Challenges and solutions to prepare the system and market operator to operate the grid with a 100% of instantaneous renewable energy

Board Paper

Group 2

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Executive summary

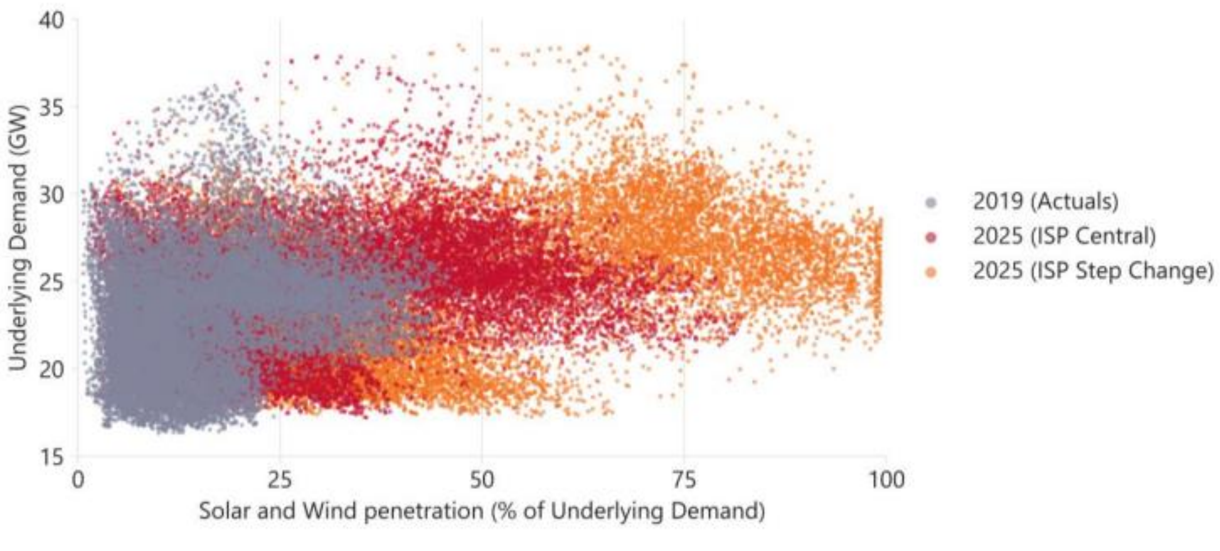
The Australian Energy Market is transforming at a rapid pace toward clean renewable energy sources of energy.

The step change scenario of draft 2022 ISP show large amounts of large scale wind and solar PV as well as distributed PV predicted between now and 2050. These new sources of energy provision or generation will produced using invertor based resources/technology. It also show a large amount of coal fired synchronous generation decreasing almost entirely by 2045.

The challenge given to Syndicate Group 2 was to discuss the challenges and solutions that we as an industry will need to do to prepare the system and the market for a 100% instantaneous renewable energy? The following areas were evaluated however the focus of this paper are on the highlighted areas below:

- **Technical/Engineering**
- Market and regulatory framework
- **Industry culture and capability**
- Data and technology

The amount of instantaneous renewable energy (large scale and distributed PV) experienced and predicated on the grid as a percentage of demand is shown in the graph below:



It can be seen from 2019 actual results (grey points on the graph) that percentages close to 50% have been reached already. It has been recently reported that South Australia and Tasmania have reached figures as high as 92% and 82% respectively and have operated their systems successfully. These days will become more frequent into the future if more inverter based generation are dispatched.

The technical/engineering challenges are:

- Secure system operation with increasing uncertainties;
- Increased DPVs (Distributed PVs);
- Decreased system inertia and the consequent frequency issue;
- Decreased system strength;
- Potential gap between supply and demand due to the intermittency of the renewables.

There is also the challenge of the changes required in the industry culture, capability and role clarity required to solve these future problems.

The technical solutions at a high level will revolve around performing intensive power system studies using state of the art software collaboratively between TNSP's and AEMO.

The solutions are briefly discussed below for each challenge stated above:

Secure system operation with increasing uncertainties - The higher the penetration levels of inverter based generation, the more complex the operation process needs to be with new and more limits introduced for the NEMDE system to process.

