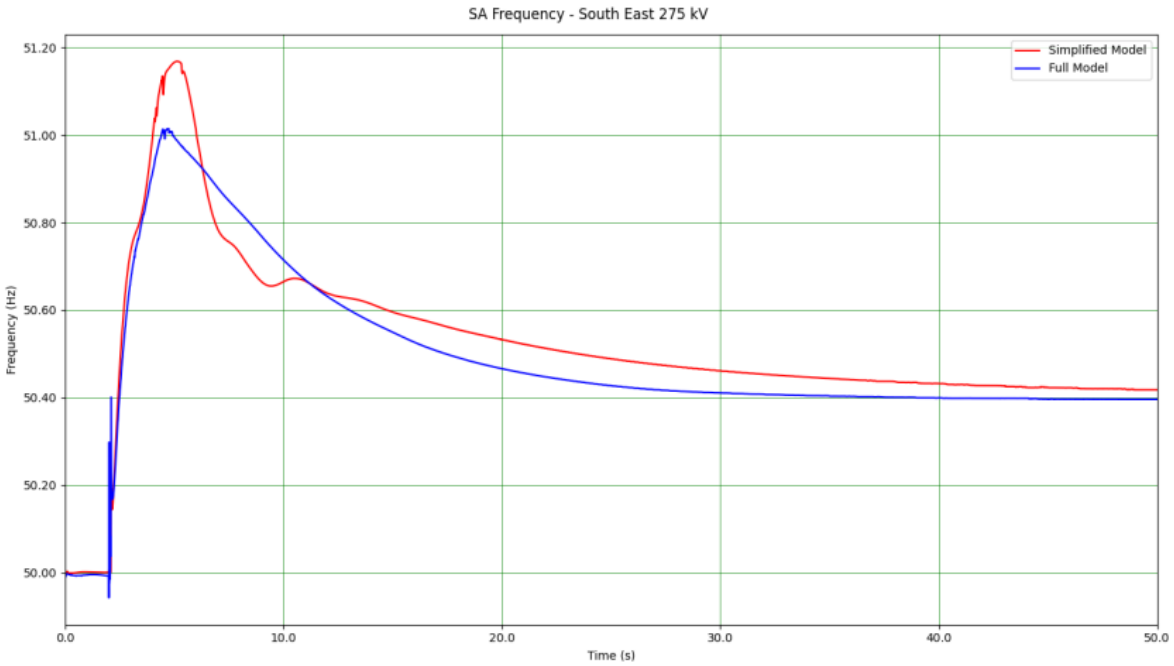


Limitations:

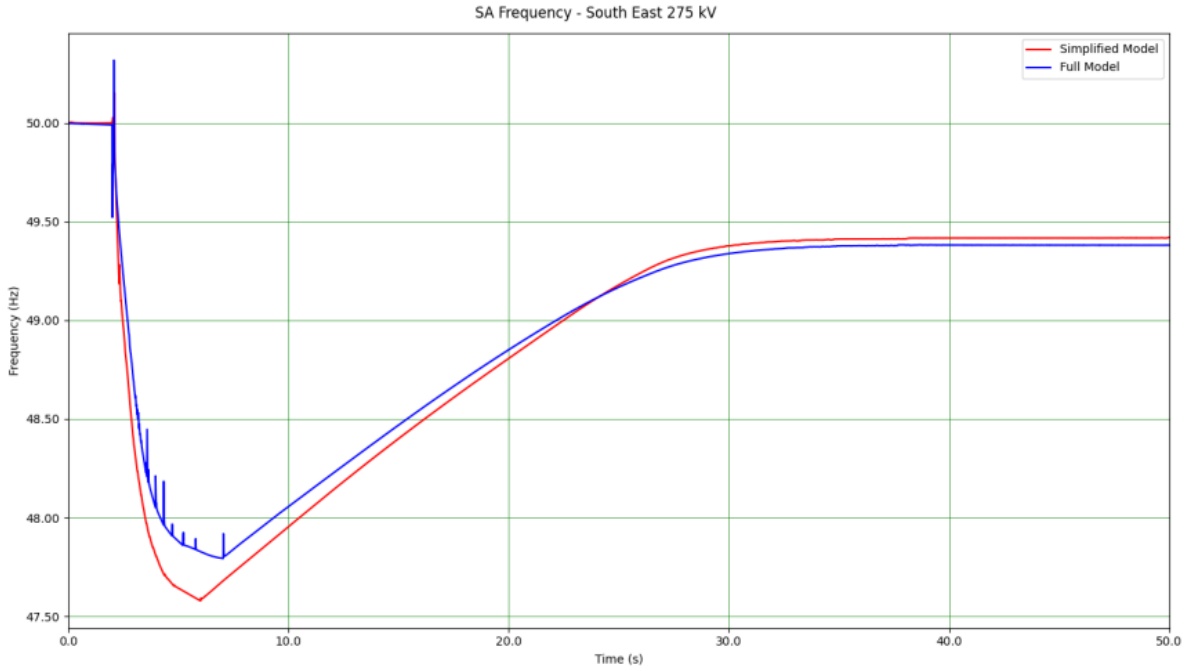
- Network impedances excluded
- Approximates fault ride through of IBR
- Power swings on interconnectors more optimistic/less conservative
- Approximates voltage-based tripping of DPV

