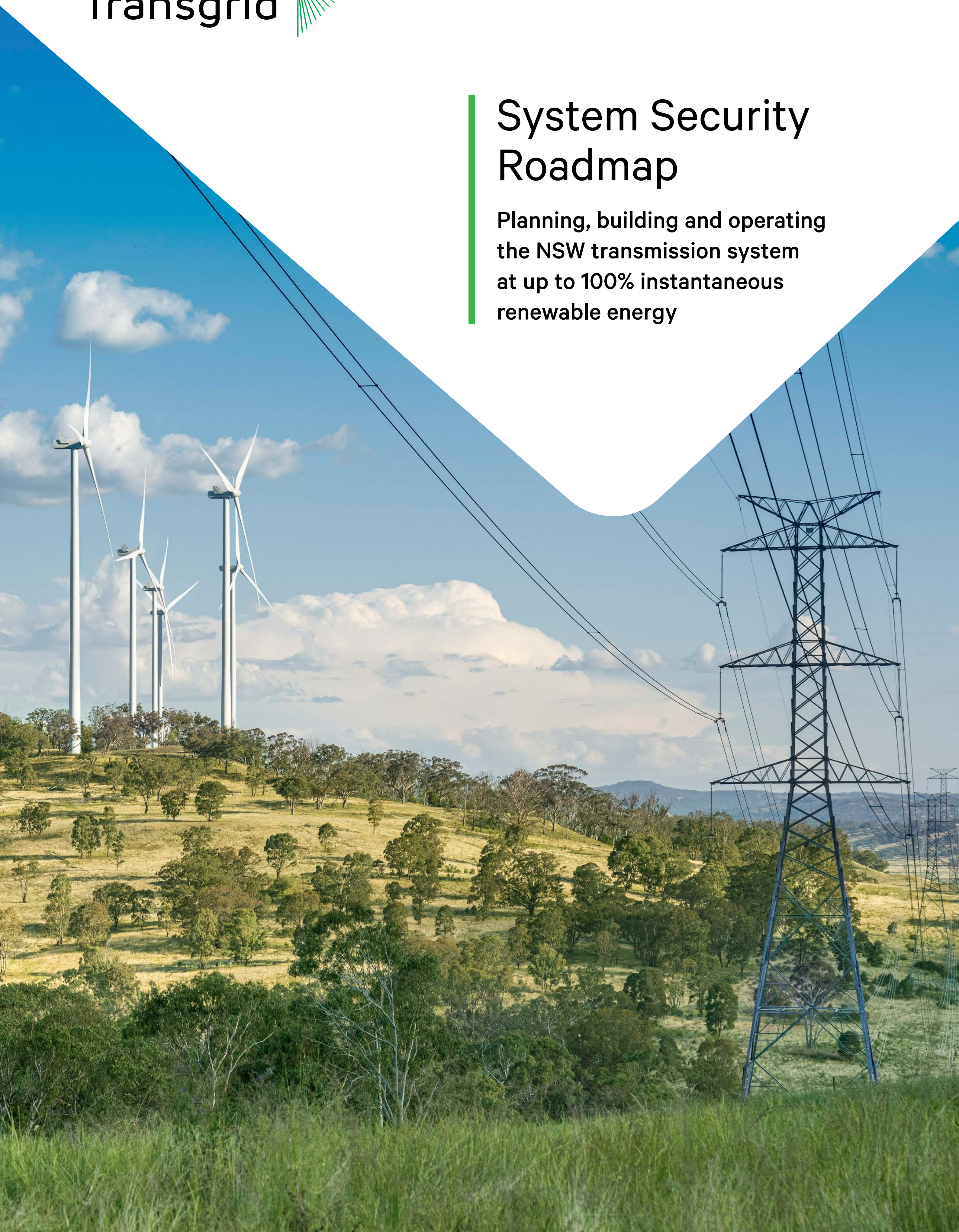
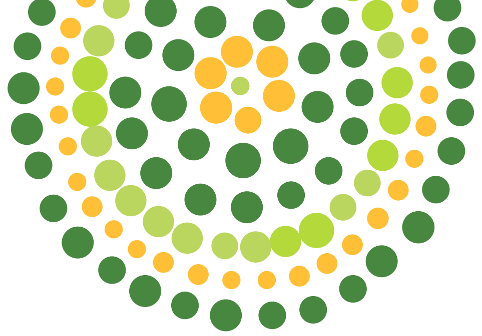
System Security Roadmap

Planning, building and operating the NSW transmission system at up to 100% instantaneous renewable energy

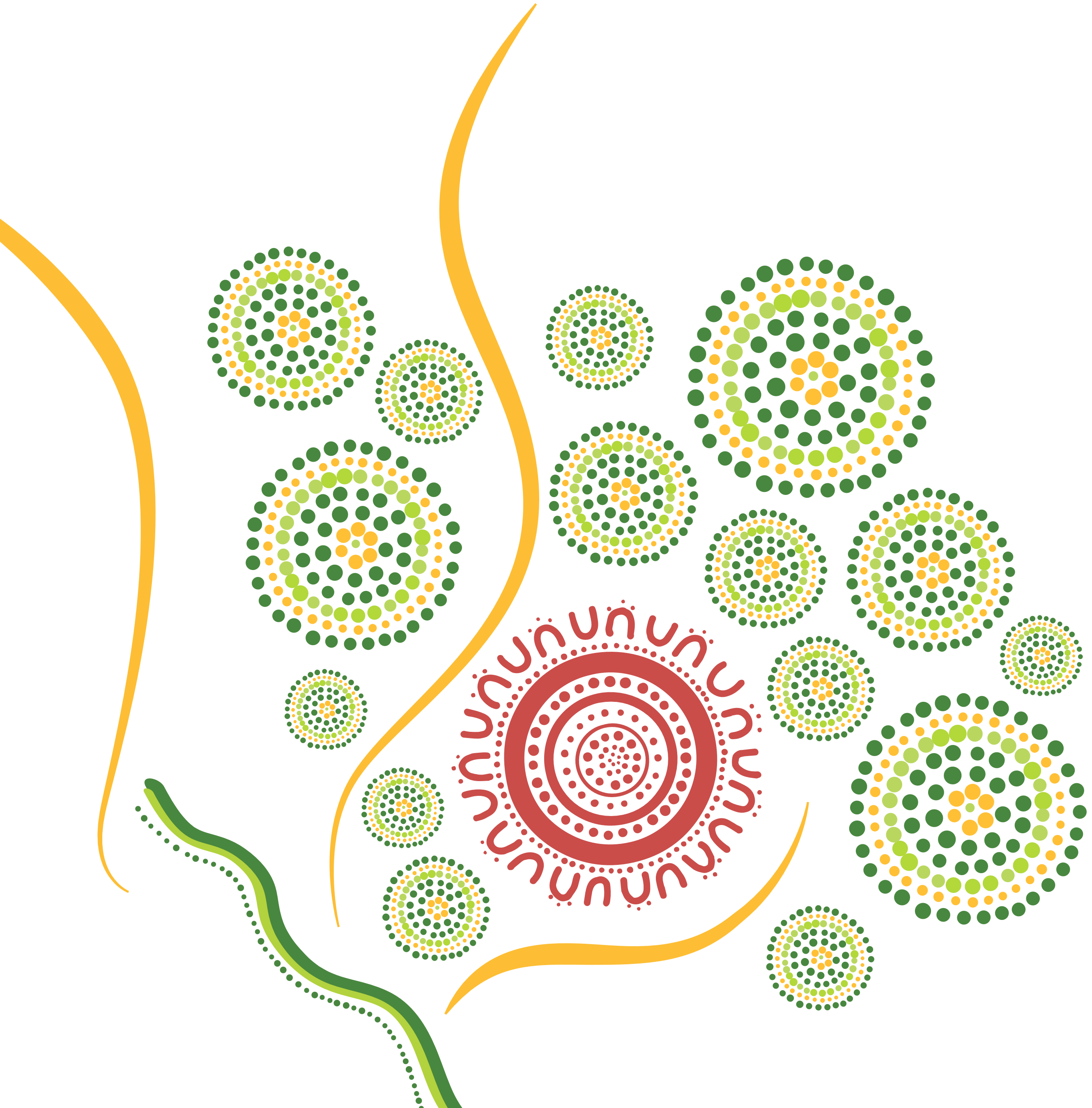




Acknowledgement of Country

In the spirit of reconciliation Transgrid acknowledges the Traditional Custodians of the lands where we work, the lands we travel through and the places in which we live.

We pay respects to the people and Elders, past, present and emerging and celebrate the diversity of Aboriginal peoples and their ongoing cultures and connections to the lands and waters of NSW and ACT.



Foreword

To help achieve Australia's 2050 net zero target, the Federal Government has committed to modernising the electricity grid to grow the annual share of renewables to 82% by 2030. This modern grid will be radically more complex and dynamic than the system it is replacing. As Transgrid builds the thousands of kilometres of new transmission required to connect this new network, we must also invest in the new technologies and capabilities required to keep it operating safely, securely and reliably. Otherwise, the impact on consumers – in terms of both cost and reliability – will be unacceptable.

As the NSW Transmission Network Service Provider (TNSP), Transgrid must plan for, build, maintain and operate the backbone of this new grid while meeting our obligations to maintain the safety, reliability and security of the transmission system in accordance with the National Electricity Rules (NER).

In the next decade, Transgrid will invest more than $14 billion to build the infrastructure required to support the energy transition. For every dollar spent on highly visible generation, storage and transmission infrastructure, we must also invest two cents on less visible system security and operability. This is essential to make sure the grid operates with the reliability and delivers energy at the cost that NSW customers have come to expect.

The scale, speed and challenge of our clean energy transition is enormous. Australia is attempting a world first: a large-scale grid dominated by wind and solar power built at break-neck speed. This energy system will incorporate a wider range of technologies, more diverse geographical locations, higher variance in demand, and greater reliance on storage and active management of power flows. Many roles are changing. New skills will be required in an industry already facing talent shortages and an ageing workforce and we must also account for global competition for clean energy infrastructure at a time of constrained supply chains.

All of this adds complexity, risk and volume to the work of the teams planning, building and operating our transitioning grid. If these risks are not addressed, Australia's clean energy transition will be beset by costly uncertainty and delays. We would face the real possibility of missed emissions targets and higher power prices as grid reliability and power supply security come under pressure.

The June 2022 National Energy Market (NEM) crisis highlighted the potential cost of energy system disruption. We are already losing hundreds of millions of dollars a year in consumer value to grid congestion. With 80% of NSW's coal generation capacity expected to retire in the next 10 years, we cannot wait and must urgently accelerate the investment in all areas of the clean energy transition.

As early coal retirement, electrification and changing consumer choices accelerate Australia's clean energy transition, market and transmission operators need to be proactive. We must innovate, collaborate, test and solve issues now if we are to achieve the goal of a rapid transition to a low emissions energy system while maintaining reliability.

Transgrid proactivity exemplifies our commitment to keep costs down for the electricity customers of NSW. Transmission is required to drive down the costs of wholesale electricity as generation diversifies. Acting now will ensure that we stay on pace with the demands of the clean energy transition and avoid constraints to the energy system that would cost customers in the long run. We are building now so consumers don't have to pay later.

Drawing on international learnings, independent modelling and Transgrid's own experience of the energy transition, this paper:

- Outlines the complexities involved in transitioning to and operating a modern electricity network and our role in navigating this future
- Identifies the technologies and capabilities required to construct and operate a grid securely at up to 100% instantaneous renewable generation

We hope this Roadmap informs stakeholder understanding of the technologies, capabilities and capacity needed to plan, build, operate and manage a 100% instantaneous renewable power system with the levels of reliability, security and safety customers expect.

Brett Redman

Executive summary

Australia is executing one of the world's most ambitious and rapid clean energy transitions. Surging renewable energy generation, storage and the decline in coal generation is reshaping our power system.

Twenty years ago, eight coal generators provided nearly all of NSW's power, with 12GW of capacity. By 2033, 80% of current coal-fired capacity will have retired, with hundreds of large scale wind and solar generators, storage systems, and millions of rooftop solar installations providing 28GW of new capacity to the NSW power system.

As a result of this surge in renewable generation capacity, the Australian Electricity Market Operator (AEMO) projects that short periods of time where renewable generation exceeds total demand across the NEM could occur as early as 2025 and will be common by 2030.

Planning, building, managing and operating a grid capable of 100% instantaneous renewable energy generation requires a fundamental transformation. The transmission network must grow to ensure reliable supply from increased but intermittent renewable generation capacity. As coal generators retire from the power system, new sources of system security services will be urgently needed.
The increasing supply of renewable power will also make the power system more volatile and dynamic, and the grid will operate closer to the edge of its technical limits for power system security.

The combination of more renewable generation, declining coal generation, lower minimum demands, new grid infrastructure and new technologies is creating an exponentially more complex power system. System complexity is not a 'future problem'; it is already making the power system more difficult to operate and increasing risks to consumers.

In response, the builders, asset managers and operators of this system will need to solve new problems, harness emerging technologies and uplift their skills. Without modern tools and new skills to operate the network, the risk to Australia's power supply will become unacceptable.

Uplifting three essential pillars is vital to continue to plan, build and operate a safe, reliable and low emissions power system able to operate securely at up to 100% instantaneous renewable energy.

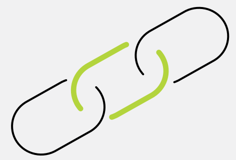
- The transition to renewable energy is the only pathway to lower energy prices and easing the growing cost-of-living pressures on Australians. There can be no transition without transmission.
  - Transgrid is investing $14 billion in transmission infrastructure in NSW over the next decade. Every dollar spent on transmission is projected to return more than twice this in benefits to customers. Transmission enables cheap, renewable electricity to flow to consumers, and more supply will help lower high wholesale energy prices.
  - Accelerating the delivery of transmission projects will increase and bring forward consumer benefits, while delaying them will cost consumers more. Every day that the delivery of the transmission backbone is delayed is estimated to cost average residential consumers an extra $1 on their energy bills.
- Replacing the system security services that were previously provided by coal generators is a non-negotiable step in the energy transition and the pathway to lower energy prices for consumers.
  - To provide these new sources of system security in NSW, approximately $2.2 billion of investment is required over the next decade, representing around 1.5% of total electricity system costs.
  - Proactively investing in new system strength capacity is projected to deliver $5 in benefits to consumers for every $1 spent, by unlocking low-cost renewable energy and reducing dependence on aging and high-cost fossil fuel generators to provide these services on an ongoing basis.
- A step-change in analytical and operational capabilities and capacity is required to plan, manage and operate an increasingly complex power system.
  - An investment of $300 million is required in the next decade to uplift Transgrid's operational technology tools, headcount and training, representing approximately 0.2% of total electricity system costs in NSW.
  - Investing in operability uplift is projected to deliver over $4 in benefits to consumers for every $1 spent by ensuring grid operators are equipped to deal with emerging challenges, and avoiding disruptive and costly power outages that may otherwise occur.

It will be technically possible to operate the NSW power system at 100% instantaneous renewables, but only once the foundational pre-requisites of energy reliability, system security and operability are in place. These are not negotiable.

In light of the rapid transformation of the power system, a urgent acceleration in the delivery of these investments and capabilities is required.

This report outlines the work involved in each pillar and Transgrid's plans to deliver each of them. All three are essential for the NSW power system to respond to and thrive in the new energy landscape, providing clean, reliable and affordable electricity to Australians.

Transgrid's delivery of three critical pillars will enable the NSW transmission system to operate safely and securely at up to 100% instantaneous renewable energy.

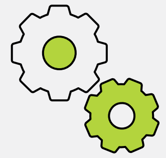


Energy Reliability

Deliver large-scale transmission infrastructure to connect and share new renewable generation and storage with customers as ageing coal generators retire.

System Security

Deploy new power system technologies and services to maintain the secure operating envelope of the grid without the operation of thermal generation.



Operability

Advanced tools and additional resources and training to plan, manage and operate a complex power system capable of 100% instantaneous renewable generation.

