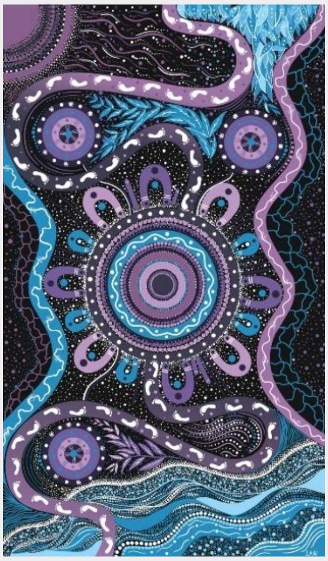
AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

2024 Transition Plan for System Security

December 2024

A report for the National Electricity Market – the interconnected power system in Queensland, New South Wales, Australian Capital Territory, Victoria, South Australia, and Tasmania



We acknowledge the Traditional Custodians of the land, seas and waters across Australia. We honour the wisdom of Aboriginal and Torres Strait Islander Elders past and present and embrace future generations.

We acknowledge that, wherever we work, we do so on Aboriginal and Torres Strait Islander lands. We pay respect to the world's oldest continuing culture and First Nations peoples' deep and continuing connection to Country; and hope that our work can benefit both people and Country.

'Journey of unity: AEMO's Reconciliation Path' by Lani Balzan

AEMO Group is proud to have launched its first Reconciliation Action Plan in May 2024. 'Journey of unity: AEMO's Reconciliation Path' was created by Wiradjuri artist Lani Balzan to visually narrate our ongoing journey towards reconciliation – a collaborative endeavour that honours First Nations cultures, fosters mutual understanding, and paves the way for a brighter, more inclusive future.

Important notice

Purpose

Following the Australian Energy Market Commission's Improving Security Frameworks rule change, AEMO is required to publish the Transition Plan for System Security, specific to clause 5.20.8 of the National Electricity Rules. This publication provides a plan to maintain power system security through the energy transition to a low- or zero-emissions power system. It further outlines the work AEMO is undertaking to improve this understanding and to specify the range of services that may be required. This publication is based on information available to AEMO as of 2 December 2024 unless otherwise indicated.

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Version control

Version	Release date	Changes
1.0	2/12/2024	First release

Executive summary

The Transition Plan for System Security

AEMO is publishing this first annual *Transition Plan for System Security* (Transition Plan) to meet new obligations arising from the Improving Security Frameworks (ISF) rule change[1] in March 2024. This new report outlines a plan to maintain power system security for the National Electricity Market (NEM) through the transition to a low-emissions power system, and complements AEMO's *Integrated System Plan*[2], System Security reports[3], and the Engineering Roadmap program[4].

AEMO maintains power system security with the help of network service providers (NSPs), market participants, and increasingly with the support of consumer energy resources (CER). As the system evolves towards increasing contributions from renewables, additional planning is required to maintain power system security. The Transition Plan communicates this planning through two aspects:

1. Providing a structured approach for maintaining power system security by planning for and navigating key transition points[5], and
2. Defining capabilities and progressing understanding of what is needed to achieve system security in a low-emissions power system. This includes specifying the range of services that will be required and the range of technologies capable of providing them.

Use of Transitional Services

The Transition Plan further reports on the initial steps being taken by AEMO to use the new Transitional Services procurement framework[6] to meet the Transitional Services Objective:

- Type 1 transitional services contracts to procure services necessary for the energy transition that cannot otherwise be provided through existing frameworks.
- Type 2 transitional services contracts to trial new sources of security services or new applications of existing technologies to support system security.
- Australia leads the world in rooftop solar contributions to the power system[7], so significant that at times there may not be sufficient demand available to utilise it efficiently[8]. To support system security at these times of Minimum System Load[9] (MSL), Type 1 contracts are potentially needed in the near term (discussed further in

[1] See https://www.aemc.gov.au/rule-changes/improving-security-frameworks-energy-transition.

[2] See https://aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp.

[3] See https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/system-security-planning.

[4] See https://aemo.com.au/en/initiatives/major-programs/engineering-roadmap.

[5] Transition points are events that require material changes in the approach to managing power system security, described further below and in detail in Section 1.2.1.

[6] At https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2024/transitional-services-guideline-consultation/transitional-services-guideline.pdf.

[7] See https://www.iea.org/reports/australia-2023/executive-summary.

[8] See https://aemo.com.au/-/media/files/learn/fact-sheets/2024/fact-sheet-operating-electricity-grids-with-rooftop-solar-installations.pdf.

[9] See https://aemo.com.au/-/media/files/learn/fact-sheets/2024/rooftop-solar-management-fact-sheet.pdf.

Section 2.1.2 and Section 2.2.2). AEMO is in the initial stages of considering how best to utilise and maximise value from the Type 2 framework (discussed further in Section 3.2.3).

AEMO has recently released a Transitional Services Guideline to develop a procurement approach for these services[10], noting they complement but do not replace other services designed to maintain system security.

Section 1.1.5 and Section 3.2 of this Transition Plan explore AEMO's latest understanding of technology capability to provide security-related essential system services (for example with grid-forming [GFM] inverters). It is not always possible to deliver system security through specified "quantities" of individual services at particular network locations, and the Transition Plan instead considers the power system as a whole to capture interactions and ensure system security under all operating conditions. AEMO remains technology-agnostic and anticipates security services will be able to be provided by an increasing range of technologies in the future.

Power System Security – achieved when controls and services are available to keep the power system operating within defined technical limits and capable of returning it within those limits after credible disturbances. This differs from reliability which concerns the ability to supply adequate power to satisfy consumer demand in accordance with defined standards[11].

Transition Plan for System Security – a new report required by the ISF rule change, outlining a plan to maintain power system security for the NEM through the transition to a low-emissions power system.

Transition Point – events and milestones that require material changes in the operational approach to managing power system security, including:

- Major changes to the asset mix or configuration in the NEM, such as retirement of large synchronous generators.
- Threshold events, such as projected seasons where operational demand could drop below minimum levels.
- Operational shifts as changes in available security mechanisms allow relaxation of constraints such as minimum numbers of online synchronous generators.

Transitional Services Framework – a new framework defined by the ISF rule change, enabling AEMO to procure transitional services necessary for the energy transition that cannot otherwise be provided through existing frameworks (Type 1 contracts), and to trial new sources of security services or new applications of existing technologies (Type 2 contracts).

Horizon planning

To ensure that resources and services will be available to maintain system security throughout the energy transition, provided by both existing and future technologies, the Transition Plan provides details of planning processes over short-, medium- and longer-term horizons:

[10] At https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2024/transitional-services-guideline-consultation/transitional-services-guideline.pdf.

[11] See https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Power-system-requirements.pdf.

- **Horizon 1** – operational planning for known transition points arising over the next two years which must be managed predominantly with today's assets and technology. This could include services being delivered through Type 1 Transitional Services contracts.
- **Horizon 2** – identifying potential future transition points in the two-to-five-year planning horizon to enable early preparation, and defining capabilities and progressing understanding of the security capabilities and services that will be required to manage them. Type 2 Transitional Services contracts could be used to prove relevant technological capabilities for this horizon.
- **Horizon 3** – progressing understanding of all elements of a low- or zero-emissions power system, initiating long lead-time activities (5+ years) that will enable preparation and investment in solutions to meet emerging needs.

AEMO notes that immediate actions are required for all horizons to support adequate preparation for the longer-term energy transition.

Evolving the Transition Plan with the help of stakeholders

Power system security is of critical importance to the energy transition, and AEMO relies on cooperation and support across the energy sector to deliver it. An orderly transition that allows efficient dispatch of the power system's lowest-cost available resources at all times while maintaining system security is in the interest of all stakeholders, particularly consumers.

AEMO's planning processes build and complement the significant analysis completed by stakeholders across the energy sector including NSPs, governments, and market participants. Through this report, AEMO identifies that:

- There are several areas requiring concerted uplift from transmission and distribution NSPs to support system security, and
- The resourcing and efforts required to trial and prove new technologies, assess quantities and locational requirements, and progress through upcoming transition milestones are new, different, and in addition to current activities.

The Transition Plan is intended to evolve over time, based on stakeholder feedback on each publication and AEMO's learnings from the continually evolving power system. Feedback on this inaugural edition will be particularly valuable for enhancing future publications. Stakeholder questions for targeted feedback are included in Section 1.3.2.

Key activities and initiatives

Figure 1 Key activities and initiatives in the Transition Plan for System Security

Now - 2 years | 2 - 5 years | 5+ years

Horizon 1

Now - 2 years: Planning for specific operational transition points, working within the constraints of today's system and available technology.

80% | FOCUS | 20%

Transition point planning

- Enabling operation of South Australia with one synchronous generating unit under certain conditions
- Managing approaching minimum system load events in Spring 2025 (regional) and Spring 2026 (NEM-wide)

Defining capabilities and progressing understanding

- Managing system security when coal and gas generators are offline, alongside new frameworks for system strength and inertia
- Potential contracting of Type 1 Transitional Services to reduce need for directions (e.g., for minimum system load events)

Now - 2 years | 2 - 5 years | 5+ years

Horizon 2

Preparation for 2 - 5 years ahead: Planning for transition points before they arise in operations. Building understanding and defining capabilities of services needed to manage future transition points.

50% | FOCUS | 50%

Transition point planning

- Conducting power system studies for emerging operational transition points
- Preparing for announced retirements of coal stations

Defining capabilities and progressing understanding

- Accelerating demonstration and delivery of essential system services from grid forming inverters
- Developing enduring requirements to support system operation with high rooftop solar contribution
- Potential contracting of Type 2 Transitional Services to demonstrate new technology capability

Now - 2 years | 2 - 5 years | 5+ years

Horizon 3

Preparation for 5+ years ahead: Screening for transition points in the planning horizon. Growing understanding of the requirements of a low-emissions power system. Outlining long lead-time activities to support investment in solutions to meet emerging needs.

20% | FOCUS | 80%

Transition point planning

- Screening for future operational transition points

Defining capabilities and progressing understanding

- Conducting power system studies for operation at up to 100% renewables contribution for periods of time
- Planning for periods when rooftop solar could potentially meet 100% of NEM demand
- Evolving system restart processes and resources

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1 Introduction and overview

1.1 Context

1.1.1 The energy transition

The National Electricity Market (NEM) is rapidly transitioning from large synchronous generators that provide both energy and security services to increasing contributions from a much wider range of non-synchronous technologies. These technologies are being deployed at all levels of the system, including through consumers' own generation and storage resources.

For a power system to operate securely, control of frequency, voltage, stability and resilience to disturbances must be maintained[12]. However, there are opportunities for the mechanisms and resources that deliver security services to evolve through the energy transition. To facilitate this, planning and operational processes must also evolve.

The resourcing and effort required from AEMO and key stakeholders to progress through upcoming transition milestones are new, different, and in addition to current activities. They require continuing close collaboration between AEMO, distribution and transmission network service providers (DNSPs and TNSPs), energy consumers, and the wider energy industry.

1.1.2 The Improving Security Frameworks rule change

In early 2024, the Australian Energy Market Commission (AEMC) made the National Electricity Amendment (Improving security frameworks for the energy transition) Rule 2024 (ISF Rule)[13] which included several measures to address system security issues efficiently and proactively through the transition.

One of these measures added a National Electricity Rules (NER)[14] requirement for AEMO to publish an annual *Transition Plan for System Security* (Transition Plan) by 1 December to convey its understanding of the security needs of the system and how these needs may evolve.

The publication of this initial Transition Plan describes AEMO's planning and coordination with other key stakeholders including network service providers (NSPs), market participants and governments for specific threshold events along the transition timeline, and how AEMO's understanding of the technical requirements for power system security will evolve and be applied in managing the transition.

This view will be updated with additional detail through each annual publication, including the specification and deployment of security-related services.

[12] See https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Power-system-requirements.pdf.

[13] See https://www.aemc.gov.au/rule-changes/improving-security-frameworks-energy-transition.

[14] See https://www.aemc.gov.au/regulation/energy-rules/national-electricity-rules.

NER 5.20.8 Publication of the Transition Plan for System Security

(a) AEMO must publish annually by 1 December the Transition Plan for System Security on its website.

(b) The purpose of the Transition Plan for System Security is to make available to Market Participants and other interested persons an analysis of:

> (1) how AEMO is planning to maintain power system security through the transition to a low- or zero-emissions power system; and
>
> (2) AEMO's current technical understanding of what is needed to achieve power system security in a low- or zero-emissions power system and the work AEMO is undertaking to improve this understanding and to specify the range of services that will be required in a low- or zero-emissions power system.

1.1.3 The Transitional Services framework

The ISF rule changes additionally introduced a new framework for transitional services which allows AEMO to procure security services necessary for the energy transition, and to trial new sources of security services. These consist of:

- **Type 1** contracts, which are for the provision of services that are required for power system security and that cannot otherwise be provided through an existing framework, for example, by an inertia network service, a system strength service or a market ancillary service[15].
- **Type 2** contracts, which are to support trialling new technologies or a new application of existing technologies for the management of power system security in a low- or zero-emissions power system[16.]

AEMO has recently released a Transitional Services Guideline[17] which outlines how AEMO must procure transitional services while meeting the Transitional Services Procurement Objective (TSPO) which balances emissions reduction, power system security, and minimising costs to end consumers[18].

AEMO currently envisages that Type 1 contracts will help secure critical system services required to manage minimum system load thresholds falling within the next two years, as outlined in Section 2.1.2.

AEMO has also identified initial technical priorities for investigation via Type 2 trials, discussed further in Section 3.2.3. Any initial Type 2 contracts entered into will focus on trials and research to build knowledge and capability for managing security through longer-term transition points as the system moves towards low- or zero-emissions operating conditions. Findings from Type 2 trials will be shared in subsequent editions of the Transition Plan and will inform the development of industry understanding of security requirements and enabling technologies for NEM operation at very high contributions of renewable and non-synchronous resources.

The number and scale of transitional services contracts entered into each year will vary depending on AEMO's evolving needs for specific transitional services, and the suitability and availability of potential transitional services

[15] NER 3.11.11(b)(1)

[16] NER 3.11.11(b)(2)

[17] At https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2024/transitional-services-guideline-consultation/transitional-services-guideline.pdf.

[18] NER 3.11.11(c)

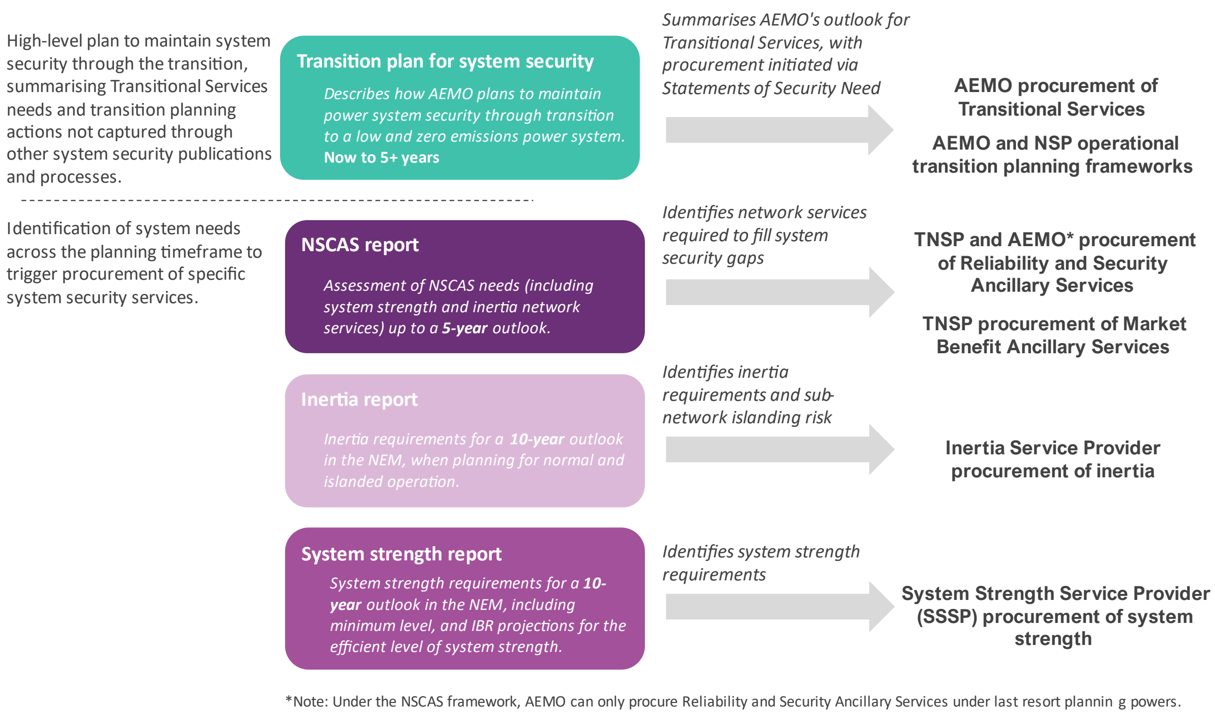
providers. As a general estimate for the initial two-year period, AEMO expects to enter into up to 10 Type 1 contracts, with one or two Type 2 contracts anticipated per year.

1.1.4 Related workstreams and publications

AEMO has previously presented its understanding of the work required to achieve an operational transition to 100% renewables in the *Engineering Roadmap to 100% Renewables*[19]. The Transition Plan builds on this report and other regulatory publications including the *Integrated System Plan* (ISP)[20], the *Electricity Statement of Opportunities* (ESOO) for the NEM[21], the *General Power System Risk Review* (GPSRR)[22], and annual inertia, system strength and network support and control ancillary services (NSCAS) reports[23].

Figure 2 below illustrates the NER obligations for each of the four system security planning reports that AEMO publishes annually by 1 December, and how they interact with procurement of required services. These reports present a view of upcoming required services for system security, whether that be with specific shortfalls as noted by the system security planning reports, or interim service delivery and trials through Type 1 and Type 2 transitional services. The Transition Plan complements these reports, coordinating analysis for specifically identified events, actions and power system phenomena requiring targeted planning and operational focus.

Figure 2 AEMO system security report alignment



[19] At https://aemo.com.au/-/media/files/initiatives/engineering-framework/2022/engineering-roadmap-to-100-per-cent-renewables.pdf.

[20] At https://aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp/2024-integrated-system-plan-isp.

[21] 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.

[22] At https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/system-operations/general-power-system-risk-review.

[23] Reports are published at https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/system-security-planning.

1.1.5 System security services

Historically, large gigawatt-scale power systems were developed with large synchronous generators that supplied all the system's energy as well as the majority of its security-related essential system services such as frequency control, inertia, voltage control, and system strength. Today, the system is transitioning to a supply mix that is dominated at times by generation from variable, inverter-based resources (IBR), both utility-scale and consumer-owned.

To maintain a secure and reliable system, a range of interdependent technical attributes and operational requirements must be met at all times (detailed below in Table 1), with a range of system security services[24] that may be procured to meet these requirements.

