NEM Engineering Framework

March 2021 report

The Engineering Framework takes a holistic view of the changing characteristics of the energy system to help facilitate an orderly operational transition of the National Electricity Market (NEM).

The purpose of this March 2021 report is to:

- Explain what the Engineering Framework is, why it's needed, and AEMO's proposed approach to preparing for future system conditions.
- Summarise the work in progress across industry to prepare for future system operation.
- Invite stakeholder input on the future operating conditions which AEMO will use to inform its future priorities and others may choose to use for their own purposes.
- Invite stakeholders to engage in this planning process and identify areas to collaborate.

This publication has been prepared by AEMO using information available at 25 March 2021. Across industry, there is a lot of work that is both in progress and upcoming. Where possible, links are made to pages rather than specific documents, so they remain current as long as possible. However, the currency of information cannot be guaranteed after the date of publication.

This report is presented using an interactive format. To navigate through this document, click:

(home icon)	Click here to return to the contents page
(arrows icon)	Click on the navigation pane at the bottom of each page to navigate to any part of the publication.
Link	Click on blue underlined text to go to another resource or jump to a linked part of this report. An index of links is provided at the end of this report. Numbers like this[25] refer to the list of links.
Focus area heading	Click on a focus area or theme heading to take you to the relevant section

Contents

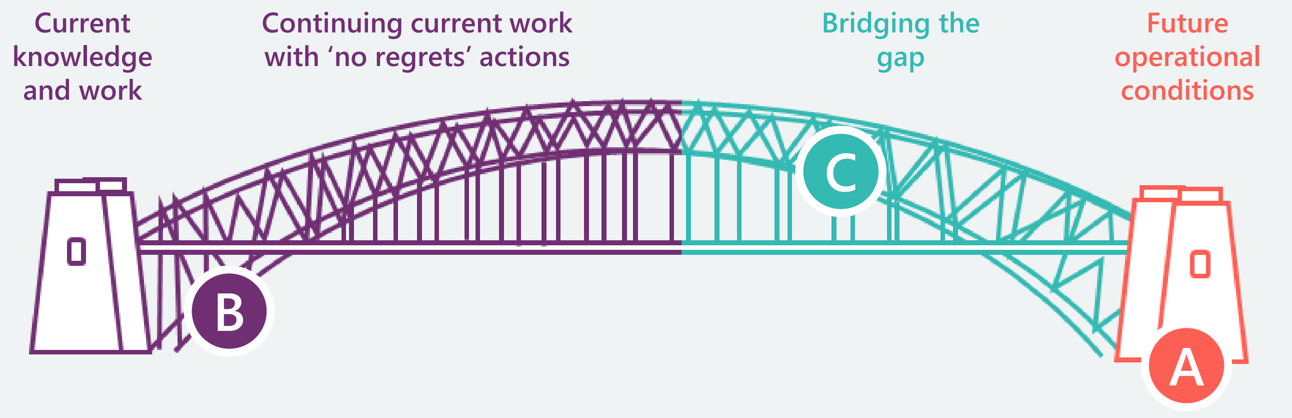
The NEM Engineering Framework aims to:

A — Facilitate a discussion to identify possible **future operational conditions** for the NEM power system

B — Consolidate a common view of the **current work underway across industry** to adapt the power system and existing avenues for **engagement**

C — Collaborate on **identifying where increased industry focus is needed** to bridge the gap between current work and future operational conditions

Figure 1: Proposed Engineering Framework approach



How AEMO seeks to work with stakeholders:

Consolidating information about the major efforts already underway across industry **(this report, from page 14)**

Ongoing industry **collaboration (future)**

Consulting on future operational conditions **(this report, from page 9)**

Introduction | Approach

The upcoming consultation process with stakeholders aims to discuss and agree on the operational conditions (Section 3) we as an industry need to prepare for.

AEMO has identified 10 focus areas to frame the current work and avenues for engagement (Section 4 onwards). These focus areas have evolved following consultation on the Engineering Framework information pack[40].

The 10 focus areas are spread across three broad themes:

- **Attributes** are the fundamental technical elements of power system operation that are needed to ensure reliability and security. These are defined in the power system requirements paper[57].
- **Operability** is the ability to manage the power system within security and reliability standards. It includes the data, tools, training, analytical capability and market mechanisms to support operation.
- **Integration** is the process of adapting both the existing system and the innovative ways in which parties are interacting with the power system, so the system will continue to meet consumer expectations.

These proposed focus areas will also be used to collaborate on identifying where increased industry focus is needed to bridge the gap between current work and future operational conditions.

Figure 2: Focus areas for Objective B and Objective C

- Resource Adequacy
- Frequency Management
- Voltage Control
- System Strength
- System Restoration

- Control Room and Support
- System Analysis

- Resilience
- Performance Standards
- Distributed Energy Resources

Stakeholder engagement | Feedback to date

In December 2020, AEMO published an information pack[40] outlining our desire to work with industry to develop an Engineering Framework to complement and support ongoing industry efforts to manage the changing NEM power system.

AEMO had early discussions throughout December 2020 and January 2021 with stakeholders, including market bodies, transmission and distribution network service providers (NSPs), and consumer advocates, and hosted an industry workshop in February 2021.

This engagement yielded strong support for the proposed concept, and important suggestions on how the Framework process could provide maximum value.

In developing this March 2021 Report, AEMO has acted on these suggestions as follows.

Greater clarity on how the Framework fits with other industry processes

The bridge analogy in Figure 1 seeks to show more clearly the role of the Engineering Framework in enabling the operability of the NEM throughout its transition.

Figure 3 articulates the different roles and responsibilities of key energy sector actors in contributing to the future design and operation of the NEM power system and market. Within this context, it explains how the Engineering Framework fits within AEMO's ongoing work and responsibility as national planner, system and market operator.

Setting goals and measuring progress

Stakeholders asked how goals will be set and progress measured as part of the Framework.

To this end, AEMO seeks through this March 2021 Report to start a discussion with industry on the target future operational conditions we should be collectively preparing for. These operational conditions can form the basis for goals and progress measurements.

Greater transparency on AEMO activities and development of future AEMO priorities

AEMO sought to capture stakeholders' desire for more transparency in this March 2021 report with refined objectives and proposed approach for the Framework, and subsequent collaboration on next steps.

This report also seeks to collate and share information regarding current work in progress across industry (including AEMO's current activities) to adapt the system.

The Framework will then serve as a vehicle moving forwards to collaborate with stakeholders to inform how efforts by AEMO and across industry should be prioritised.

Stakeholder engagement | Where the framework fits

Figure 3: How the Engineering Framework fits with other industry processes

How the Framework fits in with AEMO's roles and responsibilities

Scenarios are developed, in consultation with industry, for input into planning and forecasting publications (e.g. ESOO, ISP)

Integrated System Plan is an actionable roadmap for eastern Australia's power system to optimise consumer benefits through a transition period of great complexity and uncertainty.

Engineering Framework takes a holistic view of the changing characteristics of the energy system to help facilitate an orderly operational transition of the NEM.

Planning for Operability includes declaration of need for services to ensure a secure and operable system over the next five years (NSCAS, inertia, system strength)

Operational Planning includes a range of preparatory actions for the system and control room personnel, leading up to real-time (PASA, outage management, situational awareness, PSFRR)

Real Time Operations involves running the system securely and reliably day-to-day (PASA, Dispatch, market notifications)

Roles and responsibilities across industry

Consumers and industry participants are the ultimate users and should define desired system performance outcomes

Governments set the direction of the system evolution through policy

NSPs are the planners and operators for their networks

AEMO is the national transmission system planner, system operator, and energy market operator

ESB provides high level thinking on market design

AEMC details specific market design and implementation

AER regulates energy networks, retailers and wholesale markets

Coordinated approach to design of the power system and market

ESOO: Electricity Statement of Opportunities, ISP: Integrated System Plan, NSCAS: Network Support and Control Ancillary Services, PASA: Projected Assessment of System Adequacy, PSFRR: Power System Frequency Risk Review, ESB: Energy Security Board, AEMC: Australian Energy Market Commission, AER: Australian Energy Regulator

AEMO is looking to work closely with stakeholders on how efforts across industry are prioritised, so we can collectively act early to address the most urgent issues.

How you can get involved

From Section 4 onwards you will find links to specific existing opportunities to get involved in activities grouped under each focus area. We welcome feedback on any key work in progress not captured in this report.

AEMO will be looking to have an open industry discussion in April and also targeted stakeholder discussions through May and June to help identify operational conditions and any early priorities.

Questions to keep in mind as we start consultation include:

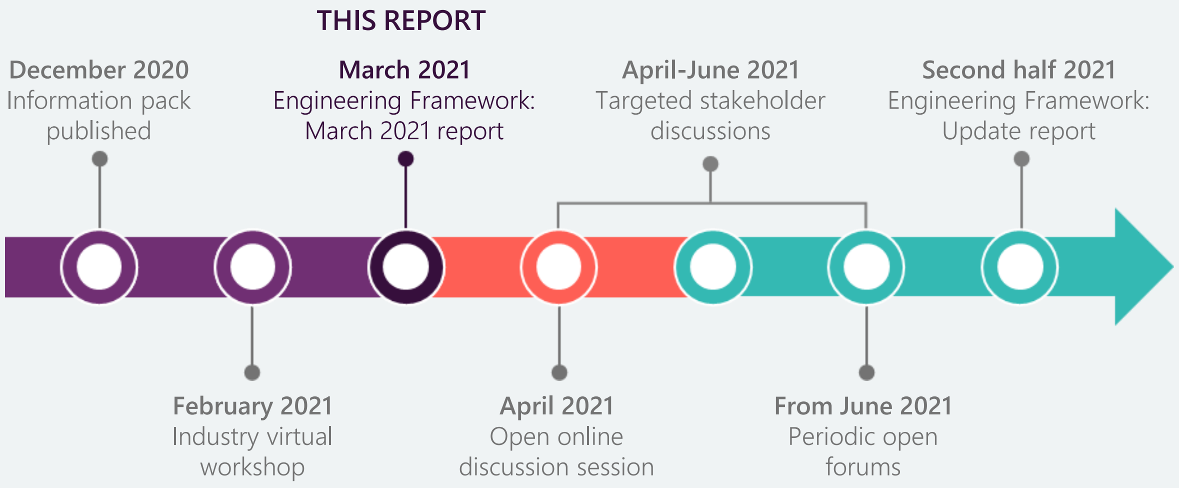
1. **How would you like to be involved in the consultation process shown in Figure 4?**
2. **In the approach section, AEMO has outlined a series of aims and focus areas. Are there ways we could improve this approach?**
3. **This report discusses the concept of operational conditions. What types of operational conditions need further discussion?**

When you see the outcome of initial discussions on operational conditions, think about where you see the biggest gaps requiring priority action. For any such priorities, what do you see as the roles and responsibilities of different parties?

Feedback from stakeholders through April to June will inform next steps. Our desire is to establish a clear plan forward, including goals, actions across industry, and timelines.

AEMO is proposing a flexible, staged approach to engaging with stakeholders, including:

Figure 4: Indicative timeline of activities



Get in touch with AEMO or sign up to our mailing list at FutureEnergy@aemo.com.au

Objective A | Operational conditions

This section of the report relates to Objective A:

A Facilitate a discussion to identify possible future operational conditions for the NEM power system

Figure 5: Proposed Engineering Framework approach – Objective A

How AEMO seeks to work with stakeholders:

Consulting on future operational conditions

Operational conditions | Historic change

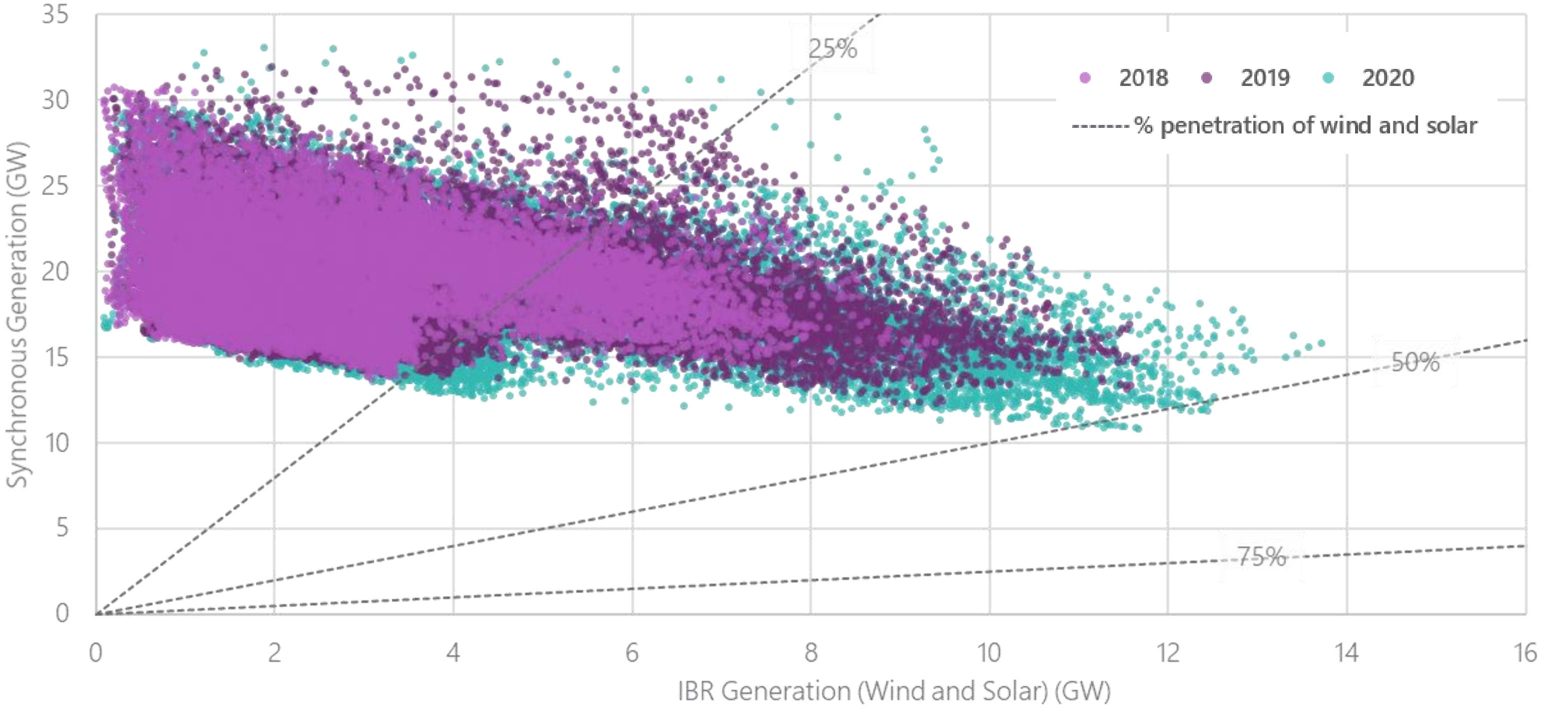
The NEM has experienced significant growth in wind and solar over the past decade. Figure 6 shows changes in half-hourly wind and solar generation compared to synchronous generation over the past three years, highlighting:

- **Higher wind and solar penetrations** – maximum levels rose from 38% in 2018, to 47% in 2019, and to 52% in 2020. There were 23 days with penetrations above 40% in 2019 and 109 days in 2020.
- **Lower minimum synchronous generation** – decreased from 13.7GW in 2018 to 10.8GW in 2020.
- **We are already in the realm of new and challenging operational conditions.** The Renewable Integration Study (RIS)[61] identified that for wind and solar penetrations greater than 50%, coordinated action was needed to support a secure transition.

The RIS also highlighted that operating a system above 75% and towards 100% wind and solar penetration is uncharted territory internationally. Figure 7 (next page) shows the changing generation mix at a regional level. Figures 6 and 7 demonstrate the rapid trajectory towards **new operating conditions**.

As an industry, we need to **actively plan and consider what changes need to be made so we are prepared to operate during these periods.** The Engineering Framework seeks to collaborate on operational conditions that may arise, so the power system continually delivers desired outcomes for consumers.

