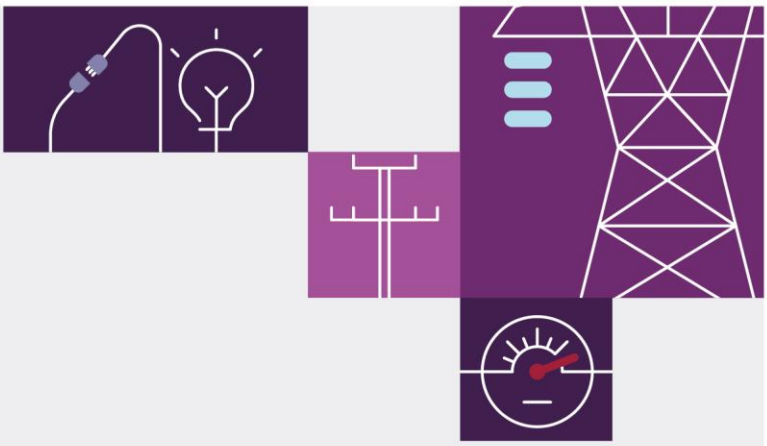
AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

Engineering Roadmap to 100% Renewables

FY2024 Priority Actions

A report for the National Electricity Market



Important notice

Purpose

This report outlines the activities the Australian Energy Market Operator (AEMO) plans to undertake in the 2023-24 financial year (FY2024) to help prepare the National Electricity Market (NEM) for operation at times of 100% instantaneous renewables.

This report seeks to continue the work from the *Engineering Roadmap to 100% Renewables* by providing transparency on the specific activities AEMO is progressing in FY2024. While the transition does require a concerted effort across industry, this report highlights the key engineering and operational readiness activities that AEMO intends to progress in this next financial year to contribute towards operating at times of 100% instantaneous renewables.

This report follows the release of the *Engineering Roadmap to 100% Renewables* using information available as of 30 June 2023. Information made available after this date may have been included in this publication where practical.

This document uses terms that have meanings defined in the National Electricity Rules **(NER), unless otherwise specified.**

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Version control

Version	Release date	Changes
1	12/07/2023	Initial publication

AEMO acknowledges the Traditional Owners of country throughout Australia and recognises their continuing connection to land, waters, and culture. We pay respect to Elders past and present.

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1.1 Key messages

Operating the first period of 100% instantaneous penetration of renewables[1]

The National Electricity Market (NEM) is rapidly transitioning to higher penetrations of renewables. Over the last year the NEM has seen coal generation closures, development and connection of new utility-scale generation and energy storage, developments in transmission build, and sustained growth in distributed energy resources (DER). 2022 saw several renewable milestones reached, including:

- 68.7% instantaneous penetration of renewables in the NEM on 28 October 2022.
- 91.5% instantaneous penetration of renewables in South Australia on 19 November 2022, when the region was synchronously islanded from the NEM.

As Australia moves rapidly away from its traditional dependence on coal generation, its energy future will be built on four pillars:

1. Low-cost **renewable energy**, taking advantage of the abundant wind, solar and hydro resources that Australia has to offer.
2. **Firming technology** like pumped hydro, batteries, and gas generation, to smooth out the peaks and fill in the gaps from that variable renewable energy.
3. New **transmission** and **modernised distribution networks** to connect these new and diverse low-cost renewable sources of generation to our towns and cities.
4. **Power systems capable of running, at times, entirely on renewable energy**.

The *Engineering Roadmap to 100% Renewables*[2] (the Roadmap) focused primarily on the fourth point, addressing what, from an engineering perspective, must be done to securely and reliably run a power system at times without fossil fuels. While the intent is to be ready for the first 100% instantaneous renewables period (which could include any renewable generation sources), the predominant challenge will involve managing high penetrations of variable, inverter-based renewables (IBR) like wind and solar generation, which make up the majority of new renewables coming into the NEM.

Readiness for 100% instantaneous renewables is a critical enabler for being able to operate the power system regularly with high penetrations of renewables, in turn supporting the transition to a net-zero energy system.

A concerted industry effort is needed to deliver the NEM's transition, and efforts are progressing on many fronts. For AEMO, many of these efforts relate to engineering and operational readiness activities, as outlined in the Roadmap.

[1] 100% instantaneous penetration of renewables refers to a half-hour period in which all demand is met from renewable sources, including grid-scale wind and solar, hydro generation, biomass, storage, and rooftop photovoltaics (PV).

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

This Engineering Roadmap FY2024 priority action report provides an overview of the actions that AEMO will undertake in the 2023-24 financial year (FY2024) to progress readiness efforts for the first periods of 100% instantaneous renewables in the NEM.

Of the 174 actions identified in the Roadmap, AEMO anticipates it will make progress towards over 80 of these actions in FY2024. This report summarises AEMO's intended efforts, highlighting a subset of activities where AEMO is seeking to drive significant progress in the year ahead, and where:

- AEMO believes significant uplift in effort is required to progress readiness for particular Roadmap preconditions[3].
- Engagement with stakeholders outside AEMO is crucial and not fully captured through other work programs.
- Delayed progression may pose a risk a risk to power system security in future.

AEMO's committed actions seek to maximise readiness for operating the NEM at up to 100% instantaneous renewables while remaining within the bounds of AEMO's existing funding structure and resourcing ability. In parallel with the commitments detailed in this report, AEMO is exploring additional funding pathways to enable the acceleration of Engineering Roadmap implementation efforts over coming years.

The report also details the progress made on the Engineering Framework FY2023 priority actions[4].

Priority actions identified for FY2024 priorities

The priority actions identified for FY2024 largely cover four key objectives that AEMO sees as pivotal to progress in this financial year:

- **Enabling high penetrations of distributed energy resources (DER)** – performance, visibility and controllability, and necessary operational coordination and data exchange, for securely operating a high DER power system, allowing consumers to optimise for their own circumstances and to harness DER flexibility in an increasingly two-way power system.
- **Conducting future power system studies** – understanding emerging issues on the power system as it moves towards uncharted operating conditions, and quantifying gaps in known system requirements for immediate emerging operating conditions.
- **Enabling new technologies to address system needs** – accelerating efforts to support grid-forming inverter development and promoting opportunities for technologies to include multiple system services as part of their solution design.
- **Building operational readiness** – enhancing operational capabilities to adapt to a changing power system, including improved modelling approach and tools, monitoring and situational awareness, and increasing readiness efforts to securely operate the power system in new configurations for the first time.

1.2 Journey to date

Preparing the NEM for a high renewable future has been an evolving process over many years, involving efforts across industry. AEMO established the Engineering Framework to contribute to the discussion, identifying the

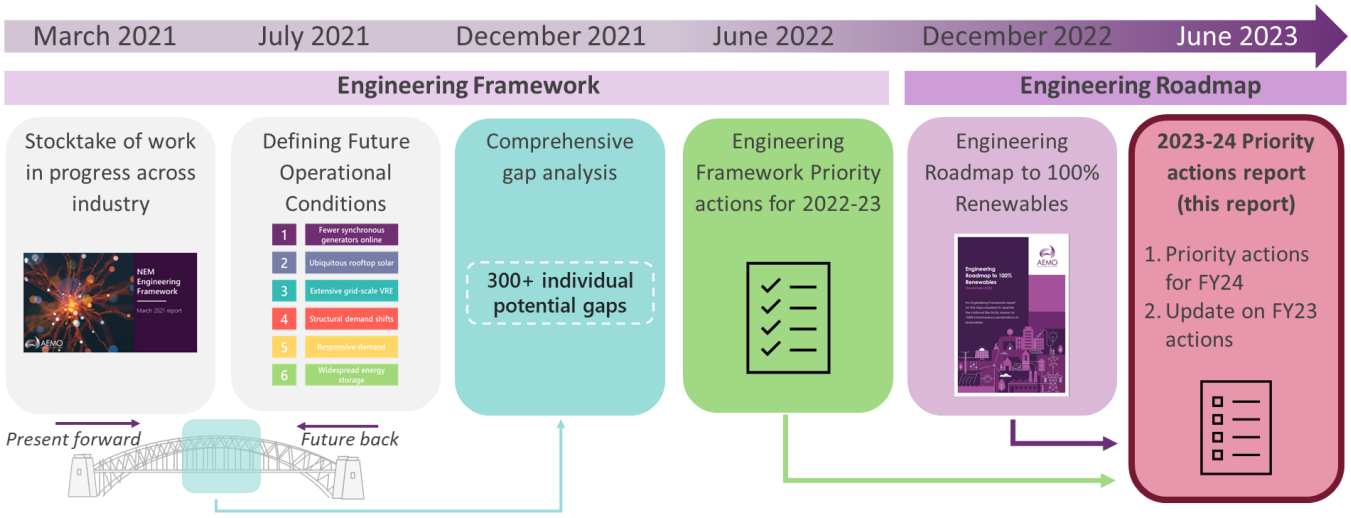
[3] 'Preconditions' is a term used in the Roadmap to describe the categories of system requirements that must be met to operate the NEM at up to 100% instantaneous penetration of renewables.