Table 1 System security services

System security service framework	Latest understanding including developments in technological capabilities
System strength framework	The AEMC's 2021 *Efficient management of system strength on the power system* rule defined the way AEMO and TNSPs specify and procure the two categories of system strength in the NEM: • Minimum three phase fault levels for each system strength node considering: – Existing requirements based on historical secure power system operation. – Protection system operation needs. – Stable operation of voltage control needs. – Sources of fault current from protection-quality[A] sources with work progressing to understand how inverter-based resources (IBR) could also contribute to this service. • Efficient levels of system strength to maintain stable voltage waveforms for future connecting IBR. AEMO is currently observing increasing interest in application of grid-forming (GFM) inverter technologies in new generator applications to self-remediate system strength impacts. Similarly, TNSPs are considering alternatives to synchronous generation to meet system strength requirements[B] including exploration of opportunities to repurpose existing synchronous generation[C,D]. AEMO is engaging in high level exploratory work to understand the ability of GFM inverters to meet protection system operation needs.
Inertia network framework	Delivery of inertia services to resist large changes in power system frequency. AEMO can also approve Inertia support activities that can adjust the required binding inertia levels. The latest updates to Inertia Requirements Methodology includes a system-wide inertia requirement and definition of synthetic inertia. This is based on previous technical studies on understanding inertia and enables synthetic inertia sources to contribute to meeting inertia requirements, if approved by AEMO according to the Inertia Requirements Methodology, under the ISF Rule. Further work assessing synthetic inertial response from GFM inverters is also underway.
Network support and control ancillary services framework	Delivery of NSCAS procured to control active and reactive power flow into or out of an electricity transmission network to: • Maintain power system security and reliability of supply of the transmission network (Reliability and security Ancillary Services), or • Maintain or increase power transfer capability of the transmission network (delivered through Market benefits ancillary services) AEMO's NSCAS Reports have more recently assessed voltage control under different demand conditions, availability of reactive margins and risks associated with power system ramping events. Voltage control from IBR is written into performance standards and proven at scale.
Transitional Services Framework	Type 1 contracts procure services: • That are required for power system security to resolve immediate concerns in system operation that do not currently have suitable procurement pathways

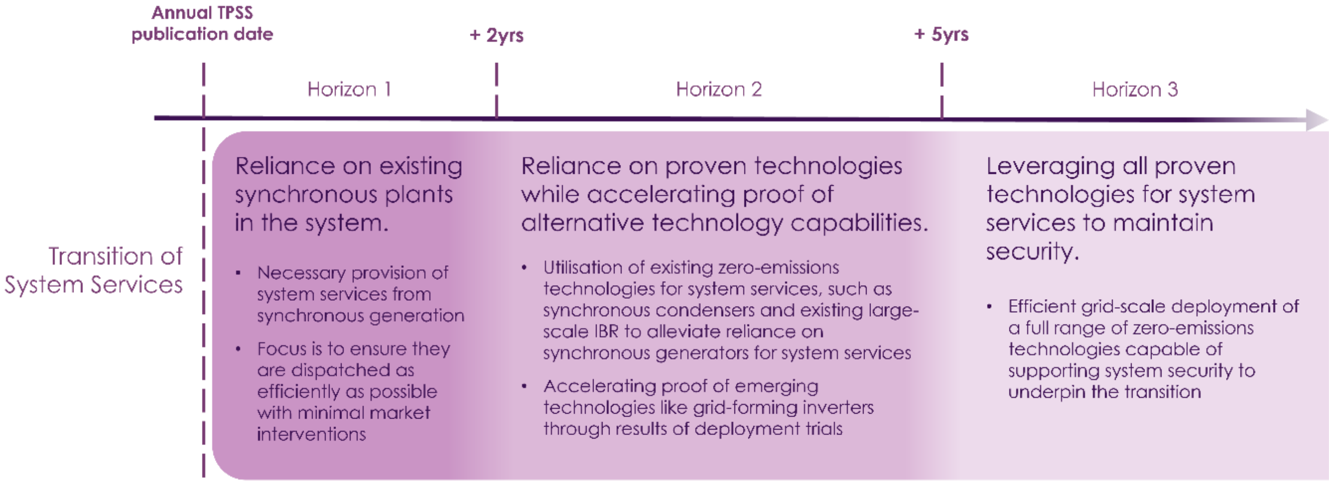
[24] "System Security Services" is a defined term under the NER that does not include FCAS and SRAS. These are included in Table 1 as ancillary services relevant to system security, which IBR and new technologies may deliver.

System security service framework	Latest understanding including developments in technological capabilities
	• Such concerns are typically unforeseen due to the unprecedented system conditions presented by transition to a low- or zero- emissions power system Type 2 contracts procure services that enable trial of new service delivery from new and existing technologies
Frequency control ancillary services (FCAS)	FCAS are market ancillary services, used to ensure sufficient frequency control in the power system to maintain the frequency operating standards for credible contingency events and small supply demand imbalances. IBR plants have proven effective in the FCAS markets, both contingency and regulation, at scale. Though most IBR participating in the FCAS markets is from battery energy storage systems (BESS), both wind farms and solar farms participate in FCAS markets. AEMO notes that the majority of FCAS needs are being delivered increasingly often through BESS.
System restart ancillary services (SRAS)	SRAS services can be: • Black start services to energise portions of the network following a black system event without needing to draw power from the power system, or • Restoration support services that may aid in the re-energisation process of parts of the network following a black system event. To date AEMO has not contracted any IBR sources to provide SRAS but has actively worked towards reducing barriers to participation. The introduction of restoration support services provides opportunities for new technologies to participate in system restoration even if they are not black start capable.

A. AEMO's May 2024 update to the 2023 ESOO noted that minimum fault level requirements "must be delivered by devices that can provide protection-quality levels of fault current – such as new synchronous condensers, service contracts with existing hydro or thermal units, or through the retrofit of those existing units themselves". See page 43 at https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/nem_esoo/2023/may-2024-update-to-the-2023-electricity-statement-of-opportunities.pdf.
B. Transgrid's preferred option to meeting the efficient levels of system strength includes 14 new synchronous condensers and 4.8 gigawatts (GW) of new GFM battery energy storage systems (BESS). See Transgrid (2024) Project Assessment Draft Report (PADR) for meeting system strength requirements in New South Wales, page 5, at https://www.transgrid.com.au/media/fo0maqsh/2406-transgrid_meeting-system-strength-requirements-in-nsw-padr.pdf.
C. Digsilent for ARENA (June 2023) Repurposing existing generators as synchronous condensers – Report on technical requirements, at https://arena.gov.au/assets/2023/06/repurposing-existing-generators-as-synchronous-condensers-report.pdf.
D. Powerlink identified the retrofitting of Townsville gas turbines (GTs) to include clutch capability as the least-cost option to address the system strength shortfall at Gin Gin. See Powerlink (January 2024) Request for Power System Security Services in Central, Southern and Broader Queensland Regions – Final Report Part 2: System Strength at Gin Gin, at https://www.powerlink.com.au/sites/default/files/2024-01/Request%20for%20Power%20System%20Security%20Services%20-%20Final%20Report%20Part%202%20-%20System%20Strength%20at%20Gin%20Gin.pdf. Similarly, Transgrid's preferred option for meeting efficient levels of system strength includes 14 new synchronous condensers and 4.8 GW of new GFM BESS; see Transgrid (2024) PADR for meeting system strength requirements in New South Wales, page 5. at https://www.transgrid.com.au/media/fo0maqsh/2406-transgrid_meeting-system-strength-requirements-in-nsw-padr.pdf.

AEMO anticipates a staged transition away from emissions-intensive synchronous generators, as shown in Figure 3.

Figure 3 System services transition timeline



AEMO's view is that there are significant challenges to achieving secure power system operation solely through a suite of specific system security services. While a range of services can currently be procured from both a planning and operational perspective, the technical envelope of the power system is assessed by considering how the systems perform in aggregate under a range of operating conditions. These conditions must include a range of specific physical configurations of assets – including network topology, generating plant and power output.

System security is currently achieved through constraints in the dispatch process and by maintaining secure generating unit commitment configurations, after assessment of the system as a whole. In planning timeframes, these findings are quantified into *system security services* for the purposes of common metrics for procurement (such as megawatt seconds [MWs] for inertia and megavolt amperes [MVA] for fault level). In both cases, the underlying concept remains the assessment of system configurations to identify gaps and assessing viable asset configurations that incorporate solutions to meet these gaps.

However, it is not necessarily the case that these asset configurations represent the only secure solutions, and it is not AEMO's intent for these assessed configurations to limit the range of viable dispatch outcomes.

AEMO anticipates a similar assessment process will occur for Type 1 contracts procured through the Transitional Services Framework.

While transitional service contracts may not necessarily translate into enduring system security service requirements, AEMO will incorporate findings from transitional services to inform any future needs for new or modified system security services that may be considered for future enduring framework changes, which could in turn reduce or remove the need for Type 1 transitional service procurement. AEMO expects the application of these contracts to also aid the building of operational experience to validate desktop assessments, and inform the build of network assets.

1.1.6 Operational metrics for power system security

AEMO assesses the operation of the power system within the technical operating envelope as defined in the NER and reports on operational performance in its annual report[25]. This includes but is not limited to meeting the frequency operating standard[26], staying within voltage limits, and meeting inertia and system strength requirements in real time.

AEMO also currently considers two additional operational metrics relevant to the energy transition – the level of renewable contribution and potential (Figure 4), and the use of directions for system security (Figure 5).

Renewable contribution records provide a high-level view of system capability to run at progressively higher instantaneous levels of renewables. Trends in the use and cost of directions provide insight into the operability of the power system considering the manual actions required by AEMO's control room to manage power system security. Together, the metrics highlight a consistency in the number and cost of quarterly directions (noting exceptions for the 2022 winter market suspension event[27]) while renewable contributions continue to increase.

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[25] See page 13 of AEMO's 2024 Annual Report, at https://aemo.com.au/-/media/files/about_aemo/annual-report/2024/annual-report-fy24-vfinal.pdf.

[26] At https://www.aemc.gov.au/market-reviews-advice/review-frequency-operating-standard-2022 and https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/system-operations/ancillary-services/frequency-and-time-deviation-monitoring.

[27] See https://www.aer.gov.au/system/files/AER%20June%202022%20Market%20Events%20Report-%20FINAL%20VERSION%20-%2014%20December%202022.pdf.

Figure 4 NEM actual and potential instantaneous renewable contribution

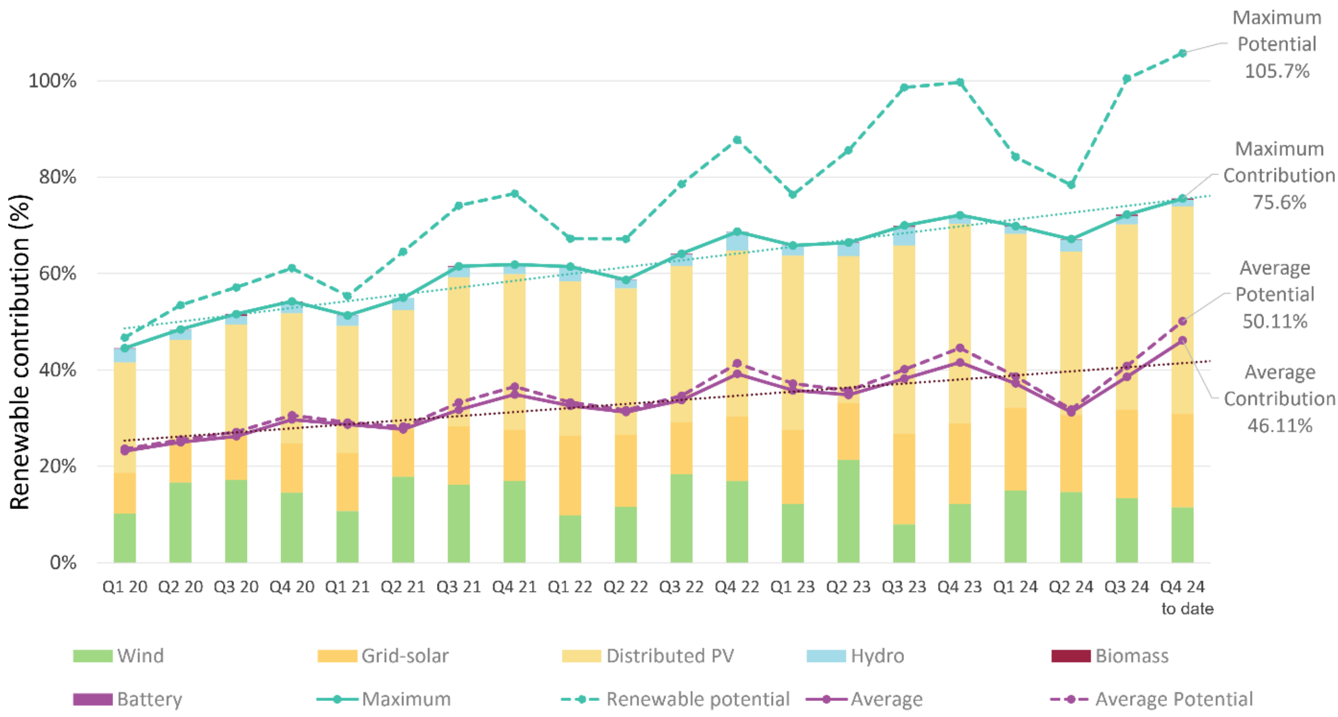
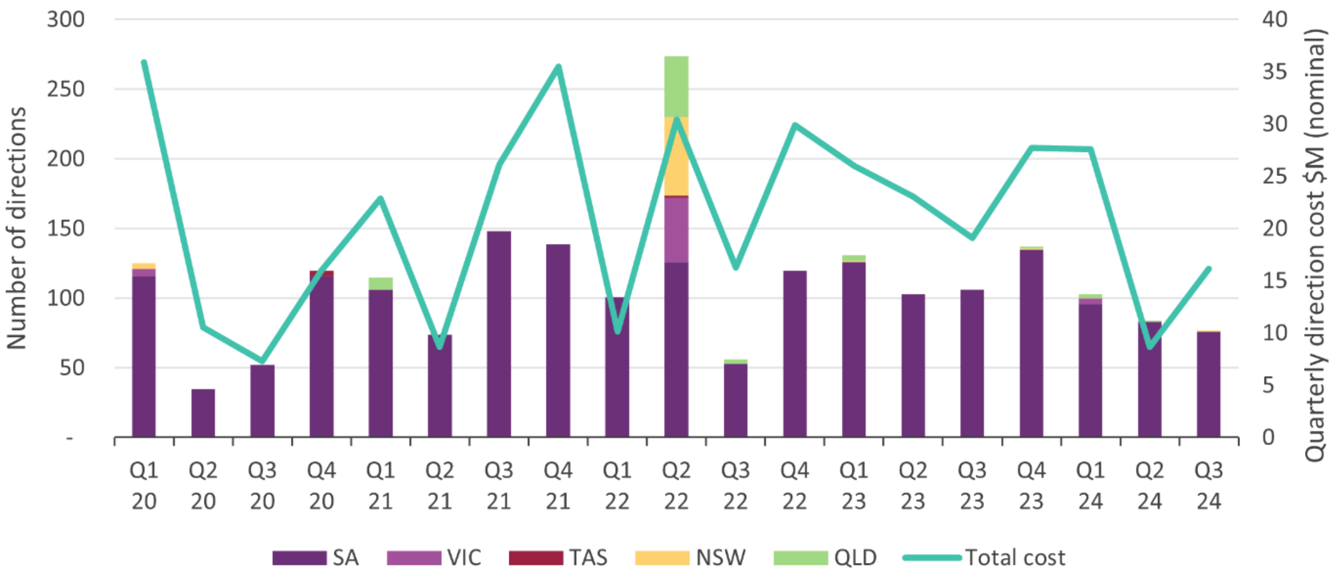


Figure 5 Trends in the use of directions



AEMO, in collaboration with TNSPs, is also undertaking further work to develop resiliency metrics to capture changes in power system resilience through the transition. Power system resilience is defined as the ability to limit the extent, severity, and duration of system degradation following an extreme event[28]. Future metrics for resilience may include consideration of:

[28] See https://www.cigre.org/article/defining-power-system-resilience.

- Diversity of bulk energy resource availability.
- Reliance on double circuit corridors.
- Changes to the availability of system restart-capable units.

AEMO will report on any identified and assessed metrics in future versions of the Transition Plan.

1.2 Approach

Managing the energy transition in operational timeframes will continue to require careful consideration of and planning for significant step changes in the composition of the system, such as the retirement of large coal-fired generators. Understanding and expanding the scope for, and scale of, alternative sources able to provide system security services, via existing or new technologies, and the timeframes in which this can occur, is a critical part of this planning. The rapidly growing role of new power system resources including consumer energy resources (CER) means that mechanisms that more fully enable their participation in and coordination with system and market operation are vital to maintaining system security and reliability at lowest cost to consumers (see Section 2.1.2).

The Transition Plan is structured accordingly, around two key approaches which tie back to its two purposes specified in the NER:

- Transition point planning provides a structured approach for maintaining power system security through the transition (addressing NER 5.20.8(b)(1)).
- Building understanding and developing capability to deliver future power system security requirements in a low- or zero-emissions power system will expand the options and services available to manage future transition points as they are identified and enter operational timeframes (addressing NER 5.20.8(b)(2)).

These two approaches are summarised in the following sections.

1.2.1 Transition points

Where there is a major change in the availability or operation of assets that the power system relies on for system security, or where its evolution reaches a critical threshold, AEMO will use a formal transition point framework to ensure the system remains secure during and after these identified transition points. As the system evolves, successful navigation of such changes requires joint consideration of both system security and other operational requirements as an integrated process.

Transition points may take the form of:

- Major changes in the asset mix or configuration of the NEM, such as large synchronous generators retiring or regularly decommitting from the market,
- Threshold events, for example operational demand falling below regional and NEM-wide minimum secure levels for maintenance of voltage and frequency control, driven by distributed photovoltaic (DPV) generation peak output growth in conjunction with low underlying consumption, and
- Operational shifts as changes in available security mechanisms allow relaxation of constraints such as minimum numbers of online synchronous generators.

AEMO presented a series of preconditions associated with operational, technical and engineering requirements as part of the *Engineering Roadmap to 100% Renewables*. These form key assessment criteria for transition points and create a structured workflow which ensures a comprehensive view and alignment with other Engineering Roadmap activities. A summary of the Engineering Roadmap themes and groupings is listed below in Table 2).

Table 2 Engineering roadmap themes and grouping

Theme	Roadmap sections
Power system security: maintaining the secure technical operating envelope of the power system under increasing renewable contributions	Frequency and inertia Transient and oscillatory stability System strength and converter driven stability Voltage control System restoration
System operability: the ability to securely and reliably operate the power system and transition through increasingly complex operating conditions	Monitoring and situational awareness Operational processes Power system modelling
Resource adequacy and capability: building and integrating the energy resources and network capability to enable the renewable potential and the flexible capacity to balance variability over different timeframes	Utility-scale variable renewable energy (VRE) Consumer Energy Resources (CER) / Distributed energy resources (DER) Structural demand shifts Transmission Distribution Firming

In operational timeframes (those considered under the Projected Assessment of System Adequacy [PASA] timeframes of up to 36 months[29]), management of these transition points involves detailed governance and coordination requirements, informed by earlier forward analysis and planning. Identification of potential future transition points relies on data gathered through operations and a broad range of planning, forecasting and information provision activities regularly undertaken by AEMO, network operators and market participants.

