SWIS Engineering Roadmap

August 2024

A report for the South West Interconnected System

Important notice

Purpose

This publication provides stakeholders with an overview of the engineering actions required to enable the SWIS to operate securely and reliably in a renewables-dominated environment, leveraging the work conducted to date by AEMO as part of the NEM Engineering Roadmap, outlined in the 2022 Engineering Roadmap to 100% Renewables and associated reports. This document has been prepared by AEMO using information available as at 1 August 2024. Information made available after this date may have been included in this publication where practical. This document uses many terms that have meanings defined in the Wholesale Electricity Market Rules (WEM Rules). The WEM Rules meanings are adopted unless otherwise specified.

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Executive summary

Energy systems across Australia are undergoing a generational transition from fossil fuelled generation to renewable sources. The Australian Energy Market Operator (AEMO) operates markets and systems across Australia to ensure safe, reliable, and affordable energy for consumers. As part of this role, it is critical to ensure that power system security and reliability are maintained through each phase of the energy transition.

Western Australia's (WA's) largest power system, the South-West Interconnected System (SWIS), is transitioning from predominantly coal-fired and gas generation to increasingly higher levels of distributed and large-scale renewable energy resources. This SWIS Engineering Roadmap focuses on the engineering actions required to enable the SWIS to operate securely and reliably in the transition to net zero, leveraging the work conducted to date by AEMO as part of the National Electricity Market (NEM) 2022 Engineering Roadmap to 100% Renewables[1] (NEM Engineering Roadmap) and associated reports.

In WA, there have already been instances in the past year, during periods of minimum operational demand, when the SWIS has had sufficient wind and solar resource availability to be powered entirely from renewable energy. However, synchronous fossil fuelled generation has continued to operate during these periods due to a series of overlapping system operability, security, and reliability challenges, as well as negative energy prices and economic curtailment.

These challenges include:

- Meeting minimum requirements for system inertia (Rate of Change of Frequency (RoCoF) Control Service) and other Essential System Services, which are predominantly supplied by synchronous generators[2].
- Supporting grid voltages and power system stability in specific regions of the SWIS that currently require synchronous generators in these areas to be online.
- Inflexibility of some synchronous generators that are unable to switch off completely during minimum operational demand periods and then switch on again when needed to ramp and supply the evening peak.

Facilitating the transition to renewables therefore requires more than simply a 'straight swap' of generation assets, as Inverter Based Resources (IBR) interact with the power system in fundamentally different ways to synchronous generation. Consideration therefore needs to be given to the specific technical challenges associated with operation at very high levels of instantaneous renewables penetration.

In order to develop the SWIS Engineering Roadmap, AEMO has considered the likely characteristics of the future power system, informed by modelling outcomes from the WA Government's Whole of System Plan[3] and SWIS

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[1] AEMO, December 2022, Engineering Roadmap to 100% Renewables (NEM Engineering Roadmap), available at https://aemo.com.au/initiatives/major-programs/engineering-framework/reports-and-resources

[2] This term is used throughout to refer to synchronous fossil fuelled generators, new technologies, including synchronous generation fuelled by renewable fuels may offer alternatives means of providing energy and/or synchronous services.

[3] See https://www.wa.gov.au/government/document-collections/whole-of-system-plan.

Demand Assessment[4], alongside findings from AEMO's Wholesale Electricity Market (WEM) Electricity Statement of Opportunities (ESOO)[5]. By the start of the next decade, AEMO expects that:

- Coal-fired generation and other aging fossil fuelled generators will retire from the SWIS.
- Electricity demand will significantly increase due to electrification and new industry development.
- The majority of electricity demand will be served by renewable energy IBR – in particular rooftop solar during daylight times – firmed by storage and backed up by gas powered generation.
- Consumer-owned distributed energy resources (DER) – like rooftop solar, batteries and electric vehicles – will be aggregated to operate like virtual power plants in the Wholesale Electricity Market (WEM).

The SWIS Engineering Roadmap was developed through extensive engagement across AEMO, leveraging AEMO WA's engineering and operational teams' insights and the substantial work underway in the NEM Engineering Roadmap. The SWIS Engineering Roadmap highlights that no one organisation can undertake all required actions, and the transition will require a coordinated effort between AEMO, Western Power, governments, industry, market bodies and communities. As such, AEMO has consulted with EPWA and Western Power in developing the SWIS Engineering Roadmap.

The SWIS Engineering Roadmap sets-out the pre-conditions or power system characteristics that must exist to allow increasing levels of renewable contribution. An action roadmap is presented that maps the engineering studies and capabilities required to achieve these pre-conditions and progressively increase penetration across a range of scenarios.

The end goal is to sufficiently prepare the SWIS such that synchronous generation can be reduced to zero at times, i.e. enable 100% renewable generation. However, the transition is underpinned by maximising year-round contribution of renewables rather than maximising instantaneous renewable contribution, and actions therefore consider the primary objective of enabling a renewables dominated power system as synchronous generation is retired from the SWIS.

While the SWIS Engineering Roadmap draws from multiple sources in making its recommendations on the actions required in the SWIS, the format leverages the NEM Engineering Roadmap. Like the NEM Engineering Roadmap, the SWIS Engineering Roadmap unpacks the engineering and operational readiness steps needed to operate the power system with predominantly renewable resources and, from time to time, at 100% instantaneous renewables.

There are three broad but pivotal themes – power system security, power system operability, and resource adequacy and capability. Under each theme, the SWIS Engineering Roadmap identifies:

- The technical preconditions that must be satisfied for each relevant aspect of power system management.
- For each precondition:
  - The current and emerging challenges associated with transitioning the SWIS, and the near-term and long-term capabilities required to manage the issues expected to arise at very high levels of renewable penetration.

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[4] See https://www.wa.gov.au/government/document-collections/swis-demand-assessment.

[5] See https://aemo.com.au/en/energy-systems/electricity/wholesale-electricity-market-wem/wem-forecasting-and-planning/wem-electricity-statement-of-opportunities-wem-esoo.

  - The actions necessary to support each fundamental power system management activity.
- For each action:
  - Project dependencies and/or relevant work undertaken as part of other initiatives.
  - Any further actions needed to achieve the preconditions.

Figure 1 summarises the themes and challenges that the transition from a system dominated by synchronous generation to a system that will regularly fluctuate from having predominantly synchronous generation to at times 100% inverter based resources.

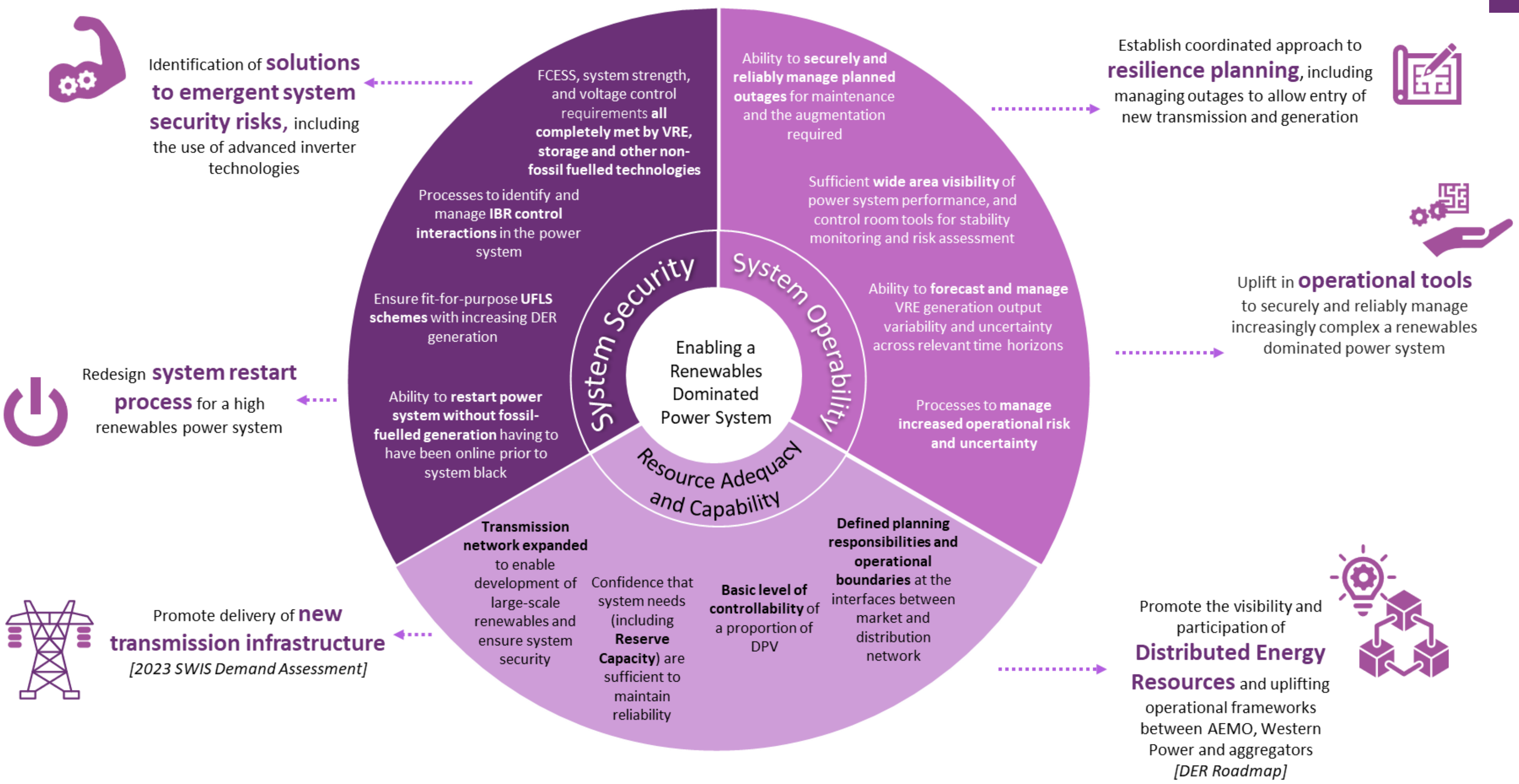

Figure 1 Enabling a renewables dominated power system.

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1 Introduction

The SWIS Engineering Roadmap builds on the significant work completed as part of the NEM Engineering Roadmap to facilitate the technical, operational, and planning requirements to advance the operational capability for higher levels of renewable generation on the South West Interconnected System.

1.1 Scope

The SWIS Engineering Roadmap focuses on the engineering solutions required to enable the SWIS to operate securely and reliably in the transition to net zero, leveraging the work conducted to date by AEMO as part of the 2022 Engineering Roadmap to 100% Renewables (NEM Engineering Roadmap) and associated reports.

1.2 Context

The coming decade will see Western Australia's major power system – the SWIS – move rapidly away from its traditional dependency on coal-fired generation to firmed renewables. These changes in the generation mix will occur alongside forecast growth in new sources of electricity demand and participation from demand side and DER.

In order to develop the SWIS Engineering Roadmap, AEMO has considered the likely characteristics of the future power system, informed by the WA Government's Whole of System Plan (WOSP) and SWIS Demand Assessment, alongside findings from AEMO's WEM ESOO. These documents highlight the pathway for WA's main power system, the SWIS, to transition to a renewables dominated power system, supported by significant storage and backup generation. The characteristics of the future power system are therefore expected to include:

- All WA Government-owned coal and high emitting technologies will have retired:
  - Synergy is in the process of retiring all state-owned coal-fired power stations by 2030.[6]
  - The Reserve Capacity Mechanism is under reform to include eligibility limits for high emitting technologies.[7]
- The majority of electricity demand will be served directly by renewable energy sources.
  - Development pathways in the Whole of System Plan and SWIS Demand Assessment have confirmed renewables will provide the bulk of energy (directly and through firming) as the system transitions to net zero.[8]

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[6] See Western Australian Government, State-owned coal-fired power stations to be retired by 2030 with move towards renewable energy, 2022, at https://www.wa.gov.au/government/announcements/state-owned-coal-power-stations-be-retired-2030-move-towards-renewable-energy.

[7] See https://www.wa.gov.au/government/document-collections/wholesale-electricity-market-investment-certainty-review.

[8] See https://www.wa.gov.au/government/document-collections/whole-of-system-plan.

- Peak demand in the SWIS will have grown significantly due to electrification and new industry development.[9]
  - The electricity system offers a pathway for high emitting energy consumers to decarbonise their operations, this has been reaffirmed by AEMO's projections in successive WEM ESOOs and the SWIS Demand Assessment.
  - New clean energy industries are forecast to expand in the future, including green hydrogen projects.
- Aggregations of DER will actively participate in WEM alongside enhanced visibility and control of unregistered DER and DER aggregations.
  - The Whole of System Plan and SWIS Demand Assessment have highlighted the role DER can play in accelerating the energy transition.[10] Enablers for this role are being undertaken through the actions identified in the DER Roadmap.[11]
- Energy Storage Resources (storage) will provide a key role in providing both Essential System Services (ESS) and demand smoothing.
  - The role of storage in firming renewables and providing essential system services has been signalled by the Whole of System Plan and SWIS Demand Assessment, while new storage projects dominate near-term capacity additions to the SWIS.[12]
- Back-up generation with firm fuel sources will still be needed to manage sustained lulls in wind and solar generation and insufficient levels of storage capacity.
  - The impacts of lulls in wind and solar continue to be explored as a consequence of a renewables dominated power system, to ensure reliability as a level of back-up generation from firm generation will continue to be required in the SWIS until alternative technologies can displace synchronous generation.

By forecasting the characteristics of the future power system, the operational tools, and capabilities necessary to manage that power system can be more clearly defined and implemented.

The SWIS Engineering Roadmap highlights that no one organisation can undertake all required actions, and the transition will require a coordinated effort between AEMO, Western Power, governments, industry, market bodies and communities. Figure 1 summarises how the engineering and reform processes are collectively contributing to building readiness for operation of a renewables dominated power system.

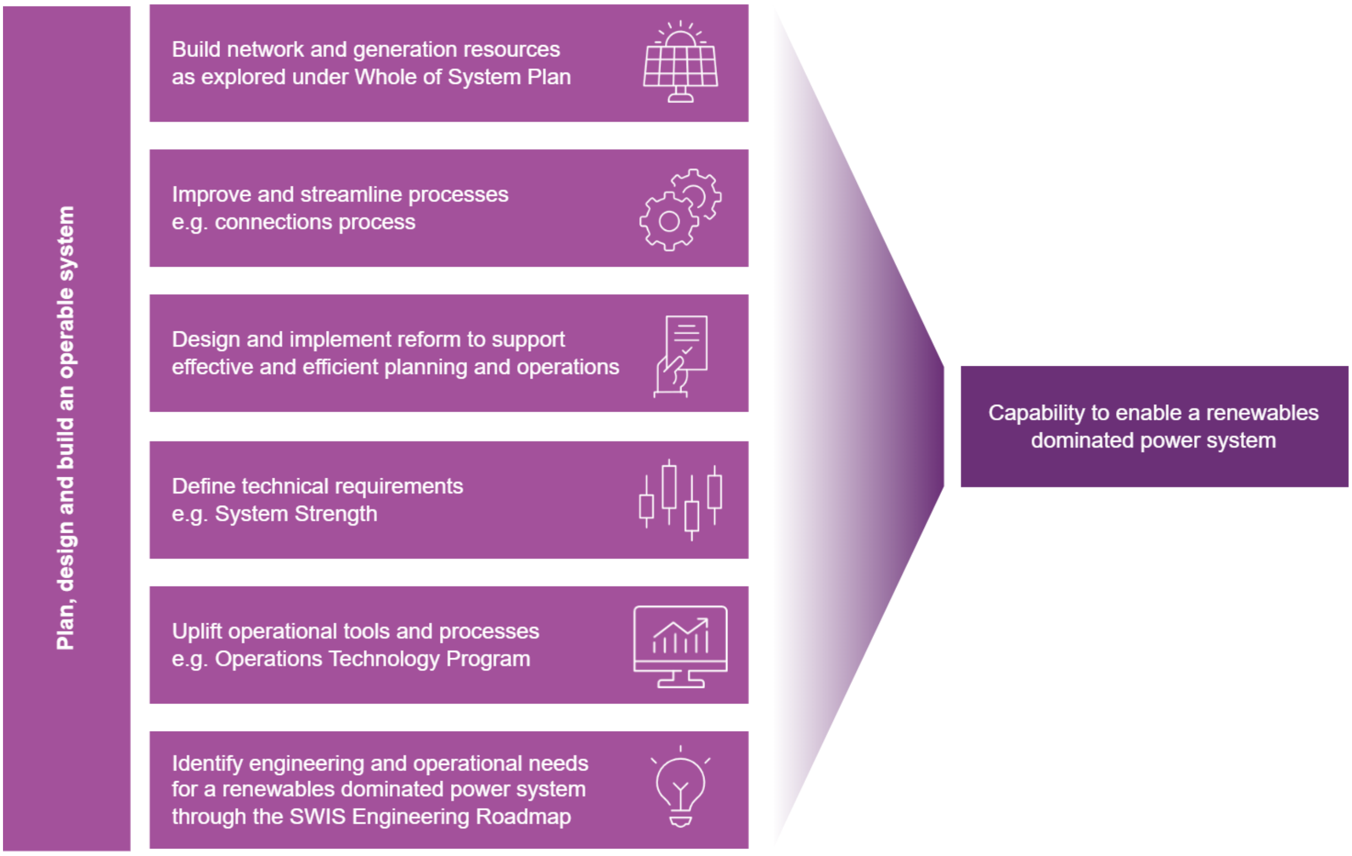
[9] See https://aemo.com.au/en/energy-systems/electricity/wholesale-electricity-market-wem/wem-forecasting-and-planning/wem-electricity-statement-of-opportunities-wem-esoo.

[10] See https://www.wa.gov.au/government/document-collections/whole-of-system-plan.

[11] See https://www.wa.gov.au/government/distributed-energy-resources-roadmap.

[12] See https://www.wa.gov.au/government/document-collections/whole-of-system-plan.

