Study Committee C5

Electricity markets and regulation

PS 2 – Changes to markets and regulation to enhance reliability and resilience

Paper ID 2022 625 / 10625

Building a better working world

Market design principles for reliability and resilience with high penetration of asynchronous generation and low inertia

Ben VANDERWAAL*, Ian ROSE, Dominic PRICE, David YEOWART, Brian JOSEPH

EY Australia

Motivation

- It is well known that frequency in large electricity grids is not uniform, particularly during disturbances involving changes in the supply-demand balance
- The Australian National Electricity Market (NEM) is in the forefront of exposure to the risks of frequency instability during contingencies due to the vast distances between major load centres and major generation centres. The low inertia of the NEM is a contributing factor. Frequency instability may manifest as high rate of change of frequency (RoCoF), large frequency deviations between locations, and large angular shifts between locations
- The frequency variability between locations is often disregarded in studies of ancillary services and frequency stability, including in Australia. The rules for the NEM have not been set up to deal with declining inertia due to high variable renewable energy (VRE) penetration, except to ensure that each region can operate isolated prior to or following a contingency leading to a separation between regions
- With reducing inertia due to displacement of synchronous machines by inverter connected renewables the assumption of uniform frequency is no longer valid because ancillary services relying on local frequency measurements may not act in time, or may overact
- The aim of the investigation was to assess the frequency variability in the NEM, a widely spaced grid, with much lower inertia, and to assess how frequency stability may be maintained as VRE generation increases

Method/Approach

- We built a multi-node frequency model to observe how frequency propagates through the system when the only inertia and frequency response is that which is provided by the existing practically zero emissions supplies, including conventional hydro, pumped storage hydro and synchronous condensers
- The model application is a DC power flow equivalent model such as has recently been applied to the European Union (EU) and reported in the EU-SysFlex studies. The transmission system was represented on a full nodal basis by lossless line reactances

Experimental setup & test results

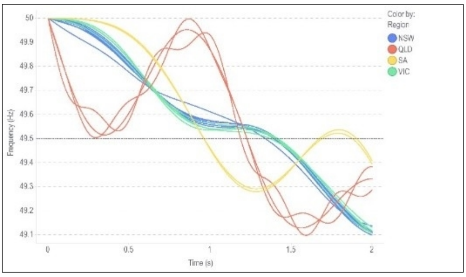
- Design principle to utilize full NEM power system snapshot (PSS/E) without modification
- Configure generation dispatch and demand profile to replicate historical observed event for testing
- Configure generation dispatch and demand profile to forecast circa 2025 potential zero emissions (100% renewable) grid supply dispatch interval
- Test potential largest credible risk contingency event to observe frequency response of multiple key nodes throughout the power system
- Test locational options to resolve breaches of RoCoF, frequency nadir and angular difference limits

Discussion

- In the absence of strategic, location specific inertia and fast frequency response services:
    - RoCoF is observed to breach system security design limits, quickly followed by breach of angular spread which is likely to lead to transient instability and system separation
    - Efficient operation of the market will decline as pre-contingent network flows will have to be materially reduced to minimise system separation risk

Conclusion

- Strategically located inertia and/or fast frequency response services have been demonstrated through the modelling application to enable the NEM to theoretically operate securely with zero emissions generation resources



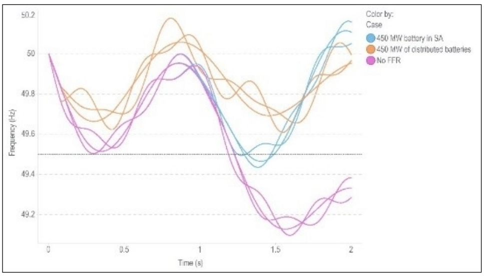


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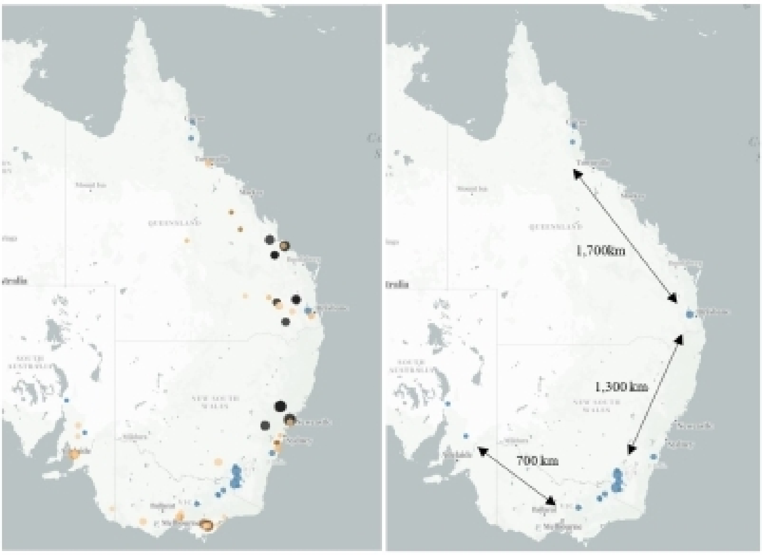
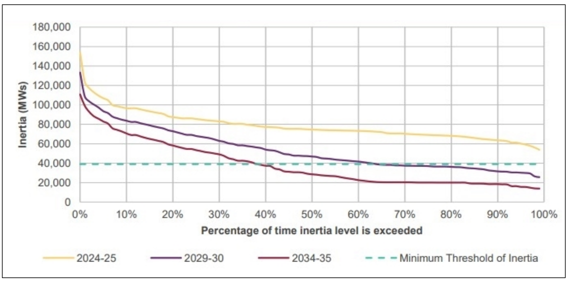
Figure 1: Current sources of inertia across the NEM (left) and the remaining sources of inertia from renewable sources including hydro, PHES and synchronous condensers (right).