1.2.2 Building capability and understanding

Identification of transition points is necessary but not sufficient in planning for the energy transition. AEMO must cater for a range of plausible futures and potential security challenges so that:

- Necessary system capabilities can be defined,
- Existing and new technical solutions for service provision can be identified and tested, and
- The understanding of system requirements can continue to grow.

Much of the work described in AEMO's Engineering Roadmap publications falls into this final category. The Transition Plan describes how results of this work informs planning for different stages of the transition.

[29] See https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2023/reliability-forecasting-guidelines-and-methodology-consultation/final/mt-pasa-process-description.pdf.

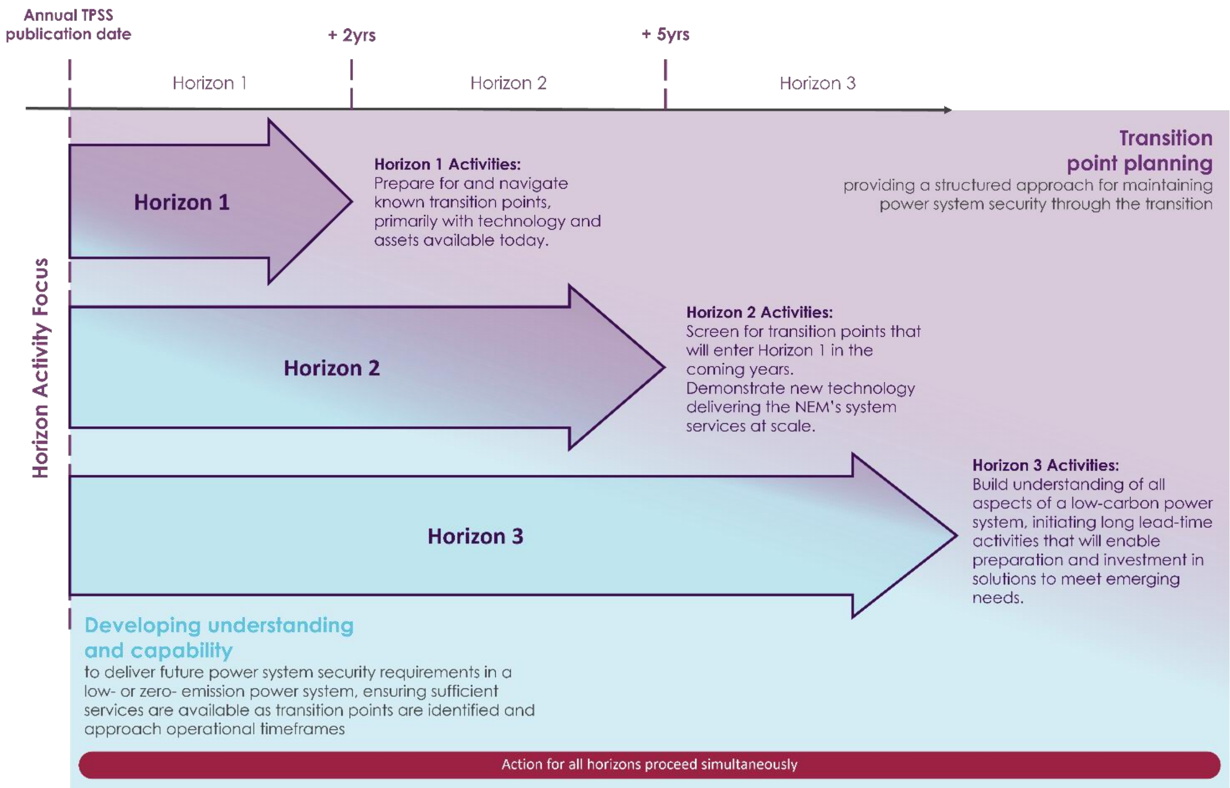
1.2.3 Combining approaches across three horizons

In combination, the above two approaches seek to ensure that system requirements at every point in the transition can be met. AEMO's transition planning efforts for a low- or zero-emissions power system aim to remove barriers ahead of time, so the power system is capable of operating securely with increasing contributions from renewable generation when the market dispatches it. Anticipating and removing engineering and operational barriers to efficient dispatch supports the ability of the market to access the lowest cost sources of energy at all times.

Efforts to address short-, medium- and long-term security challenges need to progress in parallel. This report uses three time horizons, all of which require immediate focus as described in the following sections of this report:

- **Horizon 1** (near-term, next two years) – planning for specific transition points, working within the constraints of today's system and available assets and technology (Section 2).
- **Horizon 2** (medium-term, two to five years ahead) – preparing for transition points before they arise in operations, and building understanding and defining capabilities of services needed to manage future transition points (Section 3).
- **Horizon 3** (longer-term, beyond five years) – screening for future transition points in the planning horizon, growing understanding of the broader requirements of a low-emissions power system, and outlining long lead time activities to support investment in solutions to meet emerging needs (Section 4).

Figure 6 Activity focus across Horizons



NER 5.20.8(b)(1)	how AEMO is planning to maintain power system security through the transition to a low- or zero-emissions power system.
NER 5.20.8(b)(2)	AEMO's current technical understanding of what is needed to achieve power system security in a low- or zero-emissions power system and the work AEMO is undertaking to improve this understanding and to specify the range of services that will be required in a low- or zero-emissions power system

Immediate actions are required across all horizons to support the energy transition, but the division of effort between transition point planning and capability-building varies for each horizon.

1.3 Future development

1.3.1 Annual updates

The Transition Plan will be updated annually, with future editions considering:

- Progress with identified transition points, including their movement between horizons.
- Newly identified transition points and associated actions and initiatives.
- AEMO's use of Type 1 and Type 2 transitional services, in particular how learnings from Type 2 technology trials inform future activities.
- Other security-related initiatives underway through the Engineering Roadmap.

1.3.2 Stakeholder input and engagement

Responses to the Engineering Roadmap FY2025 Priority Actions report

In publishing the latest update to the Engineering Roadmap, AEMO invited feedback on the form and content of the Transition Plan. Feedback received included:

- Requests for information on the opportunity for service provision.
- Highlighting potential impacts of "two-shifting" practices of coal units during the day.
- Implications for the connection of renewable energy zones (REZs).
- Requests for further information regarding Minimum System Load (MSL) management.
- The importance of forward visibility and detail of upcoming transition points.
- The criticality of coordination between AEMO and NSPs on transition planning studies and tools.

Reliability Panel review

Under the ISF Rule, after the Transition Plan is published AEMO will be required to consider, and in the next Transition Plan respond to, any Reliability Panel input. This input would be in the form of targeted written public commentary from the Panel, provided within six months of AEMO publishing each edition of the Transition Plan.

Forward stakeholder engagement plan

Coordinated and collaborative engagement across the entire energy sector is vital to deliver an effective, efficient, and timely transition plan. Through this report, AEMO identifies that:

- There are several areas requiring concerted uplift from TNSPs and DNSPs to support system security, and

- The resourcing and efforts required to trial and prove new technologies, assess quantities and locational requirements, and progress through upcoming transition milestones are new, different, and in addition to current activities.

AEMO also recognises increasing interactions between CER and power system security management frameworks and continues to build stakeholder engagement to support this. AEMO seeks feedback from any interested stakeholders on the following points to inform development of subsequent Transition Plans.

Questions

1. What information should AEMO include in subsequent Transition Plans for System Security to help stakeholders navigate upcoming transition points?
2. Where is additional effort required to maintain system security while transitioning to higher contributions of renewables?
3. What potential Type 2 transitional services may support renewable contribution towards 100%?
4. How would you like to be engaged for the development and publication of the *Transition Plan for System Security*?

Interested parties are encouraged to submit feedback to these questions **to futureenergy@aemo.com.au by 1 March 2025.**

There will be further opportunities to engage with AEMO and inform the content and approach of both the Engineering Roadmap and Transition Plan. Interested parties are encouraged to contact futureenergy@aemo.com.au to register for updates.

2 Horizon 1

Horizon 1 transition points comprise well-defined and quantifiable changes in power system resources or operating conditions expected to occur within a two-year timeframe which require material changes in managing the system's security envelope. They are characterised by relatively short lead times for ensuring that resources and processes are in place to efficiently manage these changes.

Transition points in Horizon 1 have been identified through AEMO's operational processes and a range of planning, forecasting and information provision activities regularly undertaken by AEMO, network operators and market participants. Related work includes:

- AEMO's System Security Planning functions, ESOO projections, ISP preparation, and GPSRR.
- Transmission Annual Planning Reports prepared by network operators or planning bodies.
- Engagement with NSPs through the National Electricity Market Operations Committee (NEMOC) and other AEMO forums.
- Operational reporting such as incident reports and the recently published *Supporting Secure Operation with High Levels of Distributed Resources*[30] report.

2.1 Transition point planning

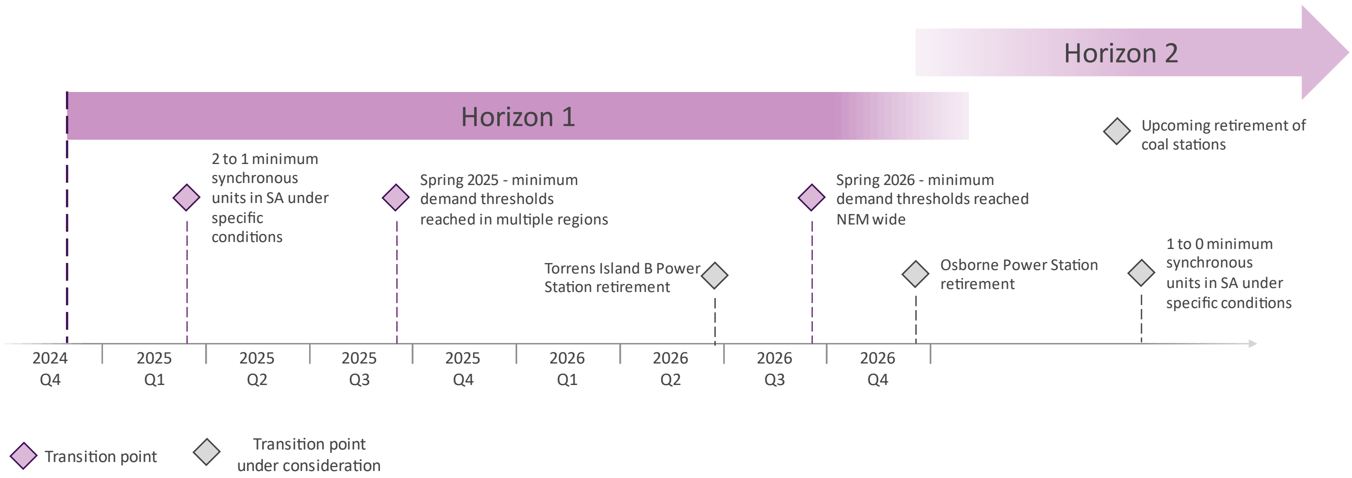
As AEMO continues to establish its transition planning efforts, several Horizon 1 points have already been identified and addressed through our normal operational processes, for example AEMO's seasonal readiness activities. As the transition planning process evolves, the aim is for transition points to enter Horizon 1 having been identified previously as longer-term (Horizon 2 and 3) potential transition points, and with significant preparatory work already undertaken.

In Horizon 1, the emphasis on preparing for and managing transition points is highly operational, with detailed planning, coordination and governance required.

[30] At https://wa.aemo.com.au/initiatives/major-programs/nem-distributed-energy-resources-der-program/managing-distributed-energy-resources-in-operations/managing-minimum-system-load.

Figure 7 below includes the transition points considered in this report for Horizon 1. Planning for transition points in purple is included in detail in Sections 2.1.1 and 2.1.2 below, while the changes in grey are currently under consideration by AEMO as other potential transition points that may also require dedicated preparation. This includes some considered categories for potential Horizon 2 transition points, such as planning for announced coal station retirements within the next five years.

Figure 7 Horizon 1 transition points considered in this report



For this first edition of the Transition Plan, AEMO has grouped the transition points in Figure 7 into Section 2.1.1 and Section 2.1.2 below:

- Section 2.1.1 transition points relate to progressing operational shifts in the form of a reduction in the level of directions for synchronous units in South Australia at times, driven by continued change in the energy resource mix. AEMO is assessing each region for Horizon 1 transition point planning on a prioritised basis, with material transition points occurring in South Australia first. Future iterations of this report are expected to include more region-based transition point planning.
- Section 2.1.2 considers transition points in the form of minimum demand thresholds, which could bind first in Victoria this summer and Queensland in spring 2025, followed by a coincident NEM-wide minimum threshold. Thresholds and their projected dates are based on known constraints and current forecasts and are driven by the continued rapid growth in DPV capacity.

For each Horizon 1 transition point in this report, activities are grouped by the relevant roadmap sections of AEMO's *Engineering Roadmap to 100% Renewables*[31].

2.1.1 Reducing minimum synchronous unit requirements in South Australia

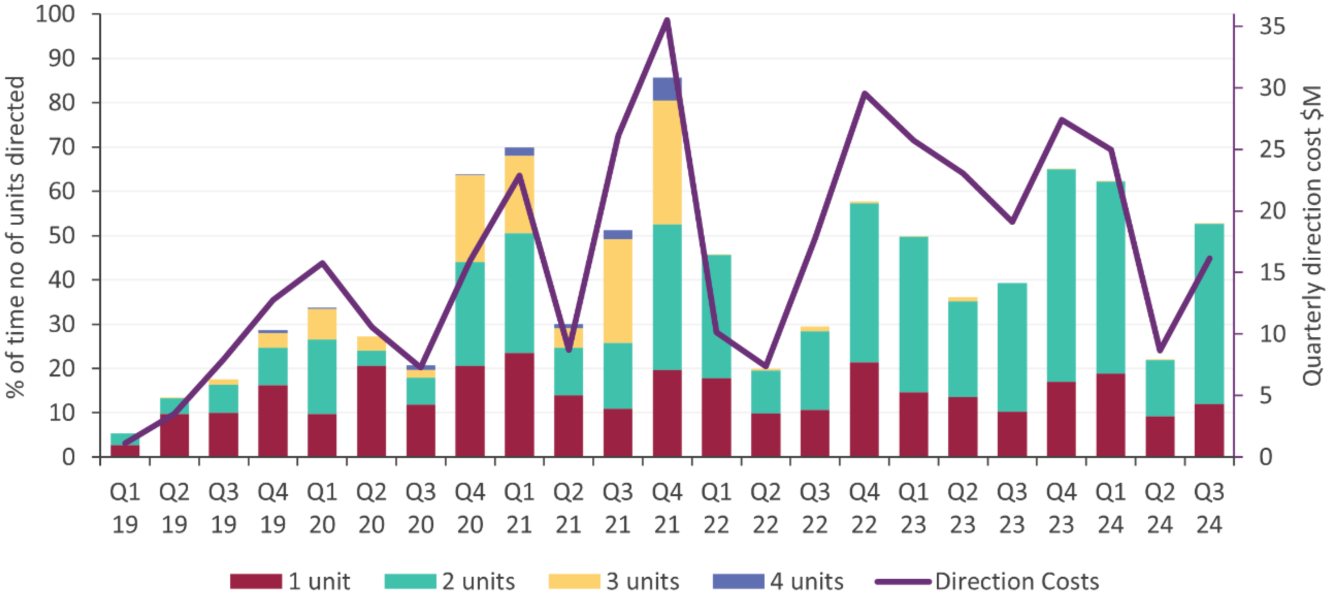
South Australia has continued to experience constant and rapid change in the energy resource mix with increased wind, solar and battery storage technologies. AEMO has focused much attention on understanding how to operate the South Australian power system securely within technical limits and reduce reliance on AEMO intervention.

[31] At https://aemo.com.au/-/media/files/initiatives/engineering-framework/2022/engineering-roadmap-to-100-per-cent-renewables.pdf.

Past operational milestones in South Australia have included operating with DPV contribution equivalent to 100% of regional demand, and a reduction in the minimum number of online synchronous generating units from four to two. These milestones were only possible through the deep collaborative efforts of the South Australian energy sector, including the concerted engineering uplift to maintain power system security under these conditions. The activities undertaken in South Australia over the past two years include establishing last resort DPV curtailment mechanisms, improvement in rooftop solar compliance with technical standards through closer coordination between SA Power Networks, AEMO and original equipment manufacturers (OEMs), and the detailed power system studies and operational readiness that have supported the ongoing reduction in the minimum number of synchronous generators online.

While commissioning of ElectraNet's four synchronous condensers in Q4 2021 led to an immediate reduction in the extent of system security directions required to keep sufficient synchronous generation online (Figure 8), the need for directions has remained significant, with substantial ongoing costs to maintain at least two large synchronous generating units online at all times.

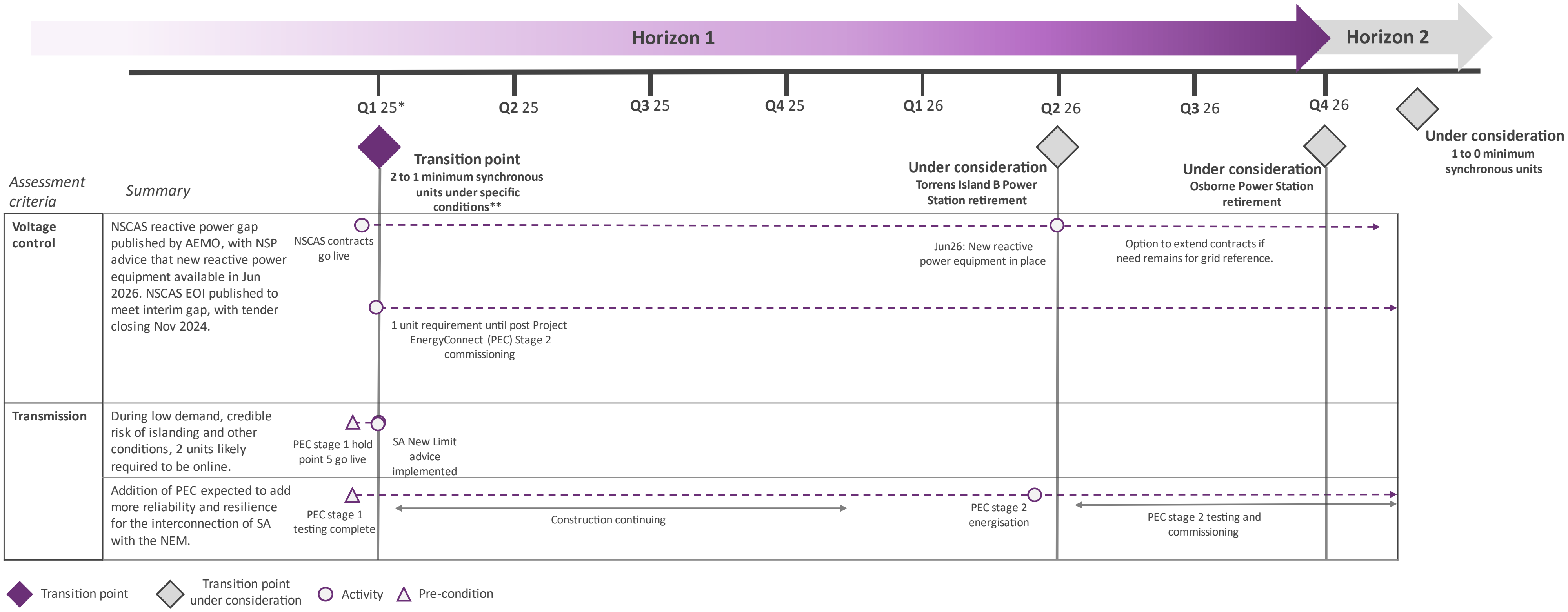
Figure 8 South Australian security directions: proportion of time by number of directed units, direction costs quarterly



AEMO is now focused on how to securely reduce the number of synchronous generators required online in South Australia from the current minimum of two large units, enabling a reduction in accompanying directions, as well as preparing for the retirement of two synchronous gas-fired stations within the operational horizon.