Figure 1 The SWIS Engineering Roadmap as part of broader industry drivers towards a renewables dominated power system.



1.3 Previous work

The SWIS Engineering Roadmap leverages the significant work conducted to date by AEMO as part of the NEM Engineering Roadmap and associated reports. The delivery of the SWIS Engineering Roadmap will further leverage commonality between actions in the NEM and SWIS through a coordinated approach to delivery – ensuring efficiencies in delivery and in order to achieve best value to consumers.

The SWIS Engineering Roadmap builds on the following related work previously completed in the SWIS to prepare for a renewables dominated future:

- WA State Government energy sector reforms and initiatives, including the Energy Transformation Strategy (ETS). See Appendix A1 for more details on these reforms and initiatives.
- AEMO Integrating Utility-scale Renewables and Distributed Energy Resources in the SWIS report[13] (AEMO 2019 report)
- AEMO Renewable Energy Integration – SWIS Update report[14] (AEMO 2021 update report)

[13] AEMO (2019), *AEMO Integrating Utility-scale Renewables and Distributed Energy Resources in the SWIS*. See https://aemo.com.au/energy-systems/electricity/wholesale-electricity-market-wem/system-operations/integrating-utility-scale-renewables-and-distributed-energy-resources-in-the-swis

[14] AEMO (2021), *Renewable Energy Integration – SWIS Update,* September 2021. See https://aemo.com.au/-/media/files/electricity/wem/security_and_reliability/2021/renewable-energy-integration--swis-update.pdf

The AEMO 2021 update report recommended 13 actions under four main areas – technical standards and services, distribution-system focused, market related, and regulatory to enable the power system and market to transform at a more rapid rate than forecast. Priority was given to bringing on-line Fast Frequency Response (FFR) services (ahead of the introduction of new Frequency Co-optimised Essential System Services (FCESS)), updating Under-Frequency Load Shedding (UFLS) arrangements, and enabling the management of Distributed Photovoltaic (DPV) systems. The work being done under ETS Stage 2, including ongoing DER Roadmap work, Reserve Capacity Mechanism (RCM) Review outcomes and further reforms, will continue to support the transition (see Appendix A1 for more details).

The progress of the 13 recommended actions, and their relevance to the SWIS Engineering Roadmap, are shown in Table 1 below.

Table 1 AEMO 2021 update report recommendations, related work, and linkages to SWIS Engineering Roadmap actions

	Recommendation	Relevant initiative	Solution	SWIS Engineering Roadmap action(s)
	Technical standards, services, and mechanisms			
1	Enable FFR service – PRIORITY	ETS Stage 1 – WEM reforms (commenced 1 October 2023)	Full	N/A – managed by new FCESS
2	Dynamic monitoring, and medium-term and long-term solutions for Under-Frequency Load Shedding (UFLS) – PRIORITY	DER Roadmap – Technology integration (in progress)	Partial	Frequency stability and inertia – see section 4.2.1
3	Enable ramping service	ETS Stage 1 – Non—Co-optimised Essential System Service (NCESS) Framework (procurement mechanism rules commenced) ETS Stage 2 – RCM Review[15] (introduction of a flexibility capacity product)	Full, flexibility capacity product introduced for the 2025 Reserve Capacity Cycle	Additional needs for managing ramping and reserves – see section 4.4.2
4	Ongoing inverter monitoring and compliance	DER Roadmap – Technology integration (in progress) ETS Stage 2 – Energy and Governance Legislation Reform (Project EAGLE)[16] (in progress)	Full once completed	DER – see section 4.4.3
	Distribution system related			
5	Management of DPV systems - PRIORITY	DER Roadmap – Emergency Solar Management (commenced February 2022) ETS Stage 1 – NCESS procurements for Minimum Demand Service (2023 and 2024-2025 Capacity Years)[17]	Partial until extended to all DPV systems	DER – see section 4.4.3
6	Market and incentive frameworks for DER participation	ETS Stage 2 – Project Eagle (in progress) DER Roadmap – DER Participation (in progress)	Full once completed in 2025	DER – see section 4.4.3

[15] Available at: https://www.wa.gov.au/government/document-collections/reserve-capacity-mechanism-review

[16] Available at: https://www.wa.gov.au/government/document-collections/energy-and-governance-legislation-reform

[17] Available at: https://aemo.com.au/consultations/tenders/tenders-and-expressions-of-interest-for-ncess-minimum-demand-service-wa

	Recommendation	Relevant initiative	Solution	SWIS Engineering Roadmap action(s)
		ETS Stage 1 – NCESS procurements for Peak Demand Service (2024-2025[18] and 2025-2026[19] Capacity Years)		
7	Develop visibility of, and incentives for, flexible loads	DER Roadmap – DER Participation (Visibility Framework developed) ETS Stage 2 – Demand Side Participation Review (in progress)	Full once completed	DER – see section 4.4.3
	Wholesale market related			
8	Changing the approach to hybrid facilities	ETS Stage 2 – Demand Side Participation Review (in progress)	Full once completed	N/A – not in SWIS Engineering Roadmap scope
9	Improving market incentives to address system variability	ETS Stage 2 – Cost Allocation Review (in progress)	Full once completed	N/A – not in SWIS Engineering Roadmap scope
	Regulatory architecture and functionality			
10	Centralised SWIS reliability standard and supporting frameworks	ETS Stage 2 – Project Eagle (in progress) DER Roadmap (in progress)	Full once completed in 2025	N/A – not in SWIS Engineering Roadmap scope
11	Framework for contingency planning and management to support power system resilience	ETS Stage 2 – Project Eagle (in progress)	Yet to be determined	Operational processes – see section 4.3.2
12	Build on the utility of the inaugural Whole of System Plan (WOSP)	ETS Stage 1 – Electricity Networks Access Code (ENAC) and WEM Rules amendments commenced) including changes to priority projects SWIS Demand Assessment	Full	N/A – not in SWIS Engineering Roadmap scope
13	Embed requirements for interoperability and cybersecurity	DER Roadmap – Technology integration (in progress)	Full when completed	DER – see section 4.4.3

1.4 Structure of this report

Section 2 provides an overview of the opportunities and challenges underpinning the operations of the future system, as well as the potential pathways and planning required to operate a renewables dominated power system. Section 3 discusses the capabilities that AEMO must ensure within the future fleet to manage the future power system. Section 4 presents details on the specific actions in the SWIS Engineering Roadmap.

[18] Available at: https://aemo.com.au/consultations/tenders/tenders-and-expressions-of-interest-for-ncess-reliability-services-wa

[19] Available at: https://aemo.com.au/consultations/tenders/expressions-of-interest-and-tender-for-ncess-reliability-services-2025-27-wa

2 Towards operating a renewables dominated power system

The SWIS will operate at increasingly high levels of renewables, with instances where there are sufficient renewables available to meet total demand. However, there are engineering challenges that will need to be addressed as traditional synchronous generation is displaced.

2.1 Operating a renewables dominated power system

2.1.1 Instances of sufficient renewables to meet total demand

There have already been instances when there was sufficient renewable energy resource availability to meet the entire SWIS operational demand[20], and these instances will continue to occur during minimum operational demand periods i.e. around midday on mild Spring weekends or public holidays when DPV increasingly supplies the majority of underlying demand[21].

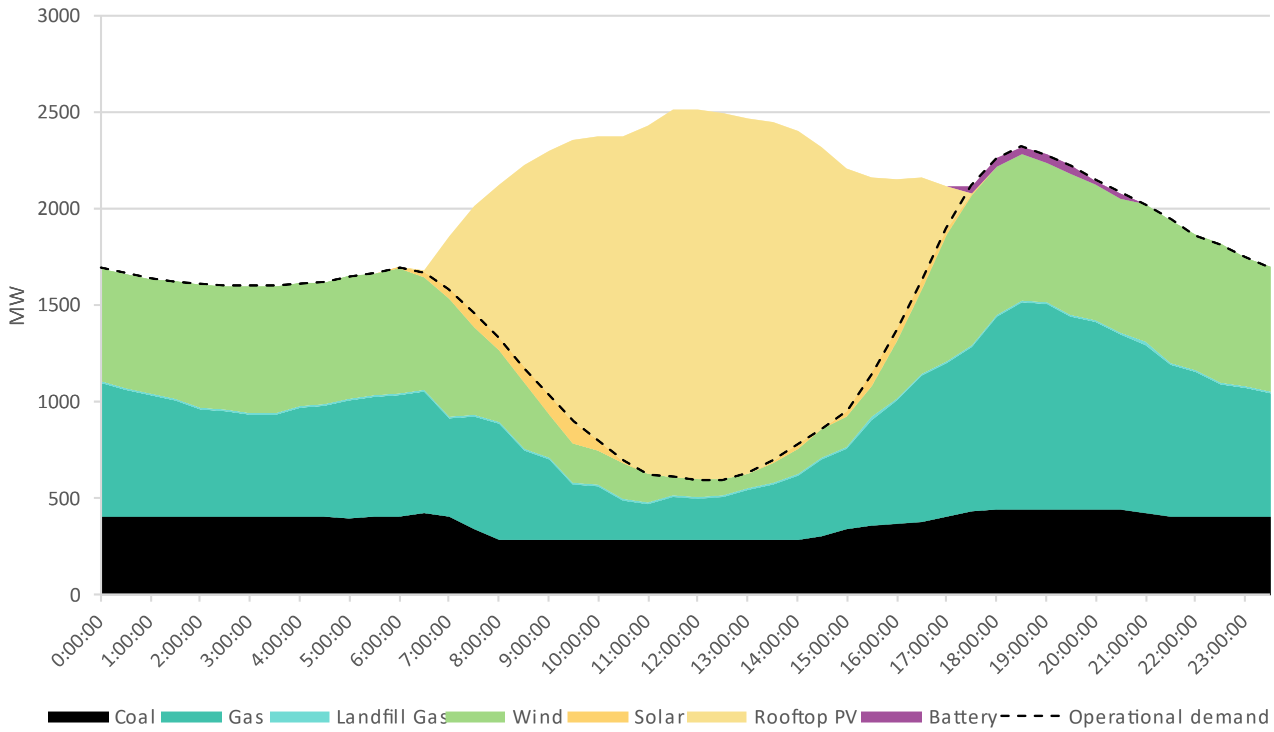
One such instance occurred during the 12:00-12:30 Trading Interval on 25 September 2023, when the current minimum operational demand record of 595.1 MW[22] was set. An estimated 76% of the underlying demand was met by DPV across this half hour interval.

[20] Operational demand is the total amount of electricity that is supplied to consumers via the SWIS. It does not include electricity demand that is met by 'behind-the-meter' generation, such as DPV, or demand that is avoided by directing loads to consume less.

[21] The total amount of electricity demand used by consumers at their power points. This electricity can be sourced from the grid, or from behind-the-meter DER, such as DPV and battery storage.

[22] As reported in AEMO's Quarterly Energy Dynamics Q3 2023 report, derived using average half hour non-loss adjusted sent-out SCADA data.

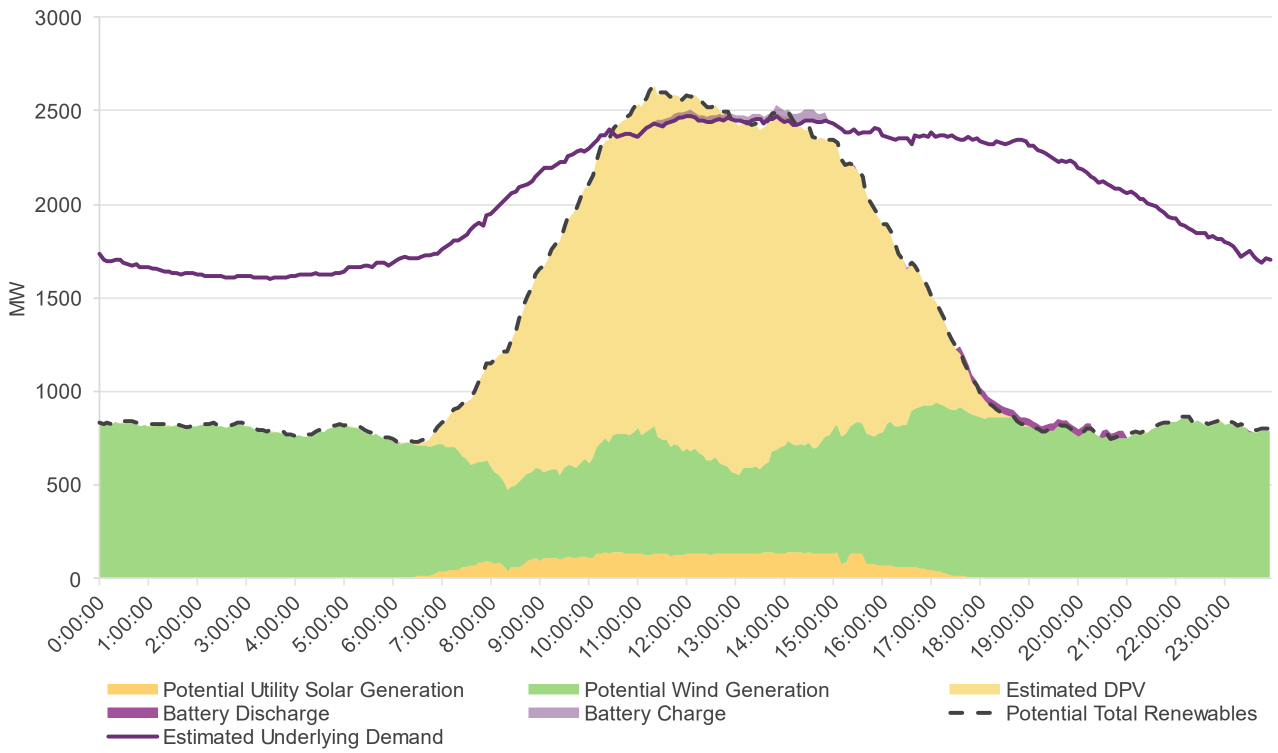
Figure 2 Minimum operational demand record in the SWIS set on 25 September 2023



At the time, there was over 610 MW of utility-scale renewable energy resources available, i.e. enough to supply the operational demand of 595.1 MW. However, when the market price is lower than the bid of a semi-scheduled renewable facility, it is dispatched below its instantaneous potential, a market response known as "economic offloading". Low and negative spot prices often occur during the middle of the day, when there is abundant DPV reducing demand from the grid.

Figure 3 below shows the total volume of renewable energy that was available on 25 September 2023, along with an estimate of the underlying demand. There was enough renewable energy available to supply the SWIS for roughly three hours from 10am to 1pm.

Figure 3 Availability of renewable energy facilities on 25 September 2023



The synchronous generating units that were dispatched bid in at the market floor price and remained online for a variety of reasons, including:

- Provision of essential system services.
- Provision of voltage control at key nodes in the SWIS.
- Contractual obligations, i.e. co-generation facilities that need to stay online to produce steam.
- Unit inflexibility in not being able to quickly decommit and recommit later in the day to supply the evening peak.

Some of the drivers for synchronous unit dispatch at minimum operational demand are purely technical, while others are economic or contractual in nature.

2.1.2 SWIS minimum demand thresholds

The AEMO 2019 report found that without accommodating new technologies, voltage in the SWIS could not be controlled within technical limits as the level of minimum operational demand approached an indicative threshold of 700 MW; this was expected to be reached between 2022 and 2024.

The AEMO 2021 update report revisited the technical challenges associated with the transforming generation supply mix that were identified by the earlier report. The findings confirmed that the drivers of change in power system conditions remained challenging, with some changes occurring at a faster rate than originally forecast.

However, the implementation of specific reforms, operational initiatives, tools, and network investments (such as the installation of shunt reactors by Western Power) had materially improved AEMO's operational capability and the ability of the power system to be managed securely at lower levels of operational demand (the current minimum operational demand record for the SWIS is 595 MW).

In June 2022, EPWA published the Low Load Project Stage 1 Report[23], which articulated the technical challenges for operating the SWIS at low operational demand. In particular, the following technical challenges were identified and investigated in detail:

- Maintaining frequency stability after system disturbances, particularly as minimum operational demand periods also represent low system inertia conditions, while contingency sizes can remain large due to DPV disconnection after network disturbances.
- Managing sufficient reactive power / voltage control.
- Maintaining adequate ramping capability.
- Managing system strength.
- Maintaining under-frequency load shedding (UFLS) levels.

An outcome of the Low Load Project was to establish the concept of a minimum demand threshold (MDT) which may then be modified to reflect the fleet capability to manage minimum operational demand events.

2.2 Pathway towards a renewables dominated power system

2.2.1 Understanding minimum demand thresholds

The use of an MDT[24] to manage system security is a simple, albeit coarse proxy for describing the technical factors that drive system security. Underlying the MDT is a series of assumptions regarding the synchronous generating units that would be expected (or required) to remain online in order to maintain secure operation i.e. to provide sufficient voltage control, inertia, ramping capability, frequency control, etc.

The secure threshold can also be expressed as the minimum synchronous generation level required for the system to remain secure and operable. This is conceptually analogous to the minimum synchronous generating unit configurations used in regions of the NEM, where minimum sets of generating units must be dispatched in combinations that are known to be secure.

