2022 Inertia Report

December 2022

A report for the National Electricity Market

Important notice

Purpose

The purpose of this publication is to report on the boundaries of the inertia sub-networks, inertia requirements for each inertia sub-network, and AEMO's assessment of any identified inertia shortfalls for the coming five-year period for the National Electricity Market. AEMO publishes this 2022 Inertia Report in accordance with clause 5.20.5 of the National Electricity Rules. This publication is generally based on information available to AEMO as at November 2022 unless otherwise indicated.

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Version control

Version	Release date	Changes
1.0	1/12/2022	Initial release.

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Executive summary

Proactive provision of system security services will be crucial for Australia's energy transition

The National Electricity Market (NEM) is continuing to see a once-in-a-century transformation in the way electricity is generated and consumed in eastern and south-eastern Australia. Legacy assets will be replaced with low-cost renewables, energy storage and other forms of firming capacity, and the grid will need to be reconfigured to support two-way energy flow.

AEMO's most likely scenario is currently the *Step Change* scenario[1]. *Step Change* is considered by energy industry stakeholders to be the 'most likely' plausible future operating environment for the energy sector. *Step Change* sees 40% of coal-fired generation capacity in the NEM withdrawn over the next five years, 60% by 2030, 87% by 2035 and about 96% by 2040.

Many power system security services – including inertia – have traditionally been provided by thermal synchronous generating units. In the face of changing synchronous generator behaviour, declining minimum operational demand, and rapid uptake of variable renewable energy (VRE) sources connected to the power system through inverters, proactive provision of system security services will be crucial for ensuring a secure power system.

AEMO is declaring new inertia shortfalls for the coming five years

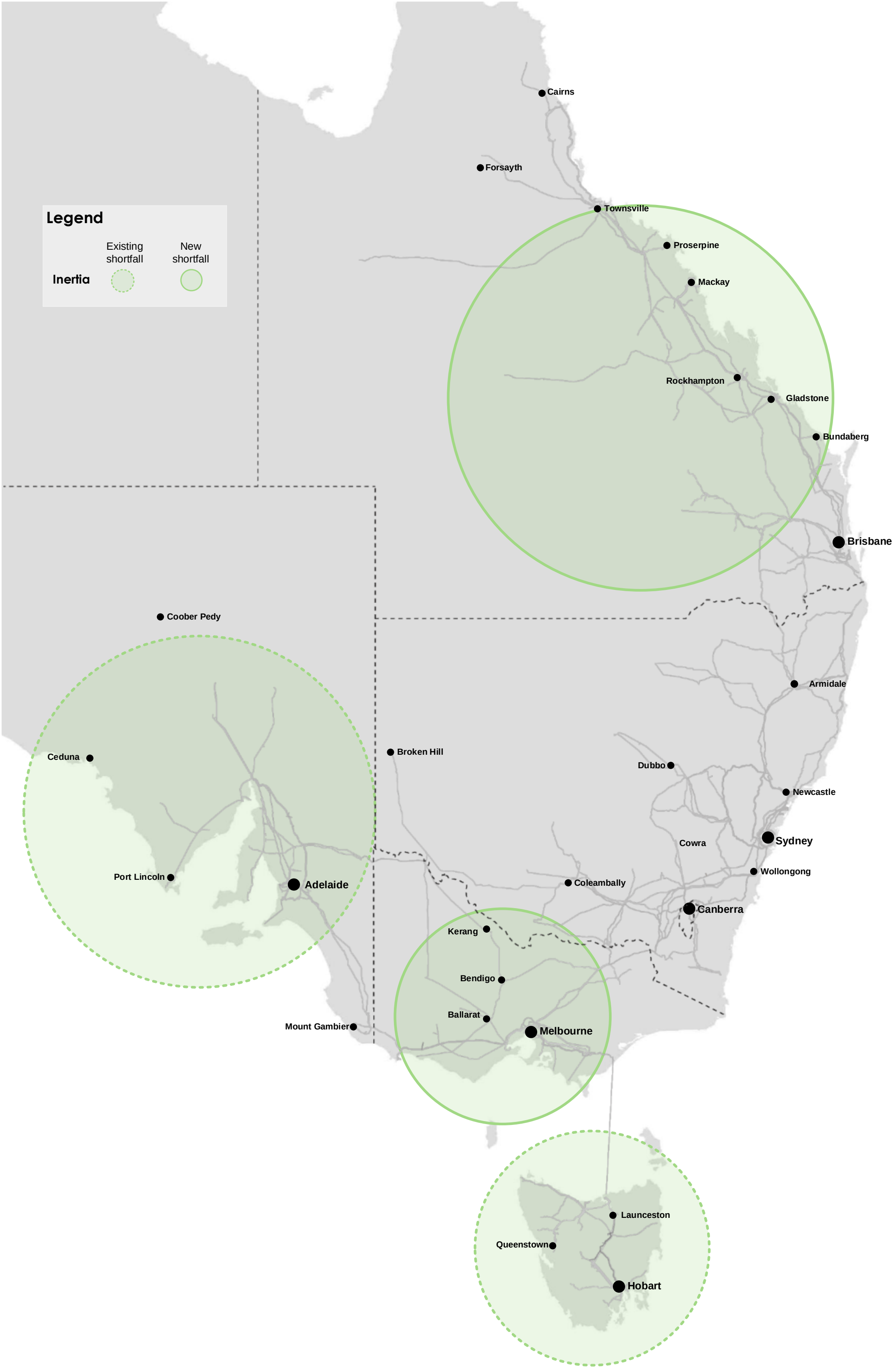
In this 2022 inertia report, AEMO applies the inertia rules framework to the generation and transmission network outcomes in the *Step Change* scenario. Forecast inertia is continuing to decline across the NEM as synchronous generator behaviour changes, penetration of inverter-based resources (IBR) increases, and minimum demand projections decline. AEMO declares new inertia shortfalls in Queensland and Victoria, as well as confirming existing shortfalls in South Australia and Tasmania. These shortfalls will need to be addressed by the responsible Inertia Service Providers, which are the transmission network service providers or jurisdictional planning bodies. Table 1 summarises the inertia declarations made in this report. Figure 1 summarises the new and existing inertia shortfalls across the NEM.

Table 1 2022 inertia review outcomes for the NEM, for the five-year period to December 2027

New South Wales	Queensland	South Australia	Tasmania	Victoria
				
No shortfall declared, although inertia declines observed in forecast.	New shortfall ranging from 8,200 megawatt seconds (MWs) to 10,352 MWs against the secure operating level, from 1 July 2026.	Existing shortfall is confirmed consistent with the 2021 assessment.	Existing shortfall is confirmed consistent with the 2021 assessment.	New shortfall ranging from 2,421 MWs to 2,482 MWs against the secure operating level, from 1 July 2026 onwards.

[1] More information about AEMO's *Step Change* scenario can be found at the *Integrated System Plan* (ISP) website via https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2022-integrated-system-plan-isp.

Figure 1 A map of the NEM showing current regional inertia shortfalls



Regulatory reforms and technological innovation will change inertia requirements over time

AEMO expects that a variety of solutions will be feasible to address the inertia shortfalls declared in this report, including:

- Physical inertia provided by synchronous generators.
- Fast frequency response (FFR) providers, such as batteries.
- Synchronous condensers fitted with flywheels – potentially optimised with investment for system strength services under the new framework[2].

AEMO is also in the process of implementing a new very fast frequency control ancillary services (FCAS) market. Over time, as this market develops, it may provide services which alleviate the need for inertia in each region.

The shortfalls declared in this report prepare the NEM for the *Step Change* scenario. Should industry need to plan for a high or 100% renewable energy penetration scenario in the very near term, or if any new earlier-than-expected generator retirements are announced, additional services will be required more urgently. This report includes the results of a study of a 100% renewable penetration scenario, under which up to 40 new synchronous condensers could be needed to meet system strength requirements while also addressing inertia requirements if fitted with flywheels.

AEMO looks forward to working with the Inertia Service Providers to consider solutions to address the inertia needs across the NEM.

[2] In October 2021 the Australian Energy Market Commission (AEMC) made a final determination on a new system strength rules framework for the NEM, accessible via https://www.aemc.gov.au/rule-changes/efficient-management-system-strength-power-system.

Contents

Tables

Figures

1 Introduction

Inertia allows the power system to resist large changes in frequency arising from an imbalance in power supply and demand due to a contingency event[3].This section outlines the context for the 2022 Inertia Report:

- Trends impacting inertia assessments (Section 1.1).
- Relationship to other AEMO documents (Section 1.2).
- Ongoing regulatory reforms (Section 1.3).
- Information provided in this report (Section 1.4).

1.1 Trends impacting inertia assessments

The National Electricity Market (NEM) is in the midst of a transformation, replacing its traditional energy resources with variable renewable energy (VRE) largely based on inverters[4]. This section describes how a number of these trends are relevant for the provision of inertia.

Accelerated uptake of inverter-based resources and withdrawal of synchronous generators is creating a need for new inertia solutions

Australia is currently installing utility-scale inverter-based resources (IBR) faster than at any time in history and the trend is projected to increase. At the same time, the NEM's transformation will be influenced by the generation and feed-in capability of millions of individual consumer-owned solar photovoltaic (PV) systems. From 2025, there are forecast to be times when the NEM will have enough renewable energy resources to meet 100% of its demand.

AEMO and key industry stakeholders currently consider that AEMO's *Step Change* scenario is the most likely scenario for the purposes of electricity system planning and investment. *Step Change* modelling completed for the 2022 *Integrated System Plan* (ISP) suggests that 14 gigawatts (GW) of synchronous generation resources will withdraw from the market by 2030. While this level of withdrawal has not been formally announced, coal-fired generators are continuing to bring forward their withdrawal from the market.

As inertia has traditionally been provided by synchronous generators, the increasing decommitment of synchronous generators and increased penetration of IBR means additional remediation is needed to ensure the power system has enough inertia to remain secure through this once-in-a-generation transformation of the power system.

[3] For definitions and descriptions of inertia and power system security, see AEMO's Power System Requirements, updated in July 2020, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Power-system-requirements.pdf. For definitions and descriptions of inertia and power system security, see AEMO's Power System Requirements, updated in July 2020, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Power-system-requirements.pdf.

[4] AEMO. 2022 *Integrated System Plan* (ISP). June 2022, at https://aemo.com.au/-/media/files/major-publications/isp/2022/2022-documents/2022-integrated-system-plan-isp.pdf?la=en.

Projections for declining inertia across the NEM mean AEMO must now consider the inertia requirements for multiple connected regions

When assessing inertia requirements and shortfalls for regions of the NEM, AEMO considers both:

- The likelihood of the region becoming islanded from some or all other parts of the NEM, and
- How much inertia could typically be provided from any other parts of the NEM to which the region does remain connected.

AEMO has historically considered the likelihood of individual regions becoming completely islanded from the NEM. This has included looking at whether the region has previously islanded and the likelihood of interconnector trip events. For example, Queensland is considered sufficiently likely to island because there was a separation event in 2018 when a lightning strike affected the interconnector to New South Wales, and because the two circuits of the interconnector are on the same easement which raises the potential for a bushfire (or some other event) to affect both circuits at the same time.

However, AEMO is now expanding its consideration to include situations where two regions island together and become separated from the remainder of the NEM. AEMO considers this to be prudent in the face of declining forecasts for inertia availability across the NEM, with forecasts for decommitment of services from synchronous generators which have traditionally provided inertia services. In these cases, AEMO considers the likelihood of the two regions islanding together, and whether inertia-sharing between the regions is feasible for addressing any observed inertia shortfalls.

Innovative solutions are continuing to emerge

AEMO considers that the rise of IBR will provide viable alternatives to the inertia sources traditionally provided from synchronous generators, although the complete replacement of traditional synchronous inertia with IBR remains to be demonstrated at scale.

Of the two inertia requirement types declared by AEMO – a minimum threshold level, and a secure operating level – AEMO considers that secure operating level requirements can increasingly be met using fast frequency response (FFR) services from battery-connected IBR to arrest major changes in rate of change of frequency. This in turn reduces the amount of synchronous inertia required to ensure a secure operating level. Although AEMO has not yet considered the use of FFR to meet the minimum threshold levels, this could be an important area of innovation for the future.

AEMO is continuing to work with transmission network service providers (TNSPs), market participants and equipment manufacturers to unlock the potential for new technologies to form part of the mix of solutions proving inertia or inertia-like services to ensure power system security in the NEM.

1.2 Relationship to other AEMO documents

The annual inertia report draws inputs from a number of related AEMO reports and processes, and in turn informs and underpins a range of reports and processes owned by AEMO and TNSPs.

In 2020 the annual inertia report was published as part of the 2020 System Strength and Inertia Reports. In 2021, it was published in the 2021 System Security Reports, which also incorporated the system strength report and the Network Support and Control and Ancillary Services (NSCAS) report. In 2022, AEMO is publishing the inertia report as a standalone document, given that it covers a five-year horizon rather than the 10-year horizon now considered for the system strength report, and to facilitate separate publication of the reports when required.