Increased DPVs (Distributed PVs) - A large part of the DPV will be "uncontrolled and invisible" roof top solar which is (in certain states) already becoming a large if not largest distributed generator. This presents a problem for traditional fast control for voltage control and stability, frequency control and system strength and inertia.

Decreased system inertia and the consequent frequency issue

With increasing levels of renewables and the consequent, inevitable replacement of synchronous generating units, the system inertia, conventionally originated from the rotating mass from the synchronous machines, declines accordingly. This shortfall causes system stability and recovery during system disturbances mainly on the transmission system.

Decreased system strength

With the accelerating of the synchronous sources closure, new frameworks to determine the system strength requirement for fault level nodes are to be established as the source of the underlying system strength will inevitably change. Options that could be deployed in the short term are limited and require investigation but solutions for the future grid are synchronous condensers from non-network (to be contracted) and network services (RIT-T process to be followed), grid forming solar PV and grid forming wind generation. A case in question is AEMO recently recognising that an innovative technology around solar inverters for assisting with system strength is evolving[7]. It will also good to explore the feasibility and cost of securing system strength services from old coal or gas station generators being refurbished and converted to synchronous condensers.

Changing culture and capability in the Industry

Power systems experts will be needed to do more scenario modelling (load flow calculations, system stability studies and EMT studies), as well as more detailed operational forecasting. In addition, data scientists are needed to manage and work with big data and evaluate the quality of the data we use to draw conclusions about the electricity market and power system operations. As a society, we need social scientists to work closely with policymakers and regulators, and more importantly, with consumers to ensure they realize the crucial role they play in ensuring a reliable and efficient electricity market.

On the other hand, the regulators and policymakers recognize customer needs and have put in place a business model that will benefit the entire grid and will offer each customer a reliable, equal power supply.

The challenge we anticipate facing in the future requires high tech experts to fill in the gaps as we move toward finding efficient and cost-effective high-tech solutions.

Our solution requires a clear vision of the national electricity market and power system operation across different regions to support the NEM as a unified market with strong leadership from Government through all the companies involved.

1 The Question

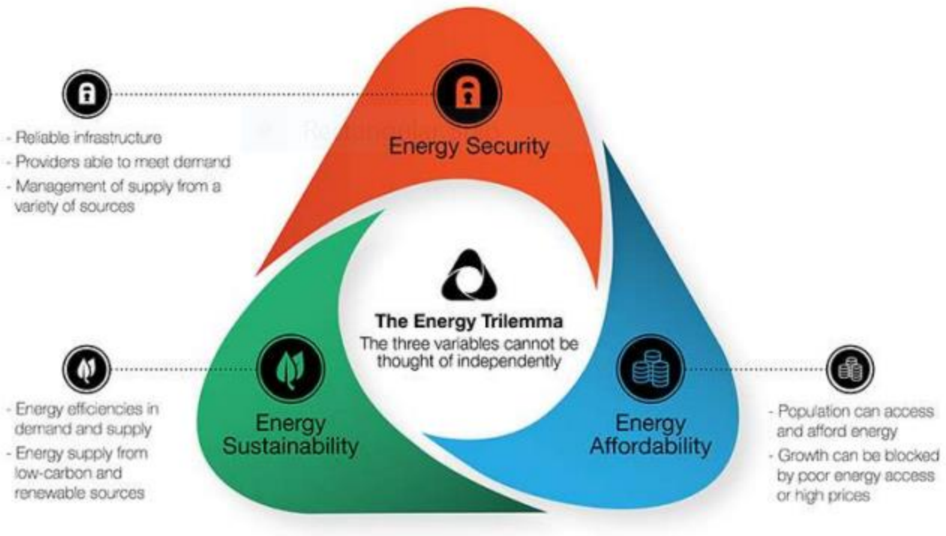
What are the challenges and solutions that we as an industry need to do to prepare the system and the market for a 100% instantaneous renewable energy? The following areas will be evaluated:

- **Technical/Engineering**
- Market and regulatory framework
- **Industry culture and capability**
- Data and technology

2 Background

The Australian Energy Market is transforming at a rapid pace. The Energy Trilemma in Figure 1 illustrates the three areas (security, affordability and sustainability of energy) that will be necessary for good energy policy design of the future. Managing the three areas together are complex and trade-offs may be necessary at times as we proceed into the future e.g., as we transition to a cleaner sustainable future with more renewable energy sources, new complexities in managing security of supply in the Grid emerge.