Monitoring synchronous generation levels is complementary to MDT, and one that will be increasingly valuable to monitor as more renewable energy capacity is added to the SWIS, when the secure threshold can bind at times of the day that do not necessarily coincide with minimum operational demand. For example, consider the following two dispatch scenarios over a single day presented in Figure 4:

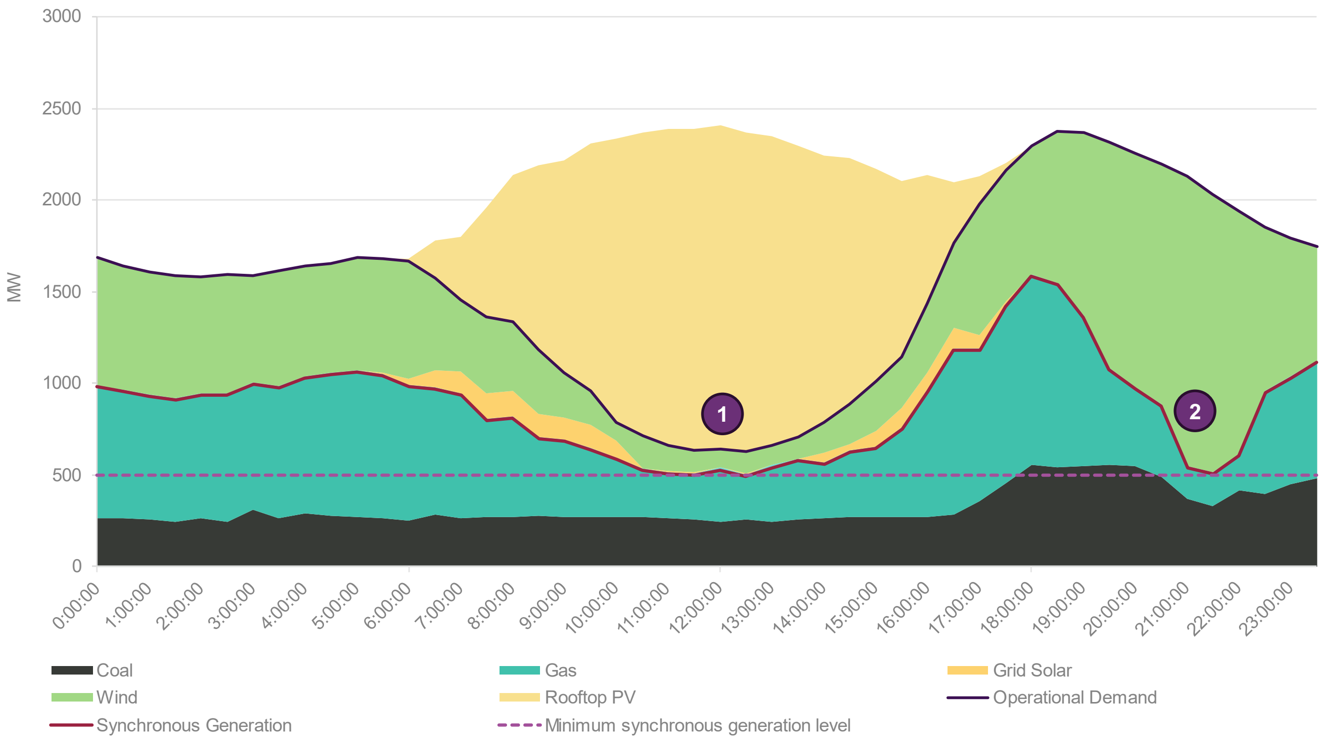
- Scenario 1 occurring at the time of minimum operational demand but with no renewables dispatched; and
- Scenario 2 occurring at a time of higher demand but with high levels of renewables in merit.

[23] https://www.wa.gov.au/system/files/2022-08/EPWA-SWIS%20Low%20Demand%20Project%20Stage%201.pdf

[24] Defined as the minimum operational demand level below which the SWIS is no longer secure and emergency actions are required. It is expressed as a MW range and depends on the specific collection of generators that are online at any point in time, from: https://www.wa.gov.au/system/files/2022-08/EPWA-SWIS%20Low%20Demand%20Project%20Stage%201.pdf

In the first scenario the minimum synchronous generation level is binding at the time of minimum operational demand. However, in the second scenario, the minimum synchronous generation level binds at higher demand where there is the renewable potential to displace enough synchronous generation to create an insecure state.

Figure 4 Comparison of a hypothetical day with both low renewables dispatch during daytime minimum operational demand (see 1) and high levels of renewables dispatch during a period of higher demand (see 2) both requiring similar levels of synchronous generation.



2.2.2 Operational transition points to increasing renewables penetration

Operational transition points refer to key events and milestones that enable changes in the way AEMO manages the technical operating envelope. For example, an operational transition point could be the installation of an energy storage system or synchronous condenser at a particular location that allows one less synchronous generator to be required online for system security.

The minimum synchronous generation level is a means to manage the key technical needs of today's power system, and the staged evolution of the metric could be coordinated through secure navigation of operational transition points. The objective of the roadmap is to prepare the system to move through transition points with progressively lower synchronous generation, with the eventual operation towards 100% renewables[25].

Tracking minimum synchronous generation levels is aligned with the latest international thinking, for example, EirGrid's Minimum Conventional Units Online constraint requiring enough large synchronous generating units online to provide voltage control and sufficient levels of inertia[26].

[25] Allowing for the operation of synchronous generators that are powered by renewable resources i.e. landfill gas and bioenergy.

[26] https://www.eirgridgroup.com/site-files/library/EirGrid/TSO-Imperfections-and-Constraints-multi-year-plan-2023-2027-Consultation.pdf

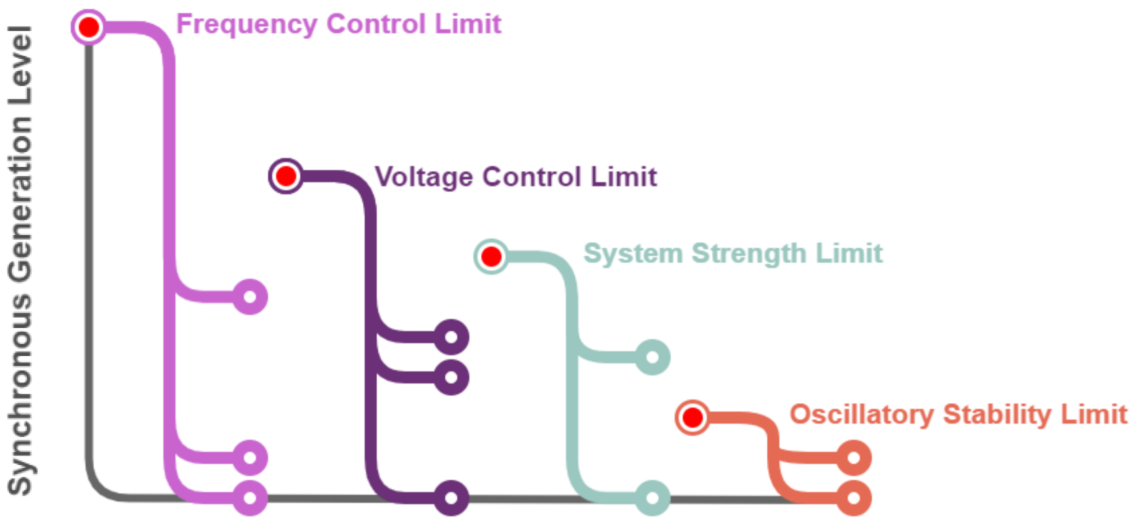
2.2.3 New capabilities and services required to navigate operational transition points

It is expected that the following technical factors will determine the limits informing the minimum synchronous generation level:

- Voltage control.
- System strength.
- Transient and oscillatory stability.
- Frequency stability and inertia.
- Ramping capability.

While many of these factors are largely interdependent, it is expected that each limiting factor will bind under different circumstances and scenarios. Therefore, it is proposed that there are concurrent workstreams to implement measures to overcome the limiting factors in parallel, i.e. in lieu of simply trying to overcome one limit at a time, as some technical solutions may have long lead times. The conceptual approach to reducing levels of synchronous generation is shown in Figure 5, highlighting that actions to reduce operable levels of synchronous generation for one limit may expose a new binding limit.

Figure 5 Conceptual illustration of minimum synchronous generator levels



Navigating operational transition points will require one or more specific enablers that overcome the technical barriers preventing the reduction in output or decommitment of synchronous generation. For example, maintaining voltage control capability in a specific region may be the limiting factor that prevents a synchronous generator from being decommitted. Replacing this capability with a combination of renewable generation, energy storage and/or network assets would alleviate this limit and allow the synchronous generator to decommit without jeopardising system security. It is important to note that solutions can be in the form of new network assets that are an outcome of normal network planning processes.

The new capabilities and services required to relax each operational transition point will be identified by detailed power system modelling and studies and may form the basis for future procurement of NCESS or consideration of new services in the WEM.

2.3 Planning for a renewables dominated power system

Many factors will contribute to renewables penetration. Many of those factors identified in the NEM Engineering Roadmap[27] are also applicable to the SWIS, such that actual renewables penetration may be lower than the overall renewable resource potential. These factors include:

- **Market behaviour:** some renewable generators may choose not to generate at their full available resource potential when the wholesale price of energy is negative, or non-renewable generators bidding themselves into the market for technical or commercial reasons.
- **Network constraints:** limits on transmission line capacity will mean that not all resource potential can be dispatched in the market and carried by the network to consumers, at all times.
- **System requirements:** the need to maintain sufficient essential system services may result in synchronous generators being dispatched to provide essential system services where the capability of non-fossil fuel alternatives to provide these services is insufficient.
- **Limitations on the level of DPV generation:** to manage power system security and distribution network conditions, curtailment of this renewable resource may be necessary.
- **Forecast demand:** growth in demand due to electrification and from the supply of cooling load, hydrogen production and Large Industrial Loads.

2.3.1 Preparing the SWIS for the energy transition

The SWIS Engineering Roadmap aims to ensure the SWIS is prepared to operate as a majority renewables system, with instances at or near 100% renewables penetration as an outcome of market dispatch where there are no synchronous generating units producing energy[28]. Such an outcome will likely result from an incremental decrease in the minimum number of synchronous generators that are generating in the SWIS at any given time as they adapt their operating practices to reflect market and system conditions.

Some generators have the capability to come online and offline throughout the day; others with less flexible operating arrangements may see their capacity withdrawn from the market for longer periods for a variety of reasons. For example, generators may be available but not dispatched into the system in any interval if more economic generation is available. Generators may also choose to temporarily decommit from the market to undertake maintenance or due to fuel availability.

The SWIS Engineering Roadmap seeks to position the SWIS in readiness to operate during the energy transition, as preparation needs to occur well ahead of the last synchronous generating unit going offline. Preparation requires:

[27] https://aemo.com.au/initiatives/major-programs/engineering-framework/reports-and-resources

[28] Energy delivered to the market excludes any behind-the-meter fossil fuel generation used for self-consumption.

- **Proactive planning studies** to define operational transition points and what is technically required to relax each transition point.
- **Operational readiness** to operate the system in new conditions.
- **Resource adequacy planning** and jurisdictional and commercial decisions around fossil fuelled generator operating practices will need to consider how the energy and dispatchable capacity requirements of the SWIS can be met by other means.

Planning and enabling the investment required to efficiently, securely, and reliably operate the SWIS at up to 100% renewable penetration will require an extensive effort across AEMO, Western Power, Market Participants, and the WA State Governments ahead of time.

2.3.2 Proactive planning studies

Power system studies are required to be performed to ensure the SWIS operates within the technical envelope with decreasing amounts of synchronous generation. The outcome of these studies will be the definition of operational transition points and the technical measures that are required to relax each transition point.

2.3.3 Operational Readiness

Operational transition points are a means to enable management of the technical operating envelope of the SWIS in real-time operations while meeting power system security obligations and reliability requirements. Identification of upcoming transition points is required to ensure sufficient time is available for investment and other preparatory activities to be completed. By successively achieving secure operations at new operating points as, the transition can be approached as a series of carefully planned and executed operational transition points – identifying and addressing potential issues before they emerge operationally.

The control room and operational teams will need to be prepared to operate the system by conducting controlled operational trials near the edges of the known technical envelope. This will include, but not be limited to, the following actions:

- Operationalisation of transition points.
- Establishing protocols for operating in new operational states.
- Controller preparation through digital training simulations.

2.3.4 Resource adequacy planning

Existing market mechanisms, the Reserve Capacity Mechanism, Short-Term Energy Market (STEM) and the real-time energy market are expected to continue to incentivise market participants to efficiently deploy their generation and storage assets in order to meet SWIS demand at all times, even at or near 100% renewable operation.

- Planning for resource adequacy will require new considerations for a renewables dominated power system, due to a range of factors, including: dunkelflaute events and the management of duration limited storage technologies.
- Impact of correlated weather events of reduced renewables generation at high system operational demand.

- Lack of flexible / fast committing resources and/or energy storage depth to cover material forecast errors and/or volatile weather conditions.

AEMO expects to continue to explore these factors in annual WEM ESOO and WA Gas Statement of Opportunities (GSOO) reports. The WOSP also considers these factors in its 20-year outlook on the future of the SWIS.

3 Operationalising the transition through new capabilities and services

To enable increasing levels of IBR generation (including utility-scale wind and solar generation), new technologies and capabilities will be required to enable the SWIS to operate at lower levels of synchronous generation.

At a high level, the following types of (interrelated) capabilities and services are needed to relax operational transition points and operate at lower levels of synchronous generation:

- **Voltage control**: providing the capability for adequate voltage control (to meet the standards in the Technical Rules) at all nodes in the SWIS;
- **System strength**: ensuring that there is sufficient system strength at all nodes in the SWIS to allow IBR generation to operate stably and for protection systems to operate correctly;
- **Ramping**: managing load uncertainty and generation variability across relevant time horizons;
- **Management of duration-limited resources and renewable energy droughts**: ensuring sufficient firming and backup generation to manage shortages in wind and/or solar generation over various timeframes; and

These capabilities are in addition to the following existing ESS that are currently procured in the market:

- **Frequency and RoCoF control services**: to manage frequency over 5 minutes (Regulation) and in response to contingency events (Contingency Reserve and RoCoF Control Services), these services are co-optimised with energy and procured every 5 minutes in the real-time market; and
- **System restart services**: ensuring the SWIS can be restarted in the event of a system black.

The following subsections look at the new capabilities and services that will be required in more detail.

3.1 Voltage control

Traditionally, voltage control in the SWIS has largely been provided by synchronous generation (and to a lesser extent, non-synchronous generation), as well as network assets such as Static VAR Compensators (SVC's) and shunt reactive plant. Because voltage control is highly locational, there has not been a need in the past to provide alternative voltage control capability in areas with synchronous generators that are frequently dispatched (either as base load generation or to provide ESS), for example the Muja / Collie, Kwinana, and Northern Terminal / Pinjar areas.

However, as the SWIS progressively transitions to lower levels of synchronous generation, there will be a need to replace the voltage control capability from decommitted synchronous generators. These will be locationally specific needs and potential solutions may be cross-cutting with other services i.e. a grid-forming BESS or synchronous condenser can potentially provide voltage control, system strength and inertia (RoCoF Control Service).

Box 1: Voltage control in the SWIS during minimum demand periods

In the SWIS, voltages in the high voltage network are required to be controlled to within ±10% of the nominal voltage (as per the Technical Rules). Voltage control planning in the SWIS has traditionally focused on maximum demand (or highly loaded) periods, where low voltages are the problem. This has led to the proliferation of shunt capacitor banks at most zone substations in the network. It is only in the last 5-6 years that high voltages during minimum demand have emerged as an issue. While Western Power has recently embarked on a program to install shunt reactor banks to provide reactive power absorption capability, the burden of voltage control during minimum demand periods still lies with the generation fleet.

In some key areas, like the Collie region, there are currently few alternatives to synchronous generators for providing voltage control.

3.2 System strength

System strength is an umbrella term for a range of power system phenomena and issues that are loosely related to network fault levels (also called short circuit levels), namely:

- Fault current contribution for the correct operation of protection systems;
- Voltage sensitivity and the propensity for voltage oscillations; and
- Voltage waveform stability for grid-following IBR to remain synchronised after disturbances.

It is worth noting the distinction between system strength needs that are the purview of network service providers in meeting their technical performance standards (e.g. correct operation of protection systems and voltage stability) and system strength needs that also affect generators (e.g. voltage waveform stability for stable operation of IBR and converter-driven oscillations).

Similar to voltage control, system strength is highly locational and has traditionally been provided in the SWIS by synchronous generation. However, unlike voltage control, the system strength capability provided by decommitting synchronous generators does <u>not</u> necessarily have to be replaced one-for-one. Instead, there are a range of potential remediation options depending on the specific circumstances, such as:

- Areas with low concentrations of grid-following IBR may not require high system strength for voltage waveform stability.
- Planned replacements of shunt reactive plant selected with smaller ratings to keep voltage step changes within limits upon switching, even at low system strength.
- New technologies such as grid-forming inverters, may act to support voltage waveforms and extend hosting capacity for co-located grid-following IBR.
- Protection systems could be upgraded to operate effectively at lower fault currents (i.e. less reliance on overcurrent schemes), acknowledging that a balance needs to be struck between maintaining higher system strength and the potentially high cost and complexity of upgrading protection systems.

Box 2: System strength issues in the SWIS

There are currently no pre-existing system strength issues currently identified in the SWIS, though there are areas of the SWIS like the North Country, East Country and South East regions that can exhibit low system strength under outage (N-1) conditions. However, with a decreasing number of synchronous generators online and more grid-following IBR being connected to the system, it is expected that system strength issues will emerge in the future, particularly near the radial extremities of the grid.

3.3 Ramping

Ramping refers to the capability of the generation fleet to respond to variability in system demand and Variable Renewable Energy (VRE) generation. This includes the fleet's capability to respond to real-time changes within dispatch intervals (intra-interval variability), ramps across consecutive dispatch intervals (inter-interval variability) or increase generation from the middle of the day to meet the peak demand at the end of the day (intra-day variability). The analysis for this SWIS Engineering Roadmap has considered the system needs that may be met by ramping services and identifies the specific actions to support the provision of ramping services to manage uncertainty and provide for the quantum of ramping required over different time scales.

In addition to the ramping service, a mechanism will be required to incentivise controllable facilities that are capable of responding to a dispatch instruction and ramping to enter the market and be available ahead of the dispatch interval(s), including outside of peak periods, in which volatility is forecast.

3.3.1 Intra-interval ramping

Variability in system demand and generation occurring within 5-min dispatch intervals are presently managed through a combination of:

- Mandatory primary frequency control from scheduled and semi-scheduled generators, and
- Regulation FCESS that is competitively procured in the real-time market.

The current arrangements are sufficient and at this stage, it is not envisaged that additional intra-interval ramping capability is required.