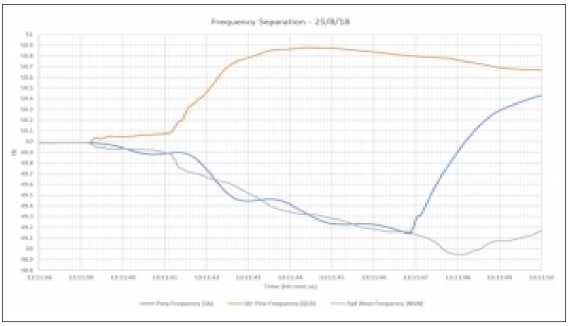
Conventional inertia is declining

- Non-synchronous generation resources are rapidly displacing conventional generation sources
- The chart to the right shows AEMO's Integrated System Plan (ISP) forecast of decline of inertia on the mainland, which may be faster under some scenarios
- We tested a system dispatch interval notionally in the year 2025 in which the assumed dispatch resulted in approximately 27,000 MWs of inertia



Impact of contingency events today

- As early as in 2018 in the NEM, generation contingency and system separation events are pushing the system to the limits of security thresholds. e.g. a separation event between two regions may cascade to multiple regions
  - https://www.aemo.com.au/-/media/Files/Electricity/NEM/Market_Notices_and_Events/Power_System_Incident_Reports/2018/Qld---SA-Separation-25-August-2018-Incident-Report.pdf
- Power system frequency is already heterogeneous, illustrating the emergence of observed modelling outcomes becoming more extreme as conventional synchronous generation withdraws from the system



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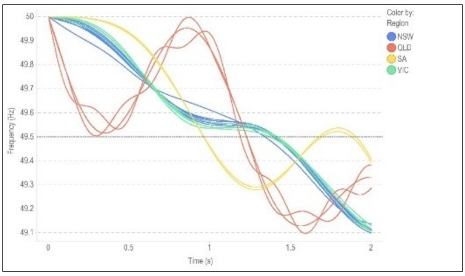
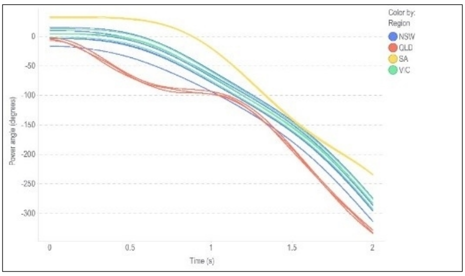
RoCoF, frequency nadir and angular spread in the first 2 seconds are critical

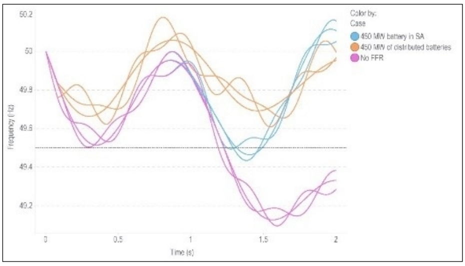
- In the absence of strategic locational inertia and frequency response services the system is likely to be insecure at times

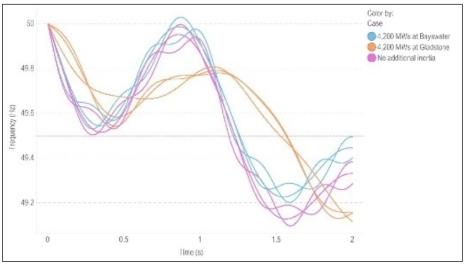




- Distributed BESS configured to provide fast frequency response services materially improves outcomes

- Strategically located inertia can arrest first swing RoCoF providing sufficient time for response from more distant services





Mechanisms to manage frequency security are already in place

The key mechanisms for ensuring the NEM maintains the frequency operating standard (FOS) amidst the uptake of VRE and retirement of traditional thermal generation are:

1. Managing the size and location of the Largest Credible Risk (LCR)
2. The volume and distribution of inertia available
3. The volume and distribution of Fast Frequency Response (FFR)
4. Adjustments to the network topology via augmentations
5. The control of powerflow via dispatch constraints

Conclusion

- The NEM is facing unprecedented levels of new VRE generation, both from large-scale solar and wind farms and from rooftop solar systems. This applies throughout the 5000 km NEM grid

Conclusion (cont.)

- At present, dispatchable synchronous generation, mainly coal-fired is maintaining the inertia at a level consistent with the past
- The consequence of maintaining dispatchable synchronous generation on line is that VRE generation is either not being expanded at a sufficient rate to meet emission reduction goals, or the VRE generation is curtailed to allow the coal fired synchronous generation to remain above its safe minimum loading levels of about 40% of capacity
- If the coal fired generation cycles off the inertia levels may reduce to below the level at which the system can remain stable under contingency conditions
- Market rules that meet the conflicting requirements are needed to provide a pathway to delivering a resilient, zero emissions power supply system
- More simulation and modelling is needed to fully understand the functioning of the NEM under all situations and to construct the necessary changes to the market rules, including dynamic locational inertia and/or FFR requirements and market mechanisms to incentivise competitive and efficient supply options

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