Table 2 shows the AEMO reports and processes which are related to the inertia reports.

Table 2 AEMO reports and processes related to the Inertia Report

Report or process	Frequency and contents	Time horizon considered (years)	Reference
System Strength Report	Annual assessment of system strength nodes and standards for each NEM region, as well as shortfalls before December 2025.	5	https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/system-security
Network Support and Control Ancillary Services (NSCAS) Report	Annual assessment of system security needs and gaps for each NEM region, excluding system strength and inertia.	5	https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/system-security
General Power System Risk Review	Annual review of major power system risks in the NEM.	5	https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/system-operations/general-power-system-risk-review
Electricity Statement of Opportunities (ESOO)	Annual assessment of 10-year supply, demand and reliability outlook for the NEM, that may trigger the Retailer Reliability Obligation.	10	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
NEM Engineering Framework	A toolkit to define the full range of operational, technical and engineering requirements needed to prepare the NEM for future operating conditions, including 100% instantaneous penetration of renewables.	10	https://aemo.com.au/en/initiatives/major-programs/engineering-framework
Victorian Annual Planning Report (VAPR)	Annual assessment of the Victoria region to inform stakeholders about network performance, planning, challenges and opportunities in the next 10 years.	10	https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/vapr/2022/2022-victorian-annual-planning-report.pdf?la=en
Integrated System Plan (ISP)	A comprehensive roadmap for the NEM, updated every two years, optimising consumer benefits through a transition period of great complexity and uncertainty.	> 20	https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2022-integrated-system-plan-isp

1.3 Ongoing regulatory reforms

AEMO has prepared this report consistent with the existing National Electricity Rules (NER). Three ongoing regulatory reforms in the NEM can be expected to significantly affect inertia requirements and shortfall assessments in coming years:

- Very fast frequency control ancillary services (FCAS) markets will be introduced in the NEM in late 2023.
- The Australian Energy Market Commission's (AEMC's) Reliability Panel is reviewing the Frequency Operating Standard (FOS).

- A rule change request for 'efficient provision of inertia' has been submitted to the AEMC, and the Energy Security Board (ESB) is continuing to consider reform initiatives which may include inertia.

Very fast FCAS markets will be introduced in late 2023

In July 2021 the AEMC determined that two new market ancillary services will be introduced in the NEM[5]. The new services – very fast raise and very fast lower services – are intended to help control system frequency and keep the future electricity system secure. AEMO will establish these markets to procure fast frequency response to help efficiently manage power system frequency following contingency events during low inertia operation.

As discussed in Section 1.1, FFR can be expected to increasingly play a role in managing contingency events during periods when there is a lower level of inertia in the power system. FFR has already been deployed as an alternative to inertia to address inertia shortfalls declared against the secure operating level of inertia for South Australia.

AEMO has consulted on amending its market ancillary services specification to provide a detailed description and performance parameters for the new very fast raise and lower services[6]. AEMO is now preparing to establish the market arrangements for very fast FCAS by October 2023.

While the implementation of the very fast FCAS markets can be expected to affect AEMO's assessment of inertia forecasts and resulting shortfall declarations, there is a significant degree of uncertainty about their impact. AEMO therefore considers it prudent to declare the 2022 inertia requirements and shortfall assessments with reference to the existing rules and markets to ensure that power system security requirements are met. AEMO will re-assess this position when sufficient information becomes available on the operation of the new markets.

AEMC Reliability Panel review of the Frequency Operating Standard

The AEMC's Reliability Panel is responsible for setting the frequency standards within which the NEM must be operated, in the form of the FOS. Frequency and inertia in the power system are closely related. The higher the amount of inertia, the more the system frequency can withstand large contingency events.

The Reliability Panel commenced a review of the FOS in April 2022[7]. AEMO is working with the AEMC to progress its review, which includes consideration of the merits of establishing a rate of change of frequency (RoCoF) standard for the NEM. AEMO expects that the existing inertia requirements in the NEM will need to be re-assessed against any updated FOS. This re-assessment could be major or minor, depending on the nature of the amendments to the FOS.

A rule change request for 'efficient provision of inertia' has been submitted to the AEMC, and the Energy Security Board is continuing to consider reform initiatives which may include inertia

The AEMC has published a rule change request submitted by the Australian Energy Council which seeks the establishment of an inertia spot market in the NEM, as well as a joint AEMC and AEMO paper relating to the

[5] AEMC. Final Report National Electricity Amendment (Fast Frequency Response Market Ancillary Service) Rule 2021. July 2021. At https://www.aemc.gov.au/rule-changes/fast-frequency-response-market-ancillary-service.

[6] AEMO. Amendment of the market ancillary service specification (MASS) – Very Fast FCAS. Consultation page, at https://aemo.com.au/consultations/current-and-closed-consultations/amendment-of-the-mass-very-fast-fcas.

[7] Project documents for the FOS review are at https://www.aemc.gov.au/market-reviews-advice/review-frequency-operating-standard-2022.

efficient provision of inertia[8]. In addition, the ESB is continuing to progress the post-2025 NEM review which may incorporate initiatives relating to inertia in the power system[9].

Any major amendments to the rules framework for the provision of inertia in the NEM can be expected to affect the inertia assessments considered in this report. AEMO has prepared this report consistent with the existing rules and will continue to work with the AEMC and other stakeholders as any regulatory reforms are progressed.

1.4 This report

The following inertia assessment information can be found in this report:

- Regulatory requirements for this report (Section 2).
- Method and inputs applied to prepare the inertia assessments in this report (Section 3).
- Inertia outcomes for each region, comprising a minimum threshold level of inertia, a secure operating level of inertia, and declaration of any inertia shortfalls over the five-year horizon (Section 4).
- Results from a study of the NEM with 100% renewable penetration at times of minimum demand (Section 5).
- Next steps (Section 6).
- Generator, network and market modelling assumptions (Appendix A1).

[8] These documents are provided on the AEMC's website page for the pending rule change relating to efficient provision of inertia, at https://www.aemc.gov.au/rule-changes/efficient-provision-inertia.

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

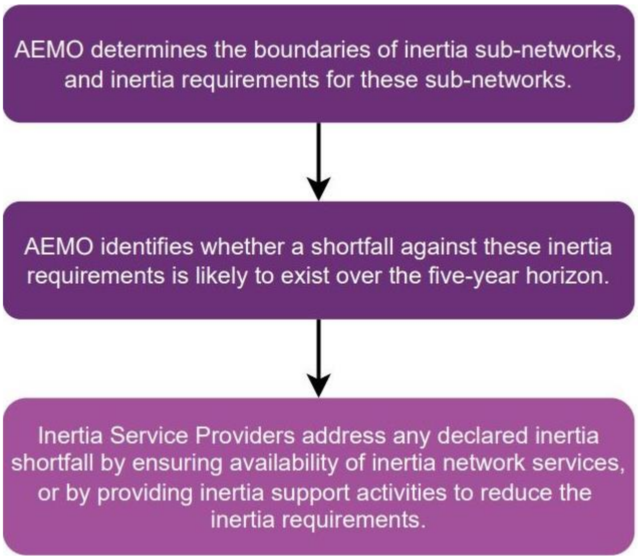
2 Regulatory requirements

AEMO is required to assess inertia sub-networks and requirements annually for each region of the NEM and declare any identified shortfalls or gaps for the coming five-year period[10]. This section describes the regulatory requirements for the inertia framework.

2.1 Division of inertia responsibilities

Figure 2 below indicates the present division of responsibilities for the provision of inertia in the NEM.

Figure 2 Division of inertia responsibilities



2.2 Assessing inertia requirements

Inertia requirements

AEMO applies the Inertia Requirements Methodology[11] to determine the inertia sub-networks of the NEM and then calculate their relevant requirements which comprise the minimum threshold level of inertia and the secure operating level of inertia.

The minimum threshold level represents the minimum amount of inertia needed to operate in a satisfactory operating state[12] when islanded, and applies when the sub-network is at credible risk of islanding. The secure operating level represents the inertia required to operate in a secure operating state[13] when the sub-network is islanded.

[10] NER Version 188, Clause 5.20.5

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

[12] NER Version 188, Clause 4.2.2

[13] NER Version 188, Clause 4.2.4

Declaration of an inertia shortfall

AEMO must assess the following to declare an inertia shortfall:

1. The level of inertia typically provided in the inertia sub-network with regard to typical patterns of dispatched generation in central dispatch as per the market modelling results in Appendix A1.
2. Whether, in AEMO's reasonable opinion, there is or is likely to be an inertia shortfall in the inertia sub-network and AEMO's forecast of the period over which the inertia shortfall will exist.
3. Where AEMO has previously assessed that there was or was likely to be an inertia shortfall, whether in AEMO's reasonable opinion that inertia shortfall has been or will be remedied.

Before AEMO is able to declare an inertia shortfall, it must also consider the following factors:

- Over what time period and to what extent the inertia that is typically provided in the inertia sub-network is or is likely to be below the secure operating level of inertia;
- The levels of inertia that are typically provided in adjacent connected inertia sub-networks and the likelihood of the inertia sub-network becoming islanded; and
- Any other matters that AEMO considers to be relevant in making its assessment.

Arrangements for how AEMO requires that the responsible Inertia Service Provider make services available to address the shortfall (or reduce the requirement) are covered in NER clauses 5.20B.3, 5.20B.4 and 5.20B.5.

Likelihood of islanding

When determining whether there is or is likely to be an inertia shortfall in a sub-network, AEMO must take into account the likelihood of it becoming islanded and also typical levels of inertia available in adjacent connected sub-networks[14]. This year, AEMO conducted additional inertia assessments of cases where two or more inertia sub-networks are at risk of forming a combined island. These regions may be unlikely to island individually, due to the number and strength of connections they have to each other or other regions. However, the available inertia levels across all regions have materially reduced since 2018, reducing the amount of inertia available to support adjacent inertia sub-networks. Therefore, AEMO now considers it important to assess the potential for inertia shortfalls on the formation of a multi-region island.

This assessment method can be applied to any combination of adjacent regions within the NEM for which islanding is considered feasible. In this report, AEMO has applied this approach to consider the inertia available to each inertia sub-network from the remaining adjacent sub-network within a two-region island comprising:

- New South Wales and Queensland, and
- Victoria and South Australia.

The method of assessment is outlined in Section 3 and the results are detailed in Sections 4.1 (New South Wales) and 4.5 (Victoria). As in previous years, Section 4 also includes AEMO's assessment of the likelihood of individual regions islanding and their available inertia levels.

[14] As per NER clause 5.20B.3(b)(2)

3 Method and inputs

This section provides the method and inputs applied for some key parameters in this report. Further detail is provided in the appendices.

Inertia sub-networks

AEMO must determine boundaries for inertia sub-networks, for which inertia minimum and secure requirements are assessed. AEMO may adjust these boundaries from time to time. Inertia sub-networks must be aligned within the boundaries of a NEM region, or wholly confined within a region.

AEMO has not made any adjustments to existing inertia sub-network boundaries, which correspond with the boundaries of NEM regions.

Inertia requirements

AEMO must determine inertia requirements for inertia sub-networks from time to time by applying the Inertia Requirements Methodology[15]. The requirements are the minimum threshold level of inertia and the secure operating level of inertia.

AEMO has not determined any changes to the existing inertia requirements across the NEM in this report.

Likelihood of combined regions islanding

As discussed in Section 2.2, in addition to its usual consideration of the likelihood of inertia sub-networks islanding individually, AEMO has conducted additional inertia assessments of cases where two or more inertia sub-networks are at risk of forming a combined island. These assessments were performed for a New South Wales and Queensland island, and a South Australia and Victoria island (noting Tasmania is excluded as it provides no inertial support to Victoria).

In assessing the groupings of NEM regions that presented the highest likelihood of islanding together, AEMO considered that the greatest risk is presented for the transmission network lines connecting the Snowy area to South-Western New South Wales and Victoria. This power system has been separated at this cut-set of the transmission network on two previous occasions – in January 2007 and January 2020 – resulting in synchronous separation between the New South Wales region and the Victoria region[16].

AEMO considers it prudent for Inertia Service Providers to plan for their region islanding through a range of different possible network conditions. This could include completely islanding with part or all of their adjacent region(s), or islanding with only part of their own region. As such, actual separation events could include (for example) part of New South Wales islanding with Victoria. However, for the purposes of this report, AEMO has based its assessment on projected inertia levels in New South Wales and Queensland, and in Victoria and South Australia.

[15] AEMO. Inertia Requirements Methodology. July 2018. Accessible via https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/Inertia_Requirements_Methodology_PUBLISHED.pdf

[16] Non-credible contingency events resulting in the separation of Victoria from New South Wales have been previously analysed in the 2018 Power System Frequency Risk Review (PSFRR) and more recently in the 2020 Stage 1 PSFRR. The 2022 PSFRR was published in July 2022 and considers the contingency of Loss of the Victoria – New South Wales Interconnector (VNI). AEMO's PSFRR documents can be accessed via https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/system-operations/general-power-system-risk-review/power-system-frequency-risk-review.