Figure 1. The Energy Trilemma[1]

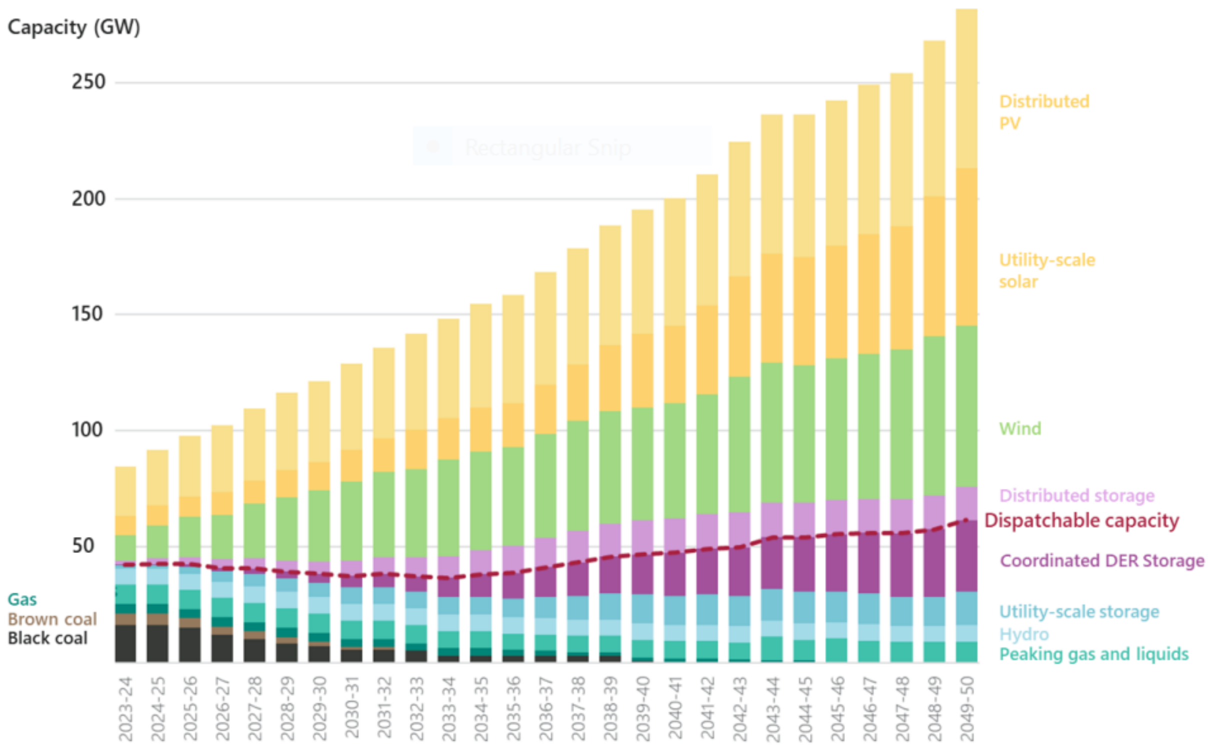


AEMO is supporting the "step change scenario" that is transitioning to a cleaner more sustainable future. This is depicted in Figure 2 below from the draft 2022 ISP (Integrated System Plan). It shows:

1) large amounts of new renewable energy generation made up of wind, utility scale solar, distributed PV (DPV) coming online up to 2050.
2) existing synchronous generation made up of coal fired power stations reducing at a rapid rate up to 2030 and disappearing around 2045.

[1] https://www.ie-ei.eu/Ressources/FCK/image/Theses/Energy%20System%20in%20Australia_David%20Desfosses.pdf

Figure 2 Step change scenario [2]



The challenge set recently by AEMO CEO Daniel Westerman[3], to run the system at 100% renewables, is mainly around harnessing and preparing the skills and capabilities in the industry to engineer secure and reliable grids capable of running with high amounts renewables energy as this is the future we moving to. "If we are not in a position in the future to offer a 100% renewable energy grid, we're going to be constraining off zero-cost energy for consumers, and I don't think that's the right thing," he said. "We have to be in a position where that is allowed onto the market." Daniel Westerman AEMO July 2021.

