AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

Power System Requirements

July 2020

Reference paper

Important notice

PURPOSE

AEMO prepared this document to provide information about the technical and operational requirements of the power system. It was updated in 2020 based on information available since its initial publication.

This update is based on information available at 26 June 2020. Information made available after this date may have been included in this publication where practical.

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VERSION CONTROL

Version	Release date	Changes
1.0	6/3/2018	Initial release
2.0	24//7/2020	Refresh of information in document to align with latest information, including: • Updates to references and links, including addition of reading list in Section 5. • Updates to content throughout to reflect current power system information, trends and active projects; in particular, updates to DER information, primary frequency response (S3.2.2), system strength (S3.3), and system restoration (S3.4). The grid formation section has now been incorporated in the System Restoration section (S3.4), with updated notes reflecting AEMO's latest thinking. • Additional information and links in Section 4 to include AEMO's more recent publications and thinking, including the Renewable Integration Study, Integrated System Plan, and DER Program. • References to "non-synchronous" changed to "inverter-based", and references to "rooftop PV" changed to "distributed PV".

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1. Introduction

Modern **power systems** are giant, multi-faceted machines. To operate the complex 'system of systems' in Australia's **National Electricity Market (NEM)**, AEMO oversees in aggregate millions of separate electricity **supply** and **demand** decisions in real time, all day, every day.

The NEM, like power systems worldwide, is being transformed from a system dominated by large thermal power stations, to a system including a multitude of power **generation** resources and technologies of various sizes[1,2]. At the same time, customers are engaging with their electricity supply in new ways.

The energy transformation involves a shift from:

- Firm to variable energy sources.
- **Synchronous** to **inverter-based resource (IBR)** generation.
- A centralised to a decentralised system.
- Passive to active **consumers**.

All bolded terms are defined in the glossary at the end of this paper for easy reference.

AEMO's challenge is to continually meet the needs of the power system, in the face of major structural changes and the resulting uncertainty across investment and operational timeframes.

While the power system is being transformed, the laws of physics that determine electrical flows do not change. To maintain a secure and reliable system, a range of interdependent technical and operational needs must be met at all times.

Physically, the NEM operates on one of the world's longest interconnected power systems, stretching from Port Douglas in Queensland to Port Lincoln in South Australia and across the Bass Strait to Tasmania – a distance of around 5,000 kilometres. By international standards, the NEM is unusually long and sparse, which affects power system dynamics.

Interactions in any power system are highly complex and dynamic. Operating a power system involves a continuum of decisions. AEMO needs to know what is happening in real time, and anticipate what is likely to happen in the coming seconds, minutes, hours, days, weeks, years, even decades.

This work culminates in the continuous matching of supply with demand and constant provision of essential **voltage** and **frequency** management services, ensuring sufficient reserves so the power system is robust enough to cope with unexpected events and stay within the power system operational design limits.

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[1] A short overview of the changes underway in the power system is in AEMO's Future Power System Security video at https://www.youtube.com/watch?v=Ffi_TWasa9A.

[2] An overview of the challenges associated with the changing power system, particularly over the next five years, is in AEMO's Renewable Integration Study 101 webinar at https://www.youtube.com/watch?v=34W46QjO3ls.

2. Operability

To achieve a secure and reliable power system, capable of supplying consumers with the electricity they demand with a very high degree of confidence, AEMO and network service providers (NSPs) must have access to a number of critical operational levers to manage the power system within its technical limits. 'Operational pre-requisites' are summarised in Table 1 and discussed in the remainder of this chapter.

Table 1 Operational pre-requisites for the power system

Attribute	Description
Dispatchability of the power system	Ability to manage dispatch and configure power system services to maintain system security and reliability. "Dispatch" refers to the process whereby AEMO issues set points to generators (and certain loads) to operate at a certain output.
Predictability of the power system	Ability to: • Measure or derive accurate data on energy demand, power system flows, and generation output across numerous time frames (real time, hours/days/weeks/years ahead) as key inputs into planning and operational decision-making. • Forecast upcoming power system conditions and have confidence in how the system will perform.

Using these operational levers, AEMO keeps the power system in balance using **security-constrained economic dispatch**.

Every five minutes, AEMO dispatches the market to meet demand and ancillary services using the 'least-cost' combination of generation (or demand response) available. To do this, AEMO's dispatch computer calculates an optimal solution to a security-constrained dispatch problem, which contains a large number of variables, parameters, limits, and constraints, including:

- Forecast demand – AEMO's estimate of the aggregate electricity to be consumed by all customers in each NEM region during the next 5-minute period.
- Forecast output from wind and solar generators, non-scheduled generation (generation that does not participate in the market), and distributed energy resources (DER, such as distributed photovoltaic [DPV] systems).
- The prices and quantities contained in the bids and offers submitted by generators and loads that participate in the market.
- Network flows – constraining generation where required to keep power flows within the technical limits of available network infrastructure (further details are in Section 3.1).
- Frequency – maintaining frequency in the NEM close to 50 hertz (Hz) (further details are in Section 3.2).
- Voltage – co-ordinating the voltage profile across the main transmission grid using resources from generators and network assets to maintain voltages within technical limits (further details are in Section Error! Reference source not found.).
- Equipment limits – ensuring equipment remains within its technical limits.

The optimal solution will be to dispatch the 'least-cost' combination of generation (and dispatchable load) to meet demand and ancillary services, based on bids and offers, while remaining within the security and reliability parameters.

2.1 Dispatchability

The balancing process hinges on the **dispatchability** of the overall portfolio of available energy resources and key characteristics of each technology.

The concept of the dispatchability of an energy resource can be considered as the extent to which its output can be relied on to 'follow a target'.

To ensure a resilient power system, however, operators need a deeper understanding of the characteristics of the portfolio, both in investment and operational timeframes. As well as understanding whether energy assets can adhere to a dispatch target, AEMO also needs to understand how controllable the assets it has at its disposal are, how much they can be relied upon, and how flexible they are. These dimensions of dispatchability are introduced below.

2.1.1 Controllability

The controllability of a resource relates to the resource's ability to reach a set point (output target) requested by an AEMO dispatch process, whether that be zero megawatts, the maximum available capacity of the unit, or something in between.

It can also apply to demand response and batteries, for instance, an industrial load that can be turned down or up to meet system requirements, or aggregated household resources such as pool pumps, refrigerators, and air conditioners. At a minimum, this capability might be limited to the ability to switch off if required to manage security or reliability.

Examples of fully controllable resources include thermal generators like coal or gas power stations that have control systems that interface directly with AEMO's dispatch systems.

Full control is not always practical or possible, and some assets, like wind farms, may be visible to AEMO's systems but not fully controlled by them. For example, wind farms tend to produce at their full output given the wind resources available, which means that unless already capped at below their full potential output, they can only be dispatched down.

Other assets, such as DER, are not typically configured for central control. DPV systems comprise the majority of the large and growing DER fleet in the NEM today. The majority of DPV systems simply feed surplus energy into the grid, irrespective of the needs of the power system at the time. However, innovation is occurring in the aggregation of individual DER units to offer capacity, energy, and ancillary services in a controlled manner to the market. Various technical trials (such as Virtual Power Plant [VPP] demonstrations[3]) and consideration of market participation pathways (including the wholesale demand response mechanism[4] and two-side markets[5]) are currently ongoing.

2.1.2 Firmness

System operators need to have some level of confidence that resources are available. The firmness of a resource relates to the resource's ability to confirm its energy availability.

For example, how long can the source provide a requested amount of energy once dispatched, and how far in advance can the energy be guaranteed by the source? This could be a probabilistic quantification for wind and solar. Firmness also relates to whether a resource is dependable or prone to technical failures.

Knowing how firm the portfolio of resources is allows the operator to efficiently and effectively orchestrate the balance of supply and demand in real time and to identify the need for new investment in the future.

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[3] For more information on VPP demonstrations, see https://aemo.com.au/initiatives/major-programs/nem-distributed-energy-resources-der-program/pilots-and-trials/virtual-power-plant-vpp-demonstrations.

[4] For more information on the wholesale demand response mechanism, see https://www.aemo.com.au/initiatives/trials-and-initiatives/wholesale-demand-response-mechanism.

[5] For more information on the Energy Security Board's Post 2025 work on two-sided markets, see http://www.coagenergycouncil.gov.au/publications/two-sided-markets

This level of confidence also provides a benchmark for system operators to calculate efficient levels of reserve capacity, that is, the additional headroom needed to protect the system from unexpected **contingency** events.

2.1.3 Flexibility

The ability of the system to respond to expected and unexpected changes in the supply-demand position (such as changes in variable renewable energy generation output, generation failures, and variations in demand) over all necessary timeframes, is another critical dimension of dispatchability.

The flexibility of a resource is the extent to which its output can be adjusted or committed in or out of service. This includes:

- The speed of response to start up and shut down.
- The rate of ramping.
- Whether it can operate in the full range of capability, or has restrictions (such as a minimum generation requirement, or a limitation on the amount of bulk energy that can be produced).

Flexible energy resources include demand response. This can be in the in the form of controllable and uncontrollable loads, varying electricity usage in response to market signals, both behind-the-meter resources and large industrial facilities directly connected to the transmission network, such as aluminium smelters.

Flexibility is relevant over a range of timeframes. In the short term (as close as five minutes), flexibility is required to manage variations in demand or the sudden drop-off of generation, such as a sudden reduction in wind or utility-scale PV resource output. A more gradual ramping period (2-3 hours) may be required as the contribution of DPV reduces as the sun sets and consumer demand increases towards the end of the day.

Further information on the need for system flexibility, key changes to sources of flexibility, and a regional analysis on flexibility needs over varying timescales is available in AEMO's Renewable Integration Study Stage 1 report, Appendix C[6].

While a power system has a strong supply of generally conventional generation technologies, this may sufficiently capture a system operator's needs.

However, like the NEM, power systems around the world are entering a transitional period where both the generation and demand side are becoming more variable, decentralised, and digitised.

In this context, system operators require a far more detailed understanding of what the portfolio is capable of at any given time.

2.2 Predictability

To be able to keep the power system continuously in balance, AEMO must be able to anticipate supply and demand, to have the right mix of resources available.

Historically, demand followed a predictable pattern, and supply was dispatched to meet demand. Both supply and demand are becoming increasingly influenced by variable factors (such as wind speed and cloud cover)[7]. As variable renewable energy generation becomes more prevalent, the power system needs to be able to manage the unpredictability associated with the weather[8].

Consumers are more actively managing their energy supply and consumption, including by installing DPV. These DPV systems are installed behind the meter and their output and behaviour also impacts the

[6] AEMO. Renewable Integration Study Stage 1 report, Appendix C. April 2020, available at https://www.aemo.com.au/-/media/files/major-publications/ris/2020/ris-stage-1-appendix-c.pdf?la=en.

[7] DPV manifests within the power system as negative demand because it is located behind the customer's meter.

[8] The Renewable Integration Study Stage 1, Appendix C on Variability and Uncertainty details the challenges of managing the power system with increasing levels of variability and uncertainty. See https://aemo.com.au/-/media/files/major-publications/ris/2020/ris-stage-1-appendix-c.pdf?la=en.

predictability of demand to the bulk system operator. While these devices are individually small, at the aggregate scale seen today (over 9 gigawatts [GW] of installed DPV capacity in the NEM) their contribution is becoming significant.

2.2.1 Visibility

The visibility of a resource relates to how accessible information on plant characteristics, output and conditions are to the system operator.

AEMO continuously determines and revises the limitations on the system, taking into account information on the prevailing and projected power system and plant conditions, and predicting the impacts of reasonably foreseeable events.

To be able to anticipate changes and maintain the supply-demand balance, system operators require visibility[9] of system and plant conditions and understanding of how they may change.