Inertia shortfalls

When assessing an inertia shortfall, AEMO compares the levels of inertia typically available in each region of the NEM against that region's inertia requirements. Consistent with the 2021 System Security Reports, AEMO has assessed shortfalls based on the 99th percentile results of the selected market modelling projection, rather than results one standard deviation from the mean as outlined in the 2018 Inertia Requirements Methodology. Given the spread of market dispatch and results, AEMO considers the 99th percentile is a more appropriate threshold to meet the NER requirements for declaring shortfalls against typical patterns of dispatched generation.

Shortfall declarations in this report are made for the five-year period from December 2022 to December 2028. However, the inertia projections presented in this report are based on market modelling using financial years, so inertia projection data is presented for 2022-23 to 2027-28.

When considering the potential for inertia shortfalls in the event of combined islands (New South Wales and Queensland, and Victoria and South Australia), AEMO compared the combined inertia level projection across the two sub-networks against the secure operating level and minimum threshold level of inertia of the sub-network with the largest credible contingency size.

Shortfall declarations in this report are made for the five-year period from December 2022 to December 2028. However, the inertia projections presented in this report are based on market modelling using financial years, so inertia projection data is presented for 2022-23 to 2027-28.

Demand outlook

The inertia assessments have been prepared[17] using the latest 2022 *Electricity Statement of Opportunities* (ESOO) Central scenario 50% probability of exceedance (50POE) minimum demand projection[18].

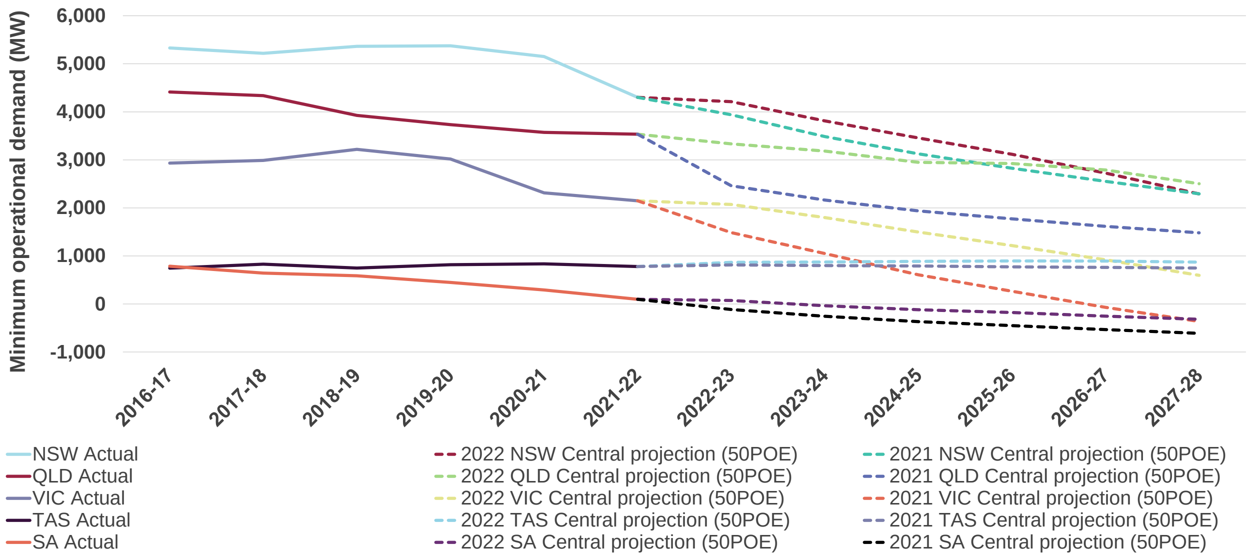
The 2022 ESOO projects declining minimum demand values for many regions of the NEM. However, the 2022 Central scenario has a higher underlying demand across many regions when compared with the previous year's forecast. Figure 3 below shows the differences in the minimum demand projections used in the 2021 and 2022 inertia assessments[19].

[17] Demand was scaled to 2022 ESOO operational sent-out demand values, however different values for transmission losses and auxiliary loads were used in the load calculations associated with the specific casefiles used for studies.

[18] AEMO National Electricity and Gas Forecasting portal at http://forecasting.aemo.com.au/Electricity/MinimumDemand/Operational.

[19] No minimum demand assessment was performed in Tasmania, so it is not included in this figure. See Section 4.4 for details.

Figure 3 Minimum demand projections used in 2021 and 2022 inertia reviews



Generator, network and market modelling inputs

Building on the 2022 ISP outcomes, the projected generation dispatch in this report follows the *Step Change* scenario and is the basis for projections of inertia shortfall declarations. The majority of new generation is forecast to connect in renewable energy zones (REZs) across the NEM. In addition to this assessment, AEMO has conducted a 100% renewable energy sensitivity for a minimum demand snapshot of the system, the results of which are used to highlight potential system security issues in the event the NEM transitions faster towards 100% instantaneous renewable energy penetration.

Table 3 summarises the use of key inputs for market modelling projections prepared for this report. Appendix A1 has further details.

Table 3 Key inputs for market modelling projections

Input	*Step Change* assessment for this report
Generator withdrawal and operation	Generator withdrawal consistent with the 2022 Final ISP *Step Change* scenario results.
New generation connections	Committed and anticipated generation per the latest NEM Generation Information. IBR projections from *Step Change* results were added into the time-sequential modelling used to project fault levels for the five-year horizon and the 10-year forecasts.
Transmission network projects	Committed, anticipated and actionable ISP transmission network augmentation projects were included consistent with 2022 ISP commissioning dates. See Appendix A1.2 for further detail. The recently announced Ararat synchronous condenser in Western Victoria was also included, as was the Waratah Super Battery.
Minimum unit requirements for system security	All minimum unit requirements were removed, to allow the projections to be assessed, except for the South Australia assumption that two units will be kept on until Project EnergyConnect (PEC) is commissioned.
Demand forecast	Apply 2022 ESOO Central projection for the *Step Change* scenario for demand (which differs from the 2022 ISP *Step Change* scenario for demand).

AEMO's NEM Generation Information, available at https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-planning-data/generation-information.

Frequency control ancillary services

AEMO's assessment of inertia forecasts and shortfalls accounts for inertia impact from the FCAS markets[20] by assuming that registered participants in the raise and lower fast FCAS markets will be available to provide their maximum capability, if they can reasonably be expected to be enabled at the time when the inertia requirements will apply. However, in cases where those participants might be able to provide fast frequency response that service has not been modelled in the forecast.

AEMO has not incorporated the impact of any FFR in the inertia forecasts used to assess shortfalls, because the trade-off between inertia requirements and available FFR has not been studied in detail for regions outside of South Australia. In addition, AEMO has assumed in this report that any FFR would be considered as a solution to an inertia shortfall rather than necessarily expected to be available to address a requirement. AEMO is preparing for the implementation of the very fast raise and lower FCAS markets, as discussed in Section 1.3. At this stage, AEMO will not be making assumptions about what services might be available from those markets.

[20] For information about the FCAS markets in the NEM, see AEMO's website at https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/system-operations/ancillary-services.

4 Inertia assessment

This section provides the inertia assessment for each region of the NEM, including describing the inertia requirements, providing inertia projections, and declaring inertia shortfalls.

4.1 New South Wales

AEMO projects that inertia in New South Wales will decline over the coming five-year outlook period, including declining below the secure operating level of inertia in the final year of the period. However, a shortfall is not declared, on the basis that New South Wales is not considered sufficiently likely to island on its own. If New South Wales and Queensland were to island together, it is expected that sufficient additional inertia would be available from Queensland to meet the inertia requirements in New South Wales.

Table 4 provides the inertia requirements and projections for New South Wales individually, and for the island of New South Wales and Queensland[21]. Figure 4 and Figure 5 illustrate their respective inertia duration curves for the five-year horizon.

Table 4 Inertia requirements and projections for New South Wales and its adjacent regions (Queensland)

<table>
<tr><th colspan="4">Inertia requirements</th></tr>
<tr><th></th><th>2021</th><th>2022</th><td rowspan="7">The secure operating level of inertia and minimum threshold level of inertia for New South Wales are held steady at the values determined in July 2018.
In making its assessment of any inertia shortfall for a region, AEMO must consider inertia typically provided in adjacent regions and the likelihood of islanding. Islanding of New South Wales alone is considered to be unlikely. This finding is largely driven by the diversity and number of AC interconnectors that exist between New South Wales, Victoria and Queensland, as well as South Australia after the completion of Project EnergyConnect.
However, based on declining inertia levels projected for both New South Wales and Queensland, and historical islanding events between New South Wales and Victoria[22] which led to New South Wales and Queensland islanding together, AEMO has assessed the inertia levels for a combined island of New South Wales and Queensland and accounted for these in the inertia requirements for each inertia sub-network.
Net distributed PV trip has not been incorporated in this assessment, and the secure operating level is not provided as a ratio of synchronous inertia and fast frequency response or Fast FCAS for New South Wales.</td></tr>
<tr><td>New South Wales secure operating level (MWs)</td><td>12,500</td><td>12,500</td></tr>
<tr><td>New South Wales and Queensland secure operating level (MWs) (and related MW Fast FCAS)</td><td>-</td><td>16,600 at 455 MW Fast FCAS in Queensland</td></tr>
<tr><td>New South Wales minimum threshold level (MWs)</td><td>10,000</td><td>10,000</td></tr>
<tr><td>New South Wales and Queensland minimum threshold level (MWs)</td><td>-</td><td>11,900</td></tr>
<tr><td>Net distributed PV trip (MW)</td><td>Not assessed</td><td>Not assessed</td></tr>
<tr><td>New South Wales risk of islanding (individual)</td><td>Unlikely</td><td>Unlikely</td></tr>
</table>

[21] Combined island levels are not *inertia requirements* as defined in the NER, which apply to each inertia sub-network, but they have been assessed and considered as described in the table.

[22] For example, New South Wales and Victoria separation event on 4 January 2020, via https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2020/final-report-nsw-and-victoria-separation-event-4-jan-2020.pdf?la=en.

Inertia requirements						
New South Wales and Queensland risk of islanding (combined)	-	Possible				
Inertia projections (*Step Change*)						
	2022-23	**2023-24**	**2024-25**	**2025-26**	**2026-27**	**2027-28**
Available inertia for 99% of the time in New South Wales (MWs)	19,934	20,518	19,073	14,343	14,647	9,798
Available inertia for 99% of the time in New South Wales and Queensland (MWs)	42,709	43,103	41,739	34,547	33,707	27,057
Inertia shortfall against secure operating level in New South Wales and Queensland (MWs)	None	None	None	None	None	None

Inertia requirements

Figure 4 Projected inertia for the five-year outlook, *Step Change* scenario, New South Wales

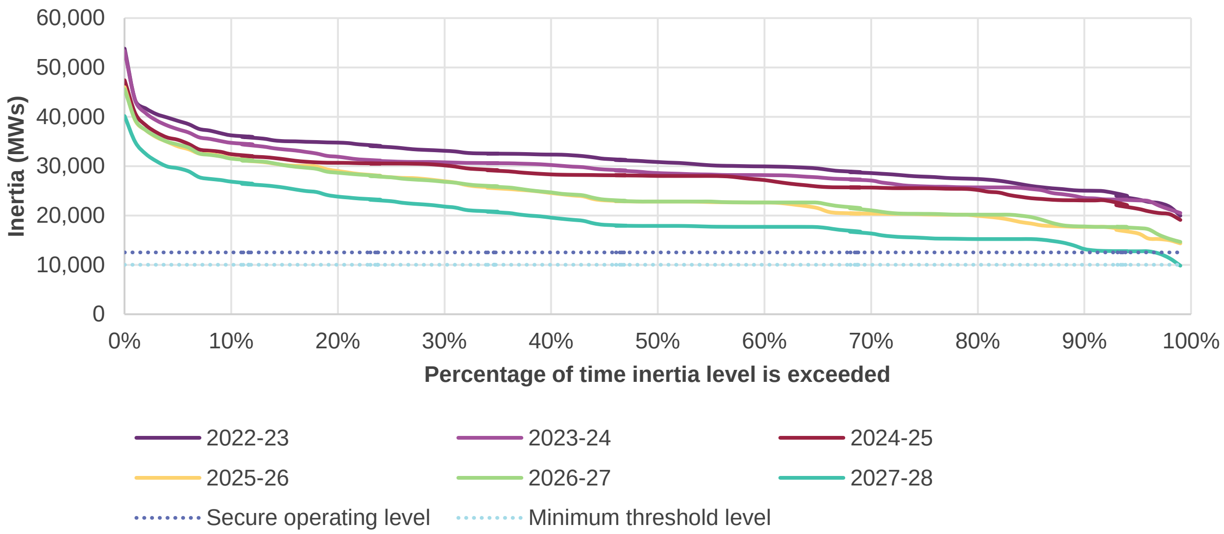
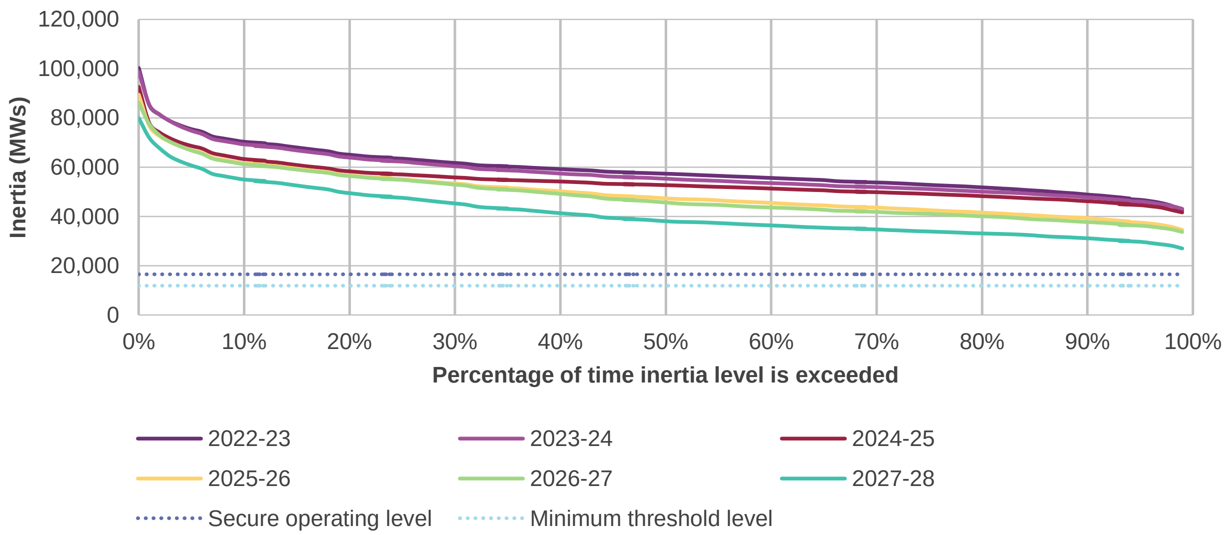