Our existing system is made up of large centralised thermal power stations, increasingly high uptake of rooftop solar and increasing amounts of utility-scale wind and solar farms and most recently batteries and synchronous condensers. Power generated from utility scale renewables is currently curtailed to maintain voltages within the required ranges in order to manage frequency control, contingency events and second-by-second supply-demand variation.[4]

[2] AEMO ISP 2022 Draft

[3] https://www.pv-magazine-australia.com/2021/07/14/australia-to-be-ready-for-100-instantaneous-renewable-generation-by-2025-to-end-constraints-on-renewables-new-aemo-boss-clarifies/

[4] https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/nem_esoo/2021/2021-nem-esoo.pdf?la=en

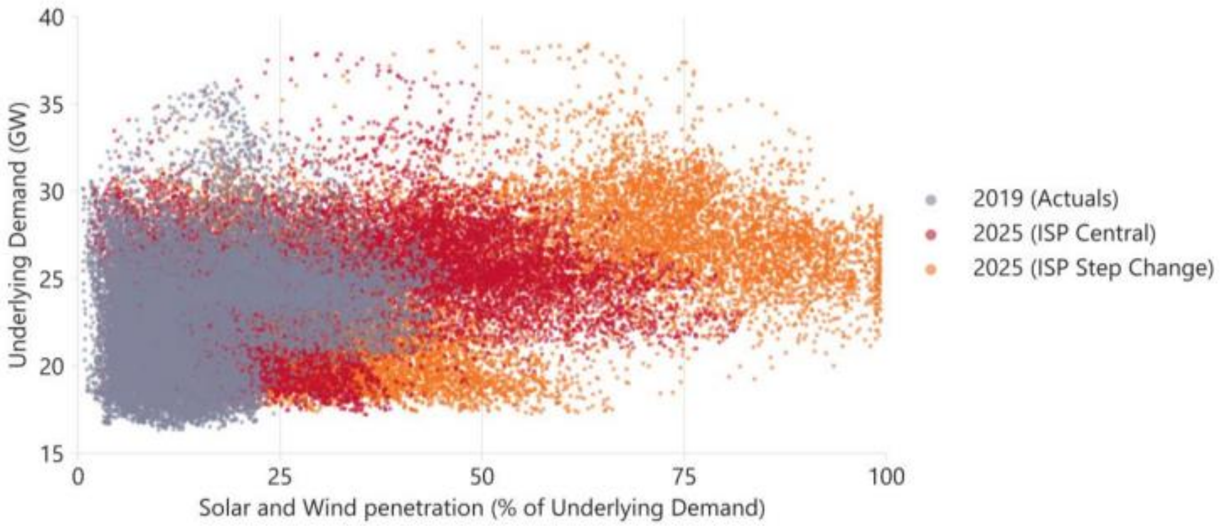
3 What are the key challenges and who are the stakeholders impacted?

Technical/Engineering

The challenges of running the Grid at a 100% renewables energy will mainly revolve around technical issues in the short term (system and market operations) e.g., running a power system that is more variable in nature with mainly wind and solar PV that run with inverter-based resources (IBR) instead the conventional synchronous machines that we are accustomed to from coal fired and gas fired power stations. There will be a small percentage of hydro including pumped hydro that will be available to run.

Currently, there are goals set by AEMO to run the NEM on 100% instantaneous renewables by 2025. Based on the AEMO Renewable Integration Study (RIS) stage 1 report published in 2020, it can be achieved under ISP's Step Change Scenario.

Figure 3 Instantaneous penetration of wind and solar generation, actual in 2019 and forecast for 2025 under ISP Central and Step Change generation builds[5]



However, how the system can actually transition to the 100% instantaneous renewables status depends on a series of challenges that only emerge with the replacement of the most conventional element in the power grid – synchronous generating units. These challenges vary from:

- Secure system operation with increasing uncertainties;
- Increased DPVs (Distributed PVs);
- Decreased system inertia and the consequent frequency issue;
- Decreased system strength;
- Potential gap between supply and demand due to the intermittency of the renewables.

[5] AEMO Renewable Integration Study (RIS) stage 1 Report

Secure system operation with increasing uncertainties

The existing NEM dispatch process (NEMDE) is designed for the conventional power system, aiming to keep the system within its maximum physical limits by providing the 30-minute pre-dispatch and the 5-minute dispatch.

