Renewable Integration Study

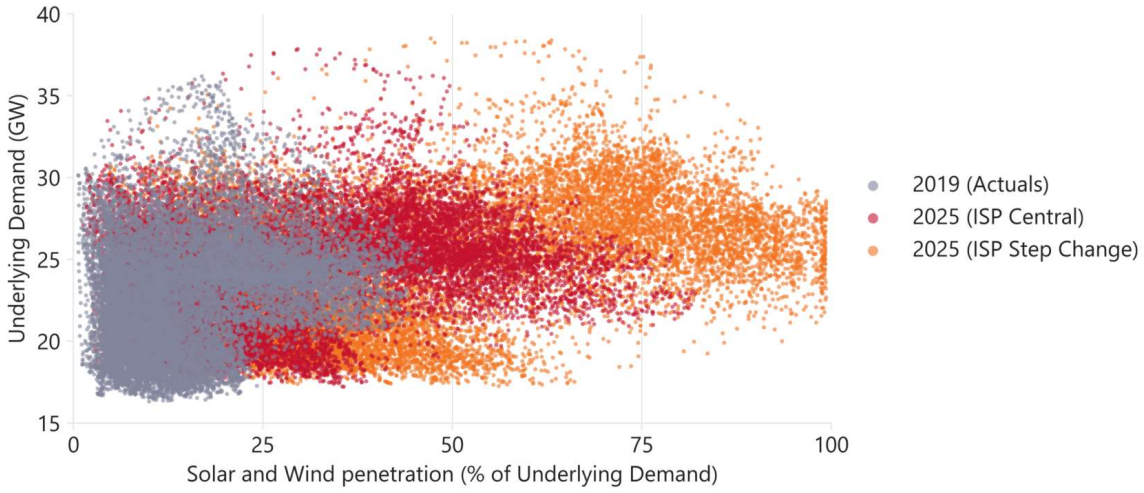
Instantaneous penetration summary graphic

*The **Renewable Integration Study (RIS)** is the first stage of a multi-year plan to maintain system security in a future National Electricity Market (NEM) with a high share of renewable resources. The RIS aims to explore system curtailment limits that impact wind and solar penetration in the NEM power system, specifically:*

- *Limits that affect how much wind and solar PV generation can operate at any one time, and what the limits are NEM-wide and for individual regions.*
- *How close NEM regions are to these limits now, and how close they are expected to be by 2025.*
- *Actions that can overcome these barriers so the system can operate securely with higher penetrations of wind and solar generation.*

The RIS's headline instantaneous penetration graphic summarises the changes out to 2025. This fact sheet provides an explanation on understanding this graphic and a range of frequently asked questions.

Figure 1 Instantaneous penetration of wind and solar generation, actual in 2019 and forecast for 2025 under ISP Central and Step Change generation builds



Note: Penetration on this graph represent NEM half-hourly wind and solar generation divided by the underlying demand which includes demand response, energy storage, and coupled sectors such as gas and the electrification of transport.

The penetration summary graphic

The NEM has undergone significant engineering and operational changes in the past decade as the proportion of wind and solar generation has increased. Key to understanding challenges of integrating wind and solar is obtaining a view of both the current and potential future states, which is summarised in Figure 1. This graphic is featured as Figure 1 (p6) and Figure 5 (p19) in the RIS Stage 1 Report.

What is instantaneous?

The instantaneous penetration of wind and solar refers to the proportion of underlying demand in the NEM that is supplied at any point in time by wind and solar. Typically, the instantaneous penetration of wind and solar is higher in the middle of the day when the sun is shining strongest, and lower in the night-time when only wind is able to generate.

Instantaneous penetration is different to the proportion of annual energy – the latter being the total contribution of wind and solar to all energy generated over the entire year. In 2019 the largest instantaneous penetration of wind and solar was ~50% of underlying demand, while the proportion of annual energy generated by wind and solar was ~16%.

Coloured dots

The different colours in Figure 1 represent different years. The actual observed instantaneous penetrations for 2019 are in grey, while two different 2025 scenarios from the Draft 2020 Integrated System Plan (ISP) are shown in red (Central) and orange (Step Change).