Figure 6: Wind and solar vs synchronous generation in the NEM



Interpreting the penetration plot

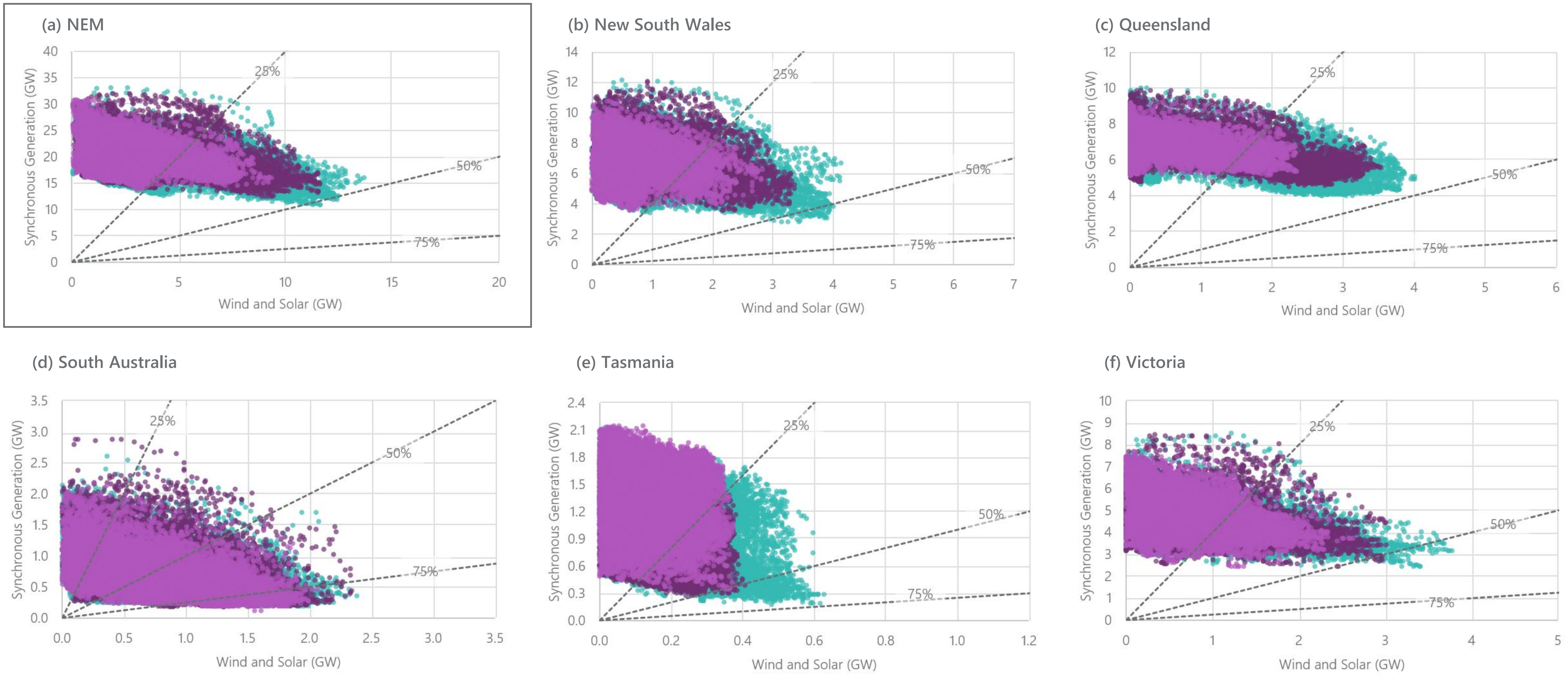
Figure 6 shows actual wind and solar generation vs synchronous generation in the NEM for each half-hour period for the 2018, 2019 and 2020 calendar years.

- Synchronous generation (**vertical axis**) is calculated as the output of all scheduled and non-scheduled synchronous generation in gigawatts (GW) over a 30-minute period. This includes, but is not limited to, sources such as hydro, black coal, brown goal, gas, and liquid fuel.
- Inverter-based resources (IBR) generation (**horizontal axis**) is calculated as the total output of semi-scheduled and non-scheduled wind and solar and distributed PV over a 30-minute period.
- The **dashed lines** represent 25%, 50% and 75% penetrations of wind and solar. For example, points to the right of the 50% line indicate half-hour periods where wind and solar generation was greater than synchronous generation.

Operational conditions | Historic change

Figure 7: Wind and solar vs synchronous generation, NEM-wide and by region

2018 2019 2020 ------- % penetration of wind and solar



Operational conditions | Explained

What are operational conditions

"Operational conditions" means a particular network configuration, generation mix and loading at a point in time or over a period of time.

These conditions, and the transition between different conditions, have to be managed in AEMO and NSP control rooms across the NEM, now and in the future.

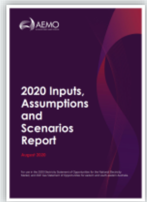
Power system operation is becoming increasingly dynamic, complex and variable. There is increasing potential for system conditions to change more rapidly on a given day, and faster than incumbent processes, systems or technology were designed to respond.

The ISP identifies an optimal development path for the NEM consisting of major transmission investments and other development opportunities. This is based on economic and engineering assessment[46] over a range of energy futures[29].

The ISP analysis assumes necessary actions have been taken over time to enable an optimal energy transition. Future power system operability hinges on us, as an industry, assessing future operational conditions and taking necessary actions to prepare.

Figure 8 shows how operational conditions, discussed in this report, relate to scenarios like those used in the ISP.

Figure 8: Comparison of scenarios and operating conditions

	Scenario	Operational conditions
What it is	Scenarios span a range of key uncertainties, including rates of change in technology development, renewable and distributed generation, decarbonisation policies, climate trajectory and electrification of other sectors.	Operational conditions are a particular network configuration, generation mix and loading at a point in time or a over a period of time.
Publications where explored	 **Inputs, Assumptions and Scenarios Report[29]**	 **Engineering Framework**
Example	The **Sustainable Growth scenario,** proposed for the 2022 ISP, reflects a future with high global and domestic decarbonisation ambitions, strong consumer action on DER, and higher levels of electrification of other sectors. This would be supported by strong economic and population growth.	Operation on a particular **day with very high penetrations of wind and solar** in the NEM (or a particular region) and no synchronous plant online, then transitioning to a highly synchronous system to meet peak demand in the evening. There are a range of factors, beyond investment in network support, that would be needed to manage this day. The **Engineering Framework** aims to unpack these requirements.

As Objective A says, AEMO would like to facilitate discussion with industry to define a range of possible future operational conditions for the NEM power system.

A range of operational conditions

There are some example operational conditions that we have included in the purple call out box (right) as discussion starters for industry consultation.

There are also a range of factors to consider when defining the set of operational conditions:

- They may be either **'transitional' or 'end-point' conditions**. For example, progressive operation with fewer synchronous generators online in a region, versus operation with no synchronous units online. When defining operational conditions that need to be managed in the short to medium term, it is also important to understand the long-term trajectory of our system (for example, operating with net zero emissions by 2050, as outlined in recent government announcements[103]).
- There are a **range of conditions that are already being worked through by industry** in the operational space. It is important that this work continues parallel to discussions under the Engineering Framework.
- The **timing** of when these conditions will start to emerge will be impacted by a range of policy settings, commercial decisions, and consumer preferences (as defined under different modelling scenarios). However, as an industry we still need to plan for the emergence of these conditions, so we understand the lead time needed for each condition and prepare accordingly.

Where to next?

As the next stage in this process, AEMO would like to work with stakeholders to identify the set of operational conditions we need to prepare for as an industry.

Example operational conditions

- Operation at very low operational demand.
- Operation with daily cycles from very low to very high levels of synchronous generation.
- Operation with high penetrations (>75%) of wind and solar in one or more neighbouring regions.
- Operation of a system with high volumes of price-responsive energy storage or demand response.

Once these future operational conditions are agreed, as an industry we can:

- Prioritise planning for each condition
- Identify additional work required to safely transition to these operational conditions.
- Identify which parties are best placed to lead this work.

Objective B | Work underway summary

The remainder of this report relates to Objective B:

B Consolidate a common view of the current work underway to adapt the system and existing avenues for engagement

Figure 9: Proposed Engineering Framework approach – Objective B

How AEMO seeks to work with stakeholders:

Consolidating information about the major efforts already underway across industry

This Section 4 summarises work underway for each of the 10 focus areas. Sections 5-7 then provide an overview of the key changes occurring for each focus area, more detail of the work underway across industry in response to these changes, and an outline of existing avenues for engagement.

A summary of the key work in progress, with links to the relevant sections for more detail, is provided below.

Attributes

Resource Adequacy	• The **Projected Assessment of System Adequacy** (PASA) is AEMOs principle method of forecasting adequacy of the power system in an operational timeframe. AEMO is currently redeveloping this system to better serve the future NEM. To learn more about the Short Term (ST) PASA system, see this webpage[60], and to learn about the ST PASA replacement project, see this webpage[62]. • The AEMC is progressing two reserve services rule changes: an **operating reserve market** and the **introduction of ramping services**. The draft determination for both rule changes is scheduled for 24 June 2021. To have your say, please visit the AEMC's dedicated webpage[10]. • The ESB is running a **Resource Adequacy** focus area under the Post 2025 Market Design project. For more information see its dedicated webpage[97] and latest directions paper[98], released in January 2021. The next ESB options paper is anticipated in April 2021.
Frequency Management	• AEMO is progressing a number of **frequency control projects** to support the changing NEM power system. For details see our frequency control work plan[42] and update[43]. • AEMO also releases regular publications related to frequency control in the NEM. These include inertia outlooks, assessments and shortfalls, which culminate in the annual Inertia Report[23], and a review of frequency risks associated with non-credible events through the Power System Frequency Risk Review[55]. • AEMO is currently progressing a **Market Ancillary Service Specification** (MASS) review for integration measurement requirements for distributed energy resources (DER) to participate in frequency control ancillary services (FCAS) and other general items. For full information and to have your say, see the dedicated webpage[47]. • AEMO is currently developing an **Advanced Inverter White Paper** to increase understanding of the application of grid-forming inverters, including the provision of synthetic inertia. This is currently planned for release by July 2021. • The AEMC is currently progressing rule changes on **Fast Frequency Response** (FFR) and **Primary Frequency Response** (PFR). All information about and opportunities to get involved can be found on the AEMC's dedicated webpage[4]. The draft determination for the FFR rule change is scheduled for 22 April 2021, and for the PFR rule change is scheduled for 16 September 2021. • Market design options for inertia are being considered by the **ESB's Essential System Services workstream** under the Post 2025 Market Design project. To find out more, see the ESB's dedicated webpage[97] and latest directions paper[98], released in January 2021. The next ESB options paper is anticipated in April 2021.

Work underway summary | Attributes

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Attributes

Voltage Control	• NSPs are responsible for building, maintaining, and planning their networks, including for managing the voltage profile. As part of this role, transmission and distribution NSPs identify issues on their network, develop solution options, and invest in new equipment, as outlined in their respective annual planning reports. • As a backup function to TNSP planning processes, AEMO assesses the need for any additional system security services required to manage voltages in the transmission network through the network support and control ancillary services (NSCAS) process. AEMO's 2020 NSCAS report identifies several areas[22] requiring broader industry consideration. • The **NEM Operations Committee** (NEMOC) and the **Executive Joint Planning Committee** (EJPC) are currently working with AEMO, transmission and distribution service providers, and industry to improve the planning and coordination of voltage control. Minutes of NEMOC meetings are available on this webpage[49].
System Strength	• AEMO produces an annual system strength outlook in its annual System Strength Report[23], including assessment and declarations of any likely shortfalls now or in the future. Further details on this webpage[53]. • AEMO is currently developing a plan for South Australia, which will be published in Q2 2021. It will outline the assessments and the timing required to safely transition the South Australian power system to lower levels of synchronous generators online. • The AEMC is leading industry collaboration to deliver lowest-cost, efficient levels of system strength in the system, through the efficient management of system strength on the power system[5] rule change. This follows completion of its investigation into system strength frameworks in the NEM[13]. The Draft Determination for this rule change consultation is scheduled for 21 April 2021. • High-level market design options for system strength are being considered by the **ESB's Essential System Services workstream** under the Post 2025 Market Design project. To find out more, see the ESB's dedicated webpage[97] and latest directions paper[98], released in January 2021. The next ESB draft paper is expected in April 2021.
System Restoration	• In November 2020, the system restart ancillary services (SRAS) guideline[64] was updated to contain a description of **new restoration support services** that may be procured to assist with restoration. Restoration support services can now be provided by inverter-based resources (IBR), which will become more important as synchronous generation declines. • AEMO issued an invitation to tender for SRAS[24]; this was sent out in December 2020.

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Operability

Control Room and Support	• The ESB, through its Essential System Services workstream under the Post 2025 Market Design project, is considering a range of **market design and scheduling mechanisms to support operation of the power system** as real time approaches. Any near real-time mechanism that is designed will need to be implemented in the control room through uplifts to data, processes, tools and training. To find out more about the proposed mechanisms, see the ESB's dedicated webpage[97] and latest directions paper[98], released in January 2021. The next ESB options paper is anticipated in April 2021. • The AEMC is progressing several rule changes around scheduling and commitment, including a unit commitment schedule[2] and system services mechanism[18]. The draft determinations for these rule changes are anticipated on the 24 June 2021 and 30 September 2021, respectively. • The draft determination for both rule changes is scheduled for 24 June 2021. AEMO is currently **redeveloping the ST PASA system** to better serve the future requirements of the NEM, including better accounting for uncertainty. To learn more, see this webpage[62]. • A program of work is also underway to improve the infrastructure available to **monitor, record and transfer high-speed time synchronised data** for real-time decision-making and offline analysis. • AEMO is working to uplift its control room tools and capabilities to **better manage new technologies and system conditions**. Key areas of uplift include integrating Virtual Power Plants (VPPs), Wholesale Demand Response (WDR), and preparing to manage low or negative operational demands. • AEMO has an ongoing program to **modernise and improve forecast accuracy**, including the exploration of probabilistic forecasting techniques, ensemble forecasting, scenarios and stronger relationships with the meteorological industry for weather inputs to forecasting.
System Analysis	• AEMO has developed a Dynamic Model Acceptance Test Guideline[36] for industry, defining the process AEMO uses to **assess participant models**. This is supported by the requirements outlined in the Power System Model Guidelines[56] and section 7.2 of the Power System Frequency Risk Review[55], helping improve the **robustness and consistency of modelling inputs**. • AEMO is pursuing multiple initiatives to **improve DER modelling capabilities**, such as new measurements of the response of induction motors under fault and low voltage conditions and the composition of commercial loads. To learn more, see this webpage[33]. • AEMO is developing a **Real-time Simulator** that reduces modelling time while maintaining a high level of detail, allowing for scenario analysis as events impact the system in real time. A project update is available on this webpage[25]. • **Fit-for-purpose industry access** to detailed Electromagnetic Transient (EMT) models is continuing to be explored by AEMO. • The NEMOC **Power System Modelling Reference Group** works to improve the quality of modelling data used by industry.

Work underway summary | Integration

Integration		
	Resilience	• AEMO is updating and expanding existing network constraints to keep power flows across the Heywood interconnector within limits that should allow the **under frequency load shedding** (UFLS) scheme in South Australia **to operate effectively** if needed. Information can be found in this document[44]. • The framework for protected events is being improved through development of **a system to consider high impact, low probability** events. • The AEMC is progressing a rule change on **enhancing operational resilience in relation to indistinct events**. Submissions for the rule change are now complete and the AEMC is expected to complete the rule change in July 2021. For information on the rule change, please visit the AEMC's dedicated webpage[6]. • The Power System Frequency Risk Review[55] is being reviewed in an AEMC rule, potentially expanding to a General Power System Risk Review[11]. • The Summer Readiness Plan[63] is a collaboration between AEMO, generators, TNSPs and governments to **manage heightened risks to power system operation**.
	Performance Standards	• AEMO's DER Standards workstream is collaborating with industry on the implementation of changes to the national standard for **small-scale DER inverters** (AS/NZS4777.2 updated in December 2020[107]) and capabilities enabling **demand response from residential appliances** (in the ongoing review[26] of the AS/NZS 4755 standard) and also engaging with DNSPs on performance standards for larger, **commercial scale DER** systems. • The Distributed Energy Integration Program (DEIP) Electric Vehicle Grid Integration working group[80] is exploring data needs across the energy sector, technical requirements and potential standardisation necessary to best integrate growing uptake of **electric vehicles** (EVs). • The DEIP Standards, Data and Interoperability working group[30] is focused on **device capability, interoperability** and **cyber security** needs for DER integration, covering both individual device level requirements and coordination across systems operated by different parties to enable aggregated management.