[4] At: https://www.aemo.com.au/-/media/files/initiatives/engineering-framework/2022/nem-engineering-framework-priority-actions.pdf?la=en.

potential *gaps* that require consideration as AEMO and industry collectively prepare for future *operational conditions*. This subsequently evolved into the *Engineering Roadmap to 100% Renewables*, leveraging the Engineering Framework gaps, to identify the implementation steps required to prepare for 100% instantaneous penetrations of renewables.

Figure 1 below summarises the journey to date from the Engineering Framework to the *Engineering Roadmap to 100% Renewables*, culminating in this current report on FY2024 priority actions.

Figure 1 Progress of Engineering Roadmap activities to reach this report



The Engineering Framework used a future-back approach of reviewing present day[5] activities and capabilities against a set of future *operational conditions*[6], to develop a *gap analysis*, as detailed in the NEM Engineering Framework Initial Roadmap[7]. This report identified over 300 potential gaps requiring further consideration.

As part of the *Engineering Roadmap to 100% Renewables*[8], the potential gaps were reviewed, and 174 actions were identified to prepare the NEM for operation at up to 100% instantaneous renewables. A subset of these actions were prioritised and actioned in FY2023[9].

A summary on the progress made across these FY2023 actions is provided in Section 1.3 of this report and detailed in Appendix A1.

Section 2 summarises the next set of priority actions which AEMO intends to progress throughout FY2024.

[5] NEM Engineering Framework – Stocktake, March 2021, at https://aemo.com.au/-/media/files/initiatives/engineering-framework/2021/nem-engineering-framework-march-2021-report.pdf?la=en&hash=3B1283D31B542115CC56E0ECCDFB3D69.

[6] NEM Engineering Framework – Operational Conditions Summary, July 2021, at https://aemo.com.au/-/media/files/initiatives/engineering-framework/2021/nem-engineering-framework-july-2021-report.pdf?la=en&hash=04E2BEFE4A1A7281B6294B1C8228AD59.

[7] NEM Engineering Framework – Initial Roadmap, December 2021, at https://aemo.com.au/-/media/files/initiatives/engineering-framework/2021/nem-engineering-framework-initial-roadmap.pdf?la=en&hash=258E0F1A2E8E6EE6C00437E75BB170FF.

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

[9] NEM Engineering Framework – Priority actions FY23, June 2022, at https://aemo.com.au/-/media/files/initiatives/engineering-framework/2022/nem-engineering-framework-priority-actions.pdf?la=en&hash=F5297316185EDBD4390CDE4AE64F48BB.

1.3 Progress made in FY2023

AEMO identified 46 actions to progress in FY2023, that would contribute to the overall readiness for the first periods of 100% instantaneous renewables in the NEM. Over the past year, considerable effort has been made to progress these actions, with 38 of the committed activities completed for the year. The remaining eight actions are well progressed, with many anticipated to be completed early in FY2024.

Appendix A1 has details of each of the committed actions for FY2023 and the progress made to date.

Notable achievements in FY2023 include:

- Publication of new system strength standards, requiring services to ensure fault levels are maintained and to facilitate future renewable generation connections.
- Collaboration with industry to develop an initial qualitative specification for grid forming inverters.
- Establishment of the Operations Technology Program[10] progressing uplift across operational capability needs identified in the Operations Technology Roadmap.
- Further collaboration with industry to develop an understanding of DER compliance with technical settings. This has been shared with market bodies to guide development of enduring governance frameworks for DER installation and performance compliance.
- Enabling the deployment and growth of grid-forming inverter capabilities through support for the Australian Renewable Energy Agency's (ARENA's) large-scale battery funding round.
- Initial exploratory studies to characterise future power system conditions where 100% instantaneous renewables could plausibly occur, and to assess the impacts of decreasing synchronous generation on existing stability limits.

In parallel with the Engineering Roadmap, AEMO and CSIRO (as Australian representatives of the Global Power System Transformation [G-PST] Consortium) have been working with leading Australian and international engineering, academic and research partners to progress research on nine pressing Roadmap-related research topics[11].

1.4 Continuing increases in renewable penetration

Growth in new renewable capacity continues to stimulate increasing instantaneous penetrations of renewables[12] in the NEM, as seen in Figure 2. Instantaneous renewable resource potential[13] is also increasing over time, trending toward projections under the 2022 *Integrated System Plan* (ISP) *Step Change* scenario that there will be

[10] At https://aemo.com.au/en/initiatives/major-programs/operations-technology-program.

[11] See https://www.csiro.au/en/research/technology-space/energy/g-pst-research-roadmap.

[12] Instantaneous renewable penetration is calculated using the NEM renewable generation share of total generation. The measure is calculated on a half-hourly basis, because this is the granularity of estimated output data for distributed PV. Renewable generation includes grid-scale wind and solar, hydro generation, biomass, battery generation and distributed PV, and excludes battery load and hydro pumping. Total generation = NEM generation + estimated distributed PV generation.

[13] Renewable resource potential is calculated in this report as the sum of forecast generation availability from grid-scale wind and solar, estimated distributed PV generation, and actual dispatched generation from energy limited sources such as hydro generation, biomass and battery generation whose generation in one interval will impact availability in the next. As with instantaneous renewable penetration, instantaneous renewable resource potential is calculated on a half-hourly basis.

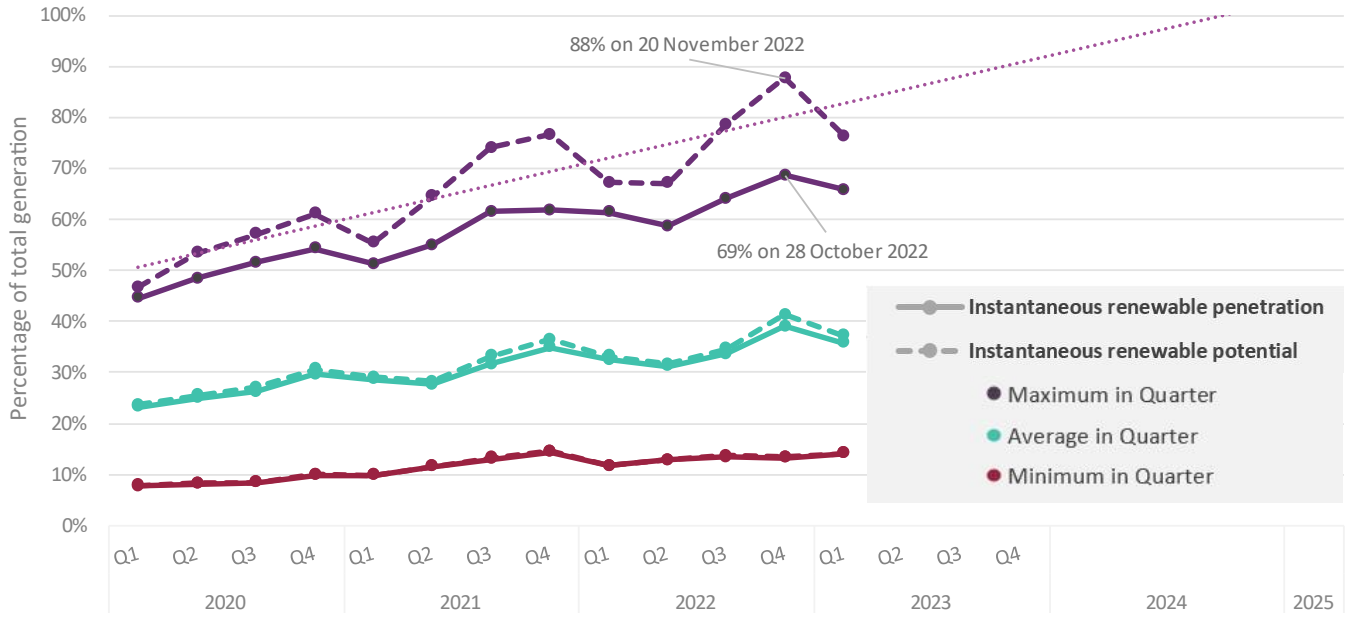
enough renewable resource potential to reach 100% of grid demand, for a small number of dispatch periods, as early as 2025[14].

Renewable potential and penetration

Renewable potential refers to the total available energy from renewable generators at an instant in time given the weather conditions at that time, regardless of whether those generators ultimately provide all that electricity into the NEM.

Renewable penetration refers to the proportion of NEM generation sourced from renewables at a given instant in time. This can be less than the corresponding renewable potential at that time.

Figure 2 NEM quarterly instantaneous renewable penetration and resource potential



Separation between renewable potential and penetration can be a consequence of market behaviour, network constraints, system requirements and application of local limitations to distributed photovoltaics (DPV).

Figure 2 shows that, on average, the difference between renewable potential and renewable penetration across all instances in time is very low. However, there are likely to have been a few limited intervals where the difference is greater, evidenced by the difference in maximum quarterly penetration versus maximum quarterly potential.