This information needs to be both comprehensive and made available in a timeframe that allows for an optimised response. Examples of information received include real-time information regarding electrical demand, the output level of generating systems, energy conversion model data for wind and solar forecasting, availability of demand response, state of charge for batteries, system voltages and system frequency, and power flows on major network elements.

Unlike transmission-connected generation sources (such as large-scale wind or solar, gas, hydro, or coal), the millions of DPV systems in the NEM power system are required to submit static data upon installation to the DER Register. The DER Register, implemented in March 2020, provides improved information to AEMO and the industry on the static characteristics of DER devices and is a first step towards increasing system visibility over DER[10].

With increasing levels of localised, individual generation coming into the power system, the continued safe, secure, and reliable supply of electricity to consumers becomes more dependent on increased visibility of these DER components to AEMO. More details about the need for visibility of the power system, and the techniques AEMO currently uses to operate and control the power system, can be found in AEMO's Renewable Integration Study Stage 1 report[11], and Visibility of Distributed Energy Resources[12].

2.2.2 System performance

Performance standards specify agreed minimum levels of technical performance and capability for network elements, generators, or devices. Performance standards that are comprehensive and well defined, and promote behaviour that supports the secure operation of the power system, are important in being able to effectively model power system dynamics under a range of system conditions (see Section 2.2.3 on modelling).

For system performance, the principles and guidelines for achieving and maintaining power system security are defined in the National Electricity Rules (NER) Chapter 4.

For generating systems that are registered in the NEM[13], performance standards are governed under the NER Chapter 5 and agreed between the connecting generator, NSP, and AEMO.

For low-voltage, distribution-connected generation, the AS/NZS4777.2 standard for inverter-connected energy systems defines the minimum performance and capability requirements that apply to DER. This Standard is currently (at June 2020) being reviewed to better align the defined performance with those of transmission connected generation and to ensure that the behaviour of these devices supports the reliable

[9] Visibility is sometimes referred to as observability.

[10] For more information on the DER register, see https://aemo.com.au/en/energy-systems/electricity/der-register.

[11] AEMO. Renewable Integration Study Stage 1, April 2020, available at https://aemo.com.au/-/media/files/major-publications/ris/2020/renewable-integration-study-stage-1.pdf?la=en&hash=BEF358122FD1FAD93C9511F1DD8A15F2.

[12] AEMO. Visibility of Distributed Energy Resources, January 2017, available at https://www.aemo.com.au/-/media/files/electricity/nem/security_and_reliability/reports/2016/aemo-fpss-program----visibility-of-der.pdf?la=en&hash=251EB64B76EAF1DC09658D6107F229B1.

[13] These are typically generating systems that are greater than 5 MW, that are not exempt from registering in the NEM.

and secure operation of the grid. This includes specifying minimum disturbance ride-through capabilities that align with power system needs, improving responses to autonomously maintain the grid within technical limits, and providing minimum system measurement and control to provide certainty of the inverter response.

Improved performance and capability of DER inverters will become critical for system security as distribution-connected generation systems begin to dominate certain operational periods. More information on the need to align performance standards of small-scale devices can be found in AEMO's Technical Integration of DER report[14] and the AS/NZS 4777.2 page of the AEMO website[15].

2.2.3 Power system modelling

A power system model is a set of mathematical equations, typically a combination of algebraic and differential equations, which can be used to emulate the response, over time, of a real physical system. Power system operators require adequate models and tools to simulate system performance under future conditions, to have confidence in how the overall system will perform.

To model power system behaviour on an ongoing basis, AEMO needs up-to-date information about the behaviour of plant connected to the power system. These models are critical inputs, used to assess technical performance standards, to determine power system operational limits[16], including inertia and system strength requirements, as well as to assess the connection requirements for future generators. Examples of information used by AEMO in power system modelling are:

- **Transmission network** – this may include information on network elements, such as transmission lines, transformers, or other equipment used to transport electricity.
- **Generation –** AEMO requires modelling information to represent the physical arrangement of the generating system and its connection to the network. Models and information must be provided to AEMO under a range of circumstances which are defined in AEMO's Power System Model Guidelines[17].
- **DER** – DER behaviour during system **disturbances** in the NEM has been well documented by AEMO over recent years, including in AEMO's Technical Integration of DER Report[18], Renewable Integration Study Stage 1 Appendix A Report[19] and power system incident reports[20]. There is evidence that a significant proportion of DER can disconnect or cease operation during power system disturbances. Analysis from these disturbance events has been used to incorporate DER behaviour into AEMO's power system models. Based on this analysis and modelling, further work is being completed to refine DER response to disturbances to support beneficial power system outcomes via updates to the AS/NZS4777.2 standards (see section 2.2.2 on Performance Standards above).
- **Load** – focus has also been directed to better understand the dynamic response of load to system disturbances and everyday voltage management. Effort is currently underway through AEMO's DER

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[14] AEMO. *Technical Integration of DER*, April 2019, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/DER/2019/Technical-Integration/Technical-Integration-of-DER-Report.pdf

[15] See https://aemo.com.au/initiatives/major-programs/nem-distributed-energy-resources-der-program/standards-and-connections/as-nzs-4777-2-inverter-requirements-standard.

[16] The development of limits advice, based in part on power system models, is used to ensure operation of the power system within a secure envelope. For further information on limit advice, see https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/system-operations/congestion-information-resource/limits-advice.

[17] See https://aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/Power_Systems_Model_Guidelines_PUBLISHED.pdf.

[18] AEMO. Technical Integration of DER, April 2019, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/DER/2019/Technical-Integration/Technical-Integration-of-DER-Report.pdf.

[19] AEMO, Renewable Integration Study Stage 1 Appendix A, April 2020, available at https://aemo.com.au/-/media/files/major-publications/ris/2020/ris-stage-1-appendix-a.pdf?la=en.

[20] Such as the Queensland and South Australia system separation on 25 August 2018, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Market_Notices_and_Events/Power_System_Incident_Reports/2018/Qld---SA-Separation-25-August-2018-Incident-Report.pdf.

Program[21] to improve understanding of load response to disturbances and their representation in power system modelling.

Improved accuracy and confidence in AEMO's simulation models allows the system to be run in a less conservative manner (for example, holding less frequency control reserves), leading to more efficient outcomes for consumers. Without knowledge of how DER and loads respond to faults, constraints and **interconnector** transfer limits may be too conservative (underutilising network capacity), or too optimistic (risking system security).

2.2.4 Forecasting

Power system operators require accurate forecasts of upcoming system conditions across operational and longer-term horizons, to be able to effectively maintain the supply-demand balance and therefore the system within its technical envelope.

Over longer-term horizons (10-20 years), AEMO conducts modelling and analysis to provide the market with information through the Energy Adequacy Assessment Projection (EAAP)[22], Electricity Statement of Opportunities (ESOO)[23] and Integrated System Plan (ISP)[24].

In operational timeframes, AEMO produces forecasts for wind and solar, through the Australian Wind Energy Forecasting System (AWEFS) and Australian Solar Energy Forecasting System (ASEFS)[25] and demand forecasts through the Demand Forecasting System (DFS) up to a week ahead.

The forecasting of wind and solar (including DPV) is more important than ever for the operation of the power system. The forecasting of wind and solar (including DPV) is more important than ever for the operation of the power system. These generation sources are increasingly influencing the resource availability forecast estimate across the NEM, and in turn affects the ability of the system to maintain the supply-demand balance.

Technological development and innovation have resulted in significant improvements in weather forecast accuracy, however the level of accuracy and precision achievable by best practice weather forecasts can still lead to significant challenges in predicting variable renewable energy (VRE) output and variability in the power system.

Increasing penetrations of variable renewable generation sources, and a rapid increase in DER installed behind the meter and demand response, mean AEMO must include uncertainty as a key element in forecasting methodologies so it can be managed in a least-cost way.

AEMO and other market participants, in particular wind and solar generators, are continually developing their operational forecasting capabilities. For example, advances in participants providing their own wind and solar dispatch forecasts has been ongoing since 2018[26].

Challenges in forecasting wind and solar resources in operational timeframes and actions to improve forecasting technologies to account for uncertainty are highlighted in AEMO's Renewable Integration Study Stage 1, Appendix C[27].

AEMO is working with market participants to pursue new and innovative approaches to forecasting demand and supply and system service levels.

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[21] For more information on AEMO's DER Program, see https://aemo.com.au/en/initiatives/major-programs/nem-distributed-energy-resources-der-program

[22] For information on AEMO's EAAP, see https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-reliability/energy-adequacy-assessment-projection-eaap.

[23] For information on AEMO's ESOO, see https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-reliability/nem-electricity-statement-of-opportunities-esoo.

[24] For information on AEMO's ISP, see https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp.

[25] For more information on AEMOs solar and wind energy forecasting systems, see https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/operational-forecasting/solar-and-wind-energy-forecasting.

[26] For information on the joint project between AEMO, ARENA and industry to provide participant dispatch forecasts since 2018, see https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/operational-forecasting/solar-and-wind-energy-forecasting/participant-forecasting.

[27] AEMO. Renewable Integration Study Stage 1, Technical Appendix C. April 2020, available at https://aemo.com.au/-/media/files/major-publications/ris/2020/ris-stage-1-appendix-c.pdf?la=en.

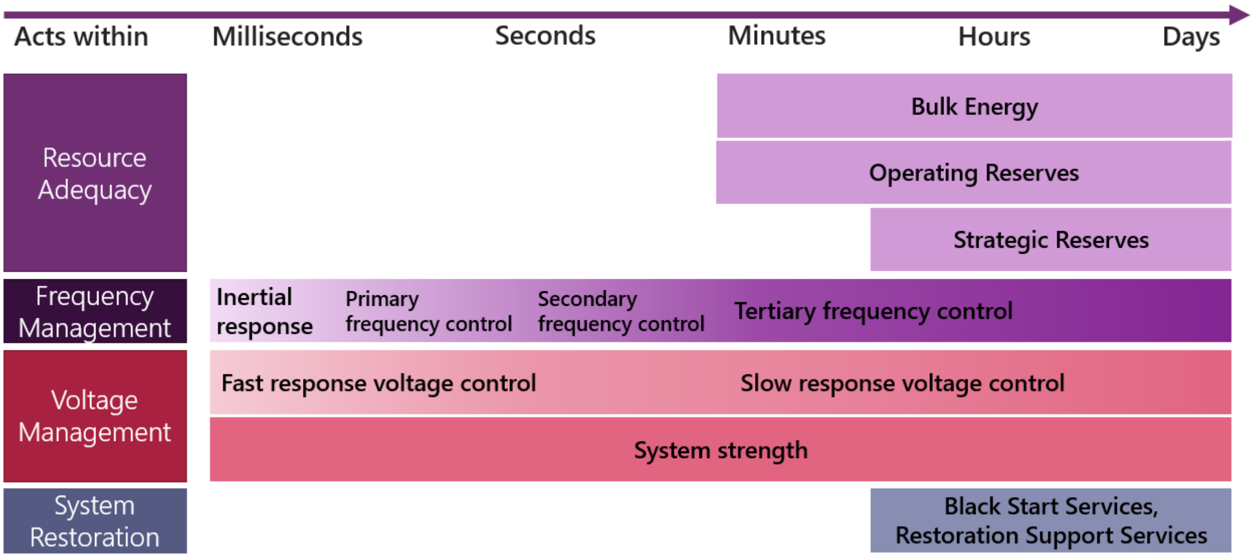
3. Technical attributes

Technical attributes of the power system are the fundamental technical elements that must be maintained to ensure that the power system can delivery energy to consumers with a high degree of confidence (reliability) and with a safe and acceptable level of performance (security). This section summarises the fundamental 'technical attributes' of the power system. For each, a description of the attribute, services needed to meet the attribute requirement and current areas of focus are discussed. Table 2 lists these technical attributes and Figure 1 shows the timescale in which each service responds.