Work underway summary | Integration

Integration

Distributed Energy Resources (DER)

- The ESB's **Data Strategy** consultation paper[87] identifies consumer and DNSP data access as key gaps for DER integration. The **Consumer Data Right** reform[28] seeks to improve consumer access to their energy usage data. DNSPs have programs underway to improve **DER and low voltage network visibility**. The **DER Visibility and Monitoring Best Practice Guide** (website[89]) is a collaborative industry effort to standardise DER monitoring data to enhance its usability.
- ECA's **Power Shift** research program[90] and **Social Licence for DER Control** study[91] explores how energy management services and programs can be implemented to better empower consumers to optimise their energy choices and encourage consumer participation. The AEMC's **regulatory framework for metering services** review[17] is considering how smart meter deployment can enable more granular information and price signals allowing consumers to optimise and lower their costs.
- AEMO's **DER Operations** workstream[32] is focused on identifying and addressing the bulk power system operational impacts of increasing DER penetration. DNSPs continue to plan for DER growth, implementing measures to improve **hosting capacity**. The AER's **assessing DER integration expenditure** review[72] is consulting on economic assessment guidance for these investments, while its **ring-fencing** review[73] explores DNSPs' role enabling stand-alone, micro-grid and grid-scale storage.
- DNSP and industry trials, the DEIP **dynamic operating envelopes** workstream[79], and the ENA's **smart grid roadmap** (website[92]) consider actions necessary for distribution network to transition from fixed to dynamic export limits for DER applying only when the distribution network is constrained.
- The AEMC's **access, pricing and incentive arrangements for DER** consultation[1] and DEIP **access and pricing** workstream[76] are exploring the role of DNSPs to facilitate DER export and how network access and pricing frameworks can evolve to better address emerging challenges and optimise opportunities.
- The ESB's **Post 2025 market design** (project website[97]) is examining opportunities for DER to provide different system services, and development of a **Maturity Plan** evaluating roles and responsibilities for an effective two sided market.

Attributes

- Resource Adequacy
- Frequency Management
- Voltage Control
- System Strength
- System Restoration

Attributes | Resource adequacy

Balancing supply and demand is essential to operating a secure power system. Key changes underpinning both the supply and demand side are challenging reliable system operation. There is ongoing work looking at mechanisms to manage peak demand and balance a system with increasing variability and uncertainty.

Resource adequacy, as defined in AEMO's Power System Requirements paper[57], relates to having a sufficient overall portfolio of energy resources to continuously achieve the real-time balancing of supply and demand. The requirements to achieve this are:

- Flexibility to respond to changes in the supply-demand balance.
- Sufficient available energy across the system to meet demand.

Key changes

Variability – the RIS[61] showed that supply and demand variability in the NEM is increasing. As the penetration of wind and solar goes above 50%, based on current firming generation and operation, system flexibility limits may bind.

Uncertainty – the RIS[61] also showed that uncertainty (the ability to predict future supply, demand and grid conditions) is increasing. The level of accuracy and precision in predicting variable renewable energy (VRE) output is limited, even when using best practice forecasts. As the system becomes more reliant on wind and solar, this uncertainty will need to be managed to balance supply and demand.

Displacement of online thermal plant – some thermal generators may not be dispatched in periods of high penetration of VRE. Thermal generation is the largest source of firming flexible energy in the NEM. If these plant are offline they can take minutes to days to start up. This means that the right mix of resources may not be available when needed to meet ramping requirements.

Thermal generator retirement – the NEM has an ageing thermal fleet with plant approaching end of life. As this generation retires, resource availability needs to be managed to ensure there is sufficient firm, flexible capacity to keep the system reliable.

Work in progress

Market design

As supply and demand uncertainty continues to rise, additional operating reserves may be required to ensure secure system operation. These additional reserves could be obtained through changes to existing regulatory frameworks, or through the development of reserve services markets. These options are being explored by the AEMC and ESB.

The AEMC is currently consulting on rule changes for an operating reserve market[15] and ramping services[12].These markets mechanisms should help ensure there are sufficient flexible system resources to assist operation in times with high uncertainty.

The ESB, through its post-2025 market design program[97] is exploring a range of market and regulatory enhancements through its essential system services (operating reserve mechanism), resource adequacy mechanisms, and ageing thermal transmission workstreams.

The ESB's January 2021 directions paper[98] highlighted a range of possible policy options to ensuring the right mix of resources is available to service the system needs at any given time. These include:

- Mechanisms to ensure the orderly exit of thermal plants as they retire.
- Investigation into a NEM-wide approach to jurisdictional investment schemes for new investment in the market.

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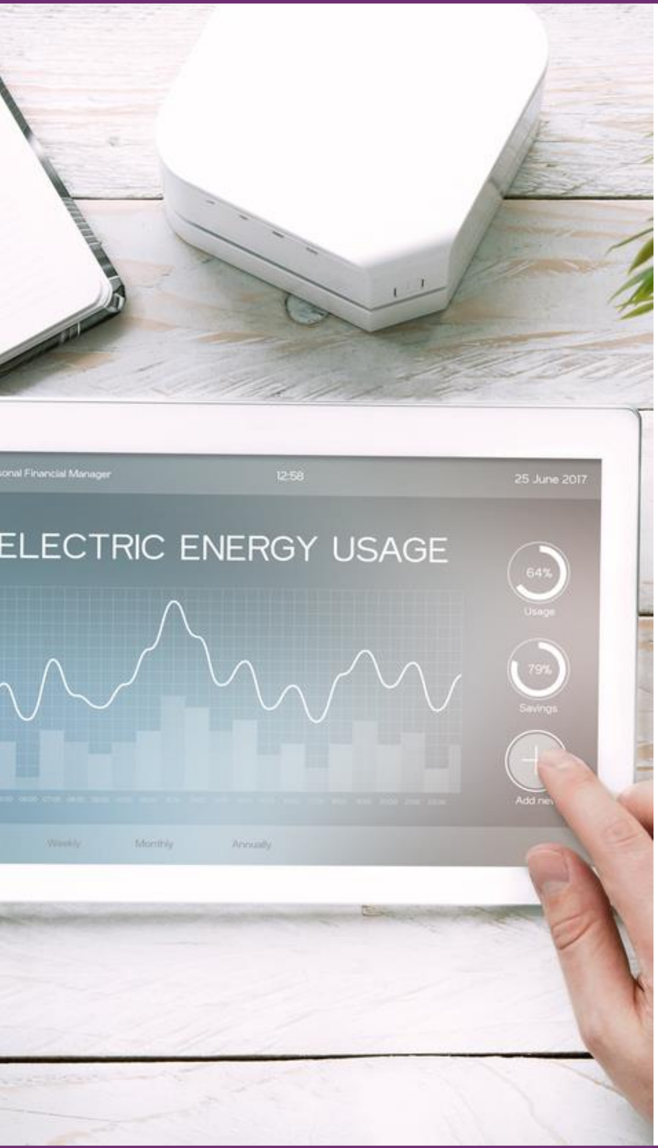


System operation

AEMO has several systems that work together to ensure sufficient energy is dispatched across the system to meet demand. This includes systems for solar, wind and load forecasting, PASA, and dispatch. However, increasing variability and uncertainty has focused our attention on ensuring there is also sufficient flexibility to continually respond to changes in energy requirements. This is where the current work in progress is focused.

There is an ongoing body of work to improve forecast accuracy, which was identified in the RIS as a key enabler to operation with a high penetration of VRE. Additionally, forecasting accuracy of wind and solar has improved since the introduction of participant self-forecasting[52] in 2018.

Insight into system reliability in operational timeframes is achieved through the ST PASA system. Replacement of the ST PASA system[62] has been identified as a critical project, which will allow a real-time assessment of ramping requirements and modelling of newer technologies such as batteries and VPPs, among other improvements. This will better inform participants of system needs so they can respond or allow power system controllers to take appropriate actions if necessary.

This work described in this section is further detailed in the control room and support focus area.

Planning

Forecasts and planning over a longer time horizon are important to support strategic investment in new generation and transmission infrastructure, so consumers can access energy when and where they need it, now and in the future.

The Electricity Statement of Opportunities (ESOO)[39] provides a forecast of electricity supply, demand and reliability in the NEM, including an assessment against the reliability standard for a 10-year outlook. This forecast is used to inform investment decisions by market participants, investors and policy-makers.

The ESOO has also been evolving to include new sensitivities, climatic and weather patterns, and operational patterns to take account of reliability under different futures. Such scenarios allow industry preparation and investment for these potential events.

In 2019, the implementation of the Retailer Reliability Obligation[74] provided a process to ensure retailers (or other relevant entities) have sufficient quantity of contracts to cover their demand where a material reliability gap is identified in the ESOO. Further enhancements to this framework are also being explored though the ESB's post-2025 market design program[97] in the resource adequacy mechanisms workstream.

The ISP[20] highlights a range of opportunities, including connection of new renewable energy zones (REZs) and development of new interconnection between adjoining regions (such as Project EnergyConnect between South Australia and New South Wales). The completion of these projects provides additional system flexibility by improving sharing of resources between adjacent regions.

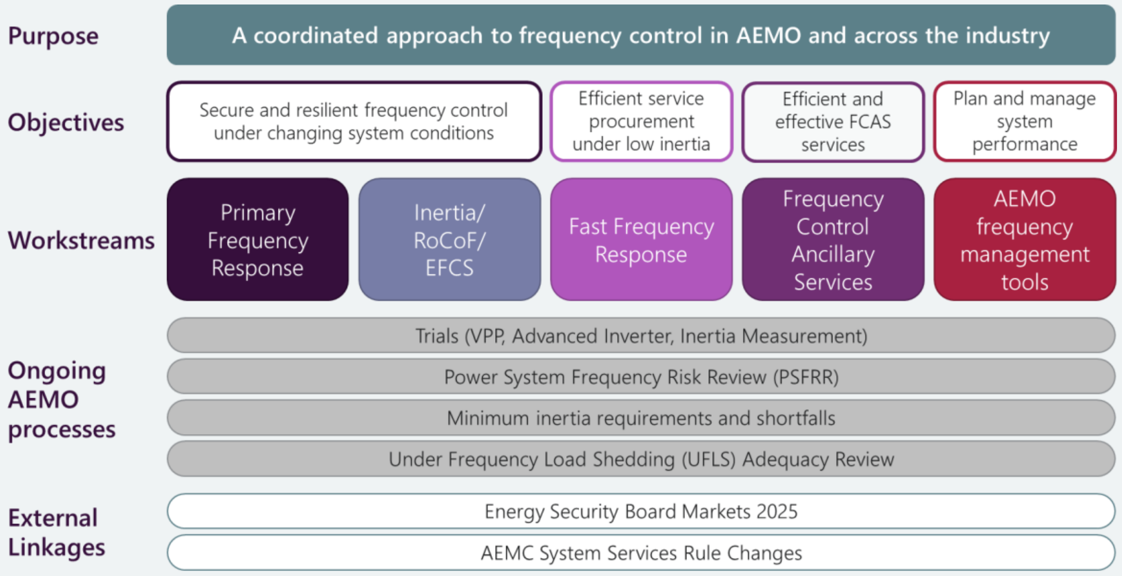
Attributes | Frequency management

To operate, the power system must have the ability to set and maintain frequency. Driven by a forecast reduction in inertia out to 2025, combined with a decline in load relief, and increased risk size, the power system will operate in configurations where the system dynamics are different to those experienced today.

AEMO's frequency control workplan[42] (September 2020) and subsequent update[43] (March 2021) provide a detailed workplan to systematically address frequency control issues.

The plan contains five workstreams (Figure 10), which provide detail on individual tasks and timelines, and on coordination with ongoing market and regulatory processes.

Figure 10: Frequency control work plan overview



Key changes

Reduction in inertia – historically, NEM mainland inertia has never been below 68,000 megawatt seconds (MWs). By 2025, AEMO forecasts that inertia could drop to as low as 45,000 MWs. As inertia decreases, an increased volume of frequency services, or services that can respond more quickly, are necessary to arrest the change in frequency before technical limits are exceeded.

Primary Frequency Response – between 2014 and 2020, the PFR provided by generators in the NEM declined. Since the implementation of the Mandatory PFR rule[14] in late 2020, this trend has reversed. PFR enhances the power system's resilience for contingency events, which is becoming increasingly important under lower inertia conditions. It is also needed to improve frequency control under normal conditions. Consistent PFR provision is needed for AEMO to model system events, which is essential for system planning and AEMO's ongoing management of power system security.

DER behaviour – understanding the behaviour of DER devices, including how they impact existing frequency controls (such as UFLS) is becoming increasingly critical as penetrations rise. It is important to understand the dynamics of the changing system (such as the ability of the system to recover following a disturbance) and the effectiveness of existing emergency mechanisms to ensure that the tools to manage system security are fit for purpose in a changing landscape.

Work in progress

Primary Frequency Response

To address the immediate need to improve frequency control in the NEM, in March 2020, the AEMC made the Mandatory PFR rule[14] to require all capable scheduled and semi-scheduled generators in the NEM respond to changes in the locally measured power system frequency. AEMO is in the process of coordinating changes to generator control systems in accordance with this rule. This process is being rolled out in three tranches based on the registered capacity of the applicable generating units until mid-2021. Regular progress updates are available on AEMO's dedicated webpage[58].

The AEMC is also consulting on enduring PFR arrangements through the PFR incentive arrangements rule change[16].

Attributes | Frequency management

Inertia, rate of change of frequency and emergency frequency control schemes

A range of tasks are underway at AEMO to understand, quantify, and manage the impact of lowering system inertia and increasing penetrations of DER.

AEMO's annual Inertia report[23] sets out minimum inertia requirements across the NEM and identifies whether a shortfall is likely to exist now or into the future. AEMO has so far declared inertia shortfalls in South Australia and Tasmania.

AEMO is investigating the need for a System Inertia Safety Net (see Task 10, Frequency Control workplan update[43]) to maintain a minimum level of inertia at times not currently considered as part of the existing inertia requirements. Market design options for inertia are being considered by the ESB's Essential System Services workstream under the Post 2025 Market Design project[97].

The Power System Frequency Risk Review[55] assesses the potential for "non-credible" events to cause frequency changes large enough to initiate generator disconnections and result in widespread transmission outages or a black system. It assesses current emergency frequency control schemes, protected events, and options for future management of these events. This periodic review was last released in December 2020.

Work is being undertaken by AEMO to understand and quantify the impact of DER penetration on UFLS as well as developing new management strategies to provide secure frequency control during periods where UFLS may be insufficient.

These tasks are outlined in the Frequency Control workplan update[43], and include the implementation of an updated constraint[44] to manage rate of change of frequency (RoCoF) in South Australia when the Heywood interconnector is importing energy to the region.

AEMO is also developing a white paper to increase understanding on the application of grid-forming inverters, including the provision of virtual inertia.

Fast Frequency Response

As inertia decreases, frequency services that can respond more quickly will be better able to arrest the change in frequency before technical limits are exceeded.

The AEMC is considering arrangements for FFR type services as part of the FFR rule change[8]. To support this rule change, AEMO has developed an FFR implementation report to provide technical advice on the development of FFR arrangements in the NEM. This report is expected to be published to the AEMC website[8] in the coming weeks.

Efficient and effective FCAS services

As the system transitions to new operating states, the current FCAS frameworks need to be reviewed and adapted to the new circumstances. For example, the current MASS review[47] is consulting on ongoing measurement requirements for DER to participate in FCAS markets, in addition to a 'General MASS Review'.

The Frequency Control workplan update[43] also outlines investigation into specific regional issues as well as general FCAS improvements.

AEMO frequency management tools

To effectively plan the system and manage frequency operationally, AEMO requires the ability to model the power system under expected and plausible operational conditions. This concept is also explored in the System Analysis focus area.

AEMO is progressing improvements to our existing modelling capabilities in the area of frequency control. This is a key enabler for many other elements of the Frequency Control workplan.

Attributes | Voltage control

Voltage control in the NEM is changing as the power system evolves, and will need to be adapted to securely and efficiently operate the system of the future. NSPs and AEMO are collaborating on how to plan and operate to manage system voltages.

AEMO's Power System Requirements[57] paper describes how critical voltage control is to maintaining a secure and reliable power system. There are a variety of changes that are influencing the management of voltage control and voltage sources.

Key changes

Operation with decreasing levels of synchronous generation online – high VRE output displaces synchronous generation, which is a significant source of static and dynamic reactive power in key network locations.

Increasing distributed PV (DPV) – the growth of DPV installed behind the meter by households and business reduces demand on the transmission system, which causes voltage rise. It also causes voltage rise on the distribution system, as power is fed back from the end of long feeders.