By 2033, Transgrid must

Energy Reliability

Deliver 2,500km of transmission lines and supporting infrastructure ($14 billion) to:

- Enable the connection of 17GW of new largescale renewable and storage capacity
- Integrate 5 renewable energy zones into the transmission backbone
- Expand transmission interconnection between regions and states

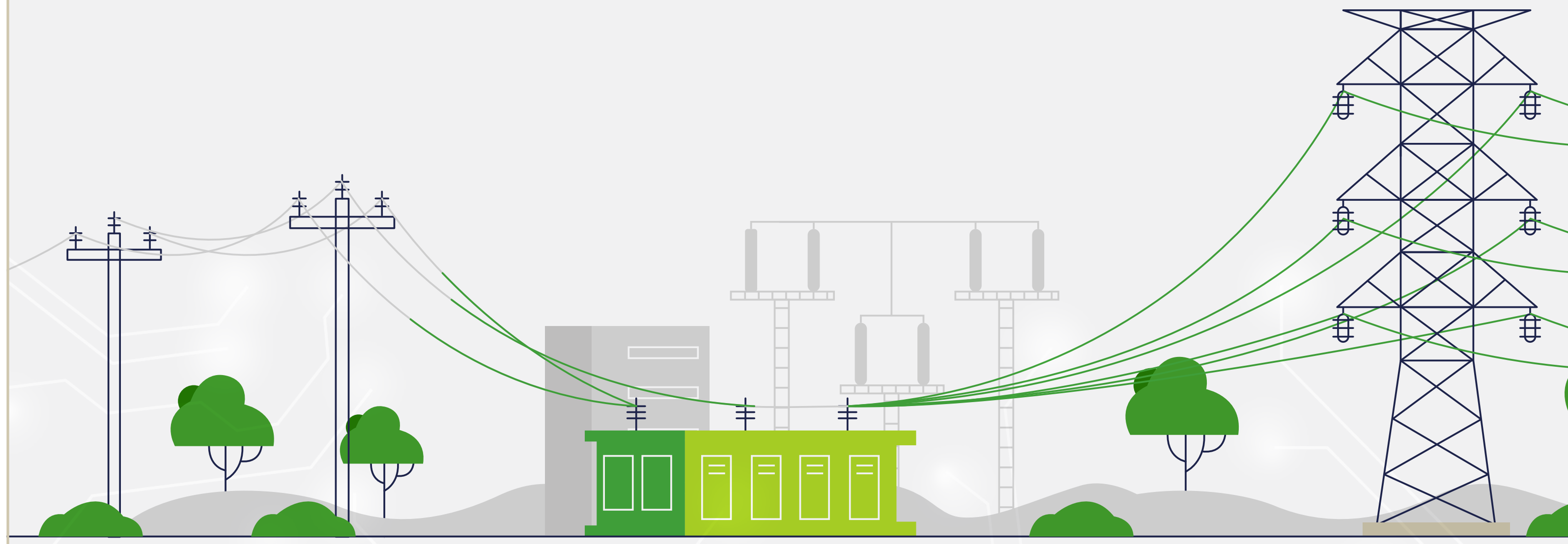
System Security

- Deploy the equivalent of 21 synchronous condensers to replace system strength from retiring coal generators ($2.2 billion)
- Co-optimise supply of other system security services including inertia and voltage support
- Trial and prove the suitability of new technologies to support system security
- Establish secure operating envelopes to manage system security in real-time during high renewable and low demand periods

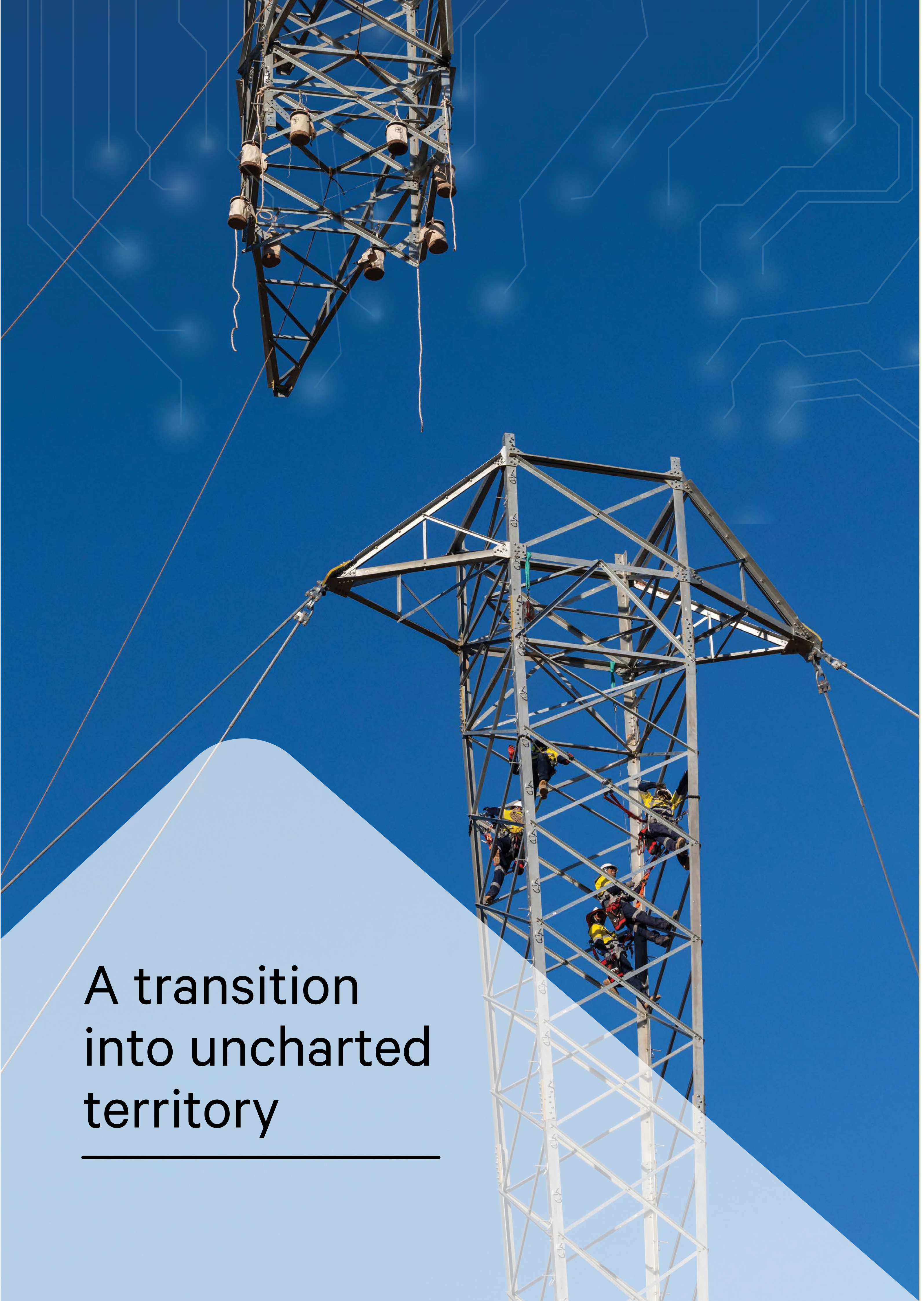
Operability

- Deploy Operational Technology tools to increase network visibility, forecasting, situational awareness and decision support to enhance real-time operations, planning and asset management ($140 million)
- Increase operations, planning and asset management headcount and training to plan, manage and operate a more complex power system ($16 million per annum)

Figure 1: Transgrid's three critical pillars to support Australia's clean energy transition



Contents



A transition into uncharted territory

Australia is executing one of the world's most ambitious and rapid clean energy transitions. Surging renewable energy generation, storage and the decline in coal generation is reshaping our power system. In response, we must change the way we plan, manage and operate the system.

The end of coal generation dominance

Historically, coal generation has dominated the NSW power system. In 2007, coal represented 88% of NSW's electricity generation. Fast forward 15 years to 2022 and that figure was 68% and falling.[1]

The surge in renewables and storage is making it more difficult for coal generators to remain profitable.[2] A combination of aging assets, volatile fuel prices, falling daytime electricity prices and environmental and social license pressures are accelerating coal owners' plans for plant retirements. This can be observed in the acceleration of coal retirement timing compared to what was projected in 2020. Further acceleration is possible.

AEMO's 2022 Integrated System Plan projects that by 2033, only 17% of NSW's electricity generation will come from coal.

Over the next decade, 80% of NSW's coal capacity is expected to retire, representing 7GW of generation capacity exiting the system.[3]

The planned rate of decommissioning of coal units in NSW is four times higher than has been observed in Europe or the United States over the last 5 years, proportional to total generation capacity.[4]

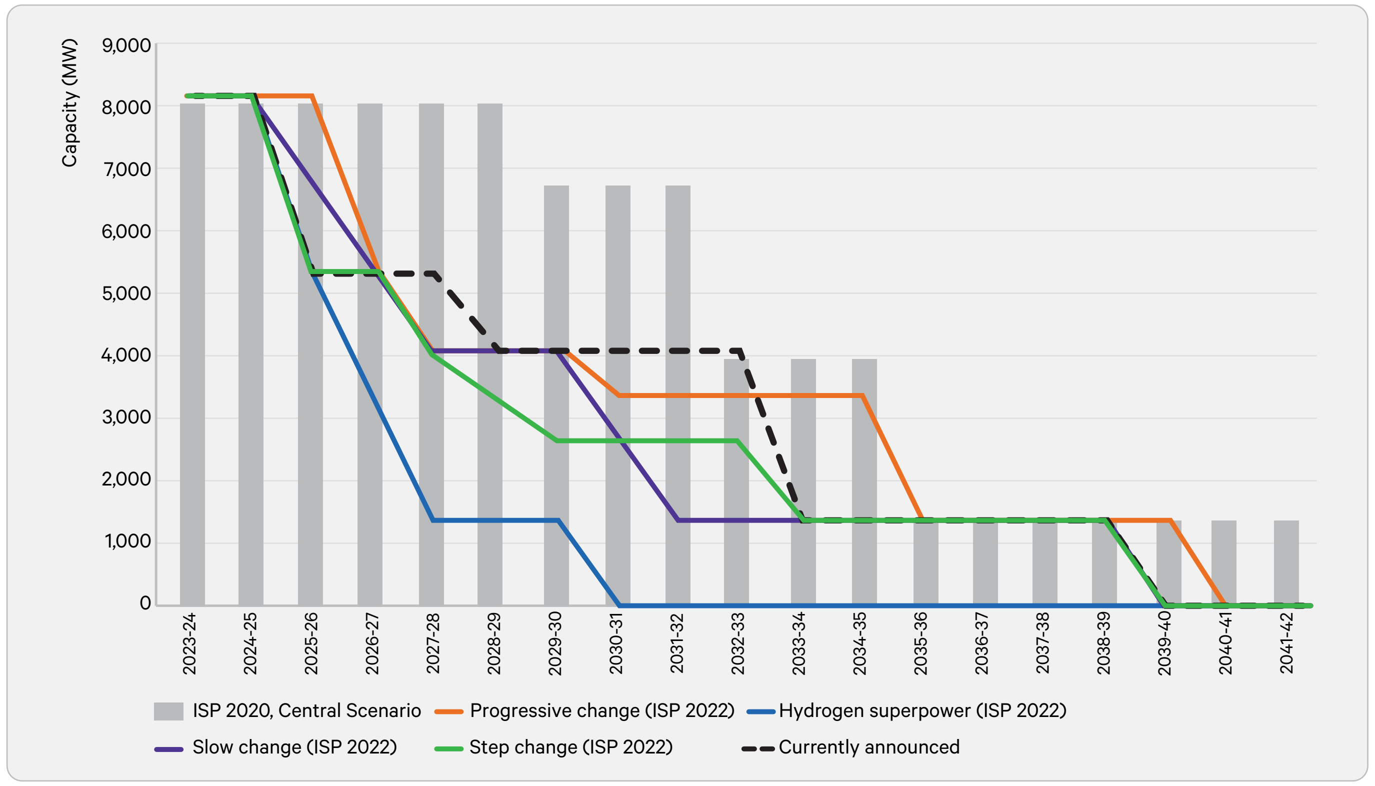


Figure 2: NSW coal retirement trajectory. AEMO 2022 draft and final Integrated System Plan and 2020 Integrated System Plan

1. OpenNEM, 2023, Energy, NSW, https://opennem.org.au/energy/nsw1/?range=all&interval=1y
2. AEMO, 2023, Quarterly Energy Dynamics Q1 2023
3. AEMO, 2022, Integrated System Plan, https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2022-integrated-system-plan-isp, additional to the Liddell Power Station that recently ceased operations.
4. https://globalenergymonitor.org/report/boom-and-bust-coal-2023/

Rise of the renewables

To achieve a net zero goal by 2050, 50GW of large scale renewables and storage is projected to be built in NSW. This is six times the capacity of coal generation exiting the system.[5]

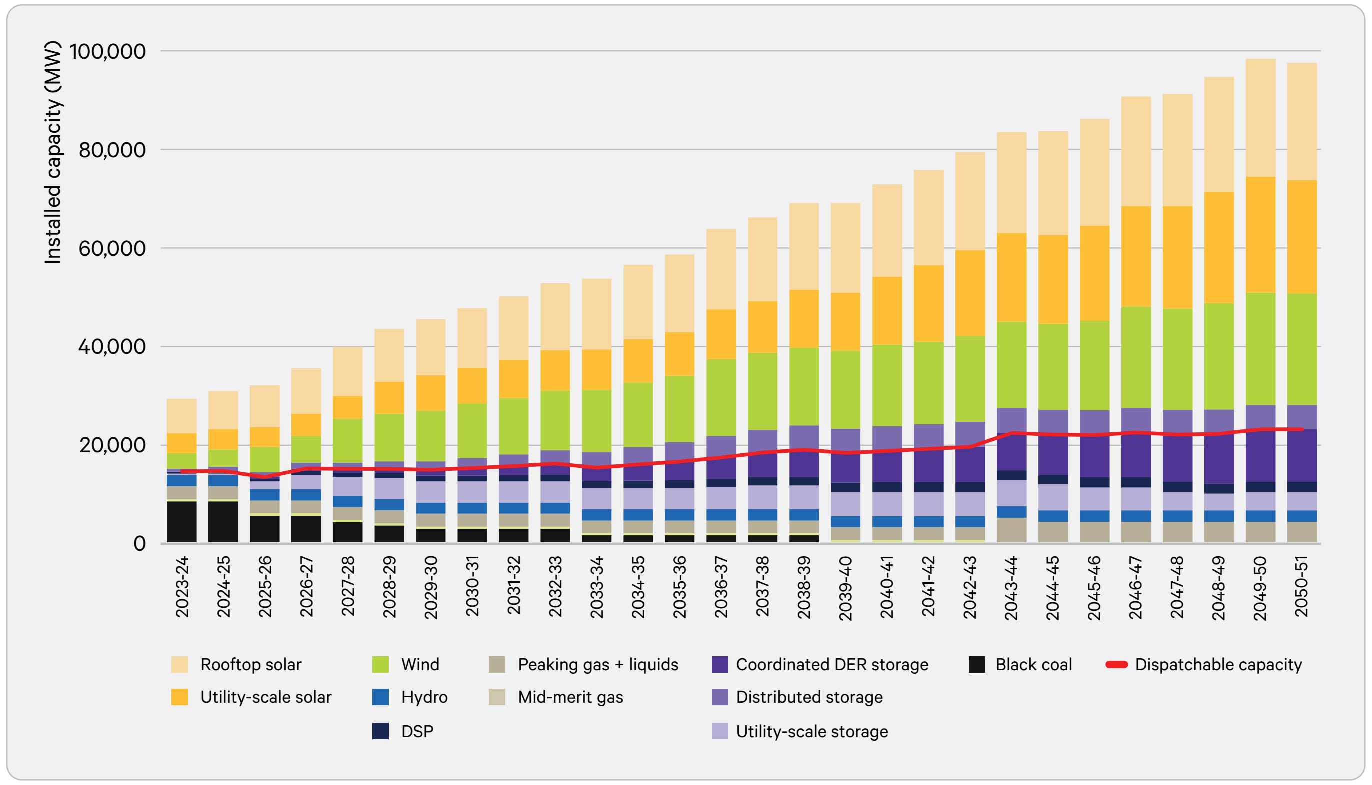


Figure 3: Projected generation capacity in NSW by technology (AEMO, 2022 Integrated System Plan)

By FY2033, renewables are projected to represent over 80% of electricity production in the NEM[6], up from 35% today, and is expected to grow to 97% by 2050. Coal generation on the other hand will fall from 68% in FY2022 to 17% in FY2033 and 0% by FY2040. During the same period, total NSW generation will rise from 68GWh to 139GWh per year to meet the growing demand for electricity, primarily as a result of the electrification of cars, industry and buildings.

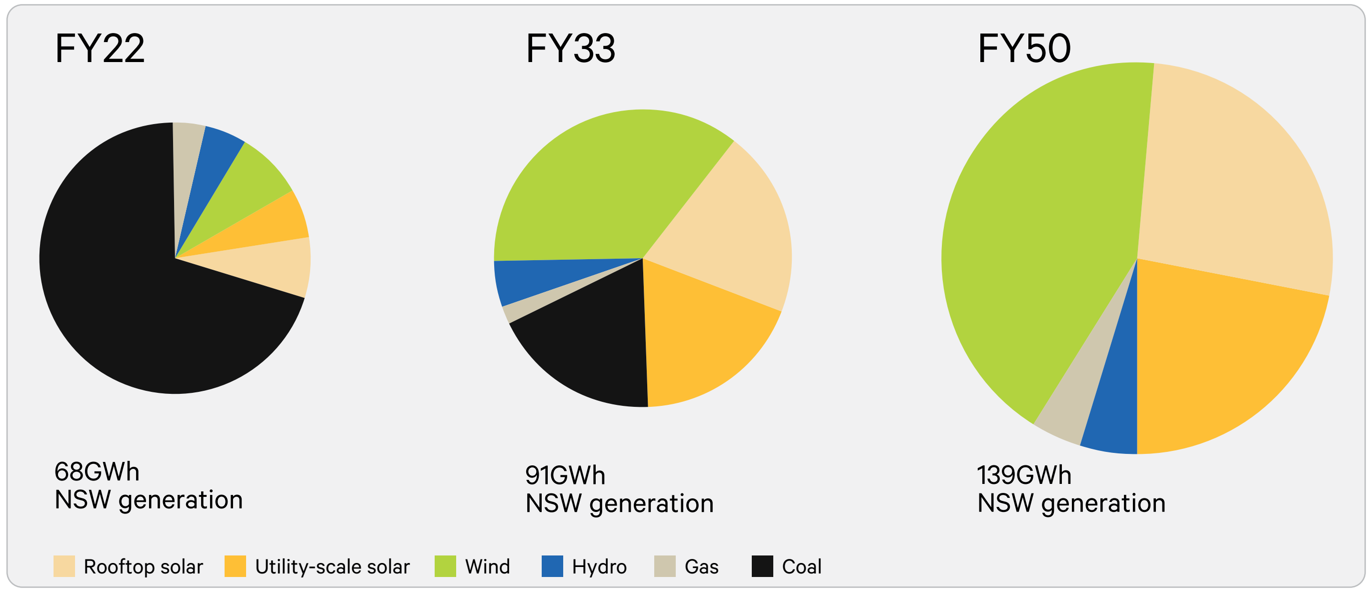


Figure 4: Actual FY2022 and projected electricity generation in NSW by technology FY2033 and FY2050[7]

5. AEMO, 2022, Integrated System Plan, https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2022-integrated-system-plan-isp
6. AEMO, 2022, Integrated System Plan, https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2022-integrated-system-plan-isp
7. AEMO, 2022, Integrated System Plan

Geographic dispersion

Renewable generators are far more geographically dispersed than existing coal power stations. Installing the vast fleet of wind and solar farms and battery energy storage systems in regional NSW will require a momentous change in the electricity network. To reach these new renewable generators, we need new transmission connections from renewable energy zones (REZs) to the transmission backbone and strong interconnections between states to share power, energy storage and system security services. Figure 5 shows the evolution of the NSW generation fleet, moving from centrally located near load centres to geographically dispersed across regional NSW.