Simplified model benchmarking

Simplified PSS®E model and OPDMS full NEM PSS®E model SA frequency, SA separation at HYTS, Export Case 1

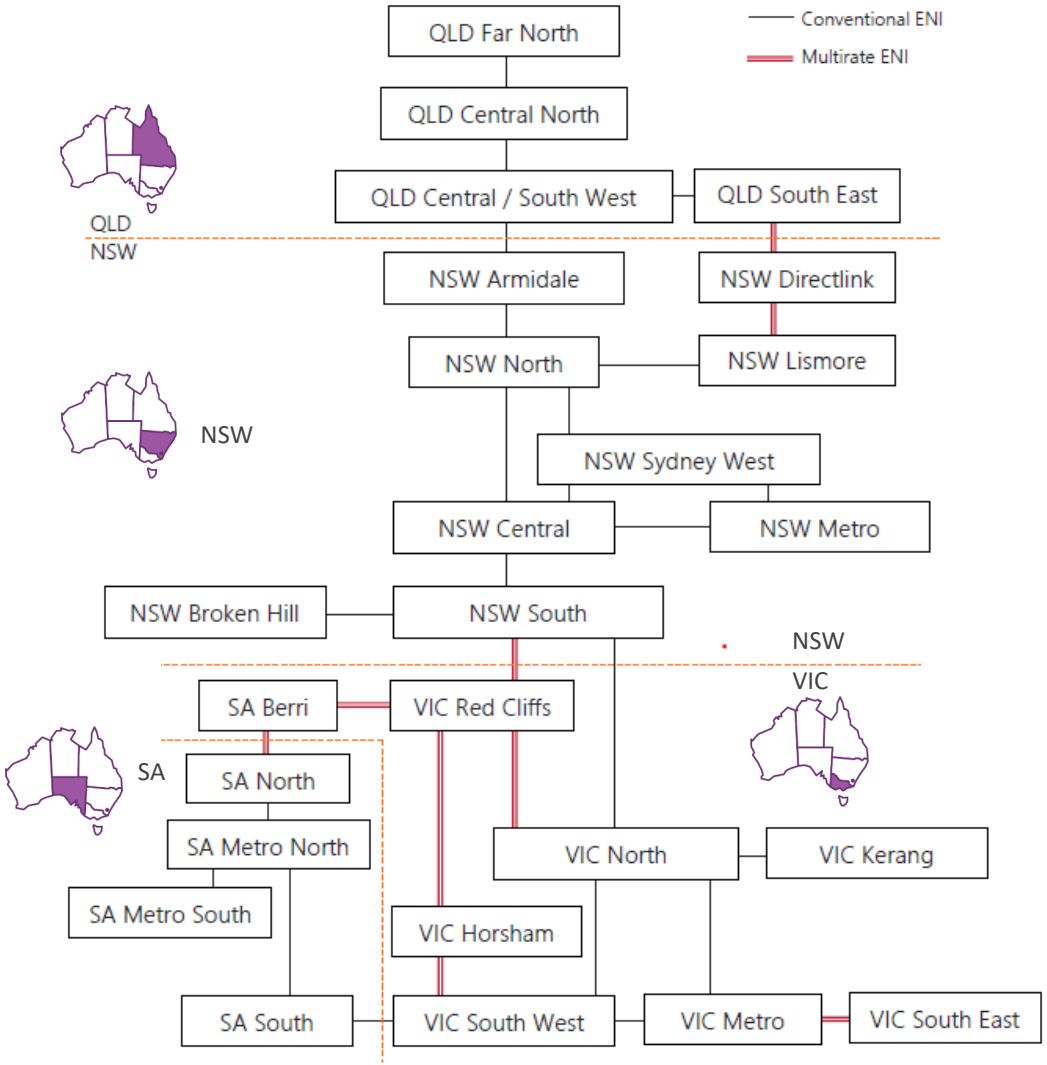


Simplified PSS®E model and OPDMS full NEM PSS®E model, SA frequency, SA separation at MLTS, Import Case 1