Figure 5 Projected inertia for the five-year outlook, *Step Change* scenario, New South Wales and Queensland



4.2 Queensland

AEMO is declaring a shortfall ranging from 8,200 megawatt seconds (MWs) to 10,352 MWs, from 1 July 2026, against the secure operating level of inertia in Queensland. It is likely that a variety of services will be able to meet this shortfall efficiently, including inertia support activities such as fast frequency response from batteries.

Table 5 provides the inertia requirements and projections for Queensland individually, and for the island of New South Wales and Queensland[23]. Figure 6 illustrates the secure operating level of inertia requirements for Queensland. Figure 7 and Figure 8 illustrate the inertia duration curves for the five-year horizon for Queensland individually and for the island of New South Wales and Queensland.

Table 5 Inertia requirements and projections for Queensland and its adjacent regions (New South Wales)

Inertia requirements

	2021	2022
Queensland secure operating level (MWs) (and related MW Fast FCAS)	24,100 MWs at 390 MW Fast FCAS 16,600 MWs at 455 MW Fast FCAS	24,100 MWs at 390 MW Fast FCAS 16,600 MWs at 455 MW Fast FCAS
Queensland and New South Wales secure operating level (MWs) (and related MW Fast FCAS)	-	16,600 MWs at 455 MW Fast FCAS
Queensland minimum threshold level (MWs)	11,900	11,900
New South Wales and Queensland minimum threshold level (MWs)	-	11,900
Net distributed PV trip (MW)	270	270
Queensland risk of islanding	Possible	Possible
New South Wales and Queensland risk of islanding	-	Possible

The secure operating level of inertia in Queensland is dependent on the Fast FCAS available and is also likely to be able to be reduced by any fast frequency response that may be made available through inertia support services.

The 2021 and 2022 requirements do not assume fast frequency response from utility-scale batteries as part of the typical dispatch used to set the requirements. Figure 2 shows the relationship between inertia required and available Fast FCAS.

Based on declining inertia levels projected for both New South Wales and Queensland, and historical islanding events between New South Wales and Victoria[24] which led to New South Wales and Queensland islanding together, AEMO has assessed the inertia levels for a combined island of New South Wales and Queensland and accounted for these in the inertia requirements for each inertia sub-network.

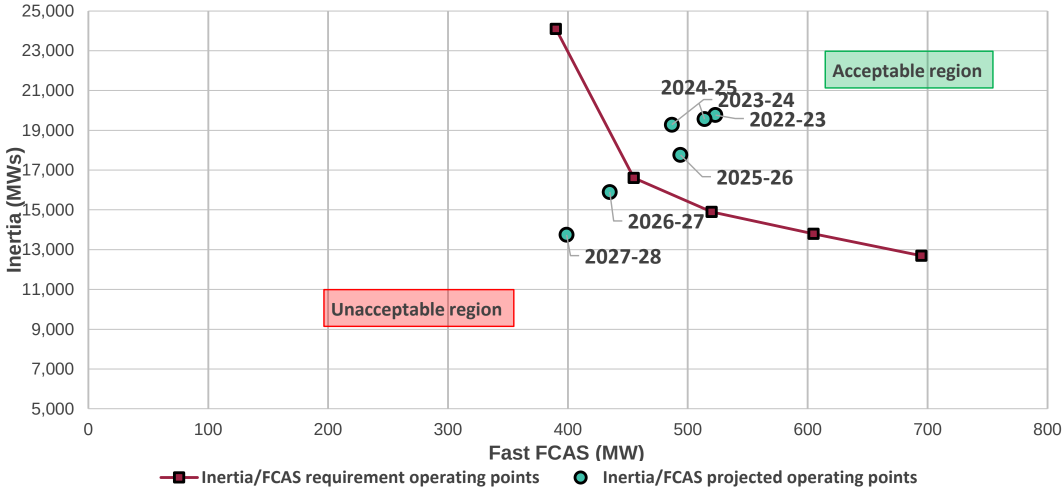
AEMO considers that the 2021 net distributed PV disconnection size assumed for Queensland is appropriate to re-apply for this 2022 assessment. The distributed PV disconnection size is under active consideration across the NEM, and AEMO will continue to work with Inertia Service Providers on this matter.

[23] Combined island levels are not *inertia requirements* as defined in the NER, which apply to each inertia sub-network, but they have been assessed and considered as described in the table.

[24] For example, New South Wales and Victoria separation event on 4 January 2020, via https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2020/final-report-nsw-and-victoria-separation-event-4-jan-2020.pdf?la=en.

Inertia requirements

Figure 6 2022 secure operating level of inertia requirement and five-year projections for 99th percentile, Queensland [A, B, C, D]



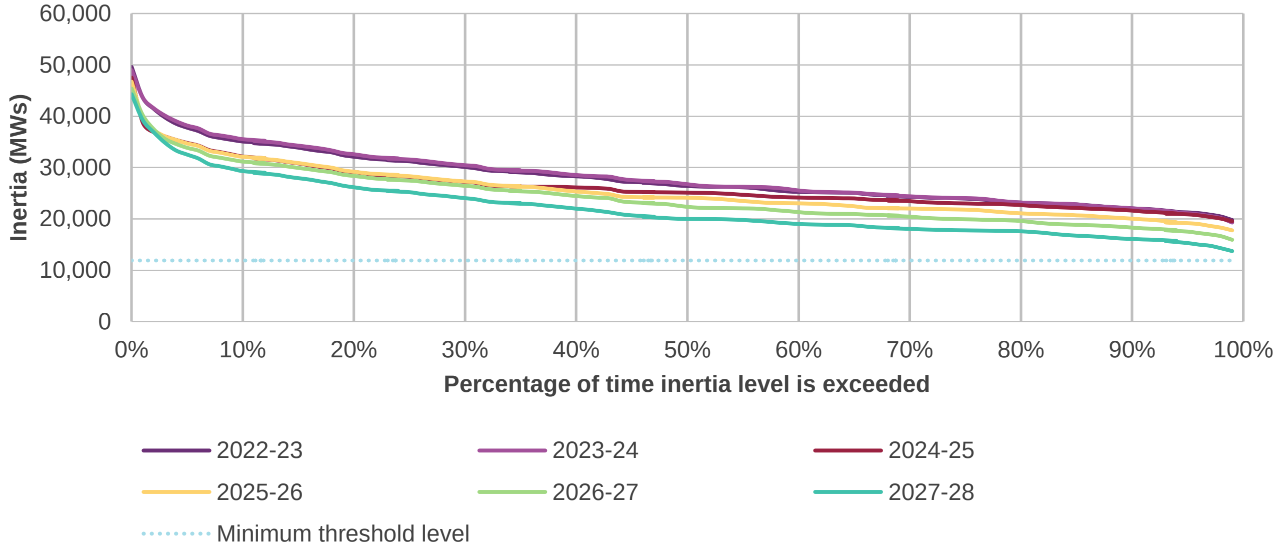
A. The figure represents the relationship between the level of inertia required against the amount of Fast FCAS required for each level of inertia. The Fast FCAS does not include any fast frequency response from utility-scale batteries or other IBR.
B. Square data points show the operating points which have been modelled and provide a secure system. A line is drawn between the operating points to broadly indicate where the system may be considered to be secure.
C. The area above and to the right of the purple line is acceptable from a system security perspective, and the area below and to the left is unacceptable.
D. The projection for inertia and Fast FCAS for each year in the five-year outlook period is shown with a purple circle (99th percentile of time, *Step Change* scenario). The projections can include both synchronous generating units and committed utility-scale batteries, noting that the impact of any fast frequency response (as opposed to Fast FCAS) in the projections is not displayed on this inertia-Fast FCAS figure.

Inertia projections (*Step Change*)

	2022-23	2023-24	2024-25	2025-26	2026-27	2027-28
Available inertia for 99% of the time in Queensland (MWs)	19,770	19,281	19,563	17,761	15,900	13,748
Fast FCAS projected available at 99th percentile in Queensland (MW)	523	487	514	494	435	399
Available inertia for 99% of the time in Queensland and New South Wales (MWs)	42,709	43,103	41,739	34,547	33,707	27,057
Inertia shortfall against secure operating level for Queensland (MWs)	None	None	None	None	8,200	10,352
Inertia shortfall against secure operating level in New South Wales and Queensland (MWs)	None	None	None	None	None	None

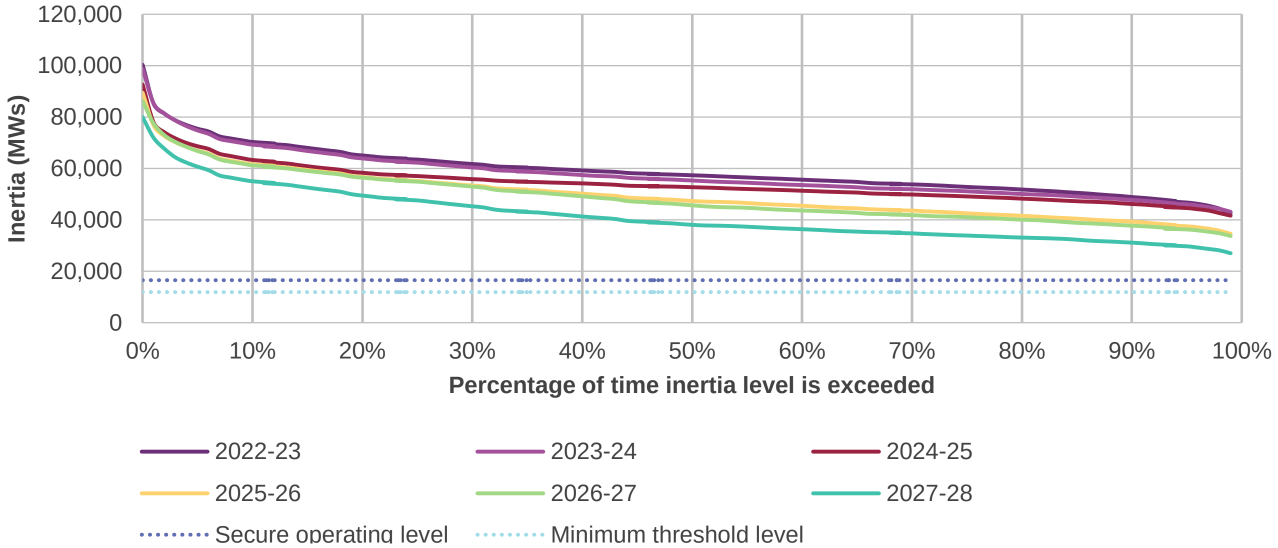
Inertia requirements

Figure 7 Projected inertia for the five-year outlook, *Step Change* scenario, Queensland [A]



A. Inertia projections are shown against the minimum threshold level of inertia. The secure operating level is not shown as a single value because it is a function of available inertia and Fast FCAS.

Figure 8 Projected inertia for the five-year outlook, *Step Change* scenario, New South Wales and Queensland



4.3 South Australia

AEMO has confirmed the existing shortfall against the secure operating level of inertia in the South Australia region. Fast frequency response is likely to provide an efficient response to address this shortfall, which is sized at 360 MW from July 2023 until Project EnergyConnect is operational.