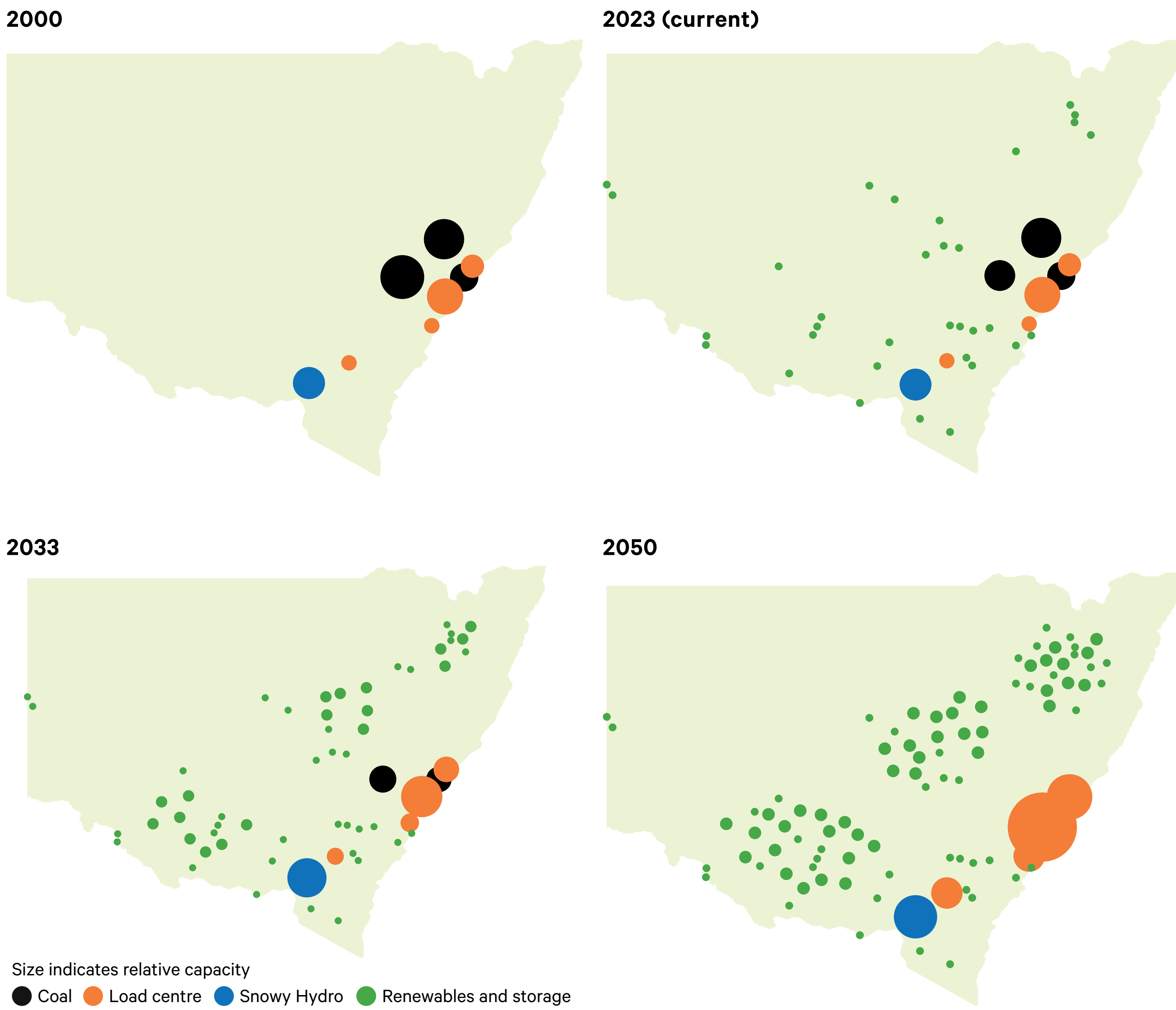


Figure 5: The NSW power system in 2000, 2023 (current) and projected in 2033[8] and 2050 (conceptual image)

8. AEMO, 2022 Integrated System Plan

Prosumer prominence

The deployment of rooftop solar has outpaced expectations; one in four Australian homes now have solar on their roof. This growth is expected to continue; 13.5GW of rooftop solar is projected to be installed in NSW by FY2033, twice the capacity that was projected in 2020 and three times the capacity projected in 2018, as shown in Figure 6.

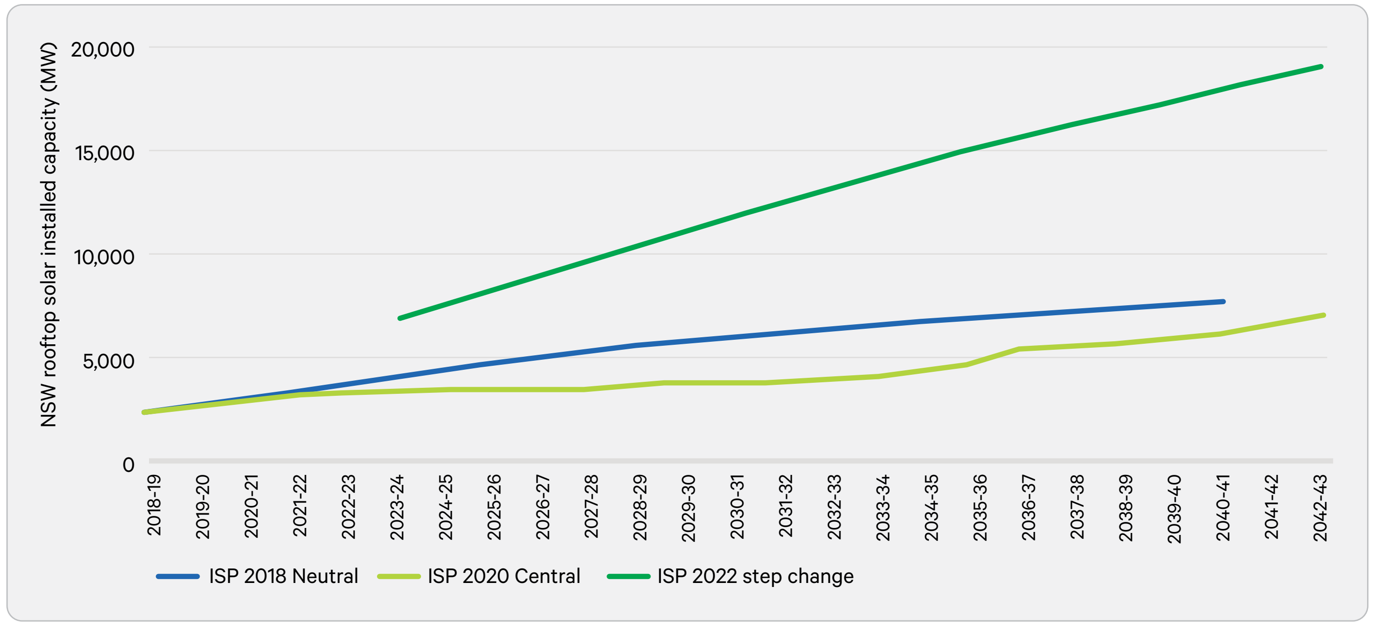


Figure 6: 2018, 2020 and 2022 forecasts of rooftop solar growth in NSW[9]

This rapid growth in rooftop solar is driving down the minimum demand seen on the NSW transmission system. While minimum demand historically occurred during the very early morning, this has shifted to the middle of the day, typically in spring or autumn, when there is significant rooftop solar generation and little need for heating and cooling.

Figure 7 shows the rapidly declining projections for minimum demand in NSW, commensurate with the projected uptake of rooftop solar. Based on the current projections, there may be periods within the next 15 years when rooftop solar can supply all the state's electricity needs.

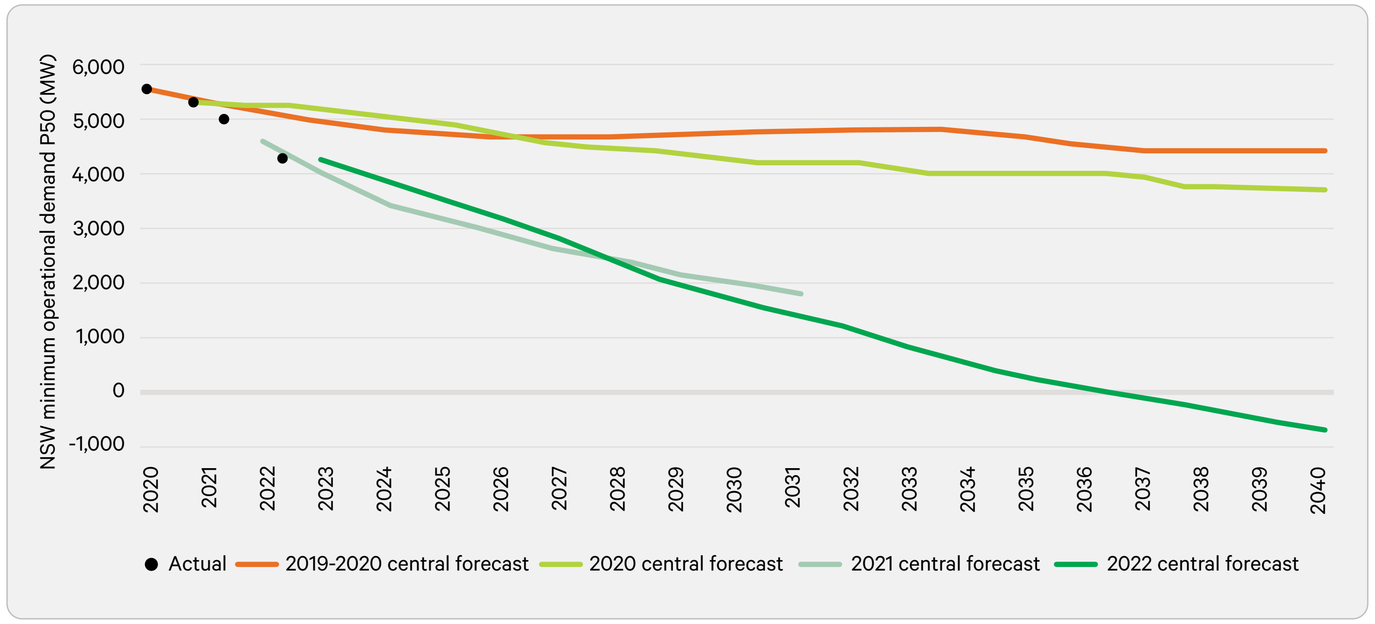


Figure 7: Forecast minimum operational demand in NSW[10]. Yearly record for minimum demand indicated.

9. AEMO, Integrated System Plans 2018, 2020, 2022
10. AEMO 2019-2022, NEM Electricity Statement of Opportunities (ESOO)

As minimum demands declines, the power system faces difficult operating conditions on three fronts:

- The NSW electricity system currently relies on 7 coal generating units to be online at all times to support the stability and security of the power system. If minimum demand falls below roughly 2GW (forecasted to occur at the end of this decade), then there may not be enough electricity demand to keep those 7 coal units running, leading to unsecure and potentially catastrophic conditions.
- The transmission system was designed to bring power from large generators to the distribution network and then to customers, not the other way around. As demand falls, parts of the distribution network will start sending power back into the transmission system. These reverse power flows create extremely difficult operating conditions for transmission and distribution network operators alike, including for grid protection settings and load shedding schemes.
- As rooftop solar drives down minimum demands, grid voltages in those areas rise, changing the operating dynamics of the system and requiring more frequent switching of reactive plant to compensate (or installation of more reactive plant). Significant cloud movement can create rapidly changing voltage levels on the transmission system.

Rooftop solar isn't the only technology that will fundamentally alter the way our power system operates. Household batteries and electric vehicles are projected to surge in the coming decade, increasing the variability and complexity of power flows across the system.

Approaching 100% instantaneous renewables

It will not be long before renewable energy generation will be able to match electricity demand in the NEM for short periods of time. This is likely to first occur on mild and sunny autumn and spring days, with strong contributions from rooftop solar.

South Australia has already experienced periods where wind and solar produce more than 100% of state demand.[11]

Figure 8 presents the instantaneous penetration of renewables (horizontal axis) for every 30 minutes of the year in 2018-19, 2019-20 and 2020-21, with a maximum of 55% instantaneous renewable energy penetration observed in 2020-21. In October 2022, the NEM reached a record 68.7% instantaneous share of renewable energy generation.[12]

AEMO projects that short periods of 100% instantaneous renewable energy generation may be possible as early as 2025, as indicated by the purple dots for 2024-25.

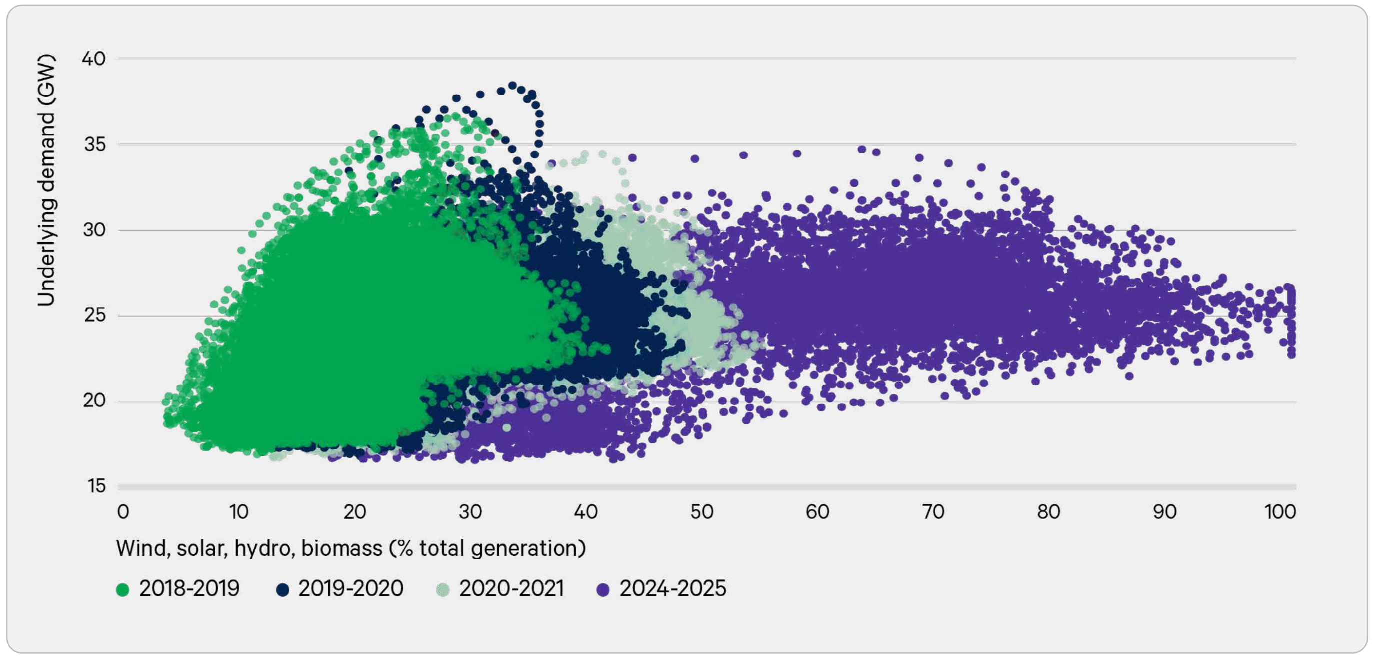


Figure 8: NEM-wide instantaneous penetration of renewable resources (large-scale and distributed)[13]

11. South Australia installed four synchronous condensers in 2021 to provide grid security services and in addition, two gas units run at all times to keep the South Australian power system secure. This extra generation is exported to Victoria which currently has a much lower penetration of renewables.
12. AEMO, 2023, Quarterly Energy Dynamics Q1 2023
13. AEMO, 2021, NEM Electricity Statement of Opportunities (ESOO)

AEMO projects that by 2030 dispatch at 100% renewables will be common as minimum demand decreases and installed renewable capacity increases. This will become more frequent through to 2050.