Figure 9 includes the expected dates for these transition points to occur, and the activities required to address any gaps in system requirements and other assessment criteria to ensure these milestones are achieved securely. Further detail on each of these criteria is included in the sub-sections below.

Figure 9 Assessment criteria and activities relating to South Australia Horizon 1 transition points



PEC: Project EnergyConnect, EOI: expression of interest.

* When referring to quarters throughout this diagram, work is due to be completed either during, or by the end of the calendar year quarter.

** This refers to operation with as few as one synchronous unit and will only apply under specific conditions. Refer to the information box below for further detail.

Conditions for operation with one synchronous generating unit in South Australia

When conditions allow AEMO to maintain system strength, inertia, voltage control and grid reference to adequate levels, the number of synchronous units required to be online in South Australia may be reduced to a single unit.

Example conditions where the number of synchronous units required to be online in South Australia *cannot* be reduced to a single unit include:

- Periods where any of the four synchronous condensers are not available.
- When there is insufficient reactive plant available.
- Where there is the loss of any circuit on the Heywood interconnector or during periods where Heywood is reclassified as a credible contingency.
- During low demand conditions.
- Some cases where weather reports forecast the potential for a large ramp event.
- When fast start generation is unavailable, either maintain two units online, or maintain one unit online and direct one unit to remain warm such that it can ramp within 30 minutes following the credible contingency trip of a generator.

There are other transition points expected to occur for South Australia within, or shortly outside, this period (listed below) which AEMO is also preparing for, however dedicated plans have not been developed for these events, because analysis of the risks they might present to power system security is ongoing. This will include assessment as to whether they can be successfully navigated under existing operational planning frameworks, without the need for dedicated transition point planning.

AEMO has also decided to include these points below for transparency and if determined that these changes require dedicated transition point planning, they will be included in future iterations of this report:

- **Torrens Island and Osborne Power Station retirements** – the expected power station retirement dates, as advised by the plant owners, have been listed as transition points for which AEMO will need to work with the local NSP and Jurisdictional System Security Coordinator to remove these power stations from the operational procedures, and assess the impact on power system security. The impact on reliability will be included in the NEM ESOO.
- **1 to 0 synchronous units in South Australia** – within the Horizon 2 timeframe, it is expected that South Australia will transition to periods of operation with no synchronous units online. To ensure voltage control is adequate under these conditions, this transition point may be considered after Horizon 1 and following Project EnergyConnect (PEC) stage 2 commissioning.

Voltage control

ElectraNet limits advice has determined that one synchronous generator is adequate to meet voltage control and reactive power requirements in the Adelaide metropolitan area when the operational demand in South Australia is high enough and a certain number of reactive power control devices around Adelaide metropolitan area are online. Based on this limits advice, AEMO published an NSCAS gap in December 2023. Ongoing work in this space includes:

- ElectraNet is progressing a transmission network voltage control regulatory investment test for transmission (RIT-T) that will identify mitigation measures for the management of transmission network voltages as a function of reducing South Australia demand, which includes four new reactors. These reactors are expected to be in place in June 2026.
- AEMO has published an NSCAS expression of interest (EOI) to meet the gap between now and June 2026. These contracts are expected to go live by Q1 2025 and enable the transition away from directions for voltage control to begin.
- South Australia could be operated with one unit where operational demand is high enough such that transmission line voltages can be maintained within 0.9 and 1.1 per unit (pu) post credible contingency. This will vary based on the availability of reactive power control equipment. A single unit is expected to be required to maintain grid reference until PEC stage 2 commissioning is complete.

Transmission

There are two critical areas being addressed in relation to transmission infrastructure to enable a reduction in the number of synchronous units online in South Australia:

- The ability to re-secure the power system following a contingency event.
  - AEMO has an obligation under NER 4.3.1 to maintain power system security in accordance with the general principles stated in NER 4.2.6 by returning the power system to a secure operating state within 30 minutes of a credible contingency event. With current transmission infrastructure, two synchronous units online will likely be required depending on the availability of fast start units, and other operating conditions (for example reclassification of lines, severe weather warnings etc). PEC stage 1 hold point 5 is a pre-condition required to enable the implementation of South Australia's new limit advice for operation with less than two synchronous units, along with the abovementioned NSCAS contracts.
- Improved reliability and capacity of the interconnection of South Australia with the rest of the NEM.
  - The addition of PEC will also increase the reliability and capacity for the interconnection of South Australia with the rest of the NEM:
    - The advised completion date of PEC stage 1 testing during Q1 2025 will increase reliability by enabling higher transfer capability from Victoria.
    - Construction of PEC is anticipated during 2025, with advised dates for inter-network testing and release of power transfer capability falling in Q2 2026.

Completion of PEC stage 1 is a pre-condition to both challenges.

2.1.2 Integrating consumer energy resources

The growth of consumer energy resources

Australians continue to invest in DPV and other CER at world-leading levels. More than one-third of homes across the country now host rooftop solar systems, helping households and businesses reduce their energy bills and directly contributing to the decarbonisation of the energy system.

There are increasingly frequent periods where DPV generation is very high relative to current levels of underlying daytime consumption and generation that exceeds household usage is exported to the local distribution system or even further upstream. Underutilised DPV output represents a major opportunity for consumers and businesses to capitalise on abundant cheap electricity by shifting more consumption to the middle of the day, reducing energy costs. CER and behind the-meter flexibility (including electric vehicle [EV] and home or neighbourhood battery charging) can be harnessed to better utilise high DPV generation.

Concerted efforts to enable coordination and integration of DPV and CER within the power system as uptake continues will support the secure and reliable delivery of electricity to all consumers now and into the future.

This is a complex task given the millions of individual consumers and devices involved, the large number of stakeholders across the CER ecosystem and supply chain, and the extent of integration and coordination required across different systems and parties. Effective integration of CER involves the intersection of power system engineering, technological innovation, consumer choice and experience, and government policy.

Impacts on minimum operational demand and system security

Increasing growth in peak DPV output without offsetting growth in consumption or storage means that demand drawn from the transmission system – operational demand – will fall to lower and lower minimum levels. This is posing challenges to both distribution network and bulk power system operation, especially in sub-regions and regions with higher DPV uptake relative to local load.

Minimum operational demand in the NEM has been falling on average more than 1.2 gigawatts (GW) per year as maximum DPV output grows, and is projected to continue on this trajectory unless consumption in the middle of the day grows faster than current projections[32]. During these periods, there is limited demand being supplied from the main transmission system. At present, the power system relies on large-scale synchronous generators to deliver a range of system security services. In doing so, these generators must operate at or above minimum safe operating levels (MSOLs). In periods of very low operational demand, the limited amount of large-scale generation required means that it may not be possible to dispatch sufficient synchronous generation above MSOLs to deliver these essential security services.

A range of solutions to these challenges is being actively considered, noting that implementation through regulatory mechanisms can take some time but the need for action is already urgent, particularly in some regions.

Section 3.2.2 in Horizon 2 outlines opportunities to:

- Reduce the amount of generation that needs to remain online to provide essential services.

[32] See Section 7.6 of the 2024 ESOO, 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.

- Increase demand and energy storage capacity through market integration.

Operational requirements to maintain security during Horizon 1 minimum demand periods

- Horizon 1 actions focus on immediate operational measures required to maintain system security in the current environment. Options, some of which may be enabled through the Transitional Services Framework, include:
- Reducing generation from non-essential generating units (scheduled, semi-scheduled, and non-scheduled).
- Utilising the capability of large-scale battery units to store excess energy.
- Decreasing DPV generation.
- To manage high risk, low demand periods that may occur (for example under some transmission outage conditions), an "emergency backstop" capability is required to allow emergency curtailment of DPV when needed to maintain system security at times of oversupply when other options are insufficient.

"Emergency backstop" capability refers to operational measures to reduce aggregate DPV generation if required for system security.

If there are insufficient emergency backstop capabilities, alternative and even higher impact interventions may be needed, such as:

- Distribution voltage management – in some regions, it is possible to increase distribution voltages to the level required to deliberately trip/curtail DPV. This is a valuable backup mechanism to resecure the system if needed in rare emergency events but should not be used on a regular basis. It may require jurisdictional support to operationalise.
- Shedding of reverse-flowing feeders – the only mechanism remaining to increase operational demand to the levels required would be to shed entire feeders that are in reverse flows (for example, 11 kilovolts [kV] or 22 kV circuits). This would also shed all consumer load on the feeder and have a very high impact on homes and businesses.

The National CER Roadmap

In July 2024, Australia's Energy Ministers agreed to a National CER Roadmap[33], building on advice from the Energy Security Board (ESB) around critical technical capabilities for ongoing power system security. The CER Roadmap sets out an overarching vision and plan to unlock CER at scale and identifies measures to "unleash the full potential of CER" by establishing the required mechanisms, tools and systems. This includes both:

- Reforms to increase the opportunities for market participation of CER, including through enhanced coordination, allowing customers to respond to market-based incentives which will also help meet the challenges of low operational demand. This is discussed further in Section 3.2.2.
- Measures to support ongoing power system security, particularly the requirement for "backstop mechanisms to be in place" by the end of 2025 for "emergency response to ensure operational security when required".

[33] See https://www.energy.gov.au/sites/default/files/2024-07/national-consumer-energy-resources-roadmap.pdf.

Work program to support secure operation with high levels of DPV and CER

AEMO is working on all these options, including through the National CER Roadmap, supported by findings published through compliance reporting, the Engineering Roadmap Priority Actions reports and the ESOO.

The ESOO identified rapidly falling minimum operational demands as a challenge to secure operation and provided analysis of drivers and potential solutions[34]. The recently published report *Supporting secure operation with high levels of distributed resources*[35] provides a thorough analysis of minimum system load challenges and actions to manage them. The following content in this section provides a brief summary of information from this report, mapped to Horizon 1 transition points.

Figure 10 shows indicative timeframes for when active preparation of emergency backstop capabilities is required during Horizon 1. Specifically, to prepare for secure operation during MSL events within the two-year window of Horizon 1, AEMO's focus is on creating and implementing operational procedures which can be in place in advance of the relevant season in which forecast MSL events may first occur.

Having operational processes in place will ensure adequate planning and preparedness for secure operation at these thresholds and will include the operation of tools such as backstop capability and transitional services. For MSL events in Horizon 2 and 3, further analysis and studies must be completed to identify sustainable long-term solutions to managing continuing downward trends in operational demand.

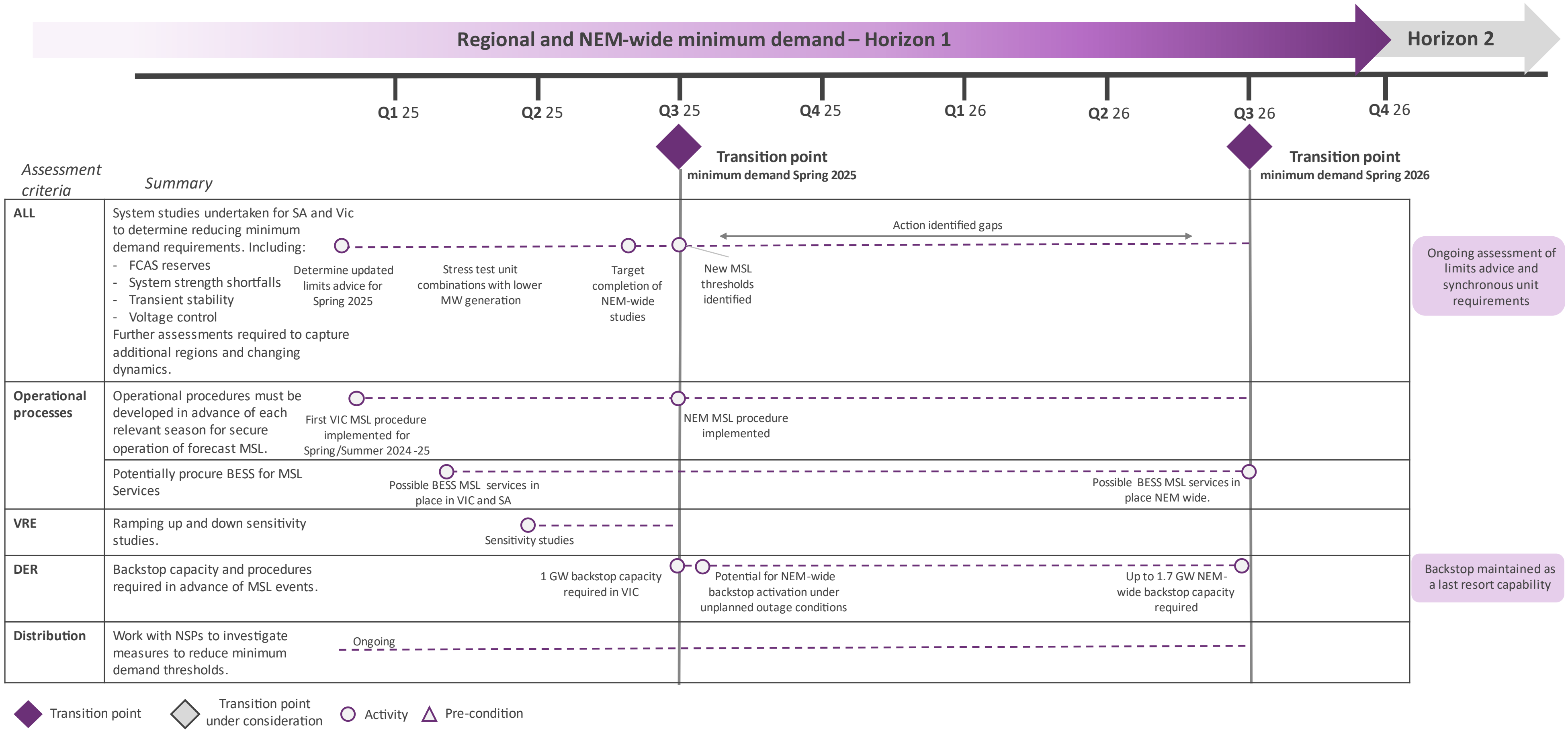
Other measures already underway in Horizon 1 will also contribute to increasing the visibility and predictability of CER by more accurately estimating and forecasting the locational and aggregate megawatts (MW) contribution of CER, including:

- Uplifting data quality of the Distributed Energy Resources (DER) Register by the end of Q2 2025.
- Implementation of the 'Integration of Price Responsive Resources' rule change to incentivise virtual power plant (VPP) participation.

[34] See sections 2.4 and 7.6 of the 2024 ESOO, 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.

[35] At https://wa.aemo.com.au/initiatives/major-programs/nem-distributed-energy-resources-der-program/managing-distributed-energy-resources-in-operations/managing-minimum-system-load.

Figure 10 Minimum demand transition points



*When referring to quarters throughout this diagram, work is due to be completed either during, or by the end of the calendar year quarter.

Spring 2025 – minimum demand thresholds reached in multiple regions

South Australia, Victoria and Queensland have already reached the point where the 90% probability of exceedance (POE) forecast of minimum operational demand is lower than their respective secure thresholds in conditions with plausible outages.

This means forecasts of demand for which there is a 90% probability of exceedance, that is, a 10% probability that the annual minimum demand will be equal to or lower than the 90% POE value for a given year. These therefore represent rare, but plausible, conditions for which AEMO needs to prepare in accordance with its obligations to maintain a secure operating state.

In these conditions, maintaining system security may require activation of all available actions to increase demand, potentially including high-impact actions such as shedding of reverse flowing feeders.

The next transition point is expected by spring 2025, encompassing further progression of regional challenges[36]:

- The New South Wales/Australian Capital Territory region 90% POE minimum demand forecast passes the secure threshold for outage conditions. At present, there is no legislative mechanism requiring DPV systems to have active management capabilities in the New South Wales region. AEMO is engaging with governments and NSPs on introduction of an emergency backstop capability in line with the New South Wales CER Strategy[37] action item to consult on emergency measures.
- South Australia, Victoria and Queensland 90% POE minimum demand forecasts reduce to beyond the point where the projected capability of actions to increase demand is sufficient to meet secure thresholds.

Key operational activities needed to help manage these conditions include:

- Progressing backstop capabilities to ensure coverage on all new DPV systems.
- Analysing transmission system needs in low demand periods.
- Establishing MSL procedures in collaboration with NSPs and impacted participants.
- Potentially procuring Type 1 transitional services to maintain demand above thresholds.

Operational processes

As identified above, new operational procedures will be needed by AEMO's control room to manage minimum demand periods across more regions in the NEM. To date, South Australia and Queensland already have operational processes, with Victorian procedures recently developed and implemented in preparation for the current 2024-25 spring/summer[38]. These include potential directions for battery energy storage systems (BESS) to achieve a low state of charge immediately prior to MSL 3 events, such that the BESS can increase demand by charging during the MSL 3 event.

[36] For more details, including regional forecasts, thresholds and detailed actions, see *Supporting Secure Operation with High Levels of Distributed Resources,* at https://wa.aemo.com.au/initiatives/major-programs/nem-distributed-energy-resources-der-program/managing-distributed-energy-resources-in-operations/managing-minimum-system-load.

[37] See New South Wales Consumer Energy Strategy 2024, at https://www.energy.nsw.gov.au/sites/default/files/2024-09/NSW_Consumer_Energy_Strategy_2024.pdf.

[38] See *Victorian Minimum System Load Procedure Overview*, at https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/power_system_ops/2024-11-01-vic-msl-procedure-factsheet_final.pdf.

In advance of spring 2025, as operational demand continues to fall and power system needs evolve, operational procedures and processes will need to adapt accordingly. Actions which may be undertaken by AEMO include:

- Identification and potential procurement of MSL management services from BESS (as a Type 1 Transitional Service), to reduce the use of directions to BESS.
- Addition of processes for the New South Wales/Australian Capital Territory region that consider backstop capability, and development of NEM-wide studies.
- Extending existing South Australia and Queensland procedures to consider system normal (beyond only island or outage events).
- Complete review of existing procedures to ensure they remain fit for purpose as changes occur (such as changes to constraints, or changes to minimum loading thresholds).

Frequency control

System studies of frequency control are needed to assess system needs during operation of low demand periods – specifically, studies to consider adequate supply of frequency reserves during these periods and the impact of fast frequency response (FFR) from BESS to manage large credible contingencies (for example, under high Victoria to New South Wales export conditions). To determine this impact, studies will be undertaken as a priority, beginning in Q1 2025 and completed prior to Spring 2025.

System strength

During minimum demand periods, there will be reduced synchronous generators online to provide system strength. Further assessments are needed across regions to ensure that sufficient unit combinations exist during operation of minimum demand periods. To increase confidence, AEMO intends to stress test and review these combinations under very low load conditions in preparation for the 2025 spring season.

Transient and oscillatory stability

Transient and oscillatory stability studies for the spring 2025 transition point will need to focus on the assessment of the system normal export transient stability limit and calculating the limits of the Victoria – New South Wales interconnector (VNI) during low demand conditions.