Renewable Integration Study

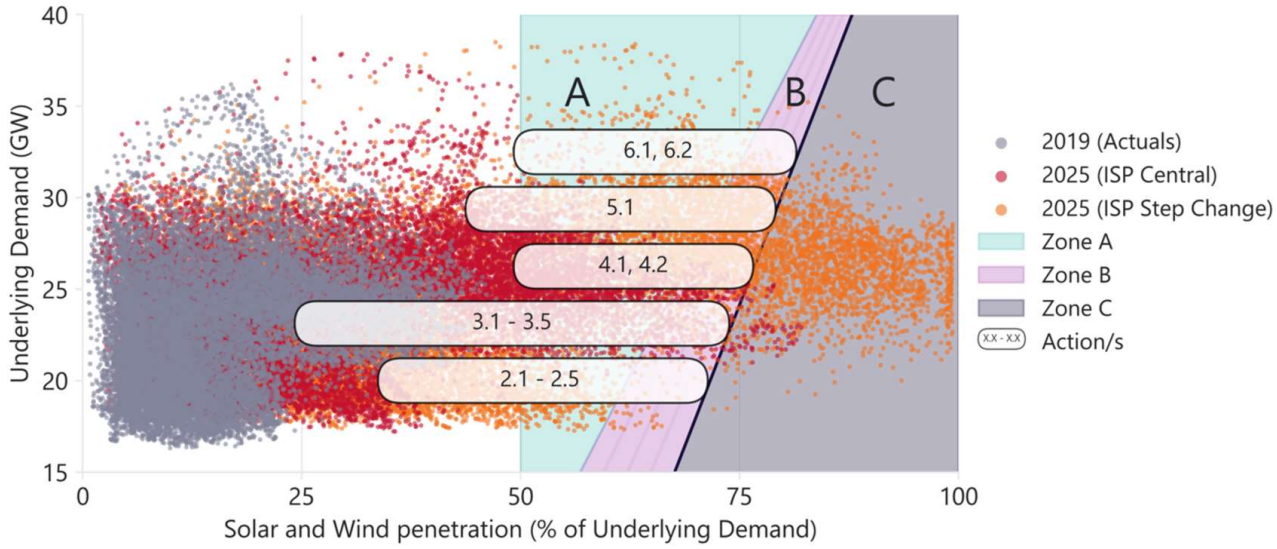
Instantaneous penetration summary graphic

Each dot represents the combination of instantaneous penetration (x-axis) as a percentage of underlying demand (y-axis), at the start of every half hour period in the year. The instantaneous solar and wind penetration includes semi-scheduled and non-scheduled wind and solar as well as distributed PV (DPV[1]). Underlying demand refers to electrical load on the network, including large-scale commercial and industrial loads, residential loads, home batteries, electric vehicles, large-scale batteries and pumped hydro.

2025 forecasts

The two 2025 forecasts in Figure 1 were produced by taking the Draft 2020 ISP's Central and Step Change Scenario expansion plans for the year 2025 (which outline optimal generator and interconnector builds) and running these through a model that assumes full utilisation of wind and solar resources. The outputs of this model include lost energy from network congestion but does not include system curtailment[2] or participant spill[3], whereas the 2019 actuals account for all forms of 'lost' energy.

Figure 2 Summary of identified system limits and actions, overlaid on instantaneous penetration of wind and solar generation, actual in 2019 and forecast for 2025 under ISP Central and Step Change generation builds



Note: Penetration values on this graph represent non-overlapping half-hourly wind and solar generation divided by total underlying demand across the NEM during the same half-hours. Actual 2019 penetration includes all curtailment; 2025 projections only include network congestion.

System limit overlays and the instantaneous summary graphic

Figure 2 is an extension of Figure 1, where the challenges and actions are overlaid on the original graphic. This graphic is featured as Figure 3 (p14) and Figure 20 (p60) in the RIS Stage 1 Report.

Zones

Each zone in Figure 2 indicates the level of wind and solar penetration where different broad renewable integration challenges emerge.

- **Zone A** indicates where managing variability and uncertainty will become increasingly challenging.
- **Zone B** indicates where inertia and system strength limits impact secure operation. The diagonal dotted lines in Zone

[1] DPV includes all grid-connected solar installations that are not part of central dispatch. This includes rooftop PV (<100 kW) and PVNSG (100kW-30MW.)

[2] System curtailment is when wind and solar are limited due to a need to maintain minimum levels of essential system services for system security.

[3] Participant spill is when wind and solar generation removes itself from the market (self-curtailment) due to market signals.

Renewable Integration Study

Instantaneous penetration summary graphic

B indicate the approximate staged progression of these limits that is suggested out to 2025, as operational experience is obtained, and frequency management reforms are progressed.