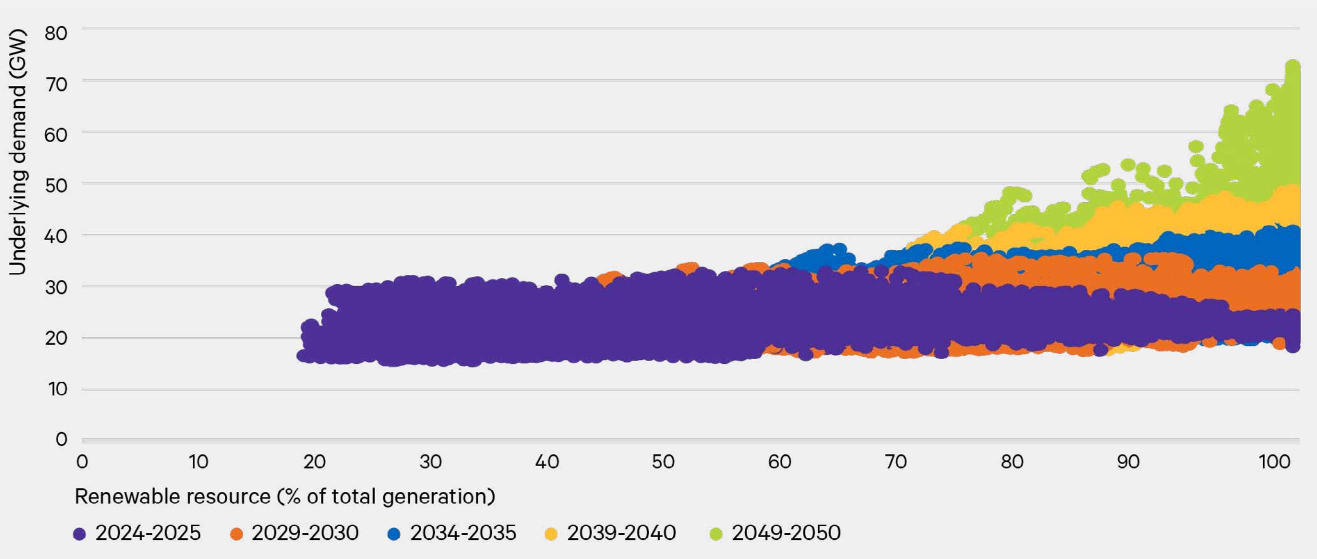


Figure 9: NEM-wide instantaneous penetration of renewable resources (large-scale and distributed)[14]

While in the future there may be sufficient capacity for potential renewable generation to supply 100% of demand, having sufficient power generation is alone not enough. Grid operators will not be able to run the grid at 100% instantaneous renewable power until sufficient new infrastructure has been deployed to manage power system security without running coal or gas units.

A declining power system heartbeat

Coal, gas and hydro generators are synchronous machines, electro-magnetically coupled to the grid. As a by-product of normal electricity generation, these machines provide 'system security'. They help the power system to maintain a stable and reliable flow of electricity – even in the face of unexpected events or disruptions such as lightning strikes or equipment breakdowns. We can think of these machines as providing the heartbeat of the power system.

In contrast, existing renewable technologies require a strong grid pulse to operate stably. If the grid's electricity signal wavers due to a disturbance, then renewables may in turn become unstable and disconnect, exacerbating any stability issues.

As coal generators retire from the power system, the grid will lose essential sources of system security. Without sufficient replacement services, the grid will not be able to operate safely, or at very high levels of renewables for even a short period of time.

Ensuring a strong power system heartbeat is vital for the reliable operation of a highly renewable power system.

Radically more dynamic and volatile

The increasing supply of renewable power is radically altering the behaviour of the NSW power system, making it more volatile and dynamic – trends that will only increase as thermal generation retires. Variable power production from renewables in response to changing weather conditions will occur in different parts of the network at different times of day. This will be compounded by increased load variance across power networks as prosumer technologies revolutionise the distributed consumption and localised production of power.

As we approach and eventually achieve 100% instantaneous renewable energy, the average demand profile will become less stable and the difference between the day's high and low operational demand will increase. As seen in Figure 10 on the day of NSW's record minimum demand in April 2023, demand fell to 4.1GW during the day before peaking at almost 8GW in the evening.

14. AEMO, 2022, Integrated System Plan

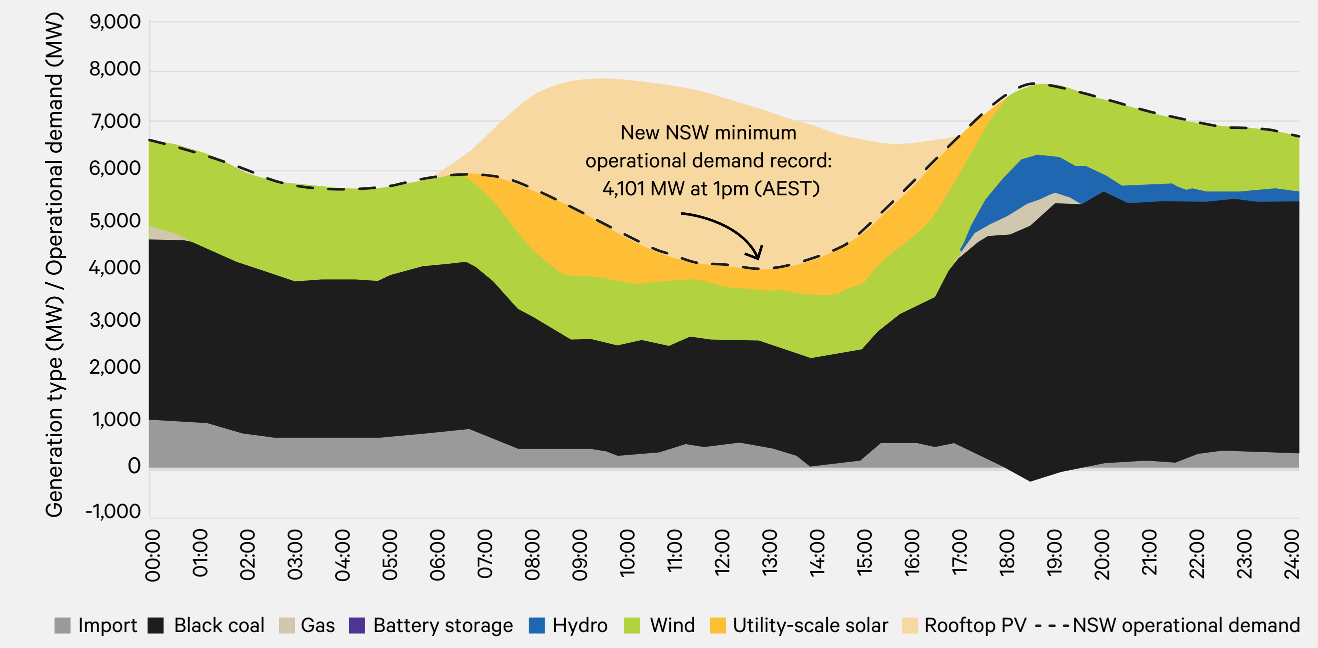


Figure 10: Generation mix and demand profiles for NSW on a recent record minimum demand day[15]

Figure 11 presents a conceptual representation of a day that first hits 100% instantaneous renewable energy. Significant thermal generation is seen during the early morning, is then replaced by significant rooftop and largescale solar and wind during the middle of the day, before thermal generation ramps back up in the evening. This will result in large swings in power flows between the transmission and distribution systems to facilitate storage and changes in generation.

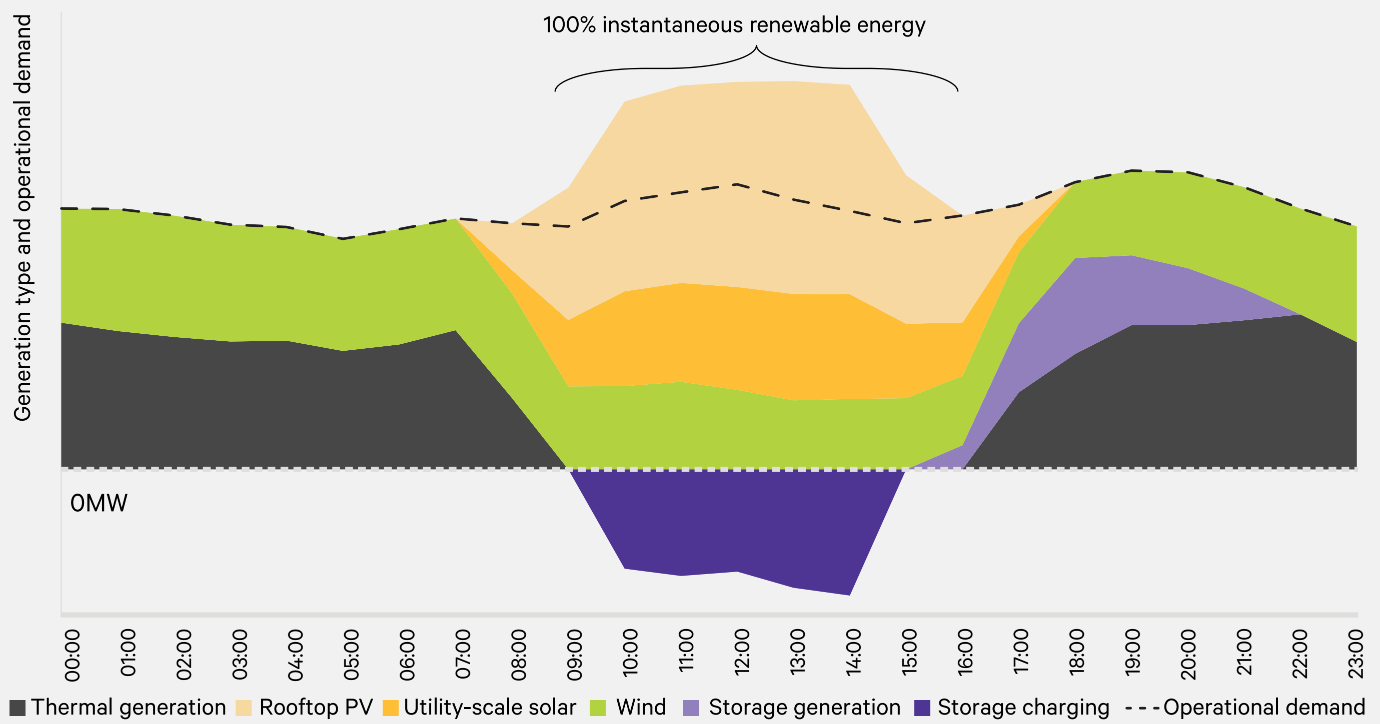


Figure 11: Operational demand and generation mix on a conceptual day operation at 100% instantaneous renewables[16]

15. AEMO, 2023, https://twitter.com/AEMO_Energy/status/1645626614250868736/photo/1

16. Adapted from AEMO, 2021, NEM Engineering Framework, Operational Conditions Summary, https://aemo.com.au/en/initiatives/major-programs/engineering-framework

Exponential increase in complexity

Each change to the power system as we approach 100% instantaneous renewable energy in the coming years will have a compounding effect on the energy system's complexity – and on the complexity of planning, managing and operating it. Changes include:

- The growth in renewables which is adding hundreds of new connections to the transmission system, and millions of connections to the distribution system. Increased renewable penetration will mean more variable and unpredictable generation, not to mention more interactions within network control rooms.
- Dynamic power swings and equipment switching will become more accentuated as generation shifts between sources, storage and distribution across a greatly expanded power network. This will lead to new operating conditions, with increasing voltage swings and reverse power flows and more frequent cycling of network equipment.
- The retirement of coal generation will remove key system security services required to keep the grid stable. With less inherent stability in the grid, the electricity system will become more susceptible to shocks.
- Connecting new renewables and constructing new transmission infrastructure will require more frequent outages. Maintaining reliability while delivering new generation and transmission infrastructure and balancing existing maintenance requirements will increase the complexity of system planning and operations.
- New actors and roles, such as network operators for renewable energy zones, will increase the number of parties involved in system management, increasing the complexity of control and communication during real time system operations.
- Innovative new technologies for energy storage and system security services will become part of keeping the grid reliable, secure and stable. Network Service Providers will need to test, analyse and ratify new technologies to support their operations immediately – and continue to adopt operational innovation in the future.

> Increased power system complexity is not a future problem, but one we must solve now.

How Transgrid is preparing the NSW power system for 100% instantaneous renewables

"By 2025 there will start to be sufficient renewable resource potential in the NEM to, at times, meet 100% of demand… the first period of 100% instantaneous operation is a critical part of enabling future power system operability at net-zero emissions." [17]

The NSW and national power system is transforming at an extraordinary speed. The NSW transmission system must undergo an equally transformative uplift in its physical capacity and operational capability. Transgrid must ensure security and reliability against the inherent risks of increased scale, complexity and change.

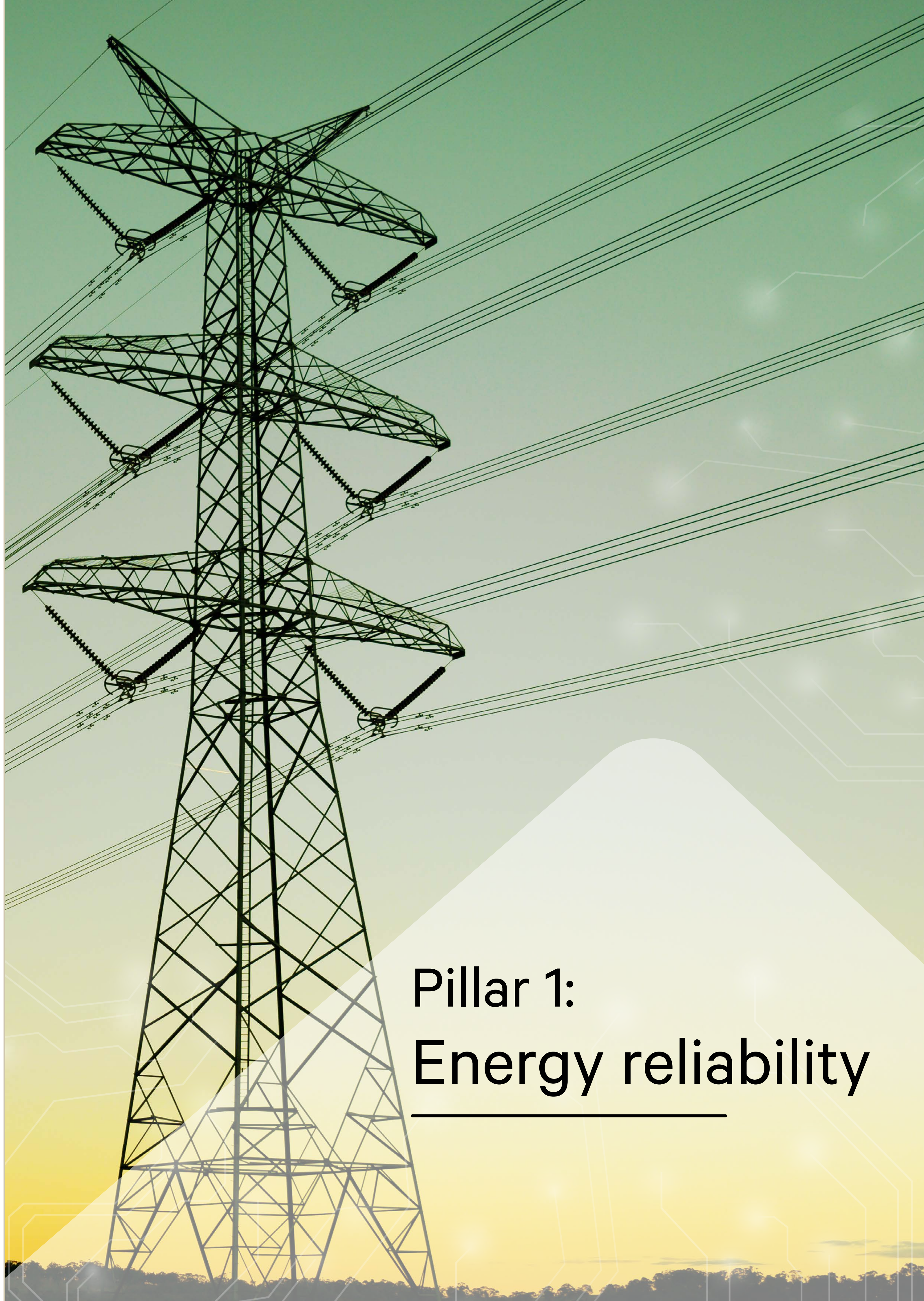
Transgrid will need to invest in, or contract for, new system security services and uplift of its operational technology tools and capacity to build, plan, manage and operate the power system. The following sections outline the three essential pillars necessary to enable the secure operation of the NSW power system at up to 100% instantaneous renewables, and Transgrid's plans to deliver on each.