Table 2 Technical attributes, and services required to deliver them

Technical attribute and section of report where addressed	Requirement	Service(s) needed to meet requirement
Resource adequacy and capability • **There is a sufficient overall portfolio of energy resources to continuously achieve the real-time balancing of supply and demand. (See Section 3.1)**	Provision of sufficient supply to match demand from consumers	Bulk energy
		Strategic Reserves
	Capability to respond to large continuing changes in energy requirements	Operating reserves
	Network transport capability	Transmission and distribution services
Frequency management • **Ability to set and maintain system frequency within acceptable limits. (See Section 3.2)**	Frequency within limits	Inertial response Primary frequency response Secondary frequency control Tertiary frequency control
Voltage management • **Ability to maintain voltages on the network within acceptable limits. (See Section 3.3)**	Voltage within limits	Slow response voltage control Fast response voltage control
		System strength
System restoration • **Ability to restart and restore the system in the unlikely event of a major supply disruption. (See Section 3.4)**	Ability to restore the system	Black start services Restoration support services

Figure 1 Operation timescales for services needed



While the services are detailed separately, it is important to note that there are many interrelationships between these services, and a deficiency in one service can lead to issues in several system attributes. This chapter provides an overview of each service and how it is currently sourced in the NEM. In some cases, there is no current framework for procuring the relevant service, as historically these services have been provided as a by-product of sufficient size of in-service synchronous generators. Frameworks for these services are being explored through the Energy Security Board's Post 2025 program, to develop advice on market frameworks to enable the provision of the full range of services to customers necessary to deliver a secure, reliable and lower emissions electricity system at least-cost[28].

3.1 Resource adequacy and capability

Resource adequacy and capability relates to having a sufficient overall portfolio of energy resources to continuously achieve the real-time balancing of supply and demand. Achieving this balance is an intricate optimisation, operationally in real time and over longer-term planning timescales, of available energy resources – a diverse mix of centralised generation and DER, demand response, and network capacity. It is the capability of the overall, aggregated portfolio of available energy resources which is important in the real-time balancing of supply and demand.

To manage uncertainty, it is necessary to have enough spare capacity to manage the full range of reasonably foreseeable outcomes, in both investment timeframes and operational timeframes. Energy reserves refers to generating capacity (or demand response) that can be used when required, but is not actively engaged in supplying bulk energy. There are a range of different types of reserves, depending on the timeframe in which they are to be able to be called into use. At a high level, these can be classified as either strategic reserves or operating reserves[29]. Reserves may take a variety of forms, such as "headroom" in market participants' portfolios or an explicit service procured by the system operator.

The key components of resource adequacy and capability are summarised in Table 3.

[28] For more information see http://www.coagenergycouncil.gov.au/energy-security-board/post-2025.

[29] In very short timeframes – sub 5-minute to milliseconds – reserves take the form of frequency control services, which are discussed in Section 3.2.

Table 3 Overview of resource adequacy and capability requirements and services

Requirement	Description	Service and section of report where addressed
Provision of sufficient supply to match demand from consumers	• Capacity adequacy – ability of the energy resource mix to achieve balance at a single point in time. The most onerous requirements are typically: – **Maximum demand** conditions – highest plausible system demand, even if it occurs infrequently[30]. – Rare dispatch conditions – outside the norm for the given time of year and time of day. Examples include: periods of low variable renewable generation during a particularly warm or cold night, when demand is high; and periods when a key energy resource is unavailable or has reduced capability, such as the extended outage of an interconnection to a neighbouring region, or gas supply disruptions. • Energy adequacy – ability of the energy resource mix to achieve balance over a period of time. This includes fuel source adequacy (having enough capacity to meet energy balancing needs over the longer term, typically over a season or year).	Bulk energy (3.1.1) Strategic reserves (3.1.2)
Capability to respond to large continuing changes in energy requirements	The overall generation supply mix must have sufficient flexibility to ensure the power system can respond to significant changes in energy requirements over a wide range of time periods. Sufficient flexible capability is necessary to continue to balance supply and demand over these periods.	Operating reserves (3.1.3)
Network transport capability	The ability to deliver sufficient power to consumers when and where it is required. This includes provision of sufficient network services. Well-planned transmission networks[31] contribute to resource adequacy by enabling the dispatch of a geographically diverse range of energy sources, allowing: • Access to the best quality fuel resources and economic dispatch of low-cost resources, which can be constrained by network congestion. • Guarding against disruptions that might impact the price or availability of any one resource, especially critical during long-term, unplanned outages of large generation units. • Firming of the overall, aggregated output of disperse variable resources, reducing dependence on potentially more expensive generators with firm and flexible capabilities. Power transfer across the network must be within the secure **technical envelope** of the system. Flows can be constrained to maintain power system security. Provision of security services can, therefore, improve network transport capability.	Transmission and distribution services (3.1.4)

Under current NEM frameworks, the reliability standard is the primary criterion used to evaluate whether the power system has sufficient supply resources to meet future consumer demand.

[30] In our long-term, 20-year demand forecasts, AEMO forecasts the maximum demand which could be expected at any one time each year, for:

- A summer of average weather – based on weather patterns likely to occur one in every two years, these are called 50% probability of exceedance (POE) forecasts.
- A summer of extreme weather – based on weather patterns that have a one in 10 year chance of occurring, these are called 10% POE forecasts. The actual maximum demand can be highly variable from year to year.

For more information, see AEMO's Electricity Statement of Opportunities, at https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-reliability/nem-electricity-statement-of-opportunities-esoo.

[31] Modernisation of distribution networks can also help with resource adequacy by allowing demand response and DER to more dynamically contribute to achieving supply-demand balance in a more coordinated fashion. This would result in greatly enhanced controllability of decentralised resources located behind the meter (on consumers' premises), allowing AEMO and network operators to better mobilise this capacity and co-optimise with secure system operation.

AEMO uses the reliability standard to assess and report on whether there is sufficient generation capacity to meet forecast demand. As a driver of investment decisions, it is relevant in investment timeframes. At present, the NEM framework does not indicate how the reliability standard should apply in operating timeframes.

The key reliability metric is the maximum expected unserved energy (USE), or the amount of demand which the power system is forecast to be unable to meet. The reliability standard accepts that up to 0.002% of demand might not be met in a region each financial year due to insufficient energy resources. In addition, not all instances of energy shortfalls are counted when applying the standard.

Since the reliability standard intends that at least 99.998% of all demand is met and not all energy shortfalls are counted, it accepts some energy shortfalls. This approach is based on a probabilistic analysis, and was developed when there was significantly less variability in supply and demand than there is today. The changing demand profiles experienced today would suggest there is merit in discussing whether this mechanism remains sufficient for the future.

AEMO continually assesses supply adequacy and the status of available energy reserves. The Projected Assessment of System Adequacy (PASA) and other processes identify low or lack of reserve (LOR) conditions for each NEM region based on specific threshold triggers. LOR conditions indicate the system may not have enough spare energy if something major and unexpected happened, like the loss of a generator or interconnector. The lowest notice, LOR1, tells the market more reserves are needed to cover a major contingency – the highest, LOR3, indicates the balance of supply and demand is so tight that load shedding is imminent or has begun. LOR conditions are created by variations in both supply and demand.

3.1.1 Bulk energy

Bulk energy is the core product supplied by the power system. The NEM's performance in meeting the reliability standard is measured in terms of whether there is a shortfall in the supply of bulk energy.

This service represents the provision of electricity from generators to match demand from consumers, at least cost. It relates to the overall energy adequacy of the aggregated portfolio of available energy resources. Traditionally, bulk energy has been provided from large **synchronous generators**, procured through the wholesale spot market.

Longer-term contracts between generators and retailers reduce risks associated with spot market volatility and often underpin investment in generation that ultimately provides the bulk energy.

Over the last decade the NEM has seen significant growth in DPV, such that in South Australia, we are experiencing world-leading levels. Due to DPV generation offsetting demand, penetrations of DPV are seen as a reduction in the overall energy required to be dispatched (called **operational demand**). Current projections indicate that operational demand in South Australia may be negative by 2023. The ongoing reduction in daytime demand as DPV growth continues will impact system operation, including impacting areas such as the provision of essential system services from the remaining online synchronous fleet (such as inertia and **system strength**), reduced effectiveness of system restoration, and voltage control challenges. More information on reduced operational demand can be found in AEMO's Renewable Integration Study Stage 1 report Appendix A[32] and AEMO's Minimum Operational Demand Thresholds in South Australia report[33].

Operationally, AEMO's pre-dispatch process assesses if adequate supply resources are available to meet demand forecasts and real-time requirements. It estimates 5-minute targets from one hour prior to dispatch, and 30-minute targets up to 40 hours prior. The centrally-coordinated dispatch process is then conducted every five minutes according to current bids, offers, rebids, and any network constraints.

[32] AEMO. Renewable Integration Study Stage 1, Appendix A. April 2020, available at https://aemo.com.au/-/media/files/major-publications/ris/2020/ris-stage-1-appendix-a.pdf?la=en.

[33] AEMO. Minimum Operational Demand Thresholds in South Australia, June 2020, available at https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/sa_advisory/2020/minimum-operational-demand-thresholds-in-south-australia-review.pdf?la=en.

3.1.2 Strategic reserves

Strategic reserves refers to reserve capacity that sits outside the market to procure additional bulk energy services as insurance against unexpected demand growth and/or reductions in supply. At present, the NEM does not include a strategic reserve mechanism for generation. Instead, market participants may make a commercial decision to maintain reserves within their portfolios to ensure they can meet their contractual obligations.

If in place, strategic reserves could be called on in the event of an anticipated supply shortfall, providing insurance against supply interruptions as a result of generator closures or unavailability due to plant failures or fuel shortages, or unexpectedly high demand.

Where required to meet the reliability standard, AEMO may elect to contract for reserves through the Reliability and Emergency Reserve Trader (RERT) provisions in the NER. This occurs during periods where risks of supply disruptions have been indicated. Under the RERT, AEMO can maintain a panel of providers which can provide short notice (between three hours and seven days) and medium notice (between seven days and 10 weeks) reserve if required. If the market is unsuccessful in alleviating a LOR condition, AEMO will intervene by exercising the RERT mechanism where available or issuing a direction.

3.1.3 Operating reserves

Generators can require many hours' notice before they can start generating; similarly, demand response may require numerous hours' notice. To ensure the system operates in real time with high technical integrity, it is necessary to have operating reserves available, to ensure the system is able to cope with unexpected variations in supply and demand.

The NEM currently has no specific mechanism apart from system operator intervention to ensure that operating reserves are available, although alternative approaches are being considered.

Traditionally, operating reserves have taken the form of the unused capacity of synchronous generators which are generating below the full capacity they have made available to the market. In contrast, since their fuel source is free, wind and solar generators are generally dispatched to their full potential output given the prevailing wind/sun conditions. With fewer synchronous generators in the supply mix[34], operating reserve margins are declining.

At the same time, variability is increasing, and hence the amount of headroom required to prudently manage the power system is increasing.

If slower response generators are unable to come online quickly enough to meet a need for increased generation, and wind and solar plant are already fully dispatched, it becomes increasingly necessary to rely on more expensive fast start generation such as open cycle gas turbines.

A key characteristic to be considered when assessing the power systems' need for operating reserves is flexibility (see Section Error! Reference source not found.).

For more information on the increase in variability in the NEM and the ability of the system to respond flexibly, see AEMO's Renewable Integration Study Stage 1, Appendix C[35].

Most electricity markets around the world mobilise operating reserves in a range of different timeframes, to ensure the most efficient combination of resources is able to be dispatched when needed. For instance, operating reserves could be triggered on a day-ahead, hour-ahead, or 15-minutes ahead basis.