3.3.2 Inter-interval ramping

The SWIS is experiencing significant inter-interval load swings caused by fluctuations in DPV generation as the result of weather patterns (such as fast-moving cloud fronts) that cause rapid increases and decreases in DPV output. High wind volatility can further impact the needs for ramping of scheduled facilities in the SWIS. The difficulty in accurately predicting weather movements impacts AEMO's ability to forecast, for example, locational volatility in DPV output and its total contribution to operational demand both in real time and over a day. Consequently, as DPV penetration increases across the SWIS, AEMO is increasingly required to undertake significant re-dispatch of dispatchable generators and procure additional FCESS, since dispatching generation up and down to manage rapid changes in renewable energy sources consumes available Regulation ESS.

As contribution from VRE continues to rise, it will be increasingly important for AEMO to forecast and manage ramps in DPV generation and the associated impact on system load. This will be especially important in dealing with, for example, scuttling cloud (mixed sky) days. On such days, the system's operation could vacillate between two different operating envelopes; one that is representative of a clear sky day and another that is representative of a completely cloudy day.

Managing the variability in operational demand, which is already as great as 700 MW within 30 minutes on a day with rolling cloud cover, could be enabled through procuring additional quantities of ESS, but may require more targeted mitigation.

In the context of minimum operational demand, it is becoming increasingly impractical and/or inefficient to keep online sufficient quantities of dispatchable generation with the headroom to ramp up or down to respond to cloud-based ramping events. Alternative solutions may be needed to operationalise the headroom required to address volatility in operational timeframes, but without having to keep material quantities of dispatchable generation online in every relevant interval.

3.3.3 Intra-day ramping

Traditionally, the Reserve Capacity Mechanism (RCM) provides the means of incentivising generation, storage, and demand side response to enter the market and to be available to meet the forecast maximum peak demand in two years' time. Typically, this peak demand occurs in the Summer. More recently, the generation fleet that is online (or must be brought on-line) to meet peak demand has been required to 'ramp up' quickly from increasingly lower levels of generation at the middle of the day when operational demand is at a minimum (the duck curve effect). This ramp in generation is potentially in the order of 2 GW over four hours. Increasingly, this capability will be required outside of the traditional 'hot season' as well, as the effects of DPV generation are also felt on the SWIS during cold sunny days in winter.

The RCM Review has led to the gazettal of WEM Rule amendments to integrate a 'flexibility capacity product' alongside the existing 'peak' capacity product in the WEM. The Flexible capacity product will have capability to start, ramp and stop quickly to address inter-day variability[29] in recognition of the fact that the power system's needs cannot be met by all capacity that is eligible for the existing 'peak' capacity service. The requirement for the new product will be set by the quantity needed to meet the size of the largest operational ramp expected from any four-hour period forecast for the relevant capacity year.

3.4 Managing duration limited resources and renewable energy droughts

As volumes of VRE generation increase in the SWIS, particularly through the uptake of rooftop solar PV and as a larger proportion of Reserve Capacity is provided by VRE technologies and storage, the times at which available supply is likely to be insufficient to meet demand will occur outside of the traditional 'peak' demand intervals.

[29] Energy Policy WA (2022), *Reserve Capacity Mechanism: Stage 1 Consultation Paper,* 29 August, p.22. See https://www.wa.gov.au/system/files/2022-08/EPWA%20-%20Reserve%20Capacity%20Mechanism%20review%20-%20consultation%20paper%201.pdf and Energy Policy WA (2022), *Reserve Capacity Mechanism: Information Paper (Stage 1) and Consultation Paper* (Stage2), 3 May, p.30 at https://www.wa.gov.au/system/files/2023-05/epwa_reserve_capacity_mechanism_review_information_and_consultation_paper.pdf

The varying contribution of VRE, storage and firm generation to reliability was captured in the RCM Review through introduction of Capability Classes in the RCM, to categorise types of Reserve Capacity and allow their contribution to reliability to be more clearly assessed (see section A1.3.1). The RCM Review also introduced a framework to consider the duration needs of storage technologies. The duration (formally hard coded at four hours) is now set on the basis of the forecasted proportion of total Reserve Capacity and therefore the length of peak demand events it must be capable of meeting (see section A1.3.1).

These reforms provide a framework to more clearly explore the reliability outcomes of the SWIS as the generation and storage composition of the system changes. A key theme to be explored is the impact of periods of renewable energy drought (also known as dunkelflaute, which may extend to several days[30]), which are an emerging issue for systems with high share of renewables. The characteristics of renewable energy droughts for a power system vary widely between systems, due to:

- Resource diversity for each generation type, typically driven by spatial diversity and level of interconnection;
- Proportions of technologies in the renewable generation fleet;
- Seasonal weather conditions across the renewables fleet; and
- Incidents of low probability high impact weather conditions.

Quantifying the probability and magnitude of such events will allow AEMO to review the residual demand to be met by firm and duration-limited generation technologies, requiring uplift of the statistical tools AEMO uses to calculate renewables generation availability across time. It is expected that any shortfalls resulting from insufficient fleet capability will be identified as part of AEMO annual WEM ESOO, highlighting a need for Capability Class 1 generation if forecast expected unserved energy exceeds the level set by the planning criterion. AEMO will undertake detailed studies to identify these periods and manage generation adequacy requirements.

[30] See https://www.mdpi.com/1996-1073/14/20/6508

4 Action roadmap

The SWIS 'action' Roadmap is divided into the three broad themes that are pivotal to operating the power system at high levels of renewables - **Power system security**, **System operability**, and **Resource adequacy and capability**. This section identifies, under each theme and related aspects of power system management (as per Table 2 below), the preconditions necessary to support the SWIS throughout its transition. The current and emerging challenges associated with transitioning the SWIS are also identified for each precondition.

Actions include the capabilities required to manage the issues expected to arise at very high levels of renewable penetration. The actions are grouped according to the aspect of power system management that they support.

Table 2 SWIS Engineering Roadmap themes and related aspects of system management

SWIS Engineering Roadmap theme	Aspect of power system management
Power system security - maintaining the secure technical operating envelope of the power system under increasing renewable penetrations	Frequency stability and inertia Transient and oscillatory stability System strength and converter driven stability Voltage control System restoration
System operability - the ability to securely and reliably operate the power system and transition through increasingly complex operating conditions	Operational processes Power system modelling Reserves and Firming
Resource adequacy and capability - building and integrating the energy resources and network capability to enable the renewable potential and the flexible capacity to balance variability over different time frames	Utility-scale VRE Structural demand shifts Transmission Distributed Energy Resources Distribution

4.1 Stakeholder engagement

The actions presented capture a broad range of enabling capabilities. A coordinated and collaborative engagement is required across industry to ensure an effective, efficient, and timely transition plan. AEMO has commenced, and will expand, targeted engagement with organisations who may be directly impacted by the actions presented. Further to this, AEMO is seeking feedback from any interested stakeholders on the following points to inform priority actions under the roadmap.

Questions

- What actions are priorities to accelerate renewable penetration towards a renewables dominated power system?
- Are there any priority actions you think are missing from the presented actions?
- How would you like to be engaged for the development of priority actions?

There will be further opportunities to engage with AEMO and inform the delivery of the SWIS Engineering Roadmap. Interested parties are encouraged to contact wa.futuresystemdesign@aemo.com.au to register for updates and submit feedback.

4.2 Power system security

Maintaining power system security as the SWIS undergoes the energy transition means maintaining the secure technical operating envelope of the power system under increasing renewable penetrations. In operational timeframes it means:

- Voltages are kept within normal operating bands and must be recovered appropriately following disturbances;
- Voltage step change limits are not breached, generators remain stable following a credible contingency event and power system protection devices operate correctly;
- Following a disturbance or event, the power system recovers to within normal limits within an appropriate timeframe and remains controllable within those limits (with no undamped oscillations);
- the power system must remain synchronised; and
- Power system frequency does not change at a rate that would prevent the operation of automated protection systems (e.g. UFLS relays), damage or cause generators or loads to trip, and that frequency does not decay below key frequency limits following a credible contingency event.

The SWIS Engineering Roadmap assumes that the general principles for maintaining power system security under the WEM Rules will continue to apply:

- The power system should be operated such that it is and will remain in a secure operating state, to the extent practicable.
  - The SWIS is in a secure operating state when it can return to operating in accordance with all relevant requirements of the technical envelope and other security principles following a credible contingency.
- Following a contingency event, AEMO should take all reasonable actions to return to a secure operating state as soon as possible, and in any case within 30 minutes.
  - The exception is when the SWIS is experiencing a low reserve condition or when it is in an emergency operating state;
- Sufficient inertia should be available to meet applicable RoCoF Control Service requirements;
- Sufficient capability should be maintained at applicable locations in the SWIS to meet the applicable power system stability requirements, including any system strength requirements; and
- Sufficient system restart services (SRS) are available, in accordance with the System Restart Standard, to restore the SWIS in the event of a system shutdown or a major supply disruption.

It will be critical to ensure power system security is maintained as the stability and dynamics of the power system change due to the transition from a largely synchronous generation-based power system to one characterised by many (small and large) IBR technologies.

Roadmap actions associated with power system security largely fall into two categories:

1. Actions to better understand power system limits and expand the technical envelope.
2. Actions to ensure capabilities are available to allow the system to be operationally maintained within the expanded technical envelope as the fleet composition of synchronous generation reduces.

This section is divided into the key system management tasks AEMO must undertake to maintain power system security – managing frequency and inertia, transient stability and oscillations, system strength and converter driven stability, voltage control, and system restoration.

4.2.1 Frequency stability and inertia

In a synchronous AC power system, frequency reflects the balance between active power generated and consumed. In both the WEM and the NEM, AEMO is responsible for managing power system frequency and time error in accordance with the Frequency Operating Standard (FOS).

Actions in this section assume that the current FCESS will continue to be the primary mechanisms by which AEMO ensures frequency is maintained through the energy transition. This assumption is supported by two foundational premises: frequency will continue to act as an indicator of supply-demand balance in the power system; and that it will continue to be necessary to maintain frequency within relatively narrow bounds around a nominal value for equipment to operate safely.

As the power system evolves, with increasing DC applications, and continued proliferation of IBR and other power-electronic devices within AC power systems, these assumptions may change, and will require new control strategies and methods to capitalise on the wider frequency ranges that may be tolerable.

Potential changes to existing services

Frequency and RoCoF control arrangements in the WEM have recently been revised as part of the new market that launched on 1 October 2023, and are currently being reviewed as part of the Essential System Services Framework Review[31].

There are several barriers to unlocking the full potential of grid-forming BESS in providing ESS. The first is to amend the service definition for the RoCoF Control Service to allow non-synchronous sources of inertia, such as synthetic inertia from grid-forming BESS, to participate in the market. However,

[31] Available at: https://www.wa.gov.au/government/announcements/essential-system-services-framework-review

there are technical considerations that will need to be worked through, for example, whether equivalence between synchronous inertia (measured in MWs) and synthetic inertia can be drawn, the need for raise and lower inertia services and the specification for synthetic inertia provision. These studies are actively being progressed by AEMO in collaboration with industry.

Table 3 Identified preconditions and associated challenges – Frequency and inertia

Preconditions	Current and emerging challenges
Ability to keep system frequency within defined limits following credible and non-credible events, including RoCoF containment and effective emergency frequency control arrangements	• Reducing inertial response due to ongoing displacement or retirement of synchronous generation, replaced with IBR. – Increasing potential for high RoCoF conditions following credible and non-credible contingency events, which may not be managed by RoCoF Control Service quantities as synchronous generation retires. • Reducing load available for shedding in the daytime due to increasing DPV uptake, reducing effectiveness of UFLS schemes to arrest frequency decline during a non-credible contingency. – With continued DPV growth, existing UFLS schemes will trip net-generating, reverse flowing the feeders, exacerbating the initiating MW imbalance.
Frequency response and FCESS reserve requirements completely met by VRE, storage, demand response.	• Changing contingency FCESS reserve requirements. – Contingencies to be considered and associated risk profiles are changing with evolving generation and load mixes. – Increasing secondary risks such as DPV disconnection during disturbances and run-back schemes. – Increasing regulation FCESS volumes required due to increasing variability in the supply-demand balance and forecast uncertainty with ongoing growth in DPV and VRE. • Reduction in available frequency response due to VRE and DPV displacing synchronous generation online. – Could result in challenges in maintaining sufficient narrowband primary frequency response (PFR), regulation and contingency frequency control in the power system, since DPV does not currently supply these services. • Reduction in reserve availability for frequency control. – Low availability of raise FCESS in periods with high VRE online operating without headroom. • Low availability of lower FCESS service when synchronous generators are at minimum load.

Figure 6 Actions to achieve identified preconditions – Frequency and inertia

Preconditions	In-progress	Future Actions
Ability to keep system frequency within defined limits following credible and non-credible events, including RoCoF containment and effective emergency frequency control arrangements	Review the RoCoF Safe Limit based on an assessment of RoCoF Ride-Through Capability and availability of RoCoF Control Service	
		Establish understanding and specification of 'synthetic' inertial response from IBRs, and equivalence to synchronous machines, and potential plant level constraints on the capability to provide synthetic inertia
		Specify accreditation requirements for RoCoF Control Service from synthetic inertia providers
	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	
	AEMO and Western Power to review UFLS adequacy with increasing aggregate DPV uptake, including assessing the possible need for an UFLS redesign	
		Use phasor measurement units (to be installed by Western Power) to provide increased accuracy of system inertia estimation in real time
		AEMO and Western Power remediate or redesign Over Frequency Generation Shedding (OFGS) arrangements for effective operation
Frequency Co-optimised Essential System Services (FCESS) reserve requirements completely met by VRE, storage and demand response.		Forecast the efficacy of FCESS (Regulation, Contingency Reserve, RoCoF Control Service) under high renewables penetration scenarios

4.2.2 Transient and oscillatory stability

This section covers actions related to the ability of the power system to remain stable and in synchronism when subject to small (oscillatory stability) and large disturbances (transient stability)[32]. This requires the presence of synchronising torque and damping torque, historically provided by synchronous generators.

Additionally, for a high renewables system, this requires sufficient system strength to ensure new oscillation modes associated with the stability of IBR are managed, see section 4.2.3.

AEMO is working in collaboration with Western Power to better understand the identification and mitigation of challenges relating to stability as the composition of the SWIS generation fleet changes. This work is informed by long-term planning studies, including the SWIS Demand Assessment in terms of the forecast composition and distribution of new renewables and storage.

Table 4 Identified preconditions and associated challenges – Transient and oscillatory stability

Preconditions	Current and emerging challenges
Appropriate stability limits in place for projected reductions in operation of synchronous generators	• Reducing synchronising torque and inertia with reduced operation of synchronous generators. – Uncertain impact of reducing inertia on transient stability limits. – Unknown transfer limits at 100% renewables
Appropriately damped power system oscillations	• Reducing damping torque with less synchronous generation online and changing network topology with VRE development. – Small signal oscillation modes will change as the system topology, inertia and control systems evolve. – Ongoing oscillations following a large contingency event could be inadequately damped • Root cause of oscillatory modes not well understood in SWIS

[32] See https://www.wa.gov.au/system/files/2023-04/WEM%20Procedure%20-%20Power%20System%20Security%20-%20Consultation%20-%20EXTERNAL.pdf

Figure 7 Actions to achieve identified preconditions - Transient and oscillatory stability

Preconditions	In-progress	Future Actions		
Appropriate stability limits in place for projected reductions in operation of synchronous machines		Studies to validate stability constraints for reducing inertia scenarios as synchronous fossil fuel units decommit/exit and identify any new stability limits that might arise, in collaboration with Western Power		Establish processes to address new stability issues as they are identified
Appropriately damped system oscillations		Uplift modelling techniques to assess power system oscillations in high IBR system configurations	Assess power system oscillations for future system configurations, including any specific remediation schemes, in collaboration with Western Power	Establish processes to remediate issues in the management of power system oscillations as they are identified

4.2.3 System strength and converter driven stability

System strength can be characterised as:

- maintaining sufficient fault current contribution to ensure correct operation of protection systems.
- the ability of a power system to withstand changes in generation output and load levels while maintaining a stable voltage waveform. This includes the ability of the power system to both remain stable under normal conditions and return to steady-state conditions following a disturbance.

Synchronous generation has historically provided the bulk of system strength in the SWIS as a byproduct of operation. However, many of these synchronous generating units (typically coal and gas generators) are being decommitted, and in the case of the Synergy coal-fired generation fleet, progressively retired. As such, maintaining system strength through alternative means will become an increasingly critical precondition in enabling the energy transition in Western Australia.

In 2020, "converter driven stability" was added by the IEEE Power system Dynamic Performance Committee as a new stability class to account for the faster, more complex dynamics arising from IBR[33]. The impacts of system strength on converter driven stability in the SWIS are yet to be fully characterised; however, early identification and management is essential for enabling a future with high IBR as a stable voltage waveform is critical to maintain operation of grid-following IBR (such as rooftop solar PV), particularly during system disturbances.

Table 5 identifies the preconditions necessary to enable the first periods of 100% instantaneous renewable penetration.

[33] Hatziargyriou, Nikos, et al., (2020), *Stability definitions and characterization of dynamic behaviour in systems with high penetration of power electronic interfaced technologies*, IEEE PES Technical Report PES-TR77, April.

Table 5 Identified preconditions and associated challenges – System strength and converter driven stability

Preconditions	Current and emerging challenges
System strength requirements met by alternatives to system configurations that require minimum loading on synchronous fossil fuel generators	• Reduction in system strength due to reduced operation of synchronous generation and connection of inverter based VRE and DER, impacting: – Stability of the voltage waveform in response to small changes, as well as during or after a fault. – Protection system maloperation or failure to operate. – Adverse interactions between several IBR or between IBR and the network. – Recovery from non-credible events. – Power quality and voltage unbalance. – Potential impact on connection and synchronisation of DER.