Increasing VRE generation in distant locations – the growth of renewable generation in regional locations (where solar and wind resources are plentiful, but far from demand centres and existing transmission infrastructure) is increasing power transfer over long distances, which requires reactive support and also the need for fast reactive response.

Low daytime demands – reducing daytime demand (as DPV has grown) is increasing the usage of already ageing reactive plant. This is because this plant has been sized to manage previous differences between night-time minimum and maximum demand. In addition, the increased need for reactive plant to manage daytime minimums for a greater proportion of the year reduces essential maintenance windows during off peak periods.

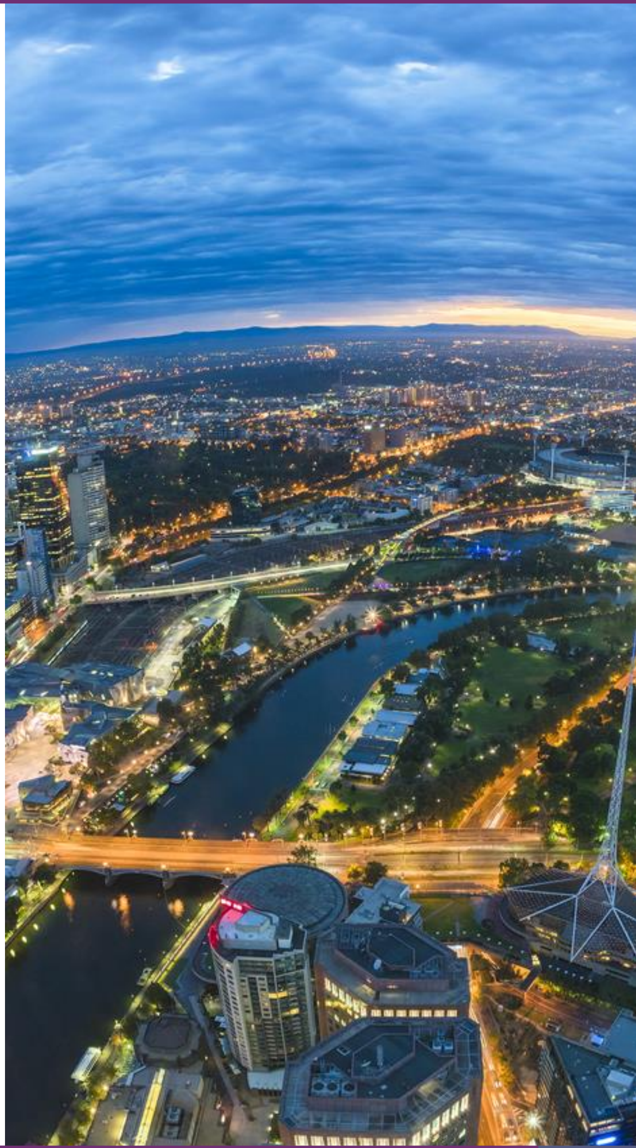
Changing demand characteristics – the replacement of synchronous and induction motors by inverter-based equipment is reducing the demand for reactive power and this is resulting in higher voltages.

Increased manual control – increasing embedded generation is changing the reactive flow between the transmission and distribution system. This requires AEMO control room operations to manually interact with the DNSPs to adjust reactive power interchange at the interface with the TNSP. While there is an increasing reactive capability connecting at the distribution system, in some cases, there may not be established processes to immediately act on the instruction.

Work in progress

System operation

Operationally, AEMO coordinates and manages the voltage profile across the transmission network. In real time, AEMO's Var Dispatch Scheduler[68] automatically determines optimised dispatch of reactive power devices on the transmission system. If the Var Dispatch Scheduler cannot maintain voltages, AEMO coordinates with NSP control rooms to take action. This can include network reconfiguration (switching transmission elements out of service), generator directions, activating NSCAS contracts[51] or requesting NSPs to change equipment setpoints.



The NEMOC[49] and the EJPC are currently working with AEMO, TNSPs, DNSPs and industry to improve the planning and coordination of voltage control, including:

- Integrating reactive support from a larger pool of smaller units (i.e. transmission connected wind and solar) compared to a smaller number of large synchronous units.
- Investigating opportunities for DER to provide reactive support via updated performance requirements for devices or coordinated management within the distribution network.
- Providing learnings from real-time operational experience and operational analysis back to planning teams to improve voltage profile operability.

Planning

NSPs are responsible for building, maintaining, and planning their networks, including for managing the voltage profile across the network (in the planning timeframe). As part of this role, NSPs identify issues on their network, develop solution options, and invest in new equipment, as outlined in their annual planning reports.

Costs are recovered through the AER network regulation process, with significant investments subject to cost-benefit assessment (through the regulatory investment tests for transmission [RIT-T] and distribution [RIT-D]).

Joint planning arrangements (AEMO-TNSP, TNSP-DNSP) facilitate the consideration of options to address identified limitations from an integrated, whole-of-network perspective.

As a backup function to TNSP planning processes, AEMO's NSCAS framework[51] assesses the need for additional system security services required to manage voltages in the transmission network, over a five-year horizon.

TNSPs are responsible for having arrangements in place to address the NSCAS gap identified by the NSCAS report through the procurement of non-market ancillary services (e.g. agreements with generators). If AEMO does not consider an NSCAS gap will be met (where it relates to preventing power system security and reliability), AEMO can procure the necessary services as a last-resort.

AEMO's 2020 NSCAS report[22] identifies emerging operational challenges and opportunities requiring broader industry consideration:

- Reducing levels of minimum demand, potentially co-incident between regions, will require flexible operation of elements of the power system and possibly investment in new equipment.
- Further DPV increases and declining minimum demand, together with increasing amounts of VRE, means delivery of voltage management and reactive power support from wind and solar generators will become more important.
- New large-scale renewable generation may be able to provide significant reactive power support at times of minimum demand.
- The shift of minimum demand to daytime periods expands the time that reactive power absorbing plant is needed to manage network voltages. As a result, challenges are emerging for critical maintenance on equipment to prepare for peak load periods.
- Some traditional network planning assumptions may no longer be fit for purpose in the context of declining minimum demand. AEMO is collaborating with TNSPs investigating whether planning assumptions need to change.

Attributes | System strength

The NEM power system is at the international forefront of managing issues associated with low system strength, and industry is adapting to operating in these low system strength conditions. If improvement opportunities associated with system strength can be realised, there are security, efficiency and resiliency gains for consumers, participants and investors.

System strength is a complex topic and is continually evolving. AEMO published System Strength Explained[66] in 2020 and, in response to stakeholder feedback, also ran an Industry Workshop[65] to promote shared understanding. Figure 11 outlines the roles and responsibilities are for system strength in the NEM.

As synchronous generation is displaced, system strength reduces. As IBR increase, the demand for system strength increases, which affects the available system strength levels.

Key changes

Connecting IBR – it is becoming more challenging to meet generator performance standards in weak areas with these new resources, especially where there are multiple other IBR connections nearby.

Participant provision of system strength services – efforts are uncoordinated and not delivering scale-efficient solutions to support the transition of the NEM power system.

Increased constraints on renewable energy – the absence of an operational mechanism to increase system strength above the minimum secure levels and a mechanism to enable the timely planning for provision of system strength services is increasing constraints on renewable resources.

Increasing operator burden and costs – the burden and costs for operators are growing, associated with maintaining the minimum levels online, through both out of market directions and contracting.

Maintaining resilience to non credible events – this is becoming more challenging with reducing system strength margins.

Plant maintenance – this is becoming more difficult with more frequent periods of low system strength. Also, the complexity of analysis to assess low system strength conditions is increasing the time to assess conditions during outage planning and real- time operations.

Work in progress

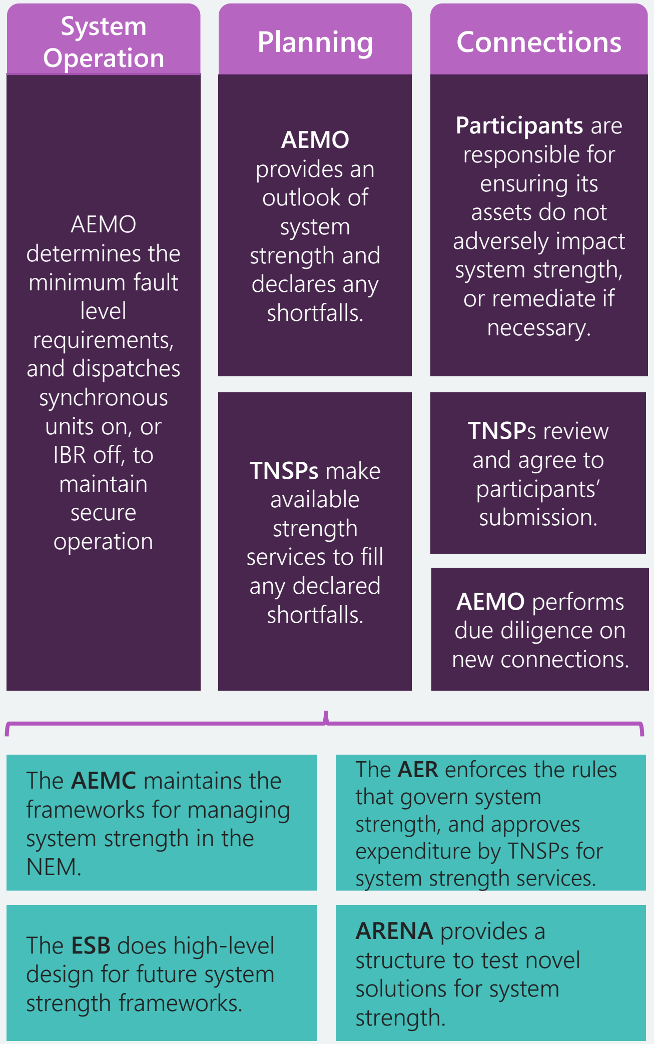
System operation

AEMO is responsible for securely operating the NEM power system, and has been pioneering new analytical techniques to analyse the stability of the power system with reducing levels of system strength.

AEMO has published the output of this analysis as minimum combinations of generators for South Australia, Victoria[67], Queensland[23] and Tasmania[23], and is currently carrying out analysis for New South Wales.

These combinations are continually being refined and updated as newer information becomes available and different conditions (such as network and generator outages, and changes in participant behaviour) occur on the power system.

Figure 11: System strength roles and responsibilities



Attributes | System strength

AEMO has developed standard operational processes, control room tools, and operator training to intervene (through directions/ instructions) for system strength services under the current framework. This process is still manual and adds significant extra workload on operators in the control room responding to uncertain pre-dispatch conditions.

AEMO is currently developing a plan for South Australia which will be published in Q2 2021. It will outline the assessments and the timing required to safely transition the South Australian power system to lower levels of synchronous generators online.

Planning

The ISP[20] aims to identify investment choices and recommend essential actions to optimise consumer benefits. These investments include the provision of system strength services as part of whole-of-system planning for new REZs.

The System Strength and Inertia report[23] sets out minimum fault level requirements and identifies possible shortfalls over a five-year outlook.

As part of this process, AEMO collaborates with TNSPs to identify points in the transmission network where minimum fault levels should be set. In turn, TNSPs consult with DNSPs to coordinate minimum levels with distribution network protection requirements.

AEMO has so far declared system strength gaps and worked with local TNSPs to address low system strength in South Australia, Tasmania, Victoria, and Queensland.

AEMO published the 2020 System Strength report[23] in December 2020. These shortfalls currently do not cover hosting new generators, as these are currently managed separately under the National Electricity Rules (NER) 'do no harm' provision (see Connections below).

NSPs are responsible for planning their network, including connecting new generators, expanding the network assets, and maintaining minimum fault levels declared by AEMO for system security.

AEMO is continuing to look at actions required to operate the system with fewer synchronous machines online, and expects to publish further materials on this later in 2021.

Connections

Participants are responsible for demonstrating they can meet the required performance when they connect to the grid. NSPs and AEMO are responsible for carrying out due diligence to check performance of the generators and the system before they connect.

A review of existing frameworks

The AEMC is leading industry collaboration to deliver lowest-cost, efficient levels of system strength in the system, through the efficient management of system strength on the power system[5] rule change. This follows completion of their investigation into system strength frameworks in the NEM[13]. This process has recognised the asymmetric risk in not preparing for future system conditions. It aims to increase proactivity for the scale-efficient provision of system strength services to support the future security and efficiency of the NEM power system.

The ESB, as part of its Post 2025 market design program[97], is assessing market mechanisms that increase certainty around system dispatch of energy and essential system services, including system strength and minimum synchronous units as real time approaches. The ESB will recommend a comprehensive market design to the ministerial forum of Energy Ministers by mid-2021.

Technology solutions

There is ongoing work to improve inverter control systems across the NEM and the globe, including leveraging existing technology (such as synchronous devices) to solve system strength- related problems.

Grid-forming IBR capability is also showing promising potential to support operation of the power system at increasing penetrations of IBR and lower levels of synchronous machines. Australia is leading the world with a number of trials supported by the Australian Renewable Energy Agency (ARENA), which are aiming to support and test this new technology. As noted in the frequency management focus area, AEMO is developing a white paper on grid- forming capability.

Attributes | System restoration

Black system events occur rarely in the NEM (South Australia in 2016, northern Queensland in 2009, and New South Wales in 1964). While these events are rare, system operators must have resources available to restart and restore the system. Currently, system restart and restoration relies on synchronous generation. As the system transitions and synchronous generation retires, we will need to find new ways of restarting and restoring the system.

To restore the power system after a major supply disruption, SRAS sources must be in place that can independently restart to initially energise a section of the power system, in order to restart other generators. The restored generators and SRAS are then used to start up additional supply and restore more load so power is gradually restored.

In the NEM, SRAS can be divided into black start services and restoration support services:

- **Black start services** need to independently start without the need for external supply and have the capability to deliver power and energise the network to restart other generation.
- **Restoration support services,** in conjunction with black start service(s), assist the initial energisation of the power system and generation restart. This service is procured on an as needs basis, while black start services are always procured.

The System Restart Standard[104] sets the benchmark for AEMO to procure SRAS to meet the requirements of the NEM. To date SRAS are used to restart **generation only.** This standard does not cover the loss or restoration of load.

In the short term, synchronous generation will be required for black start, because:

- Energising a network generally requires short circuit power.
- A firm energy source is needed long enough to support the restoration process.

Only a portion of synchronous generators in the NEM are capable of providing black start services, as they must be designed specifically to do so. The location of both the black start and restoration support services is critical to the restoration process, as they need to be strategically located to be able to successfully energise network to restart other generators.

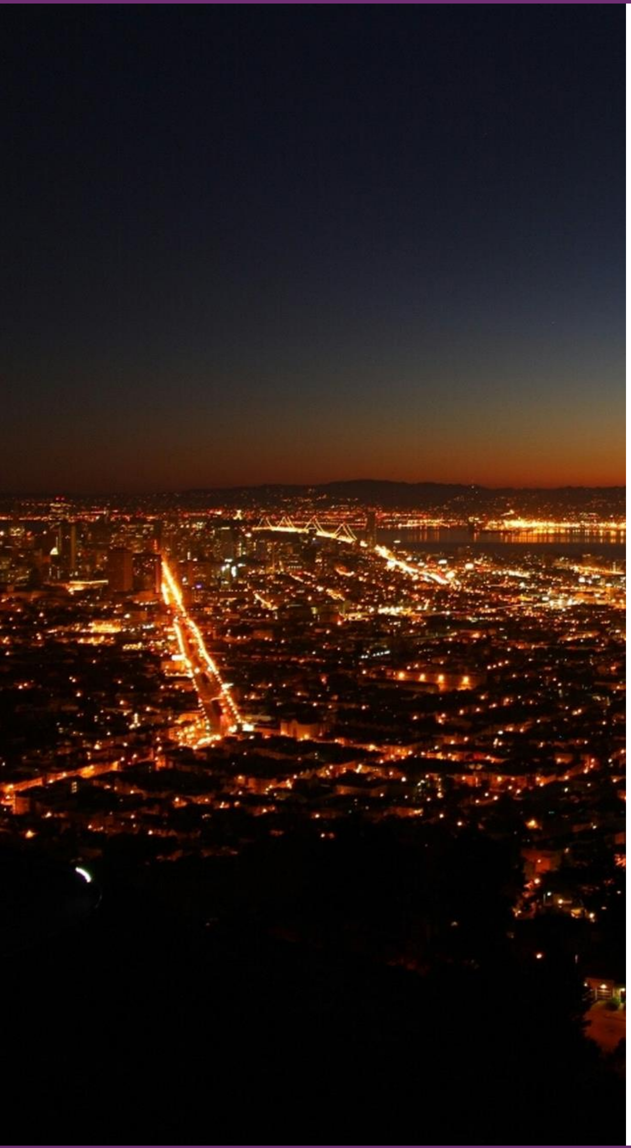
Key changes

Thermal synchronous generators offline (not SRAS) – these are used to continue the restoration of the system. When offline, these generators can become cold, which means they can take 2-3 times longer to start and can slow the restoration process.