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[34] The reduction in synchronous generators in the supply mix may be due to a range of factors including retirements and displacement of online synchronous generators during periods of high wind and solar penetrations.

[35] AEMO. Renewable Integration Study Stage 1, Technical Appendix C. April 2020, available at https://aemo.com.au/-/media/files/major-publications/ris/2020/ris-stage-1-appendix-c.pdf?la=en.

The NEM relies on spot market prices (which can rise as high as the Market Price Cap, set at $15,000 a megawatt hour (MWh) for the 2020-21 financial year[36]) to provide an incentive for market participants to ensure their generating capacity is available when needed, even though they are only paid if they are actually dispatched.

As variability and uncertainty increases, AEMO and the industry are focused on assessing mechanisms to provide sufficient flexibility, other than market intervention[37].

3.1.4 Transmission and distribution services

To ensure a reliable power supply to end use customers, network infrastructure capable of transporting the electricity from generation to load must be in place. Transmission and distribution infrastructure requirements are driven by the need to meet demand during peak periods for each part of the network.

Investment in network capacity within or between regions can facilitate the entry of new generation, allow additional generation to be dispatched, or allow the transfer of energy between regions (which is becoming increasingly important due to variability in supply).

Any expansion in network capacity can also help to deliver energy reserves and flexibility.

In the absence of sufficient transmission capacity to transport electricity, generators are unable to get their products to market.

The NEM is an unusually long, sparse power system. Broadly, it is a grouping of several historically self-sufficient power systems via relatively low capacity interconnectors. Power transfers across these interconnectors are subject to constraints of various kinds.

As synchronous generation is displaced by variable renewable generation, transmission capacity has an important role in promoting diversity, so power can be transferred, for example, from a region where the wind is blowing to a region where it is not blowing.

The changing generation mix also has consequences for AEMO's ability to ensure that all parts of the power system are able to access critical services such as frequency control. There may be benefits for the broader resilience of the power system in having frequency control services broadly dispersed throughout the power system.

The NEM is moving away from a situation where regions of the NEM were mostly self-sufficient, towards a situation where interconnectors have an increasing role in providing reliability and security services.

Network infrastructure investments typically have high upfront costs, long lead times, and very long asset lives (around 50 years). Network investments are currently coordinated by the regulated networks, with input from AEMO under its National Planning function. Network services providers in the NEM are required to invest at levels that enable them to meet service performance obligations and reliability standards (set by state and territory agencies).

Currently, there are approximately 66 GW of transmission and sub-transmission-connected generating systems, with 17 GW being wind and solar capacity, including DPV. There is approximately an additional 7.4 GW of transmission and sub-transmission-connected generating systems proposed across the NEM, with 5.2 GW of this being wind and solar projects[38].

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[36] See the AEMC schedule of reliability settings at https://www.aemc.gov.au/sites/default/files/2020-02/Schedule%20of%20reliability%20settings%20-%20Calculation%202020-21%20financial%20year_0.pdf.

[37] For more information on current work in this area, see Energy Security Board, *System* Services and Ahead Markets, April 2020, available at https://prod-energycouncil.energy.slicedtech.com.au/sites/prod.energycouncil/files/System%20services%20and%20ahead%20markets%20paper%20-%20COAG%20April%202020.pdf.

[38] Figures sourced from AEMO's *Draft 2020 Integrated System Plan, 2019 Input and Assumptions workbook v1.3,* available at https://aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp/2020-integrated-system-plan-isp.

These renewable energy sources are proposed in predominantly remote and weak[39] locations without adequate transmission capacity. Generators located in congested parts of the network may be partially or fully constrained off.

These trends entail significant changes for power system flows and transmission infrastructure needs. In this period of change and uncertainty, AEMO's ISP – which provides a strategic, NEM-wide plan for infrastructure development which is actionable and can be implemented effectively – is critical.

The ISP, which is published every two years, is a whole-of-system plan that provides an integrated roadmap for the efficient development of the NEM out to 20 years. It assesses the most efficient combination of network and generation assets to achieve a secure and reliable energy system under a range of scenarios[40].

3.2 Frequency management

To operate, the system must have the ability to set and maintain frequency[41,42].

Power system frequency is controlled by the constant balancing of electricity supply and demand. If electricity supply exceeds demand at an instant in time, power system frequency will increase. If electricity demand exceeds supply at an instant in time, power system frequency will decrease.

To maintain this balance, AEMO relies on frequency control services, which are mostly designed to inject or remove power from the grid to restore the balance of supply and demand. The services which maintain frequency must collectively provide a continuous response to arrest any deviation in frequency, and then return it to desired levels.

Historically, these services have typically been defined as a series of cascading services with different active operation times and functions.

Table 4 provides an overview of the services currently used to set and maintain frequency. Figure 2 shows how frequency control services contribute to restoring power system frequency after a disruption.

Table 4 Overview of frequency management services[A]

Service	Description
Inertial response	A rapid and automatic injection of energy to suppress rapid frequency deviations, slowing the rate of change of frequency.
Primary frequency response	**Active power**[B] controls act in a proportional manner to respond quickly to measured changes in local frequency and arrest deviations.
Secondary frequency control	Automatic generation controls and manual dispatch commands act to restore frequency to 50 Hz and relieve providers of primary frequency response.
Tertiary frequency control	Active power controls, such as the start-up of new units or set point changes on already operating units, act to replace depleted secondary frequency control resources to ensure the system continues to remain within its normal operating band.

A. Grid formation has been removed as a frequency management service in this version of the power system requirement paper. In a large power system, such as the NEM, during stable operation there is no one source that sets and maintains frequency, however the ability of a source to provide frequency control for stable operation is considered a useful restoration support service (see Section 3.4).
B. Instantaneous rate at which electrical energy is consumed, generated, or transmitted.

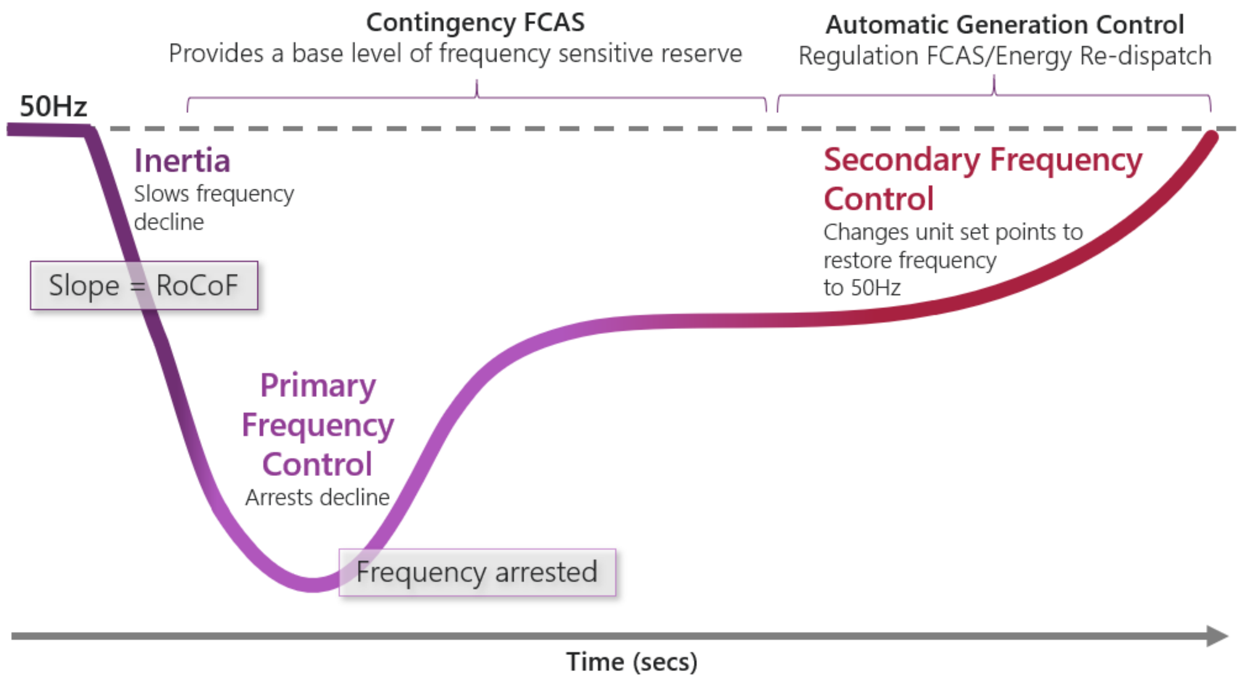
[39] Parts of the system lacking system strength (see Section 3.3.3).

[40] More information about the ISP is available at https://aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp.

[41] Further background information about frequency control can be found in AEMO's Frequency Control factsheet, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/2016/AEMO-Fact-Sheet_Frequency-Control---Final.pdf.

[42] Further background information on the history of frequency control in the NEM and the roles of different frequency control services can be found in AEMO's Mandatory Primary Frequency Response Rule Change Proposal to the AEMO, available at https://www.aemc.gov.au/sites/default/files/2019-08/Rule%20Change%20Proposal%20-%20Mandatory%20Frequency%20Response.pdf.

Figure 2 Frequency control services acting to restore power system frequency after a disturbance



From Table 4, tertiary frequency control services are not shown, because they are used once frequency has been stabilised back to 50 Hz.

There is also an emerging opportunity for resources with **fast frequency response (FFR)**[43] capabilities to provide frequency control services. FFR is a class of Primary Frequency Response that provides system benefits at low levels of synchronous inertia. AEMO has published a paper[44] which seeks to provide a common language for discussion across industry on FFR and provide early guidance on FFR services which may be valuable to assist in the efficient management of power system frequency. Further work has also been done to evidence the need for faster frequency response in a lower inertia system to ensure the Frequency Operating Standard continues to be met in the NEM. This work is available in AEMO's Renewable Integration Study Stage 1, Appendix B[45].

The forecast reduction in inertia out to 2025, combined with the decline in load relief, will mean that more, and/or faster, frequency sensitive reserve will be needed to ensure the FOS continues to be met for all credible events.

In the event of a large disturbance causing an extreme frequency change which is beyond the capability of frequency control services, emergency frequency control schemes are used as a last resort to try and arrest the frequency disturbance. Emergency frequency control schemes involve the automatic disconnection of generation or load in an attempt to rapidly rebalance the system. As more DPV is installed across the power system, these emergency mechanisms are impacted, for more details refer to AEMO's Renewable Integration Study Stage 1, Appendix A[46].

3.2.1 Inertial response

Inertial responses provide a rapid and automatic injection of energy to suppress rapid frequency deviations, slowing the rate of change of frequency (RoCoF), as shown in Figure 2. This response has predominantly been

[43] A very rapid response to re-balance megawatts on the power system. May be automatic in response to frequency, or a centrally controlled response (that is, a control scheme to shed load).

[44] AEMO. *Fast Frequency Response in the NEM – Working Paper*, August 2017, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/2017/FFR-Working-Paper---Final.pdf.

[45] AEMO. *Renewable Integration Study Stage 1 Report, Appendix B.* April 2020, available at https://aemo.com.au/-/media/files/major-publications/ris/2020/ris-stage-1-appendix-b.pdf?la=en.

[46] AEMO. *Renewable Integration Study Stage 1 Report, Appendix A,* April 2020, available at https://aemo.com.au/-/media/files/major-publications/ris/2020/ris-stage-1-appendix-a.pdf?la=en.

provided in the NEM by the inherent electromechanical inertial response of large synchronous generators, as a by-product of energy production. It arises because the rotating parts of synchronous generating units (such as the turbine and rotor) connected to an AC power system spin in lock step with the system frequency. The response is provided by the physical properties of the machine, and does not require control system interaction.