Figure 8 Actions to achieve identified preconditions – System strength and converter driven stability

Preconditions	In-progress	Future Actions
System strength requirements met by alternatives to system configurations that require minimum loading on synchronous fossil fuel generators	Develop System Strength framework in the WEM	Forecast System Strength needs in accordance with Power System Security Guideline to support forecast hosting capacity Identify minimum requirements for network operation Maintain system strength sufficient for hosting capacity and safe network operation Identify and progress opportunities for the conversion of suitable existing generating units to establish synchronous condenser capability Specify grid-forming inverter technology to support / provide system strength for the SWIS, building upon studies and trials conducted in the NEM Treatment of Grid-forming inverter projects in the connections process, consideration of any required process changes Develop metrics to quantify provision of system strength from grid forming IBRs, to enable consideration of such technologies as credible options in planning assessments, and utilisation in operational timeframes to meet system strength needs Develop framework and associated process to allow for collective retuning of plant to mitigate emergent issues Enhance AEMO control room situational awareness tools and look-ahead capability for system strength, including integration of Wide Area Monitoring capability (dependent on interface to Western Power owned PMU's.

4.2.4 Voltage control

Voltage control is the ability to manage reactive power in an AC power system to ensure network voltage levels meet a target voltage range. The target range is set out in the Western Power Technical Rules. Voltage control reflects the capability of generation and the network to serve the power demanded by loads and is constrained by maximum power transfer capability and voltage drop associated with power flow through inductive reactance in the network.

Adequate dynamic reactive reserves are maintained to ensure acceptable voltage outcomes across the system in the event of a contingency. Reserve requirements are sized based on prevailing system conditions and the severity of the critical contingency. Voltage instability can lead to cascading outage situations with loss of load or tripping of transmission lines and other network components through protection action, potentially triggering generator loss of synchronism and frequency instability.

Minimum fault levels are also required for voltage control to limit the step change in voltage following the switching of reactive plant. This is covered under the minimum fault level requirement under system strength and converter driven stability in Section 4.2.3.

Table 6 Identified preconditions and associated challenges – Voltage control

Preconditions	Current and emerging challenges
Sufficient steady state and dynamic reactive support to maintain reactive margins and voltage disturbances within limits, completely provided by non-fossil fuelled technologies	• Reduced synchronous generation operation. • Reducing dynamic reactive capability and system strength impacting voltage stability margins. • Reducing steady state voltage control.
Reactive support and voltage control for highly variable, long distance VRE power flows to load centres, and more variable daily demand profiles across networks	• VRE and Renewable Energy Hub development. – Reactive support requirements for increasing power transfers over long distances from VRE to load centres. • Larger, more variable intraday changes in the voltage profile due to changes VRE power flows, including changes in rooftop PV output due to cloud cover. With increasing renewables, the voltage profile will vary as a function of more frequent, less predictable weather changes (wind speed and solar irradiance), not just the typical daily load profile.

Figure 9 Actions to achieve identified preconditions – Voltage control

Preconditions	In-progress	Future Actions
Sufficient steady state and dynamic reactive support to maintain reactive margins and voltage disturbances within limits, completely provided by non-fossil fuel technologies		Plan and manage changing requirements for static and dynamic reactive power to address reduction in provision from synchronous fossil fuel generation Studies to assess impact of fossil fuel generation exit and decommitment on voltage stability limits Progressive updates to Western Power limit advice as the network evolves Establish sufficient inductive reactive margins for managing high voltages during light load periods, with ongoing reduction in minimum demand due to DPV uptake Establish mechanisms for ensuring sufficient reactive support during outage conditions Review requirements for available inverters to maintain reactive support during low generation periods Establish operational processes for utilising and coordinating reactive capability from IBRs Enable greater range of devices and approaches for VAr dispatch Studies to assess fault level requirements for avoiding excessive step changes in voltage due to switching of reactive plant, and adequate reactive reserve
Reactive support and voltage control for highly variable, long distance VRE power flows to load centres, and more variable daily demand profiles across networks		Conduct quasi dynamic studies over minutes-hours timescales to assess the impact of increasing variability of VRE, demand and power transfers, on intra-day voltage profiles Identify challenges to maintaining secure voltages over the minutes-hours timescale, and options for mitigation Update operational voltage control processes and tools to manage impact of increasing VRE and DPV variability on voltage control

4.2.5 System restoration

AEMO is responsible for the preparation and update of operational plans and contingencies to restart the SWIS in the event of a system shutdown. The WEM Rules require AEMO to have a System Restart Plan (SRP) that outlines the actions that AEMO, in coordination with Western Power, will take to prepare for restoration of the power system. Following a system black event, the system is to be restarted to achieve the target frequency of 50 Hz; deviations to this frequency during the restart process are to be managed by balancing the available supply with demand.

The original SRP was not designed for high rooftop PV penetration scenarios. However, high levels of rooftop PV create complexities for critical operational contingencies, such as a reduced number of feasible paths with stable blocks of loads that are vital for the operation of the large synchronous Black Start generators. Addressing these challenges requires a different approach to network operation than contemplated by the original SWIS design, which was predicated on forecastable demand with predictable generation on the transmission network[34].

In 2020 as part of the DER Roadmap program of work, AEMO reviewed its SRP and made two key updates – the establishment of pre-defined restart pathways and the prioritisation of the pathways with low rooftop PV generation. These changes would ensure greater certainty in the availability of stable blocks of loads. However, as more DER are installed, the level of installed DPV will reach a point where the current approach, although revised, is no longer viable without some extra capabilities or mechanisms to manage DER through the system restart process.

AEMO is currently investigating what strategies and initiatives national and international stakeholders are pursuing to develop confidence that the SWIS system restart process is manageable when there are few suitable restart pathways available.

Table 7 Identified preconditions and associated challenges – System restoration

Preconditions	Current and emerging challenges
Effective restart arrangements, plans, procedures in place for first 100% renewables period, including adequate system restart capable plant built in suitable locations	• Reduced availability of black start capable units as synchronous generation exits. – Limited selection of black start pathways following the decline of available black start resources. • New approaches will be needed to energise VRE centres in remote locations. – Increasing VRE connection in remote locations far from existing SRAS pathways.
Ability to maintain stable load blocks during the restart process	• Ongoing growth in DPV generation reducing the daytime availability of stable load blocks required for the system restoration process.

34 AEMO (2021) *Renewable Energy Integration-SWIS Update*. See https://aemo.com.au/-/media/files/electricity/wem/security_and_reliability/2021/renewable-energy-integration--swis-update.pdf?la=en

Figure 10 Actions to achieve identified preconditions – System restoration

Preconditions	In-progress	Future Actions
Effective restart arrangements, plans, procedures in place for first renewables dominated power system, including adequate system restart capable plant built in suitable locations	AEMO and Western Power to review relevant processes under the System restart plans and procedures, and appropriate investment signals	AEMO and Western Power to review relevant processes under the System restart plans and procedures, and appropriate investment signals
		Investigate and demonstrate new technology (such as emerging grid forming capability) to provide or assist in the restart process (and any limitations) through power system modelling and small-scale trials
		Define response behaviour from IBR required to be connected in the early stages of restart, on necessary capability required to operate their plant during restart
		Investigate need for new System Restart services to provide supporting capabilities (e.g. Voltage control) for primary system restart providers, including tests for that capability
Ability to maintain stable load blocks during the restart process		Progress operational processes for system restart that include of the active management of DER to assist in the restart during high DPV generation conditions.

4.3 Power system operability

System operability is the ability to securely and reliably operate the power system and transition through increasingly complex operating conditions. In terms of the transition to renewable energy sources, the operating conditions will be characterised by:

- Faster, more complex system dynamics with reducing inertia and stability outcomes that are increasingly determined by fast-acting IBR controls as synchronous generation operates less and less;
- Increasing impact of weather on the supply-demand balance and energy adequacy with increasing volumes of VRE and DPV;
- Increasingly decentralised operation through the ongoing uptake of DPV and other DER in the distribution network; and
- Changing system risk profile and underlying resilience of the system as the system topology and resource mix evolve.

Managing this complexity requires a step change in AEMO's current operational capability in planning, forecasting, monitoring, and situational awareness, reporting and analysis, and will necessitate new or additional capability, for example, in the control room.

4.3.1 Monitoring and situational awareness

As part of its power system security responsibilities, AEMO is required to monitor the operating status of the power system. This section covers the uplift required for appropriate control room awareness of system state and operational risk in the renewable transition. It covers actions that serve as prerequisites for several other Roadmap preconditions, as follows:

- High-speed monitoring to understand system stress and identify interactions and transient behaviour that cannot be easily detected through traditional SCADA, required for real time and look-ahead dynamic security assessment, online risk monitoring, power system model validation and post event root cause analysis;
- Fit-for-purpose weather monitoring required for operational forecasting;
- Operational coordination to establish visibility of increasing decentralised participation, required for state estimation, scheduling and dispatch.

Table 8 Identified preconditions and associated challenges – Monitoring and situational awareness

Preconditions	Current and emerging challenges
Sufficient weather monitoring to forecast plausible VRE generation output variability and uncertainty	• Greater reliance on VRE – Variability requiring greater visibility of forecasts and uncertainty.
Sufficient wide area visibility of power system performance and control room tools to leverage this data for real time stability monitoring and risk assessment	• Insufficient high-speed power system monitoring. • Limited ability to identify oscillations and other emerging forms of instability expected to emerge as the power system evolves.

Figure 11 Actions to achieve identified preconditions – Monitoring and situational awareness

Preconditions	In-progress	Future Actions
Sufficient weather monitoring to forecast plausible VRE generation output variability and uncertainty		Deploy new weather monitoring infrastructure to support participant and AEMO forecasting requirements for key network locations with high renewable penetration
Sufficient wide area visibility of power system performance and control room tools to leverage this data for real time stability monitoring and risk assessment		Western Power to establish SWIS-wide PMU coverage and sufficient supporting infrastructure for communication and processing of high-speed data Implement a Wide Area Monitoring System (WAMS) enabling time-synchronised monitoring of dynamic behaviour across the power system

4.3.2 Operational processes

This section of the Roadmap covers uplift required across key operational processes to securely and reliably operate the power system and manage new operating conditions as they emerge in the renewable transition. It sets out preconditions relating to operational processes required for scheduling and dispatching the power system, and to manage the secure technical envelope, including operational forecasting, outage coordination, constraints and dynamic security assessment, reserve management and operator training. Detailed information about these operational processes is provided in AEMO's WEM Procedures.

Table 9 Identified preconditions and associated challenges – Operational processes

Preconditions	Current and emerging challenges
Ability to operationally forecast energy adequacy and quantify VRE variability and uncertainty over different timeframes	• Current deterministic approach to operational forecasting focused mainly on capacity adequacy will not be adequate in a high renewable power system. • There is a limit to the accuracy of deterministic forecasts of weather-driven variability in the supply-demand balance, even using current best practice approaches • Increasing operational forecasting workload and pace of development required.
Ability to securely and reliably manage planned outages for maintenance and the augmentation required in the transition to 100% renewables	• Limited opportunities to schedule maintenance of key system elements due to their criticality for system security as margins reduce. • Increasingly complex studies and coordination required within and across regions in the outage planning process. • No framework in place to ensure required plant is online for system security during planned outages. Largely managed in an ad hoc manner.
Dynamic security assessment and contingency analysis capability across the range of stability phenomena – real-time and look-ahead	• Limited ability to identify and monitor stability issues in real time and diagnose root cause in order to mitigate issues. • Transient, voltage and small signal stability assessment tools in place. No frequency security tool in place. • Limited 'look ahead' capability for dynamic security assessment.
Significant uplift in industry training standards to ensure operator capability and sufficient training for new tools, procedures, and processes	• Any new operational tools and procedures required in the transition to 100% renewables operation will also require significant training to be undertaken

Figure 12 Actions to achieve identified preconditions – Operational processes

Preconditions	In-progress	Future Actions
Ability to operationally forecast energy adequacy and quantify VRE variability and uncertainty over different timeframes		Develop weather scenario driven load forecasting techniques to enable the uplift of the quantification and management of uncertainty, variability and risk. Shift from deterministic forecasts to probabilistic and consensus forecasting techniques to enable the quantification and management of uncertainty, variability and risk.
Ability to securely and reliably manage planned outages for maintenance and the augmentation required in the transition to 100% renewables		Develop enhanced tools and risk assessment approaches for outage assessment studies and improved coordination of Network and Facility outages.
Dynamic security assessment and contingency analysis capability across the range of stability phenomena – real-time and look-ahead		Develop Operational Simulator to undertake real-time EMT simulation capability for contingency analysis Investigate the use of look ahead Dynamic Security Assessment (DSA) capability across the range of system needs (including voltage, transient, small signal, frequency), accounting for risk and uncertainty over a variety of forward horizons Establish AEMO and Western Power control room tools to utilise PMU data for real time stability assessment, monitoring and situational awareness
Significant uplift in industry training standards to ensure operator capability and sufficient training for new tools, procedures and processes		AEMO control room and operational support staff require development and implementation of robust procedures and processes for the range of new operational tools and practices required in the transition to 100% renewables operation Training programs required for new procedures and processes, including delivery of plausible 100% renewables scenarios within AEMO's Operator Training Simulator, to assist with understanding and managing power system behaviour in normal and abnormal conditions

4.3.3 Power system modelling

Power system modelling is increasingly critical for AEMO, Western Power and Market Participants in navigating the energy transition. Power system modelling underpins the connection of new generation and loads, planning the system needs to operate the power system across a broadening range of operating conditions.

Current tools and capability are required to be uplifted, to allow AEMO and Western Power to effectively model future system outcomes across a range of operating conditions in a renewables dominated power system.

Table 10 Identified preconditions and associated challenges – Power system modelling

Preconditions	Current and emerging challenges
Models and data to establish confidence in the technical operating envelope of the power system under a range of plausible operating conditions	• Decline in model quality, while system operation becomes increasingly complex. • Greater uncertainty margins necessary to account for limited adequacy of available models.
Ability to saleably and accurately model a large number of scenarios in operational and planning timeframes	• Increasing reliance on complex dynamic models requiring greater ongoing efforts in model maintenance. • Largely manual study case development process for future system studies. Can take months to include augmentations and connections, and represent dispatch and demand conditions for different study snapshots. • Increasingly computationally-intensive studies. Limited high performance computing capability.
Future system studies to assess the secure technical envelope of the power system with reducing, and eventually no, synchronous generation online	• Limited understanding of likely system behaviour and performance under higher IBR penetration. • Existing approaches or knowledge no longer valid under significantly different future system conditions. • Increasing uncertainty and complexity in future system conditions that could lead to a broad range of system configurations.
Studies to develop limit advice and assess system adequacy in operational transition to first 100% periods	• Manual, resource intensive Electromagnetic transient (EMT) studies required in advance of real time operations. • Limits advice generally reviewed only when changes to network are made e.g. during generator connections. • Emerging critical operational transition points in transition to 100% renewables will require significant, concerted effort across Western Power and AEMO to enable operational transition.

Figure 13 Actions to achieve identified preconditions – Power system modelling

Preconditions	In-progress	Future Actions
Models and data to establish confidence in the technical operating envelope of the power system under a range of plausible operating conditions	Uplift AEMO processes and governance for managing power system data, models and tools AEMO and Western Power collaborate to establish and baseline power system data, model quality and model performance requirements. Develop and resource prioritised model uplift workplans	Collaborate with industry and market bodies to ensure acceptable model provision, quality and performance
Ability to scalably and accurately model a large number of scenarios in operational and planning timeframes	Assess and implement a streamlined approach to operational grid model management to facilitate a step change improvement in the speed and accuracy of study case development Develop and benchmark stability assessment methods and tools appropriate for assessing relevant power system phenomena in high IBR conditions	Develop processes and automated tools to enable fast and accurate application of any generator dispatch pattern or connection point demand forecast to study cases Assess high performance computing requirements for power system modelling, implement capability and establish efficient workflows across simulation tasks Develop a prioritised plan to address gaps in AEMO and Western Power capability to effectively model the phenomena that will need to be studied in the transition to 100% renewables
Future system studies to assess the secure technical envelope of the power system with reducing, and eventually no, synchronous fossil fuel generation online		Perform planning studies to determine operational transition points by assessing system security and operability issues with lower levels of synchronous generation Embed ongoing studies of potential future operational scenarios and events (critical outages, ramping events etc) into network planning process, through system security reports, connections studies, and ongoing joint planning activities Western Power studies to inform limit advice required for AEMO development of constraint sets and operational procedures Assess and validate of constraints with real-time stability assessment tools, and system events as they occur, as transition points are achieved
Studies to develop limit advice and assess system adequacy to enable operational transition to first 100% periods		Collaboration with Western Power to assess key high-impact, low-probability non-credible risks and establish mitigation measures Processes to monitor risk exposure, with 'roll back' measures in place if risk exceeds operational risk tolerance

4.4 Resource adequacy and capability

The SWIS will require sufficient energy resources and network capability if more renewable potential is to be unlocked, and also flexible capacity to balance variability over different timeframes. The SWIS will need:

- Available dispatchable capacity to transition in and out of periods with high levels of renewables.
- Energy adequacy before and after any period of 100% renewables penetration to minimise the amount of fossil fuelled generation that needs to be online to meet reserve requirements.

The SWIS Engineering Roadmap covers actions necessary to establish the bulk renewable energy, network capability, and resource flexibility necessary to enable this outcome, including:

- Building, connecting, and integrating the renewable energy required to reach 100% renewable resource potential for longer periods of the year (i.e. not just the minimum operational demand days), including utility-scale VRE and DER.
- Planning for structural demand shifts that could materially influence overall capacity and energy requirements, depending on the pace of end use electrification. This includes creating the required flexibility in demand to align with periods of high and low energy production from the VRE.
- Building and modernising network infrastructure, including transmission network capacity to transfer power from renewable generation centres to load centres, and distribution network capability to accommodate increasing DPV and other DER uptake.
- Dispatchable capacity to firm renewable generation variability and uncertainty over different timescales (minutes, hours, and days).