To date, the VNI thermal limit has been deemed sufficient under MSL conditions, however it is expected that VNI export limits (transient and voltage stability limits) will reduce considerably if one or more transmission elements are out of service in parts of Victoria and New South Wales.

Voltage control

Work on uplift of voltage management modelling and limits advice is required by January 2025 in preparation for implementation of new MSL procedures for spring 2025. To date, updated Victorian voltage management advice has been prepared and implemented in advance of summer 2024-25. However, this analysis will need to be repeated for lower demand projections for spring 2025.

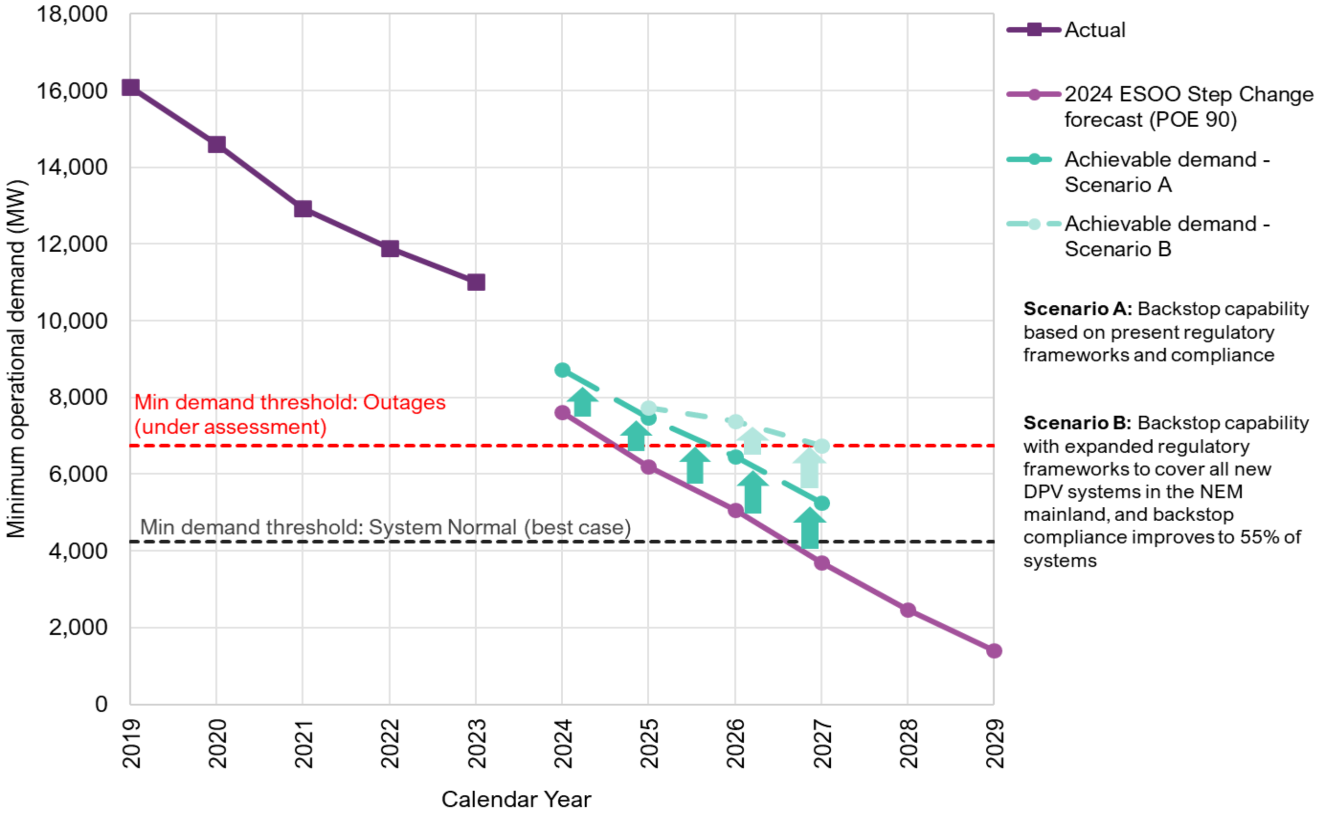
Variable renewable energy (VRE)

It is anticipated that under full interconnected conditions, ramping up capability and reserve requirements are deemed sufficient for Victoria. However, under Victorian and South Australian island conditions, ramping up and down sensitivity analysis is required to confirm if there is sufficient capacity to meet ramping events, including during minimum system load events. This will increase confidence of operation during spring 2025 minimum system load events.

Spring 2026 – minimum demand thresholds reached NEM wide

Additional to the regional issues, these challenges are also projected to emerge for the whole NEM as early as spring 2026. Figure 11 below, adapted from AEMO's 2024 ESOO[39], illustrates the potential for system security challenges to be observed during the Horizon 1 period and provides an indication of scenarios to help delay the risk. AEMO estimates that a minimum NEM-wide operational demand of approximately 4.3 GW (black dotted line) is required to support the minimum generation levels of units providing required essential services across the NEM, with the present operational toolkit. Further, AEMO estimates that under outage conditions (which are most likely to occur during spring) the minimum operational demand threshold increases to 6.8 GW (red dotted line). Considering the forecast minimum demand, this means that under emergency conditions (involving unplanned outages) action which increases demand on the transmission network may be required as a last resort to maintain power system security across the whole NEM during Horizon 1.

Figure 11 NEM-wide minimum demand thresholds



The current estimated capability of emergency backstop mechanisms accounting for these factors is shown in Figure 11 under two scenarios. Scenario A represents the current frameworks and compliance levels. On this

[39] See Figure 44, 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.

trajectory, NEM-wide 90% POE minimum demand forecasts fall below the point where the projected capability of actions to increase demand remains adequate to meet secure thresholds in scenarios with plausible outages. This transition point corresponds to greater than 80% of underlying demand being met by DPV and larger non-scheduled PV generation.

Scenario B represents extended coverage of backstop to apply to all new DPV in the NEM mainland along with significant improvements in compliance in all regions. This highlights that in Horizon 1, not only is backstop capability (that is already underway) critical to keep demand above outage and system normal thresholds, but that a major uplift in compliance and scalability across other regions is also needed to maintain system security during these events.

Power system requirements

Completion of dedicated NEM-wide MSL studies based on AEMO's current understanding of minimum unit requirements is expected to be completed by the middle of 2025 to ensure timely identification of any power system requirement gaps. This will also assist in developing operational procedures in time for spring 2026.

Operational processes

New operational procedures for the management of NEM-wide minimum demand are required by spring 2026.

AEMO will review the need for Type 1 transitional services to maintain demand above thresholds in New South Wales and Queensland. Backstop mechanisms will be required in all regions. Generator directions and constraints may be required to maintain minimum numbers of synchronous units online in each region. The available tools will be integrated into AEMO MSL procedures, ensuring appropriate actions are taken in a timely manner to maintain system security. If there are insufficient emergency backstop capabilities, alternative higher impact interventions may be needed, such as shedding of reverse flowing feeders or distribution voltage management (whereby local voltages are deliberately increased to trigger inverters to trip).

Distribution

The minimum demand thresholds included in Figure 11 above are based on the known current levels of generation that must remain online to provide essential system services. Measures to change these thresholds, including working with NSPs to utilise technologies that can deliver system services during low demand periods, are discussed in Horizon 2 (Section 1), alongside CER-related activities that will enable DPV and CER participation in scheduling and market mechanisms to help increase operational demand during minimum demand events.

2.2 Defining capabilities and progressing understanding

The ISF rule change requires AEMO to both describe the work being undertaken to understand and achieve power system security in a low-emissions power system, and to specify the range of services that will be required[40].

In the Horizon 1 timeframe, meeting power system security needs will include procuring proven technologies to maintain real-time power system security, particularly as synchronous generation is increasingly displaced by

[40] NER 5.20.8

renewables (Section 2.2.1). The ISF rule change provides a framework to address the evolution of the power system toward high IBR generation without reliance on directions for synchronous units through the use of scheduled services to meet system security needs (Section 2.2.2).

2.2.1 Managing the decommitment of synchronous generation

When projected market dispatch results in a solution outside of the secure technical operating envelope, AEMO needs to intervene in the NEM, typically through directions to market participants. Similar to South Australia, Queensland, New South Wales and Victoria all currently require minimum synchronous generation combinations to be maintained online for system security. In each of these regions AEMO has previously had to direct generation online to maintain power system security.

Coal generators have recently trialled switching off during the middle of the day to avoid periods of negative pricing. The term "decommitment" is used to include both these and other times when coal and gas generators go offline.

Currently, instances where market dispatch for Queensland, New South Wales, Victoria and Tasmania result in a solution outside the secure technical operating envelope are rare. Going forward, the frequency of these events will change, depending on:

- The pace of growth in IBR connections, including CER, and
- The way synchronous generators make their capacity available to the market. For example, increasing exposure to negative wholesale pool prices may lead generators to amend their trading strategies.
- Should these occurrences become more frequent, and where relevant to the technical operating envelope of the region and the planning required to achieve it, AEMO may consider defining further Horizon 1 transition points.

When looking at options to move beyond the currently defined secure operating combinations, AEMO will need to ensure sufficient levels of system strength and inertia are available. AEMO will also need to assess other system security requirements, including voltage control and oscillatory stability, and ensure operational tools and processes are able to cope with the changing system conditions.

The ISF rule change provides a framework to address the evolution of the power system toward high IBR without reliance on market intervention. Under this framework, AEMO is required to both describe the work being undertaken to understand and achieve power system security in a low-emissions power system, and to specify the range of services that will be required.

In the Horizon 1 timeframe, this will include upcoming service provision arrangements required for AEMO and system strength service providers (SSSPs) to prepare for times when market outcomes would not result in the dispatch of minimum synchronous generation combinations required to maintain system security, including ensuring minimum levels of inertia and system strength are available. Actions required now could include scheduling contracts entered into by SSSPs with synchronous machines, investment for new synchronous machines, or other innovative solutions. Given the urgency of investment required to maintain a secure system within this operational timeframe, any delays in the delivery of these solutions risk the need for additional power system interventions. Section 2.2.2 describes the work underway to implement scheduling arrangements for these services.

2.2.2 Scheduling of system services contracts

AEMO reports annually on the system needs for system strength, inertia, and NSCAS across the planning timeframe[41], triggering procurement processes for system services to address these needs. as discussed in Section 1.1.4 and Section 1.1.5.

From 1 December 2025, AEMO is required to schedule these system security services. Where AEMO identifies a gap in system needs, these services can be scheduled from 12 hours ahead of the period for which the gap is identified. Scheduling for system security will evolve the NEM's dispatch framework, requiring preparation by both AEMO and the market. AEMO will develop a scheduling system in a phased approach, with the first phase from 1 December 2025 expected to include a manual approach to bidding and operating these services. Future implementation phases will increase the automation of bidding and enablement.

The scheduling of system security services will help provide power system requirements through service-based arrangements, reducing the need for AEMO to direct synchronous plant online. This may especially assist during the autumn and spring seasons when transmission and synchronous generation outages are typically scheduled. These outages are becoming increasingly difficult to schedule due to a reliance on key assets to maintain system security. This is expected to worsen in the short to medium term as AEMO increasingly relies on the remaining synchronous generators online to provide power system requirements during MSL events that usually occur during these shoulder seasons. Scheduling for system security services will assist with reducing the need to direct plant online for system security, easing pressure on outage schedules.

[41] At https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/system-security-planning.

3 Horizon 2

Now - 2 years | 2 - 5 years | 5+ years

Horizon 2

Preparation for 2 - 5 years ahead: Planning for transition points before they arise in operations. Building understanding and defining capabilities of services needed to manage future transition points.

50% | **FOCUS** | 50%

Transition point planning

- Conducting power system studies for emerging operational transition points
- Preparing for announced retirements of coal stations

Defining capabilities and progressing understanding

- Accelerating demonstration and delivery of essential system services from grid forming inverters
- Developing enduring requirements to support system operation with high rooftop solar contribution
- Potential contracting of Type 2 Transitional Services to demonstrate new technology capability

Where Horizon 1 activities address near-term transition points, the focus of Horizon 2 activities shifts towards a mix of i) transition point planning and ii) progressing capability for solutions that may be required in the next two to five years.

Planning for potential transition points requires identification and then assessment, with early identification supporting stakeholders to make earlier planning and investment decisions. Possible Horizon 2 transition points can be identified through operations and the broad range of planning, forecasting and information provision activities regularly undertaken by AEMO, NSPs and market participants. In addition, AEMO is:

- Conducting detailed studies for identified future transition points, and
- Developing future power system models that complement and augment existing planning processes.

Section 3.1 discusses the work currently underway on these activities, focusing on transition point planning and power system model development.

Horizon 2 activities also seek to progress understanding to accelerate the readiness of technical, regulatory, and operational solutions to system security challenges likely to arise in this timeframe.

Section 3.2 outlines initiatives to define capabilities and progress understanding, including for the security and operability challenges with very high contribution of DPV, enabling CER/DER market participation, and improving understanding of grid-forming (GFM) inverters.

3.1 Transition point planning

A key part of Horizon 2 preparation involves identifying upcoming transition points in the planning time horizon, before they reach operations. Some of these transition points have already been identified (such as the Eraring retirement, discussed further below), while others may require ongoing assessment through existing processes to determine whether they will require dedicated management as individual transition points.

3.1.1 Identifying Horizon 2 transition points

Transition points beyond Horizon 1 can be informed by engineering judgement and emerging trends in the current power system including:

- Anticipated retirement, or more frequent decommitment, of large coal-fired power stations.
- Increasing contribution of DPV reducing operational demand
- Increasing variable generation in geographically concentrated REZs affecting power flow conditions and contingency size.
- Anticipated widespread deployment of new system strength solutions which could include synchronous condensers, the conversion and/or altered operation of existing synchronous plant, and GFM BESS.
- Ongoing introduction of new technologies such as GFM inverters.
- Increasing contribution of fast acting IBR to provide various system security services such as FCAS and inertia.
- Network topology changes that will unlock more hosting capacity in the system in specific locations that may encourage the connection of additional plant and equipment in these locations.
- Uptake of inverter-based load in various parts of the NEM.
- Rapid pace of transition that may see multiple changes occurring at once.

In addition, AEMO is becoming increasingly aware of the complexities and difficulties associated with planning network outages for maintenance, new connections and other routine inspection activities. While medium- and longer-term system security assessments typically focus on traditional (N-1) criteria (that is, the ability to remain in a satisfactory operating state following a single contingency event), there is an increasing need to develop forward-looking plans to prepare for issues including:

- Managing more complex attributes of power system security when the system cannot be operated intact.
- Ensuring that processes and mechanisms are able to return the system to a secure operating state following a contingency event, irrespective of the state of the network just prior.
- Each of the above trends, or combinations of them, may manifest into a transition point that requires detailed analysis.

Once identified, transition points and possible consequences need to be understood in greater detail, often through the development of new and complex power system modelling. AEMO is looking to develop and implement analysis, methods and indicator metrics to help efficiently identify future operability challenges that could help determine any additional unidentified transition points.

3.1.2 Power system studies of transition points

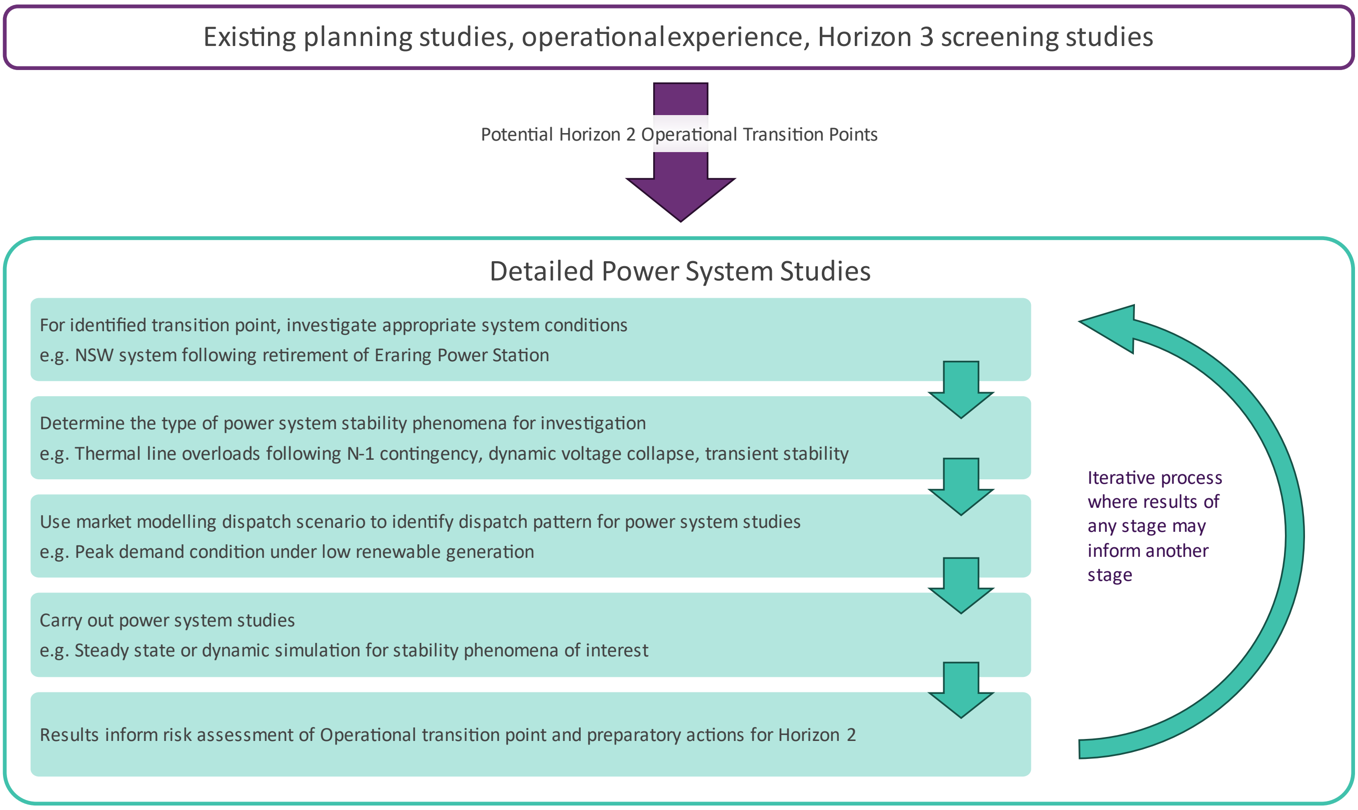
Extending existing model capability

Assessing the impact of potential transition points requires detailed consideration. Studies are required for each transition point to quantify risks on power system security and thereby inform any needs for investment or changes to processes. Early clarity on risks and consequences supports greater stakeholder confidence in investment and planning decisions, ahead of transition points manifesting in Horizon 1 timeframes.

In designing these studies, it is worth noting that AEMO and TNSPs currently conduct a range of planning studies[42] to signal investment in the Horizon 2 timeframe. The results of these existing studies complement and can be used to inform any further detailed studies as part of transition planning.

Figure 12 below provides a high-level overview of the anticipated process followed for undertaking detailed studies.