Currently, a major cause for these periods where renewable penetration is below renewable potential is large-scale renewable generation being dispatched below its instantaneous potential because of low spot prices in the middle of the day. During these times, operational demand is reduced due to distributed generation behind the meter, and less grid-connected generation is required to meet this demand, causing low and sometimes negative spot prices. If the spot price is lower than the bid of a scheduled renewable generator, then it will not be

[14] AEMO's 2022 ISP noted that the share of potential resource that is actually dispatched will depend on a range of market factors. See https://aemo.com.au/-/media/files/major-publications/isp/2022/2022-documents/2022-integrated-system-plan-isp.pdf?la=en.

dispatched at these times. If there was more load shifting to the middle of the day to increase daytime operational demand, renewable penetrations would be anticipated to increase closer to the renewable potential. AEMO's *Quarterly Energy Dynamics* reports provide regular updates on renewable penetration and curtailment[15].

FY2023 saw several notable penetration and generation milestones being reached:

- 68.7% instantaneous penetration of renewables was reached in the NEM on 28 October 2022. The corresponding renewable potential at this time was 77.5%.
- Record instantaneous renewable potential was also achieved in the same quarter on 20 November 2022 at 87.5%, with instantaneous renewable penetration reaching at 65.5% at that time.
- When South Australia was operating as a synchronous island on 19 November 2022[16], its renewable penetration[17] reached 91.5%.
- DPV capacity in the NEM continued to increase, leading to a record 11,504 megawatts (MW) of instantaneous generation on 11 February 2023[18].

Operating through these conditions provides ongoing insight into the behaviour of the NEM power system with increasing penetrations of renewable generation. Realising the renewable resource potential of the NEM, and ultimately operating at up to 100% instantaneous penetrations of renewables, will be dependent on how the market responds to meeting the system's energy and essential system service needs.

AEMO's aim is to ensure the necessary engineering and operational readiness efforts are completed in a timely manner so that when market participants are ready, the power system can be safely operated at ever higher instantaneous penetrations of renewables.

[15] At https://aemo.com.au/energy-systems/major-publications/quarterly-energy-dynamics-qed.

[16] South Australia was separated from Victoria for a week following a storm event. See https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2022/trip-of-south-east-tailem-bend-275-kv-lines-november-2022.pdf.

[17] AEMO does not typically calculate instantaneous renewables penetration for individual NEM regions, because these metrics would not fully represent the influence of interconnector flows. However, during islanding conditions this metric can provide a useful point of comparison with other gigawatt-scale power systems.

[18] See https://aemo.com.au/-/media/files/major-publications/qed/2023/qed-q1-2023-report.pdf.

Limitations to 100% renewable penetration – a case study

South Australia is already leading the world with its penetrations of wind and solar, as well as innovations which aim to reduce the cost to consumers of maintaining energy security at very high levels of renewable energy. This region recently observed a consecutive 10-day period where solar and wind generation exceeded local demand (9-19 December 2022)[A].

South Australia has been able to progressively reduce the minimum number of synchronous generators required during normal operation from four to two, with the introduction of four synchronous condensers. Currently two synchronous generators are still needed online, with the second generator catering for the loss of the first. To transition to a one minimum synchronous generator requirement, AEMO and ElectraNet have undertaken studies, identifying critical limitations:

- Requirement for grid formation and grid reference[B].
- Adequate voltage control – during periods of low demand or low transfers between South Australia and Victoria.
- Frequency control required to maintain the rate of change of frequency (RoCoF) in line with present limits advice.
- Maintenance of sufficient ramping capability under system normal conditions.

Currently, it is anticipated that further desktop system studies and real-life trials will be required to ensure the operational readiness of the South Australian power system to operate at fewer synchronous generators.

Additional limitations are also evident when South Australia is operating as an island, as observed during the power system event in November 2022 when the region was islanded for a period of seven days. During this time, 92% instantaneous renewable penetration was reached for the islanded region during one half-hour period, with limitations imposed to maintain the minimum synchronous units online. Due to the introduction of the Smarter Homes[C] package and underwriting of enhanced voltage management by the South Australian Government, SA Power Networks was able to access sufficient solar curtailment of up to 400 MW of DPV during this period. Curtailment was required during times of these islanded periods to manage for the net loss of DPV as part of potential credible contingency events. Ensuring acceptable performance from DER in response to disturbances, and the ability to securely operate the power system with increasing penetrations of DER, will be critical to maximising the utility of this abundant energy resource

The insights from South Australia provide a useful guide to priority focus areas for the whole NEM when considering the engineering requirements for operating with up to 100% instantaneous renewables.

A. South Australia was interconnected to the NEM for this entire period and had at least two synchronous generators operating to provide system security services. Excess generation during the period was exported to Victoria.
B. AEMO, *Transition to Fewer Synchronous Generators in South Australia – Assessment of Grid Reference*, February 2023, at https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/congestion-information/sa-transition-to-fewer-synch-gen-grid-reference.pdf.
C. See https://www.energymining.sa.gov.au/industry/modern-energy/solar-batteries-and-smarter-homes/regulatory-changes-for-smarter-homes/remote-disconnect-and-reconnection-of-electricity-generating-plants.

2 Priority Engineering Roadmap actions for FY2024

AEMO's *Engineering Roadmap to 100% Renewables* provided a structured breakdown of the preconditions that need to be satisfied to prepare the NEM for operation at its first instances of 100% instantaneous renewables. Across these pre-conditions, 174 actions were identified.

Since the Roadmap was published in December 2022, AEMO has reviewed these actions and worked through an internal prioritisation process to identify where AEMO can provide the most value in FY2024.

Many of the Roadmap actions fall under existing activities conducted through AEMO's business-as-usual obligations or in-train programs of work such as the Operations Technology Program[19] and Connections Reform Initiative[20]. This includes actions to uplift AEMO's internal processes that will improve efficiency and establish business capability for future needs.

The priority actions highlighted in this report go beyond those existing activities, focusing on actions where:

- AEMO believes significant uplift in effort is required to prepare for associated preconditions.
- Engagement with external stakeholders is crucial and not fully captured through other work programs.
- Delayed progression may pose a risk to power system security in the near future.

The priority actions highlighted in this report largely cover four key objectives:

- **Enabling high penetrations of distributed energy resources (DER).**
- **Conducting future power system studies.**
- **Enabling new technologies to address system needs.**
- **Building operational readiness.**

Stakeholders are encouraged to refer to the *Engineering Roadmap to 100% Renewables*[21] for further information on the full list of actions.

[19] At https://aemo.com.au/en/initiatives/major-programs/operations-technology-program/operations-technology-roadmap.
[20] At https://aemo.com.au/en/consultations/industry-forums-and-working-groups/list-of-industry-forums-and-working-groups/connections-reform-initiative.
[21] At https://aemo.com.au/-/media/files/initiatives/engineering-framework/2022/engineering-roadmap-to-100-per-cent-renewables.pdf?la=en.

2.1 Enabling high penetrations of distributed energy resources

Over the past 10 years, AEMO has observed a significant increase in the number of DER[22] connected in the NEM. This trend is expected to continue with increasing penetration of DPV, small-scale batteries, and electric vehicles (EVs) and their associated supply equipment (EVSE), so it is essential the right frameworks are in place to address existing and potential challenges.

'Enabling high penetrations of DER' refers to ensuring that these technologies are integrated in a way that maintains secure and reliable power system operation, and that enables a two-way power system. This is a critical area of focus because poor integration can reduce the visibility, predictability, and controllability of the power system, posing a risk to power system security. Poor integration will ultimately inhibit the ability of consumers to utilise their own resources and participate in future markets.

AEMO has identified eight priority actions in FY2024 to enable higher penetrations of DER, as outlined in Table 1. These actions seek to progress the following Roadmap preconditions:

- DER behaviour during disturbances is quantified and managed.
- Basic level of controllability for a sufficient proportion of the DPV fleet.
- Clearly defined operational roles and processes for managing system security and coordination across parties at times of high DER penetration.
- Clearly defined operational responsibilities at the boundary between distribution network and bulk power system operation.
- Distribution network service providers (DNSPs) able to determine and securely manage their technical operating envelope, connecting and integrating DER and variable renewable energy (VRE) within their networks.

[22] Behind-the-meter household resources are also often referred to as consumer energy resources (CER). For work identified as part of the Engineering Roadmap, the broader term DER has been used, to encompass other connection types beyond households such as commercial, small industrial and medium voltage connections at the distribution network and smaller than 5 MW.