Transgrid's three critical pillars to support Australia's clean energy transition

Energy Reliability	System Security	Operability
Deliver large-scale transmission infrastructure to connect and share new renewable generation and storage with customers as ageing coal generators retire	Deploy new power system technologies and services to maintain the secure operating envelope of the grid without the operation of thermal generation	Build capabilities and capacity to plan, manage and operate a complex power system capable of 100% instantaneous renewable generation

Figure 12: Transgrid's three critical pillars to support Australia's clean energy transition

17. AEMO, 2022, Engineering Roadmap to 100 per cent Renewables 2022



Pillar 1: Energy reliability

Pillar 1: Energy reliability

There is no transition without transmission

More than 2,500km of new transmission lines is needed to facilitate the transition of the NSW electricity system from a centralised, fossil fuel dominated grid to one powered by renewable energy. Only once sufficient renewable energy, storage and transmission capacity has been built can the grid operate at 100% instantaneous renewables.

Over the next decade, Transgrid plans to invest more than $14 billion to build new transmission infrastructure, providing the interconnectivity necessary to achieve the economic and environmental goals of the clean energy transition. Every dollar spent on transmission is projected to return more than twice this in benefits to customers. Transmission enables cheap, renewable electricity to flow to consumers, and more supply will help lower high wholesale energy prices.

Accelerating the delivery of transmission projects will increase and bring forward consumer benefits, while delaying them will cost consumers more. Every day that the delivery of the transmission backbone is delayed is estimated to cost average residential consumers an extra $1 on their energy bills.

1.1. Foundation for clean energy production

The backbone of the existing NSW transmission system was built to bring power from centrally located coal-fired power stations to major population and load centres. It only needed weak interconnections between states and out to regional areas.

In a grid powered by geographically distributed renewable energy, regional interconnection is essential, providing:

- Access to the lowest cost energy resources, fostering wholesale market competition and lowering prices
- Access to geographically dispersed renewable energy to offset high-emissions fossil fuel-based generation
- Energy sharing between regions, reducing the requirements for energy storage and dispatchable generation, lowering system costs and energy prices
- The connection of strategically located large energy storage projects including Snowy 2.0, so these firming resources can be shared between regions
- An increase in diversity of supply options, improving system security and resilience

As coal generators leave the system and new geographically dispersed renewable generators are built, the transmission system must evolve to connect new resources and to strengthen interconnection.

1.2. The cost of congestion

Congestion occurs because there are physical limits to the network's ability to carry electricity securely and safely. The increased deployment of renewables into a grid with limited spare capacity is increasing congestion, meaning that at times with high wind and solar generation there is often not enough transmission capacity to transmit all the power to consumers, so an increasing proportion is spilled (or curtailed).

Curtailment of renewable generation is up 40% in 2023 compared to the year prior, driven primarily by increases in NSW and Victoria.[18]

Figure 13 presents the lost financial value in the NEM due to transmission congestion or power system security constraints being reached and potential low-cost renewable power being replaced with more expensive fossil-fuel generation. This has grown significantly since 2018 and a record $500 million was lost due to constraints in 2022. The largest lost value due to congestion and system security constraints is observed in NSW.

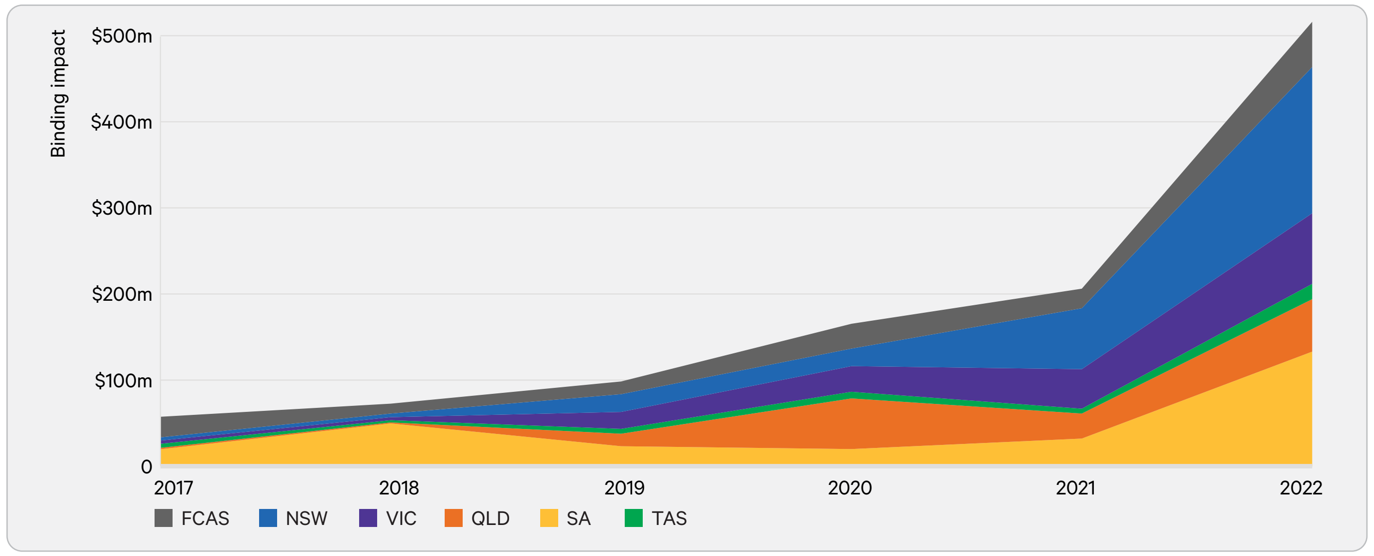


Figure 13: Lost financial value due to congestion and constraints in the NEM [19]

18. https://aemo.com.au/newsroom/news-updates/aemo-ceo-speech-at-ceda-rewiring-the-nation
19. AEMO, 2022, Congestion Information Resource, https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/system-operations/congestion-information-resource/statistical-reporting-streams

> "From January to March 2023, the links from Victoria to NSW and Tasmania were at their limits for 42% and 57% of the time respectively. And during those hours when the sun is producing free electrons, the links were binding for two-thirds of the time to NSW, and over 80% of the time to Tasmania. In other words, parts of our energy highway are at gridlock."
>
> Daniel Westerman, AEMO[20]

The implications of limited transmission interconnectivity between states are also starting to show. Price separation is appearing between states with higher penetrations of renewables. In Q1 2023, wholesale prices were negative in Victoria and South Australia for 50-60% of the time between 9am – 5pm.[21]

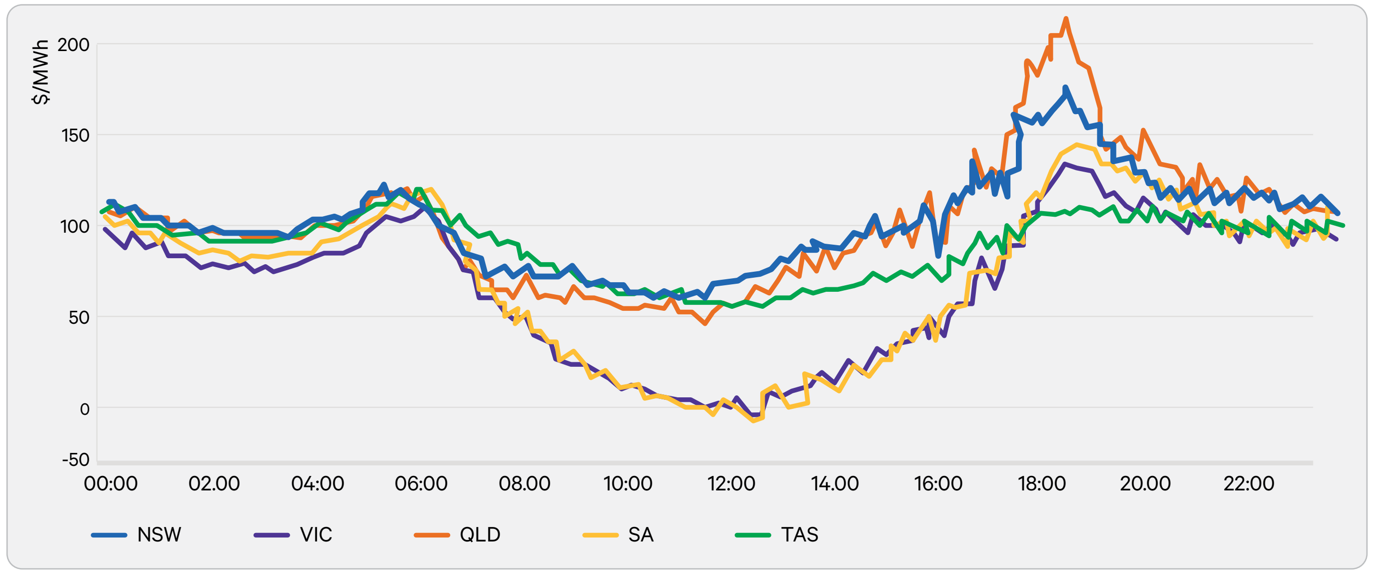


Figure 14: Average NEM prices by state in Q1 2023.[22]

20. https://aemo.com.au/newsroom/news-updates/aemo-ceo-speech-at-ceda-rewiring-the-nation
21. https://aemo.com.au/newsroom/news-updates/aemo-ceo-speech-at-ceda-rewiring-the-nation
22. AEMO, 2023, Quarterly Energy Dynamics

1.3. The new energy superhighway

AEMO's Integrated System Plan, the NSW Government's Electricity Infrastructure Roadmap and Transgrid's Transmission Annual Planning Report outline a co-developed and comprehensive plan to support the transformation of the energy system. These plans have identified essential development paths for transmission infrastructure in NSW, as part of a broader plan for 18 separate transmission projects and more than 10,000 km of new transmission lines across the NEM.[23]

In NSW, the new energy superhighway – strengthening the backbone of the power system – will include:

Southern Superhighway (2024–2028)

- EnergyConnect 2024-26
- HumeLink 2026
- VNI West 2028

1,600km Line

$7b* Investment

3GW Direct renewables plus Snowy 2.0

- **EnergyConnect** – Delivery date 2024 (stage 1) and 2026 (stage 2), enabling the sharing of energy and unlocking renewables between NSW, South Australia and Victoria
- **HumeLink** – Delivery date 2026, enabling the integration of new, clean energy from South-West NSW REZ and unlocking the full capacity of Snowy 2.0 to be shared with the Sydney, Wollongong and Newcastle load centres
- **VNI West** – Accelerated delivery date to 2028, facilitating greater energy sharing between NSW and Victoria and connecting into EnergyConnect

Sydney Ring (2028–2031)

- Hunter Transmission Project 2028
- Sydney Southern Ring 2031

240km Line

$2.5b* Investment

10GW Renewables

- **Hunter Transmission Project#** – Delivery date 2028, reinforcing supply to Sydney, Newcastle and Wollongong load centres and facilitating the flow of electricity between the Central West Orana renewable energy zone and Sydney. This also includes enabling the 850MW Waratah Super Battery to unlock extra transmission capacity into the Sydney region
- **Sydney Southern Ring** – Delivery date 2031, strengthening southern connection to Sydney, facilitating additional flow from HumeLink

Northern Superhighway (2028–2033)

- New England REZ transmission link 2028 (phase 1)
- QNI Connect 2033

580km Line

$5b* Investment

6GW Added network capacity

- **New England renewable energy zones transmission link** – Delivery date 2028 (phase 1), enabling New England REZ capacity to reach Sydney, Wollongong Newcastle load centres
- **QNI Connect** – Delivery date 2033, enabling greater sharing of renewable energy between NSW and Queensland

23. AEMO, 2022 ISP, pg. 12-13

* Estimated investment cost based on AEMO's Draft 2023 Transmission Expansion Options Report, AEMO 2022 Integrated System Plan and Transgrid estimates

\# The Hunter Transmission Project is a NSW State Government Priority Transmission Infrastructure Project. It is present here to show its essential need in closing the Sydney Ring. Investment costs are presented as per AEMO's Draft 2023 Transmission Expansion Options Report.

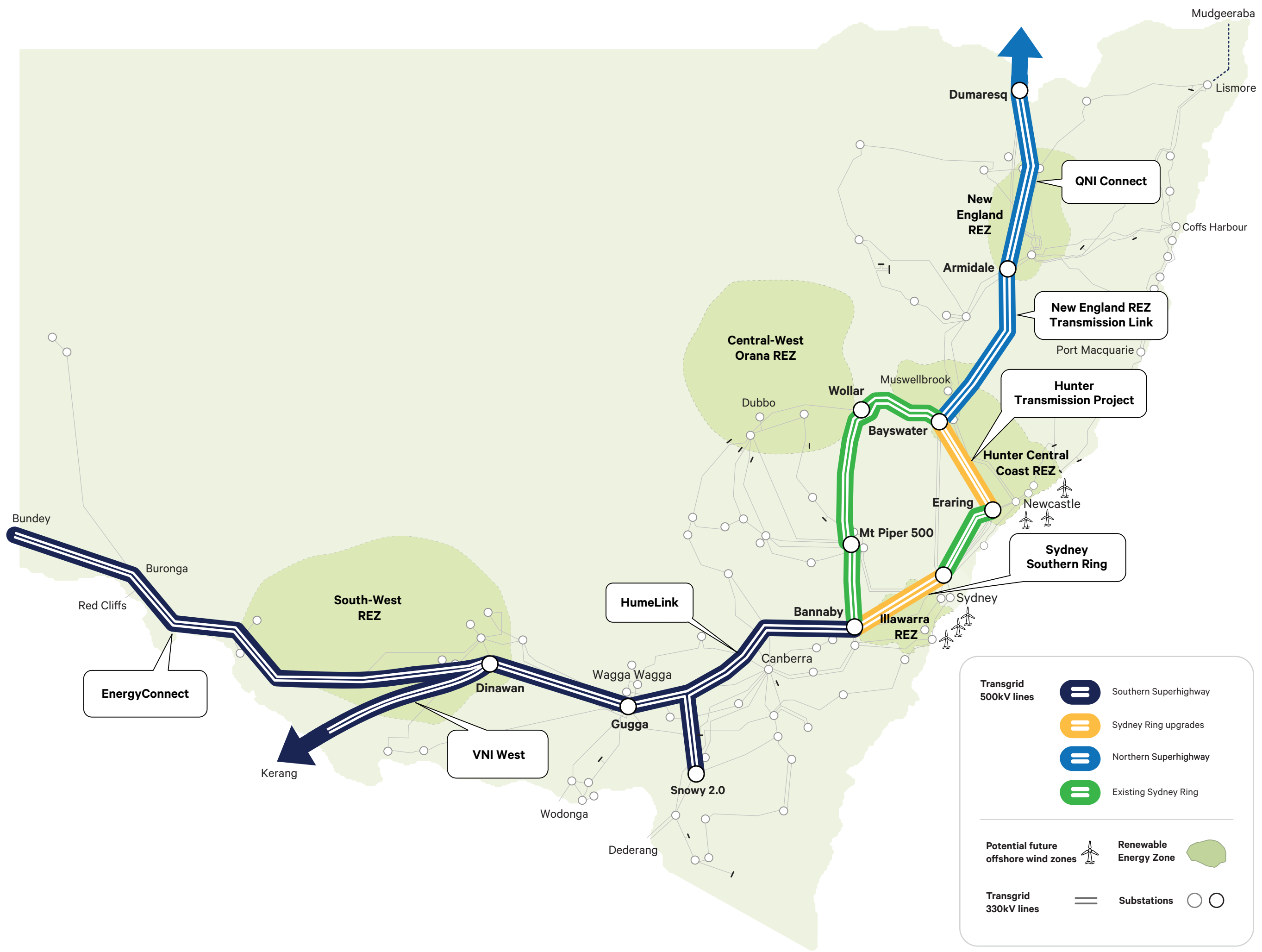


Figure 15: Key NSW transmission infrastructure development projects

The connection of renewable energy zones, upgrades to the transmission backbone and strengthened connections between states will help to alleviate the costly congestion that is growing across the grid. Transmission infrastructure must match renewable capacity development and be ready before thermal generator retirement.

- **Delays will lead to higher energy bills.** For every day that the optimal development path of AEMO's Integrated System Plan is delayed, average residential consumer bills will increase by around $1 (in 2022 real dollars). A one-year delay in the optimal development path's transmission investment will cost residential and business customers in the NEM $900m per year over the period of 2026-40. A four-year delay would cost a staggering $82bn over that same 15-year period.[24] The extra cost would be due to the need for expensive gas or coal generation to replace underutilised renewable capacity – an eventuality that would also jeopardise emissions targets.
- **Accelerating interconnection will increase reliability.** Developing more interconnectors will enable NSW, Victoria and South Australia to support each other through unexpected outages, with insurance value working in both directions. NSW is forecast to exceed the 0.002% Unserved Energy reliability standard by 2027-28 if transmission projects, such as HumeLink and the Hunter Transmission Project, are not completed by this time.[25]

24. Nexa Advisory with Endgame Economics, 2022, Modelling Electricity Bill Impact of Transmission Project Delays, https://www.energynetworks.com.au/news/energy-insider/2022-energy-insider/what-a-difference-a-day-can-make-to-energy-prices/ & ENA, 2023, What a difference a day can make to energy prices, https://www.energynetworks.com.au/news/energy-insider/2022-energy-insider/what-a-difference-a-day-can-make-to-energy-prices/

25. AEMO, 2022 Electricity Statement of Opportunity, pg.57

1.4. A global race for resources

Australia is not alone in pursuing a clean energy transition. We are one of many countries racing to secure critical, large-scale equipment, materials and skilled labour to deliver critical energy infrastructure projects in an environment of geopolitical volatility.