With the penetration of the renewables, new limits are introduced – minimum physical limits are now a new factor to be catered for to maintain minimum levels of system strength and inertia. Currently operating process are unable to fully catch the maximum and minimum physical limits simultaneously. The higher the penetration levels are, the more complex the operation process needs to be.

Increased DPVs

DPV generation has now exceeded the largest generator in NEM. By year 2025, the projected capacity could reach near 20 GW under the Step Change scenario. A large part of the DPV will be **“uncontrolled and invisible” roof top solar** which is (in certain states) becoming a large distributed generator and there are very little rules that exists to connecting these distributed PV systems and controlling them to manage grid stability. The lasted standard published for new rooftop PV systems (AS/ANZ 4777) connection from 18 December 2021 is the only standard available.

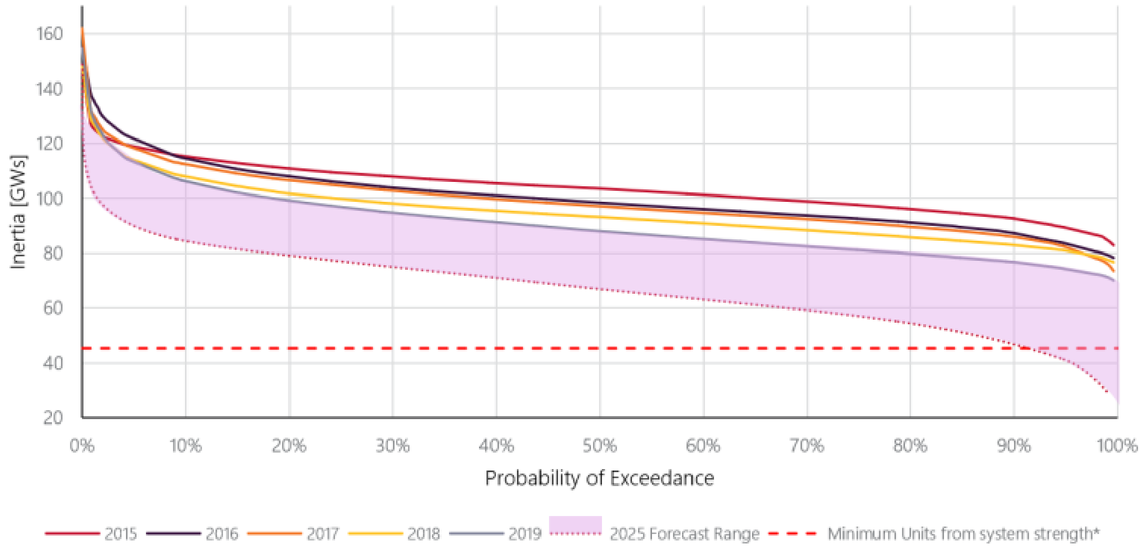
This is going to hugely affect both of the distribution and transmission networks, including:

a. The effectiveness of emergency mechanisms, such as UFLS;
b. Transmission network voltage control, such as overvoltage due to reduced load;
c. Net load variability with DPV ramps;
d. Loss of large amounts DPV during transmission and distribution disturbances if they do not have voltage ride through capability;
e. Insufficient load to support minimum synchronous generation requirements

Decreased system inertia and the consequent frequency issue

With increasing levels of renewables and the consequent, inevitable replacement of synchronous generating units, the system inertia, conventionally originated from the rotating mass from the synchronous machines, declines accordingly. As a result, the system will see weaker capability to provide Primary Frequency Response (PFR) and larger rate of change of frequency (RoCoF), if the renewables are not harnessed efficiently. At the same time, the load relief property from motor-based loads is declining as more load is put behind electronic interfaces.

Figure 4 inertia historical and future range of NEM mainland inertia[6]



There has been FCAS market since 2001, with ongoing changes to frequency control to reflect the fast pace of the transitioning of the NEM. At the same time, some reserve provider such as batteries, can provide rapid response to help the system ride through low frequency events.

However, with higher level of IBR penetration and even 100% instantaneous renewables, current FCAS market will not be functional enough to provide the service all frequency events may require. Also, DER (especially DPV) behaviour and utility-scale IBR behaviour are making the system more complex. The possibility of IBRs being tripped coincidently, if not operated/controlled properly, because of the interaction between each other is driven the complexity and consequent risk even higher.