For the period to December 2027, AEMO has assessed that the minimum threshold level of inertia will be met. However, the existing shortfall against the secure operating level of inertia remains. ElectraNet has services in place to address the shortfall until 30 June 2023 and is presently finalising services to meet the shortfall for 2023-24. The shortfall will persist until Project EnergyConnect (PEC) Stage 2 is operational[25] and until ElectraNet has implemented a scheme to effectively manage the non-credible loss of either of the Project EnergyConnect or Heywood interconnectors[26]. The end date for the shortfall could be affected by the provision of sufficient services through the establishment of very fast FCAS markets (from October 2023), or the completion of updates to a special protection scheme for South Australia (scheduled for July 2024). AEMO and ElectraNet will monitor these and other events and will re-assess the shortfall if required.

Table 6 provides the inertia requirements and projections for South Australia individually, and for the island of Victoria and South Australia[27]. Figure 9 illustrates the secure operating level of inertia requirements for South Australia. Figure 10 and Figure 11 illustrate the inertia duration curves for the five-year horizon for South Australia individually and for the island of Victoria and South Australia.

Table 6 Inertia requirements and projections for South Australia and its adjacent regions (Victoria)

<table>
<tr><th colspan="4">Inertia requirements</th></tr>
<tr><th></th><th>2021</th><th>2022</th><td rowspan="6">The secure operating level in South Australia is dependent on the amount of inertia support activities available, such as FFR. If more FFR (MW) is available, then less synchronous inertia (MWs) is required. Figure 9 shows the relationship between inertia required and FFR provided.
Based on declining inertia levels in Victoria and South Australia, between New South Wales and Victoria (which led to a Victoria and South Australia islanding with a small section of New South Wales), AEMO has assessed the inertia levels for the combined islanding of South Australia and Victoria and accounted for these in the inertia requirements for each inertia sub-network.
AEMO considers that the 2021 net distributed PV disconnection size assumed for South Australia is appropriate to re-apply for this 2022 assessment. The distributed PV disconnection size is under active consideration across the NEM, and AEMO will continue to work with Inertia Service Providers on this matter.
This analysis incorporates an assumption that at least two synchronous generating units will remain online if South Australia is islanded,[28] until Project EnergyConnect Stage 2 is operational and ElectraNet implements a scheme to effectively manage the non-credible loss of either of the Project EnergyConnect or Heywood interconnectors.</td></tr>
<tr><td>South Australia secure operating level (MWs) (and related MW FFR)</td><td>6,200 MWs with 360 MW FFR
4,400 MWs with 367 MW FFR</td><td>6,200 MWs with 360 MW FFR
4,400 MWs with 367 MW FFR</td></tr>
<tr><td>South Australia and Victoria secure operating level (MWs)</td><td>-</td><td>13,900</td></tr>
<tr><td>South Australia minimum threshold level (MWs)</td><td>4,400</td><td>4,400</td></tr>
<tr><td>South Australia and Victoria minimum threshold level (MWs)</td><td>-</td><td>9,500</td></tr>
<tr><td>Net distributed PV trip (MW)</td><td>300</td><td>300</td></tr>
</table>

[25] Including a minimum period of operation and minimum commissioning tests successfully completed.

[26] Including operational measures in place to manage any periods where the scheme is not effective.

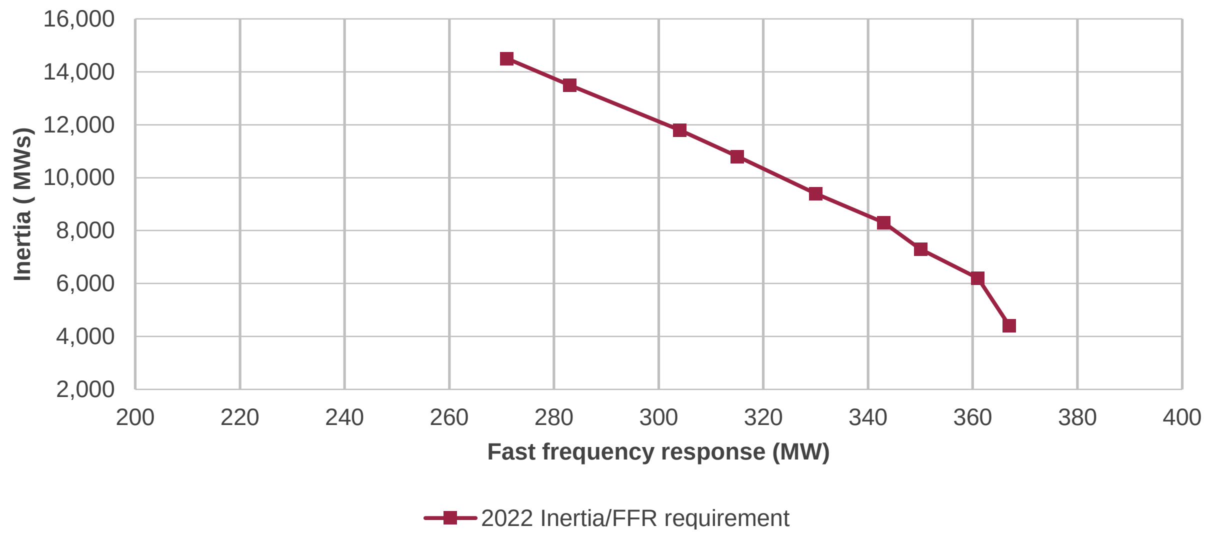
[27] Combined island levels are not *inertia requirements* as defined in the NER, which apply to each inertia sub-network, but they have been assessed and considered as described in the table.

[28] ElectraNet is undertaking work to assess if operating with less than two units is possible before Project EnergyConnect Stage 2 is operational.

Inertia requirements			
South Australia risk of islanding	Likely	Likely	AEMO and ElectraNet are continuing to collaborate on synchronous generator requirements in South Australia, including regular industry briefings[A].
Victoria and South Australia risk of islanding	-	Likely	This analysis incorporates 70 MW (and 10 MWh) of capacity reservation provided to the South Australia Government by Hornsdale Power Reserve.

A. Information provided to industry stakeholders regarding synchronous generator requirements in South Australia can be accessed via https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/system-operations/congestion-information-resource/related-resources/operation-of-davenport-and-robertstown-synchronous-condensers.

Figure 9 2022 Secure operating level of inertia requirement, South Australia [A B]



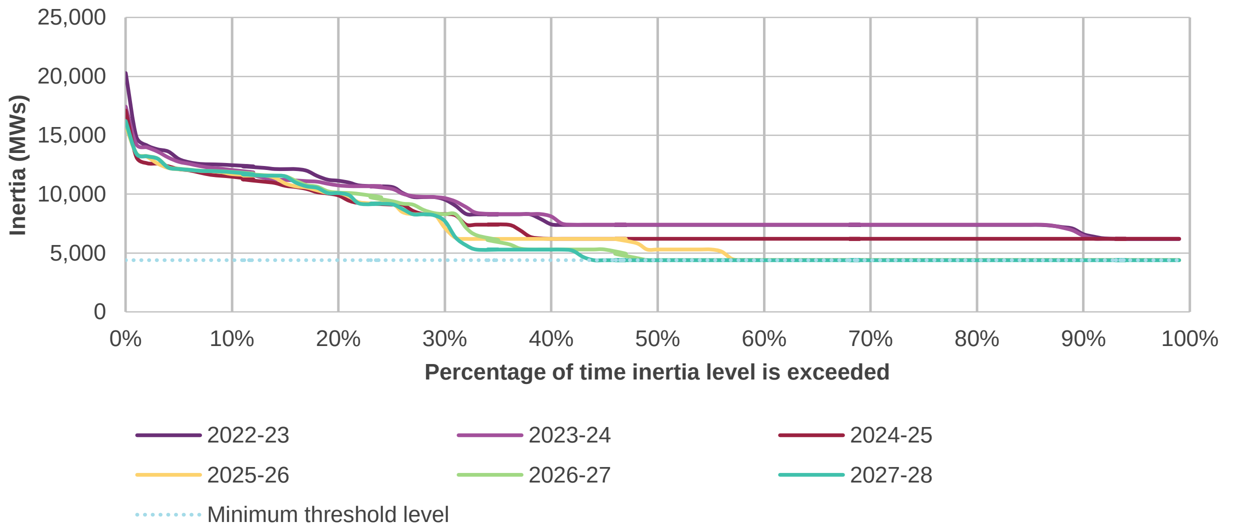
A. The figure represents the relationship between the level of inertia required against the amount of FFR required for each level of inertia.
B. Square data points show actual operating points which have been modelled and provide a secure system. A line is drawn between the operating points to broadly indicate where the system may be considered to be secure.

Inertia projections (*Step Change*)						
	2022-23	**2023-24**	**2024-25**	**2025-26**	**2026-27**	**2027-28**
Available inertia for 99% of the time in South Australia (MWs)	6,200	6,200	6,200	4,400	4,400	4,400
Available inertia for 99% of the time in South Australia and Victoria (MWs) [A]	19,649	19,471	17,800	14,008	11,479	11,418
Inertia shortfall against the secure operating level for South Australia (MW FFR equivalent)	200 MW of FFR (or equivalent MWs)	360 MW of FFR (or equivalent MWs) [B]	360 MW of FFR (or equivalent MWs) [B]	360 MW of FFR (or equivalent MWs) [B]	None	None
Inertia shortfall against the secure operating level in South Australia and Victoria (MWs) [C]	None	None	None	[892]	[3,421]	[3,482]

A. The inertia levels for Victoria at the 99th percentile have been post-processed to account for the recently announced Ararat synchronous condenser, which will provide around 1,000 MWs of inertia to the Victoria region. While AEMO recognises that the four synchronous condensers at Buronga and Dinawan built with Project EnergyConnect may impact the amount of inertia available to Victoria and South Australia in an islanding event, more information is required about control schemes being implemented as part of Project EnergyConnect, final equipment design, and the impact of ongoing regulatory changes, before then can be included in the projection. .
B. This shortfall is declared consistent with the values assessed in the 2021 System Security Reports. This shortfall is expected to be extinguished when Project EnergyConnect Stage 2 is operational and ElectraNet has implemented a scheme to effectively manage non-credible loss of the Project EnergyConnect or Heywood interconnectors. This is expected to occur in 2025-26.
C. This shortfall is presented here for completeness, shown in square brackets. Given the relative availability of forecast inertia in each region to meet its own secure operating level of inertia, AEMO is declaring this shortfall for Victoria, not for South Australia.

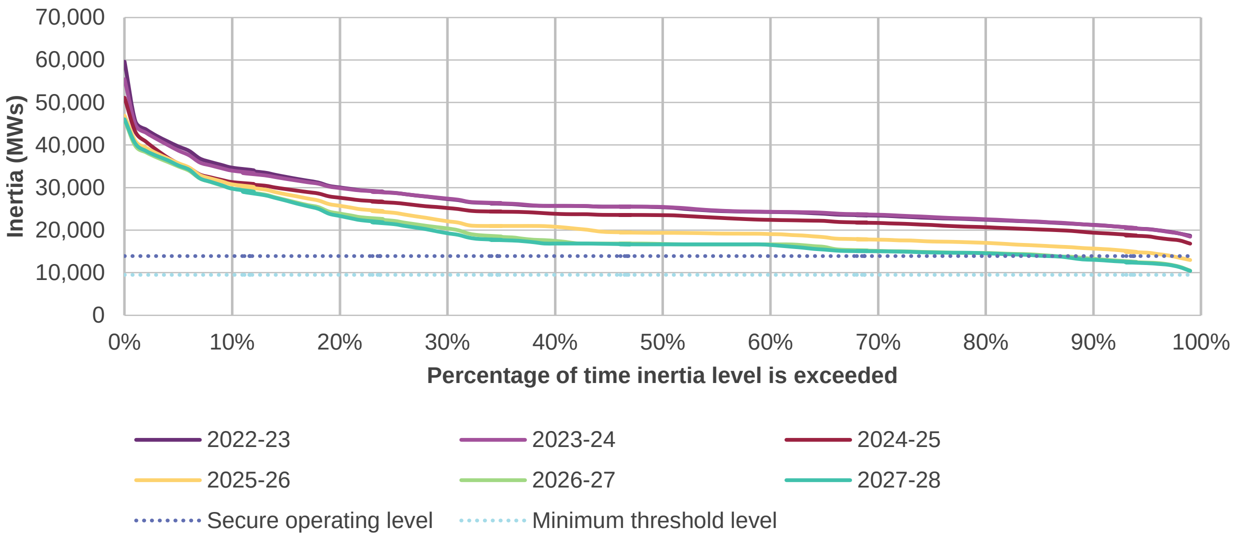
Inertia requirements

Figure 10 Projected inertia for the five-year outlook, *Step Change* scenario, South Australia [A]



A. Inertia projections are shown against the minimum threshold of inertia. The secure operating level of inertia is not shown as a single value because it is a function of available inertia and fast frequency response/inertia support activities.