This means that transmission projects, renewable and storage developments and system security infrastructure in Australia will be increasingly subject to procurement and supply chain risks, including shortages, price volatility and extended lead times. From March 2020 to March 2022, prices for both aluminium and copper, key components in transmission infrastructure, more than doubled and surged past pre-pandemic levels.[26]

The war in Ukraine has also affected critical energy technology supply chains, with Russia and Ukraine accounting for 33% of world-wide imported semi-finished steel products and 17% of class one Nickel production.[27] Gas shortages in response to the war have driven up the rate of electrification across Europe and increased the speed of their energy transition further.

While producers of transmission infrastructure are working to increase their production capabilities, many are reluctant to build significant new capacity for what is seen as a one-off spike in demand.[28]

1.5. Accelerating and securing the delivery of critical infrastructure

Transgrid is working to ensure our supply chain remains strong and accelerate where possible. Our Powering Tomorrow Together program will accelerate and secure critical infrastructure projects, using a bundling approach to de-risk supply chain and financial pressures.

The Powering Tomorrow Together program, the bundling of procurement for the EnergyConnect, HumeLink and VNI West projects will allow Transgrid to negotiate long-term supply agreements for new equipment and materials necessary, with advance orders that put us ahead of global competition. Transgrid has already secured key equipment with Hitachi Energy, including signing a contract to supply 15 500kV shunt reactors for use on the VNI West and HumeLink projects. The Powering Tomorrow Together program will support further purchasing at scale, ensuring the supply of:

- 14,500 km of transmission line conductor – enough to stretch from Sydney to Los Angeles
- 58,000 tonnes of steel to build 1,350 transmission towers

Bundling projects into the Powering Tomorrow Together program will yield a capex saving of approximately $500 million, from savings in procurement, labour and avoided inflation costs that can be passed onto consumers. Combined with the savings from a three-year acceleration of VNI West made possible by this program, NSW residential customer bills are projected to be reduced by $12 a year.

Powering Tomorrow Together

$500m
capex savings

saves **$12** on customer bills each year

3-year acceleration of VNI West to **2028**

Figure 16: projected savings from the Powering Tomorrow Together program

26. McKinsey, 2022, Building resilient supply chains for the European energy transition
27. McKinsey, 2022, Building resilient supply chains for the European energy transition https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/building-resilient-supply-chains-for-the-european-energy-transition
28. The Economist, 2023, Technology Quarterly 2023, https://www.economist.com/technology-quarterly/2023/04/05/adding-capacity-to-the-electricity-grid-is-not-a-simple-task

1.6. More than just poles and wires

To improve energy reliability, reduce delivery times and lower costs for consumers, Transgrid is developing multiple innovation projects using alternatives to traditional infrastructure. These projects are about unlocking capacity in our existing transmission network:

- Installing SmartValve technology at the Stockdill and Yass substations has enabled 170MW of extra energy to flow between Victoria and New South Wales – enough extra energy to power 30,000 NSW and ACT homes. SmartValves help to increase energy flows on existing transmission lines by diverting electricity from lines that are experiencing constraints to those better able to carry the electrical loads.
- Combining procured battery energy storage as a service at Parkes and Panorama with dynamic reactive power support devices will defer the construction of a new transmission line between Wellington and Parkes.
- Procuring battery energy storage as a service from a battery energy storage system in South-West NSW to increase transfer capacity on the existing network and defer the construction of a new transmission line between Darlington Point and Dinawan.
- Procuring battery energy storage as a service at Gunnedah or Narrabri will cater for increased electricity demand from new industrial loads in the North West Slopes area of NSW, limiting new investment in traditional transmission infrastructure.
- Procuring compressed air storage as a service for backup supply at Broken Hill, when the single 220kV transmission line is out of service due to a planned or unplanned outage. Backup power supply was historically provided by two diesel-fired turbines owned and operated by Essential Energy.
- Facilitating the delivery of the 850MW Waratah Super Battery and delivering a special protection scheme and additional network upgrades to unlock capacity and energy security following the planned closure of the Eraring Power Station in mid-2025. The Waratah Super Battery provides a virtual transmission solution that unlocks latent capacity in the existing transmission system, allowing consumers in the Sydney, Newcastle, Wollongong demand centres to access more energy from existing generators.

These projects are just the beginning. As the clean energy transition powers forward, Transgrid must continue to test, trial, prove and implement innovative technologies that can unlock extra transmission capacity on our network and lower costs for NSW consumers.

1.7. Securing talent, growing skills

To ensure the delivery of Transgrid's critical transmission projects, we will need to add over 400 permanent employees and many more contracted workers over the next 5 years. Much of this work will be in regional New South Wales, bringing new opportunities to these communities.

In the context of a major clean energy skills shortage, Transgrid is looking to develop future talent through up-skilling or side-skilling parts of the existing industrial workforce and nurturing emerging talent entering the workforce for the first time.

- **Retaining, redeploying and reskilling the talent we know**. We are creating more flexibility in how people can move around the organisation, so teams and skills can be redeployed as demand for roles shifts. Training will play a crucial role in this, enabling employees to handle ever more complex issues and contribute across functions. To ensure we have the construction talent on the ground to deliver transmission projects, we are implementing a re-engagement program to help contractors transition between projects.
- **Attracting new talent from other markets**. Transgrid has established a roadmap to recruit talent from other industries and from overseas. Within Australia, this includes pursuing alternative pathways for talent in the energy sector via cross-boarding development in aligned skills industries, including emergency services, defence, mining, manufacturing and oil and gas.
- **Developing future talent in Australia**. Transgrid is increasing the training available in regional centres that will host most of the state's clean energy infrastructure. We are partnering with the regional universities in Wagga Wagga and Newcastle to develop opportunities and collaborative support for research, infrastructure, training, and education and employment pipelines for regional areas.

Pillar 2: System security

Decoupling system security from coal generation

As coal generators become less available and retire, and new inverter-based renewables connect to the grid, new sources of system security services are urgently needed. Only once we have decoupled the provision of system security services from thermal generation can the grid operate at 100% instantaneous renewables.

Over the next decade, Transgrid expects that the provision of new system security infrastructure to replace security services currently provided by coal generators in NSW requires an investment of approximately $2.2 billion.

To 2033, system security investment in NSW is expected to represent approximately 1.5% of NSW's total electricity system spending, including spending on generation, storage, system security, the distribution network and consumer spending on distributed energy resources.

Proactively investing in new system strength capacity is projected to deliver $5 in benefits to consumers for every $1 spent, by unlocking low-cost renewable energy and reducing dependence on aging and high-cost fossil fuel generators to provide these services on an ongoing basis.

2.1. System security: the heartbeat of the power system

System security services have traditionally been provided by synchronous machines, such as coal, gas and hydro generators, as an inherent by-product of their generation of electricity. We can think of synchronous machines as providing a strong heartbeat to the power system, helping ensure that the signal of the electricity waveform remains strong.

These units are 'electro-magnetically' coupled to the grid, meaning every generating unit in the whole of the NEM spins in sync, 50 times per second. The mass of the spinning turbines (each weighing tens or hundreds of tonnes) and their electro-magnetic coupling allow them to absorb or respond to shockwaves that result from unexpected events or disruptions to the network (such as equipment trips or failures). These synchronous machines help the system operate within a secure technical envelope, by providing reactive support, inertia and fault ride through capabilities.

Wind, solar and battery storage systems use inverter-based methods for grid connection and typically require a strong voltage waveform from the grid to 'lock' onto and follow. Hence, they are known as 'grid-following' renewables or batteries.[29] If the grid's voltage waveform wavers due to a disturbance, then grid-following renewables may become unstable and disconnect. They need a strong source of system security to operate stably.

Just like a human heartbeat, ensuring that the grid's heartbeat remains strong and consistent as coal generators retire from the system and renewables are connected is critical to maintain the functioning of the power system.

Under the NER, Transgrid is responsible for ensuring the power system 'heartbeat' in NSW remains strong, by maintaining specified levels of key system security services including system strength, inertia and voltage control.

2.2. Gaps in system security are emerging

The NSW power system has historically relied on a minimum combination of coal generating units to be online at all times, to provide the stable heartbeat of system security to keep the grid operating within its safe technical envelope. This can no longer be assumed.

More than 80% of NSW's coal capacity is projected to retire in the next ten years.[30] Yet even prior to retirement, there could be periods of the year where only half of the coal units are generating power, and therefore providing system security, a result of co-incident planned maintenance, unplanned outages and decisions by owners to 'economically decommit' their plant during periods of low wholesale market prices.

29. Some utility scale battery storage systems have the ability to operate in grid-forming modes. Future technological developments could extend grid-forming modes of operation to other renewable generation sources. See "What is a grid forming battery" on page 26.

30. Or 7GW of coal capacity, as projected under AEMO's Step Change scenario (in addition to the recent retirement of the Liddell

Figure 17 shows that by FY2025, periods are projected when generation dispatched in the energy market does not include enough synchronous units to keep the NSW power system secure, as shown by the yellow line falling below the minimum requirements (dotted black line). This will become more common; AEMO estimates this will occur for at least 30% of the time in FY2026 (following the planned retirement of the Eraring Power Station, dark green line) and 100% of the time by FY2028 (following the anticipated retirement of Vales Point Power Station, light green line).[31]

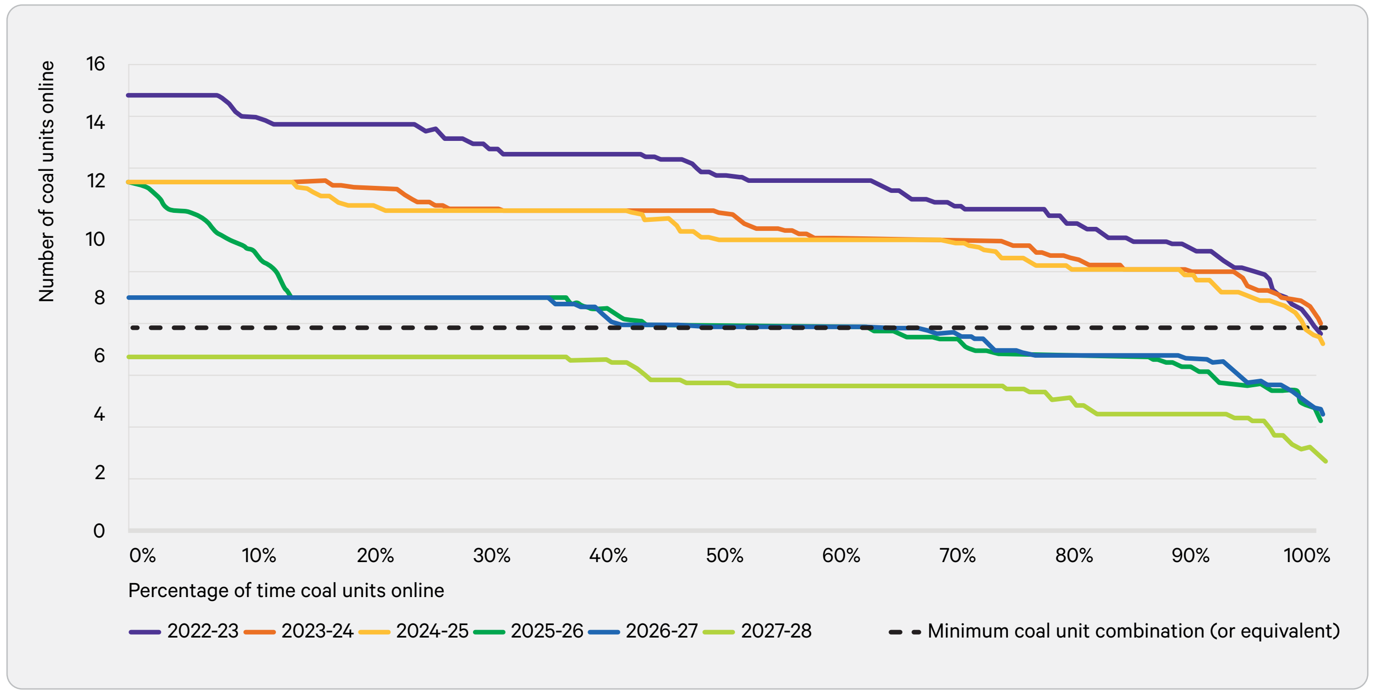
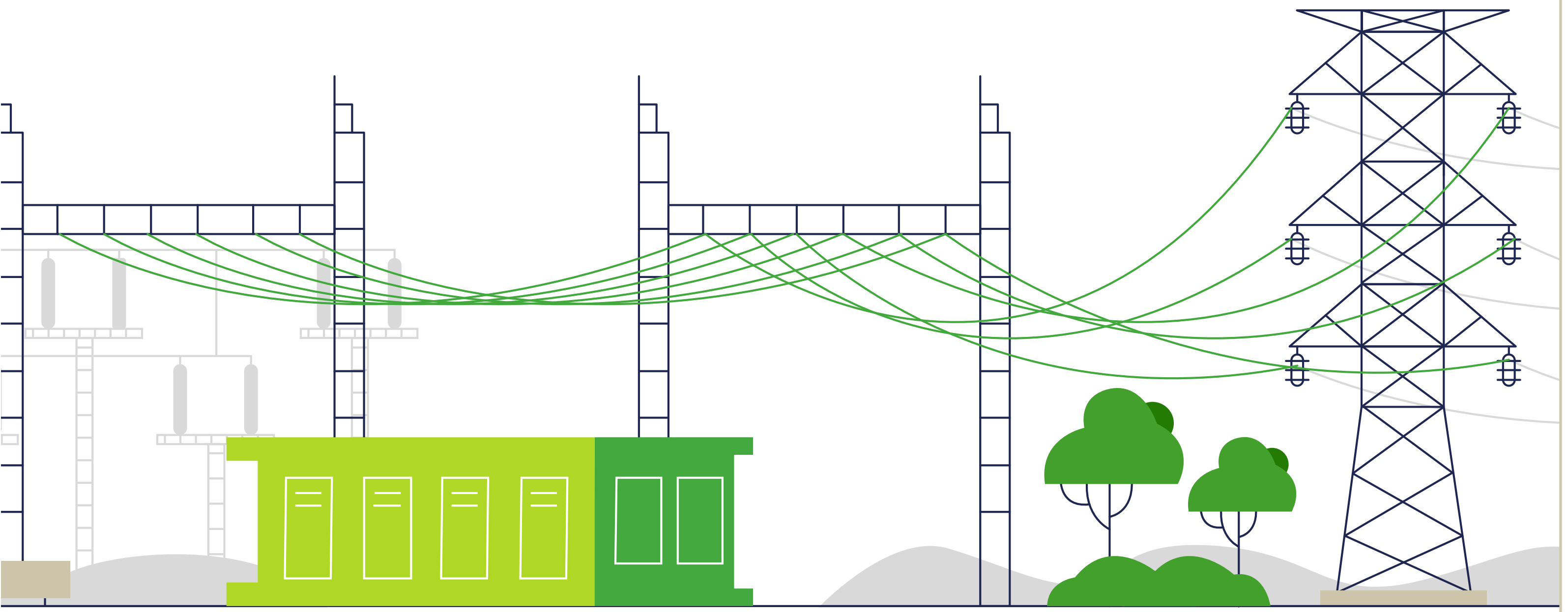


Figure 17: Number of coal units projected online under Step Change scenario in NSW[32]

In the operational timeframe, if there aren't sufficient synchronous generators online to provide system security services, AEMO must intervene to keep the grid secure. This can include directing generators (or loads) to operate in a certain way to deliver essential services, or directing Network Service Providers to return lines or elements to service. Yet as Figure 17 shows, in the coming years there may not be sufficient synchronous generators available. New replacement capacity is urgently needed.



Power Station in NSW).

31. AEMO, 2022, System Security Reports, https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/system-security-planning
32. AEMO, 2022, System Security Reports

The power system is operating within a secure operating envelope when technical parameters of the power system are maintained within defined limits, such as voltage, frequency, current, power quality and fault levels. These technical limits are necessary to keep the power system safe and secure.

Key system security terms include:

System strength: the power system's ability to maintain and control the voltage waveform at any given location in the power system, both during steady state operation and following a disturbance.[33] A power system with inadequate system strength risks instability and supply interruptions. In a system with low system strength:[34]

- Generators may be unable to remain connected during disturbances;
- Control of the system voltage becomes more difficult;
- Protection systems that ensure safe network operation may not operate correctly.