Table 1 FY2024 actions that seek to enable higher penetrations of DER

Roadmap section	Roadmap action	Current status	Priority action for FY2024	Target outcome for FY2024
Distributed energy resources	Short-term measures to improve installation compliance of new DPV inverters to AS/NZS4777.2:2020, reducing potential DPV disconnection during disturbances (including amendment of the Standard).	Completion of FY2023 Action A10. High rates of inverter non-compliance with technical standards across Australia are impacting system security [23]. AEMO has already pursued actions in collaboration with some original equipment manufacturers (OEMs) to remotely correct inverter settings and to develop a training course for installers. The Australian Energy Market Commission (AEMC) review into consumer energy resources technical standards[24] has recommended immediate actions for industry.	Pursue further short-term measures to improve installation compliance of new DPV inverters to AS/NZS4777.2:2020 (through an amendment to the Standard to remove legacy grid code options for selection) and continued engagement with industry to encourage further action (for example, with OEMs and DNSPs).	Immediate non-compliance risk is addressed and capped.
Distributed energy resources	Establish strong governance frameworks for assessing and enforcing ongoing compliance of DER inverters to meet performance requirements.	Completion of FY2023 Action A10. AEMO has contributed to the AEMC review into consumer energy resources technical standards[25] recommending early consideration of enduring governance frameworks and the need for clearly defined roles and responsibilities.	Work with market bodies and jurisdictions to promote effective, enduring regulatory arrangements for small-scale DER standards implementation and compliance.	Clear pathway in place towards establishing governance frameworks that will deliver enduring solution(s) to DER performance management.
Distributed energy resources	AEMO to collaborate with DNSPs to establish effective and consistent disturbance withstand performance standards for <5 MW connections in the distribution network.	Progression of FY2023 Action A21. AEMO has undertaken early engagement with DNSPs to better understand the current practices and challenges for the connection of <5 MW plant in distribution networks and impacts to system security, highlighting areas of focus.	Define AEMO's minimum requirements for disturbance withstand and grid support capability for <5 MW connections. Identify possible pathways for minimum requirements to be applied.	Performance requirements for 200 kilowatts (kW) to 5 MW DER systems are clearly defined. Pathway identified to enforce these requirements.
Distributed energy resources	Establish effective emergency DPV shedding schemes, operational roles and procedures in each NEM region, before minimum system load challenges emerge.	Completion of FY2023 Action A11. A requirement for DPV emergency curtailment capability has arisen in South Australia and Queensland and is projected to emerge across the NEM mainland by 2024. Curtailment mechanisms have been established through jurisdictional action in South Australia and Queensland (>10 kW systems), progressing in Victoria (>200 kW by January 2024, <200 kW by July 2024) and being considered in other regions.	Specify functional requirements and operational processes for robust and reliable emergency backstop mechanisms. Continue to engage with jurisdictions and DNSPs on implementation, as well as market bodies towards nationally aligned approaches and associated roles and responsibilities.	Functional requirements defined and serving as design criteria for implementations across different regions. Pathways in place for emergency backstop mechanisms across all NEM mainland regions.

[23] AEMO, *Compliance of Distributed Energy Resources with Technical Settings*, April 2023, at https://aemo.com.au/-/media/files/initiatives/der/2023/compliance-of-der-with-technical-settings.pdf?la=en.

[24] AEMC, Review into consumer energy resources technical standards, at https://www.aemc.gov.au/market-reviews-advice/review-consumer-energy-resources-technical-standards.

[25] Ibid.

Roadmap section	Roadmap action	Current status	Priority action for FY2024	Target outcome for FY2024
Distributed energy resources	Establish roles and responsibilities between AEMO, DNSPs, transmission network service providers (TNSPs) and participants for managing bulk power system security in a high DER future, and associated planning and operational processes.	Completion of FY2023 Action A12. South Australia's experience with increasing DPV uptake highlights the increasing need for coordination across parties to manage system security during high DPV periods. Similar operational challenges emerging in other regions. Work underway to define functional requirements. Collaborative working group established with DNSPs.	Define functional requirements for securely and reliably operating a high DER power system, including visibility and predictability, performance, and controllability. Collaboratively assess and progress actions necessary to meet functional requirements. This includes clarity on operational boundaries between the distribution network and bulk power system operation, as well as operational coordination, and data exchange between AEMO, NSPs and other parties (such as retailers and aggregators).	Functional requirements technically defined. Gaps in definition of roles and responsibilities identified. Pathway identified for establishing enduring roles and responsibilities.
Distributed energy resources	Establish minimum DER device requirements for interoperability (including EVs and EVSE).	Completion of FY2023 Action A36. Voluntary standardised minimum communication protocols are defined in the Common Smart Inverter Profile – Australia (CSIP-Aus). Through the Energy Security Board (ESB), market bodies are considering actions that could lead to an efficient and NEM-consistent implementation of CSIP-Aus.	Promote minimum DER device capability for coordination and aggregation. Actively participate to establish interoperability requirements within AS/NZS4777 and AS4755, including alignment with CSIP-Aus.	Encourage the establishment of minimum DER device requirements for interoperability.
Distributed energy resources	Define performance standards for DER cybersecurity and interoperability.	Completion of FY2023 Action A28. AEMO has engaged jurisdictions on the increasing scale of cyber threat and power system risks, and made the case for effective roles, responsibilities, and controls to be established.	Continue to educate industry on the growing power system security risk due to cyber compromise with increasing DER uptake. Promote the need to establish a clear policy lead to develop DER cyber security responsibilities.	Policy direction established to specify and embed appropriate cyber security posture, roles, and responsibilities, informed by threat assessment of risks and potential mitigation options.

2.2 Conducting future power system studies

As the power system moves into uncharted operating conditions, new phenomena and system requirements may appear. Understanding the power system requirements of this future is a necessary step to determining the secure operating envelope of its new conditions. To achieve this and understand these requirements prior to actual system operation, it is essential to conduct future-focused power system studies.

Many studies are already underway as part of existing business-as-usual activities, including:

- Modelling for system strength, inertia and Network Support and Control Ancillary Services (NSCAS) reports to provide planning insights into near term system security[26].
- Modelling for the General Power System Risk Review (GPSRR)[27] to assess current and future risks associated with events and conditions that could cause cascading failures or supply disruptions and evaluate mitigation options.
- Modelling for system restoration and emergency frequency control scheme reviews.
- Development of limits advice and conversion of these limits into constraint equations for emerging operational conditions.

Each of the above form much-needed data points for future system operation, but have historically been limited to NER obligations due to budget and resource constraints across AEMO and transmission network service providers (TNSPs).

In comparison, to further progress the industry's collective understanding of the rapidly evolving power system, the actions identified in Table 2 seek to probe more exploratory areas, progressing the following Roadmap preconditions:

- Future system studies to assess the secure technical envelope of the power system with reducing, and eventually no synchronous fossil fuel generation online.
- Studies to develop limit advice and assess system adequacy in operational transition to first 100% periods.

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

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

Table 2 FY2024 actions that seek to conduct further future-focused power system studies

Roadmap section	Roadmap action	Current status	Priority action for FY2024	Target outcome for FY2024
Power system modelling	Perform targeted planning studies to assess system security issues across all power system phenomena with lower levels of synchronous fossil fuel generation.	Future infrastructure needs are understood at a high level but not quantified for 100% instantaneous renewables.	Conduct screening studies of fault level requirements over a range of 100% renewable energy system conditions.	Indicative range of system strength solutions to satisfy fault level requirements under additional plausible 100% scenarios.
Power system modelling	Undertake a program of power system studies to assess power system security in the NEM at times of 100% renewable generation and assess future system requirements with fewer large synchronous generators.	Completion of FY2023 Action A2. Anticipation that future system conditions (such as high DPV penetration, low synchronous generation) will move the system into uncharted operating territory about which understanding is limited. Impacts of potential future system configurations on system-wide dynamic behaviour are unknown.	Perform targeted future system dynamic studies, identify emerging phenomena, and interactions between phenomena.	Modelling outcomes to expand understanding of future system behaviour, identify potential risks to future system security, and identify system requirements to support future operation. Identification of potential critical operational conditions requiring consideration in future hold point transition process[28].
System restoration	AEMO to assess system restart requirements and capability with increasing aggregate DPV impact.	Progression of FY2023 Action A19. Issues in South Australia identified with ongoing growth in DPV generation reducing the daytime availability of stable load blocks required for the system restoration process.	Conduct system restoration studies for high DPV conditions.	Assessment of available system restart services, and where required, progress on modifications to system restart processes to meet system restart requirements during high penetrations of DPV.
Distributed energy resources	Ongoing AEMO assessment of minimum load and DPV contingency thresholds for system security.	Completion of FY2023 Action A9. Ongoing reduction in minimum demand due to DPV uptake now critically impacting some NEM regions.	Further assessment of system security issues associated with increasing penetrations of DPV.	Publication of technical report identifying gaps in system capability to operate the system with high penetrations of DPV.
Frequency and inertia	Review and assess appropriate mix of frequency control measures and adequacy of frequency control ancillary services (FCAS) arrangements with reducing synchronous inertia, increasing variability, and as the system topology evolves.	Recent reforms have included changes to the frequency operating standard (FOS)[29], very fast FCAS markets[30], primary frequency response (PFR) incentive arrangements[31]. Implementation of these changes is now underway.	Review NEM frequency control performance following implementation of recent reforms and determine any required changes to existing measures.	Publication of technical report on current frequency control landscape in the NEM.