This inertial response was historically abundant in many parts of the network. This is, however, no longer the case in certain parts of the network that have high levels of inverter-based resources (IBR). A lack of inertial response can present risks to system security in the event that these regions become separated from the rest of the NEM.

AEMO is required to calculate the minimum inertia requirements of each inertia sub-network (region) in the NEM and determine if an inertia shortfall is likely to exist now or in the future, according to the Inertia Requirements and Shortfalls Methodology[47].

The inertia outlook for each NEM inertia sub-region is listed in the ISP[48]. Following declaration of a shortfall, transmission network service providers (TNSPs) are required to provide inertia network services to address the shortfall. AEMO has so far declared inertia shortfalls in South Australia and Tasmania.

Currently, inertia thresholds are calculated for a region with a credible or protected risk of separation and for an islanded region following separation for a credible trip of the largest credible risk within the islanded region. There are currently no formal requirements for minimum inertia during system intact under normal conditions.

AEMO's Renewable Integration Study Stage 1, Appendix B[49] report recommends consideration of an inertia safety net for system intact, that can be progressively lowered to facilitate a staged approach. The proposed inertia safety net for system intact would operate in parallel with the existing regional inertia requirements that are in place when there is a credible risk of islanding, or a region has been islanded.

3.2.2 Primary frequency response

Primary frequency response (PFR) is the first stage of frequency control in a power system. It is the response of generating systems and loads to arrest and correct locally detected changes in frequency by providing a proportionate change in their active power output or consumption, as shown in Figure 2. PFR is automatic; it is not driven by a centralised system of control and begins immediately after a frequency change beyond a specified level is detected.

In the NEM, the normal operating frequency band (NOFB) is currently set between 49.85 Hz and 50.15 Hz[50]. PFR provides a continuum of response and is relevant both outside and within the NOFB.

Outside of the NOFB, a minimum amount of headroom and footroom for PFR to respond is procured through the contingency frequency control ancillary services (FCAS) markets (fast, slow, and delayed).

Contingency events, such as the sudden failure and disconnection of a generator or load, can cause a sudden imbalance in supply and demand, leading to a rapid frequency change which can shift frequency outside its NOFB.

Contingency FCAS acts to contain these significant deviations and co-operate with regulation FCAS to restore the frequency back to normal levels. In the NEM, these contingency raise or lower services are currently specified such that they must act within 6 seconds for the fast service, 60 seconds for the slow service, and 5 minutes for the delayed service. The fast service arrests the deviation in frequency and the slow and delayed

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[47] AEMO. *Inertia Requirements Methodology,* July 2018, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/Inertia_Requirements_Methodology_PUBLISHED.pdf.

[48] AEMO's ISP documentation is available at https://aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp.

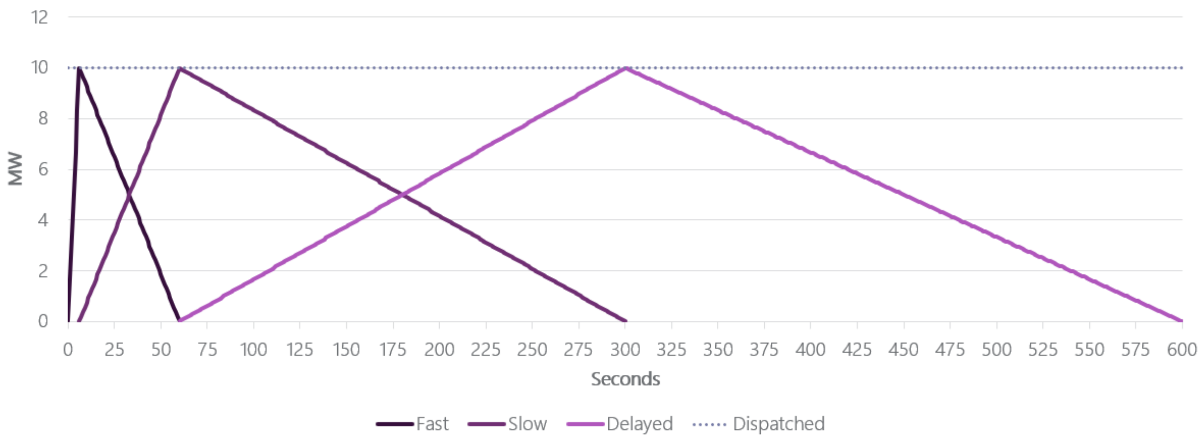
[49] AEMO. *Renewable Integration Study Stage 1, Appendix B,* April 2020, available at https://aemo.com.au/-/media/files/major-publications/ris/2020/ris-stage-1-appendix-b.pdf?la=en.

[50] Reliability Panel, *Frequency Operating Standard*, November 2017, available at https://www.aemc.gov.au/sites/default/files/content/c2716a96-e099-441d-9e46-8ac05d36f5a7/REL0065-The-Frequency-Operating-Standard-stage-one-final-for-publi.pdf

services replace the fast service to contain frequency for the full five minutes and may also provide some assistance in stabilisation. A simplified contingency response profile, displaying the trade-off between services, is shown in Figure 3, for an FCAS provider that ramps in a perfectly linear manner to a maximum of 10 megawatts (MW).

Further information on the specification of these services is available in AEMO's Market Ancillary Services Specification (MASS)[51].

Figure 3 Simplified contingency response profile



Source: AEMC (2018), Frequency Control Frameworks Review, p.206, available at https://www.aemc.gov.au/sites/default/files/2018-07/Final%20report.pdf.

Within the NOFB, until recently there was no requirement for any generator to provide PFR. However, a recent rule change by the Australian Energy Market Commission (AEMC) on Mandatory Primary Frequency Response[52] now places obligations on all scheduled and semi-scheduled generators in the NEM to operate their plant in accordance with the *primary frequency response requirements*[53].

PFR can be sourced from many different types of devices:

- PFR was historically sourced from synchronous generators governor response, load response (motors), and other devices that provide immediate response based on local control that is sensitive to frequency change.
- Today, utility-scale batteries, wind farms, solar farms, and VPPs can contribute to supporting frequency through PFR. Batteries, wind farms, and VPPs now make up a portion of the FCAS provider pool. AS/NZS 4777.2 (the standard for small-scale inverters) already specifies a frequency response from DER. Expansion of the frequency response requirements on these small-scale devices is currently under review.
- Fast switched loads, such as distributed and large industrial loads, are also able to provide PFR (usually to raise frequency) when combined with frequency responsive relays. These switched loads are tripped when local frequency at the connection point breaches their under-frequency trip setting. In the NEM there is an increasing number of intervals where switched reserve is providing a high proportion of overall FCAS, trending to an average proportion of 30%. More information on switched reserve is available in AEMO's Renewable Integration Study Stage 1, Appendix B Report[54].

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[51] AEMO, Market Ancillary Services Specification, available at https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/system-operations/ancillary-services/market-ancillary-services-specification-and-fcas-verification-tool.

[52] For more information and documents relating to this Rule Change, see https://www.aemc.gov.au/rule-changes/mandatory-primary-frequency-response.

[53] For more information on AEMO's Primary Frequency Response Requirements, see https://aemo.com.au/en/initiatives/major-programs/primary-frequency-response.

[54] AEMO, Renewable Integration Study Stage 1, Appendix B, April 2020, available at https://aemo.com.au/-/media/files/major-publications/ris/2020/ris-stage-1-appendix-b.pdf?la=en.

3.2.3 Secondary frequency control

After PFR services initially arrest frequency, secondary frequency control services provide an injection or removal of power from the grid, in response to a remote signal, to bring the system frequency back to 50 Hz. Secondary frequency control is currently managed in the NEM through the use of regulation FCAS services and energy re-dispatch. During normal system operation, regulation frequency control services respond to an external signal from AEMO which fine-tunes their dispatch targets (set points) to correct deviations in frequency within the NOFB.

Regulation FCAS bids and offers are co-optimised with energy as part of security-constrained economic dispatch.

In the NEM, regulation FCAS is delivered by generators controlled by AEMO's automatic generation control system (AGC).

The AGC calculates how much additional generation is required, or how much generation needs to be reduced, to correct deviations in frequency. The AGC will then change the electricity production target for the generators enabled for regulation FCAS to correct the frequency deviation.

3.2.4 Tertiary frequency control

Because the NEM has a relatively short dispatch interval of five minutes, tertiary frequency control, which acts to relieve sources of primary and secondary frequency control, is effectively achieved through the central energy re-dispatch process which re-balances the system every five minutes.

In other power systems around the globe, especially where much longer dispatch intervals exist, a tertiary frequency control product may be a separately procured service used to manage imbalance between dispatch cycles.

3.3 Voltage management

Voltage control in the power system acts to maintain voltages at different points in the network within acceptable ranges during normal operation, and to enable recovery to acceptable levels following a disturbance. Acceptable voltage ranges are defined in the NER[55].

Voltage control is managed through balancing the production or absorption of reactive power[56]. Reactive power does not 'travel' far, meaning it is generally more effective to address reactive power imbalances locally, close to where it is required. Adequate reactive power reserves are maintained to ensure the security of the transmission system in the event of a credible contingency.

AEMO operates the power system to maintain voltage levels across **connection points** in the transmission network within limits set by NSPs and to a target voltage range. This involves the coordination of available reactive power resources in the network and from generators.

If voltages still remain outside their technical limits, other tools available to system operators include:

- Network reconfiguration – operational switching of transmission elements in and out of service to redirect network flows.
- Contracts with TNSPs and generators – agreements for specific reactive support under specific circumstances.
- Load shedding – automatic or manual load shedding as an emergency last resort.

NSPs are responsible for planning, designing, and operating their networks so that voltages at connection points are within technical limits. Reactive power support and other associated costs are recovered through

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[55] AEMC. Schedule 5.1a of the NER, available at http://www.aemc.gov.au/Energy-Rules/National-electricity-rules/Current-Rules.

[56] The rate at which reactive energy is transferred. Reactive power, which is different to active power, is a necessary component of alternating current (AC) electricity. Management of reactive power is necessary to ensure network voltage levels remains within required limits, which is in turn essential for maintaining power system security and reliability.

the network regulation process. Generators' responsibility for providing voltage support at their connection points is determined as part of the generation connection application process and set out in the generator performance standards. AEMO undertakes a further annual review to identify any potential gaps in voltage management from a system-wide perspective as part of the Network Support and Control Ancillary Services (NSCAS) process.

3.3.1 Fast response voltage control

Fast response voltage control provides rapid adjustments in reactive power to support voltage stability during and after system disturbances. Adequate reactive reserves also need to be maintained to ensure the security of the transmission system.

Equipment that provides fast dynamic voltage control includes:

- Automatic voltage regulation from synchronous generators acting to maintain planned voltage levels.
- Active compensation – fast acting equipment[57] using power electronics to control power flow and compensate reactive power as needed in the system. These include **static VAR compensators (SVCs)**, synchronous condensers, and **static synchronous compensators (STATCOMS)**.
- IBR, such as wind turbines and solar inverters.

Fast response voltage control is related to voltage stability and hence system strength. Further discussion on system strength is available in Section 3.3.3.

3.3.2 Slow response voltage control

Slow response voltage control relates to managing small adjustments to reactive power during normal operation as demand and generation varies, in timescales within seconds or minutes.

Slow response voltage control is primarily provided locally by:

- Voltage regulators – control voltages farther from the substation and installed at substations and along **distribution system** feeders.
- Transformer[58] load tap changes – to increase and decrease voltages as needed.
- Passive reactive power compensation from capacitors and **reactors** within substations, providing base level voltage and reactive support.

3.3.3 System strength

System strength is a complex concept, and an area of emerging understanding internationally[59]. Definitions vary across jurisdictions and continue to evolve as the international power system community's collective understanding of power system phenomena continues to grow.