Black start generators may retire – new services may not be made available. IBR (wind, solar, battery, HVDC, DER) are currently not contracted for black start, due to limitations on available energy, provision of short circuit power, or control systems requiring an a grid reference to measure.

New generators connecting in geographically disperse locations – this can make the restoration process more difficult as they would have to energise and support long sections of the network to get to other generating systems.

Reducing stable load blocks – these are needed for stable operation of SRAS and other synchronous generators during the restoration process. DPV can reduce the availability of stable load, and can also vary the load, which could delay or inhibit restart.



Work in progress

IBR and restoration

In July 2019, AEMO submitted a rule change proposal[37] to improve the reliability and sustainability of system restoration as synchronous generation declines.

As a result, in October 2020, AEMO updated its SRAS Guideline[64] to contain the technical details of the new *restoration support services* that may be procured to assist with restoration, along with black start services. Historically, every three years AEMO issues an invitation to tender for SRAS[24]; this was sent out in December 2020.

While there are currently no IBR providing restoration or black start services, the SRAS guideline is technology-neutral and either service can be provided by capable IBR.

Capabilities of existing IBR to provide restoration support services are outlined in the SRAS Guideline (Section 3.4) and include:

- Provision of steady-state and dynamic voltage control.
- Provision of steady-state and dynamic frequency control.
- Provision of sufficient fault current for correct operation of protection systems in its restoration path.
- Stabilising load to provide or facilitate load pickup sufficient to support black start services or other large generators on the restoration path.

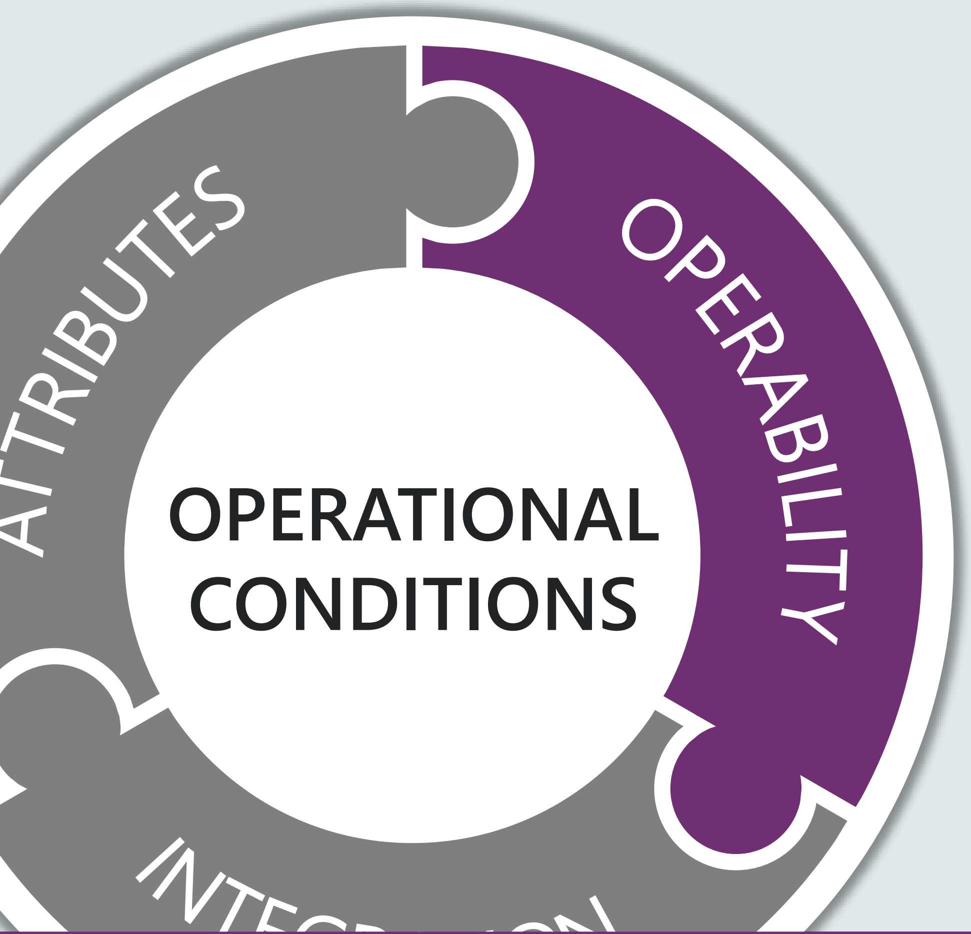
International evidence has also shown that grid-forming inverters, which are IBR, can provide black start services using HVDC, wind, solar and batteries. International case studies of system restoration using grid-forming inverters and future applications for the NEM are being explored as part of AEMO's white paper on grid-forming capability (see frequency management focus area).

The application of grid-forming inverters in the NEM for system restoration is particularly relevant given the growing interest in long duration storage batteries. If these batteries could be large enough to generate sufficient short circuit power, had grid-forming control systems, and were strategically located, they could be utilised in the future to provide black start services to the power system.

International research

Learnings from the NEM are being shared internationally through the CIGRE working group C2.26[85] (Power system restoration accounting for a rapidly changing power system and generation mix).

This working group aims to identify and address emerging risks on system restoration, investigate opportunities for increased utilisation of new and emerging technologies (including DER) during system restoration, and enable system operators and network owners to continue to execute a successful system restart when required despite a rapidly changing power system.



Operability

- Control Room and Support
- System Analysis

Operability | Control room and support

This section focuses on AEMO's control room tools and support. However, discussions on future system needs must also consider the requirements of NSP control rooms.

As the power system transitions, almost all aspects of power system operation are challenged. Managing the changed needs of this system will require new operational practices, supported by an uplift of control room tools, data, systems and capabilities. Further, as new mechanisms are designed to support the market and system operation, tools and processes will need to be reviewed and modified to integrate these changes.

The operation of the power system is enabled via the dispatch of the market. There are two electricity transmission control centres that coordinate and regulate the distribution of power generation in the NEM. These control rooms and market are supported by operational teams that specialise in a range of functions including forecasting, outage management, situational awareness, constraints, real time analysis and modelling.

The RIS[61] summarised current system operation, which is based around experience, monitoring, testing, and system analysis.

Key changes

Increased uncertainty – changing system behaviour (including the adoption of new technologies, weather-driven generation, and displacement of conventional generators) is increasing the uncertainty.

Displacement of online synchronous sources – many system attributes that the NEM power system relies on are still provided by synchronous machines. As these generators retire, new ways of ensuring system attributes are provided and coordinated will be required.

Increasing decentralisation – as discussed in the DER focus area, growth in behind-the-meter consumer technologies, including DPV, are changing operators' visibility and the controllability of the system, as well as the way the system behaves during normal operation and after a disturbance.

Increasing complexity for security analysis – the growth in IBR is driving a trend towards the use of EMT studies to accurately assess system behaviour. These studies are inherently more complex to model and computationally heavy to run.

Work in progress

Mechanism to support operations

Development of new market system services and mechanisms is important to value and procure system services that are essential for secure operation. AEMO sees a need for operational mechanisms to support the ongoing operation of the system through the transition as a means to ensure the system can be secure.

The development of these products and mechanisms should help manage the conditions of increasing operational uncertainty and complexity. They will also reduce the need for manual intervention, however this will be replaced by a need to schedule and dispatch the new services and also necessitate new tools, processes and training to operate the system.

As part of its Post 2025 market design program[97], the ESB is assessing market and scheduling mechanisms that deliver secure power system operations.

For example, the ESB and AEMC are considering a range of system services markets and mechanisms[3] to support the secure operation of the system through market dispatch processes. These include changes to frequency response, an operating reserve mechanism, and arrangements for services that are not suitable to real-time markets (e.g. system strength) supported by structured procurement and operational scheduling mechanism to schedule those resources (a unit commitment schedule[2] or system services mechanism[18]). The ESB will recommend a comprehensive market design to the ministerial forum of Energy Ministers by mid-2021, and the AEMC is considering the associated rule changes.

If rules are made to implement these new system service markets and mechanisms, changes would be required to control room tools, systems, and processes.

For example, in the frequency management focus area a new market for FFR and incentives for PFR were discussed. Implementation of the design options being considered may require uplift to the NEM Dispatch Engine, in addition to other tools and control room training.

High speed data

To understand the changing system complexity and effectively respond to rapidly developing power system events, AEMO and NSPs must have access to new and better sources of information.

For example, theoretical simulations and reviews of past events have shown that a reduction in system strength can cause instability and impact power system security. However, AEMO currently has no real-time visibility of these phenomena. Without this visibility, the control room cannot determine the real-time security of the system and respond accordingly.

In collaboration with TNSPs, AEMO is accessing adequate coverage of high-speed time-synchronised monitoring devices throughout the NEM power system, that can monitor, record, and transfer data back to AEMO.

To translate this enhanced data into analytics for decision-making, an upgrade to the Wide Area Monitoring System has just been rolled out and integrated into the control room. This will provide enhanced visibility, analytics and alarming for quicker and more effective response to rapidly developing power system issues. It will also inform the definition of more accurate demand and generation characteristics to tune and improve its power system models, to better reflect actual system performance.

Operational forecasting

Wind, solar and load forecasts are important inputs to control room decision-making. A program has been initiated to uplift capacity and functionality and to modernise and improve forecast accuracy. This program is aimed at better understanding and responding to the uncertainty in the forecasts through probabilistic forecasting techniques, ensemble forecasting, scenarios, and stronger relationships with the meteorological industry for weather inputs to forecasting (including fit-for-purpose weather observation infrastructure).

This program will provide integrated visualisations to enhance operators' situational awareness and allow them to better manage downside risks, high impact low probability events, and extreme weather scenarios.

Operability | Control room and support

Fit-for-purpose tools and systems

Building systems, tools, and processes that effectively ingest, analyse, and present data is critical in improving the ability of operators to make rapid decisions based on targeted information.

An important system used in the control room is ST PASA. This is used by AEMO and market participants to alert of any system reliability issues over the next seven days (see resource adequacy focus area).

AEMO's ST PASA replacement project[62] aims to review and uplift the current system, so that the design of the system matches the future requirements of the NEM.

This includes better accounting for uncertainty, modelling of newer technologies (including batteries and DER), uplifting underlying models to better reflect the physical system, and accommodation of a wider range of credible threats to the power system.

AEMO also has a program of work to review, consolidate and uplift its current control room tools and displays using advanced security analysis, data analytics, and visualisation to support fast and accurate operational decisions.

This program will also focus on the adaptability of tools, so the tools can be easily adjusted to provide the control room the information it needs to make informed decisions, even as the system varies.

Other changes and reforms required to be integrated into the control room

Other work areas are also being progressively integrated into the control room. These include:

- Continued efforts to prepare for very low or negative minimum demands by spring 2021.
- The integration of new technologies, including VPPs[69] and WDR[71].
- The shift from a 30-minute to a 5-minute settlement[41] period.
- In collaboration with industry, development of new operational management practices for DER, as described in the DER focus area (security and reliability section), such as new UFLS constraints[44] (and a potential future protected event) and DER mechanisms for security.

Operability | System analysis

Effective power system analysis is a key enabler for the secure transition of the NEM. As the system evolves, the tools used to understand it are becoming less effective. To successfully manage the system of the future, as an industry we will need to adapt our current tools and processes, develop new tools, and leverage the latest technology.

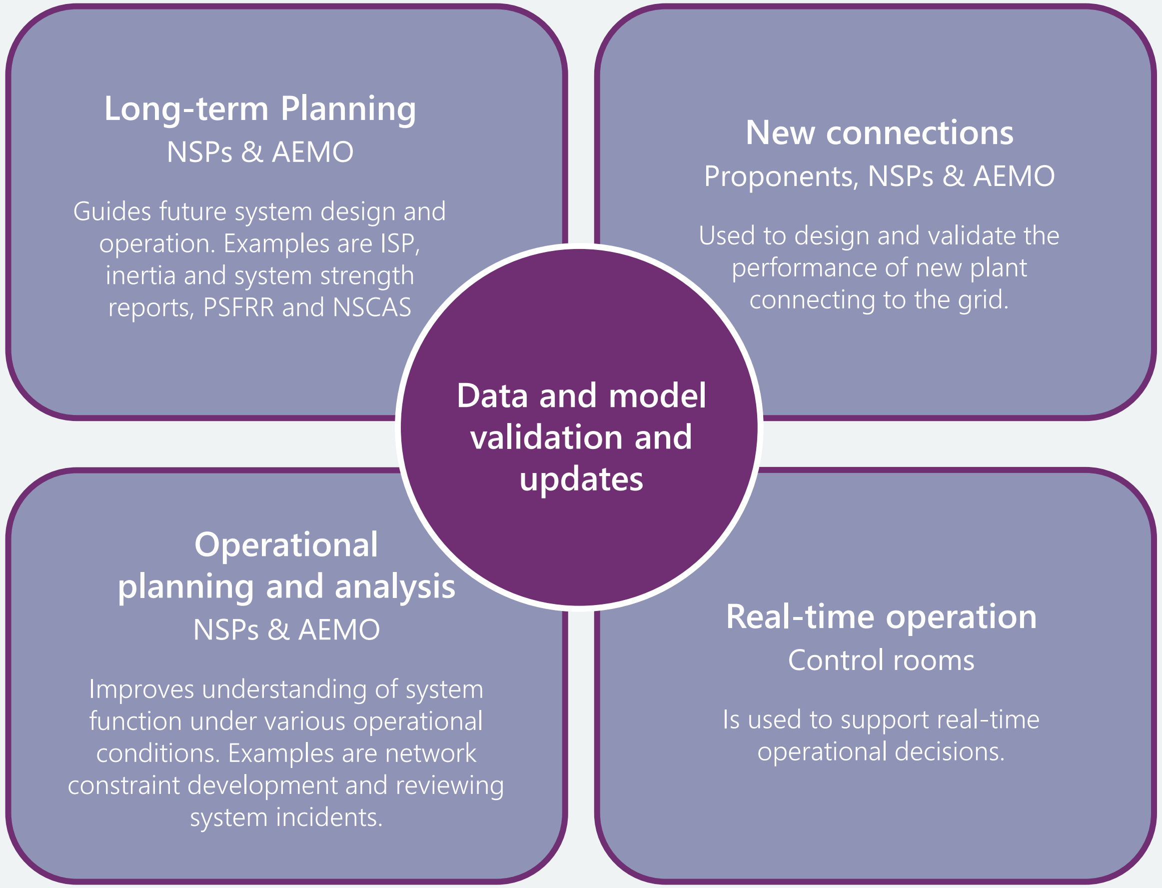
Power system analysis involves complex interactions between many pieces.

One piece is **data**, which has to be collected and validated, stored and transformed for use. Another is **models**, which require a variety of **software** and **hardware** and need continuous testing.

Finally, there are limits on how these data and models can be used, with access rights and restrictions on intellectual property.

Some of the key users of power system and analysis, and some examples of how power system analysis is utilised by the different users, are shown in Figure 12.

Figure 12: Key groups that utilise system analysis



Key changes

Modelling requirements – system behaviour is becoming more complex and the number of modelling elements is increasing with the addition of new, primarily inverter-based, generation, as outlined in the System operation section of the RIS[61] (page 25). This increases the complexity of analyses and simulations.

Data inputs – greater volumes of data inputs and modelling elements are increasing the burden of data management.

Participant access – detailed EMT models have become the standard for assessing new generator connections. These models cannot be easily shared with participants due to confidentiality restrictions, making it challenging to connect new generators.

These changes are occurring over a period of rapid technological development. Improvements to computing hardware and software have significantly increased modelling capabilities. Fibre optic cables to enable high speed data transfer and monitoring have allowed operators to see further into the network at higher resolution.