[28] Discussion on hold point transition was presented in Section 3.4 of the *Engineering Roadmap to 100% Renewables*.

[29] Review of the frequency operating standard 2022, at https://www.aemc.gov.au/market-reviews-advice/review-frequency-operating-standard-2022.

[30] Fast frequency response market ancillary service rule change, 2021, at https://www.aemc.gov.au/rule-changes/fast-frequency-response-market-ancillary-service.

[31] PFR incentive arrangements 2022, at https://www.aemc.gov.au/rule-changes/primary-frequency-response-incentive-arrangements.

2.3 Enabling new solutions to address system needs

A range of technologies will be needed to meet future power system needs, delivering capabilities to replace the essential system services that will no longer be available from large synchronous generators when they are offline. AEMO has a keen interest in accelerating the development and understanding of these technologies so their capabilities can be harnessed in a timely manner, while ensuring that their performance is appropriate and can be relied upon to maintain a secure and resilient power system.

Significant work is already underway in this space. Through the Roadmap, AEMO is collaboratively progressing the development of resources and processes to accelerate the understanding and uptake of grid-forming inverters. The Connections Reform Initiative[32] (CRI) provides a platform to engage closely with stakeholders to develop solutions to cater for emerging challenges with the connection of existing and new technologies. Implementation activities are also underway within AEMO and across industry to cater for changes to the frequency operating standard (FOS), very fast frequency control ancillary services (FCAS) markets, primary frequency response (PFR) incentive arrangements, and system strength solutions that all need to consider ways to enable new technologies to address system needs.

Table 3 details actions that seek to progress the following Roadmap preconditions:

- Frequency response and FCAS reserve requirements completely met by VRE, storage, demand response and other non-fossil fuel technologies.
- System strength requirements met by alternatives to system configurations that require minimum loading on synchronous fossil fuel generators.

[32] See https://aemo.com.au/en/consultations/industry-forums-and-working-groups/list-of-industry-forums-and-working-groups/connections-reform-initiative.

Table 3 FY2024 actions that seek to further enable new solutions to address system needs

Roadmap section	Roadmap action	Current status	Priority action for FY2024	Target outcome for FY2024
Frequency and Inertia	Identify and progress opportunities (where economic) for common solutions to address inertia requirements in conjunction with identified system strength needs, such as adding flywheels to synchronous condenser installations.	TNSPs considering solutions to meet system strength obligations. The AEMC is considering opportunities to align inertia and system strength frameworks in the NEM[33].	Promotion of inertia provision as part of system strength solutions (of any technology type), where this would lead to more efficient/timely deployment of capability to meet future system needs.	Increased consideration of efficient provision of inertia throughout system strength solution decision-making and investment processes.
System strength	Technically define power system support capabilities for grid-forming inverters to guide OEMs and developers.	Voluntary grid-forming inverter specification published May 2023.	Collaboratively develop resources to support the practical application of the voluntary grid-forming inverter specification, including research and analysis to quantify the benefits and limits of the power system support capabilities of this technology.	Development of a quantitative test specification addendum to support the voluntary grid-forming inverter specification.
System strength	Trial and understand grid-forming inverter technology to support / provide system strength.	Grid-forming battery energy storage systems (BESS) in the NEM are now providing real-world demonstration of the capability of this technology to support a stable voltage waveform and provide synthetic inertial response. Development of grid-forming BESS capacity in the NEM is expected to be world-leading in FY2024, providing the opportunity to demonstrate these capabilities at scale and share learnings both domestically and internationally.	Utilise existing and proposed grid-forming projects to build knowledge and consensus on the system support capabilities of this technology, throughout the development, connection application, commissioning, and operation phases.	Timely and consistent approach to the connection of grid-forming BESS in the NEM, including projects under the ARENA large-scale battery funding round[34]. Learnings from these new projects to be shared to support future regulatory and process development, and to inform the ongoing enhancement of this technology by OEMs and researchers worldwide.

[33] See https://www.aemc.gov.au/sites/default/files/2023-05/Forward%20direction%20note.pdf.

[34] See https://arena.gov.au/news/arena-backs-eight-grid-scale-batteries-worth-2-7-billion/.

2.4 Building operational readiness

The Operability section of the Roadmap identified the uplift required in AEMO and NSP operational capability to successfully navigate previously untested and uncharted operating territory on the way to the first periods of 100% renewable operation, keeping within operational risk tolerances and aligning with societal expectations for secure and reliable supply. Relevant activities underway in this area include:

- The first tranche of activities identified in AEMO's Operational Technology Program, covering uplift in operational systems and processes, including power system operation and market management systems, operational forecasting, reserve assessment and operational data management[35].
- Uplift in AEMO control room and operational support process and procedures for managing system strength, inertia and issues associated with increasing DPV uptake. This includes collaboration with NSPs and participants to develop standardised, industry accredited operator training modules[36].
- Ongoing TNSP rollout of phasor measurement units (PMUs) and AEMO implementation of a Wide Area Monitoring System (WAMS) to enable time-synchronised monitoring of dynamic behaviour across the power system.
- Leveraging increased system monitoring capabilities (through PMU and WAMS) for ongoing power system model validation.

Table 4 details additional priority actions in FY2024, seeking to progress on the following Roadmap preconditions:

- Ability to operationally forecast energy adequacy and quantify VRE variability and uncertainty over different timeframes.
- Studies to develop limit advice and assess system adequacy in operational transition to first 100% periods.

[35] Operations Technology Program key priorities for 2023 and 2024 are listed at https://aemo.com.au/initiatives/major-programs/operations-technology-program/projects.

[36] As proposed in AEMO's National Training Framework for Power System Operators, at https://aemo.com.au/en/learn/industry-courses/national-training-framework-for-power-system-operators.

Table 4 FY2024 actions that seek to further uplift operational capabilities

Roadmap section	Roadmap action	Current status	Priority action for FY2024	Target outcome for FY2024
Power system modelling	Processes to monitor risk exposure, with 'roll back' measures in place if risk exceeds operational risk tolerance.	Technical assessment now complete on system needs to relax the current minimum synchronous generation requirements in South Australia[37]. ElectraNet regulatory investment test for transmission (RIT-T) assessing options to meet voltage control requirements.	Collaborate with industry participants and relevant stakeholders on a plan for initial operation of South Australia with fewer synchronous generators online.	Progression towards high level test plan, or other suitable transitional arrangements, to demonstrate potential for the South Australian power system to be operated with no synchronous generating units.
Power system modelling	Detailed assessment of system needs and required services to transition into and out of high renewable generation periods.	AEMO and TasNetworks scoping study in progress for operating the Tasmanian region with 100% IBR generation.	Pending outcomes of preliminary scoping, explore system requirements to support operation of Tasmanian region with 100% IBR generation.	Clarity on system requirements to support operation of the Tasmanian network with up to 100% IBR generation.
Operational processes	Deploy weather monitoring infrastructure to support participant and AEMO forecasting requirements for renewable energy zones (REZs), DPV generation within load centres and other key network locations.	FY2023 Action A30 well-progressed to build support for this future requirement and scope a project to deliver desired outcomes.	Collaboration between Bureau of Meteorology and AEMO to develop a sustainable business model for acquiring, curating and releasing new weather observations that will provide enhanced nowcasts[38] and forecasts for the energy sector. This aims to improve the management of the energy system, VRE generation and prospective REZs.	Business model developed and funding proposal(s) submitted if required.

[37] Regular updates for this work are at 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.

[38] Nowcast refers to an estimation method that is applicable where actual observations are not available (for example, AEMO's estimated actual DPV output in a region or current estimated solar irradiance across the Australian outback). In the weather forecasting industry, the term also covers short-term forecast horizons out to 6 hours ahead which are not adequately covered by Numerical Weather Prediction (NWP) models. Techniques used to create nowcasts are extrapolation. interpolation, scaling and persistence.

A1. FY2023 action status

The table below presents the full list of priority actions identified and undertaken by AEMO during the course of the financial year 2022-23, and their current status. It includes details of both the end-state objective required to meet the objective of the first periods of 100% instantaneous renewables, and the commitment made for FY2023. In many cases, further work is required to meet the end-state objective, these actions have been detailed in the FY2024 actions above in Section 2.