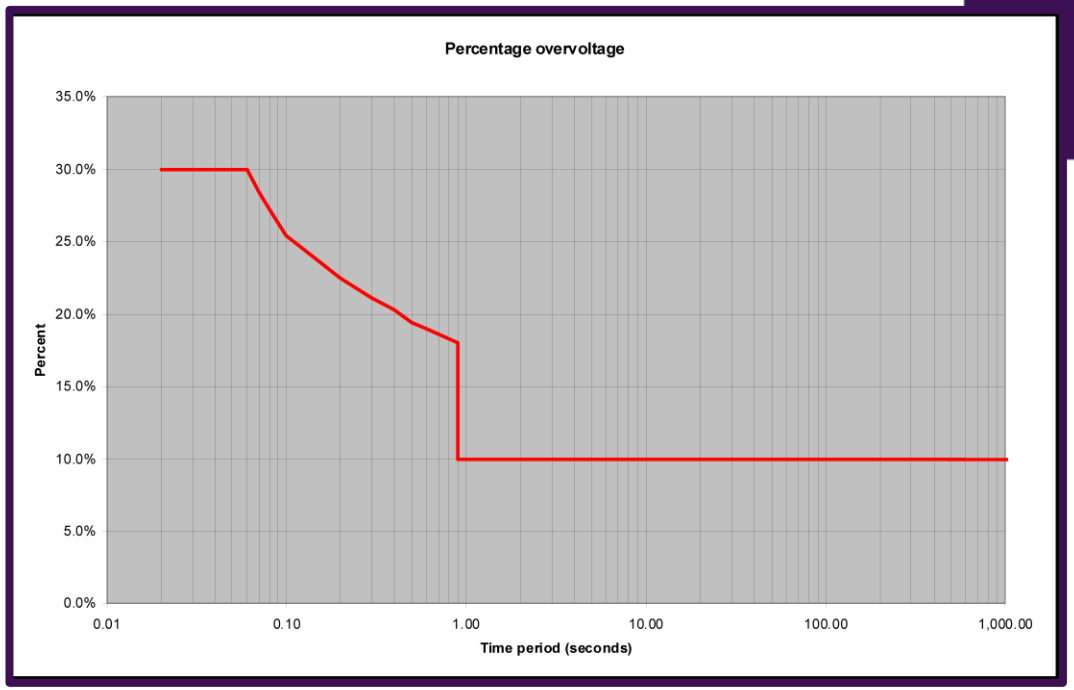
EMT studies – NEM Mainland PSCAD model

- NEM Mainland PSCAD model used to conduct EMT studies
- Based on OPDMS PSSE cases and contains:
  - All transmission network elements
  - Key distribution network elements
  - Majority of generator and network support devices modelled using site-specific representations
- PSSE used for loadflow and data mapped and imported to PSCAD to initialise
- PSCAD studies provide more accurate representation of the system, but much longer simulation times