Figure 11 Projected inertia for the five-year outlook, *Step Change* scenario, Victoria and South Australia



4.4 Tasmania

TasNetworks has an agreement in place with Hydro Tasmania for provision of inertia services until April 2024. In this report, AEMO has confirmed that shortfalls exist from April 2024 onwards against the minimum threshold and secure operating levels of inertia for Tasmania.

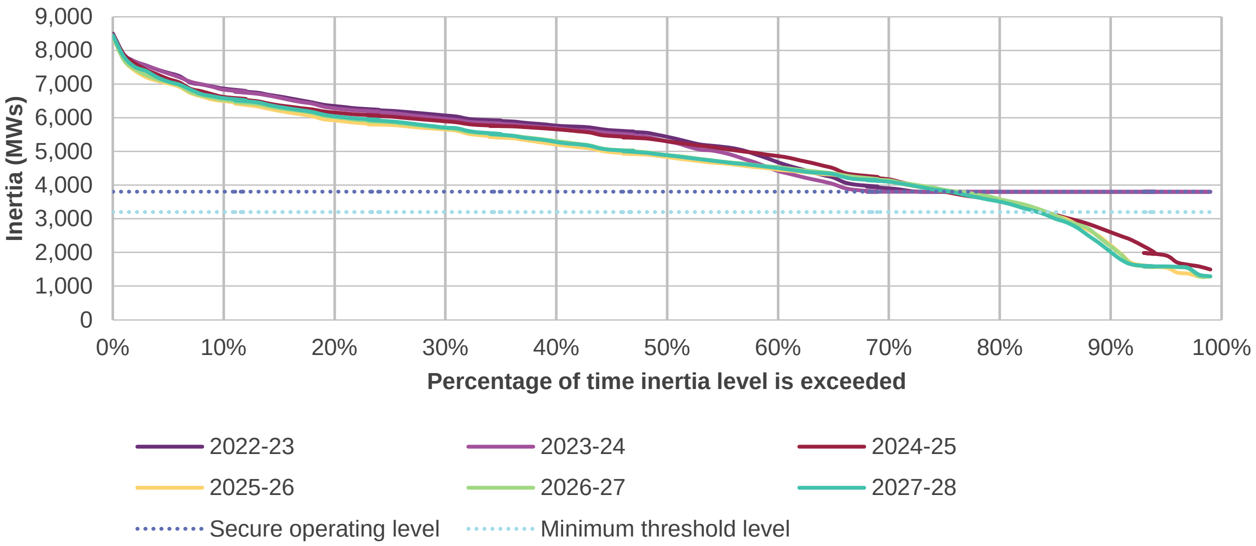
TasNetworks is presently finalising services to be provided to address the existing shortfalls. Table 7 provides the inertia requirements and projections for Tasmania. Figure 12 illustrates the inertia duration curves for the five-year horizon.

Table 7 2022 Inertia requirements and projections for Tasmania

<table>
<tr><th colspan="7">Inertia requirements</th></tr>
<tr><th></th><th>2021</th><th>2022</th><td colspan="4" rowspan="5">The secure operating level and minimum threshold level of inertia for Tasmania are held steady at the values determined in November 2019.
TasNetworks has a services agreement in place with Hydro Tasmania to provide inertia services until mid-April 2024 to ensure that the inertia requirements are met. TasNetworks is continuing to identify services to meet the shortfalls declared from April 2024 onwards.
In effect, Tasmania is always operated as an island with respect to inertia because its interconnector to the NEM (Basslink) is a DC connection and does not transport synchronous inertia (although it does provide frequency control when headroom is available).</td></tr>
<tr><th>Secure operating level (MWs)</th><td>3,800</td><td>3,800</td></tr>
<tr><th>Minimum threshold level (MWs)</th><td>3,200</td><td>3,200</td></tr>
<tr><th>Contracted inertia (MWs)</th><td>2,620</td><td>2,620</td></tr>
<tr><th>Risk of Islanding</th><td>Always islanded</td><td>Always islanded</td></tr>
<tr><th colspan="7">Inertia projections (Step Change)</th></tr>
<tr><th></th><th>2022-23</th><th>2023-24</th><th>2024-25</th><th>2025-26</th><th>2026-27</th><th>2027-28</th></tr>
<tr><th>Available inertia for 99% of the time (MWs)</th><td>3,800</td><td>3,800</td><td>1,495</td><td>1,291</td><td>1,291</td><td>1,291</td></tr>
<tr><th>Inertia shortfall against secure operating level (MWs)</th><td>Contracted</td><td>Contracted</td><td>2,305</td><td>2,509</td><td>2,509</td><td>2,509</td></tr>
</table>

Inertia requirements

Figure 12 Projected inertia for the five-year outlook, *Step Change* scenario, Tasmania [A]



A. For the dispatch intervals in 2022-23 and 2023-24 where the total available inertia falls below the secure operating level, post-processing has been done to indicate that the inertia requirements have been met by the inertia contract in place until April 2024.

4.5 Victoria

AEMO projects that inertia in Victoria will decline below the minimum threshold level and the secure operating level throughout the coming five-year outlook period. While Victoria islanding from the remainder of the NEM is not considered likely, it is possible that Victoria and South Australia could island together. In this case, AEMO has assessed that there would be insufficient additional inertia available from South Australia to meet the inertia requirements in Victoria. As such, AEMO is declaring an inertia shortfall in Victoria ranging from 2,421 MWs to 2,482 MWs against the secure operating level, from 1 July 2026 onwards.

The size and presence of the Victorian inertia shortfall is subject to change as the design of synchronous condensers and controls schemes between Victoria, South Australia and New South Wales are being finalised. AEMO will collaborate with ElectraNet and Transgrid to review this gap in 2023. Table 8 provides the inertia requirements and projections for Victoria individually, and for the island of Victoria and South Australia[29]. Figure 13 and Figure 14 illustrate their respective inertia duration curves for the five-year horizon.

Table 8 Inertia requirements and projections for Victoria and its adjacent regions (South Australia)

Inertia requirements			
	2021	**2022**	The secure operating level and minimum threshold level of inertia for Victoria are held steady at the values determined in December 2020. These have been calculated including fast frequency response capability provided by the Victorian Big Battery. Declaration of any inertia shortfall for a region must also consider the likelihood of islanding. Islanding of Victoria alone remains unlikely, consistent with AEMO's 2021 and 2018 assessments. This finding is largely driven by the diversity and number of AC interconnectors that exist between Victoria and the adjacent regions. However, historical islanding events have occurred between New South Wales and Victoria[30] (which led to a Victoria and South Australia islanding with a small section of New South Wales). Based on declining inertia levels in both Victoria and South Australia, AEMO has assessed the inertia levels for the combined islanding of South Australia and Victoria and accounted for these in the inertia requirements for each inertia sub-network. Note, any solution delivered to meet the inertia shortfall for South Australia identified in Section 4.3 may reduce the size of the inertia shortfall declared for Victoria, but it will not be sufficient to fully (or even mostly) address the shortfall. Further analysis will be required to determine the impact of additional inertia services in South Australia on the shortfall declared for Victoria. Net distributed PV trip has not been incorporated in this assessment, and the secure operating level is not provided as a ratio of synchronous inertia and fast frequency response or Fast FCAS for Victoria. AEMO notes the recent announcement of system strength services to be provided from a synchronous condenser in Ararat in Western
Victoria secure operating level (MWs)	13,900	13,900	
Victoria and South Australia secure operating level (MWs)	-	13,900	
Victoria minimum threshold level (MWs)	9,500	9,500	
Victoria and South Australia minimum threshold level (MWs)	-	9,500	
Net distributed PV Trip (MW)	Not assessed	Not assessed	
Risk of Victoria islanding	Unlikely	Unlikely	
Risk of Victoria and South Australia islanding (combined)	Possible	Possible	

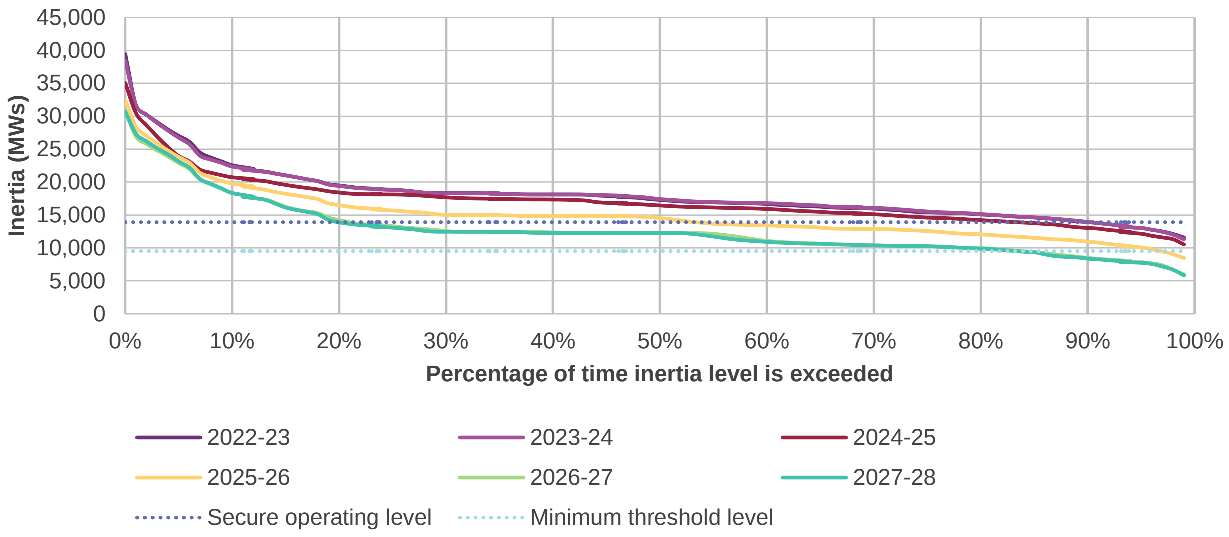
29 Combined island levels are not *inertia requirements* as defined in the NER, which apply to each inertia sub-network, but they have been assessed and considered as described in the table.

30 New South Wales and Victoria separation event on 4 January 2020, via https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2020/final-report-nsw-and-victoria-separation-event-4-jan-2020.pdf?la=en.

Inertia requirements						
			Victoria from late 2025[31]. This synchronous condenser will provide inertia to the power system, and the impact of this inertia has been included in the inertia forecasts provided in this report. More information on the timeline and specifications of the proposed synchronous condenser can be found in the 2022 Victorian Annual Planning Report[32].			
Inertia projections (*Step Change*)						
	2022-23	**2023-24**	**2024-25**	**2025-26**	**2026-27**	**2027-28**
Available inertia for 99% of the time in Victoria (MWs) [A]	12,565	12,317	11,505	9,444	7,009	6,803
Available inertia for 99% of the time in Victoria and South Australia (MWs) [A]	19,649	19,471	17,800	14,008	11,479	11,418
Inertia shortfall against the secure operating level of inertia in Victoria and South Australia (MWs) [B]	None	None	None	None	2,421	2,482

A. The inertia levels for Victoria at the 99th percentile have been post-processed to account for the recently announced Ararat synchronous condenser, which will provide around 1,000 MWs of inertia to the region While AEMO recognises that the four synchronous condensers at Buronga and Dinawan built with Project EnergyConnect may impact the amount of inertia available to Victoria and South Australia in an islanding event, more information is required about control schemes being implemented as part of Project EnergyConnect, final equipment design, and the impact of ongoing regulatory changes, before they can be included in the projection.
B. Given the relative availability of forecast inertia in each region to meet its own secure operating level of inertia, AEMO is declaring this shortfall for Victoria, not for South Australia.