Work in progress

Fit-for-purpose data and models

Validation helps ensure data and models are broad enough, accurate enough, and are in the correct format for effective power system analysis. The Dynamic Model Acceptance Test Guideline[36] defines the process AEMO uses to assess participant models. This is supported by the requirements outlined in the Power System Model Guidelines[56] and Section 7.2 of the Power System Frequency Risk Review[55], helping improve the robustness and consistency of modelling inputs.

Focus areas for model uplift are being identified and developed, improving AEMO's understanding of the rapidly changing power system. There are multiple initiatives to improve DER modelling capabilities[33], such as new measurements of the response of induction motors under fault and low voltage conditions, and the composition of commercial loads. Improved modelling of behind-the-meter systems during power system disturbances helps better inform the requirements for future operation.

AEMO is working with NSPs in the NEMOC[49] Power System Modelling Reference Group to improve the quality of modelling data used by industry.

As discussed in the Frequency Management focus area, AEMO is progressing improvements to our existing modelling capabilities in the area of frequency control.

In addition to offline system modelling improvements, there are ongoing improvements to online modelling capabilities. An example is the Real-time Simulator[25], which is currently in proof of concept phase. The real-time simulator will reduce modelling time while maintaining a high level of detail, allowing for scenario analysis as events impact the system in real time. This acts as a final defence mechanism to enable secure operation in a rapidly changing system.

As discussed in the Control Room and Support focus area, AEMO is upgrading to the Wide Area Monitoring System, which will use data from high-speed time-synchronised monitoring devices. This improved data will enhance situational awareness and improve decision-making in real time.

Participant model access

AEMO has worked with industry to develop an interim approach that allows proponents to commission studies with the wide-area PSCAD model while maintaining model confidentiality. Proponents can provide a scope of work to AEMO for the studies they want performed, and AEMO will engage a consultant on the proponent's behalf who will perform the studies and provide the proponent with the relevant plots at their proposed point of connection.

AEMO is continuing to explore options to provide enduring fit-for-purpose model access to participants.

Integration

- Resilience
- Performance Standards
- Distributed Energy Resources

Integration | Resilience

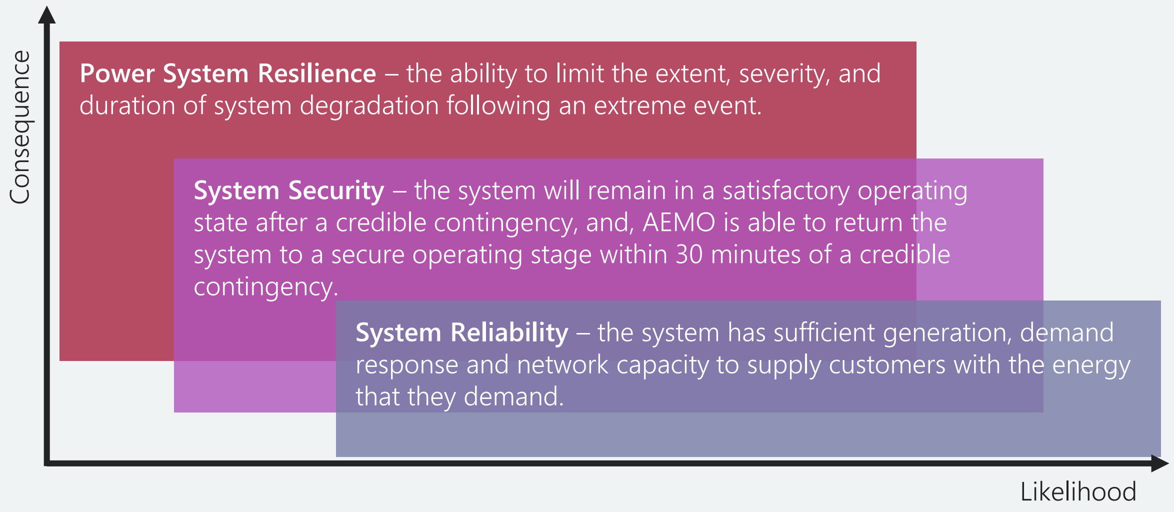
Power system resilience is the ability to limit the extent, severity, and duration of system degradation following an extreme event. Examples include coping with multiple generator or network plant failures and during high-impact weather events.

Resilience is not yet defined in the NER. However, Figure 13 provides a definition using the CIGRE Working Group C4.47's definition[86]. The figure shows that resilience is distinct from both security and reliability, although there is overlap in how a hazard is considered across all three concepts.

Power systems provide an essential service that acts as an enabling function[102] across almost all sectors of our lives. There is increasing evidence that high impact, low probability events are more common than expected and have wider social costs than previously accounted for (see IEEE Blackout Experiences[101] and Deloitte SRAS assessment[88]).

Achieving resilience involves a sequence of decisions occurring over many years as part of the integrated system design process up to actions that can be taken when operating the system.

Figure 13: Conceptual relationships between definitions relative to impact magnitude



The importance of resilience, and interactions between sectors, has been recognised in other international jurisdictions, such as the European Union with the release of the EU strategy on energy system integration[99].

The strategy calls for 'whole of system' coordination and planning, from energy to end use sectors, such as building, transport, and industry.

Key changes

Appendix 8 of the 2020 ISP[21] explored changes that are affecting power system resilience. Some of these include:

Power system transition – the rapid transformation of the power system continues to test the boundaries of the technical operating envelope. Synchronous plant is retiring and being replaced by IBR, which have different physical characteristics and are connected in different locations.

Climate change – heightened climate impacts, particularly extreme weather, affect plant performance and electricity demand and increase operational uncertainty.

System control services – special protection schemes and remedial action schemes are increasingly used to defer investments in physical assets. As reliance on these increases, the risk of maloperation or unexpected operation increases, reducing system resilience.

Cyber security – the increasing reliance on information and communications technology is rendering critical systems and infrastructure more at risk from cyber incursions.

Societal integration – Australia's electricity system is becoming increasingly 'coupled' with other sectors, including building and transport. This means the potential for hazards to propagate between sectors is increasing.

Quantitative cost benefit analysis – the use of quantitative cost benefit analysis has become central to the justification of all regulated investments and market structures. Limitations in climate, energy, and economic modelling mean that quantification of acute hazards is difficult.

Integration | Resilience

Work in progress

Operational resilience

AEMO makes operational plans for the most challenging periods of the year, to put in place appropriate tools, capabilities and regulatory backing to manage foreseen (and unforeseen) risks to the system. One example is the Summer Readiness Plan[63], which focuses on power system risks over summer, such as peak demand and bushfires. Past performance is reviewed and lessons learnt are incorporated into the operational processes.

The existing protected events framework[7] considers high impact, low probability events. AEMO is developing a submission to the Reliability Panel where the separation of South Australia is considered a protected event when UFLS may be inadequate.

The AEMC is currently considering the enhancing operational resilience[6] rule change. This change proposes to give AEMO formalised ability to change the operational profile of the system to manage "indistinct" risks, such as large storm systems, using an enhanced protected events and operations framework.

Planning for resilience

The investigations done by TNSPs and AEMO under the Power System Frequency Risk Review[55], explained under frequency management, are critical in planning for a resilient system, because extreme events are not always credible.

There is a rule change under consideration by the AEMC to adapt the Power System Frequency Risk Review to become the General Power System Risk Review[11], which is expected to consider whole-of-power-system risks rather than just frequency.

NSPs have been focused on the resilience of their infrastructure to extreme weather, with programs assessed on a cost-risk basis in the network regulation process. Energy Networks Australia (ENA) has also explored the potential for stand-alone power systems[93] to enhance network resilience.

The AER's recent Value of Customer Reliability[75] review consulted on how the consequences of wide spread and prolonged outages could be better estimated for resilience planning, and the AER is currently exploring opportunities for research partnerships to progress this work.

AEMO's ESOO[39] is also increasingly considering aspects that impact system resilience. In 2020 it studied the impact of ageing thermal assets, declining minimum demand, and climate risk through consideration of high impact and low probability weather events. It also highlighted that, without additional investment, there may be resilience and reliability issues in New South Wales if similar conditions to those experienced during the bushfire activity of 4 January 2020 were to occur after the retirement of Liddell Power Station.

The ISP[20] provides a least-regret, dynamic and transparent roadmap for the NEM through Australia's energy transition. The 2020 ISP addressed the changes to resilience by:

- Weighing the benefit of additional redundancy through transmission network investments against the costs.
- Establishing a dedicated section[21] to analyse resilience, including considering the impact of climate change and the characteristics of a resilient power system.

Future ISPs will include more comprehensive climate change impacts analysis, using learnings from the Electricity Sector Climate Information project[38].

Integration | Performance standards

Collaboration across industry will be critical for the development of fit for purpose performance standards to meet the evolving needs of an increasingly complex power system.

AEMO's Power System Requirements[57] paper outlines the role of technical performance standards in enabling the predictable operation of a large-scale power system like the NEM.

Performance standards allow different technologies, systems and parties to interact in a way that supports secure and reliable power system operation.

Figure 14 shows both the physical and information, communication and technology (ICT) systems enabling power system operation, their components and functions, and the different instruments where technical performance standards across these large inter-dependent systems are defined. Each instrument has a specific context and purpose, commensurate with the scale and sophistication of the application. Importantly, requirements may not always be designed solely with power system outcomes in mind.

Technical performance standards are critical for specifying:

- How physical components interface with the power system, perform under different conditions and the services they can provide.
- How communication necessary for system operation takes place, including measurement, sensing and control actions.
- The data and information required to be exchanged between parties for participation, system operation and planning over different timescales.

Integrating new technologies and forms of participation requires broad engagement and collaboration across industry. Adoption of new standards will require implementation guidance and ongoing evaluation to ensure that they remain fit for purpose.

Key changes

New forms of participation – technology shifts will continue to result in new devices, innovation in services and novel interactions with the power system. Forward-thinking performance standards can help optimally integrate emerging technologies as uptake increases over time.

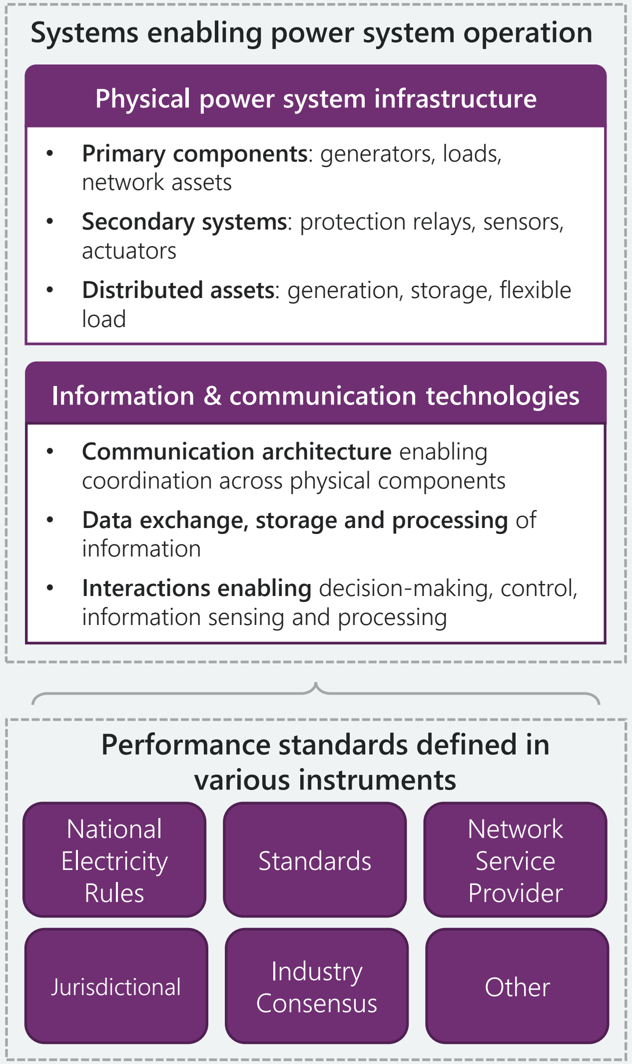
Increasing number of actors – interoperability will be increasingly important for integrating devices and systems developed and operated by many different parties, allowing for easier coordination between new and existing products, services and processes.

Climate change – resilience to extreme weather will increasingly impact plant performance and system operation. Technical requirements for physical infrastructure can be specified to promote resilient power system outcomes by design.

Operational complexity – digitalisation is contributing to increasingly complex data, information exchange and control interactions in the power system, across a range of different technology pathways, operating protocols, and actors.

Volume of data exchange – the volume and frequency of data exchange is increasing. This will require scalable and secure exchange architecture and protocols to support increasing sensing and monitoring data at higher resolutions and computationally intensive processing and applications.

Figure 14 Understanding performance standards



Integration | Performance standards

Work in progress

Much of the current work on performance standards across industry relates to emerging technologies. Several of the areas discussed below are related to DER integration. For a full discussion on DER integration stages and the work in progress related to DER, see the DER focus area.

Generation and storage

AEMO will soon review performance standards for centralised generation larger than 30 megawatts (MW) in size, as per the NER (updated in 2018[9]). This review will consider power system security, evolving power system conditions, and changes in technology and the capability of equipment.

AEMO is collaborating with industry on the transition to the updated standard for small-scale inverters (AS/NZS4777.2). This standard was revised in December 2020[107] to strengthen disturbance withstand and grid integration capabilities, and subsequently incorporated within the AEMC's minimum technical standards for DER[19].

AEMO is also currently engaging with DNSPs to better understand technical requirements for larger, commercial DER systems.

The ENA continues to work with DNSPs to promote national consistency in DER connection requirements[94]. It also maintains a consolidated list of DNSP DER inverter power quality response mode settings[95] intended for installers.

Demand response

Capabilities enabling residential demand response are currently being evaluated in the ongoing review of the AS4755 standard[26]. This standard sets out minimum requirements for the remote coordination of household appliances, storage and EV supply equipment.

AEMO is currently working on the implementation of a WDR[71] mechanism for the aggregated participation of large market loads in the NEM. Key activities include:

- A high-level design[70] outlining how AEMO will operationalise the mechanism.
- Consultation on new and amended guidelines and procedures, and changes to market systems across dispatch, settlement, portfolio management and baselining.

Elements of the WDR design will be transitory, and are anticipated to evolve over time. Promoting a flexible design will support the development of new participation pathways through technology, innovation, and new business models.

Electric Vehicles

Taskforces[34] under the DEIP Vehicle Grid Integration workstream[80] are considering how the growing uptake of EVs can be best integrated into the electricity system, including: data requirements, grid integration and interoperability standards for EVs and charging equipment.

Operational data communication

AEMO's Power System Data Communication Standard[54] sets out the standards parties must adhere to when transmitting operational data to and from AEMO for market and power system operation.

Integration | Performance standards

Prompted by the WDR implementation and other emerging challenges, AEMO is currently considering possible areas for review in the standard, including:

- How operational data for aggregations is exchanged, including potential application of internet-based data streaming protocols.
- Stronger security obligations across physical, personnel, cyber, and supply chain risks.
- Substation SCADA architectural design requirements and data link redundancy.
- Operational visibility of larger, commercial scale DER systems (>200 kilowatts (kW)).
- Requirements for latency, data accuracy and repair times in case of equipment failure.
- Reliability and latency requirements for high-speed monitoring data.

DER interoperability and aggregation

DER interoperability and system integration is being explored in industry trials, with collaboration through the DEIP Standards, Data and Interoperability Working Group[30] to identify and progress priorities.

As highlighted in the DER focus area, several trials are exploring technical requirements for DER aggregation and coordinated management. AEMO's MASS review[47] is also considering technical requirements for aggregated participation in FCAS markets.

Control schemes

AEMO, in collaboration with NSPs, periodically reviews the adequacy of emergency frequency control schemes in the NEM through the Power System Frequency Risk Review[55].

Cyber security

In 2018, AEMO, in collaboration with industry and government stakeholders, established the Australian Energy Sector Cyber Security Framework[27]. The framework assists energy sector organisations to assess, evaluate, prioritise, and improve their cyber security capability.

Additionally, the Commonwealth Department of Home Affairs is currently reviewing the *Security of Critical Infrastructure Act* and will introduce a Positive Security Obligation[84] that requires in-scope entities to manage the security and resilience of their critical infrastructure assets.

Power system models

Connection applicants are required to submit technical models to NSPs and AEMO in accordance with modelling requirements[50] in the NER. This is required to accurately represent:

- The physical arrangement of the generating system and its connection to the network.
- The performance of the generating plant under all expected operational conditions.