Success criteria

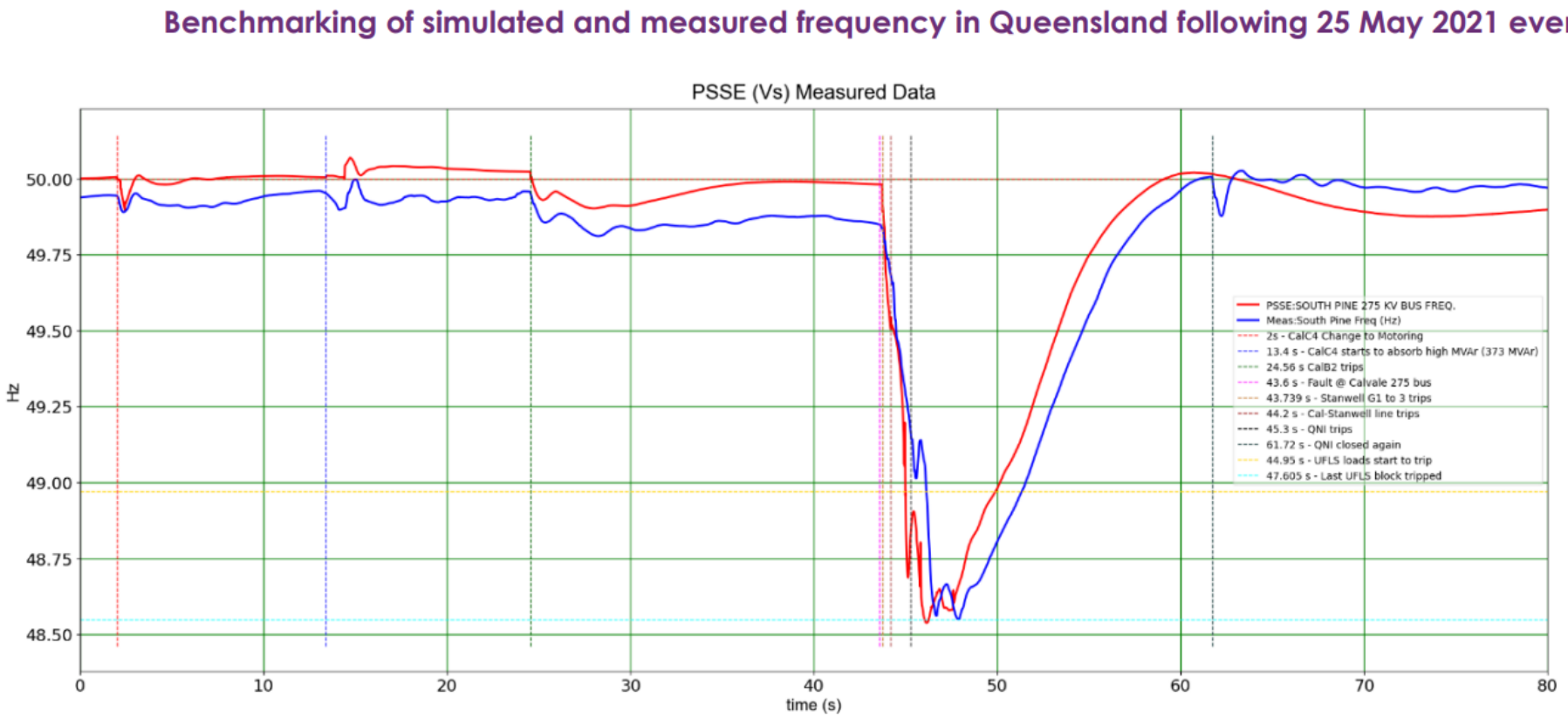
- Pre-disturbance and post-disturbance voltages at key transmission nodes are within an acceptable range.
    - +/- 10% in steady state, in line with figure for response to credible contingency
- System frequencies are maintained within the limits as defined in the Frequency Operating Standard.
    - Within 49 Hz to 51 Hz for a separation event or credible contingency
    - Within 47 Hz to 52 Hz for non-credible
- Oscillations are adequately damped (halving time < 5 seconds)
- No instability or tripping of IBR is observed due to the contingency.
- The non-credible contingency does not lead to the loss or instability of a system interconnector or a cascading failure.
- The PSS®E or PSCAD simulation successfully completes, and no numerical instability is observed.



Benchmarking for 25 May 2021 – Callide C4 turbine generator failure

Source: CS Energy: Callide Unit C4 turbine generator failure – 25 May 2021. For AEMO's report on this incident, refer to: https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2021/trip-of-multiple-generators-and-lines-in-qld-and-associated-under-frequency-load-shedding.pdf

Benchmarking of Callide incident (Queensland)