Figure 12 High level proposed process overview



Detailed power system modelling capability is available to understand the impacts of near term transition points on *today's power system* (see Section 3.1.3 on coal retirement), but there is an urgent need for robust, fit-for-purpose power system models that deliver studies with appropriate levels of confidence for upcoming transition points.

Developing forward-looking power system models

In Horizon 1, AEMO can generally rely on existing models and study tools for power system studies. This is because of greater certainty in available study parameters and established study processes. To adequately study potential transition points in Horizon 2 however, it is necessary to develop fit-for-purpose, forward-looking power system models. It is impractical to enhance the confidence level of forward-looking power system models by

[42] See AEMO system security reports at https://www.aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/system-security-planning, and also state TNSP planning documents (TAPRs).

calibrating them against past, real power system performance, which is the normal model validation process. This is because the validity of today's power system performance under the forward-looking scenarios will largely be unknown.

Studies of a future system are inherently complex and will require assumptions due to:

- The uncertainty of dynamic behaviour of the future generation fleet. Under the NER, generators seeking connection are allowed to negotiate performance standards with AEMO and NSPs. The power system models of existing and committed generators reflect the agreed performance standards, while the performance standards of future generators will depend on the outcome of the negotiation process, before being adequately reflected in their models. Furthermore, the existing power system modelling framework allows AEMO to request and receive site-specific models of the plant. Where available, these models then go through rigorous testing and validation processes to provide confidence in their accuracy. Such an option is not possible for future generator and network models.
- The uncertainty of solution delivery to meet system security services. Under the NER, TNSPs are responsible for providing certain essential services such as inertia services and system strength services. There are a range of potential solutions to meet future system security needs, such as synchronous condensers and GFM inverters. The performance and modelling of such devices will vary based on their design, installation location, the combination of different types of devices to be installed in the power systems, and will be further complicated by unforeseeable technology innovation, and future regulatory framework changes which will govern the performance of these devices.
- The uncertainty of timely delivery of network augmentation. While this challenge is currently being addressed by existing planning procedures through scenario planning exercise and sensitivity analysis, the assumption of delivery timeframes of critical network augmentations can affect the negotiation of relevant generator performance standards and the specification of essential services.
- The uncertainty in future dispatch patterns. While market modelling outcomes do provide some information about the future generation dispatch pattern and power flow conditions future generation dispatch pattern and power flow conditions could fall outside the operating envelope of the power system. These would require careful examination and nontrivial modifications to be translated for power system studies.

To address these challenges and to allow forward transition point planning activities to be undertaken with confidence, AEMO is taking the following actions:

- Developing future models of generators and relevant network augmentations, based on existing knowledge of technology and model performance.
- Testing forward-looking models following existing guidelines and established industry best-practice. For example, when developing future generator models, the Dynamic Model Acceptance Guidelines or other relevant model function test procedures can be followed to ensure the device models are of high quality.
- Adopting scenario-based modelling and sensitivity analysis. For example, scenarios can be developed based on most generators of certain types of technology and performance levels, different service provision combinations, and perform sensitivity analysis to understand the criticality of certain factors on the overall power system stability phenomena.

These detailed power system models are different from the economic models used to develop the ISP, instead considering the detailed electrical phenomena of bulk power system operation. AEMO engages with, and relies on, NSP advice for many of the above, and will continue to collaborate for these objectives. AEMO is additionally engaging with system operators and the international research community to develop these models.

AEMO anticipates that Horizon 2 studies will also help inform Horizon 3 screening studies to help identify and plan for Horizon 3 transition points.

3.1.3 Assessing retirement of coal powered stations

Given the significant potential impact of ongoing coal retirements on multiple power system requirements, in combination with other changes to the power system detailed in Section 3.1.1, AEMO considers it prudent to systematically assess the retirement (or potential decommitment) of coal-fired power stations within Horizon 2 to determine whether they require dedicated management as potential operational transition points.

Employing the methodology detailed in Section 3.1.2, this analysis builds on previous planning studies[43] performed by AEMO and TNSPs which have typically looked at projected future system conditions at a future point in time, in a region in aggregate, rather than dedicated focus on a single station. AEMO expects this work to complement existing planning studies and has progressed detailed assessment of impacts to system security following retirement of Eraring Power Station (expected to retire in August 2027[44]).

The retirement of Eraring will have a considerable impact on power system operation in New South Wales, with fewer synchronous units available, contributing to a known shortfall in system strength[45]. While the detailed study process of Eraring might account for other changes in the New South Wales power system such as the entry of Central Orana REZ and new large BESS, it is not the focus of these studies. Stakeholders who are interested in these aspects are directed towards other AEMO and Transgrid planning publications[46].

Rather, the detailed studies being conducted here consider scenarios informed by historical operating conditions that have led AEMO control rooms to resort to the following operational levers to manage power system security:

- Recalling planned network outages.
- Activating temporary limits advice that reflects the security requirements of the actual system configuration.
- Providing directions to generators or other market interventions.

The objective of these power system studies for Eraring is to examine power system operating conditions that are occurring for a limited amount of time. These operating conditions would not typically warrant investment in the planning timeframe but could become significantly more challenging to manage with a reduced synchronous fleet.

In doing so, these studies help assess operational preparedness in managing the power system post-Eraring retirement. Early outcomes of these studies suggest a reduced portfolio of options to supply demand and ensure

[43] See state TAPR reports from respective TNSPs, and AEMO system security planning reports at https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/system-security-planning.

[44] See https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/nem_esoo/2024/2024-electricity-statement-of-opportunities.pdf.

[45] See https://www.aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/system-security-planning.

[46] See AEMO planning publications at https://www.aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning, and Transgrid planning report at https://www.transgrid.com.au/tapr.

system security, concurrent with limited flexibility in network infrastructure, which could lead to a potential reduction in system resiliency.

AEMO expects to follow a similar process for other potential transition points such as Yallourn Power Station and Callide B Power Station, both due to retire in 2028[47], noting that AEMO will also be assessing the relative priority of needing to study these further retirements against other potential transition points identified through Section 3.1.1 and Section 4.1.1.

3.2 Defining capabilities and progressing understanding

The ISF rule requires AEMO to both describe the work being undertaken to understand and achieve power system security in a low-emissions power system, and to specify the range of services that will be required.[48]

In Horizon 2 timeframes, meeting power system security needs will involve a combination of continuing to rely on proven technologies such as synchronous condensers while accelerating the integration and uptake of emerging technologies such as GFM inverters (see Section 3.2.1). To further support the transition in Horizon 2, AEMO has workplans established to enable:

- The effective and secure integration of very high levels of DPV into the grid, including navigating minimum system demand, participation of DER in scheduling and market mechanisms (Section 3.2.2), and
- The introduction of transitional services discussed further below (Section 3.2.3) and in the Transitional Services Guideline[49].

3.2.1 Grid-forming inverters

The role of GFM inverters is becoming increasingly important as the energy transition continues. This technology is defined in AEMO's Voluntary Specification for Grid-forming Inverters[50] as: "*A grid-forming inverter maintains a constant internal voltage phasor in a short time frame, with magnitude and frequency set locally by the inverter, thereby allowing immediate response to a change in the external grid. On a longer timescale, the internal voltage phasor may vary to achieve desired performance*".

This control philosophy gives GFM inverters the potential capability to provide a broader range of system security services than the grid-following (GFL) inverters traditionally used by renewable generators.

AEMO and industry participants are currently working to understand, trial and accelerate the capability of GFM inverters. This work will confirm the range of security services that can be provided, and the extent to which GFM inverters can help substitute for synchronous generation. These capabilities will increasingly be required for many transition points in the Horizon 2 timeframe and beyond as the system evolves to a low- or zero-emissions future.

[47] See https://www.aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-planning-data/generation-information.

[48] NER 5.20.8

[49] At https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2024/transitional-services-guideline-consultation/transitional-services-guideline.pdf

[50] At https://www.aemo.com.au/-/media/files/initiatives/primary-frequency-response/2023/gfm-voluntary-spec.pdf

Table 3 provides a summary of AEMO's existing and planned publications related to GFM inverters and their capability to provide system security services.

Table 3 AEMO publications related to GFM inverters

Publication	Date	Achievements/objectives
Application of Advanced Grid-scale Inverters in the NEM[51]	Aug 2021	Identified the need for GFM inverter proof at scale
Voluntary Specification for Grid-Forming Inverters[52]	May 2023	GFM inverter capabilities defined for power system security.
Testing Framework for Grid-Forming Inverters[53]	Jan 2024	Simulation test methods developed to determine whether GFM inverters will provide expected power system security benefits.
The Role and Need for Inertia in a NEM-Like System[54]	May 2024	Developed understanding of synthetic vs. synchronous inertia in the NEM to guide regulatory change.
Quantifying Synthetic Inertia of a GFM BESS – Technical Note[55]	Sep 2024	Explored constraints of GFM inverter capability in providing system security services.
Access Standard Review, GFM inverter Technology Workstream	Expected FY2025	NER change facilitates the delivery of GFM inverter services and capabilities.

There are currently seven operational GFM inverter facilities in Australia, all of which connect standalone BESS to the grid, with a total installed capacity of 480 MW. There are an additional 34 projects incorporating GFM technology in the connections pipeline, with the majority of these (27 sites) being BESS projects with combined capacity of 5.2 GW, and the balance made up of hybrid sites combining BESS with renewable generation. The rise of hybrid GFM projects is partly incentivised by the system strength framework[56], where some developers are choosing to adopt GFM technology as part of their System Strength Remediation Scheme (SSRS).

Included in the connection pipeline are 8 GFM BESS projects totalling 2 GW capacity and 4.2 gigawatt hours (GWh) of energy storage that are receiving support from the Australian Renewable Energy Agency (ARENA) Large Scale Battery Storage (LSBS) funding round, which aims to accelerate the role of GFM BESS in providing system security services through demonstration at scale. AEMO is working closely with ARENA on this initiative. Publication of knowledge sharing reports as these projects progress will provide continuous learning opportunities for the industry.

While new GFM projects are being connected, it is important to gain practical insights from existing operational GFM projects. AEMO is actively monitoring the performance of the existing GFM projects through available high resolution monitoring systems to improve the understanding of this technology.

The present capability and readiness of GFM technology to deliver system security services are summarised in 44Figure 13 and described in Table 4. Significant work is underway to ensure that appropriate frameworks and specifications are in place to enable greater participation of GFM resources in providing these services.

[51] At https://aemo.com.au/-/media/files/initiatives/engineering-framework/2021/application-of-advanced-grid-scale-inverters-in-the-nem.pdf.

[52] At https://aemo.com.au/-/media/files/initiatives/primary-frequency-response/2023/gfm-voluntary-spec.pdf

[53] At https://aemo.com.au/-/media/files/initiatives/engineering-framework/2023/grid-forming-inverters-jan-2024.pdf.

[54] At https://aemo.com.au/-/media/files/initiatives/engineering-framework/2024/ao_geas-role-of-inertia-in-a-nem-like-system.pdf.

[55] At https://aemo.com.au/-/media/files/initiatives/engineering-framework/2024/quantifying-synthetic-inertia-from-gfm-bess.pdf.

[56] See https://www.aemc.gov.au/rule-changes/efficient-management-system-strength-power-system.

Figure 13 Current status of GFM readiness to provide system security services

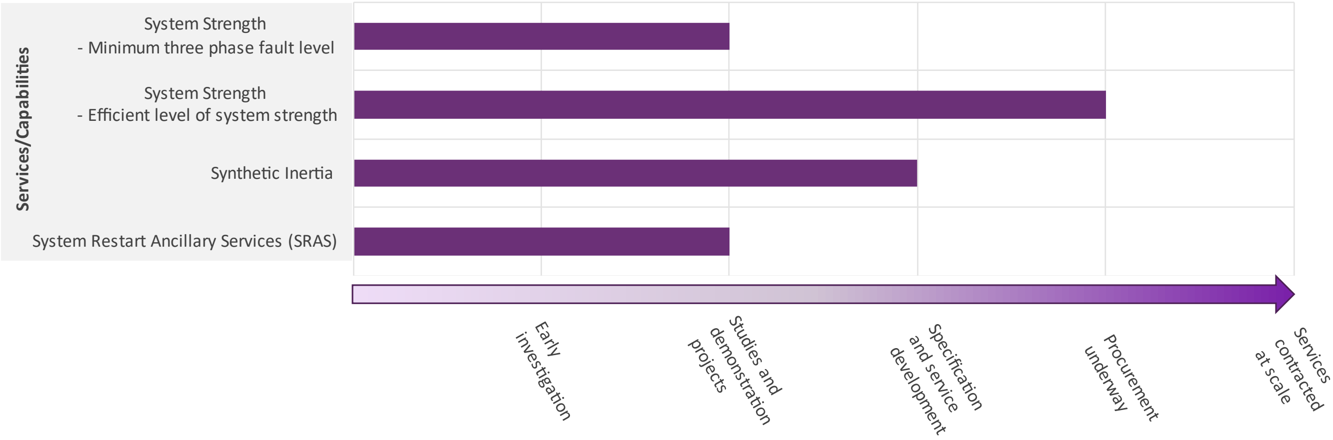


Table 4 Services relevant to GFM inverters, status of readiness and progress

Service/Capability Description	GFM inverter readiness to provide service	Work underway to advance readiness
System strength – the ability to maintain and control the voltage both during steady state operation and following a disturbance. The NEM system strength framework defines two specific procurement targets: minimum level (fault current) and efficient level (stable voltage waveform).		
• **Minimum level (fault current)**	International research acknowledges the knowledge gap in GFM capability to contribute to minimum fault level. Currently in the NEM, minimum levels of system strength must be provided by protection quality fault current[A], which GFM inverters have not yet demonstrated capability to provide.	Through the Engineering Roadmap, AEMO is engaging with TNSPs to specify studies to increase understanding of the ability for GFM inverters to provide protection quality fault current, to help guide inverter manufacturers on evolving product capabilities.
• **Efficient level (stable voltage waveform)**	Efficient levels of system strength ensure a stable voltage waveform as defined in AEMO's System Strength Requirements Methodology[B]. AEMO considers this may be met by a variety of existing or new technologies, including GFM inverters[D], and NEM TNSPs are progressing with procurement of this service. GFM inverters can emulate the inertial response of synchronous machines to provide power system inertia. This behaviour is referred to as a synthetic inertial response.	TNSPs are currently developing processes to quantify the 'amount' of efficient levels of system strength to be procured under the RIT-T process and considering options to meet their requirements. To date, Transgrid has published a technical performance specification for the procurement of stable voltage waveform support services from GFM BESS[C]. Following an EOI process, Transgrid's preferred option for stable voltage waveform includes 14 new synchronous condensers and 4.8 GW of new GFM BESS[D].
Inertia – the ability of the power system to reduce the rate at which frequency changes.		
	NEM rules allow batteries to provide SRAS, with GFM inverters providing a technical pathway for BESS to potentially meet SRAS requirements. However, during the SRAS procurement round that took place in 2023, no BESS proponents were successful due to a combination of technical and economic factors.	The AEMC's recent NEM Improving Security Frameworks rule change enables procurement of synthetic inertia to satisfy minimum security needs. AEMO's updated Inertia Requirements Methodology[E] provides an inertia network service specification to detail the performance requirements which must be satisfied to qualify as a synthetic inertia network service. The methodology takes into account AEMO's Quantifying Synthetic Inertia from GFM BESS Technical Note[F] published under the Engineering Roadmap. The technical note provides guidance on quantifying the synthetic inertia of a GFM BESS and highlights factors

Service/Capability Description	GFM inverter readiness to provide service	Work underway to advance readiness
		that should be considered while determining synthetic inertia of a GFM BESS. It is not proposing a direct replacement of synchronous inertia with synthetic inertia and acknowledges that further work is required to understand the split between synthetic inertia and synchronous inertia required to operate the power system in a secure operating state.
System Restart – restart services enable the restoration of electricity supply following a complete shut-down of all, or a substantial part of, the power system. These services are procured by AEMO in the NEM as System Restart Ancillary Services.		
	NEM rules allow batteries to provide SRAS, with GFM inverters providing a technical pathway for BESS to potentially meet SRAS requirements. However, during the SRAS procurement round that took place in 2023, no BESS proponents were successful due to a combination of technical and economic factors.	The growing pipeline of hybrid GFM BESS coupled with renewable generation provides additional opportunities for GFM technologies to participate in system restart. Further information about system restart is presented in Section 4.2.2.

A. AEMO's May 2024 update to the 2023 ESOO noted that minimum fault level requirements "must be delivered by devices that can provide protection-quality levels of fault current – such as new synchronous condensers, service contracts with existing hydro or thermal units, or through the retrofit of those existing units themselves". See page 43 at https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/nem_esoo/2023/may-2024-update-to-the-2023-electricity-statement-of-opportunities.pdf.
B. AEMO. 2022. System Strength Requirements Methodology. Section 5.1. At https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/system-strength-requirements/system-strength-requirements-methodology.pdf.
C. Transgrid. 2024. Transgrid's technical performance and power system modelling requirements for stable voltage waveform support services from grid-forming BESS. At https://www.transgrid.com.au/media/fctbpgif/2406-transgrid_stable-voltage-waveform-support-specifications-for-grid-forming-bess.pdf (document accompanies the PADR).
D. Transgrid. 2024. PADR for meeting system strength requirements in New South Wales, page 5. At https://www.transgrid.com.au/media/fo0maqsh/2406-transgrid_meeting-system-strength-requirements-in-nsw-padr.pdf.
E. At https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/system-security-market-frameworks-review/2018/inertia_requirements_methodology_published.pdf
F. At https://www.aemo.com.au/-/media/files/initiatives/engineering-framework/2024/quantifying-synthetic-inertia-from-gfm-bess.pdf

Complementing work to advance GFM inverter system security service delivery, an Access Standards Review (ASR) dedicated to GFM technology commenced in October 2024, with publication of an issues paper planned for January 2025, considering two potential changes to technical performance standards for connection:

- A potential specific category definition for GFM, to reduce the need for GFM to unnecessarily emulate synchronous generators which has been observed to lead to degraded performance.
- A focus on the benefits provided by GFM technology providing a pathway to making some of these requirements enforceable.

A further opportunity to accelerate broader GFM learnings and adoption is the possibility of using Type 2 transitional services procurement, discussed in Section 3.2.3.

3.2.2 System operability with very high DPV capacity

The growth of DPV capacity and increasingly frequent operation at times of very high DPV output represents a critical area where AEMO is progressing understanding of the challenges for management of system security and the range of potential solutions that will be required.