Figure 13 Projected inertia for the five-year outlook, *Step Change* scenario, Victoria

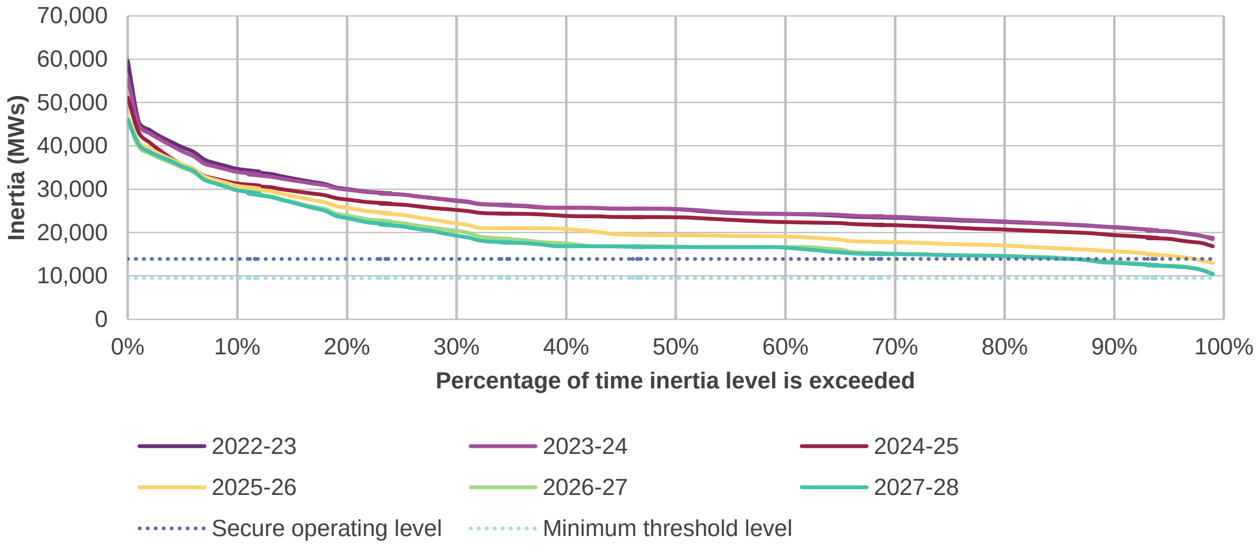


31 AEMO. 'AEMO awards contract to improved system security in Western Victoria REZ'. October 2022. Accessible via https://aemo.com.au/newsroom/media-release/aemo-awards-contract-to-improve-system-security-in-western-victoria-rez.

32 2022 Victorian Annual Planning Report, p.69, AEMO, via https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/vapr/2022/2022-victorian-annual-planning-report.pdf?la=en

Inertia requirements

Figure 14 Projected inertia for the five-year outlook, *Step Change* scenario, South Australia and Victoria



5 Preparing for 100% instantaneous renewable penetration

From 2025, there are forecast to be times when the NEM has enough renewable energy resources to meet 100% of its demand. However, the realisation of 100% instantaneous penetration of renewables will depend on a range of factors, including provision of wide-spread system security services.

As part of preparations for higher penetration of renewables, AEMO has undertaken a high-level study of operation of the mainland NEM at 100% instantaneous penetration of renewables[33] during times of low demand. The study assumes transmission network augmentations consistent with the *Step Change* scenario and considers provision of system strength, inertia and voltage control services to ensure a secure power system.

This study is considered to be a first step for assessing power system security needs in the NEM at times of 100% renewable energy penetration, and forms part of Priority Action A2 under AEMO's Engineering Framework[34]. The results presented in this section are indicative only. Further information about measures required for 100% renewable penetration in the NEM can be found in AEMO's *Engineering Roadmap to 100% Renewables*[35].

Selecting a low demand system snapshot for 100% renewable penetration

AEMO selected a power system snapshot to study based on *Step Change* scenario results, with some adjustments. Figure 15 summarises the generation dispatch considered in the study. The system snapshot reflected low NEM-wide operational demand in the middle of the day. It is plausible that this is not the only period where 100% renewables could occur, and AEMO aims to conduct further study of other scenarios at varying levels of demand and generation mixes.

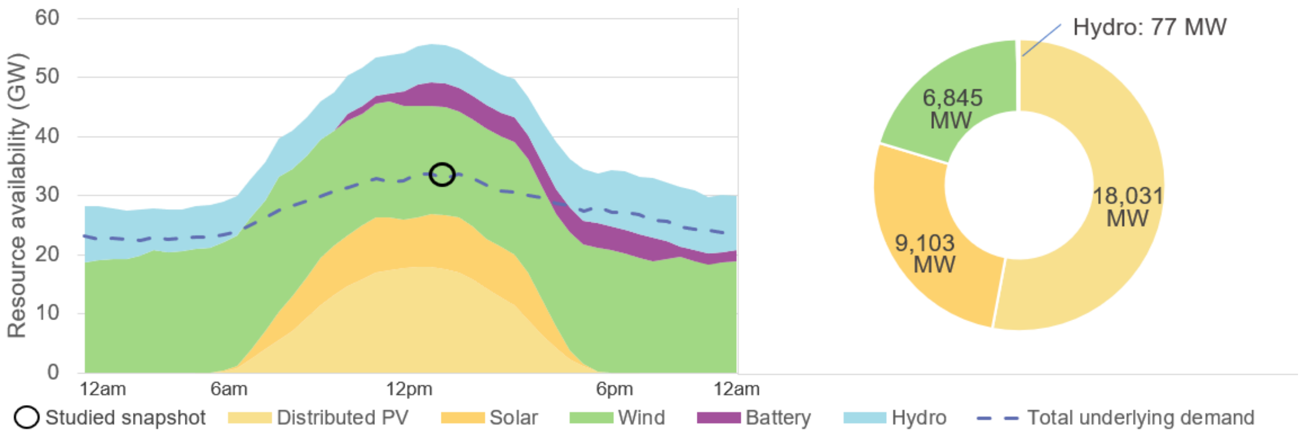
When preparing this snapshot, AEMO made some adjustments in recognition of the need to ensure sufficient renewable energy is available to cover periods leading up to and following the time of low demand, given that many fossil-fuelled generating units having a minimum start-up time of 4 to 6 hours once offline. AEMO did not include Tasmania in the study, because that region has already been operated at 100% renewable penetration due to its high proportion of hydro-powered generation.

[33] Renewables includes wind, solar, distributed PV, batteries, hydro and biofuels.

[34] See https://aemo.com.au/-/media/files/initiatives/engineering-framework/2022/nem-engineering-framework-priority-actions.pdf?la=en&hash=F5297316185EDBD4390CDE4AE64F48BB.

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

Figure 15 Resource availability and generation dispatch for low demand 100% instantaneous renewable penetration study



Three cases were assessed for power system security needs

AEMO studied three cases – a case with no mitigation measures to meet system security needs, a case with new synchronous condensers installed, and a case with both new synchronous condensers and retrofit of existing synchronous generators to operate in synchronous condenser mode.

AEMO expects that technological innovation, including but not limited to the use of grid-forming technologies, will be able to contribute to a diverse mix of solutions. AEMO does not consider that synchronous condensers alone would be the only or most efficient way for power system security services to be provided for 100% renewable penetration, but this option has been considered in this study for ease of analysis.

Table 9 provides the initial results of the study emphasising the importance of meeting the new system strength standard from 2025 onwards to facilitate the transition to a 100% renewable energy power system. Figure 16 provides a broad NEM overview of the outcomes of the study.

AEMO notes that the results presented in this section are the outcome of a steady-state analysis and are not provided for operational purposes.

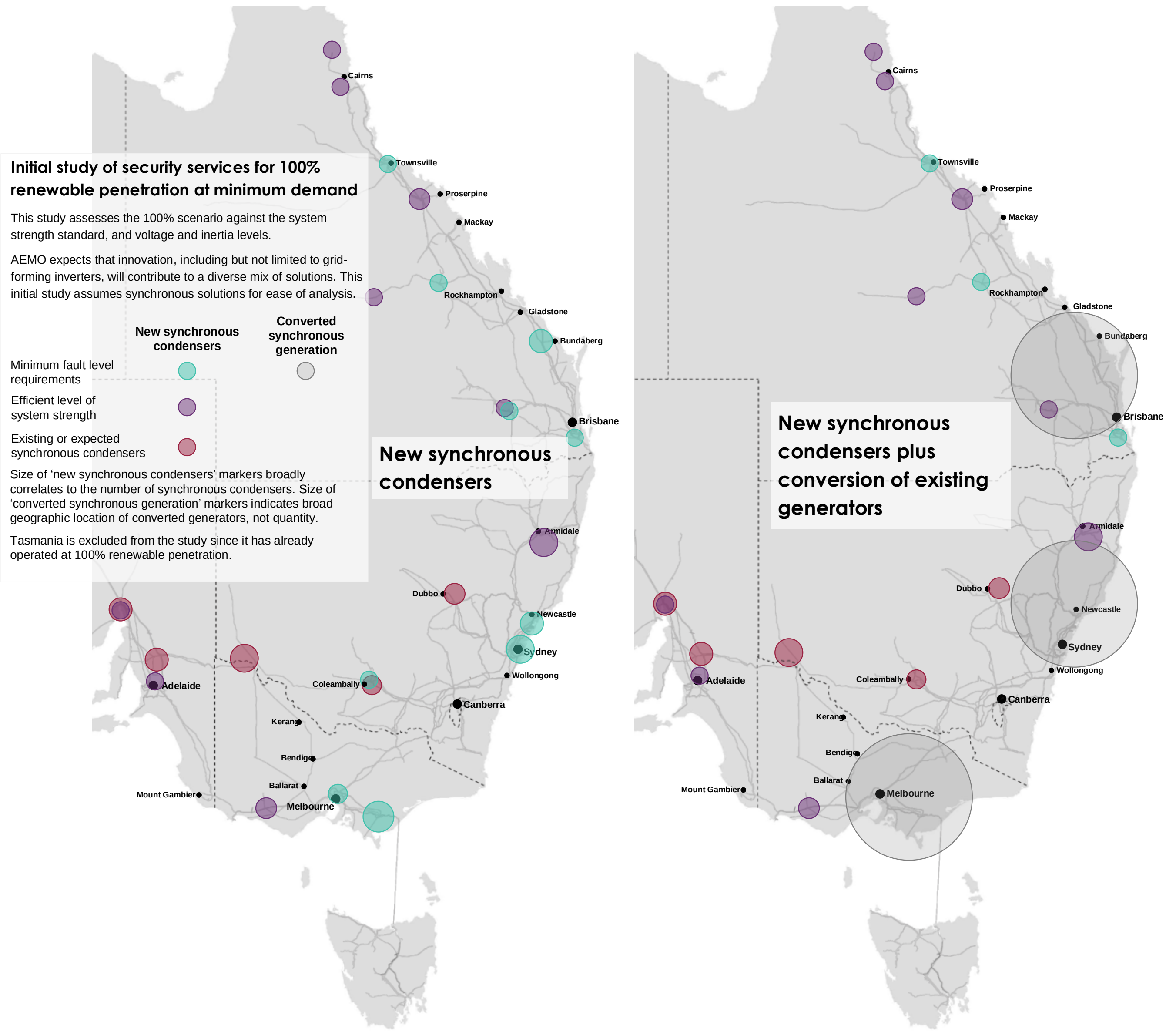
Table 9 Preliminary results for system security during 100% renewable energy penetration in the NEM at times of low demand

Solutions considered	System strength	Inertia	Voltage control
No mitigation measures	System strength shortfall identified in New South Wales, Victoria and Queensland	Inertia shortfall in all regions.	Over-voltage issues observed in Victoria and Queensland.
All system strength requirements (minimum and efficient) are addressed with new synchronous condensers [A, B]	The equivalent of up to 40 new synchronous condensers rated at 125 MVA are required across the NEM. This includes assumptions that pumped hydro synchronous generators will be available, and more synchronous condensers (or equivalent) will be required if the pumped hydro is not available.	Inertia requirements are met with the modelled system strength solution, except in some cases where support from FCAS markets and/or battery services may also be required.	No voltage range violations with the number of synchronous condensers installed for system strength.

Solutions considered	System strength	Inertia	Voltage control
All system strength requirements (minimum and efficient) are addressed with either new synchronous condensers or retrofit of synchronous generators to synchronous condenser mode [A]	15 synchronous generator units are converted to synchronous condensers and up to 25 additional synchronous condensers rated at 125 MVA are added across the NEM to meet the requirement.	Inertia requirements are met with the modelled system strength solution, except in some cases where support from FCAS markets and/or battery services may also be required.	No voltage range violations with the number of synchronous condensers installed and generator conversions completed for system strength.

A. High-level assumptions were made to estimate the services that might be required to address the efficient level of system strength, using fault level as a proxy for system strength. In practice, AEMO expects a diversity of solutions to be delivered, including but not limited to the use of grid-forming technologies.
B. AEMO selected an arbitrary number of units for conversion across the NEM, not based on advice from individual generators or local transmission planning bodies. However, AEMO recognises that efforts are underway within industry to reconsider traditional operating models of existing synchronous generators that may mean a different combination of generators may eventuate in conversion. This includes Priority Action A23 of AEMO's Engineering Framework and the Queensland Energy and Jobs Plan.

Figure 16 NEM outcomes for preliminary study of system security services during 100% renewable energy penetration in the NEM, at times of minimum demand



6 Next steps

AEMO has declared new inertia shortfalls within the five-year outlook period as a result of the 2022 assessments, as well as confirming existing shortfalls. Table 10 summarises the requests to Inertia Service Providers to deliver services to provide inertia to the affected regions.

If you wish to provide any comments or ask any questions about this report, please contact AEMO via planning@aemo.com.au.

AEMO and the Inertia Service Providers will undertake joint planning in 2023 and beyond to ensure that essential power system needs are met as the Australian energy transformation continues at pace.