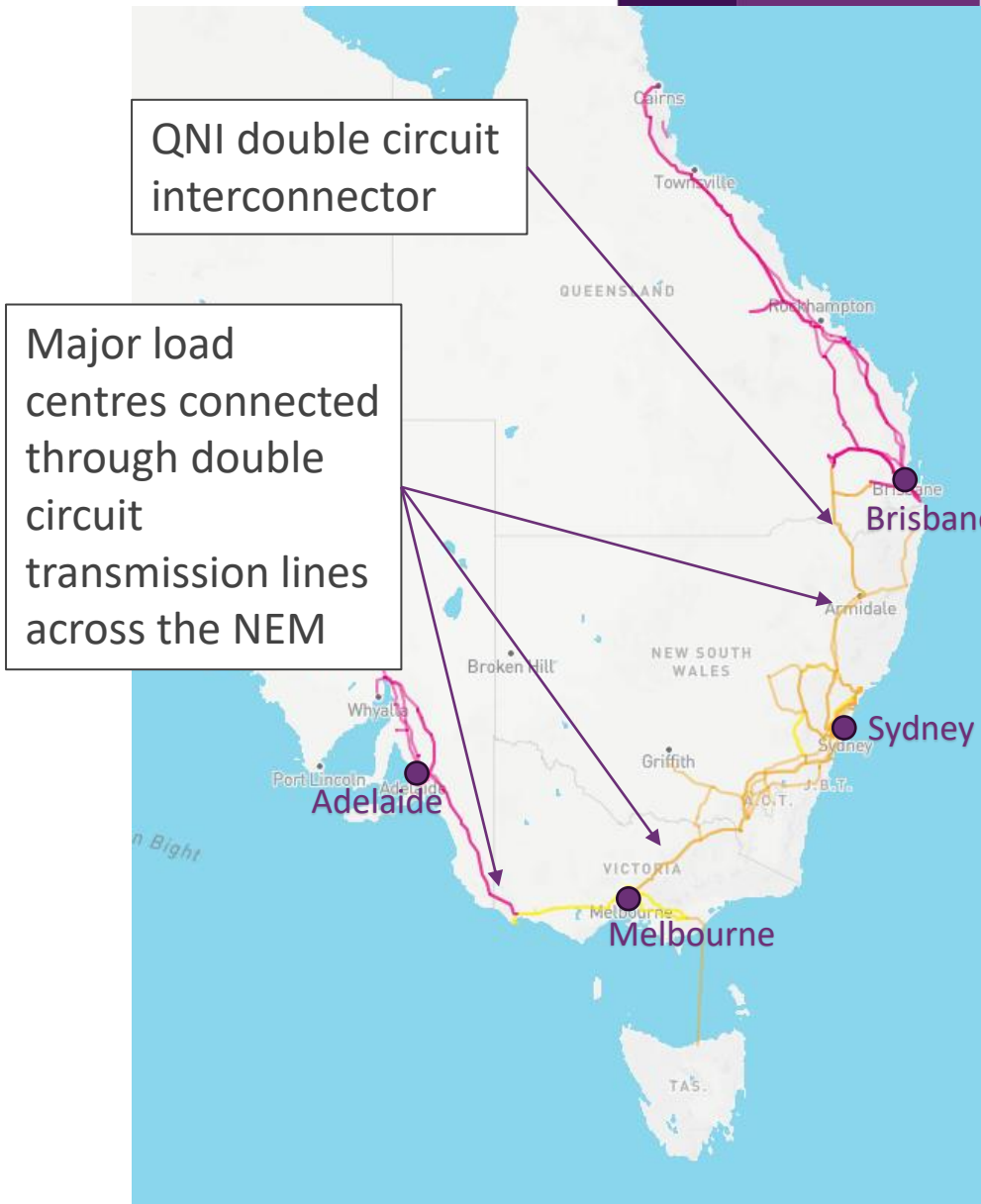
Source: AEMO: 2022 Power System Frequency Risk Review Appendices, refer to: https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/psfrr/2022-final-report---power-system-frequency-risk-review---appendices.pdf?la=en