Table 5 FY2023 Priority actions list outcomes

Action ID	Committed action for FY2023	Status of FY2023 AEMO commitment as at 30 June
A1	Implement new system strength Rules, including formal consultation on changes to the System Strength Requirements Methodology and Impact Assessment Guidelines Publish new system strength standards for the coming decade, requiring services to ensure fault levels needed for a secure system as well as services to facilitate future renewable generation connections.	Complete: The System Strength Impact Assessment Guidelines (SSIAG) final report was published on 15 March 2023. A position paper was issued on 11 May to provide industry an alternative methodology to calculate System Strength Quantity. A Minor consultation, related to editorial changes to the Available Fault Level (AFL) formula, concluded on 26 May, and the final report along with a revised SSIAG was published on 6 June 2023. A final industry webinar session was presented on 15 June 2023. AEMO published the System Strength Requirements Methodology on 30 September 2022 to plan proactively for system strength in the NEM. This methodology was applied in the annual System Strength Report that was published on 1 December 2022.
A2	Initiate a program of power system studies to assess power system security in the NEM at times of 100% renewable generation.	Complete: AEMO initiated studies to characterise system conditions based on 2022 ISP *Step Change* projections where 100% instantaneous renewables could plausibly occur considering resource adequacy needs. Learnings from existing studies were used to consider methods in screening these plausible scenarios and a selection of results from load flow studies of a low operational demand period were published as part of 2022 system security assessments. Further dynamic studies were initiated to consider the impacts of decreasing synchronous generation on existing transient stability limits.
A3	Collaborate with industry on a voluntary specification for grid-forming inverters.	Complete: AEMO has collaborated with industry to develop an initial qualitative specification for grid-forming inverters. The specification was published on 29 May 2023[39].
A4	Review current system restart framework, documenting potential areas to improve incentives for new service providers. Provide advice to Reliability Panel ahead of upcoming System Restart Standard review.	Complete: AEMO completed review of restart standard and deemed it appropriate for 2024 round of restart procurement. Further review of the appropriateness of the restart standard will be completed following the 2024 restart procurement process.
A5	Advocate for market-based approach to dispatch resources for system security, which will support the operation of the system,	Complete: AEMO has advocated for and, as part of the AEMC's consideration of this, developed a prototype of a bid-based market for provision of security, using an optimisation over the normal pre-dispatch horizon. This was called the

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

Action ID	Committed action for FY2023	Status of FY2023 AEMO commitment as at 30 June
	remunerate and signal value for system security contributions, and reduce current requirement for directions while helping build understanding of the power system over time.	Operational Security Mechanism (OSM). The AEMC has changed direction since publication of its Draft Determination, and the OSM rule change will now focus on long-term procurement through planning frameworks to address security needs in the transition, rather than operational procurement. The AEMC intends to align the inertia framework with the new system strength framework, ensure the NSCAS framework is fit for purpose and improve the directions process. AEMO will provide input to the AEMC as they develop these and any related options in FY2024.
A6	[Develop and provide] technical advice to inform AEMC Operating Reserves rule change.	Complete: AEMO's Operating Reserves Final advice published on AEMC website[40].
A7	Uplift AEMO processes and governance for management of power system data, models, and tools, including uplift of model quality.	Complete: AEMO has focused (and continues to focus) on power system modelling as a core capability that enables power system planning, connections and operational, as well as application in tools used to evaluate power system security in the real-time environment. Key actions that have been completed in FY2023: • Greater engagement with NSPs including implementation of a shared Model Issues Reporting Page (MIRP) and associated processes to address issues. • Addressed a number of data/modelling issues as an outcome of the above. • Uplift of power system modelling processes including model and script management. • Development of internal Investment Brief for implementation of an 'online shop' to streamline provision of power system modelling data to industry. • Uplift of power system modelling data, processes and capability will be an ongoing focus for FY2024, as will the ongoing evaluation of modelling methods and tools, and engagement with OEMs, participants, NSPs and other stakeholders.
A8	Begin implementation of AEMO NEM and Wholesale Electricity Market (WEM) Operations Technology Roadmap to enable AEMO to achieve the required uplift in operations technology and capability and help facilitate the renewable energy transition.	Complete: The Operations Technology Roadmap was approved for execution in October 2022, and a Program Director appointed to develop and execute the Operations Technology Program. Updates have been and will continue to be provided to various industry forums. More information can be found on the Operations Technology Roadmap page on AEMO's website[41], at https://aemo.com.au/initiatives/major-programs/operations-technology-program/operations-technology-roadmap.
A9	Determine minimum level of synchronous generation required to operate regions/sub-regions of the NEM that currently, or will soon, have very low levels of synchronous generation. Trial sub-section/region of the NEM at 100% IBR operation if feasible.	Complete: Minimum generation levels defined for each NEM region. Conditions were such that it was not feasible to complete a trial of 100% IBR generation operation in FY2023. AEMO will continue working with industry through FY2024 on the possibility of a 100% IBR generation trial.
A10	Collaborate with industry on identified non-compliance risks for small-scale inverters' performance during disturbances.	Complete: AEMO has collaborated with industry to pursue a number of near-term actions to help alleviate the risk of DER technical standards non-compliance (as aligned to recommendations in the AEMC review into consumer energy

[40] AEMC, AEMO response to Request for advice on design elements, cost and timing of operating reserve market, at https://www.aemc.gov.au/sites/default/files/2022-03/AEMO%20response%20to%20request%20for%20technical%20advice.pdf.

[41] At https://aemo.com.au/initiatives/major-programs/operations-technology-program/operations-technology-roadmap.

Action ID	Committed action for FY2023	Status of FY2023 AEMO commitment as at 30 June
	Collaborate with market bodies on enduring frameworks, roles and responsibilities for DER installation and performance compliance.	resources technical standards[42]). These actions include installer training through the Clean Energy Council (CEC), collaboration with equipment manufacturers to correct settings in some existing inverters and introduce mitigation measures for new installations. AEMO has also initiated an amendment to AS/NZS4777.2:2020 to seek to remove legacy grid codes (minimising the chances of legacy codes being accidentally selected during installation). AEMO published a technical report on the Compliance of DER with Technical Settings[43], highlighting a critical gap in the performance of more than half the DPV inverters in the NEM. The paper was developed to help inform the AEMC's consumer energy resource technical standards review[44].
A11	Advocate for and progress introduction of emergency backstop DPV curtailment mechanisms in all NEM mainland regions. Specify technical requirements and operational coordination processes [for DPV curtailment mechanisms]. Advocate for consistency in regional approaches, where possible.	Complete: Advocated for and collaborated with jurisdictions on potential introduction of emergency backstop DPV curtailment mechanisms in all NEM mainland regions. Curtailment mechanisms have been established through jurisdictional action in South Australia and Queensland[45] (>10 kW systems), progressing in Victoria[46] (>200 kW by January 2024, <200 kW by July 2024) and being considered in other regions. DPV Contingency (DPVC) and Minimum System Load (MSL) market notice framework[47] in place and operational protocols for activation implemented.
A12	Identify and progress regulatory reforms to clearly define AEMO, NSP, and participant responsibilities for system security in a high DER, low synchronous generation power system – starting with under-frequency load shedding (UFLS), last resort curtailment, system restart.	Complete: AEMO has identified system security responsibilities as a key reform priority within ESB Ministerial Advice and the forward agenda for market bodies to progress in FY2024.
A13	Provide regularly updated information on NEM inertia. Support [real-time] dynamic inertia measurement trial.	Complete: System inertia is now part of quarterly frequency performance reporting[48]. Dynamic inertia measurement trial is in progress[49].
A14	Support ARENA advanced inverter funding round.	Complete: AEMO has worked closely to with ARENA to provide ongoing technical expertise and advice for ARENA's advanced inverter funding round. Through this round, ARENA has now awarded $176 million in funding to support eight projects[50]. These projects have a total project value of $2.7 billion with a total capacity of 2 gigawatts (GW)/4.2 gigawatt hours (GWh).

[42] Review into consumer energy resources technical standards 2023, at https://www.aemc.gov.au/market-reviews-advice/review-consumer-energy-resources-technical-standards.

[43] AEMO, Compliance of DER with Technical Settings, at https://aemo.com.au/-/media/files/initiatives/der/2023/compliance-of-der-with-technical-settings.pdf?la=en.

[44] Review into consumer energy resources technical standards 2023, at https://www.aemc.gov.au/market-reviews-advice/review-consumer-energy-resources-technical-standards.

[45] Emergency backstop mechanism, 2023, at https://www.epw.qld.gov.au/about/initiatives/emergency-backstop-mechanism.

[46] Victoria's Emergency Backstop Mechanism for rooftop solar, 2023, at https://engage.vic.gov.au/victorias-emergency-backstop-mechanism-for-rooftop-solar.

[47] AEMO, Distributed Photovoltaics (DPV) Contingency and / or Minimum System Load market notice framework, at https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/system-operations/power-system-operation.

[48] Frequency and time deviation monitoring reports are at https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/system-operations/ancillary-services/frequency-and-time-deviation-monitoring.

[49] More information on the Victorian Inertia Measurement Trial is at https://aemo.com.au/en/initiatives/trials-and-initiatives/victorian-inertia-measurement-trial.

[50] See https://arena.gov.au/news/arena-backs-eight-grid-scale-batteries-worth-2-7-billion/.