Table 10 Services to be requested from Inertia Service Providers for inertia shortfall declarations

Region	Requests for inertia services
New South Wales	No requests.
Queensland	AEMO will request that Powerlink make inertia network activities (or inertia support services) available to address an inertia shortfall in Queensland, against the secure operating level, ranging from 8,200 to 10,352 MWs. AEMO will request that the activities (or services) be made available from 1 July 2026 until at least 30 June 2028.
South Australia	AEMO will request that ElectraNet make inertia network activities (or inertia support activities) available to address an inertia shortfall in South Australia, against the secure operating level, of 360 MW equivalent inertia support activities. AEMO will request that the activities (or services) be made available from 1 July 2023 until Project EnergyConnect is operational and until ElectraNet has implemented a scheme to effectively manage the non-credible loss of either of the Project EnergyConnect or Heywood interconnectors.
Tasmania	AEMO will request that TasNetworks make inertia network activities (or inertia support activities) available to address an inertia shortfall in Tasmania, against the secure operating level, ranging from 2,305 to 2,509 MWs. AEMO will request that the activities (or services) be made available from 15 April 2024 until at least 30 June 2028.
Victoria	AEMO will request that AEMO's Victorian Transmission Planning make inertia network activities (or inertia support activities) available to address an inertia shortfall in Victoria (when separated from New South Wales and islanded with South Australia), against the secure operating level, ranging from 2,421 to 2,482 MWs. AEMO will request that the activities (or services) be made available from 1 July 2026 until at least 30 June 2028.

A1. Generator, network and market modelling assumptions

This appendix provides the assumptions used in this report relating to generators, transmission network augmentations, and market modelling for generator dispatch.

A1.1 Generator assumptions

Committed and anticipated generation projects

The inertia forecasts provided in this report consider existing generators already in service as well as any committed and committed* scheduled and semi scheduled generation projects. These projections for 2022-23 to 2027-28 incorporate projects from the July 2022 NEM Generation Information[36].

The inertia forecasts also consider anticipated projects captured in the July 2022 NEM Generation Information consistent with the references in the paragraph above, as well as any new generation forecast to be built under the market modelling results for the *Step Change* scenario prepared for the 2022 ISP[37].

Further details about how projects have been incorporated in the market modelling results used in this report can be found in Appendix A1.3.

Generation withdrawal and operation

The inertia forecasts in this report are aligned with the generator withdrawals and operation in the *Step Change* scenario of the 2022 ISP[38], including the potential early retirement of Eraring Power Station[39] in August 2025.

A1.2 Transmission network augmentations

Table 11 provides the details and modelling date for the large committed, anticipated and ISP actionable transmission network augmentation projects included in the inertia forecasts in this report. These projects were not included in the assessment of the minimum threshold levels of inertia or the secure operating levels of inertia. These projects are modelled consistent with the latest information provided by TNSPs, where timing permitted.

[36] AEMO. The July 2022 NEM Generation Information is available under the Archive section of AEMO's Generation information webpage, at https://www.aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-planning-data/generation-information. Criteria for committed and committed* and anticipated are explained in the Background Information tab of the spreadsheet.

[37] At https://aemo.com.au/-/media/files/major-publications/isp/2022/2022-documents/2022-integrated-system-plan-isp.pdf?la=en.

[38] At https://aemo.com.au/-/media/files/major-publications/isp/2022/2022-documents/2022-integrated-system-plan-isp.pdf?la=en.

[39] See https://www.originenergy.com.au/about/investors-media/origin-proposes-to-accelerate-exit-from-coal-fired-generation/.

Table 11 Large transmission network upgrades included in each assessment

Transmission network upgrade	Augmentation detail	Modelling date (Calendar year) [A]	Included in assessment
South Australia system strength remediation	The South Australia system strength remediation project includes the installation of two high inertia synchronous condensers at Davenport 275 kV substation and two high inertia synchronous condensers at Robertstown 275 kV substation. Each of the four synchronous condensers provide 575 MVA nominal fault current and 1,100 MWs of inertia and were commissioned at the end of 2021.	In service	Inertia shortfall assessment.
QNI Minor	QNI Minor is the upgrade of the existing interconnector with uprating to increase thermal capacity of the existing transmission lines and installation of additional new capacitor banks and Static Var Compensators (SVCs) to increase transient stability limits on the Queensland – New South Wales interconnector.	Mid 2023 [B]	Inertia shortfall assessment.
VNI Minor	VNI Minor is an upgrade of the existing Victoria – New South Wales interconnector with the installation of an additional 500/330 kV transformer, uprating to increase thermal capacity of the existing transmission, and installation of power flow controllers in New South Wales to manage the overload of transmission lines.	2022 [C] (Victoria side) 2023 (New South Wales completion date)	Inertia shortfall assessment.
South Australia Eyre Peninsula Link	This project will replace the existing 132 kV lines between Cultana and Port Lincoln with a new double circuit line. This includes a new double circuit line from Cultana to Yadnarie built at 275 kV but energised at 132 kV and a new double circuit 132 kV line from Yadnarie to Port Lincoln.	2023	Inertia shortfall assessment.
Powering Sydney's future	This project is to install a new 330 kV cable between Beaconsfield and Rookwood substations. Derate the existing 330 kV cable and service reactor between Beaconsfield and Sydney South from 330 kV to 132 kV.	Fully completed in 2022	Inertia shortfall assessment.
Western Victoria transmission network	The Western Victoria transmission network project is split into two stages. Parts of stage 1 are already complete. **Remainder of Stage 1:** • Uprate Bendigo – Kerang 220 kV line and Kerang – Wemen – Red Cliffs 220 kV lines. **Stage 2:** • A new substation north of Ballarat. • Cut-in the Ballarat – Bendigo 220 kV line at new substation North of Ballarat. • A new 220 kV double-circuit transmission line from substation north of Ballarat to Bulgana (via Waubra). • Moving the Waubra Terminal Station connection from the existing Ballarat – Ararat 220 kV line to a new 220 kV line connecting the substation north of Ballarat to Bulgana. • Cut-in the existing Ballarat-Moorabool No.2 220 kV line at Elaine Terminal Station. • A new 500 kV double-circuit transmission line from Sydenham to the new substation north of Ballarat. • 2 x 500/220 kV transformers at the new substation north of Ballarat. • 4 x 50 MVAr 500 kV reactors, one at each end of the new 500 kV lines.	Late 2021 (Stage 1) 2026[D] (Stage 2)	Inertia shortfall assessment.
Project EnergyConnect	**Stage 1:** • A new Robertstown to Bundey 275 kV double-circuit line strung one circuit initially. • A new Bundey to Buronga 330 kV double-circuit line strung one circuit initially.	Stage 1 2024 Stage 2 2026 [E]	Inertia shortfall assessment.

Transmission network upgrade	Augmentation detail	Modelling date (Calendar year) [A]	Included in assessment
	• A new Buronga to Red Cliffs 220 kV double-circuit line strung one circuit only. • A new 330/275 kV substation and a 330/275 kV transformer at Bundey. • A new 330/220 kV substation, a 330/220 kV transformer and a 330 kV phase shifting transformer at Buronga. • Static and dynamic reactive plant at Bundey and Buronga. **Stage 2:** • Second 275 kV circuit strung on the Robertstown – Bundey 275 kV double-circuit line. • Second 330 kV circuit strung on the Bundey – Buronga 330 kV double-circuit line. • A new 330 kV double-circuit line from Buronga to Dinawan. • A new 500 kV double-circuit line from Dinawan to Wagga Wagga operating initially at 330 kV. • Two additional new 330/275 kV transformers at Bundey. • A new 330 kV switching station at Dinawan. • Additional new 330 kV phase shifting transformers at Buronga. • Additional new 330/220 kV transformer at Buronga. • Turning the existing 275 kV line between Para and Robertstown into Tungkillo. • Static and dynamic reactive plant at Bundey, Robertstown, Buronga and Dinawan. • A special protection scheme to detect and manage the loss of either of the AC interconnectors connecting to South Australia.		
Central-West Orana renewable energy zone (REZ) Transmission Link [F]	The Central West Orana REZ link includes extension of the 500 kV and 330 kV network in the Central-West Orana region of New South Wales. This REZ will also include some system strength remediation [E] as part of the build.	2025	Inertia shortfall assessment.
Waratah Super Battery project [G]	The NSW Government is procuring a new network battery – the 'Waratah Super Battery' – dedicated to supporting the electricity transmission grid. This will be a battery energy storage system with a capacity of approximately 700 MW; and transmission infrastructure to connect the battery to the existing Munmorah Substation within a former power station.	Beginning 2025	Not included.
Victorian Renewable Energy Zone Development Plan – South West REZ project [H]	A project to connect the existing 500 kV Tarrone – Haunted Gully transmission line to the Mortlake Terminal Station. Delivered by AusNet Transmission Group Pty Ltd.	2025	Not included due to timing restrictions.
Victorian Renewable Energy Zone Development Plan – Western REZ project	A 250 MVA (1,000 MWs) synchronous condenser next to the Ararat Terminal Station.	2025	Inertia shortfall assessment.
Victorian Renewable Energy Zone	A 125 MW big battery and grid forming inverter technology near Kerang to provide system strength services.	2025	Not included due to timing restrictions.

Transmission network upgrade	Augmentation detail	Modelling date (Calendar year) A	Included in assessment
Development Plan – Murray River REZ project			
HumeLink	A 500 kV transmission upgrade connecting Project EnergyConnect and the Snowy Mountains Hydroelectric Scheme to Bannaby.	2026	Inertia shortfall assessment.
Sydney Ring Northern Loop	New 500 kV loop: • A new 500 kV substation near Eraring. • A new 500 kV double circuit line between substation near Eraring and Bayswater substation. Two 500/330 kV 1,500 MVA transformers either at Eraring substation or new substation near Eraring.	2027	Inertia shortfall assessment.

A. For some of the nearer-term projects, AEMO is aware of some delays to delivery and commissioning. However, in these cases AEMO does not consider the delays to be impactful for the purposes of system strength assessments and so the modelling dates are unchanged.
B. Consistent with the ISP this timing is when full capacity is expected to be available following commissioning and interconnector testing.
C. Consistent with the ISP this timing is when full capacity is expected to be available following commissioning and interconnector testing
D. Consistent with the ISP this timing is when full capacity is expected to be available following commissioning and testing.
E. Consistent with the ISP this timing is when full capacity is expected to be available following commissioning and interconnector testing. However, construction and first energisation is expected in the second half of 2024, with commissioning activities and inter-network testing scheduled to follow first energisation. It is expected that Project EnergyConnect will progressively release transfer capacity from July 2024 onwards.
F. EnergyCo will build system strength remediation in some form for the CWO REZ. AEMO has included latest information on this remediation
G. As per NSW Government's announcement, at https://www.energyco.nsw.gov.au/waratah-super-battery-munmorah-site.
H. As per Victorian Government's Renewable Development Plan, at https://www.energy.vic.gov.au/__data/assets/pdf_file/0028/580618/Victorian-Renewable-energy-zones-development-plan-directions-paper.pdf.

A1.3 Market modelling of generator dispatch method

AEMO undertakes integrated energy market modelling to forecast future investment in and operation of electricity generation, storage and transmission in the NEM[40].

Projected generation and storage investment and dispatch from the *Step Change* scenario results for the 2022 ISP have been used for inertia forecasts in this report, with some updates to reflect the latest information. These market modelling results:

- Cover the financial years from 2022-23 to 2027-28.
- Were updated compared to the 2022 ISP results, to include updated generator statuses, particularly all existing, committed, and committed* generation, as of 22 July 2022 from AEMO's NEM Generation Information page.
- Are based on the *Step Change* scenario generator, storage and transmission build outcomes for the 2022 ISP.
- Include generator dispatch projections from a time-sequential model using the 'bidding behaviour model' for realistic generator dispatch results given the generation and build outcomes. The bidding behaviour model uses historical analysis of actual generator bidding data and back-cast approaches for the purposes of calibrating projected dispatch[41].

[40] Information about AEMO's energy market modelling can be found in the July 2020 Market Modelling Methodologies report as well as the 2021 ISP Methodology, accessible via https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/inputs-assumptionsmethodologies/2020/market-modelling-methodology-paper-jul-20.pdf?la=en and https://aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp/2022-integrated-system-plan-isp/isp-methodology respectively.

[41] Details for the bidding behaviour model are provided in AEMO's Market Modelling Methodologies report. AEMO, Market Modelling Methodologies, July 2020, via https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/inputs-assumptionsmethodologies/2020/market-modelling-methodology-paper-jul-20.pdf?la=en.

- Apply the *Step Change* scenario 50POE demand projection from the 2022 ESOO.
- Apply projections of generation outages based on Monte Carlo simulation.
- Apply projections of planned maintenance. Maintenance events are assumed to be distributed throughout the year such that they minimise planned outages at times when it is most required when consumer demand is high, to avoid exacerbating reliability risks.
- Incorporate a range of market modelling iterations for each year of the study period, capturing multiple generator outage patterns. This better captures the variability in generator outage patterns, and hence gives better regard of typical dispatch patterns.
- When applying the market modelling results to assess the inertia projections, some post model adjustments were made where necessary based on industry knowledge and known operational practices.

Inertia requirements are not based on market modelling results. Details for how inertia requirements were prepared are available in previous years' inertia reports, as they were not re-modelled for this report.