Study example

Dan

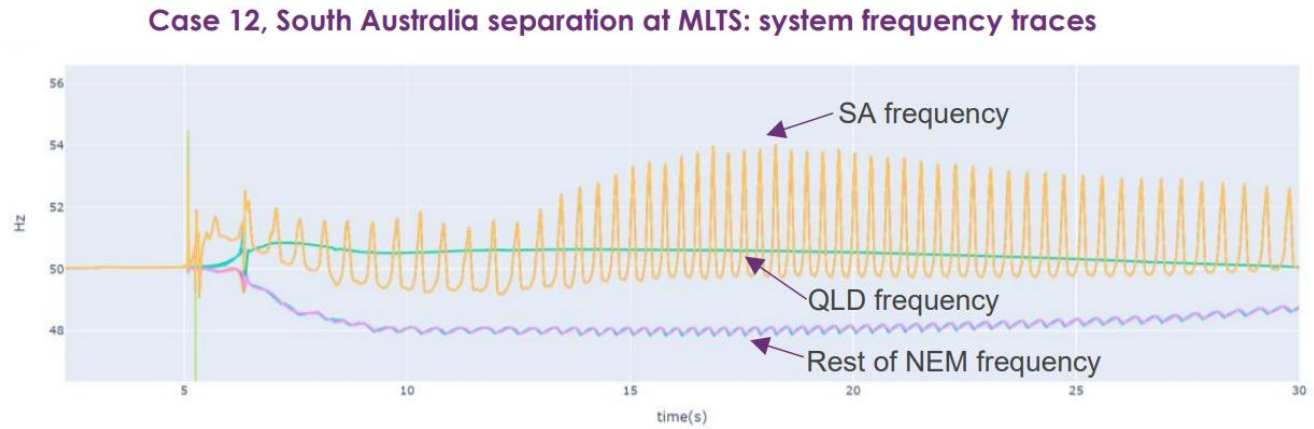
Risk review study – QNI instability

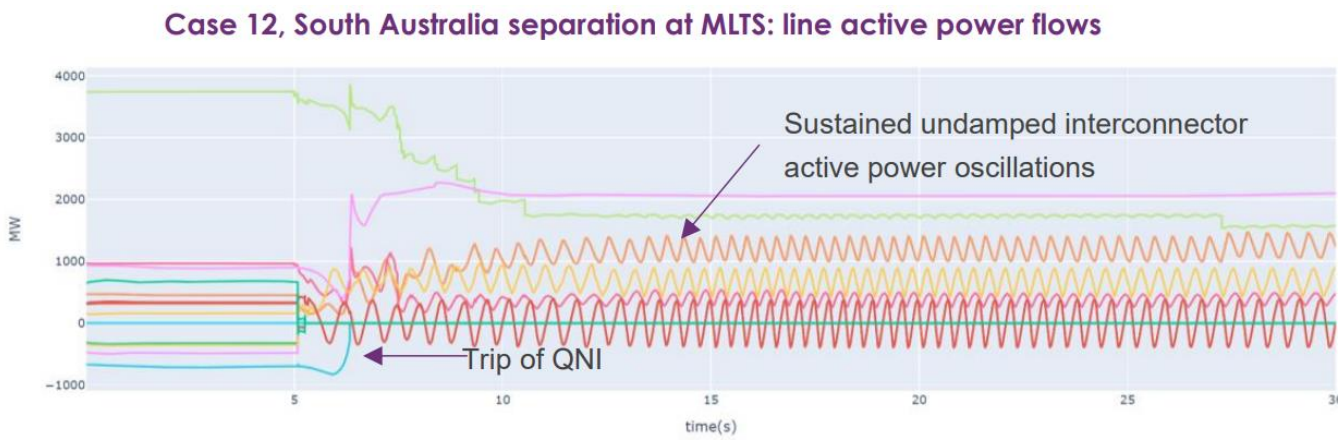
- Queensland NSW Interconnector (QNI) overview
  - Double circuit 330 kV / 275 kV interconnector between NSW and QLD
  - After QNI upgrade, interconnector limits planned to be increased up to 950 MW northwards and 1450 MW southwards
- Studies showed that (QNI) can become unstable following a range of different non-credible contingencies across the mainland NEM, with the potential for subsequent power system events to occur