High system strength improves our grids resilience to disturbances. If there's a fault or unexpected change on the grid, the voltage waveforms won't change much and will recover quickly, allowing us to operate our power system safely and stably with minimal impact to energy consumers.[35]

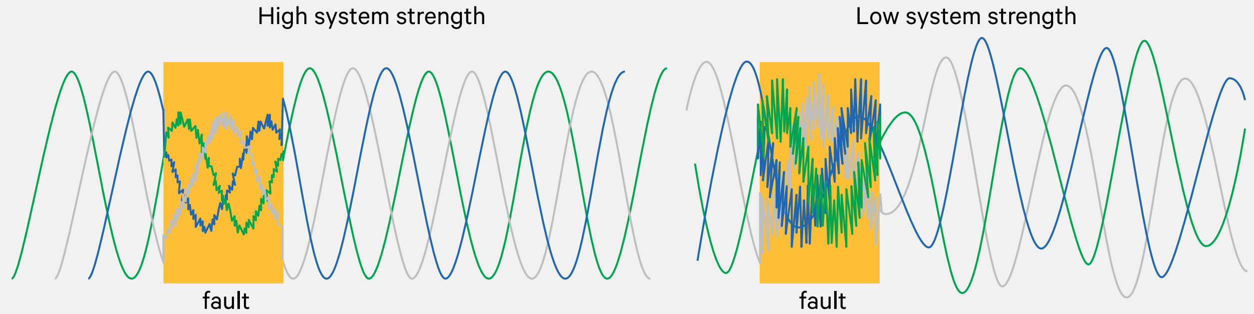


Figure 18: The difference in voltage waveforms during and after a fault, for systems with high and low system strength (stylised representation) [36]

Inertia: the immediate, inherent, electrical power exchange from a device on the power system in response to a frequency disturbance[37], caused by a sudden unbalance of supply and demand. Following a sudden disturbance, the inertia of the power system helps slow down the Rate of Change of Frequency (RoCoF), helping to stabilise the power system and reduce the risk of cascading disconnections. Cascading disconnections are possible if the frequency of the power system deviates significantly from its normal 50Hz value.

Voltage stability: the ability of the power system to maintain or recover voltage magnitudes to acceptable levels following a contingency event[38], ensuring the system doesn't enter voltage collapse.

In addition to the system security terms defined above, there are other additional forms of security and stability which needs to be carefully planned for and managed, including **transient stability, oscillatory stability, control system stability, frequency stability and power quality**.

33. AEMO, 2022, System Strength Requirements Methodology and System Strength Impact Assessment Guidelines amendments consultation, https://aemo.com.au/consultations/current-and-closed-consultations/ssrmiag
34. AEMO, 2022, System Strength Requirements Methodology and System Strength Impact Assessment Guidelines amendments consultation, https://aemo.com.au/consultations/current-and-closed-consultations/ssrmiag
35. AEMO, 2020, Energy Explained: System Strength, https://aemo.com.au/learn/energy-explained/energy-101/energy-explained-system-strength
36. AEMO, 2020, Energy Explained: System Strength, https://aemo.com.au/learn/energy-explained/energy-101/energy-explained-system-strength
37. AEMO, 2023, Inertia in the NEM explained, https://aemo.com.au/-/media/files/initiatives/engineering-framework/2023/inertia-in-the-nem-explained.pdf?la=en
38. AEMO, 2023, Power system stability guidelines, https://www.aemo.com.au/-/media/files/electricity/nem/security_and_reliability/congestion-information/2016/power-system-stability-guidelines.pdf

2.3. Resolving system strength is key to enable 100% instantaneous renewables

System strength provision is essential for the safe and secure operation of the power system. Gaps in system strength will be one of the first, and most significant, challenges for Transgrid to resolve.

As system strength gaps emerge, Transgrid must put in place new technologies and services to diversify and decouple system strength services from the operation of thermal generation units. Only with sufficient system strength services from non-thermal assets (i.e., not from coal or gas) will the grid be able to operate at 100% instantaneous renewables.

Our analysis suggests that the technologies that resolve system strength can also (with relatively minor adjustments) help meet requirements for inertia and voltage control – making system strength a pivotal service on which to focus.

By mid-2025, following the planned retirement of the Eraring Power Station, NSW is projected to have periods without enough synchronous generating units online to keep the power system operating safely.

Analysis in Figure 19 shows that this 'shortfall' will grow as coal generators progressively retire, becoming four times larger once all coal retires from NSW (the gap between the coloured bars and the minimum requirements in black). Much of the remaining system strength that NSW can rely on will come from interstate, as a function of other states meeting their own system strength requirements.

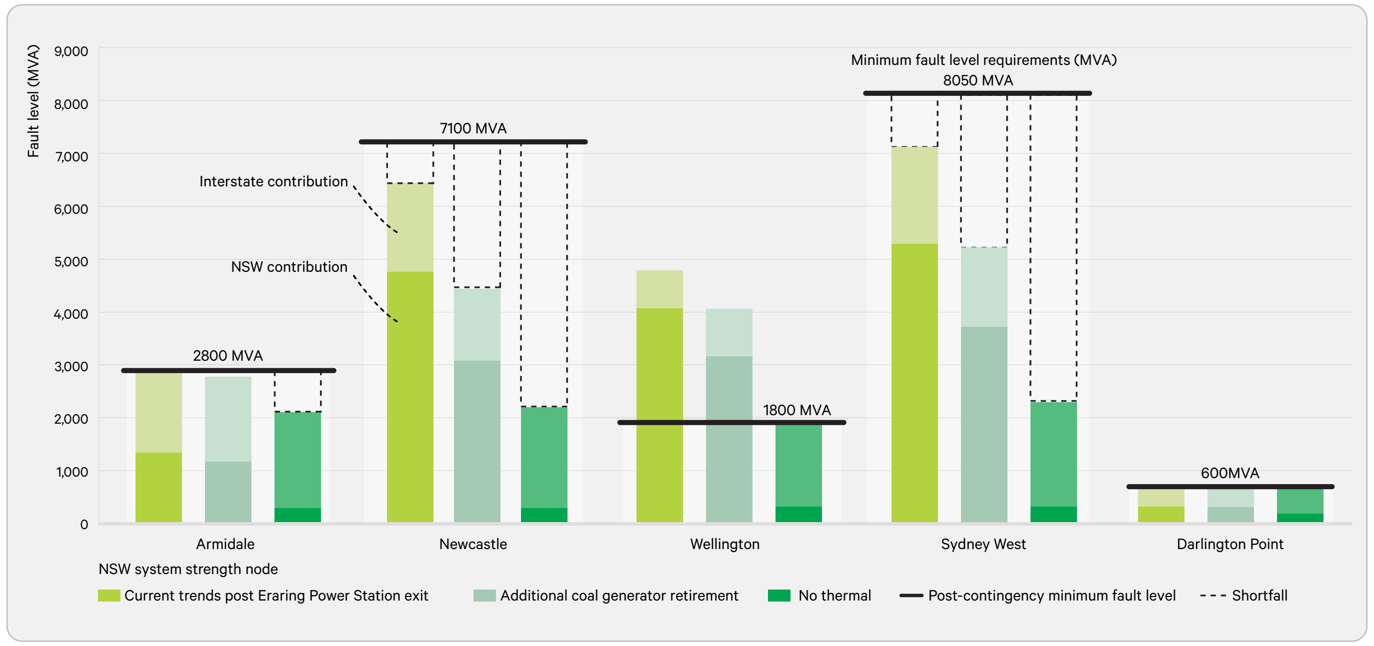


Figure 19: System strength provision in NSW to meet minimum post-contingency fault current requirements as coal units retire

In addition to providing the minimum amount of system strength to keep the power system safe, new renewable energy deployments must be matched by an equivalent growth in new system strength services. More than 20GW of new largescale inverter-based renewables will be connected in NSW by FY2033. This is projected to grow to 46GW of largescale renewables by 2050.

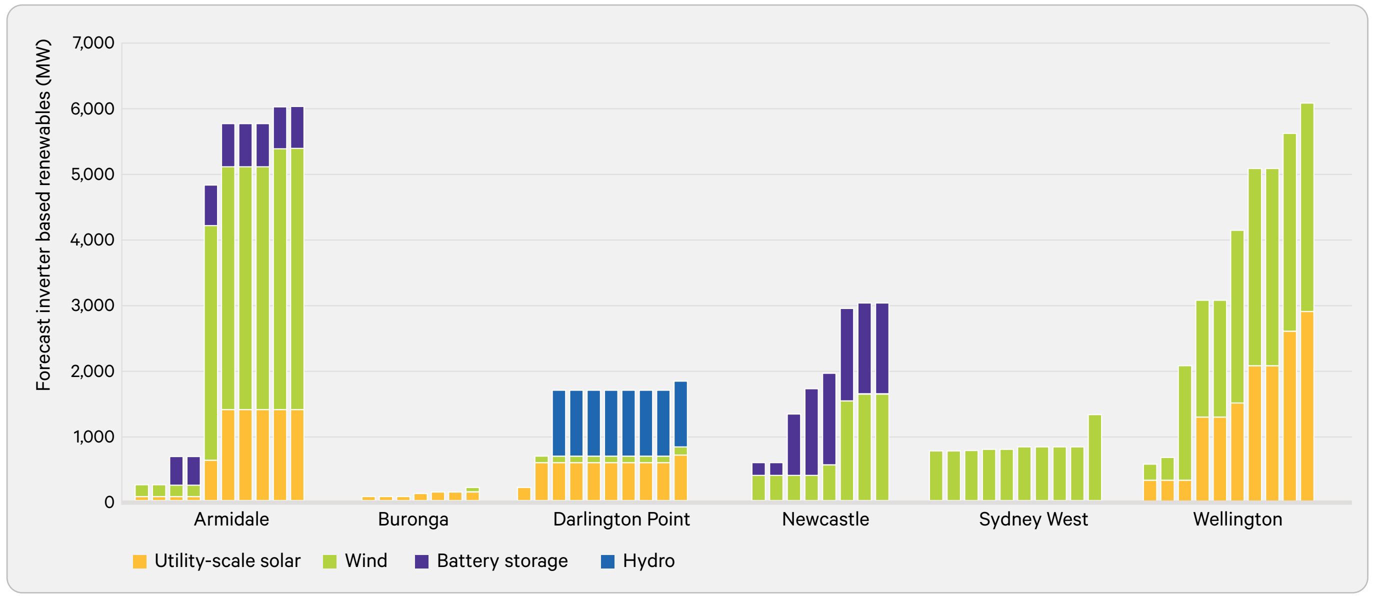


Figure 20: 10-year forecasts of inverter-based renewables projected to connect surrounding system strength nodes in NSW, under AEMO's 2022 Step Change scenario

A new regulatory approach to solving for system strength

From 2 December 2025, a new system strength framework will begin under the NER, requiring Transgrid to deliver system strength on a forward-looking basis to standards set by AEMO. Under this framework, system strength will be effectively 'unbundled' from the operation of the energy market. Transgrid will be required to establish a portfolio of solutions to ensure minimum system strength requirements are met in full at all times of the year. This is a departure from the existing 'Fault Level Rule', where only the 'Shortfall' or gap in NSW's system strength has to be filled.

In addition, Transgrid is required to deploy system strength solutions above the minimum levels to facilitate the stable connection and operation of renewables as they come online in NSW in the coming years.

The conceptual diagram below articulates how Transgrid's system strength obligations will change from 2 December 2025.

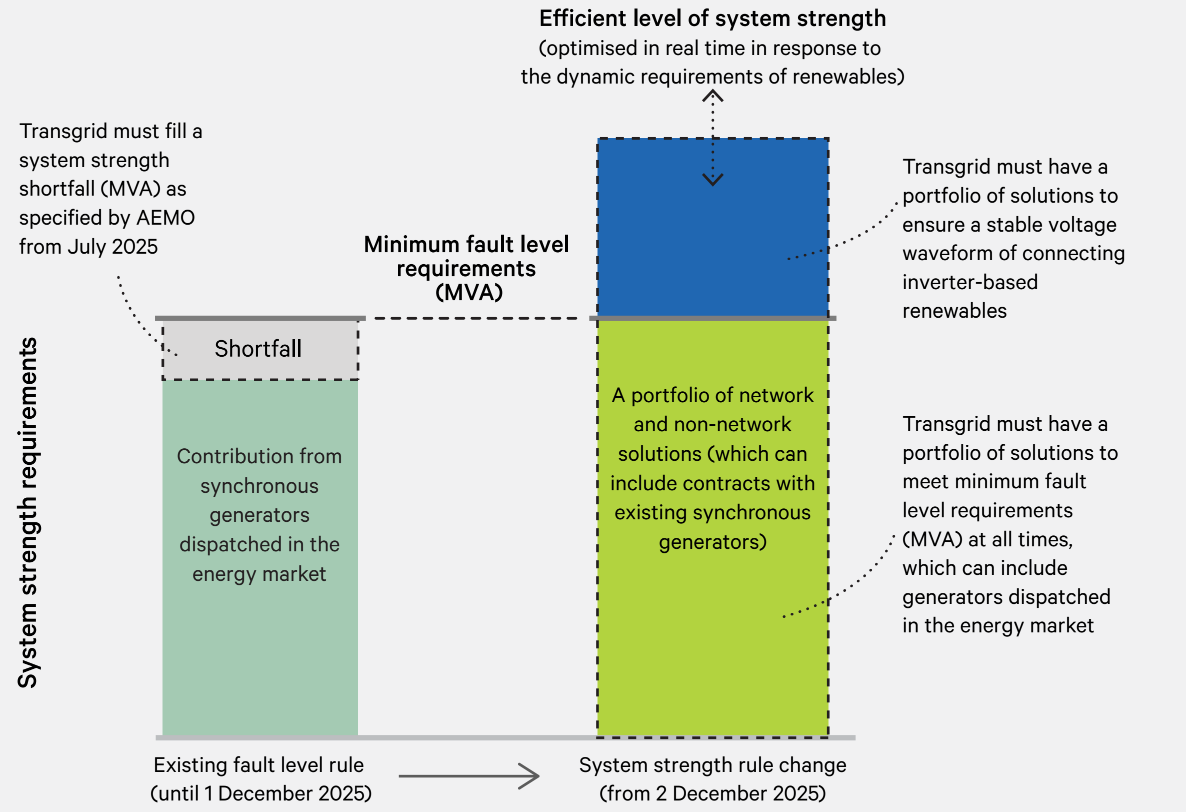


Figure 21: Transgrid's evolving responsibilities for meeting system strength requirements in NSW (conceptual)

Figure 22 shows the combined requirements for system strength remediation in NSW in the next decade: meeting the minimum levels of system strength in full (grey bars) plus additional system strength to support the stable connection and operation of new renewables (coloured bars). As the figure shows, significant system strength is required in the next decade surrounding the Newcastle and Sydney West population and load centres, and surrounding Wellington (Central West REZ) and Armidale (New England REZ).

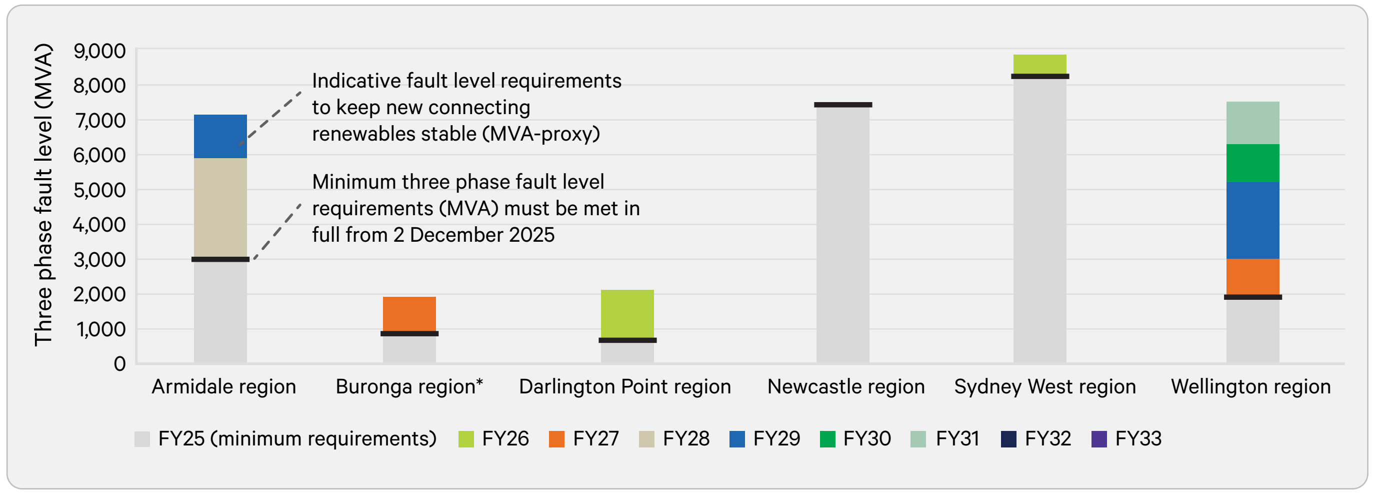


Figure 22: NSW's system strength requirements projected for the coming decade, measured in three phase fault level equivalent

2.4. A diverse range of system strength solutions are available

Transgrid expects to meet its new obligations using a diverse range of existing and novel system strength solutions. We intend to form a portfolio of solutions to best meet power system requirements at the lowest costs to consumers, through our RIT-T process. The range of possible technologies and services we are considering for this portfolio include:

- **Existing synchronous generators** dispatched in the energy market, such as coal, gas and hydro. Contributions from these sources are expected to decrease over time as thermal units retire.
- **Services outside the energy market**, such as existing synchronous hydro units that may be able to operate in 'synchronous condenser' mode, or generators considering converting coal units into synchronous condensers.
- **Synchronous condensers**, which are synchronous motors that spin freely (with no fuel combustion or power generation), used for the purpose of providing system security services.
- **Emerging technologies**, such as batteries, STATCOMs or renewable generation with grid-forming inverters. Grid forming inverter technology has significant potential to provide system strength support, in addition to other grid supporting services such as synthetic inertia, fast frequency response and voltage support.