Decreased system strength

System strength stands for a general concept to describe the ability of the power system to maintain the voltage at any location for both steady state and following a disturbance. Normally, fault level / short circuit capacity at a specified location can be utilised to represent the system strength. Higher fault level / short circuit capacity indicates higher system strength and thus greater capability to maintain the voltage.

Current regulations/rules require:

a. The fault level be maintained at certain level across the NEM at specified locations/nodes. (This includes: a) AEMO to determine any potential system strength short fall; b) Local TNSPs to provide system strength services to meet the minimum three phase fault levels at the specified nodes should AEMO declare any shortfall;
b. New generator connections should not adversely impact the stable operation of the NEM.

AEMO has already declare system strength gaps at fault level nodes in SA, Tasmania, Victoria and Queensland[7]. Along with the transitioning into the 100% renewables system, the following challenges will be identified:

a. The inverter-based renewable generators inherently “consume” the available fault level at the connection point;
b. Synchronous machines are being replaced by the inverter-based renewable generators, decreasing the main source of the fault level.

[6] AEMO Renewable Integration Study (RIS) stage 1 Report
[7] AEMO ISP 2022 Draft Appendix 7

The major stakeholder leading this initiative will be AEMO as the system and market operator. The AEMC, AER and ESB will be also major stakeholder working with AEMO in a co-ordinated fashion. All TNSPs and DNSP's will be other stakeholders who will provide inputs and key staff to work together to solve the problem jointly each with implementation actions.

API Syndicate group 2 welcomes the Reform Delivery Committee that has been set up to be chaired by AEMO Chief Market Officer Violetta Mouchaileh. Our group sees AEMO as the "pilot" or "driver" for achieving the 100% instantaneous renewable energy challenge due 2025.

Industry culture and capability

Historically the Power Industry has been one of stability and clear strict regulation. The generators were large and produced power at one of the system, the TNSP and DNSPs move the power and the customers consume and pay for the power at the other end of the system. Everyone knew their place. Change was slow and heavily regulated. Most employees took great comfort in a stable working environment of a technical nature.

Cut to today, fears of a changing climate have brought promotion of renewable energy as an alternative generator. Customers have been allowed to become essentially unregulated generators in their own homes in order to take control of their power, emissions and cost.

The whole system is in transition. The industry is faces with multiple competing new challenges outside their realm of expertise. This puts pressure on the existing industry who require upskilling and support to tackle the issues that the Australian consumers expect the industry to manage as normal par of course.

Despite a high number of recent and ongoing regulatory reviews, Australia still lacks a coherent national energy policy. Consequently, Australian investors have lost confidence. This is reflected in the not having political bipartisan support on climate and energy.

4 Proposed Actions and Solutions

To secure a smooth transitioning into the 100% instantaneous renewables, it is suggested the following actions / steps be considered.

Technical/Engineering

Secure system operation with increasing uncertainties

Redevelopment of the existing scheduling systems for Pre-dispatch and Short-Term dispatch to cater for the ongoing change of the system needs. This includes enabling availability of essential system services and better modelling of new technologies such as IBRs, batteries, etc., which are the main components of the 100% renewables penetrated power system.

The conventional economic dispatching process, which only focuses on the economics of energy per se, also needs to be updated to maintain the system security.

New framework to enhance the operational capability to deal with more complexed power system with high renewable penetration levels with widely spread sources of IBRs, storage and demand response.

Increased DPVs

Increased DPVs in the system is one of the key components to achieve 100% renewables operating status. These DPVs can cause and/or be impacted by system disturbances very easily if not harnessed carefully. The following actions/steps are suggested to be considered:

Fast-tracked short duration voltage disturbance ride-through capability of the DPVs is to be required as this may impact both distribution and transmission side of the network.

Rules are to be established to specify the minimum technical requirement for DPVs to all types of DERs installed or to be installed in the NEM to ensure the security system-wide.

Potential capability or interface for market operators to interact with the “behind the meter” DPVs is to be implemented. This can be collaborated with the management of demand response to decrease the uncertainties DPVs can bring to the network.

Decreased system inertia and the consequent frequency issue

It is declared by AEMO that inertia levels are dropping potentially by 35%. As the exit of synchronous machines in the market accelerates with the consequent decline in the effectiveness of the system frequency control, the current Mandatory Primary Frequency Response rule needs to be updated to ensure the system resilience.