Action ID	Committed action for FY2023	Status of FY2023 AEMO commitment as at 30 June
A15	Commence implementation of productionised data science environment to enable deployment of new machine learning models [for operational forecasting]. Improve wind and solar dispatch forecasts by commencing uplift in AWEFS/ASEFS forecast models. Commence development of tools to quantify and visualise DPV variability.	Complete: Operational Forecasting has implemented a Productionised R environment that will facilitate the more rapid and resilient development and deployment of forecasting tools. A new in-house Variable Renewable Energy Forecasting System (VREFS) has been designed and deployed. This will enable more rapid updates in near-term forecasts for VRE generation and will facilitate future changes to Australian Wind Energy Forecasting System (AWEFS) and Australian Solar Energy Forecasting System (ASEFS) via the Fusion Project. In line with the deployment of VREFS, the demand forecasting equivalent, XDEMTOD, has also been redesigned and reconfigured again to facilitate enhanced agility and future Fusion project works. The MaxAvail upgrade is due to enter production in June 2023, delivering an improved user interface and functionality to VRE generation participants to improve dispatch, pre-dispatch and projected assessment of system adequacy (PASA) outcomes.
A16	Collaborate with stakeholders through the Connections Reform Initiative to determine suitable implementation plan [for whitelist register of OEM products].	Complete: Development of OEM Data and Modelling implementation plan is complete.
A17	Assess narrowband frequency control during projected operational conditions with very high DPV. Investigate options to achieve sufficient aggregate response [to meet frequency control needs].	Complete: Initial feasibility study undertaken, which indicated that in the absence of further action, the NEM could be at risk of poorer frequency performance during times of high distributed PV penetration. AEMO has identified a requirement for further quantitative study to consider the relative impacts of other factors such as low power system inertia, and the materiality of risks to power system security given projected frequency performance. Initial qualitative assessment of remediation options was conducted, suggesting infeasibility of widespread deployment of narrowband PFR on existing DER devices in the NEM for purposes of frequency control. Further work may be necessary to consider sufficiency of alternative options pending outcome of further review into materiality of this issue.
A18	Review NEM-wide under frequency load shedding (UFLS) scheme adequacy [with increasing aggregate DPV impact], identify need for corrective action and progress resolution.	In progress: AEMO continuing to work on NEM-wide UFLS scheme adequacy, with updates for South Australia and Victoria published in 2023. Further commentary included in 2023 GSPRR.[51] NEM review expected to continue during FY2024.
A19	Review system restart adequacy across the NEM [with increasing aggregate DPV impact], identify need for corrective action and progress resolution.	In progress: AEMO has identified the need to reassess, and potentially revise, the restart plan for South Australia during periods of high DPV and is currently undertaking this work. Work on the plan is expected to be completed in mid FY2024.
A20	Advocate for demonstrating capability of new technology to provide system restoration ancillary services (SRAS).	Complete: AEMO has reached out to the market through the 2024 restart procurement process[52]. In particular, AEMO has encouraged BESS participants to consider providing restart support services and some have expressed interest in the possibility of being an SRAS source. AEMO has also reached out to other bodies such as ARENA about promoting new technologies to provide SRAS.
A21	Collaborate with DNSPs to understand current status of performance standards for <5 MW connections, and identify any uplift required.	In progress: AEMO has engaged with DNSPs to better understand the current practices and challenges for the connection of <5 MW plant in distribution networks. This has highlighted a number of shared challenges as the volume of these connections grows, including technical performance, interaction with FCAS and market participation requirements, and modelling requirements.

[51] See https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2023/draft-2023-general-power-system-risk-review/draft-2023-gpsrr-report.pdf?la=en.

[52] AEMO Invitation to Tender for System Restart Ancillary Services (SRAS) 2024, at https://aemo.com.au/en/consultations/tenders/sras-procurement.

Action ID	Committed action for FY2023	Status of FY2023 AEMO commitment as at 30 June
		AEMO is continuing to work with DNSPs to prioritise necessary improvement in this area, including the possible need for minimum requirements on disturbance withstand capability.
A22	Consider the requirements for energy and FCAS provision from aggregated DER within the delivery of reform initiatives.	Complete: Integrated Energy Storage Systems (IESS) stage 1 successfully delivered, enabling Small Generation Aggregators (SGAs) to participate in contingency FCAS markets.
A23	Promote the addition of synchronous condenser capability in new and existing synchronous generator investment and retirement decisions.	Complete: AEMO has worked closely with ARENA to support a feasibility study report of synchronous condenser conversion opportunities in Australia. The report is complete[53] and ARENA is now considering next steps.
A24	Work with industry to advocate for uplift in supply of skilled power system engineers in Australia.	Complete: International recruitment program to attract leading engineering specialists into Australian Energy Sector is being scoped and designed.
A25	Assess functional requirements for communication architecture in the future power system. Explore options to efficiently, securely, and scalably meet functional requirements.	Nearing completion: AEMO has engaged a consultant to complete this action, with their work expected to conclude in July 2023.
A26	Collaborate with stakeholders to review operational data exchange needs for AEMO, DNSPs, and industry to support increasing DER uptake and new forms of decentralised participation.	Complete: AEMO consulted on and published an updated Power System Data Communication Standard[54] that includes support for aggregators to provide telemetry data directly to AEMO to enable greater participation in wholesale demand response and the future Scheduled Lite reform[55]. The NEM Reform program has engaged with stakeholders on industry data exchange (IDX) including identity and access arrangements (IDAM) to understand pain points, requirements of a future state and a transition roadmap[56].
A27	Publish a fact sheet to clarify the pathway for grid-forming inverters through the existing connections process.	Complete: Fact sheet published that provides detail on the connection pathway for grid-forming inverters[57].
A28	Advocate for and collaborate with industry on foundational device capabilities, configuration, and networking practices for internet-connected DER devices.	Complete: Threat-informed minimum device security requirements have been defined and reflected in relevant standards (including CSIP-Aus[58]). AEMO has collaborated with industry, including federal government agencies to support understanding and share awareness of cybersecurity risks associated with DER, device capabilities and potential mitigation options. This has highlighted a need for an appropriate policy lead.

[53] Repurposing existing generators as synchronous condensers 2023, at https://arena.gov.au/assets/2023/06/repurposing-existing-generators-as-synchronous-condensers-report.pdf.

[54] Power System Data Communication Standard 2023, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Network_Connections/Transmission-and-Distribution/AEMO-Standard-for-Power-System-Data-Communications.pdf.

[55] Scheduled Lite Mechanism, at https://www.aemc.gov.au/rule-changes/scheduled-lite-mechanism.

[56] NEM Reform Implementation Roadmap v2 2023, at https://aemo.com.au/-/media/files/initiatives/regulatory-implementation-roadmap/reform-update-v2/nem-reform-implementation-roadmap-v2.xlsx.

[57] Grid-forming BESS Connections 2022, at https://aemo.com.au/-/media/files/electricity/nem/network_connections/grid-forming-bess-connection-fact-sheet.pdf?la=en.

[58] Common Smart Inverter Profile – Australia 2023, at https://arena.gov.au/assets/2021/09/common-smart-inverter-profile-australia.pdf.

Action ID	Committed action for FY2023	Status of FY2023 AEMO commitment as at 30 June
A29	Assess with industry, effective DER device configuration and behaviours under loss of communication and other contingency scenarios in a high DER future.	Complete: Incorporated failsafe functionality for loss of communication into CSIP-Aus. Capability allows DNSPs to require DPV default to 1.5 or 0 kW export if communications disconnected.
A30	Advocate for new weather monitoring infrastructure requirements to support renewable energy zones (REZs).	Complete: The initial phase for this project is complete. The scoping phase for this project is underway and on track. Bureau of Meteorology and AEMO staff are collaborating in developing a sustainable business model for acquiring, curating and releasing new weather observations that will provide enhanced now-casts and forecasts for the energy sector. This will improve the management of the energy system, VRE generation and prospective renewable energy zones.
A31	Explore and assess feasible visibility options [for 100kW to 5MW DER embedded in the distribution network] and AEMO-DNSP system integration actions.	Complete: Scheduled Lite rule change request has been submitted, which contemplates operational visibility of DER resources and potential incentives to ensure visibility is obtained[59]. AEMO also explored how this information may be used in operational processes.
A32	Inform development of system integration, data exchange and functional requirements for dynamic operating envelopes.	Complete: Project EDGE has analysed and produced a cost benefit analysis on different data exchange models for the CER Ecosystem and presented the material to the EDGE information forums.
A33	Advocate for need and collaborate with NSPs and service providers on [an] approach [to representing DER in network topology models].	Complete: AEMO has initiated discussions with DNSPs, service providers and members of the IEC Common Information Model Users Group Oceania Chapter on the requirement, and feasible approaches that can meet the needs of different parties, including pathways for adoption.
A34	Investigate feasibility of leveraging ability to adjust and tune generator controls in real time or over life of connection.	In progress: AEMO is providing input into CRI work (led by the CEC)[60] reviewing opportunities to apply collective retuning. AEMO is also leading a CRI workstream to review the application of NER Clause 5.3.9 (generating system alterations process) and will include consideration of NER Clause s5.2.2 (Application of settings).
A35	Explore options to simplify connection and registration processes for hybrid generation facilities.	In progress: AEMO is leading a CRI workstream to review the application of NER Clause 5.3.9 (generating system alterations process), also covering connection of BESS to existing generation. AEMO has also clarified the registrations exemption process for hybrid facilities in implementing the IESS Rule change[61].
A36	Collaborate with industry on minimum device capability for coordination and aggregation, and power system operational use cases in a high DER future.	Complete: ESB has undertaken extensive consultation on DPV and EVSE minimum capability requirements. There is strong industry support for requiring the communication protocols CSIP-Aus[62] (inverters) and OCPP (EVSEs) as minimum requirements, with the ESB exploring feasible options for national implementation.[63]
A37	Collaborate with industry on disturbance withstand, grid support and grid connection requirements for EV and EVSE.	Nearing completion: AEMO has engaged a consultant to complete this action, with their work expected to conclude in July 2023. The work involves collaborating with an industry advisory group to identify whether disturbance withstand

[59] Rule change request – Scheduled Lite Mechanism in the NEM 2023, at https://www.aemc.gov.au/sites/default/files/2023-01/ERC0352_Rule%20Change%20Request_Scheduled%20Lite%20-%20including%20Appendix.pdf.