AEMO sees system strength as the ability of the power system to maintain and control the voltage waveform at any given location in the power system, both during steady state operation and following a disturbance. System strength can be related to the available fault current at a specified location in the power system, with

[57] Collectively known as flexible AC transmission systems (FACTS) devices.

[58] A transformer is a device that reduces or increases the voltage of alternating current. Where a tap changer is fitted to a transformer, each tap position represents a change in voltage ratio of the transformer which can be manually or automatically adjusted to change the transformer output voltage. The tap position is used as a reference for the output voltage of the transformer. This process is known as "transformer tap changing".

[59] AEMO, RIS International Review, October 2019, 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.

higher fault current indicating higher system strength with greater ability to maintain the voltage waveform[60,61].

System strength in the NEM has predominantly been provided as a by-product when energy is produced by large synchronous generators and was historically abundant in many parts of the network.

System strength affects the stability and dynamics of generating systems' control systems, and the ability of the power system to both remain stable under normal conditions, and to return to steady-state conditions following a disturbance, as set out in Table 5.

Table 5 Summary of main issues associated with low system strength

Issue	Description
Inverter-based resources stability	IBR require a minimum system strength to remain stable and maintain continuous uninterrupted operation. Different types of converters use different strategies to match their output to the frequency of the system while maintaining voltage levels and power flows. In a weak AC system, this can lead to: • Disconnections of plant following credible faults, in particular in remote parts of the network. • Adverse interactions with other inverter-based plant (instabilities/oscillations have been observed in practice in the NEM). • Failure to provide sufficient active and reactive power support following fault clearance.
Synchronous machines stability	Low system strength can affect the ability of remote or small synchronous machines to operate correctly, resulting in their disconnection during credible contingencies.
Operation of protection equipment	Protection equipment within power systems work to clear faults on only the effected equipment, prevent damage to network assets and mitigate risk to public safety. In weak systems: • Some protection equipment have a higher likelihood of maloperation. • Some protection equipment may fail to operate, resulting in uncleared faults and/or cascaded tripping of transmission elements due to eventual clearance of the fault by an out-of-zone protection resulting in excessive disconnection of transmission lines and associated generation.
Voltage management	Strong power systems exhibit better voltage control in response to small and large system disturbances. Weak systems are more susceptible to voltage instability or collapse.

System strength is an area of particular focus as operation of wind and solar IBR increases and some regions may be regularly be pushed into unfamiliar territory, including periods with:

- Low number of large synchronous machines online (decreasing the region's underlying system strength).
- Very high levels of IBR online (decreasing the system strength in the vicinity of these resources).
- Both low numbers of large synchronous machines and high IBR online, including DPV.

There are currently two categories of regulations that are used to ensure sufficient system strength is maintained in the system:

- **Bulk power system** – AEMO is required to determine the fault level requirements across the NEM and identify whether a fault level shortfall is likely to exist now or in the future. The projected fault levels for

[60] AEMO's System strength in the NEM explained document is available at https://aemo.com.au/-/media/files/electricity/nem/system-strength-explained.pdf?la=en#:~:text=AEMO%20sees%20system%20strength%20as,operation%20and%20following%20a%20disturbance.

[61] See AEMO's Renewable Integration Study Stage 1 report, which includes a review on system strength, available at https://aemo.com.au/-/media/files/major-publications/ris/2020/renewable-integration-study-stage-1.pdf?la=en&hash=BEF358122FD1FAD93C9511F1DD8A15F2.

each node are listed in the ISP[62]. The System Strength Requirements Methodology defines the process AEMO must apply to determine the system strength requirement at each node[63].

  - Following the declaration of a fault level shortfall, TNSPs are required to provide system strength services to address the shortfall[64]. 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.
  - Detailed EMT studies are also being used to define the minimum unit combinations of synchronous generators for operating the current system.
  - Failure to predict a shortfall with sufficient advance notice for the TNSP to procure an efficient system strength service necessitates interventions (directions) as an interim measure.

- **Generator obligations** – in 2017, the AEMC established some of the first regulations to ensure new generator connections in areas with low system strength do not adversely impact stable operation of the NEM[65]. Generators connecting in the areas with low system strength conditions are required to demonstrate that they do not adversely impact system operation. If a new generator is assessed as having an adverse system strength impact, they are required to take mitigation measures, either through system strength connection works or remediation schemes. AEMO's Power System Model Guidelines[66] and System Strength Impact Assessment Guidelines[67] set out the modelling and assessment that is required to:
  - Allow accurate investigation and management of new and emerging power system phenomena.
  - Understand and mitigate (if necessary) the impact of new or modified generation and market network service connections on system strength.

3.4 System restoration

While AEMO endeavours to manage the system in a secure and reliable state, major disturbances (such as sudden equipment failure, multiple equipment failures in close succession, or extreme weather events) can sometimes lead to cascading failures across the system, resulting in a black system[68] or other major supply disruption[69].

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 to a secure and reliable operating state as safely and quickly as possible in the event of a major supply disruption. In the NEM these are called system restart ancillary services (SRAS)[70,71].

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[62] AEMO's ISP documentation is available at https://aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp.

[63] See AEMO's System strength requirements methodology for more information at https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/system-security-market-frameworks-review/2018/system_strength_requirements_methodology_published.pdf?la=en&hash=9748847CDF423A9C8829BD1932D7D2A4.

[64] See NER clause 5.20B.3 and 5.20B.4.

[65] See https://www.aemc.gov.au/rule-changes/managing-power-system-fault-levels

[66] 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?la=en&hash=A3DDF450DBEE1E7C1D7E2E379461538A

[67] AEMO, System Strength Impact Assessment Guidelines, July 2018, available at https://www.aemo.com.au/-/media/files/electricity/nem/security_and_reliability/system-security-market-frameworks-review/2018/system_strength_impact_assessment_guidelines_published.pdf?la=en&hash=771B8F6BC8B3D1787713C741F3A76F8B.

[68] Defined in the NER Chapter 10 as 'the absence of *voltage* on all or a significant part of the *transmission system* or within a *region* during a *major supply disruption* affecting a significant number of customers.'

[69] Defined in the NER Chapter 10 as 'the unplanned absence of *voltage* on a part of the *transmission system* affecting one or more *power stations* and which leads to a loss of *supply* to one or more *loads*.'

[70] In some cases, a disturbance event may lead to the loss of generation or load in the system, but the system is able to stabilise itself. In these cases, system restart is not required and SRAS are not deployed.

[71] AEMO. System Restart Ancillary Service Guideline, December 2017, available at https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/ancillary_services/sras-guideline-2017.pdf?la=en&hash=D4D5FF68CB155BE97D8F61182B659F71.

To restore the power system after a major supply disruption, it is necessary for at least one SRAS source to start itself up to carry out initial energisation of a section of the system[72,73]. The energised part of the power system is then used to start up additional supply and restore power to more load so that power is gradually restored[74].

SRAS is procured in each region according to the AEMC Reliability Panel's system restart standard (SRS)[75]. This process is designed to procure SRAS at the least-cost combination of sources, and considers a number of parameters, specifically aggregate reliability (which includes individual reliability, transmission reliability, strategic location, geographic location, and fuel diversity of SRAS) as well as principles AEMO needs to consider when developing boundaries of sub-networks.

SRAS is a service traditionally provided by generators with the ability to start, or remain online, without drawing electricity from the grid. However, there is increasing focus on the provision of SRAS from non-generation technologies and expanding the range of SRAS services that can be offered; for example, battery storage systems and new technologies utilising grid-forming inverters, which may be capable of providing this service[76].

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

3.4.1 Black start services

Black start capability is the capability to restart a disconnected facility and deliver power to the network using an energy source independent of the power system.

Currently, none of the existing installed IBR has black start capability sufficient to energise the adjacent transmission network and other generation. Almost all installed generation has a 'grid following' inverter type that cannot establish its own voltage source. However, 'grid forming' inverter technologies are currently being developed and deployed by some battery manufacturers. These devices exhibit similar performance to that of a synchronous generator from a system restoration perspective, and could be capable of restarting the power system[77].

Black start capability has been demonstrated for a range of IBR, both domestically and internationally, including:

- Voltage source converter (VSC) HVDC in Ireland[78] and Denmark[79].
- The use of grid forming inverters in black starting microgrids and islanded power systems, including in Australia[80].

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[72] Some synchronous generation technologies have the capability to start their main generating units using small auxiliary generating plant located on-site, without reliance on external electricity supplies. Some generating systems can continue running in isolation from the rest of network in the event of a major supply disruption, remaining available to support system restoration when requested.

[73] The System Restart Standard, set by the Reliability Panel requires AEMO to procure at least two black start sources in each electrical sub-network. See https://www.aemc.gov.au/sites/default/files/content/a31030d9-46e3-4842-8735-e09cad092069/System-Restart-Standard.PDF.

[74] Restoration of load must be done in a controlled manner following a major supply disruption to ensure the system remains balanced at all times. This involves a staggered process of bringing on equivalent blocks of additional generation and load.

[75] For information and documents related to this AEMC review, see https://www.aemc.gov.au/markets-reviews-advice/review-of-the-system-restart-standard.

[76] AEMC, System restart services, standards and testing, Rule determination, April 2020, available at https://www.aemc.gov.au/sites/default/files/documents/system_restart_services_standards_and_testing_-_final_determination.pdf.

[77] AEMO, future system restart capability, Rule change proposal, July 2019, available at https://www.aemc.gov.au/sites/default/files/2019-08/ERC0278%20Rule%20change%20request%20pending.pdf.

[78] CIGRE Study Committee C2 – System operation and control, Power system restoration – World practices & future trends, CIGRE Science & Engineering No. 14, June 2019 p.6.

[79] J. B. Kwon, "A live Blackstart test of an HVAC network using soft start capability of a voltage source HVDC converter", presented at CIGRE Aalborg Symposium, June 2019.

[80] ABB public library, accessed at https://library.e.abb.com/public/68b1b939c6ce1cdf83257dc500370bf8/54-60%204m480_EN_72dpi.pdf.

- Several wind turbine, solar inverter and battery inverter manufacturers have successfully demonstrated black start capability, often requiring the use of diesel generators or batteries[81].

3.4.2 Restoration support services

Following initial energisation from black start services, restoration support services assist the progressive restoration of the power system[82].

Synchronous generation is still the predominant source of restoration support. However, potential has been identified for some currently installed IBR to supply restoration support services; for example, by providing other services, such as voltage support (reactive power) or frequency control required for stable operation, even if they cannot initiate the restoration[83].

81 AEMO, future system restart capability, Rule change proposal, July 2019, p.5, available at https://www.aemc.gov.au/sites/default/files/2019-08/ERC0278%20Rule%20change%20request%20pending.pdf.

82 AEMC, System restart services, standards and testing, Rule determination, April 2020, available at https://www.aemc.gov.au/sites/default/files/documents/system_restart_services_standards_and_testing_-_final_determination.pdf.

83 AEMO, future system restart capability, Rule change proposal, July 2019, available at https://www.aemc.gov.au/sites/default/files/2019-08/ERC0278%20Rule%20change%20request%20pending.pdf.

4. Meeting the technical and operational needs of the power system

4.1 Ability of different technologies to provide services

The services described in Chapters 2-3 can be provided by a variety of existing technologies.

Figure 4 maps these services against the required power system technical attributes from Chapter 3 and provides a comparison of the known and emerging ability of different technologies to provide these services.

Technologies are grouped under the broad sub-categories of supply side, network, and demand side.