4.4.1 Utility-scale variable renewable energy

Utility-scale VRE in this context includes large-scale renewable generation participating in the WEM. Generating systems with intermittent output are generally classed as semi-scheduled facilities. Under this category AEMO or the Market Participant forecasts the wind and solar generation output and includes it as part of its central dispatch process.

Table 11 Identified preconditions and associated challenges – Utility-scale VRE

Preconditions	Current and emerging challenges
Connect and securely integrate increasing volumes of VRE	• 1.2 GW of VRE in the WEM today, SWIS Demand Assessment projects over 50 GW of VRE and storage in 2042.

Figure 14 Actions to achieve identified preconditions – Utility-scale VRE

Preconditions	In-progress	Future Actions
Connect and securely integrate increasing volumes of VRE	Development, construction, and connection of increasing volumes of new VRE generation	
		Develop whitelist register for OEM products such as inverters, generators, synchronous condensers, and power plant controllers
		Develop forecasts to transparently communicate opportunities for network access in the transmission network and Reserve Capacity Mechanism
		Ensure that valuation of capacity in the SWIS considers weather conditions at times of peak demand (including temperature)

4.4.2 Sufficiency of system needs (including ramping and reserves)

As power system reliability is increasingly dominated by renewables and duration limited (storage) technologies, AEMO's role in maintaining reliability will require new operational tools to ensure scheduling and dispatch of available resources to serve demand. These tools include visibility over the scheduling of energy (MWh) in addition to demand, across varying time horizons. It will be increasingly critical to message sufficiency in terms of probabilistic outcomes. These needs will include the forecasting ramping needs of the fleet, operationalising flexible capacity in the SWIS to ensure reserves are accessible to manage uncertainty of demand and generation.

Consideration must also be given to firming technologies such as gas-powered generation, as a critical supporting technology to manage longer-term shortfalls in renewable generation which may not be efficiently managed using storage. Studies to better establish the operational patterns of firming generation will allow risks and deficiencies in gas transport and storage to be identified. These studies will also identify the scope for alternative technologies and fuels, to offset gas consumption and further diversify the generation fleet.

Table 12 Identified preconditions and associated challenges – Ramping and Reserves

Preconditions	Current and emerging challenges
Sufficient monitoring and visibility tools required to manage Operation Demand ramping.	• Increasing operational demand ramping due to increasing penetration of uncontrolled DER. • Increasing volatility in grid-scale generation due to increasing penetration of VRE generation.
Sufficient energy reserves available to cover variability in Operation Demand occurring over multiple Dispatch Intervals.	• Increasing risk of extended unavailability of renewable resources, due to events such as dunkelflauten.
Identify and address any limitations on fuel supply to manage changing operational needs for firm-generation.	• Forecast changing role for firm generation in a renewables dominated power system. • The need to identify renewables sources of firm generation, including alternative fuels or technologies.
Sufficient fleet capability to meet all identified system needs	• Increasing uncertainty and complexity in identifying sufficiency of all system needs

Figure 15 Actions to achieve identified preconditions – Sufficiency of system needs (including ramping and reserves)

Preconditions	In-progress	Future Actions
Sufficient monitoring and visibility tools required to manage Operation Demand ramping.	Uplift ramping metrics and forecasting methodologies alongside a review of fleet capability and incentives	Implement forecasting methodologies (ST, MT, LT) for appropriate ramp durations Operator visibility of ramp capability of in-service and available fleet across relevant time horizons
Sufficient energy reserves available to cover variability in Operation Demand occurring over multiple Dispatch Intervals.		Establish appropriate resource adequacy assessment metrics to better reflect reliability risk, including risk due to lulls in wind and solar availability, in the transition from a primarily capacity-limited thermal power system to a more energy-limited, high renewable power system
Identify and address any limitations on fuel supply to manage changing operational needs for firm-generation.		Forecast peak utilisation of gas network and storage facilities against future utilization patterns for firm generation, review and identify any constraints which may limit future reliability. Assess technical and commercial risk of unexpected closure for changed role of firm generation in renewables dominated power system. Specify expected utilisation pattern for firm generation, identify alternative fuels and technologies against this requirement.
Sufficient fleet capability to meet all identified system needs	Develop framework to holistically assess all system needs and mechanisms to mitigate shortfalls.	

4.4.3 Distributed energy resources

DER are consumer-owned devices that can either use, generate or store electricity. DER is connected within the distribution system, which primarily serves homes and businesses. DER can include distributed photovoltaic (DPV – predominantly, rooftop solar PV generation systems), energy storage systems (storage), electric vehicles (EVs) and technology to flexibly manage loads (such as water heaters or pool pumps) at the premises[35].

DER may operate for the purpose of supplying the customer's electrical load and may also be capable of injecting power into the system. DER has traditionally been installed to serve consumer needs only, however, the opportunities to serve system and network needs at scale through aggregation is increasingly being explored. This concept would allow the value streams for consumer use-cases to be blended with market and network revenues to maximise both system benefit and financial benefit to DER owners, aggregators, and energy consumers. AEMO in collaboration with Synergy and Western Power undertook a pilot of DER aggregation under Project Symphony[36] to demonstrate the capability of DER to participate in market and network services.

The predominant form of DER in the SWIS is DPV generation. DPV is regularly the largest source of generation in the SWIS during daylight hours when there are clear sky conditions. DPV represented roughly 3 GW of installed capacity in 2024 and will continue to play a major role in the SWIS into the future. DPV installed capacity is forecast to grow to 6.5 GW by 2033-2034[37].

While significant opportunities exist for active participation of DER, the scale of uncontrolled DPV has led to several well documented challenges in the SWIS, including:

- Contributing to minimum operational demand conditions.
- DPV Tripping.
- Contributing to ramping events.

[35] Energy Policy WA (2020), *DER Orchestration Role & Responsibilities Information Paper*, May. See https://www.wa.gov.au/system/files/2022-07/DER%20Orchestration%20Roles%20and%20Responsibilities%20information%20Paper.pdf

[36] https://aemo.com.au/en/initiatives/major-programs/wa-der-program/project-symphony

[37] 2024 WEM ESOO, https://aemo.com.au/-/media/files/electricity/wem/planning_and_forecasting/esoo/2024/appendices-for-the-2024-wem-electricity-statement-of-opportunities.pdf?la=en

Information on the impacts of these challenges is discussed in Energy Policy WA's paper on Low Load Response[38], and have resulted in the introduction of emergency measures such as Emergency Solar Management (ESM)[39] and uplifts to the existing grid-connection standards (AS 4777.2: 2020)[40].

This section represents a confluence of in-flight and anticipated SWIS DER actions detailed in several existing publications, including the DER Roadmap[41], DER Roadmap progress reports[42], DER Orchestration Roles & Responsibilities Information Paper[43], as well as SWIS DER-related actions found in the Operations Technology Roadmap (OTR).[44] Other referenced initiatives include Project Symphony, the Common Smart Inverter Profile Australia (CSIP-AUS)[45] and Project Eagle[46].

[38] https://www.wa.gov.au/government/announcements/low-load-response-discussion-paper-released-managing-risks-power-system-security and https://www.wa.gov.au/system/files/2022-08/EPWA-SWIS%20Low%20Demand%20Project%20Stage%201.pdf

[39] https://www.wa.gov.au/organisation/energy-policy-wa/emergency-solar-management and https://aemo.com.au/initiatives/major-programs/wa-der-program/emergency-solar-management

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

[41] Energy Transformation Taskforce (2019), *Distributed Energy Resources Roadmap*, December. See https://www.wa.gov.au/government/distributed-energy-resources-roadmap

[42] Energy Policy WA (2021), *DER Roadmap Progress Report*, April. See https://www.brighterenergyfuture.wa.gov.au/wp-content/uploads/2021/05/EPWA_DER-Roadmap-progress-update_April2021.pdf; Energy Policy WA (2022), *DER Roadmap Two-year Progress Report*, April. See (https://www.wa.gov.au/system/files/2022-06/Distributed-Energy-Resources-Roadmap_second-year-update-WEB.pdf

[43] Energy Policy WA (2020), *CDER Orchestration Role & Responsibilities Information Paper*, May. See

[44] https://aemo.com.au/en/initiatives/major-programs/operations-technology-program/operations-technology-roadmap#:~:text=The%20OTR%20identifies%20the%20system,(G%2DPST)%20initiative.

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

[46] Energy Policy WA (2022), *Energy and Governance Legislation Reforms – Project Eagle – Information Paper,* December. See https://www.wa.gov.au/system/files/2023-01/Project%20Eagle%20Information%20Paper.pdf

Table 13 Identified preconditions and associated challenges – DER

Preconditions	Current and emerging challenges
Clearly defined operational roles and processes for managing system security and coordination with high DER penetration	• Increasing need for coordination across parties to manage system security during high DPV periods. – Operational challenges expected to emerge with increasing aggregation and coordination of DER and flexible demand in the distribution network.
Appropriate level of controllability for a proportion of the DER fleet	• DPV is an increasingly large source of generation where the bulk of the fleet cannot be curtailed, risking insecure operating conditions.
Sufficient visibility and predictability of DER behaviour	• Insufficient aggregate DER monitoring and visibility of residential DER behaviour accessible to Western Power and AEMO. • Insufficient AEMO operational visibility of larger commercial and industrial embedded DER in the distribution network. – Minimal AEMO visibility and understanding or price-responsive DER, orchestrated or coordinated by different parties and management systems.
Understanding of DER behaviour during disturbances quantified and managed	• Consumer DER adoption and usage decisions not always aligned with system needs. • Low uptake of demand response despite volume of flexible loads. • Limited participation pathways for DER to provide network and system services.

Figure 16 Actions to achieve identified preconditions – DER

Preconditions	In-progress	Future Actions
Clearly defined operational roles and processes for managing system security and coordination with high DER penetration	Establish roles and responsibilities between AEMO, the Network Operator, DSO and Participants for managing bulk power system security in a high DER future, and associated planning and operational processes	
	Establish clear roles and responsibilities across the energy sector for remote management of DER Equipment	
	Establish coordination architecture and processes for Participant-AEMO-DSO interactions required with increasing DER and flexible load management and aggregation	
Appropriate level of controllability for a proportion of the DER fleet		Expanding the Emergency Solar Management backstop mechanism to all relevant DPV (above 5 kVA not covered by SCADA)
	Enhance visibility and predictability of the amount (MW) of DPV capacity available for Emergency Solar Management, as well as estimation tools for the amount curtailed following an instruction	
	Establish operational tools to enable VPPs / DER Aggregators to integrate for the provision of contracted WEM Services (e.g. Supplementary Reserve Capacity)	
	Establish market arrangements for DER Aggregator registration and participation in central dispatch	
	Stakeholder engagement and education to facilitate development of industry capability to respond to wholesale market incentives using DER orchestration capabilities	
	Collaborate with EPWA, DSO and Aggregators to establish and implement minimum DER device requirements for interoperability (including electric vehicles [EVs])	
	Define an overarching strategy for implementing a cyber secure DER ecosystem aligned with AEMO's Cyber Security Posture	

Preconditions	In-progress	Future Actions
Sufficient visibility and predictability of DER behaviour		Enhance access to DER monitoring and forecasting information to improve capability over the long, medium, short, real-time timeframes to capture registered and unregistered DER
		Enhance DER standing data through the DER Register to include more forms of DER (e.g. controllable EV chargers / loads) and ensure data is supported by robust collection, and compliance arrangements implemented by key actors (e.g. DSO, retailers, Aggregators)
Understanding of DER behaviour during disturbances quantified and managed		Collaborate with Western Power to establish and implement roles and responsibilities and robust governance frameworks to support DER Equipment compliance
		Implement visibility arrangements for compliance that can identify non-compliant DER Equipment

4.4.4 Structural demand shifts

Structural demand shifts refer to changes to the types of load on the system, that have the potential to have major impacts on power system behaviour, due to their significant size of demand and/or unique performance behaviour. While not directly impacting the displacement of synchronous generation, many structural demand shifts are being driven by the same underlying desire to decarbonise, with electrification seen as a key enabler. Structural demand shifts can include new sources of loads owing to the electrification of various sectors – such as transportation, industry (through the replacement of fuels including gas) and residential (from gas heating, water heating and cooking) – as well as the introduction of new technologies such as from sector coupling (hydrogen electrolysers) and more flexible large industrial loads. The 2022 SWIS Demand Assessment projected 7.2 GW of new Large Industrial Loads will connect to the SWIS by 2042.

It is important that the performance standards of these new load connections keep up with their anticipated growth to ensure that they do no-harm, maintaining power system security as it transitions to higher penetrations of renewables. Simultaneously an opportunity is presented by these loads, where if integrated appropriately, they could provide support to renewables.

Table 14 Identified preconditions and associated challenges – Structural demand shifts

Preconditions	Current and emerging challenges
Fit for purpose performance requirements and connection processes for new loads, confidence in their operation during all operating conditions	• Managing significant volume of large load connections expected with end-use electrification. – Large volume of connection applications and proposals, many of which are IBR – including data centres and hydrogen electrolysers. • Performance of this plant could adversely impact power system stability, power quality and resilience: – Risk of increasing contingency sizes associated with unexpected disconnection of new large loads. – Stability impact of large load developments connecting in weak grid areas, far from generation centres. – Possible adverse interaction of large inverter based loads with other IBR leading to power system instability. – New large IBR loads may increase requirements for local system strength.
Planning for energy adequacy and flexibility requirements to consider possible structural demand shifts	• Increasing local and aggregated energy balance and power quality impacts from the sudden switching of larger domestic loads and DER devices. • Limited visibility of new load connections and understanding of their daily and seasonal profiles, including potential drivers in their behaviour. • Challenges in planning for structural reductions in load, from large industrial load closures or consumer grid defection.

Figure 17 Actions to achieve identified preconditions – Structural demand shifts

Preconditions	In-progress	Future Actions
Fit for purpose performance requirements and connection processes for new loads, confidence in their operation during all operating conditions	Define performance standards for EVSEs and their different charging configurations, to provide disturbance withstand, grid support and network connection requirements	
		Investigate application of performance requirements for new loads, implemented through connection processes
		Establish appropriate and efficient connection frameworks for new large loads to connect, considering potential adverse interactions with other IBR plant or impacts on power system stability
Planning for energy adequacy and flexibility requirements to consider possible structural demand shifts	Understand changing demand and daily and seasonal profiles of new loads and assess their impacts on resource adequacy and system flexibility	
		Improve visibility of evolving load categories and their associated behaviours, for use in both long-term and short-term forecasting
		Scenario planning to assess impacts on network resulting from events such as sudden load reductions, load closures, or consumer grid defection
		Coordination and stakeholder engagement to plan for new large loads and electrification, to ensure that energy adequacy and flexibility requirements can be met
		Investigate frameworks for loads to assist in meeting power system requirements, such as 'soak up' of excess VRE and DPV generation

4.4.5 Transmission

The transmission network will play a pivotal role in the transition to renewable energy in WA and is an enabler for unlocking the renewable generation potential of regions with high wind and solar resources. The SWIS Demand Assessment anticipates that over the next 20 years, over 4,000 km of new high-capacity transmission lines could be needed to meet industry's demand for greener energy[47]. The retirement or upgrade of aging transmission network assets will need to be managed while simultaneously overseeing the impacts from the retiring of coal-fired generation on the network. New transmission will need to be built to meet increasing demand from industries undergoing decarbonisation and the continued proliferation of electric vehicles.

Table 15 Identified preconditions and associated challenges – Transmission

Preconditions	Current and emerging challenges
Sufficient new or upgraded transmission built to enable renewable development and support system security	• Retirement or upgrade of various transmission assets reaching the end of life across multiple regions of the SWIS. • Protracted timeframes for planning assessment and project approval. • Deployment and project delivery risks due to supply chain issues and skills shortages. • Challenges in gaining social licence from local communities for new transmission.
Transmission planning efficiently enables secure and reliable system operation with progressively reduced numbers of synchronous generators online	• Transmission network impacts across multiple regions of the SWIS due to the retirement of coal-fired generation at the Muja and Collie power stations.
Resilient transmission network design and system performance outcomes	• Demand uncertainty around electrification of vehicles and the associated impacts on both the transmission and distribution network. • As power-system conditions change (such as changing generation mix), the possible events that may occur on the transmission system will change, without consideration these may cause significant risks, that could lead to cascading outages or major supply disruptions. • Enhancing protection schemes needs to keep up with the potential performance capabilities of new transmission infrastructure (such as grid forming IBR), otherwise there is a risk of sub-optimal affordability outcomes. • Limited ability to pre-emptively manage non-credible event risk in operational timeframes resulting in increasing reliance on special protection schemes. • Potential for increased continency sizes due to growing power transfers from VRE centres.

[47] 'Future Ready' scenario. See the full report: https://www.wa.gov.au/system/files/2023-05/swisda_report.pdf

Figure 18 Actions to achieve identified preconditions – Transmission

Preconditions	In-progress	Future Actions
Sufficient new or upgraded transmission built to enable renewable development and support system security	Urgently progress delivery of new transmission infrastructure identified as priority projects under the Whole of System Plan or related planning assessments	
Transmission planning efficiently enables secure and reliable system operation with progressively reduced numbers of synchronous generators online	Pre-emptive planning for earlier than expected changes in coal plant operation or large load closures	Coordinated planning for system requirements for anticipated key operational milestones with the progressive reduction in synchronous fossil fuel generation online, in the transition to 100% renewables operation
Resilient transmission network design and system performance outcomes		Undertake power system risk review of major risks, events, and conditions that could lead to cascading outages or major supply disruptions. Review the adequacy of current approaches to managing these risks and options for their future management AEMO and Western Power to consider through joint planning how a coordinated approach to network planning for resilience can be achieved

4.4.6 Distribution

Distribution networks will play a crucial role enabling the renewable transition by facilitating the entry and the integration of residential DPV and other DER in the low voltage (LV) networks, commercial and industrial generation and storage embedded in the LV/medium voltage (MV) network, and utility-scale plant in the sub-transmission network.

This section of the Roadmap is focussed on steps required to empower and enable the step change required in distribution network capability to allow Western Power to manage increasingly complex interactions within their networks, operational coordination with AEMO, and to eventually serve as a platform for system-level flexibility.