[60] See https://www.cleanenergycouncil.org.au/advocacy-initiatives/energy-transformation/connections-reform-initiative.

[61] Implementing integrated energy storage systems 2023, at https://www.aemc.gov.au/rule-changes/implementing-integrated-energy-storage-systems.

[62] See https://arena.gov.au/knowledge-bank/common-smart-inverter-profile-australia/.

[63] ESB Interoperability Directions Paper consultation, at https://esb-post2025-market-design.aemc.gov.au/integration-of-distributed-energy-resources-der-and-flexible-demand.

Action ID	Committed action for FY2023	Status of FY2023 AEMO commitment as at 30 June
	Inform EV grid integration efforts.	requirements may need to be pursued for EVs and EVSE when acting as loads. The work is also exploring existing frameworks that apply to unidirectional and bidirectional chargers, noting that AS/NZS4777.2 applies to EVSE when exporting.
A38	Highlight known data quality and completeness issues with DER register data by validating against alternate data sources. Advocate for more robust validation processes at the data collection stage for new DER installations. Advocate for stronger compliance arrangements for data entry.	Complete: AEMO has been working with DNSPs on a quarterly basis providing detail on common causes of data errors and individual datasets to DNSPs that identify errors. There has been a consistent reduction in data errors each quarter. In New South Wales, there are specific data collection challenges that AEMO is working with DNSPs and New South Wales government on to improve collection processes and utilise alternate data to fill gaps in the dataset.
A39	Establish a working group to determine and scope any necessary regulatory changes to support appropriate performance requirements for new loads.	Complete: Through the Access Standards Review, a Large Loads Technical Focus Group was established to prioritise load connections issues and develop draft recommendations which were published for public consultation. AEMO will review the 11 submissions received and incorporate them into revised recommendations[64].
A40	Assess functional requirements for setting, communicating and managing network limits with increasing levels of aggregated participation [and required AEMO-NSP-aggregator interactions]. Consider roles and responsibilities of actors.	Complete: AEMO engaged with DNSPs in the lead up to SGAs being eligible to provide contingency FCAS (commencing 31 March 2023) based on the current DNSP endorsement and FCAS verification process for Aggregators[65]. The discussion also covered functional requirements with increasing levels of DER aggregation, perspectives from different DNSP experiences and trials to inform consideration of scalable data exchange and operational coordination between parties into the future.
A41	Continue to engage with OEMs and data providers to grow pool of data available for analysis, model validation and forecasting. Collaborate with DNSPs on requirements for monitoring data needs for a high DER future. Contribute to ESB Data Strategy.	Complete: AEMO has been engaging with DPV and small-scale battery OEMs and data providers to expand the pool of data available for performance assessment and model validation. AEMO has also established a collaborative working group with DNSPs on operational forecasting and visibility requirements for a high DER future. AEMO has also contributed input on relevant use cases to the ESB Data Strategy Network Visibility initiative[66].
A42	Develop implementation options for a register of EVSE standing data, including data collection and storage processes.	Complete: The ESB's consultation paper[67] in December 2022 explored EVSE standing data needs and use cases for different parties, and feasible implementation options for an EVSE standing data register. AEMO will progress a rule change proposal for the inclusion of EVSEs in the DER Register in 2023, with the AEMC expected to commence consultation process in 2024.
A43	Promote widespread PMU roll-out and high-speed data ingestion/automation.	Complete: TNSPs are currently in the process of implementing widespread PMU roll-out and building necessary infrastructure to support. Where they are in operation, PMUs are currently used for offline analysis.

[64] See https://aemo.com.au/en/consultations/current-and-closed-consultations/aemo-review-of-technical-requirements-for-connection.

[65] Small Generation Aggregators in the NEM 2022, at https://aemo.com.au/-/media/files/initiatives/integrating-energy-storage-systems-project/factsheet-nem-small-generation-aggregators-march-2023-release.pdf.

[66] ESB Data Strategy consultation, at https://esb-post2025-market-design.aemc.gov.au/data-strategy.

[67] Electric Vehicle Supply Equipment Standing Data consultation paper 2022, at https://www.datocms-assets.com/32572/1670367035-esb-electric-vehicle-supply-equipment-standing-data-consultation-paper-december-2022.pdf.

Action ID	Committed action for FY2023	Status of FY2023 AEMO commitment as at 30 June
A44	Collaborate with industry to consider use cases for different parties remotely interacting with DER devices. Progress policy development on governance, roles and responsibilities and compliance.	Complete: The ESB's interoperability policy consultation is considering a nationally consistent approach to implementing CSIP-Aus. It is also considering options for managed EV charging and smart EVSE, including the necessary device functionality, standards and protocols at the device level to enable different use case cases[68]. AEMO is also a member of ARENA's Distributed Energy Integration Interoperability Steering Committee[69] and cyber security Working Groups.
A45	Evaluate the coordination of over-frequency management settings in all NEM regions including any recommended mitigations.	Complete: AEMO has completed its review of over-frequency management in the NEM and identified the following actions to improve the co-ordination of over-frequency management in all NEM regions: • Implementation of South Australia over frequency generation shedding (OFGS) scheme. • Implementation of Queensland OFGS. • Updated AEMO internal strategy for co-ordination of new generator over-frequency protection settings. An update on each of these actions can be found in AEMO's annual GPSRR[70].
A46	Develop clear guidance on use of electromagnetic transient (EMT) and root mean square (RMS) analysis in performance study assessments.	In progress: Guidance document completed and undergoing consultation process through CRI.

[68] ESB Interoperability Directions Paper consultation, at https://esb-post2025-market-design.aemc.gov.au/integration-of-distributed-energy-resources-der-and-flexible-demand.

[69] DEIP Interoperability Steering Committee, at https://arena.gov.au/knowledge-innovation/distributed-energy-integration-program/interoperability-steering-committee/.

[70] See https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2023/draft-2023-general-power-system-risk-review/draft-2023-gpsrr-report.pdf?la=en.

A2. Abbreviations

Abbreviation	Term in full	Abbreviation	Term in full
AEMC	Australian Energy Market Commission	**ISP**	*Integrated System Plan*
AEMO	Australian Energy Market Operator	**kV**	kilovolt/s
ARENA	Australian Renewable Energy Agency	**MW**	megawatt/s
AS/NZS4777.2	Australian Standards for Grid connection of energy systems via inverters – inverter requirements	**NEM**	National Electricity Market
ASEFS	Australian Solar Energy Forecasting System	**NER**	National Electricity Rules
AWEFS	Australian Wind Energy Forecasting System	**NSCAS**	Network Support and Control Ancillary Services
BESS	battery energy storage system	**NSP**	network service provider
CER	consumer energy resources	**NWP**	Numerical Weather Prediction
CSIP-Aus	Common Smart Inverter Profile - Australia	**OEM**	original equipment manufacturer
DER	distributed energy resources	**OFGS**	over frequency generation shedding
DNSP	distribution network service provider	**PASA**	projected assessment of system adequacy
DPV	distributed photovoltaics	**PFR**	primary frequency response
EMT	electromagnetic transient	**PMU**	Phasor Measurement Unit
ESB	Energy Security Board	**PV**	photovoltaics
EV	electric vehicle	**REZ**	renewable energy zone
EVSE	Electric Vehicle Supply Equipment	**RMS**	Root Mean Square
FCAS	frequency control ancillary services	**RoCoF**	rate of change of frequency
FOS	Frequency Operating Standard	**SRAS**	system restart ancillary services
FY	financial year	**TNSP**	transmission network service provider
GPSRR	General Power System Risk Review	**UFLS**	under frequency load shedding
GW	gigawatt/s	**VRE**	variable renewable energy
GWh	gigawatt hour/s	**WAMS**	Wide Area Monitoring Systems
IBR	inverter-based resources	**WEM**	Wholesale Electricity Market