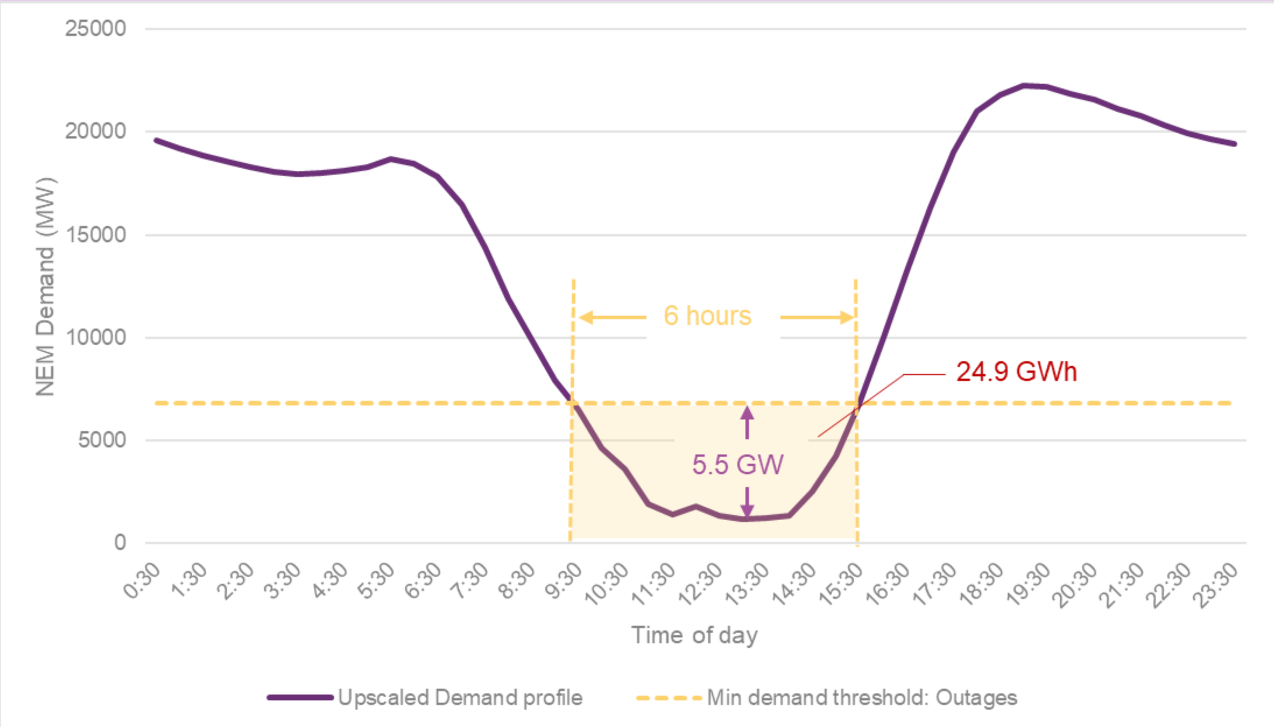
Horizon 1 to date has focused on low demand driven by high DPV output in extreme but plausible conditions (that is, with 90% POE forecasts in scenarios with outages), and has focused on the potential use of Type 1 transitional services contracts and development of backstop capability.

During Horizon 2, it is anticipated that DPV capacity will continue growing faster than underlying demand, driving potential minimum operational demand to very low levels across the NEM as a whole[57]. At times, forecast DPV generation potential could supply over 85% of underlying demand across the NEM by 2028, and 99% by 2030.

Figure 14 illustrates the scale of this challenge, representing a forecast demand profile for a low demand day in 2028 for the NEM.

In the example day below, NEM minimum demand reaches 1,417 MW. To meet the present secure threshold, approximately 5.5 GW of additional demand would be required. While this could potentially be provided through storage, load shifting or new loads, the additional demand in this example would be needed for 5-6 hours, representing 24.9 GWh of additional energy. This energy to power ratio is larger than what may be available from the typical 1-2 hr BESS being deployed today, and the typical daily availability of hot water heating or EV charging loads.

Figure 14 Sample NEM minimum demand profile in 2028 (estimated from ESOO 2024 Central Scenario 90% POE)



Toward the end of Horizon 2 in spring 2029, 50% POE (median) forecasts of minimum demand[58] fall below present secure thresholds in *system normal* conditions. As in Horizon 1, it is critical to continue establishing backstop capability to curtail DPV generation, as this will remain an essential underpinning tool throughout all

[57] See 2024 ESOO, section 7.6, 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.

[58] See 2024 ESOO, Section 2.4, 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, and *Supporting secure operation with high levels of distributed resources,* at https://wa.aemo.com.au/initiatives/major-programs/nem-distributed-energy-resources-der-program/managing-distributed-energy-resources-in-operations/managing-minimum-system-load.

horizons. However, in the absence of accelerated action across the industry to deliver complementary solutions, the use of these backstop capabilities could evolve from rare to regular occurrences.

To avoid this, and to operate securely during periods of increasingly lower operational demand during Horizon 2, it will be necessary to achieve a combination of the following:

- Reduce secure minimum demand thresholds.
- Increase underlying consumption and operational demand through load shifting and coordination.
- In parallel, CER integration can be furthered through:
- Enhancing operational capabilities.
- Improvements to data and visibility.

The National CER Roadmap[59], noted in Section 2.1.2, sets out an overarching vision and plan that will help progress these activities over Horizon 2.

Reducing secure minimum demand thresholds

At present, to ensure sufficient provision of essential system services AEMO must ensure a minimum number of large synchronous generating units remain online, which need to operate above their MSOLs. Options to operate securely during periods of increasingly lower operational demand during Horizon 2 include:

- Investigating lower MSOLs for existing synchronous units.
- Using existing and emerging technologies that are able to deliver essential system services with low or zero MSOL, as discussed in Sections 1.1.5 and 3.2.1.
- Developments in transmission infrastructure to reduce system limits at times of low loading.

Load-shifting and coordination

The minimum demand forecasts discussed above account for the additional demand from the projected growth in variety of loads including transmission- and distribution-connected storage, electrification of transport, and heating and industrial loads – much of which has the potential to be flexible in nature. Incentivising more development of these loads can increase operational demand, and when coupled with market mechanisms provides an opportunity to help shift load to times of high DPV contribution. These solutions include:

- Technologies to assist consumers to move flexible loads to times of lower energy prices which is increasingly occurring in the middle of the day when solar generation is at its peak. However, take-up of this remains low due to customer engagement of these issues and opportunities, and the complexity and uncertainty of retail offerings that can expose consumers to prices that reflect these low-priced times[60].
- Following the rule change "Unlocking CER benefits through flexible trading"[61], changes will be implemented by late 2026 to allow separate, low-cost metering and settlement of CER. This will allow retail plans to offer

[59] At https://www.energy.gov.au/sites/default/files/2024-07/national-consumer-energy-resources-roadmap.pdf.

[60] Race for 2030, Flexible demand and demand control, at https://racefor2030.com.au/wp-content/uploads/2023/03/RACE-B4-OA-Final-report.pdf.

[61] See https://www.aemc.gov.au/rule-changes/unlocking-CER-benefits-through-flexible-trading.

innovative pricing structures to flexible loads, while retaining simple structures for non-flexible loads, thus encouraging more shifting of loads such as EV charging to low-cost, low-demand periods.

- Further load shifting opportunities remain with controlled-load hot water, which has historically been used at night-time. DNSPs and retailers have already begun encouraging these loads to be shifted to daytime[62,63].
- Increasing availability of dynamic export limits (such as flexible exports, dynamic connections or dynamic operating envelopes (DOEs)) and the co-ordination of CER through VPPs may help ensure that CER storage is used at the most valuable times, for example by allowing excess solar to export to the grid in the morning while network capacity and market value is available, and saving charge capacity for the middle of the day. DPV may also be managed in response to market signals, even in the absence of storage. An example of this is the Market Active Solar Trial led by SA Power Networks[64]. In this trial, energy retailers offering VPPs are able to combine the export limits required for network management with additional economic curtailment of their customers' DPV systems, for example when wholesale prices are negative. Through this, the retailers save money by avoiding the market costs of exporting and can pass on these savings in accordance with their agreements with customers.

These market-based responses are expected to minimise, but not eliminate, the use of emergency backstops. Through Horizon 2, AEMO will continue to assess the impact of these changes and work with stakeholders to identify further opportunities to enable load-shifting and CER co-ordination opportunities to the extent that customers value them. This may include the exploration of Type 1 or Type 2 transitional services, to provide the necessary value to customers and aggregators to meet power system needs.

Enhancing operational capabilities

While CER responsiveness to market signals helps better use variable generation, it brings challenges in other areas. For example, accurate operational forecasting – which is needed to dispatch the correct amount of generation in a given period, and underpins decision making during challenging system security scenarios – carries more uncertainty when significant portions of demand are price-responsive. To maintain power system security with CER participation in the market, AEMO is working to ensure the capabilities below are enhanced:

- Implementing the outcomes of the CER Taskforce project to redefine roles and responsibilities for market and power system operations[65], which will support access to and use of distributed resources.
- Data sharing arrangements to inform planning, enable future markets, and support effective power system operation, with considerations for cyber security.
- Improved forecast capability, to accurately estimate at adequate granularity levels across the network, the impact of aggregate DER (including the impact of DOEs, load shifting, emergency DPV curtailment and price responsive DER) on generation.

[62] Energy Queensland, Annual Planning Report 2023-24, at https://www.energyq.com.au/__data/assets/pdf_file/0003/1406604/Energy-Queensland-Ltd-Annual-Report-2023-24.pdf.

[63] SAPN, Network Tariffs, at https://www.sapowernetworks.com.au/data/307915/new-network-tariffs-give-customers-more-choice-and-support-more-solar-uptake/.

[64] See https://www.sapowernetworks.com.au/future-energy/projects-and-trials/market-active-solar-trial/.

[65] See https://www.energy.gov.au/sites/default/files/2024-07/national-consumer-energy-resources-roadmap.pdf.

- Implementing processes to support the rule change on “Integrating price-responsive resources into the NEM”[66], pending final determination, which will provide the option for VPPs to participate in market scheduling,

Visibility of DPV and CER

Continued rapid DPV growth heightens the importance of providing system operators and planners sufficient CER visibility and predictability to manage its operational impacts. Throughout Horizon 2, it will become increasingly necessary to accurately estimate the locational and aggregate MW contribution of CER, and the amount of curtailable CER generation at any given time, and to accurately characterise the dynamic performance of CER devices during disturbances.

By Horizon 2, visibility of this information will be utilised to help guide planning of operational actions and procedures when at-risk periods emerge:

- Device-level standing data on individual DER installations and how they operate, including visibility of participation in aggregations, and when customers switch aggregators (churn). Much of the aggregation data will be needed in providing an understanding of DPV and CER in scheduling arrangements.
- Robust measures for monitoring a representative sample of device behaviour, including in real-time, to understand behaviour of coordinated and uncontrollable loads, for applications in operational forecasting, incident analysis, compliance assessments, and power system model validation (used to calculate power system security limits).
- High speed monitoring at a selection of network locations with high-DER installations and varying types of load, to understand disturbance permeation, and for power system model validation.

3.2.3 Type 2 services and operational trials

Type 2 transitional services allow AEMO to enter non-market ancillary services contracts, to trial either new technologies or the new applications of existing technologies that can help to manage power system security. AEMO is currently considering the technical priorities related to power system security that may be explored under this framework including potential for:

- Alternative ways to deliver services historically provided by traditional synchronous technology.
- Advancing GFM inverter service delivery readiness, as summarised in 0, through technology demonstrations and operational trials.
- Testing of subnetworks to validate desktop findings of unprecedented system conditions, such as with few or no synchronous generators online.
- Modification of existing assets to broaden the range or flexibility of their system security support capabilities.

Type 2 services enable AEMO to accelerate the demonstration, and subsequent deployment at scale, of new technologies to provide essential system services and reduce the NEM’s reliance on synchronous generators to manage system security. Initial Type 2 contracts will likely focus on trials and demonstrations to build knowledge

[66] At https://www.aemc.gov.au/rule-changes/integrating-price-responsive-resources-nem.

and capability for managing security through forthcoming transition points as the system moves towards low- or zero-emissions operating conditions.

AEMO is currently developing governance processes to manage prioritisation, procurement, delivery, settlement and cost recovery for type 2 services, and encourages stakeholders to consider applications where these services could facilitate accelerated demonstration of technologies with the potential to support power system security. Further information on how AEMO intends to define and procure Type 2 transitional services can be found in the Transitional Services Guidelines[67]. Details of specific Type 2 services will be communicated through the publication of a Statement of Security Need, which will be published separately from the Transition Plan.

Findings from Type 2 trials will be discussed in subsequent editions of the Transition Plan and inform the development of industry understanding of security requirements and enabling technologies for NEM operation at very high contributions of renewable and non-synchronous resources. At the time of publication, no transitional services agreements have been entered into and the Guidelines have only recently been finalised. Future editions of the Transition Plan will detail outcomes and learnings from transitional services in accordance with NER 5.20.8(c)(7).

[67] At https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2024/transitional-services-guideline-consultation/transitional-services-guideline.pdf

4 Horizon 3

|Now - 2 years | 2 - 5 years | 5+ years

Horizon 3

Preparation for 5+ years ahead: Screening for transition points in the planning horizon. Growing understanding of the requirements of a low-emissions power system. Outlining long lead-time activities to support investment in solutions to meet emerging needs.

20% | FOCUS | 80%

Transition point planning

- Screening for future operational transition points

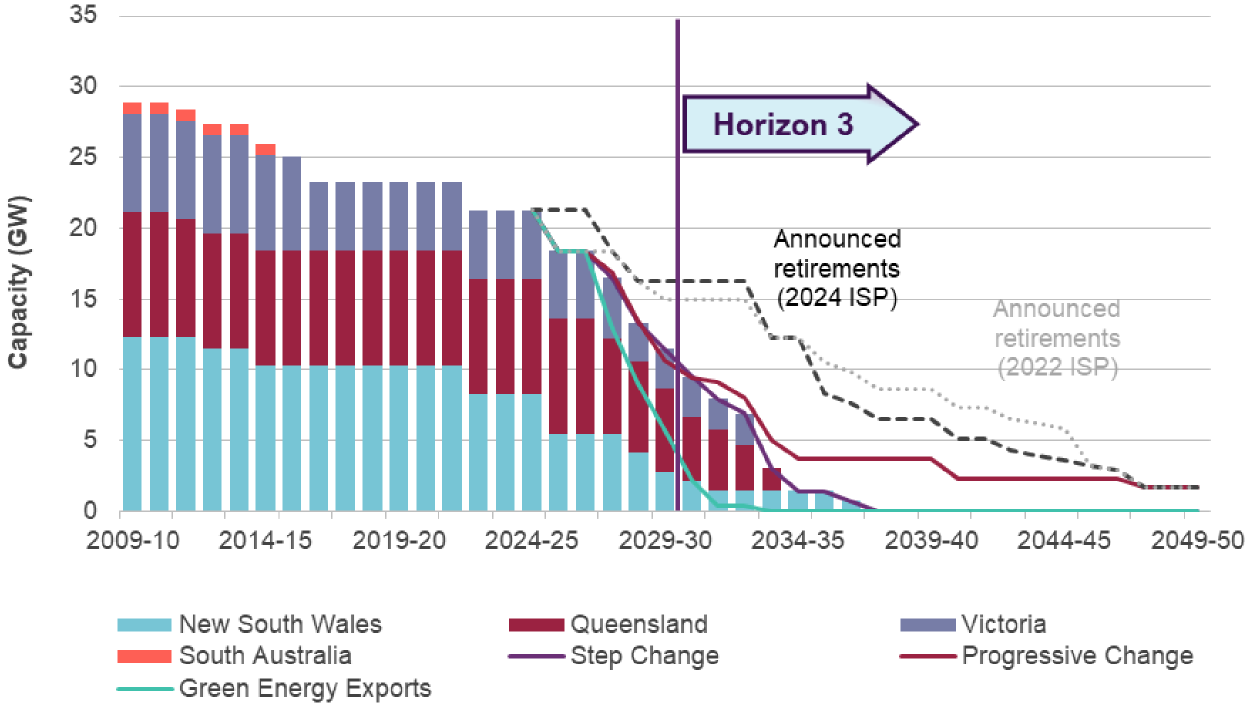
Defining capabilities and progressing understanding

- Conducting power system studies for operation at up to 100% renewables contribution for periods of time
- Planning for periods when rooftop solar could potentially meet 100% of NEM demand
- Evolving system restart processes and resources

Activities for Horizon 3 seek to prepare for the transition beyond the next five years. While distinct transition points this far in the future have not yet been specified, enduring energy transition trends in renewable generation contribution, DPV growth, and thermal plant retirement as described in Section 3.1 provide a basis for informing planning activities, model development and research priorities.

AEMO's 2024 ISP noted that "coal retirements are occurring faster than announced dates, and may occur even faster than these forecasts", with potential retirement of up to 90% of all coal plant by 2035[68], and the entire fleet by 2040 (Figure 15), meaning the NEM could be operating at times of up to 100% renewables.

Figure 15 Coal capacity, NEM (GW, 2009-10 to 2049-50)



[68] See https://aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp/2024-integrated-system-plan-isp.

Coordinated joint planning between AEMO, NSPs, and jurisdictional bodies, supported by industry, will be required to make investments that meet future system security most efficiently and in a manner that manages the inherent risk associated with project lead time uncertainty. Given the important nature of maintaining system security, AEMO considers it critical to plan the delivery of infrastructure well ahead of when issues may appear in operational timeframes. This could also include no-regrets decisions on technology capabilities that could prove valuable in Horizon 3.

The possibility of earlier-than-announced coal retirement provides a planning pathway for Horizon 3 for which future operational requirements can be considered and proactive planning undertaken. Much of this future-focused work is being completed as part of AEMO's NEM Engineering Roadmap[69], which identifies and progresses activities that help advance the operational capability of the NEM for times of high renewables.

Horizon 3 includes screening for potential transition points that may arise due to a combination of these trends (Section 4.1.1), to enable appropriate preparation for the respective planning and operational phases (Horizon 2 and Horizon 1) ahead of defining firm transition points.

In parallel, work is underway through the Engineering Roadmap to advance AEMO's operational capability to securely operate a multitude of potential Horizon 3 transition points (Section 4.2). Screening studies will help guide the focus of this engineering work. Specific Horizon 3 activities also include investigating broader framework and technical areas which have long lead times for change, such as DER functional requirements under extremely high DPV contribution (Section 4.2.1), and the system restart framework (Section 4.2.2). Any delay to this investigatory work risks missing the opportunity to drive timely and appropriate investment required to continue meeting power system needs into the future.

AEMO is also developing a research engagement strategy that will maintain a living view of AEMO's research interests and supporting engagement with research organisations. Assisting this is AEMO's ongoing collaboration with international system operators[70] to share and develop best practices for operating a high-renewables systems. While these priorities will cover innovations that extend across all three horizons, research partnerships will have particular value for Horizon 3 by reducing uncertainty around investment and the technical capabilities required to operate future conditions.

4.1 Transition point planning

A key part of Horizon 3 preparation involves identifying changes projected to occur after the next five years that may require early preparatory efforts that begin now to manage potential transition points. This requires systematic assessment to determine whether they will require heightened management as transition points when the events enter Horizon 2 and Horizon 1 timeframes.

In comparison to Horizon 2 transition points, Horizon 3 transition points carry significantly greater uncertainty, particularly given range of possible coal retirement schedules as considered by the ISP. Consequently, Horizon 3 planning involves much higher level "screening studies" for potential transition points that may arise due to a

[69] At https://aemo.com.au/en/initiatives/major-programs/engineering-roadmap.

[70] See https://aemo.com.au/initiatives/major-programs/international-system-operator-collaboration.

combination of trends. Where appropriate, Horizon 3 activities may also include detailed power system studies as described in Section 3.1.2.