Table 16 Identified preconditions and associated challenges – Distribution

Preconditions	Current and emerging challenges
Network Preparedness	• Increasingly wide and complex range of operating conditions to consider in planning and operations. – DPV impact on LV network voltage profile, power flows and protection coordination. – Congestion in MV, HV sub-transmission networks due to larger, embedded DER and utility VRE connections. • Limited data and monitoring of LV network assets and customer DER behaviour. – Impacting ability to study and define operating envelopes and consider efficiently improve DER hosting capacity. • Defining and implementing distribution network limits for aggregated DER participation.

Figure 19 Actions to achieve identified preconditions – Distribution

Preconditions	In-progress	Future Actions
Distribution network Preparedness		Collaborate with DSO / Network Operator to develop and implement Distribution Network visibility arrangements to support system security and reliability in a high DER operating conditions
	Efficiently plan and manage network hosting capacity, both network and behind-the-meter strategies, to connect and integrate DER and VRE and enable consumer choice	Efficiently plan and manage network hosting capacity, both network and behind-the-meter strategies, to connect and integrate DER and VRE and enable consumer choice
	Assess impact of increasing DPV and DER on existing feeder protection schemes	Assess impact of increasing DPV and DER on existing feeder protection schemes
		Ensure the Network Operator establishes and requires adequate disturbance withstand performance standards for all unregistered generation and storage connections to the distribution network
		AEMO to establish effective performance standards for DER to provide WEM Services when aggregated

A1. WA State Government Reforms

The SWIS Engineering Roadmap builds on the significant effort and investments made under the Energy Transformation Strategy (ETS) and further reforms to facilitate the technical, operational, and planning requirements, and regulatory environment, needed to maintain system security as the SWIS transitions. The roadmap leverages this foundational work to identify the preconditions necessary to prepare the SWIS for renewables dominated power system operation.

A1.1 WA State Government transformation initiatives

A1.1.1 Energy Transformation Strategy (ETS)

On 6 March 2019, the Western Australian Minister for Energy announced the Energy Transformation Strategy (ETS)[48], which was designed to transform the governance, planning and management of the WA electricity supply as it transitioned to a lower-emissions future. An Energy Transformation Taskforce was established on 20 May 2019 to guide delivery of the reforms[49].

The ETS responded to many of the system security concerns raised by AEMO in its *Integrating Utility-scale Renewables and Distributed energy resources in the South West Interconnected System*[50] report (the 2019 AEMO report) which examined the challenges and opportunities from integrating utility-scale and small-scale renewables. The 2019 AEMO report acknowledged the critical role the ETS reforms would have in accommodating the uptake of utility-scale renewable generation, and in enabling AEMO to manage an effective response to increasing DER penetration and grid-connected renewable generation. It made seven key recommendations for keeping the power system secure based on the expected outlook of the drivers of power system security risk.

The program of work initiated under the ETS would later be extended to a second stage (from mid-2021[51] to 2025) that built on the achievements of the first stage 1 (see section A1.2). The focus of ETS Stage 2 is on completing the implementation of the Energy Transformation Taskforce decisions and 'keeping the lights on' while integrating new technologies and developing regulatory frameworks to support a low emissions future. ETS Stage 2 is being complemented by further reforms to wholesale market arrangements (see section A1.4).

A1.1.2 SWIS Demand Assessment

On 24 August 2022, the WA State Government announced the development of the SWIS Demand Assessment[52] to understand how electricity demand will likely change over the next two decades based on the needs of existing

48 https://www.wa.gov.au/government/media-statements/McGowan-Labor-Government/McGowan-Government-launches-Energy-Transformation-Strategy-20190306

49 https://www.wa.gov.au/organisation/energy-policy-wa/the-energy-transformation-taskforce

50 Integrating-Utility-scale-Renewables-and-DER-in-the-SWIS.pdf (aemo.com.au)

51 Energy-Transformation-Strategy-Stage2-July2021.pdf (www.wa.gov.au)

52 https://www.wa.gov.au/government/media-statements/McGowan-Labor-Government/Assessment-of-electricity-demand-to-inform-WA's-future-network-20220824

industrial users and due to investment in new industries. A Treasury-led Taskforce was formed and made a 'fast-tracked' assessment of future load growth and overall electricity demand. By building on the 2020 Whole of System Plan (WOSP – see section A1.2.2 below), the assessment sought to provide some early insights into industry decarbonisation ambitions that relied on additional renewable electricity in advance of the delivery of the next WOSP, scheduled for 2025[53].

In the short time available for the SWIS Demand Assessment, only the Future Ready scenario was modelled[54] to determine the optimal mix of renewable generation and storage needed to support the anticipated demand, and to identify what network augmentations would be needed[55]. The scenario, which considers the expansion and electrification of existing connections with a conservative estimate of hydrogen loads connecting during the 2030s reflects a credible representation of SWIS demand through to 2042. Consequently, the scenario anticipates that additional gas generation is required to firm the energy system given the expected significant increase in electricity demand.

The assessment leveraged AEMO's underlying demand forecasts, EV and DPV uptake projections developed by AEMO for the 2022 WEM ESOO and extrapolated these for the SWIS Demand Assessment study horizon[56]. The modelling assumed that long duration energy storage technology with a 10-hour duration would be available from 2030 and accommodated the closure of Synergy-owned, coal-fired generators in the SWIS (as publicly announced) in lieu of an explicit emission target.

The results of the SWIS Demand Assessment were publicly released on 9 May 2023. It was found that:

- Western Australia's main transmission network would need to grow significantly to meet industrial demand;
- around 4,000 km of new transmission will be required;
- approximately 50 GW of new renewable electricity generation (predominantly large-scale wind and solar) and storage infrastructure would be required; and
- the establishment of renewable generation hubs beyond the existing SWIS could provide a cost-effective means of maximising the renewable electricity generated to meet industrial customers' demand.

The WA Government has committed to over $324 million of funding to commence delivery of the first stage of network investments the SWIS Demand Assessment had identified as being needed over the following five years. It also announced a potential package of reforms to the Reserve Capacity Mechanism (RCM) aimed at enhancing investment certainty for renewable generation and storage in the SWIS[57] (see section A1.3.1 below).

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[53] The next WOSP must be delivered by 30 September 2025 at the latest. See https://www.wa.gov.au/government/document-collections/whole-of-system-plan

[54] Four SWIS Demand Assessment scenarios were developed in total: Extreme Growth - All load growth put forward by proponents occurs, applying the highest load and most ambitious timing assumptions; High Growth - All expansion and electrification of existing and new connections put forward by proponents occurs, including rapid connection of hydrogen production loads; Future Ready - Includes expansion and electrification of existing connections plus a more conservative estimate of hydrogen loads connecting during the 2030s (assumes additional growth in hydrogen production is not SWIS connected; and, Base - Load growth is limited to expansion of existing loads and electrification of existing connections. See SWIS Demand Assessment 2023 to 2042 (www.wa.gov.au), p.5.

[55] The distribution network was not included as part of the assessment. To view the SWIS Demand Assessment, see https://www.wa.gov.au/government/document-collections/swis-demand-assessment

[56] The SWS Demand Assessment did not explore household participation though Virtual Power Plants (VPP) or Vehicle to Grid (V2G).

[57] https://www.wa.gov.au/government/document-collections/swis-demand-assessment#:~:text=Introducing%20emission%20thresholds%20for%20existing,receive%20reserve%20capacity%20credits%2Frevenues.

A1.1.3 Low Demand Project

EPWA convened a project team comprising EPWA, Western Power and AEMO staff to assess and quantify risks to power system security in the SWIS during periods of low operational demand. In June 2022, EPWA published the *Low Load Project Stage 1 Report*[58]. The following technical challenges were identified and investigated in detail:

- Maintaining frequency stability after system disturbances, particularly as minimum operational demand periods also represent low system inertia conditions, while contingency sizes can remain large due to DPV disconnection after network disturbances;
- Managing sufficient reactive power management / voltage control;
- Maintaining adequate ramping capability;
- Managing system strength; and
- Maintaining UFLS levels.

An outcome of the Low Load Project was to establish the concept of a minimum demand threshold (MDT) to allow for operational coordination and management of minimum operational demand events.

A1.1.4 Coal retirement planning

On 14 June 2022, the WA Government announced the retirement of WA's State-owned coal-fired generation by 2030[59]. This included, in addition to the retirement of Muja C Unit 5 later that year, the retirement of Muja C Unit 6 in October 2024 (rescheduled to April 2025 in response to the 2023 WEM ESOO forecasts[60]), the Collie Power Station in late-2027 and Muja D in late-2029[61]. The retirement of State-owned coal-fired generation is a driving force for the Energy Transformation Strategy, incentivising new lower-emissions technologies to connect.[62]

The retirement of State-owned facilities driven by government policies is also necessitated by the uptake of solar rooftop PV systems with consequent changes to generation profiles of coal-fired generation. The managed transition to the greater use of renewables[63] is expected to reduce the WA Government's carbon emissions by 80 per cent by 2030; this includes a 40 per cent emissions reduction on the SWIS compared to 2020-21 levels[64].

A1.1.5 Electric Vehicle (EV) Strategy

On 27 November 2020, the WA State Government published the *State Electric Vehicle Strategy for Western Australia*[65], which encompasses battery electric vehicles, plug-in hybrid electric vehicles and hydrogen fuel cell

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[58] https://www.wa.gov.au/system/files/2022-08/EPWA-SWIS%20Low%20Demand%20Project%20Stage%201.pdf

[59] https://www.wa.gov.au/government/media-statements/McGowan-Labor-Government/State-owned-coal-power-stations-to-be-retired-by-2030-20220614

[60] Unit 6 will be placed on reserve outage mode from 1 October 2024 until 1 April 2025, so it is available over the Summer 2024-25 high demand period, helping to ensure system security is maintained. See https://www.wa.gov.au/government/media-statements/Cook-Labor-Government/Muja-C-Unit-6-in-reserve-mode-and-online-for-summer-2024-25-20230817

[61] https://www.wa.gov.au/government/media-statements/McGowan-Labor-Government/State-owned-coal-power-stations-to-be-retired-by-2030-20220614

[62] https://www.wa.gov.au/system/files/2021-07/Energy-Transformation-Strategy-Stage2-July2021.pdf

[63] https://www.wa.gov.au/government/media-statements/McGowan-Labor-Government/State-owned-coal-power-stations-to-be-retired-by-2030-20220614

[64] https://www.wa.gov.au/government/announcements/state-owned-coal-power-stations-be-retired-2030-move-towards-renewable-energy#:~:text=Massive%20uptake%20of%20rooftop%20solar,supply%20and%20improving%20system%20security.

[65] https://www.wa.gov.au/service/environment/environment-information-services/electric-vehicle-strategy

electric vehicles, to prepare WA's transition to low and zero-emission electric vehicles (EVs). The strategy includes the following initiatives:

- the creation of an electric vehicle charging infrastructure network at 49 locations across WA, to be fully operational by January 2024;
- achieving a minimum 25 per cent electric vehicle target for new light and small passenger, and small and medium SUV government fleet vehicles by 2025-26;
- developing and updating standards, guidelines, and planning approvals; and
- improving levels of stakeholder awareness and knowledge.

A1.1.6 WA Renewable Hydrogen Strategy

In July 2019 the WA State Government launched the WA Renewable Hydrogen Strategy aimed at developing domestic production capabilities, expertise, and applications of renewable hydrogen, and to enable WA to become a major exporter of renewable hydrogen while contributing to decarbonisation. The WA Renewable Hydrogen Roadmap[66] is the action plan to deliver the strategy's identified goals, which are to be achieved by 2022 and 2030 in four strategic areas. The goals for 2022 in all four strategic areas have been achieved[67] and work continues to deliver the goals for 2030, as summarised in Figure 18.

Table 17 WA Renewable Hydrogen Strategy goals and achievements

Strategic area	By 2022	2022 achievement	By 2030
Export	A project is approved to export renewable hydrogen from WA	Yuri Renewable Hydrogen to Ammonia Project received project approval in 2022 (scheduled for completion in 2024)	WA to have a market share in global hydrogen exports similar to its share in LNG
Remote applications	Renewable hydrogen is being used in one remote location in WA	Horizon Power has commissioned the Denham Hydrogen Demonstration Plant	Renewable hydrogen is widely used in mining haulage vehicles
Hydrogen blending in natural gas network	Renewable hydrogen is distributed in a WA gas network	ATCO is injecting hydrogen blends into a portion of its natural gas distribution network	Demand stimulation measures which could include a broader renewable hydrogen target and certification scheme
Transport	A refuelling facility for hydrogen vehicles is available in WA	WA's first Hydrogen Refuelling Station (located at ATCO's Jandakot Operations Centre) is now in operation	Renewable hydrogen is a significant fuel source for transportation in regional Western Australia

A1.2 Energy Transformation Strategy (ETS) Stage 1

Core to the delivery of ETS Stage 1 was the development of frameworks to modernise wholesale electricity market arrangements and enhance power system security and reliability. Other core initiatives included the publication of

[66] https://www.wa.gov.au/system/files/2020-12/Western%20Australian%20Renewable%20Hydrogen%20Roadmap%20-%20November%202020.pdf

[67] https://www.wa.gov.au/system/files/2022-12/221205_Hydrogen_MissionUpdate_DIGITAL.pdf

the first Whole of System Plan (WOSP) and the DER Roadmap along with a program of work to integrate DER (particularly DPV systems), battery storage and new technologies such as electric vehicles (EVs) into the SWIS. Western Power's commercial, regulatory, and technical framework have been reformed to improve access to Western Power's network by all generation types (including large renewable generators and energy storage).

A1.2.1 Wholesale Electricity Market (WEM) Reform

The ETS focused on eight interlinked actions to deliver the power system and market of the future, which have substantially commenced as of 1 October 2023.

- New Generator Performance Standards, which have been in place since 1 February 2021, to help maintain power system security and reliability, and provide for the equitable treatment of new and legacy generators;
- Redesigned Essential System Services (ESS) to ensure their efficacy in addressing the characteristics of the changing SWIS generation mix and low daytime system load resulting from the rapid uptake of rooftop solar PV systems;
- Common reliability standards, and governance and regulatory arrangements for these standards, to better integrate the different elements of planning and operating the SWIS (and further progressed under Project Eagle);
- Reformed regulatory architecture and governance arrangements that clearly articulate roles and responsibilities and remove the gaps, duplication and inconsistency that has arisen over time (and further progressed under Project Eagle);
- The introduction of Security-Constrained Economic Dispatch (SCED) to enable the dispatch of generators around network constraints and to enable co-optimised dispatch across energy and ESS markets.
- Making changes to Reserve Capacity Mechanism (RCM) to reflect constrained network access in the assignment of capacity credits and to ensure the contractual obligations of facilities to provide capacity is reflected and locational signals are provided to new facilities;
- The adoption of facility bidding by Synergy (as a move away from portfolio bidding) for improved price transparency and better constraint management; and
- Introducing measures to mitigate the exercise of market power that may arise from the reformed market arrangements and to ensure efficient market outcomes.

The scope of the ETS also implemented some initial reforms to the governance and institutional arrangements of the WA electricity system. Further governance reforms are being undertaken as part of ETS Stage 2 under Project Eagle[68].

A1.2.2 Whole of System Plan (WOSP)

The inaugural WOSP report[69] was released by the Energy Transformation Taskforce in October 2020 to facilitate system planning by providing an informed view on the likely evolution of the SWIS and WEM from 2020 to 2040 based on data provided by industry. The WOSP modelled four scenarios that considered how changes in demand,

68 https://www.wa.gov.au/government/document-collections/energy-and-governance-legislation-reform

69 https://www.wa.gov.au/system/files/2020-11/Whole%20of%20System%20Plan_Report.pdf

technology and the economy might affect the use of electricity and guide investments to achieve lowest-cost, lower-emissions electricity. It considered the contribution that efficient investments in renewable generation and energy storage can make to the SWIS's transition to a secure and reliable lower-emissions power system.

Amendments made to the WEM Rules[70] and the Electricity Networks Access Code (ENAC)[71] established, respectively, an ongoing requirement for the publication of the Whole of System Plan (WOSP) by the Coordinator of Energy and a streamlined regulatory approach to the timely delivery of any 'priority projects' identified by the WOSP needed to support ETS delivery. Although the inaugural WOSP did not identify any large-scale transmission network related projects as 'priority projects', it did provide visibility on the changes experienced in the SWIS and the likely evolution of the SWIS to 2040[72].

Some of the other key findings reported in the WOSP include the following:

- The SWIS already had a strong mix of renewables and that under all four modelling scenarios, over 70% of generation capacity will be renewable by 2040.
- Rooftop solar PV will continue to displace other forms of generation, particularly coal-fired generation, with coal generation declining under all four scenarios.
- Growth in renewables supported by firming from storage and gas facilities.
- There is opportunity for storage and renewables to provide ESS, and revenue streams for generation will become more diverse as the new ESS and RCM arrangements are embedded.

The next WOSP is due for delivery in 2025.

A1.2.3 Transmission System Plan (TSP)

As part of the WEM reforms, a WEM Rules amendment commencing on 1 February 2021[73] required Western Power to develop and publish a Transmission System Plan (TSP) in conjunction with its Network Opportunities Map. The TSP must establish a plan for the efficient development of a transmission system for a planning horizon of at least 10 years, achieve the requirements for power system security and reliability and facilitate the long-term interests of consumers. The analysis for the TSP must be developed in consultation with AEMO and the Coordinator of Energy, and must include WEM-related impacts that have arisen from the condition of the network. Importantly, the TSP must provide a set of investment options (network and non-network solutions) for developing the transmission system. Western Power published its inaugural TSP on 1 February 2023[74].

The 2023 TSP[75] noted demand uncertainty had increased markedly, driven by energy policy, weather, and technology changes, and by network customers using the network as a platform to choose how they wanted their electricity to be supplied and delivered. It acknowledged that high growth in DPV connections was driving lower SWIS minimum operational demand, and that this presented high risks for planning and operating the

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[70] On 1 July 2021.