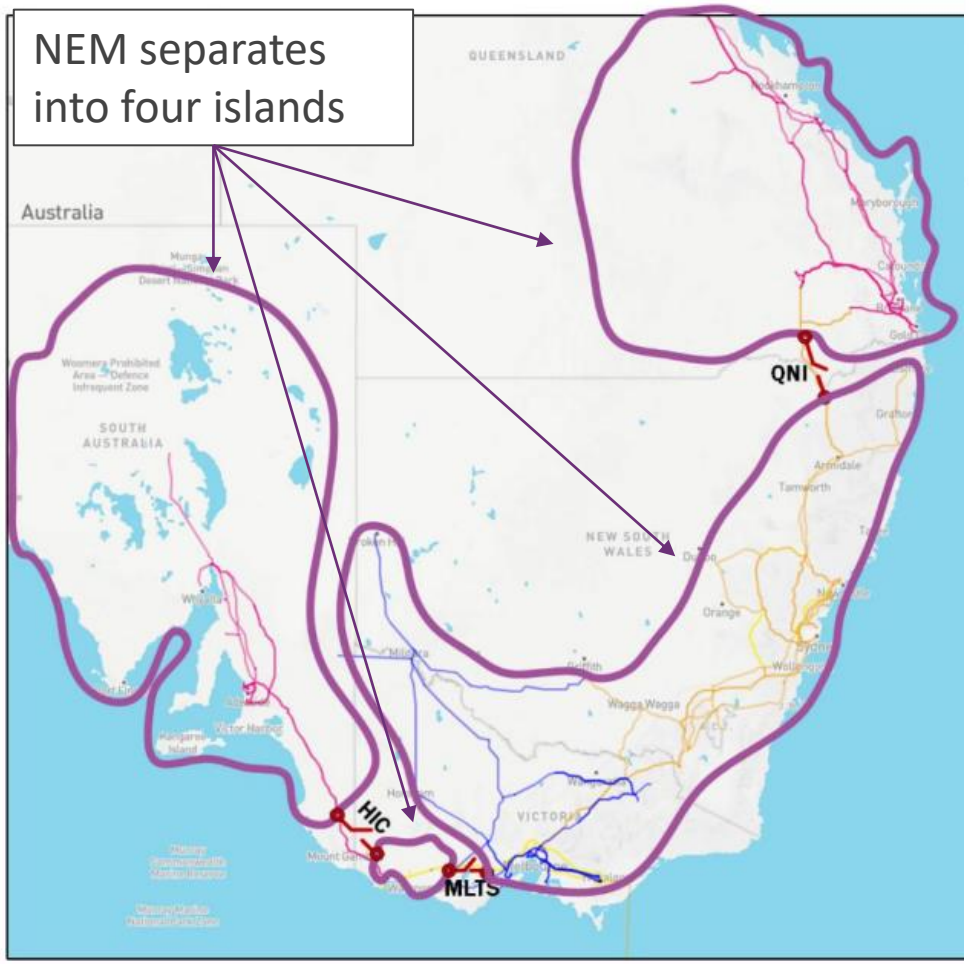


Contingency results – SA separation at Moorabool Terminal Station

- Example results from risk review studies showing instability and cascading failure







Proposed recommendations

- The results from the 2023 GPSRR future studies further support the need for remedial measures to prevent the loss of QNI and the separation of Queensland
  - AEMO recommended that the Queensland and NSW TNSPs design and implement an appropriate SPS
  - Studies undertaken by AEMO show that an SPS would be effective at preventing QNI from losing stability
  - AEMO completed risk cost assessments to compare the cost of this risk with the cost of the selected remedial action (QNI SPS)

Other risks & conditions

Luke

Other risks…

- Interconnector drift
- Generation retirement
- System restart with transitioning power system
- Aggregated fast frequency response from multiple BESS
- Future management of maximum non-credible contingency sizes
- Fuel supply interruptions/supply scarcity issues
- SCADA failures
- Communication infrastructure diversity for generators
- Manufacturer failures
- Supply chain risks
- Cyber attacks
- Weather risks/Climate change
- Ramping limitation
- Control/protection system interaction and maloperation risks
- Managing system strength