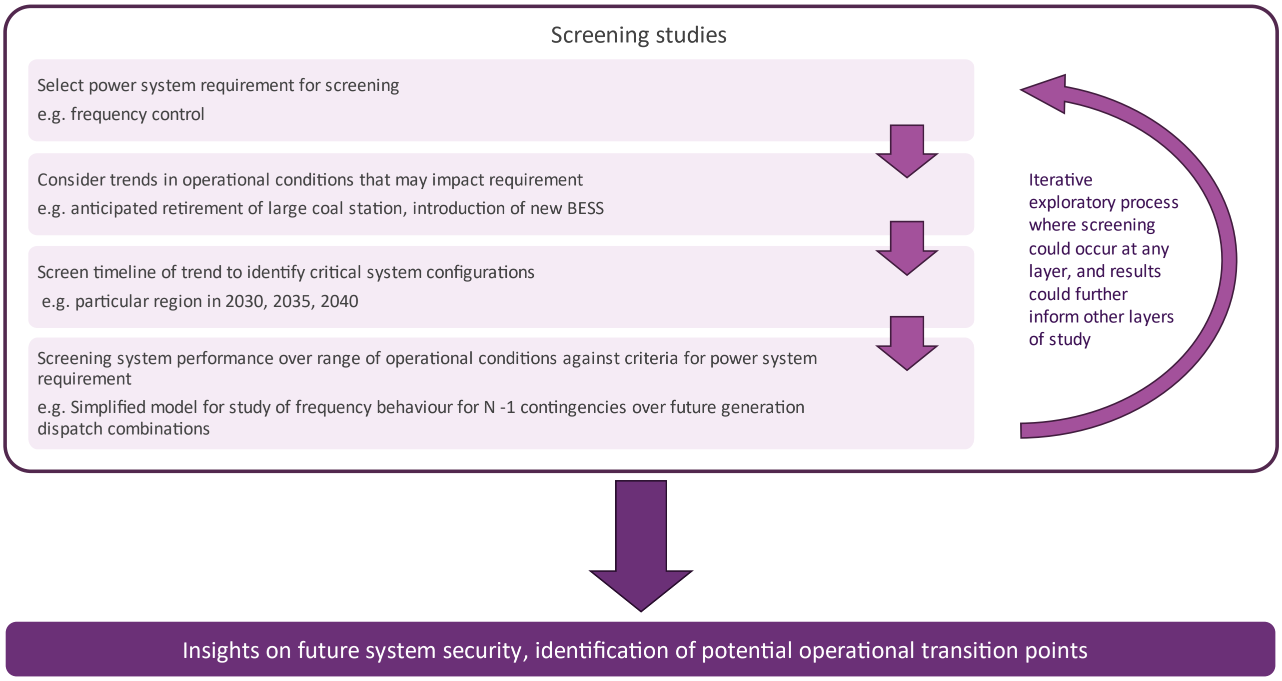
4.1.1 Screening for new transition points

AEMO has obligations to calculate system strength and inertia requirements for all NEM regions for the next ten years, considering ISP projections out to 2050[71]. This accounts for future system conditions, including earlier than anticipated coal retirement. Meanwhile TNSPs have an obligation to plan and deliver for the future operation of their transmission networks through Transmission Planning Annual Reports (TAPRs) and regulatory investment frameworks.

To identify changes requiring considerable preparation as Horizon 3 transition points, AEMO is undertaking high-level studies to identify any future potential issues of managing a given aspect of power system security (such as voltage, frequency and network stability). These "screening studies" then allow further detailed analysis for the highest priority challenges. This focused effort allows detailed study of the operability of changes, including consideration of plant capability and investment availability.

A summary of the proposed process for screening is shown in Figure 16.

Figure 16 High level process for Horizon 3 screening studies



By focusing on power system security requirements, AEMO seeks to identify potential transition points that are new to the current understanding of the system and not necessarily tied to a single trigger event. This analysis is deliberately designed to be exploratory and iterative given that the existence of new transition points so far into the future may not necessarily be initially obvious or intuitive.

[71] See https://aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp/2024-integrated-system-plan-isp.

4.2 Defining capabilities and progressing understanding

Work to understand operation of the power system under high renewable scenarios expected to occur in Horizon 3 has so far been progressed through the Renewables Integration Study[72] and the Engineering Roadmap, with the *System Strength Report* and *Inertia Report* further identifying specific requirements in this timeframe[73].

In particular, the *Engineering Roadmap to 100% Renewables*[74] published in December 2022 provided an overview of the engineering challenges and associated actions that need to be undertaken to operate the NEM at up to 100% renewables. The report identifies preconditions that must be satisfied to operate at 100% renewables, assesses the challenges associated with achieving these, and determines the range of actions necessary to achieve each precondition.

Each year, AEMO publishes an Engineering Roadmap Priority Actions Report outlining the activities AEMO intends to undertake to advance operational capability for times of high renewables. The most recent report for FY2025[75] identified 37 priority actions for the upcoming year that deliver on three focus areas of the transition (Figure 17). Actions will progress knowledge and preparation over a five- to 10-year timeframe given the current Australian regulatory framework, prompting timely investment in future solutions before they are required, including:

- Supporting participation and integration pathways for CER and load flexibility to encourage active CER participation.
- Using new technology to meet system needs more efficiently in a high IBR, renewable power system.
- Increased modelling for, and confidence in the operation of, a wide range of Horizon 3 system conditions.

Figure 17 FY2025 Priority focus areas and workstreams

Delivering foundational transition enablers

Collaborating closely with stakeholders to establish critical foundations for the future power system, defining roles and responsibilities for new technical matters, and establishing effective systems and processes for future system operation.

Providing long-range investment visibility

Identifying future power system needs that may require investment from one or more parties and providing clarity on the capability of different technologies to meet these needs.

Progressing operational readiness

Maintaining power system security in real-time operation under unprecedented penetration of variable, inverter-based, and distributed resources.

Sections 4.2.1 and 4.2.2 below provide further detail on some of the current areas of focus for understanding operation in Horizon 3 under high renewable contributions and an evolving technology mix.

[72] At https://aemo.com.au/energy-systems/major-publications/renewable-integration-study-ris.

[73] At https://www.aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/system-security-planning.

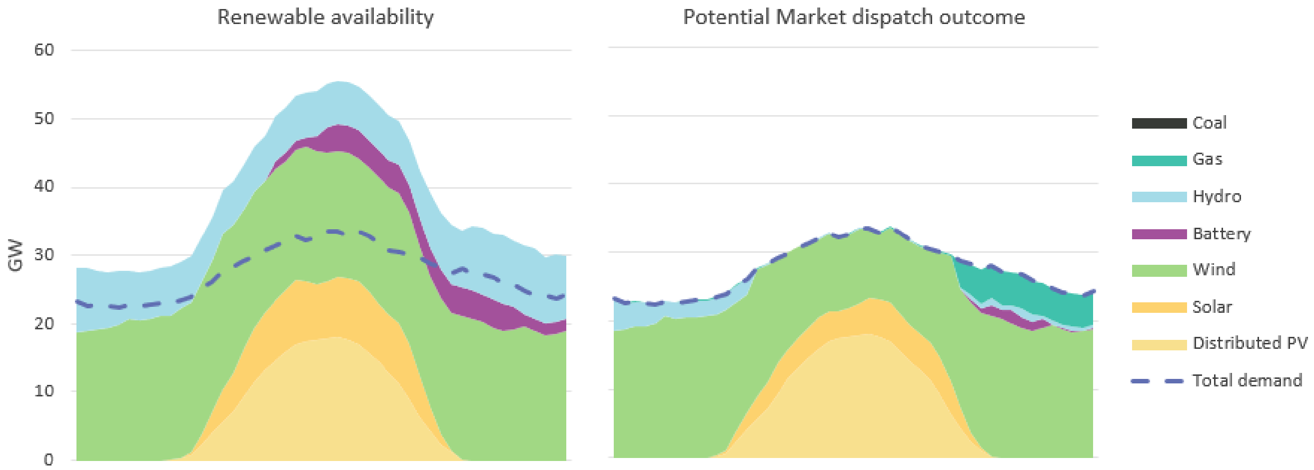
[74] At https://aemo.com.au/-/media/files/initiatives/engineering-framework/2022/engineering-roadmap-to-100-per-cent-renewables.pdf.

[75] At https://aemo.com.au/-/media/files/initiatives/engineering-framework/2024/nem-engineering-roadmap-fy2025-priority-actions.pdf.

4.2.1 Effective operation with up to 100% renewable energy contribution

In preparation for Horizon 3, consideration has been made for days where the NEM resource mix will have zero or very low levels synchronous generation at times. The example below (Figure 18), previously presented in the Engineering Roadmap, shows renewable resource potential greater than underlying demand, and assumes sufficient essential system services are available from renewable generation and network assets to operate without coal generators online for the full day. In this scenario, the system can securely operate at up to 100% renewables during the middle of the day, with gas fired generation coming online later in the day to cover afternoon demand. It is not yet clear exactly which conditions and resource mixes are likely to produce market outcomes that lead to the first period of 100% operation. AEMO has previously considered the system security needs of one plausible 100% renewable contribution scenario in the 2022 and 2023 NSCAS reports[76].

Figure 18 Day with viable 100% renewable contribution periods

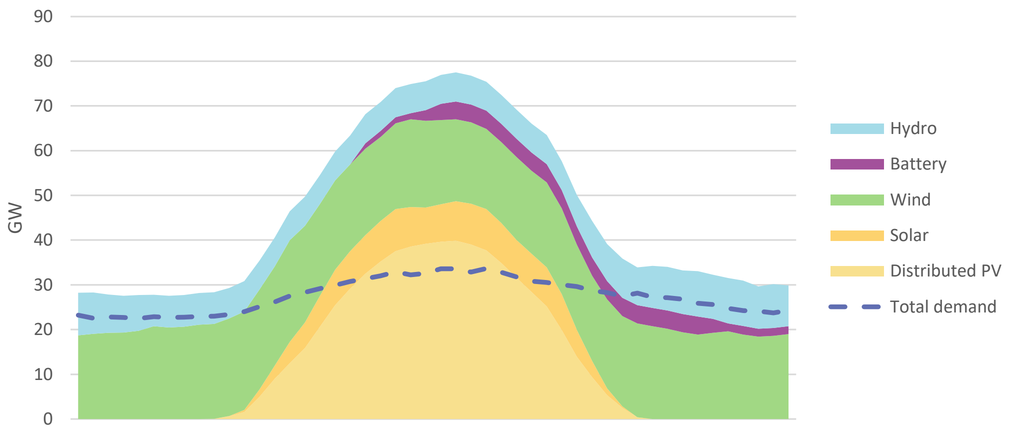


To date, DPV has been a dominant supplier of energy during times of high renewable contribution. As DPV uptake continues, one possible scenario of high renewable contribution is the potential for supply from DPV to exceed total demand in the system[77], as illustrated below in Figure 19.

[76] Found at https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/system-security-planning

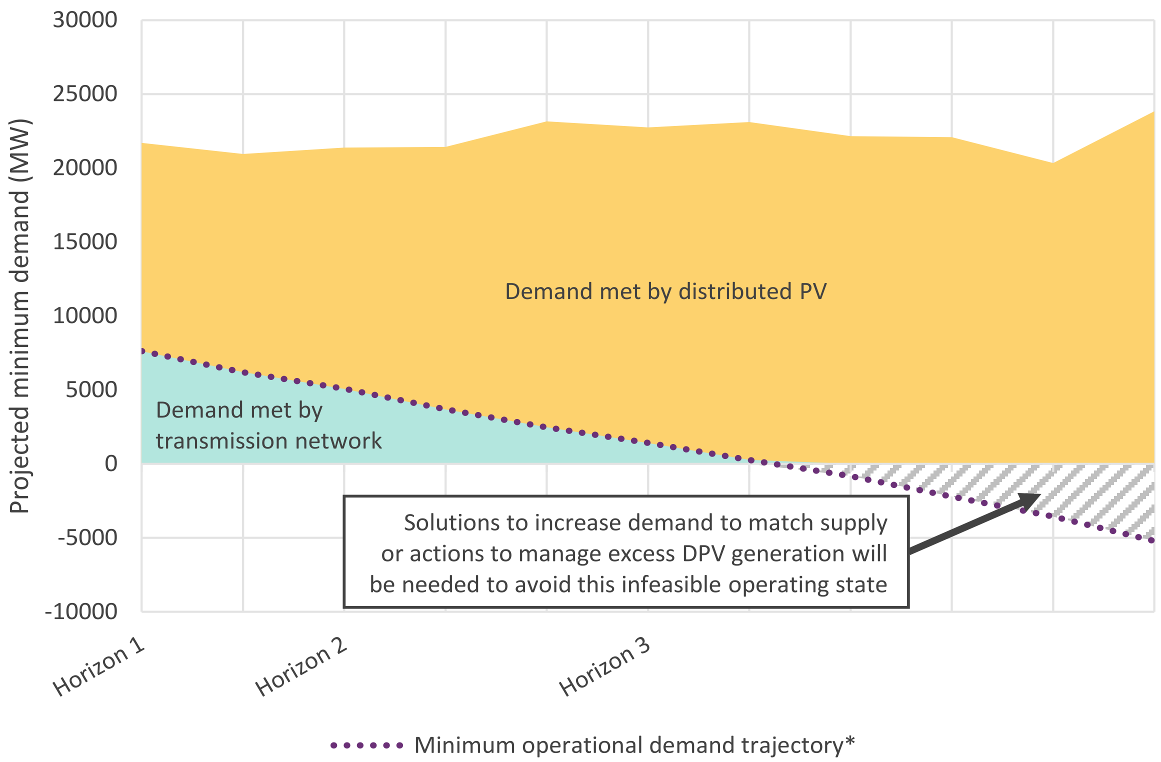
[77] See https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-reliability/nem-electricity-statement-of-opportunities-esoo.

Figure 19 Renewable resource potential where DPV could exceed total demand



Continued DPV uptake is forecast over Horizon 3 and may exceed demand growth leading to more frequent and deeper minimum operational demand periods. Figure 20 extends the trend in Figure 11 in Section 2.1.2, showing if the current status quo is maintained (slow growth in market-based solutions to increase day time demand, as highlighted in Section 3.2.2), projected NEM-wide minimum operational demand could fall below zero in Horizon 3. As this implies there is more energy in the system than required, it poses an infeasible area of power system operation and will require actions such as incentivising market-based solutions including large scale BESS and new loads, to increase demand to manage the excess energy.

Figure 20 NEM-wide minimum demand trajectory



* Chart illustrates the current trajectory of NEM-wide minimum operational demand into the future, based on analysis of 2024 ESOO POE90 demand data.

AEMO is performing further exploratory analysis on characterising potential high renewable contribution periods in Horizon 3. This will include more detailed consideration of what types of renewable generation is contributing to meeting demand at any point in time, where they are located, and how they are connected into the power system.

Successfully operating the power system under these conditions will require models that can adequately represent these operating conditions. It will further require robust understanding of the system's ability to deliver security service requirements, potentially including:

- Resource adequacy and capability (such as the level of storage investment and capability to provide different services, and manage ramping challenges in the distribution network).
- Frequency management (considering items such as sourcing of primary frequency control, and the ability to manage outage conditions).
- Voltage management (to understand implications whereby generation is sourced solely from the distribution network, and if there are limits to operating the power system in such a configuration).

In the case of managing times with high DPV, many of the actions discussed in Horizon 2 (Section 3.2.2) will need to persist, with a focus on the active market participation of a substantial proportion of CER, and the implementation of cyber security standards and processes.

4.2.2 System restoration

As the resource mix in the NEM continues to evolve, another consideration for Horizon 3 is ensuring secure system restart pathways continue to be available, given traditional sources of black start capability are set to retire. To assist with this, AEMO is undertaking future focused analysis as part of the Engineering Roadmap on options for system restart to prepare for both the upcoming 2026-29 System restart ancillary services (SRAS) procurement round, and longer-term procurement from 2030 onwards. The analysis will include a published paper with forward-looking commentary on areas which will require action to prepare the NEM to procure sufficient and resilient SRAS sources into the future. Focus areas include:

- Assessing the capability and value of new and emerging technologies providing SRAS to ensure investment in new restart sources is available in advance of existing plant decommitment.
- Continuing to examine the impact of DPV during system restart (see section below), and the opportunities for value-add pathways for CER to assist with restart.
- Increasing optionality and diversity to deliver resilient restart approaches as the transition continues and system configuration evolves, particularly in the context of REZ development.

These areas need to be assessed, and relevant solutions identified and implemented, in time for the start of Horizon 3. This will ensure that SRAS procurement for the 2030 procurement round and beyond provide secure pathways for system restart in the NEM. Further information arising from this work will be incorporated in future iterations of the Transition Plan.

System restart under high DPV

A consideration for system security in a future with very high levels of installed DPV is the impact of these resources on system restart requirements and processes. The ongoing growth of DPV generation reduces the availability of stable load blocks required for the system restoration process. This issue will continue into Horizon 3.

AEMO must develop the capability to model and assess the impact of increasing DPV on system restart. This includes understanding the implications of a weak power system, how DPV systems (which are grid-following) will synchronise during these situations, and any associated DPV impacts as generation progressively comes online.

Further, it will be necessary to establish a means of managing any uncontrolled DPV generation during the restart process, ensuring that this can be managed without services such as internet connectivity, which may not be available during a black system event. This could require adapting system restoration processes and potentially revising inverter standards so that they autonomously respond during a prolonged outage (such as a delayed ramping of export) so that stable load blocks can be maintained.

Abbreviations

Abbreviation	Term in full	Abbreviation	Term in full
AEMC	Australian Energy Market Commission	**LSBS**	Large Scale Battery Storage
AEMO	Australian Energy Market Operator	**MSL**	minimum system load
ARENA	Australian Renewable Energy Agency	**MSOL**	minimum safe operating level
AS/NZ4777.2	Australian Standards for Grid connection of energy systems via inverters – inverter requirements	**MVA**	megavolt amp/s
ASR	Access Standards Review	**MW**	megawatt/s
BESS	battery energy storage system	**MWs**	megawatt second/s
CER	consumer energy resources	**NEM**	National Electricity Market
DER	distributed energy resources	**NEMOC**	National Electricity Market Operations Committee
DNSP	distribution network service provider	**NER**	National Electricity Rules
DOE	dynamic operating envelope	**NSCAS**	network support and control ancillary services
DPV	distributed photovoltaics	**NSP**	network service provider
EOI	Expression/s of interest	**OEM**	original equipment manufacturer
ESB	Energy Security Board	**PADR**	Project Assessment Draft Report
ESOO	*Electricity Statement of Opportunities*	**PASA**	Projected Assessment of System Adequacy
EV	electric vehicle	**PEC**	Project EnergyConnect
FCAS	frequency control ancillary services	**POE**	probability of exceedance
FFR	fast frequency response	**pu**	per unit
FY	financial year	**REZ**	renewable energy zone
GFM	grid-forming	**RIT-T**	regulatory investment test for transmission
GFL	grid-following	**SRAS**	system restart ancillary services
GPSRR	General Power System Risk Review	**SSRS**	System Strength Remediation Scheme
GT	gas turbine	**SSSP**	system strength service provider
GW	gigawatt/s	**TAPR**	transmission annual planning report
GWh	gigawatt hour/s	**TNSP**	transmission network service provider
IBR	inverter-based resources	**TSPO**	Transitional Services Procurement Objective
ISF	Improving Security Frameworks	**VNI**	Victoria – New South Wales Interconnector
ISP	*Integrated System Plan*	**VPP**	virtual power plant
kV	kilovolt/s	**VRE**	variable renewable energy