[71] On 18 September 2020.

[72] https://www.brighterenergyfuture.wa.gov.au/wp-content/uploads/2020/10/2797_WOSP.V14.web_.pdf

[73] Clause 2.2C.1(bC) and Chapter 4.5B of the WEM Rules.

[74] https://www.westernpower.com.au/siteassets/documents/tenders/transmission-system-plan-tsp-2022.pdf

[75] https://www.westernpower.com.au/siteassets/documents/transmission-system-plan-2023-20230929.pdf

transmission network over the short- to medium- term. Other emerging trends and issues noted by the 2023 TSP were:

- The connection of renewable energy projects in viable regions would likely drive transmission expansion into new locations in the SWIS;
- Opportunities existed to connect large-scale generation and new large loads to the 330kV network (however, network augmentation may be required to facilitate some new customer connections);
- Although the growth in system peak demand is relatively low, some areas within the East Region, South Region and Metro South Region remain constrained during peak demand conditions[76].

Notably, the 2023 TSP advised of the targeted actions Western Power was taking to address voltage, reliability, and power quality issues during periods of low operational demand, particularly during daytime periods of high rooftop PV output. These include protection upgrade works, temporary and longer-term solutions to improve UFLS operation, the installation of a dynamic UFLS management system and the installation of load banks at various metro region substations[77]. It also flagged a potential network opportunity and solution to address minimum operational demand and network constraints via a project that aimed at increasing or shifting demand patterns between 10 AM to 3 PM, at all times of the year but particularly during the high-risk spring and autumn periods[78].

A1.2.4 WA Distributed Energy Resources (DER) Roadmap

In April 2020, the WA Government published the DER Roadmap to guide the path to a future where DER is integral to the safe, reliable, and efficient operation of the electricity system, and where the full capabilities of DER can provide benefits and value to all customers[79]. The roadmap sets out the key actions required over a five-year period to manage the energy transition and is a major pillar in the Energy Transformation Strategy[80].

The implementation of the roadmap has required extensive collaboration, and AEMO is currently engaging with the WA Government, Western Power, Synergy, other Market Participants, and industry to implement AEMO's priorities under the WA DER Roadmap work program[81].

Key among AEMO's priorities is the delivery of Project Symphony, a trial involving the orchestration of 900 DER assets across 500 households and businesses into a Virtual Power Plant (VPP) of up to 9 MW of capacity[82]. Project Symphony was foundational in that it demonstrated options for the requirements and role of, AEMO's future distribution market operations in the WEM and the SWIS. It also includes the piloting of platforms and systems to facilitate the integration that is needed to give DER Aggregators the capability to provide services to the WEM as

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[76] Western Power is progressing several projects to alleviate constraints and provide flexibility to facilitate higher utilisation levels. See https://www.westernpower.com.au/siteassets/documents/transmission-system-plan-2023-20230929.pdf , p.2.

[77] https://www.westernpower.com.au/siteassets/documents/transmission-system-plan-2023-20230929.pdf See p.116.

[78] https://www.westernpower.com.au/siteassets/documents/transmission-system-plan-2023-20230929.pdf See p.116.

[79] The DER Roadmap Progress Report and the DER Roadmap Two-Year Progress Report can be found at https://www.wa.gov.au/government/distributed-energy-resources-roadmap

[80] https://www.wa.gov.au/government/publications/der-roadmap

[81] https://aemo.com.au/en/initiatives/major-programs/wa-der-program/about-the-wa-der-program

[82] https://aemo.com.au/initiatives/major-programs/wa-der-program/about-the-wa-der-program

well as the network. Project Symphony concluded in September 2023[83]; insights from the trial will help inform the detailed design of arrangements for DER's participation in the market and power system.

Other AEMO priorities include:

- Technology integration:
  - In February 2022, AEMO and its implementation partners (the WA Government, Western Power, and Synergy) delivered the Emergency Solar Management (ESM) initiative, a last resort measure to support power system security.
  - AEMO has developed a dynamic power system model to more accurately model DER behaviour, which is now operational;
  - AEMO completed its analysis of the risk associated with poor compliance rates of DER equipment with DER standards and connections. The AS/ANZ 4777.2 compliance report was published on 27 April 2023.
  - AEMO is developing tools to better understand DER behaviour and uplifting AEMO's foundational capabilities to forecast, plan and operate a secure and reliable power system with high levels of DER penetration. This enhanced capability is being applied to under-frequency load shedding and system restart arrangements.
- WA DER Register enhancement:
  - In April 2021, AEMO expanded the DER Register to include data on small generating units;
  - AEMO is working with its implementation partner (Western Power) to improve the integrity of the DER Register data set and to further expand the DER Register to include data on Electric Vehicles (EVs).
- DER Participation:
  - In September 2022, AEMO published the *VPP Visibility Guideline* as part of its proposed design for a Visibility Framework to facilitate the off-market participation of aggregations of DER acting as Virtual Power Plants (VPPs)[84].
  - AEMO is working with implementation partners (WA Government, Western Power, and Synergy) to identify the regulatory and market development requirements to enable DER and aggregations of DER to participate in the SWIS and WEM.

The DER Roadmap program of work is scheduled for completion in 2025, with work continuing alongside (and enabled by) the Project Eagle reforms under ETS Stage 2[85]. The most recent progress update on the DER Roadmap was published in August 2024[86].

[83] https://arena.gov.au/knowledge-bank/project-symphony-end-of-project-assessment/

[84] https://aemo.com.au/consultations/current-and-closed-consultations/proposed-design-for-a-visibility-framework

[85] https://www.wa.gov.au/system/files/2023-01/Project%20Eagle%20Information%20Paper.pdf

[86] https://www.wa.gov.au/government/publications/distributed-energy-resources-roadmap-third-progress-report

A1.3 Energy Transformation Strategy (ETS) Stage 2

On 14 July 2021, the Minister for Energy launched Stage 2 of the ETS that are to be delivered over 2021 to 2025. Stage 2 initiatives are aligned to four distinct themes[87] that build on, or complete, work undertaken in Stage 1 to facilitate the ongoing energy transition and reduce carbon emissions:

- Implementing the Energy Transformation Taskforce decisions:
  - Completing DER Roadmap activities;
  - Developing the next WOSP;
  - Completing WEM Reform activities; and
- Integrating new technology into the power system:
  - Continuing technology trials;
  - Preparing for EVs as part of the State Electric Vehicle Strategy for Western Australia[88];
  - Developing tariffs that support investment in new technologies; and
- Keeping the lights on as the power system transitions:
  - Continue to modernise contingency planning and management arrangements;
  - Review and update the Reserve Capacity Mechanism (RCM);
  - Continue planning for and managing coal-fired generation retirements; and
- Regulating for the future (Project Eagle):
  - Establishing a governance framework that will facilitate the energy transition;
  - Reforming regulatory arrangements to better manage power system security and reliability.

A1.3.1 Reserve Capacity Mechanism (RCM) Review

A review of the Reserve Capacity Mechanism (RCM) has been conducted by the Coordinator of Energy in three stages over 2022 and 2023. Stage 1 focused on the definition of reliability and the characteristics of the capacity needed in future years and identified among other things the new RCM products needed to maintain supply reliability[89].

Importantly, the review recommended the introduction of a new 'flexibility capacity product' to incentivise flexible capacity that can start, ramp, and stop quickly, which will operate alongside the existing peak capacity product. Flexible capacity will be procured in the 2025 Capacity Cyle for the 2027-28 Capacity Year[90].

Analysis undertaken for the RCM Review also showed that there will likely be sufficient renewable energy to provide supply during the middle of the day. However, as the peak flattens and extends with uptake of EVs, more

[87] https://www.wa.gov.au/system/files/2021-07/Energy-Transformation-Strategy-Stage2-July2021.pdf

[88] https://www.wa.gov.au/service/environment/environment-information-services/electric-vehicle-strategy

[89] https://www.wa.gov.au/government/document-collections/reserve-capacity-mechanism-review#:~:text=The%20Coordinator%20of%20Energy%20is%20undertaking%20a%20review%20of%20the,15%20of%20the%20WEM%20Rules

[90] https://www.wa.gov.au/system/files/2023-05/epwa_reserve_capacity_mechanism_review_information_and_consultation_paper.pdf. See p.30.

firm capacity will be needed overnight. The reviews of system stress modelling showed that, after 2030, firm capacity duration increases as a larger proportion of demand is met by duration limited resources (including storage) to meet the overnight load during the 'duration gap'.

In acknowledgement that facilities with firm availability provide a greater contribution to system reliability than facilities with lower availability[91], the review introduced the following duration requirements to be applied to the three new Capability Classes[92]:

- **Capability Class 1**: a firm capacity that is not energy limited, such as a gas-fired facility that meets the fuel availability requirements.
- **Capability Class 2**: is firm capacity with energy or availability limitations, such as a battery, pumped hydro, Demand Side Programmes, or a gas-fired facility with limited fuel supply.
- **Capability Class 3**: is non-firm capacity, such as a wind or solar farm with no associated firming capability.

The rules developed as part of the review include a requirement for AEMO to forecast the availability duration gap based on the capacity of the duration limited resources in the fleet and forecast demand. This duration gap, published in the ESOO along with forecasts for subsequent years will set the duration requirements for new entrant duration-limited technologies in Capability Class 2, for which that entrant will continue to be assessed for 5-years (in consideration of investment certainty).

A1.3.2 Energy and Governance Legislative Reforms

The Energy and Governance Legislative Reforms, otherwise known as Project Eagle, will deliver a fit-for-purpose regulatory solution to address the limitations of the existing legislative and governance arrangements of the WA electricity system by building on initial ETS Stage 1 reforms[93]. The ongoing regulatory reforms reflect the need for a regulatory framework that can facilitate a well-managed transition to a decarbonised energy sector in a way that promotes the long-term interests of consumers. To do this, amendments to the Electricity Industry Act 2004 (EI Act) are necessary to enable a regulatory solution that will provide flexibility to manage power system's response to existing and emerging challenges while maintaining power system security.

The amendments will[94]:

- Build upon the introduction of an overarching State Electricity Objective (SEO) in the EI Act to replace the Wholesale Electricity Market Objective. The drafting of the SEO deliberately reflects the 'energy trilemma' of affordability, sustainability and reliability, which decision-makers must take into consideration and balance when applying the SEO to their decisions and actions.
- Expand the scope of the WEM Rules to address the matters that a range of other subordinate legislative instruments currently deal with, to enable better coordination on those matters through the removal of gaps and overlaps. In recognition of the scope expansion, the WEM Rules will be renamed the Electricity System

[91] Energy Policy WA (2022), *Reserve Capacity Mechanism: Information Paper (Stage 1) and Consultation Paper* (Stage2), 3 May, p.36 at https://www.wa.gov.au/system/files/2023-05/epwa_reserve_capacity_mechanism_review_information_and_consultation_paper.pdf

[92] Ibid., pp.34-26.

[93] https://www.wa.gov.au/government/document-collections/energy-and-governance-legislation-reform

[94] https://www.wa.gov.au/system/files/2023-05/epwabn_draft_consultation_paper_12_05_23.pdf

and Market Rules (ESMR). The ESMR will provide a more effective, end-to-end framework for governing and managing power system security and reliability.

- Provide heads-of-power to enable the regulation of distribution-related matters, address emerging challenges and implementation of arrangements for the integration of new technologies such as DER, microgrids, embedded networks and stand-alone power systems (SPS).

A draft of the SEO was released for comment in March 2023 and an Electricity Industry Amendment (Distributed energy resources) Bill 2023 passed through WA Parliament on 16 April 2024.

A1.4 Further reforms

A1.4.1 Demand-side Response (DSR) Review

A review of the WEM Rules in respect of the participation of Demand Side Response (DSR) is currently being conducted by the Coordinator of Energy, in consultation with the Market Advisory Committee (MAC)[95]. The role of DSR in the market is expected to become increasingly important due to the changing nature of the demand profile and increasing levels of renewables and DER generation as the SWIS transitions to a lower emission energy system.

At present, the direct participation of loads in the WEM is limited to its contribution to a Demand Side Programme (DSP) to provide load curtailment or as an Interruptible Load to support frequency control. However, as the energy system evolves, it is anticipated that new technologies will likely emerge that offer higher levels of load control and flexibility[96]:

- electrolysis for large-scale hydrogen production;
- electrification of metals and minerals processing;
- smart controls for commercial buildings;
- electric vehicles;
- behind the meter solar and battery storage; and
- orchestrated energy consumption devices.

The focus of the DSR Review was to ascertain what rule amendments will be needed to ensure that (under the reformed market arrangements), loads will receive adequate incentives to participate a wider range of market services and be appropriately compensated for providing them"[97]. WEM amending rules[98] have been released for industry consultation to enable:

- Changes to increase transparency of constrained access loads and treatment under the WEM Rules;
- Arrangements for hybrid facilities; and
- Implementing a dynamic baseline for DSP performance during dispatch and testing.

[95] https://www.wa.gov.au/government/document-collections/demand-side-response-review

[96] https://www.wa.gov.au/system/files/2023-03/DSR%20Review%20-%20Scope%20of%20Work.pdf See p.3.

[97] https://www.wa.gov.au/system/files/2023-03/DSR%20Review%20-%20Scope%20of%20Work.pdf See p.1.

[98] https://www.wa.gov.au/system/files/2024-03/dsrreviewamendingrules_0.pdf

A1.4.2 WEM Investment Certainty (WIC) Review

On 9 May 2023, the WA Government announced a package of further WEM reforms to address (among other things) issues recognised in the RCM Review, such as the need to enhance investment certainty for renewable generation and storage in the SWIS[99]. To this end a WEM Investment Certainty (WIC) Review would be undertaken under clause 2.2D.1 of the WEM Rules to give consideration to:

- Changing the Reserve Capacity Price curve to send a sharper signal for investment when demand for new capacity is stronger.
- Introducing a 10-year reserve capacity price guarantee for new technologies, including long-duration storage.
- Introducing a wholesale 'energy price guarantee' for renewable generators, to top-up their energy revenues. In return, renewable generators must firm up their capacity, for example, by signing bilateral contracts with storage facilities.
- Introducing emission thresholds into the WEM Rules for existing and new technologies in the WEM so that over time, only resources with emissions below these thresholds receive reserve capacity credits / revenues.
  - Existing gas facilities that qualify to provide the new flexible capacity product developed under the RCM Review will receive a 10-year exemption from the emission thresholds, to ensure an orderly transition and maintain reliability.

The MAC has established the WIC Working Group to undertake the WIC Review over 2023 and 2024, a consultation paper was released in July 2024[100].

[99] https://www.wa.gov.au/government/document-collections/swis-demand-assessment#:~:text=Introducing%20emission%20thresholds%20for%20existing,receive%20reserve%20capacity%20credits%2Frevenues.

[100] https://www.wa.gov.au/system/files/2024-07/the_wholesale_electricity_market_investment_certainty_review_initiatives_1_and2_consultation_paper.pdf

Glossary

Term	Definition
AEMO	Australian Energy Market Operator
DER	Distributed energy resources
DMO	Distribution Market Operator
DNSP	Distribution Network Service Provider
DPV	Distributed Photovoltaic, e.g. rooftop solar
DSM	Demand Side Management
DSO	Distribution System Operator
Electrical energy	Average electrical power over a time period, multiplied by the length of the time period.
Electrical power	Instantaneous rate at which electrical energy is consumed, generated, or transmitted.
ENAC	Electricity Networks Access Code
ESM	Emergency Solar Management
ESS	Essential System Services
ETS	Energy Transformation Strategy
EV	Electric Vehicle
EVSE	Electric Vehicle Storage Equipment
Firming capability	Firming capability can be dispatched to maintain balance on the power grid. It can include generation on the grid, storage, demand resources behind the meter, flexible demand, or flexible network capability.
Generating capacity	Amount of capacity (in megawatts (MW)) available for generation.
Generating unit	Power stations may be broken down into separate components known as generating units and may be considered separately in terms (for example) of dispatch, withdrawal, and maintenance.
IBR	Inverter based resource
Installed capacity	The generating capacity (in megawatts (MW)) of the following (for example): A single generating unit. A number of generating units of a particular type or in a particular area. All of the generating units in a region. Rooftop PV installed capacity is the total amount of cumulative rooftop PV capacity installed at any given time.
ISP	Integrated System Plan
Low Reserve Condition (LRC)	When AEMO considers that a region's reserve margin (calculated under 10% Probability of Exceedance (POE) scheduled and semi-scheduled maximum demand conditions) for the period being assessed is below the Reliability Standard.
maximum demand (MD)	Highest amount of electrical power delivered, or forecast to be delivered, over a defined period (day, week, month, season, or year) either at a connection point, or simultaneously at a defined set of connection points.
Mothballed	A generation unit that has been withdrawn from operation but may return to service at some point in the future.
NCESS	Non-co-optimised Essential System Service
NFIT	New Facility Investment Test
NOM	Network Opportunities Map

Term	Definition
Non-scheduled generation	Generation by a generating unit that is not scheduled by AEMO as part of the central dispatch process, and which has been classified as a non-scheduled generating unit in accordance with Chapter 2 of the NER.
Operational electrical consumption	The electrical energy supplied by scheduled, semi-scheduled, and significant non-scheduled generating units, less the electrical energy supplied by small non-scheduled generation.
OFGS	Over Frequency Generation Shedding
OTR	Operations Technology Roadmap
RCM	Reserve Capacity Mechanism
RCR	Reserve Capacity Requirement
SCADA	Supervisory Control and Data Acquisition
SCED	Security-Constrained Economic Dispatch
SRC	Supplementary Reserve Capacity
SWIS	South West Interconnected System
SWISDA	South West Interconnected System Demand Assessment
TNI	Transmission Node Identifier
TSP	Transmission System Plan
UFLS	Under Frequency Load Shedding
VPP	Virtual Power Plant
VRE	Variable renewable energy
WEM	Wholesale Electricity Market
WEM ESOO	Wholesale Electricity Market Electricity Statement of Opportunities
WOSP	Whole of System Plan