Consumer uptake of DER is already rapidly redefining power system operation. DER integration is included as a stand-alone section as it presents a unique challenge relevant to all other focus areas in this framework.

Maximising the opportunities from DER uptake will empower consumer participation in a better optimised two-way power system. This will require a staged transition informed by extensive consumer engagement and collaboration across industry.

DER consists of generation, storage, and flexible demand behind the meter or within the distribution network. Due to consumer uptake of distributed PV (DPV) since 2010, Australia is at the forefront of DER penetration globally[45].

The 2020 ISP[20] projects continued decentralisation through:

1. Ongoing growth of DPV and adoption of other DER, including batteries, EVs and demand response.
2. Increasingly sophisticated DER coordination.

Innovation in products and services will allow:

- Consumers and businesses to actively manage their energy supply and usage (via third-party service providers or energy management systems).
- More granular, better tailored information to enable informed decision-making across the energy sector.

Harnessing this capability can empower consumers to better optimise for their own circumstances and better integrate DER, to enhance its flexibility within the broader power system, for the benefit of all end users.

DER integration stages

Historically, the demand side of the power system has mainly comprised passive devices, except where controlled load has been encouraged. These devices do not actively respond to system conditions, and are not visible to or controllable by network or system operators.

Figure 15 proposes a sequence of stages for industry to collaborate towards two broad objectives:

Empowering optimised consumer participation – consumers able to make informed energy choices aligned with system needs, requiring: appropriate incentives, technology enabling energy management, participation pathways allowing consumers to optimise, and new service provider roles and responsibilities.

Secure and reliable power system operation – system operability as DER becomes an increasingly large component of the supply mix and interactions become more complex, requiring: ongoing review of needs and opportunities, necessary DER device capability and operational processes, and coordination frameworks.

Figure 15: Sequence of stages for DER integration

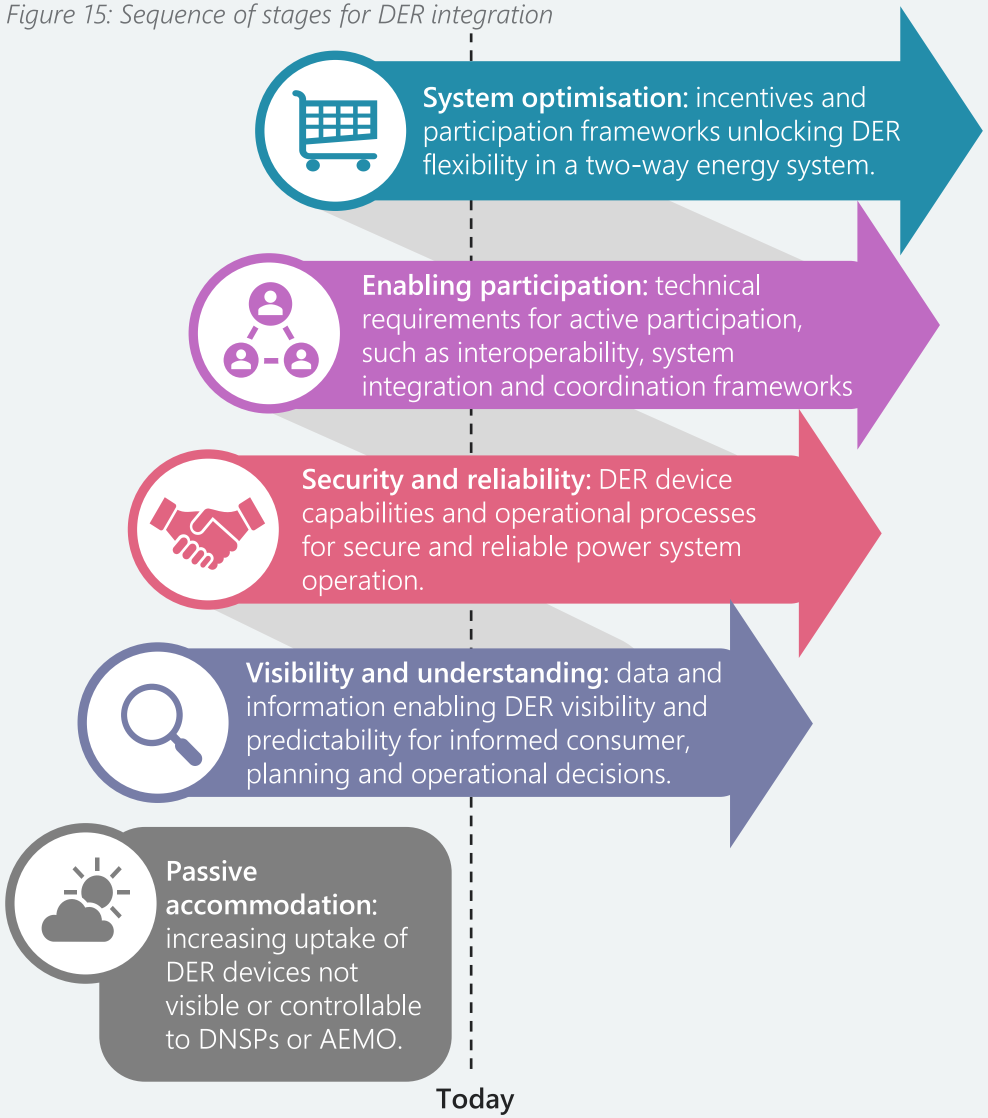


Figure 16: Timeline of key DER activities achieved in the NEM to date

2017
- **ENA** and **CSIRO's** Electricity Network Transformation Roadmap and the Finkel Review identify key no-regrets actions to integrate DER
- **AEMO** publishes Visibility of DER report outlining DER visibility needs.

Legend: Visibility; Secure/reliable; Participation; Optimisation; Roadmaps

2018
- **ENA/AEMO** launch Open Energy Networks. **ARENA** establishes DEIP and starts VPP trials
- **AEMO/ARENA/UNSW** collaborate to understand DER behaviour during power system disturbances

2019
- **AEMO** publishes Technical Integration of DER report as evidence base for improved standards and DER representation in power system models
- **AER's** DNSP DER Integration expenditure and **AEMC's** Economic regulatory framework focuses on DER
- **ESB** publishes DER Integration work program, and starts Post 2025 market design, which includes DER focus
- **ENA** develops National Connection Guidelines
- **AEMO** publishes international reviews on DER integration learnings and best practice

2020
- **AEMO**'s RIS, analysis for SA and ESOO identify urgent actions for system security
- **SA government**'s Smarter Homes accelerates DER requirements in SA
- Industry collaborates to develop DER Visibility and Monitoring Best Practice Guide
- **AEMO** launches DER register and reviews DSPI guidelines.
- AS/NZS4777.2:2020 published to support system security
- **WA** DER Roadmap, **ESB** DER Roadmap and **ENA** Smart Grid Roadmap released

Integration stages build on each other and should be considered in parallel, given the extent of inter-dependencies between them, their complexity, and the number of actors involved.

A two-sided, high DER power system will need to serve the diverse needs of millions of industrial, business and residential end users, and support devices and systems developed and operated by many different networks, retailers, aggregators, and other providers.

Work in progress

Figure 16 summarises several key DER integration milestones across industry since 2017, with colours indicative of the stages identified in Figure 15 (and see legend). This section provides a snapshot of relevant industry work underway or recently completed.

Visibility and understanding

Access to data is a key enabler for informed consumer decision-making and optimally integrating DER within the power system.

The ESB's Data Strategy[87] identifies consumer and DNSP data access as key data gaps for DER integration and proposes reforms across the energy sector to address these gaps, and build analytical capability, to support flexibility and adaptability to ongoing technology change. This aims to enable affordability, innovation and consumer protections.

The Consumer Data Right[28] reform seeks to offer energy consumers easier access to their usage data, so they can readily choose, compare or switch their energy retailer, and make more informed energy management and DER investment decisions.

Access to data on DER uptake and operation is also essential for system and network operators to plan for higher levels of DER into the future.

Standing data on small-scale DPV and storage installations is available to AEMO and the DNSPs through the DER Register[35], and some demand response resources are captured in the demand side participation information portal[31]. The DEIP EV Data Availability Taskforce has identified EV data needs for the energy sector[34], potential collection mechanisms, and delivery options.

Many DNSPs have programs underway to improve visibility of their low voltage assets to enable them to better understand the impact of growing DER uptake, and quantify network hosting capacity and implement management strategies. This includes dedicated network monitoring, access to smart meter data (currently being considered in the AEMC's regulatory framework for metering services[17]), and third-party monitoring data.

The DER Visibility and Monitoring Best Practice Guide[89] is a collaborative industry effort to standardise DER monitoring data between technology vendors and service providers, enhancing its usability for different purposes.

AEMO, through an ARENA-funded collaboration[83] with UNSW and Solar Analytics, has also been analysing monitored DPV system output data to better understand these systems' behaviour during disturbances. This has provided an evidence base for updates to standards and development of composite load models[33], better reflecting DER behaviour in power system studies. This is also discussed in the Frequency and System analysis focus areas.

Security and reliability

This stage is focused on establishing necessary DER device performance requirements and operational processes to support secure and reliable power system operation as uptake increases. This encompasses the increasing aggregate impact of passive DPV generation, growth and emergence of other DER types, as well as securely integrating increasingly complex management and coordination of DER.

As outlined in the Performance Standards focus area, AEMO's DER Standards workstream is collaborating with industry on fit-for-purpose technical standards for DER devices, reflective of their increasing aggregate impact on power system operation.

AEMO's ongoing DER Operations workstream[32] is focused on identifying and addressing these impacts. Work to date is summarised in the RIS[61], analysis for South Australia[48] and 2020 ESOO[39]. Analysis has identified a critical need for adequate last resort mechanisms to manage the power system securely during minimum system periods, when most underlying demand is supplied by DPV generation. AEMO is continuing to prepare for very low or negative minimum demands by spring 2021.

This has informed the introduction of new technical requirements for DER in South Australia, through the South Australian Government's Regulatory Changes for Smarter Homes[100]. The ESB is currently considering the development of national requirements and associated roles and responsibilities.

At the distribution level, the AER is reviewing how it assesses DNSP investment to manage increasing DER penetrations in its DER integration expenditure[72] consultation. The role of DNSPs in facilitating DER export is being explored in the AEMC's access, pricing and incentive arrangements for DER[1] rule change consultation.

Enabling participation

Interoperability between different devices and systems and coordination frameworks will be important for enabling active DER consumer participation through energy management systems, dynamic network connection arrangements, orthird-party aggregators.

Energy Consumers Australia (ECA) emphasises the importance of controlling parties obtaining a social licence for DER control[91] from system owners/lessees. This can result in consumers better understanding the benefits of control relative to their private costs, likely to increase participation in voluntary DER control programs and compliance for mandatory programs.

Interoperability between devices behind the meter (such as inverters, EVs, appliances, smart meters, and gateway devices) is critical for active participation, encouraging product innovation and consumer choice. This is discussed further in the Performance Standards focus area.

DNSPs are implementing both network and behind-the-meter strategies to enable more flexible system operation, adapting to the impact of DER on network flows. DNSP and industry trials (e.g. SA Power Networks[106], Energy Queensland[96] and Zepben's Evolve[81] project) are investigating dynamic limits on DER exports, to only apply when the distribution network is constrained.

The ENA's smart grid roadmap[92] maps out a trajectory of actions necessary for DNSPs to transition from the application of static DER export limits to dynamic limits. The DEIP Dynamic Operating Envelopes Workstream[79] is considering technical requirements for their implementation, drawing on learnings from different trials and identifying necessary reforms.

The AEMC is currently reviewing the regulatory framework for metering services[17], including the smart meter deployment as an enabler for active consumer participation. By providing more granular usage information, smart meters can facilitate better tailored price signals and innovation in energy services through integration with smart appliances and DER devices.

The AER is also currently reviewing ring-fencing arrangements for DNSPs[73] to better reflect their role enabling stand-alone power systems, microgrid supply arrangements and grid-scale storage (e.g. 'community battery' initiatives).

System optimisation

Incentives and frameworks empowering consumer participation are necessary to harness DER flexibility in a two-way energy system. Key pillars for this include pathways for service provision and participation in competitive markets, pricing and other incentives (e.g. government subsidy programs) aligned with system needs, empowering distribution networks to act as a platform for system flexibility.

Availability of devices able to respond autonomously to remote instructions and price signals will allow consumers and businesses to participate in different energy management services, respond to wholesale market signals and take advantage of time of use pricing enabled by tariffs and smart meters.

VPP trials (e.g. AEMO's VPP Demonstrations[69], AGL[77], Simply Energy[82] and SA Power Networks[105]) are exploring how aggregated DER can deliver energy and ancillary services. Initiatives exploring coordinated DER market participation, while managing distribution network constraints include Project EDGE[59] and the ANU's CONSORT[78] trial.

The ESB's Post 2025 market design[97] project is examining opportunities for DER to provide system services via a Maturity Plan to support the transition and evaluate roles and responsibilities for an effective two sided market. Initiatives being considered to activate the demand side of the market, such as the WDR mechanism[71] and a two-sided market, would enable end users with installed DER and responsive load to actively participate and trade in energy and ancillary services.

Acronyms

Acronym	Name in full
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
ARENA	Australian Renewable Energy Agency
DEIP	Distributed Energy Integration Program
DER	Distributed Energy Resources
DNSP	Distribution Network Service Provider
DPV	Distributed Photovoltaic
ECA	Energy Consumers Australia
EJPC	Executive Joint Planning Committee
EMT	Electromagnetic Transient
ENA	Energy Networks Australia
ESB	Energy Security Board
ESOO	Electricity Statement of Opportunities
EV	Electric Vehicle

Acronym	Name in full
FCAS	Frequency Control Ancillary Services
FFR	Fast Frequency Response
HVDC	High Voltage Direct Current
IBR	Inverter-based Resources
ICT	Information, Communication and Technology
ISP	Integrated System Plan
kW	Kilowatt
MASS	Market Ancillary Service Specification
MW	Megawatt
MWs	Megawatt seconds
NEM	National Electricity Market
NEMOC	NEM Operations Committee
NER	National Electricity Rules
NSCAS	Network Support and Control Ancillary Services
NSP	Network Service Provider

Acronym	Name in full
PASA	Projected Assessment of System Adequacy
PFR	Primary Frequency Response
PSCAD	Power System Computer Aided Design
PSFRR	Power System Frequency Risk Review
PV	Photovoltaic
REZ	Renewable Energy Zone
RIS	Renewable Integration Study
RoCoF	Rate of Change of Frequency
SRAS	System Restart Ancillary Services
ST PASA	Short Term Projected Assessment of System Adequacy
TNSP	Transmission Network Service Provider
UFLS	Under Frequency Load Shedding
VPP	Virtual Power Plant
VRE	Variable Renewable Energy
WDR	Wholesale Demand Response