- **Zone C** indicates the current minimum online synchronous generation required to meet the minimum synchronous unit combinations for system strength in each region.
- The **black line** represents the upper limit for wind and solar instantaneous penetration in 2025. Based on the generation mix from the Draft 2020 ISP Central Scenario, and the current operating limits of existing large synchronous machines, this is ~75%. This is the limit that is feasible to operate to if all the actions in the RIS are taken.

Looking beyond 2025, AEMO has not identified any insurmountable reasons why the NEM can't operate securely in Zone C, with instantaneous wind and solar penetrations of up to 100%.

Actions

The RIS identified a list of actions to mitigate the challenges arising from high wind and solar penetrations. In Figure 2, the horizontal spread of the white action blocks indicates the penetration of wind and solar where they would be needed. The vertical spread, with respect to underlying demand, is unrelated to when the actions will be required. Due to the lead times for each action, the RIS recommends that all actions start immediately.

- **Operational actions (2.1-2.5)** – Ensure the ability to operate the power system within security and reliability standards.
- **DPV actions (3.1-3.5)** – Required to balance increasing levels of small, distributed generation with power system requirements. These are already required in some states such as South Australia where the penetrations are high.
- **Frequency actions (4.1-4.2)** – Actions required to be able to effectively set and maintain system frequency within acceptable levels.
- **System strength action (5.1)** – Required to maintain the voltage amplitude, waveform and phase angle under system normal and contingent conditions within specifications.
- **Variability and uncertainty actions (6.1-6.2) –** Actions needed to ensure a sufficient portfolio of energy resources is available to balance supply and demand in every 5-minute interval.

More detail on these actions can be found in Table 1 of the RIS Stage 1 Report. If recommended actions are not taken, the identified operational limits will bind and constrain the output of wind and solar resources. This would limit their maximum instantaneous contribution in the NEM to between 50% and 60% of underlying demand.

Frequently asked Questions

1. Why were half hour intervals chosen to represent instantaneous penetration?

Modelling traces for weather and demand patterns were developed at a half-hour granularity for 2025. This allows a detailed analysis of the supply/demand balance over each day without adding too much computing load to running the models. The historical 2019 values were assessed at the 5-minute and 30-minute level, with conclusions found to be robust to different granularities.

2. There is a step around 20 GW of underlying demand in the 2019 data with higher renewable penetrations above this level. What accounts for that step?

The step that seen in Figure 1 is the difference between night-time and day-time demand and generation. As the sun comes up, demand increases and so does solar generation which increases the instantaneous penetration of solar and wind. Observations below 20GW of demand are mostly during the night-time when only wind generation contributes to instantaneous penetration.

3. Will it be possible to operate above 75% into Zone C?

Based on the generation mix from the Draft 2020 ISP Central scenario and the current operating limits of existing large synchronous machines, the upper penetration limit for wind and solar generation in 2025 is ~75% (black line in Figure 2). This is the limit that is feasible to operate to if all actions in the RIS are taken.

In order to operate beyond 75% in the medium term, utilisation of currently commercially available technologies will need. This could include lowering the stable minimum load levels on synchronous units needed for essential system services, or addition of synchronous condensers.

In the long term, it may prove possible to progressively substitute the minimum synchronous machine requirements with new technologies, such as batteries with advanced-inverter capabilities.

4. Do the 2025 forecasts on Figure 1 account for transmission and distribution congestion?

The 2025 forecasts do include transmission limits, which affect the instantaneous penetration of wind and solar.

At the distribution level, Appendix A of the RIS Stage 1 report gives an overview of how distribution limits affect DPV penetration. The conclusion is that any distribution challenges

aren't likely to materially limit DPV enough to stop it becoming a bulk system issue.

Transmission expansion is a critical compliment to this overall transition and RIS modelling assumes the transmission expansions that are proposed by 2025 as part of the 2020 draft ISP have been built. It is important to note that if those augmentations don't occur, then there would be different transmission constraints affecting the RIS results.

5. How is storage accounted for in Figure 1?

Storage is included in the demand side of the ISP projections as well as increased demand-side participation, electrification of heating and transport. As such, it is included implicitly in the y-axis of Figure 1 and Figure 2.

Where can I find more information?

AEMO have put together a series of **webinars** explaining the contents of the RIS, which can be found here**. For further enquiries, please contact AEMO's Future Energy Systems team at** FutureEnergy@aemo.com.au.