Figure 4 also includes:

- The "spatial level of need" – differentiating between local service requirements (which must be sourced from within a region) and global services requirements (which can be sourced from anywhere in the NEM).
- The extent to which each technology is capable of providing the service, based on demonstrated capability in Australia or equivalent large power systems internationally, or by the results of large-scale technology trials. This level of demonstrated capability is represented by the filled, half-filled, and empty circles. The extent to which a network element can enable the delivery of the service from a different location in the power system (rather than a service necessarily having to be sourced locally) is represented by the filled and hollow arrows.
- Clarifying comments regarding specific technology capabilities, particularly where there are emerging capabilities.

AEMO expects the summary in Figure 4 to evolve over time, as technology providers continue to broaden the range of services their equipment provides.

4.2 The need for a portfolio of technical solutions

Efficient policy frameworks will take a portfolio approach to sourcing system services, making optimal use of the capabilities of all assets in the power system, which, when used in combination, should be capable of providing the same or better system performance than in the past.

There is a need to operate the system under a range of operating conditions, including normal, contingency, abnormal and extreme abnormal. A suite of products and technical solution need to be available to deliver an operable system across all these scenarios.

Figure 4 allows consideration of the many linkages and patterns between the different services, and between the various technologies that can provide these services. Some of these linkages and patterns include:

- Where there are current and emerging opportunities to provide services from more than one technology (such as for energy reserves and flexibility services) – indicating the potential value in enabling a portfolio of service providers.
- Where multiple services can be provided by common groups of technologies (such as bulk energy, primary frequency response, and secondary frequency control) – indicating opportunities for co-optimising services.

- Where there are limited technologies capable of providing a service (such as for inertial response and system strength) – indicating that there may be economic efficiencies in decoupling the services from the provision of energy.

By considering these linkages, policy-makers can develop efficient policy frameworks that ensure availability of these services, drawing on complementary technologies whose collective capabilities can meet the needs of the power system.

4.3 Work programs to understand and address system needs

Building on previous work[84], AEMO is exploring how the requirements for meeting the needs of the power system may change over time, including identifying potential alternative means of sourcing these services.

The three key vehicles AEMO is currently using to explore, communicate and engage with industry on are the:

- Integrated System Plan.
- Renewable Integration Study.
- DER Program.

This document provides a foundational resource for policymakers and stakeholders, establishing a common language for the technical and operational requirements of the power system.

As the energy transformation progresses, the theories and practices associated with power system operation are undergoing continuous review and development by power system operators internationally.

AEMO will continue to work with stakeholders to convey the most up-to-date information. As part of this, we will explore the opportunities and risks of how technical services may need to change over time.

We will also continue to enhance our ability to comprehensively model the power system and understand its technical limits, given changing operational dynamics and emerging technologies.

4.3.1 Integrated System Plan

The ISP[85] is a whole-of-system plan that provides an integrated roadmap for the efficient development of the NEM over the next 20 years and beyond. Its objective is to maximise value to end consumers by designing the lowest cost, secure and reliable energy system capable under a range of scenarios.

This roadmap sets out the optimal development path and presents clear signposts for the actionable ISP projects and other initiatives that are needed immediately, shortly or in the future.

It utilises the opportunities provided by existing technologies and anticipated innovations, including emerging innovations in consumer owned DER, VPPs, large-scale generation, energy storage, networks, and coupled sectors such as gas, water, and the electrification of transport.

4.3.2 Renewable Integration Study

The Renewable Integration study (RIS)[86] is a multi-year plan to maintain system security in a future NEM with a high share of renewable resources. It explores the operability and day-to-day experience of a future NEM.

The RIS forms a cycle with the ISP. The ISP forms inputs into the RIS and the RIS supplies insights into the ISP that can be explored as sensitivities to the central modelling work. AEMO is also looking at other ways in which the RIS insights can inform long-term work at AEMO.

The RIS provides a body of technical evidence on the changing physical needs of the power system, to feed across to the AEMC rule change process and other regulatory work, including the ESB in its Post 2025 project.

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[84] AEMO's reports and analysis since 2013, related to future power system security, are available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/FPSSP-Reports-and-Analysis.

[85] For more information on AEMO's ISP, see https://aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp.

[86] For more information on AEMO's RIS, see https://aemo.com.au/en/energy-systems/major-publications/renewable-integration-study-ris.

This coordination between bodies allows issues to be addressed in a cohesive way, as well as addressing system security issues that are more urgent in nature.

4.3.3 DER Program

The DER Program[87] seeks to address opportunities for new products and consumer services, and the technical and operational challenges that increasing amounts of DER are having on the NEM. The aim is to ensure a smooth transition from a one-way to a two-way supply chain.

The DER Program aims to deliver this transition across a range of workstreams, including markets and frameworks, pilots and trials, operations, data and visibility, standards and protocols and engagement and collaboration.

[87] For more information on the DER Program, see https://aemo.com.au/en/initiatives/major-programs/nem-distributed-energy-resources-der-program.

Figure 4 Summary of required system services, and capability of technologies to provide them

Service description				Supply side		Network						Demand side		
				Centralised generation		Transfer between regions		Transfer within regions	Stabilising devices			Load	Decentralised resources	
System Attribute	Requirement	Service	Spatial level of need	Synchronous generator	Inverter-based resources	DC interconnection	AC interconnection	Transmission and distribution networks	Grid reactor, grid capacitor, static VAR compensator	Static synchronous compensator	Synchronous condenser[1]	Large industrial, residential, commercial	DPV	Battery storage
Resource Adequacy	Sufficient supply to match demand	Bulk energy	System wide	●	●	➡	➡	➡	○	○	○	●	●	●
Resource Adequacy	Sufficient supply to match demand	Strategic Reserves	System wide	●[2a]	◐[3a]	➡	➡	➡	○	○	○	●	◐[3b]	◐[3b]
Resource Adequacy	Respond to large changes in energy requirements	Operating reserves	Regional	●[2b]	◐[3a]	➡	➡	➡	○	○	○	●	◐[3b]	◐[3b]
Resource Adequacy	Transport energy generated to customers	Transmission & distribution services	Local	●[4]	●[4]	●	●	●	●	●	●	●[4]	◐	◐
Frequency Management	Maintain frequency within limits	Inertial response	Regional	●	◐[5]	◐[5]	➡	➡	○	◐[6]	●	○[7]	○	◐[5]
Frequency Management	Maintain frequency within limits	Primary frequency control	Regional	●	●[8]	➡	➡	➡	○	○	○	●	●	●[8]
Frequency Management	Maintain frequency within limits	Secondary frequency control	Regional	●	●[8]	➡	➡	➡	○	○	○	●	●	●[8]
Frequency Management	Maintain frequency within limits	Tertiary frequency control	Regional	●	●[8]	➡	➡	➡	○	○	○	●	●	●[8]
Voltage Management	Maintain voltages within limits	Fast response voltage control	Local	●	●	●	○	○	●	●	●	●	◐	●
Voltage Management	Maintain voltages within limits	Slow response voltage control	Local	●	●	●	○	○	●	●	●	●	◐	●
Voltage Management	Maintain voltages within limits	System strength	Local	●	○	○	⇨	➡	○	○	●	○	○	○
System restoration	Ability to restore the system	Black Start Services	Local	●	◐[9]	◐[9]	●	➡	○	○	○	○	○	◐[9]
System restoration	Ability to restore the system	Restoration Support Services	Local	●	●	●	●	⇨	●	●	●	●	◐	◐

Note: Classifications are indicative of general ability of each technology type. The extent to which technologies can provide each service must be assessed on the specifics of each individual system

Ability to provide service		
● Fully capable	◐ Partial or emerging	○ Unable
➡ Enables Delivery	⇨ Partial or limited Delivery	

1. This includes generators with ability to operate in synchronous condenser mode.
2a. While many synchronous generators can provide energy reserves, some less firm technologies (solar thermal or pumped hydro) will be limited by the amount of energy storage they include.
2b. There is a wide range of capabilities regarding synchronous generators ability to provide flexibility. Ultimately unit flexibility is a product of individual unit design and the economic circumstances around it's dispatch..
3a. Limited by duration for which service can be delivered.
3b. Limited by duration for which service can be delivered; existing controllability is limited.
4. The provision of local voltage support from generators and loads can improve the network transport capability near their respective connection points.
5. Some fast frequency response capabilities can be substituted for a portion of synchronous inertia, but are not considered equivalent.
6. Static synchronous compensators with energy storage devices are being trialled as an emergency provider of inertial response.
7. Except for load relief.
8. Includes fast frequency response capabilities.
9. Inverter-based resources can provide black start services, although none are currently contracted for SRAS.

5. Reference resources

AEMO has published other reports into the changing generation mix. A shortlist of relevant publications is provided in Table 6.

Table 6 Relevant AEMO publications

Publication	Notes and location	Publication date
Regular NEM-wide planning documents		
Integrated System Plan (ISP)	Prepared every two years to forecast a wide spectrum of interconnected infrastructure and energy development scenarios and plans including transmission, generation, gas pipelines and distributed energy resources. At https://www.aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp.	2018 ISP – July 2018 2020 ISP – Draft December 2019
ISP Insights	Published as required to provide a deep technical dive into select technologies or projects and their potential impact on future NEM development. At https://aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp/2020-integrated-system-plan-isp.	Ad hoc
Electricity Statement of Opportunities (ESOO)	Provides forecasts and analysis of technical and market data for the NEM for the next 10 years. At https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-reliability/nem-electricity-statement-of-opportunities-esoo.	Annual
Energy Adequacy Assessment Projection (EAAP)	Quantifies the impact of potential energy constraints on expected levels of unserved energy in the NEM for the next two years. At https://www.aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-reliability/energy-adequacy-assessment-projection-eaap	Annual (or as required)
Short term and Medium Term Projected Assessment of System Adequacy (ST PASA & MT PASA)	Provides information on peak load forecasts, total available generation capacity, demand-side management capacity, any identified capacity shortfall of ancillary services, transmission outages, any security problems, fuel supply and logistics and any facility testing. At https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/data-nem/market-management-system-mms-data/projected-assessment-of-system-adequacy-pasa.	MT PASA – published weekly for each week in the next two years ST PASA – published 2-hourly for each half-hour for the next six trading days
Network Support and Control Ancillary Services Report (NSCAS)	Assesses any requirements for NSCAS for network loading, voltage control, and transient and oscillatory stability ancillary services over the next five years that are not currently being addressed by NSPs. 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.	Annual
Summer Readiness report	Provides information on AEMO's preparations for the forthcoming summer period, designed to minimise the risk of customer supply disruption in the NEM. At https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/system-operations/summer-operations-report.	Annual

Publication	Notes and location	Publication date
Publications related to power system operation and renewables		
Renewable Integration Study	At https://aemo.com.au/energy-systems/major-publications/renewable-integration-study-ris.	April 2020
RIS International Review: Maintaining Power System Security with High Penetrations of Wind and Solar Generation – International insights for Australia	At https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_%E2%80%8Cand_Reliability%E2%80%8C/Future-Energy-Systems/2019/AEMO-RIS-International-Review-Oct-19.pdf.	October 2019
WA Renewable Integration report	At https://www.aemo.com.au/Electricity/Wholesale-Electricity-Market-WEM/Security-and-reliability/Integrating-utility-scale-renewables .	March 2019
Distributed Energy Resources (DER) Program	Full program details at https://aemo.com.au/initiatives/major-programs/nem-distributed-energy-resources-der-program.	April 2019
Power System Requirements paper	At https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Power-system-requirements.pdf.	May 2018
International Review of Frequency Control Adaptation	At https://www.aemo.com.au/-/media/files/electricity/nem/security_and_reliability/reports/2016/fpss---international-review-of-frequency-control.pdf?la=en&hash=52C6DB8F4D69BEFB42CAE9B44487438C.	October 2016
Minimum Operational Demand Thresholds in South Australia	At https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/sa_advisory/2020/minimum-operational-demand-thresholds-in-south-australia-review.pdf?la=en.	June 2020
Technical Integration of DER	At https://aemo.com.au/-/media/files/electricity/nem/der/2019/standards-protocols/epri-activation-of-der-in-the-energy-market-report.pdf?la=en.	April 2019
International Review of Opportunities to Activate DER	At https://aemo.com.au/-/media/files/electricity/nem/der/2019/standards-protocols/epri-activation-of-der-in-the-energy-market-report.pdf?la=en..	October 2019
International Review of PV Feed-in Management	At https://aemo.com.au/-/media/files/electricity/nem/der/2019/standards-protocols/epri-pv-feed-in-management-report.pdf?la=en.	October 2019
System Strength: System Strength in the NEM Explained	At https://aemo.com.au/-/media/files/electricity/nem/system-strength-explained.pdf?la=en.	March 2020
System Strength Impact Assessment Guidelines	At http://aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/System_Strength_Impact_Assessment_Guidelines_PUBLISHED.pdf.	July 2018
System Strength Requirements Methodology	At http://aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/System_Strength_Requirements_Methodology_PUBLISHED.pdf.	July 2018
Inertia Requirements Methodology	At http://aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/Inertia_Requirements_Methodology_PUBLISHED.pdf.	June 2018
ISP Insights - Building power system resilience with pumped hydro energy storage	At https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/ISP/2019/ISP-Insights---Building-power-system-resilience-with-pumped-hydro-energy-storage.pdf.	July 2019