Index of links

1. AEMC, Access, pricing and incentive arrangements for distributed energy resources, September 2020, available at https://www.aemc.gov.au/rule-changes/access-pricing-and-incentive-arrangements-distributed-energy-resources
2. AEMC, Capacity commitment mechanism for system security and reliability services, available at https://www.aemc.gov.au/rule-changes/capacity-commitment-mechanism-system-security-and-reliability-services
3. AEMC, Consultation begins on new ways to deliver system services as the power system evolves, July 2020,available at https://www.aemc.gov.au/news-centre/media-releases/consultation-begins-new-ways-deliver-system-services-power-system
4. AEMC, Directions paper published on new arrangements for frequency control, December 2020, available at https://www.aemc.gov.au/news-centre/media-releases/directions-paper-published-new-arrangements-frequency-control
5. AEMC, Efficient management of system strength on the power system, August 2020, available at https://www.aemc.gov.au/rule-changes/efficient-management-system-strength-power-system
6. AEMC, Enhancing operational resilience in relation to indistinct events, February 2021, available at https://www.aemc.gov.au/rule-changes/enhancing-operational-resilience-relation-indistinct-events#:~ :text=The%20proposed%20rule%20change%20aims,for%20and%20manage%20indistinct%20events.
7. AEMC, Emergency frequency control schemes, March 2017, available at https://www.aemc.gov.au/rule-changes/emergency-frequency-control-schemes-for-excess-gen
8. AEMC, Fast frequency response market ancillary service, February 20201, available at https://www.aemc.gov.au/rule-changes/fast-frequency-response-market-ancillary-service
9. AEMC, generator technical performance standards,, October 2018, available at https://www.aemc.gov.au/rule-changes/generator-technical-performance-standards
10. AEMC, Have your say on a new reserve service for the evolving power system, January 2021, available at https://www.aemc.gov.au/news-centre/media-releases/have-your-say-new-reserve-service-evolving-power-system
11. AEMC, Implementing a general power system risk review, February 2021, available at https://www.aemc.gov.au/rule-changes/implementing-general-power-system-risk-review
12. AEMC, Introduction of ramping services, February 2021, available at https://www.aemc.gov.au/rule-changes/introduction-ramping-services
13. AEMC, Investigation into system strength frameworks in the NEM, 2020, available at https://www.aemc.gov.au/market-reviews-advice/investigation-system-strength-frameworks-nem
14. AEMC, Mandatory primary frequency response, March 2020, available at https://www.aemc.gov.au/rule-changes/mandatory-primary-frequency-response
15. AEMC, Operating reserve market, February 2021, available at https://www.aemc.gov.au/rule-changes/operating-reserve-market
16. AEMC, Primary frequency response incentive arrangements, February 2021, available at https://www.aemc.gov.au/rule-changes/primary-frequency-response-incentive-arrangements
17. AEMC, Review of the regulatory framework for metering services, February 2021, available at https://www.aemc.gov.au/market-reviews-advice/review-regulatory-framework-metering-services
18. AEMC, Synchronous services markets, available at https://www.aemc.gov.au/rule-changes/synchronous-services-markets
19. AEMC, Technical standards for distributed energy resources, February 2021, available at https://www.aemc.gov.au/rule-changes/technical-standards-distributed-energy-resources
20. AEMO, 2020 Integrated System Plan (ISP), available at https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2020-integrated-system-plan-isp
21. AEMO, 2020 ISP: Appendix 8 Resilience and climate change, July 2020, available at https://aemo.com.au/-/media/files/major-publications/isp/2020/appendix--8.pdf?la=en
22. AEMO, 2020 Network support and control ancillary services report, December 2020, available at https://www.aemo.com.au/-/media/files/electricity/ nem/planning and forecasting/Operability/2020/2020-NSCAS-Report
23. AEMO, 2020 System Strength and Inertia Report, December 2020, available at https://www.aemo.com.au/-/media/files/electricity/nem/planning and forecasting/Operability/2020/2020-System-Strength-and-Inertia-Report
24. AEMO, AEMO Invitation to tender for SRAS 2021, February 2021, available at https://aemo.com.au/en/consultations/tenders/sras-procurement
25. AEMO, AEMO real time simulator project update, October 2020, available at https://aemo.com.au/en/newsroom/news-updates/aemo-real-time-simulator-project-update
26. AEMO, AS 4755 Demand response standard, available at https://aemo.com.au/initiatives/major-programs/nem-distributed-energy-resources-der-program/standards-and-connections/as-4755-demand-response-standard
27. AEMO, Australian Energy Sector Cyber Security Framework (AESCSF) framework and resources, available at https://aemo.com.au/en/initiatives/major-programs/cyber-security/aescsf-framework-and-resources
28. AEMO, Consumer data right, available at https://aemo.com.au/en/initiatives/major-programs/consumer-data-right-cdr
29. AEMO, Current Inputs, Assumptions and Scenarios, 2020, available at https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2022-integrated-system-plan-isp/current-inputs-assumptions-and-scenarios
30. AEMO, DEIP: Standards, data and interoperability working group, July 2020, available at https://aemo.com.au/en/consultations/industry-forums-and-working-groups/list-of-industry-forums-and-working-groups/deip-sdiwg
31. AEMO, demand side participation guidelines, March 2021, available at https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-approach/forecasting-and-planning-guidelines/demand-side-participation-information-guidelines
32. AEMO, DER operations, available at https://aemo.com.au/en/initiatives/major-programs/nem-distributed-energy-resources-der-program/operations
33. AEMO, DER operations: power system model development, available at https://aemo.com.au/en/initiatives/major-programs/nem-distributed-energy-resources-der-program/operations/power-system-model-development
34. AEMO, Distributed energy integration program electric vehicle taskforce, available at https://aemo.com.au/en/consultations/industry-forums-and-working-groups/list-of-industry-forums-and-working-groups/deip-ev-taskforce
35. AEMO, Distributed energy resources register, available at https://aemo.com.au/en/energy-systems/electricity/der-register
36. AEMO, Dynamic model acceptance test guideline, February 2021, available at https://aemo.com.au/-/media/files/electricity/nem/network connections/model-acceptance-test-guideline-feb-2021.pdf?la=en&hash=67E4FE628E31A055661BD2AC565EC9D1
37. AEMO, Electricity rule change proposal: Future system restart capability, July 2019, available at https://www.aemc.gov.au/sites/default/files/2019-08/ERC0278%20Rule%20change%20request%20pending.pdf
38. AEMO, Electricity sector climate information project, https://aemo.com.au/en/initiatives/strategic-partnerships/planning-initiatives
39. AEMO, Electricity Statement of Opportunities, 2020, available at https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-reliability/nem-electricity-statement-of-opportunities-esoo

Index of links

40. AEMO, Engineering Framework Information Pack, December 2020, available at https://aemo.com.au/-/media/files/initiatives/engineering-framework/engineering-framework-information-pack.pdf?la=en
41. AEMO, Five minute settlement and global settlement, available at https://aemo.com.au/en/initiatives/major-programs/nem-five-minute-settlement-program-and-global-settlement
42. AEMO, Frequency Control Work Plan, September 2020, available at https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/system-operations/ancillary-services/frequency-control-work-plan
43. AEMO, Frequency control workplan update, March 2021, available at https://aemo.com.au/-/media/files/electricity/nem/system-operations/ancillary-services/frequency-control-work-plan/frequency-control-work-plan-update-march-2021.pdf?la=en
44. AEMO, Heywood UFLS constraint, October 2020, available at https://aemo.com.au/-/media/files/initiatives/der/2020/heywood-ufls-constraints-factsheet.pdf?la=en&hash=066F80AE0EE3CF9701A0509818A239BB
45. AEMO, Maintaining power system security with high penetrations of wind and solar generation: International insights for Australia, October 2019, available at https://www.aemo.com.au/-/media/files/electricity/nem/security_and_reliability/future-energy-systems/2019/aemo-ris-international-review-oct-19.pdf?la=en
46. AEMO, Market modelling methodologies, July 2020, available at https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/inputs-assumptions-methodologies/2020/market-modelling-methodology-paper-jul-20.pdf?la=en
47. AEMO, Market Ancillary Service Specification consultation, 2021, available at https://aemo.com.au/en/consultations/current-and-closed-consultations/mass-consultation
48. AEMO, Minimum operational demand thresholds in South Australia, May 2020, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/SA_Advisory/2020/Minimum-Operational-Demand-Thresholds-in-South-Australia-Review
49. AEMO, NEM Operations Committee, available at https://aemo.com.au/en/consultations/industry-forums-and-working-groups/list-of-industry-forums-and-working-groups/national-electricity-market-operations-committee-nemoc
50. AEMO, Network connections: Modelling requirements, available at https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/participate-in-the-market/network-connections/modelling-requirements
51. AEMO, NSCAS procedures and guidelines, 2020, available at https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/system-operations/ancillary-services/network-support-and-control-ancillary-services-procedures-and-guidelines
52. AEMO, Participant forecasting, available at https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/operational-forecasting/solar-and-wind-energy-forecasting/participant-forecasting
53. AEMO, Planning for operability, 2020, available at https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/planning-for-operability
54. AEMO, Power system data communication standard, December 2017, available at Power System Data Communications Standard - FINAL (aemo.com.au)
55. AEMO, Power System Frequency Risk Review, available at https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/system-operations/power-system-frequency-risk-review
56. AEMO, Power system model guidelines, June 2018, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/Power_Systems_Model_Guidelines_PUBLISHED.pdf
57. AEMO, Power System Requirements Paper, July 2020, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Power-system-requirements.pdf
58. AEMO, Primary frequency response, available at https://aemo.com.au/en/initiatives/major-programs/primary-frequency-response
59. AEMO, Project Edge, November 2020, available at https://aemo.com.au/en/initiatives/major-programs/nem-distributed-energy-resources-der-program/der-demonstrations/project-edge
60. AEMO, Projected Assessment of System Adequacy, 2020, available at https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-reliability/projected-assessment-of-system-adequacy
61. AEMO, Renewable Integration Study, April 2020, available at https://aemo.com.au/energy-systems/major-publications/renewable-integration-study-ris
62. AEMO, ST PASA Replacement project, 2020, available at https://aemo.com.au/en/initiatives/trials-and-initiatives/st-pasa-replacement-project
63. AEMO, Summer operations 2020-21, November 2020, available at https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/system-operations/summer-operations
64. AEMO, System restart ancillary services guideline, available at https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/system-operations/ancillary-services/system-restart-ancillary-services-guideline
65. AEMO, System strength workshop, December 2020, available at https://aemo.com.au/en/learn/energy-explained/system-strength-workshop
66. AEMO, System Strength in the NEM explained, March 2020, available at https://www.aemo.com.au/-/media/files/electricity/nem/system-strength-explained.pdf?la=en#:~:text=System%20strength%20is%20a%20characteristic,disturbance%20on%20the%20power%20system.
67. AEMO, Transfer limit advice: South Australia and Victoria, March 2021, available at https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/congestion-information/transfer-limit-advice-system-strength.pdf?la=en
68. AEMO, Var dispatch, available at https://aemo.com.au/en/initiatives/trials-and-initiatives/var-dispatch-schedule-system-implementation
69. AEMO, Virtual power plant demonstrations, available at https://aemo.com.au/en/initiatives/major-programs/nem-distributed-energy-resources-der-program/der-demonstrations/virtual-power-plant-vpp-demonstrations
70. AEMO, Wholesale demand response mechanism high level design, March 2020, available at https://aemo.com.au/initiatives/submissions/wholesale-demand-response-mechanism-high-level-design
71. AEMO, Wholesale demand response mechanism, available at https://aemo.com.au/initiatives/trials-and-initiatives/wholesale-demand-response-mechanism
72. AER, Assessing distributed energy resources integration expenditure, November 2020, available at https://www.aer.gov.au/networks-pipelines/guidelines-schemes-models-reviews/assessing-distributed-energy-resources-integration-expenditure
73. AER, Electricity ring-fencing guideline review, November 2020, available at https://www.aer.gov.au/networks-pipelines/guidelines-schemes-models-reviews/electricity-ring-fencing-guideline-review/initiation#step-73434
74. AER, Retailer Reliability Obligation, available at https://www.aer.gov.au/retail-markets/retailer-reliability-obligation

75. AER, Values of customer reliability, September 2020, available at https://www.aer.gov.au/networks-pipelines/guidelines-schemes-models-reviews/values-of-customer-reliability

76. ARENA, Access and pricing workstream, November 2020, available at https://arena.gov.au/knowledge-innovation/distributed-energy-integration-program/access-and-pricing-workstream/

77. ARENA, AGL Virtual Power Plant, February 2021, available at https://arena.gov.au/projects/agl-virtual-power-plant/

78. ARENA, Consumer energy systems providing cost-effective grid support, February 2021, available at https://arena.gov.au/projects/consumer-energy-systems-providing-cost-effective-grid-support-consort/

79. ARENA, Dynamic operating envelopes workstream, March 2021, available at https://arena.gov.au/knowledge-innovation/distributed-energy-integration-program/dynamic-operating-envelopes-workstream/

80. ARENA, Electric vehicle grid integration workstream, February 2021, available at https://arena.gov.au/knowledge-innovation/distributed-energy-integration-program/ev-grid-integration-workstream/

81. ARENA, evolve DER Project, February 2021, available at https://arena.gov.au/projects/evolve-der-project/

82. ARENA, Simply Energy VPPx, February 2019, available at https://arena.gov.au/assets/2019/06/simply-energy-vppx.pdf

83. ARENA, UNSW addressing barriers to efficient renewable integration, January 2021, available at https://arena.gov.au/projects/addressing-barriers-efficient-renewable-integration/

84. Australian Government Department of Home Affairs, Positive Security Obligation, December 2020, available at https://www.homeaffairs.gov.au/about-us/our-portfolios/national-security/security-coordination/security-legislation-amendment-critical-infrastructure-bill-2020/positive-security-obligation

85. CIGRE, Power system restoration accounting for a rapidly changing power system and generation mix, January 2021, available at https://www.cigre.org/article/GB/power-system-restoration-accounting-for-a-rapidly-changing-power-system-and-generation-mix

86. CIGRE WG C4.47, Defining power system resilience, October 2019, available at https://e-cigre.org/publication/RP_306_1-defining-power-system-resilience

87. COAG, Energy Security Board Data Strategy – Submissions to consultation paper published, December 2020, available at http://www.coagenergycouncil.gov.au/publications/energy-security-board-data-strategy-submissions-consultation-paper-published

88. Deloitte Access Economics, Economic assessment of system restart ancillary services in the NEM, August 2016, available at https://www.aemc.gov.au/sites/default/files/content/6e6ad6c7-584c-4993-98f3-7589fec6b506/Deloitte-Access-Economics-Economic-Assessment-of-System-Restart-Ancill.pdf

89. DER Monitoring, DER visibility and monitoring best practise guide, available at https://www.dermonitoring.guide/

90. Energy Consumers Australia, Power Shift, available at https://energyconsumersaustralia.com.au/projects/power-shift

91. Energy Consumers Australia, Social licence for control of distributed energy resources: Final report, December 2020, available at https://energyconsumersaustralia.com.au/wp-content/uploads/Social-License-for-DER-Control.pdf

92. Energy Networks Australia, 2020 Energy insider, November 2020, available at https://www.energynetworks.com.au/news/energy-insider/2020-energy-insider/the-four-stages-to-a-truly-smart-grid/

93. Energy Networks Australia, Opportunities for stand-alone power systems to enhance network resilience, October 2020, available at https://www.energynetworks.com.au/resources/reports/2020-reports-and-publications/opportunities-for-saps-to-enhance-network-resilience/

94. Energy Networks Australia, National Connection Guidelines, available at https://www.energynetworks.com.au/projects/national-grid-connection-guidelines/

95. Energy Networks Australia, Power quality response mode settings, available at https://www.energynetworks.com.au/projects/national-grid-connection-guidelines/power-quality-response-mode-settings/

96. Energy Queensland, Enabling Dynamic Customer Connections for DER, December 2020, available at https://www.talkingenergy.com.au/64816/widgets/321357/documents/190166

97. Energy Security Board, Post 2025 Electricity Market Design, available at https://esb-post2025-market-design.aemc.gov.au/

98. Energy Security Board, Post-2025 Market Design Directions paper, January 2021, available at https://esb-post2025-market-design.aemc.gov.au/32572/1609802925-p2025-january-directions-paper.pdf

99. European Commission, EU strategy on energy system integration, January 20921, available at https://ec.europa.eu/energy/topics/energy-system-integration/eu-strategy-energy-system-integration_en

100. Government of South Australia: Department for Energy and Mining, Regulatory changes for smarter homes, available at https://www.energymining.sa.gov.au/energy_and_technical_regulation/energy_resources_and_supply/regulatory_changes_for_smarter_homes

101. IEEE Power and Energy Society, Blackout experiences and lessons, best practices for system dynamic performance and the role of new technologies, August 2007, available at https://resourcecenter.ieee-pes.org/publications/technical-reports/PESTR12.html

102. IEEE power and energy society, Resilience framework, methods and metrics for the electricity sector, October 2020, available at https://www.naesco.org/data/industryreports/DOE-IEEE_Resilience%20Paper_10-30-2020%20for%20publication.pdf

103. Prime Minister, Address – National press club Barton ACT, February 2021, available at https://www.pm.gov.au/media/address-national-press-club-barton-act

104. Reliability Panel, System restart standard, January 2021, available at https://www.aemc.gov.au/sites/default/files/2021-01/SRS%20Review%20-%20System%20Restart%20Standard%20-%20FOR%20PUBLICATION_0.pdf

105. SA Power Networks, Advanced Virtual Power Plant Grid Integration Trial, available at https://www.sapowernetworks.com.au/future-energy/projects-and-trials/advanced-virtual-power-plant-grid-integration-trial/

106. SA Power Networks, LV Management Business Case, January 2019, available at https://www.talkingpower.com.au/43062/widgets/230765/documents/172028

107. Standards Australia, AS/NZS 4777.2:2020, 2020, available at https://www.standards.org.au/standards-catalogue/sa-snz/other/el-042/as-slash-nzs--4777-dot-2-colon-2020

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