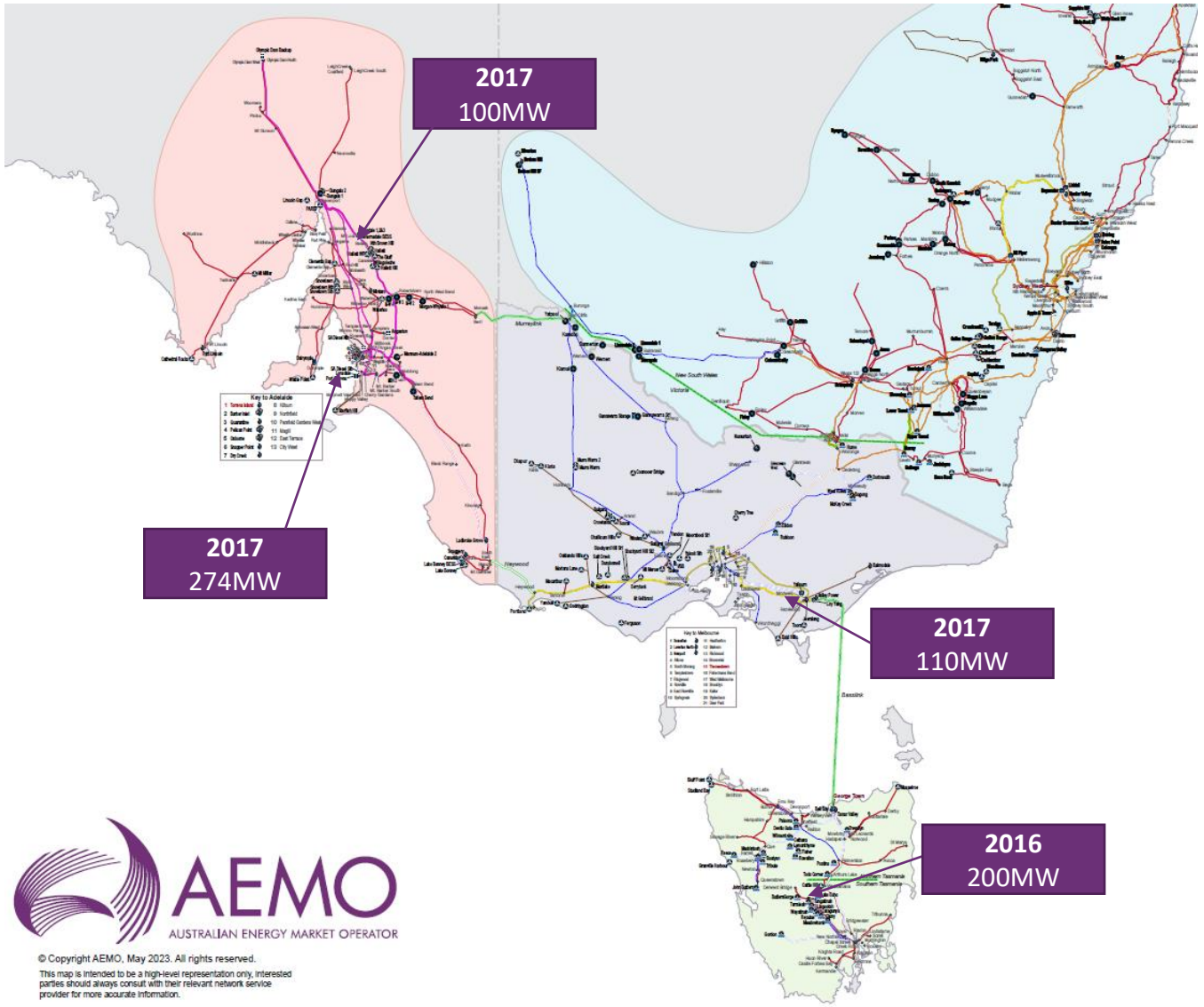
Reliability and security risks identified in the 2023 GPSRR

AEMO has identified the following NEM reliability risks for the coming summer and future years:

- Potential for higher peak demands, for example due to unexpected severe weather.
- Increased forced generator outages (including fuel availability issues or equipment breakdown).
- Increased unplanned outages of transmission elements.
- Decreases in inter-regional peak transfer capacity (including abnormal system conditions).
- Delays to the commissioning of new generation, transmission, or storage capacity.
- Operational impacts of extreme temperature on all generation technologies that may reduce output to below the rated generator capacity.

The 2023 GPSRR recommended that jurisdictions develop contingency plans that identify and scope potential locations to install emergency generation, encompassing energy and system security services.

Recent examples



Context for recommendation

- On three recent occasions jurisdictions procured emergency reserves (among other actions).
- Initiated at short notice and requiring expedited review of complex planning, procurement, fuel, environmental, community, power system and other factors

Contingency plan considerations

- Site and land availability (including zoning)
- Contracting with third parties to design, procure and deliver the required infrastructure
- Access to fuel supplies (such as gas supply, diesel storage)
- Availability of long lead items (such as high voltage transformers)
- Availability of generating assets
- Availability of suitable distribution or transmission connection points
- Potential constraints on the power system at the time generation is required
- Augmentation of the power system (for example, protection)
- Environmental constraints
- Community acceptance
- Integration including control system settings, protection and commissioning
- Capacity of individual sites, considering the above factors
- Power system outage requirements needed associated with relevant upgrades and connection
- Risks associated with procuring equipment and/or commencing construction (to minimise project timelines) in advance of finalising technical requirements

2024 GPSRR

Dan

Information on upcoming 2024 GPSRR

- Loss of HumeLink 500 kV double circuit 
- CBF event resulting in system strength issues 
- AEMO UFLS settings screening study 
- South Australia destructive wind transfer limits 
- Other risks and conditions, such as operating NSW below minimum unit requirements

2024 GPSRR timeline

- Completion of 2024 GPSRR studies (present – March 2024)
- Advanced sharing of results and findings with NSPs (April 2024)
- AEMO seeking early feedback from NSPs on draft 2024 GPSRR report (April – May 2024)
- Draft 2024 GPSRR report published for industry feedback (May 2024)
- Publication of final 2024 GPSRR report (End of July 2024)

Keep up to date with progress: https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/system-operations/general-power-system-risk-review

Or email GPSRR@aemo.com.au

For more information visit

aemo.com.au