Further plans are also required to investigate the Primary Frequency Response affected by the new structure of the network considering the effect of the renewables including DPVs and utility scale wind and solar farms, and also the interaction with batteries, emerging grid-forming inverter-based devices and other network solutions with the capability of FFR. As a result, system inertial services needs be enabled to alleviate any adverse impact from the IBRs to achieve the 100% renewable status.

Decreased system strength

Current system strength requirement is fundamentally based on a series combination of minimum synchronous machines in each state. With the accelerating of the synchronous sources closure, new frameworks to determine the system strength requirement for fault level nodes are to be established as the source of the underlying system strength will inevitably change. Options that could be deployed in the short term are limited and require investigation but solutions for the future grid are synchronous condensers from non-network (to be contracted) and network services(RIT-T process to be followed), grid forming solar PV and grid forming wind generation. A case in question is AEMO recently recognising that an innovative technology around solar inverters for assisting with system strength is evolving[7]. It will good to explore the feasibility and cost of securing system strength services from old coal or gas station generators being refurbished and converted to synchronous condensers.

On a whole, the system will need to be prepared for this 100% renewable status with multiple scenarios for regional and NEM wide system. It will be necessary to perform multiple studies with the correct models where we do not have accurate models. There will be a requirement for system operations plan for each scenario to back up credible and non-credible contingencies for the generation and transmission system. The output of this study will identify the system states that the system can be run at a 100% renewable generation which could be during low loading conditions. AEMO must lead this initiative together with representatives from each TNSP.

It may call for certain new interconnectors planned in the ISP to be fast tracked. It may call for fast tracking system strength and inertia projects or new generator performance requirements from large scale solar PV or wind project being commissioned before 2025. It may call for existing functions to be activated in existing and planned STATCOMs and BESS projects. It may call for new SynCon projects or existing ones to be fast tracked. It may also call for the design and implementation of **Special Protection Schemes** to control supply and demand deficiencies.

[7] Groundbreaking solar inverter solution points way to grid free of fossil fuels | RenewEconomy

Other

- ensure a smart digital home solution is available to enable DPV market participation and load shifting with minimal customer engagement
- seeking out potential alternative generator opportunities (such as bio-cogen in agriculture) to provide emergency load and reliability services

Industry culture and capability

Power systems experts will be needed to do more scenario modelling (load flow calculations, system stability studies and EMT studies), as well as more detailed and sophisticated operational forecasting. In addition, data scientists are needed to manage and work with big data and evaluate the quality of the data we use to draw conclusions about the electricity market and power system operations.

As a society, we need social scientists to work closely with policymakers and regulators, and more importantly, with consumers to ensure they realize the crucial role they play in ensuring a reliable and efficient electricity market. On the other hand, the regulators and policymakers recognize customer needs and have put in place a business model that will benefit the entire grid and will offer each customer a reliable, equal power supply.

The challenge we anticipate facing in the future requires high tech experts to fill in the gaps as we move toward finding efficient and cost-effective high-tech solutions.

Our solution requires a clear vision of the national electricity market and power system operation across different regions to support the NEM as a unified market with strong leadership from Government through all the companies involved.

More broadly and over the long term, the electricity sector will need to ensure that they have the people and skills to ensure Australia can meet the energy transition challenge. This will include:

- across industry support and collaboration
    - recognising the significant role of energy efficiency and demand response
    - proactive and reactive decision making strong fearless leadership
    - provide a supporting voice for improvement in the thermal comfort of homes through
        - increasing building standards for new homes
        - a new and improved insulation and window glazing program for existing housing stock
        - mandatory disclosure of energy for lease and sale of homes (to empower consumers to make better more informed choices on energy)
- increased stakeholder engagement (hearing and accommodating the views of 3million+ solar homes)
- attract and retain the best employees
    - re-vamp the image of the energy industry as a supporter of our sustainable future
    - encourage the industry to adhere to best practise ESG principles
    - empower all employees to have a voice and to feel that their role is contributing to the business
    - invest in upskilling employees and commit to equal access for all employees to on-going professional development
    - build a culture of continual improvement
    - support upskill training and transition workers from traditional generation companies and other non-traditional pathways to energy infrastructure employment

- support a previous stable industry in an era of change
- actively support and fund innovation
- aspire to a 4-day working week for all with support to improve efficiency and decrease workplace stress