Publication	Notes and location	Publication date
Rule Change Proposal - Generator Technical Requirements	At https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/2017/AEMO-GTR-RCP-110817.pdf. Details of the AEMC's final Rule determination, plus consultation papers and AEMO submissions are at https://www.aemc.gov.au/rule-changes/generator-technical-performance-standards.	August 2017
Working Paper - Fast Frequency Response in the NEM	At https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/reports/2017/ffr-working-paper---final.pdf.	August 2017
Technology Capabilities for Fast Frequency Response	At https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/reports/2017/2017-03-10-ge-ffr-advisory-report-final---2017-3-9.pdf?la=en&hash=468D48C40DBFF572166766F2B8A180C4.	March 2017
Visibility of DER	At https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/reports/2017/2017-03-10-ge-ffr-advisory-report-final---2017-3-9.pdf?la=en&hash=468D48C40DBFF572166766F2B8A180C4.	January 2017
Update to renewable energy integration in South Australia	At https://www.aemo.com.au/-/media/Files/PDF/Joint-AEMO-ElectraNet-Report_19-February-2016.pdf.	February 2016
South Australian Wind Study Report	At https://www.aemo.com.au/-/media/Files/PDF/2015_SAWSR.pdf.	October 2015
Renewable Energy Integration in South Australia	At https://www.aemo.com.au/-/media/files/pdf/renewable_energy_integration_in_south_australia_aemo_electranet_report_oct_2014.pdf.	October 2014
Wind Turbine Plant Capabilities Report	At https://www.aemo.com.au/-/media/Files/PDF/Wind_Turbine_Plant_Capabilities_Report.pdf.	2013
Wind Integration Studies Report	At https://www.aemo.com.au/-/media/Files/PDF/Integrating-Renewable-Energy--Wind-Integration-Studies-Report-2013pdf.pdf.	2013

Measures, abbreviations, and glossary

Units of measure

Abbreviation	Unit of measure
GW	Gigawatt (equivalent to 1,000,000,000 Watts, or 1,000 MW)
MW	Megawatt (equivalent to 1,000,000 Watts, or 1,000 kilowatts)
W	Watt – a standard unit of power. 1 watt = 1 joule per second, and can be used to quantify the rate of energy transfer.

Abbreviations

Abbreviation	Expanded name
AC	Alternating current
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
DC	Direct current
DPV	Distributed photovoltaic
FCAS	Frequency control ancillary services
HVAC	High voltage, alternating current
HVDC	High voltage, direct current
IBR	Inverter-based resources
NEM	National Electricity Market
NER	National Electricity Rules
NSP	Network service provider
PV	Photovoltaic
TNSP	Transmission network service provider

Glossary

This document uses many terms that have meanings defined in the National Electricity Rules (NER). The NER meanings are adopted unless otherwise specified.

Term	Meaning
Active power	Instantaneous rate at which electrical energy is consumed, generated or transmitted (see also 'Power').
Central dispatch process	This process maintains energy balance in the system through the centrally-coordinated matching of supply and demand, with the aim to maximise efficiency by optimising the contribution of available resources while maintaining system security. AEMO conducts this process in accordance with clause 3.8 of the National Electricity Rules (NER).
Connection point	The agreed point of electrical connection established between network service provider(s) and a generator or consumer.
Constraint	A physical system limitation or requirement that must be considered by the central dispatch algorithm when determining the optimum economic dispatch outcome.
Consumer	A person or organisation who engages in the activity of purchasing electricity supplied through a transmission or distribution system to a connection point.
Contingency	An event affecting the power system which is likely to involve an electricity generating unit's or transmission element's failure or removal from service.
Demand	The total amount of electricity consumed at any given time. Demand sub-definitions are used for technical purposes and are outlined in AEMO's Demand Terms in EMMS Data Model, available at https://www.aemo.com.au/-/media/files/electricity/nem/security_and_reliability/dispatch/policy_and_process/2020/demand-terms-in-emms-data-model.pdf?la=en.
Demand response	The ability of consumers to vary electricity consumption in response to a change in market conditions, such as a change in the spot price.
Dispatch	The act of initiating or enabling all or part of an offer by a scheduled generating unit, semi-scheduled generating unit, scheduled load, scheduled network service, or ancillary service provider. AEMO conducts dispatch in accordance with NER clause 3.8.
Dispatch schedule	Dispatch instructions AEMO issues to generators (in the central dispatch process) at 5-minute intervals throughout each day, based on offers submitted in the bidding process.
Dispatchability	Extent to which the output of an energy resource or portfolio of resources can be relied on to 'follow a target' and adhere to a dispatch schedule at some time in the future.
Distributed energy resources (DER)	Resources embedded within the distribution network and behind the meter which can be used individually or in aggregate to help balance supply and demand or provide system services. Examples include residential or commercial installations of distributed photovoltaic (DPV), wind turbines, energy storage, demand management systems, electric vehicles (EVs), combustion generators, variable speed motor drives, and cogeneration units. The capabilities of DER depend on the specific technology. AEMO currently has limited visibility of DER.
Distributed photovoltaic (DPV)	Includes both residential and commercial solar panel installations, typically located on consumers' rooftops.
Distribution system	Poles and wires, and other equipment transporting power from the transmission network to end users.
Disturbance	Unexpected events affecting power system operation. Large disturbances include loss of a major transmission line or a large generator or load. Small disturbances arise due to switching on or off small loads, tripping of less significant lines and small generators.
Fast Frequency Response (FFR)	A very rapid response to re-balance megawatts on the power system. May be automatic in response to frequency, or a centrally controlled response (that is, a control scheme to shed load).

Term	Meaning
Frequency	For alternating current (AC) electricity, the number of cycles occurring in each second, measured in Hertz (Hz).
Generation	The production of electrical power by converting another form of energy in a generating unit.
Generation capacity	The amount (in megawatts) of electricity that a generating unit can produce under nominated conditions. The capacity of a generating unit may vary due to a range of factors (for example, the capacity of many thermal generating units is higher in winter than in summer).
Grid formation	Grid formation refers to the ability of the power system to set and maintain frequency. If frequency can be thought of as the heartbeat of the power system, grid formation is like its pacemaker.
Interconnector	A transmission line or group of transmission lines that connects transmission networks in adjacent regions. Can facilitate AC or DC power flow.
Inverter-based resources (IBR)	IBR include wind farms, solar PV generators, and batteries that export power to the grid. They do not have moving parts rotating in synchronism with the grid frequency, but instead are interfaced to the power system via power electronic converters which electronically replicate grid frequency.
Load	A connection point or defined set of connection points at which electrical power is delivered to a person or to another network or the amount of electrical power delivered at a defined instant at a connection point, or aggregated over a defined set of connection points. The term also refers to devices at the end user's location drawing electrical energy from the network and converting it to some other useful form.
Maximum demand	The highest amount of electrical power delivered, or forecast to be delivered, over a defined period (day, week, month, season, or year), either at a connection point or simultaneously at a defined set of connection points.
National Electricity Market (NEM)	The wholesale exchange of electricity operated by AEMO under the NER. NEM regions are New South Wales, Queensland, South Australia, Tasmania, and Victoria.
Non-synchronous generator	See 'Inverter-based resources'.
Operational demand	Operational demand in a region is demand that is met by local scheduled generation, semi-scheduled generation and non-scheduled wind/solar generation of aggregate capacity ≥ 30 MW, and by generation imports to the region, excluding the demand of local scheduled loads. See 'Demand'.
Power	Rate at which energy is transferred through an electrical system. Power is comprised of two components: active power and reactive power. Discussions on energy balance (the balance of supply and demand) are related to active power, while reactive power affects voltages in the system (see also 'Active power' and 'Reactive power').
Power system	The NEM's entire electricity infrastructure (including associated generation, transmission, and distribution networks) for the supply of electricity, operated as an integrated arrangement.
Power system reliability	The ability of the power system to supply adequate power to satisfy consumer demand, allowing for credible generation and transmission network contingencies.
Power system security	Power system security arises when the power system is operating within defined technical limits, and is likely to return within those technical limits after a disruptive event occurs, such as the disconnection of a major power system element (such as a power station or major powerline).
Power system stability	Ability of the power system to return to stable operating conditions following a physical disturbance.
Reactive power	Reactive power, which is different to active power, is a necessary component of alternating current electricity (see also 'Power'). Management of reactive power is necessary to ensure network voltage levels remains within required limits, which is in turn essential for maintaining power system security and reliability.

Term	Meaning
Reactor	A device specifically arranged to be connected into the transmission system during periods of low load demand or low reactive power demand to counteract the natural capacitive effects of long transmission lines in generating excess reactive power and so correct any transmission voltage effects during these periods.
Reliability (of supply)	See 'Power system reliability'.
Reliability standard	The power system reliability benchmark set by the NER. The reliability standard for generation and inter-regional transmission elements in the NEM is a maximum expected unserved energy (USE) in a region of 0.002% of the total energy demanded in that region for a given financial year.
Security	See 'Power system Security'.
Static synchronous compensator (STATCOM)	Regulating device based on a power electronics voltage-source converter that can act as either a source or sink of reactive power to an AC network.
Static VAR compensator (SVC)	A device specifically provided on a network to provide the ability to generate and absorb reactive power and to respond automatically and rapidly to voltage fluctuations or voltage instability arising from a disturbance or disruption on the network.
Supply	The total amount of electricity generated at any given time.
Synchronous condenser	Synchronous condensers are synchronous machines, specially built to supply only reactive power. The rotating mass of a synchronous condenser will contribute to the total inertia of the network from its stored kinetic energy.
Synchronous generator	Generator which is directly connected to the power system and rotates in synchronism with grid frequency. Thermal (coal, gas) and hydro (water) driven power turbines are synchronous generators
System strength	System strength is an umbrella term that refers to a suite of interrelated factors which together contribute to power system stability. It reflects the sensitivity of power system variables to disturbance, and indicates inherent local system robustness, with respect to properties other than inertia. System strength affects the stability and dynamics of generating systems' control systems, and the ability of the power system to both remain stable under normal conditions and return to steady-state conditions following a disturbance.
Technical envelope	Technical boundary limits of the power system for achieving and maintaining the secure operating state of the power system for a given demand and power system scenario. Also called "secure technical envelope".
Transmission grid (Transmission network/system)	Towers, large poles, and wires and other equipment transporting power from generators to large energy users and distribution connection points for routing to downstream consumers.
Voltage	The electrical force or electric potential between two points that gives rise to the flow of electricity.