The retirement of coal generation and the growth in grid-following renewables will require a significant deployment in system strength infrastructure and services. Our analysis suggests that in the next 10 years, the equivalent of up to 21 large 200MVA synchronous condensers will be required to provide sufficient system strength support to NSW, with an indicative cost of $2.2 billion. While these requirements are presented as new synchronous condensers-equivalent, Transgrid believes that a mix of different technology solutions, including existing synchronous generators, will best meet the needs of the power system at the lowest cost to consumers.

Our analysis explored the range of technologies that could contribute to meeting NSW's system strength requirements, including technologies that provide system strength as a function of their operation within the energy market. As compared against minimum system strength requirements at Newcastle, Figure 23 shows:

- The growing gap in system strength provision from coal generators as they progressively retire;
- A range of potential solutions that could meet part of the need, including synchronous condensers, hydro units operating in synchronous condenser mode, a conversation of an existing coal generator to synchronous condensers, grid forming batteries, Snowy 2.0 and grid forming renewables;
- No individual solution is large enough to meet the need on its own, and a portfolio of solutions will be required to meet the need for system strength in NSW.

An overwhelming market response for system strength services

Transgrid's recent Expression of Interest process for non-network solutions to provide system strength resulted in almost 70 potential technology solutions. This included more than 10GW of existing or conversions of existing synchronous generators, a pipeline of 10GW of innovative grid-forming batteries and 5GW of other new generation and energy storage projects, including pumped hydro and gas.

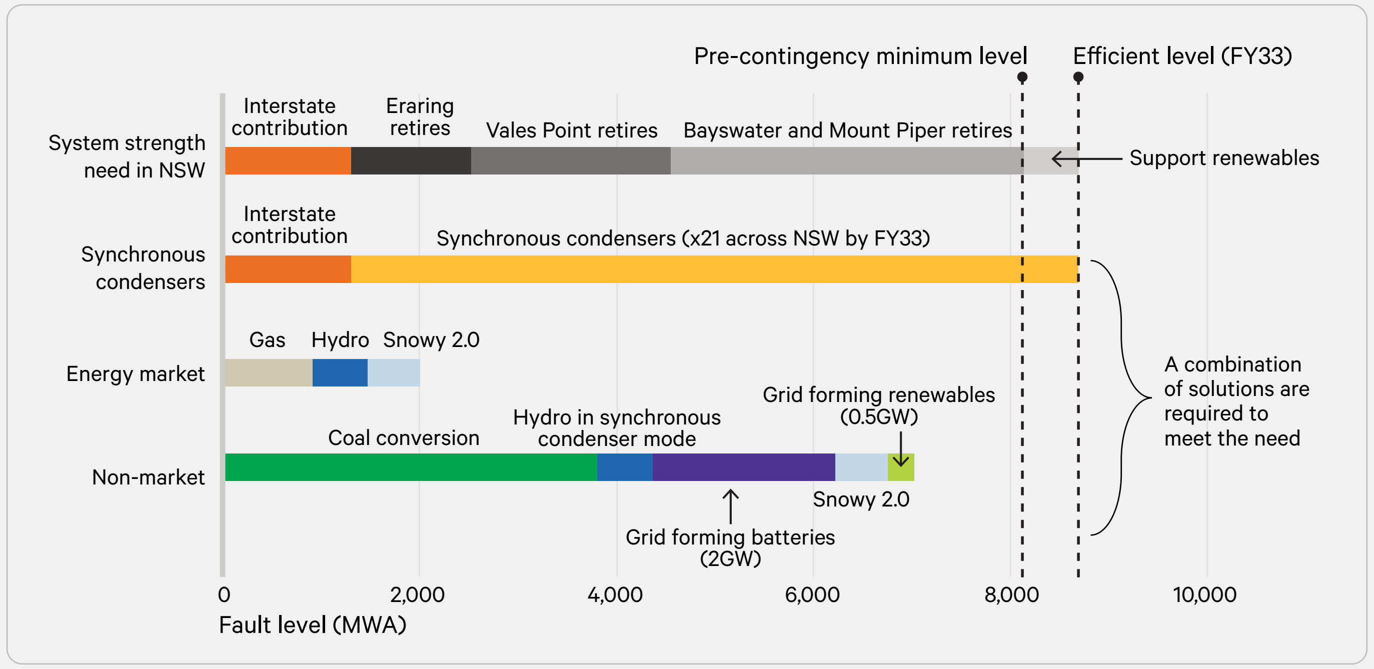


Figure 23: Possible solutions available to meet minimum post-contingency fault level requirements at the Newcastle system strength node as coal generators retire

Transgrid has commissioned economic analysis to explore the costs and benefits of installing new system strength solutions (such as synchronous condensers), versus relying on existing synchronous generators in the energy market (such as coal, gas and hydro), where possible, to meet gaps in system strength.

Results show that proactively investing in new system strength infrastructure or services in NSW will significantly lower costs for consumers, with a net economic benefit of $2.9 billion to FY2042. This would rise to $3.3 billion if one coal generator was to unexpectedly exit the market two years earlier than planned.[39]

The alternative to this investment is for existing gas units to run more frequently to cover gaps in system strength in NSW, with very high operating costs (and greenhouse gas emissions), leading to higher overall costs for consumers.

System strength shortfalls in South Australia

To fill the declared system strength gap in South Australia, ElectraNet commissioned four large high-inertia synchronous condensers in 2021. In the first full quarter following installations, the four synchronous condensers have:

- Reduced the cost of market interventions from $37 million to $7 million, delivering $30 million in savings to consumers in just 3 months. First quarter savings of $30 million indicate that the synchronous condenses could pay for themselves in 1.5 years (on a $185 million capital cost)[40]
- Reduced the required number of gas generators to be operational from four to two (and recently reduced them to just one in certain situations)
- Enabled generation limits to increase, unlocking an extra 800MW of renewable generation capacity

39. Modelling undertaken in 2023 by Endgame Economics for Transgrid
40. AEMO, 2022, Quarterly Energy Dynamics Q1 2022

2.5. Inertia and voltage support requirements follow a similar path

Just like system strength, shortfalls in inertia will grow and voltage issues will become more common as coal generators retire. To keep the power system safe and secure, Transgrid must solve both needs.

Figure 24 highlights inertia levels in NSW following the retirement of the Eraring Power Station, following a subsequent coal generator retirement and after all coal has retired in NSW. Transgrid must plan to ensure that inertia remains above the secure level.

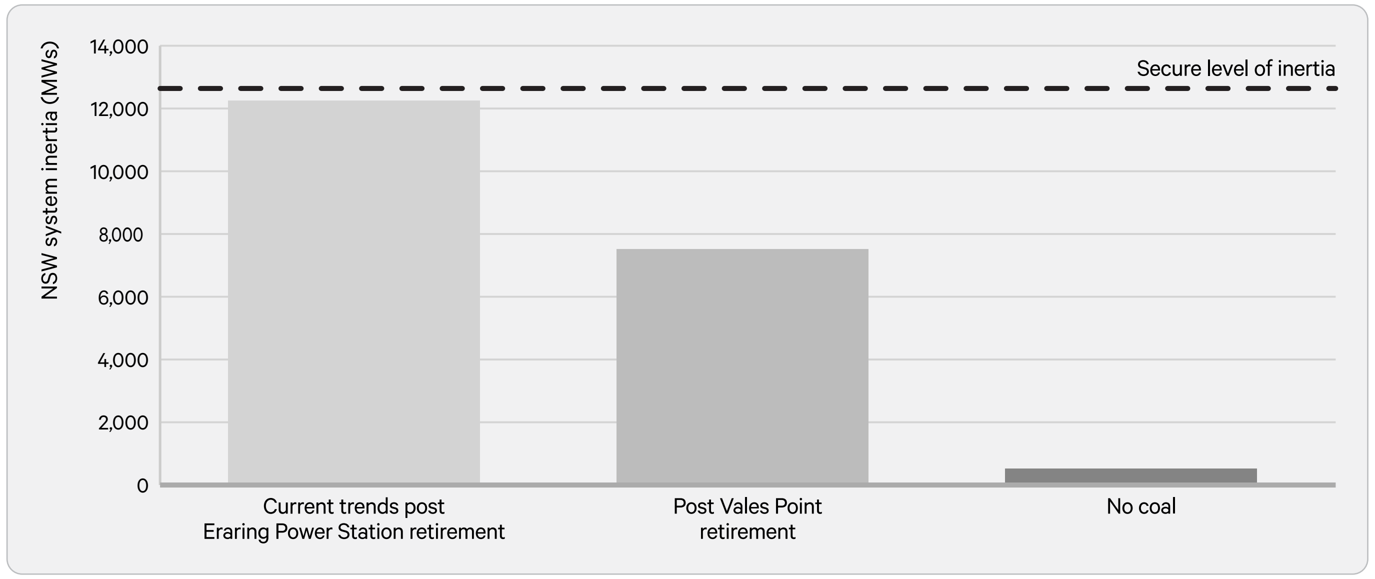


Figure 24: Inertia levels in NSW against minimum requirements as coal generators retire

The NSW transmission system is already seeing high voltages on transmission infrastructure during periods of high renewable generation and low demand, which must be actively managed. As renewable penetration increases, high voltages (and large step changes in voltage) requires remediation or they will begin to breach levels specified to ensure a safe and secure power system. During minimum demand periods, low voltage issues are projected to occur surrounding load centres. Figure 25 highlights locations of voltage violations in a grid operating at 100% instantaneous renewables, without remediation.

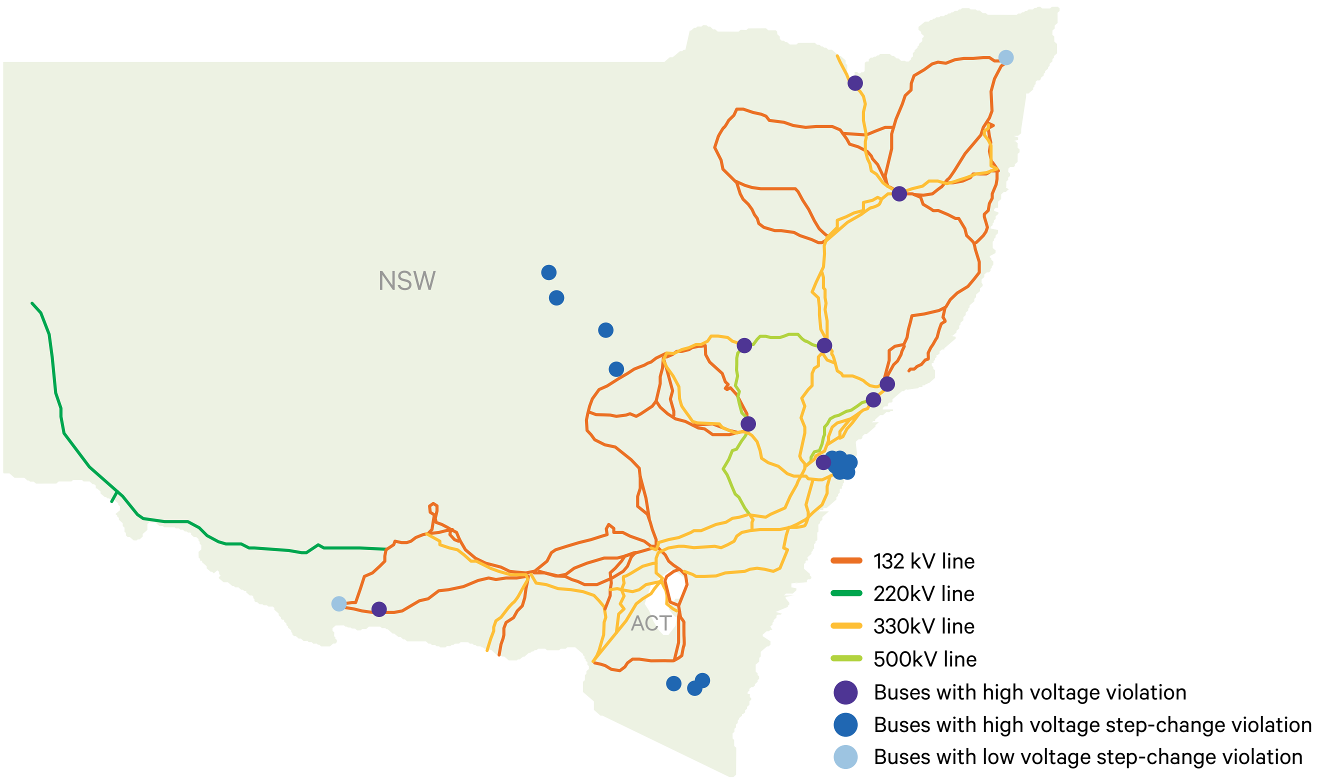


Figure 25: Locations of unmitigated voltage issues if the NSW power system is operating at 100% instantaneous renewables

2.6. A co-optimised approach to meeting system security needs

Co-optimising different technology solutions to meet inertia, system strength and voltage needs will lower the total cost to consumers. Many solutions for system strength can also solve for inertia and voltage support at minimal additional cost. For example, synchronous condensers, which provide system strenght and voltage support, can be fitted with flywheels to also provide inertia at low marginal cost. Adding grid forming capabilities to batteries, which primarily involve software changes, could enable them to provide system strength and inertia at the same time as other services.

Figure 26 shows a raft of possible solutions (including those modelled in Figure 23 for system strength) that could solve future inertia gaps.

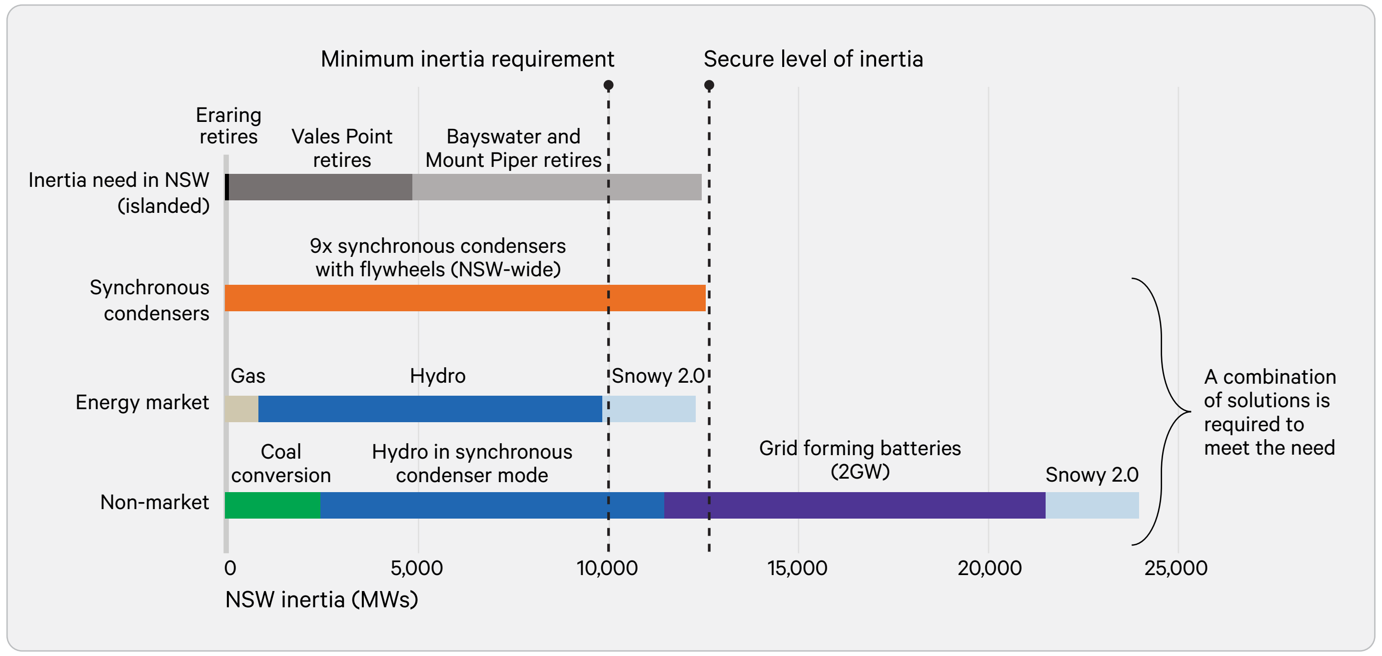


Figure 26 possible solutions available to meet NSW's inertia requirements as coal generators retire

2.7. A promising role for grid-forming inverters in supporting power system security

Grid forming batteries hold significant promise for both inertia and system strength support, in addition to other value streams they are already known to offer.

Through its Wallgrove Grid Battery project, Transgrid is already trialling the use of a 50MW/75MWh lithium-ion battery to provide synthetic inertia services to the NSW transmission network. Wallgrove is not alone; the Hornsdale Power Reserve in South Australia also provides synthetic inertia, and the Torrens Island battery is currently the largest grid forming battery in the world.

Grid forming batteries are yet to be field-tested for system strength provision, but initial analysis indicates that this technology could make a positive contribution. AEMO has recently contracted with Edify Energy's grid forming battery at Koorangie in Victoria to provide services to strengthen the grid. Transgrid is undertaking detailed power system modelling to assess whether, and how many, grid forming batteries would be required to help stabilise grid-following renewables.

Because all of Australia's existing wind and solar generators are grid-following, they need system strength to support their operation. Using grid-forming inverters on renewable plants themselves hasn't been done before in Australia, but could offer an exciting opportunity to reduce the need for additional system strength support, representing a step change in the provision of power system security.

What is a grid forming battery?

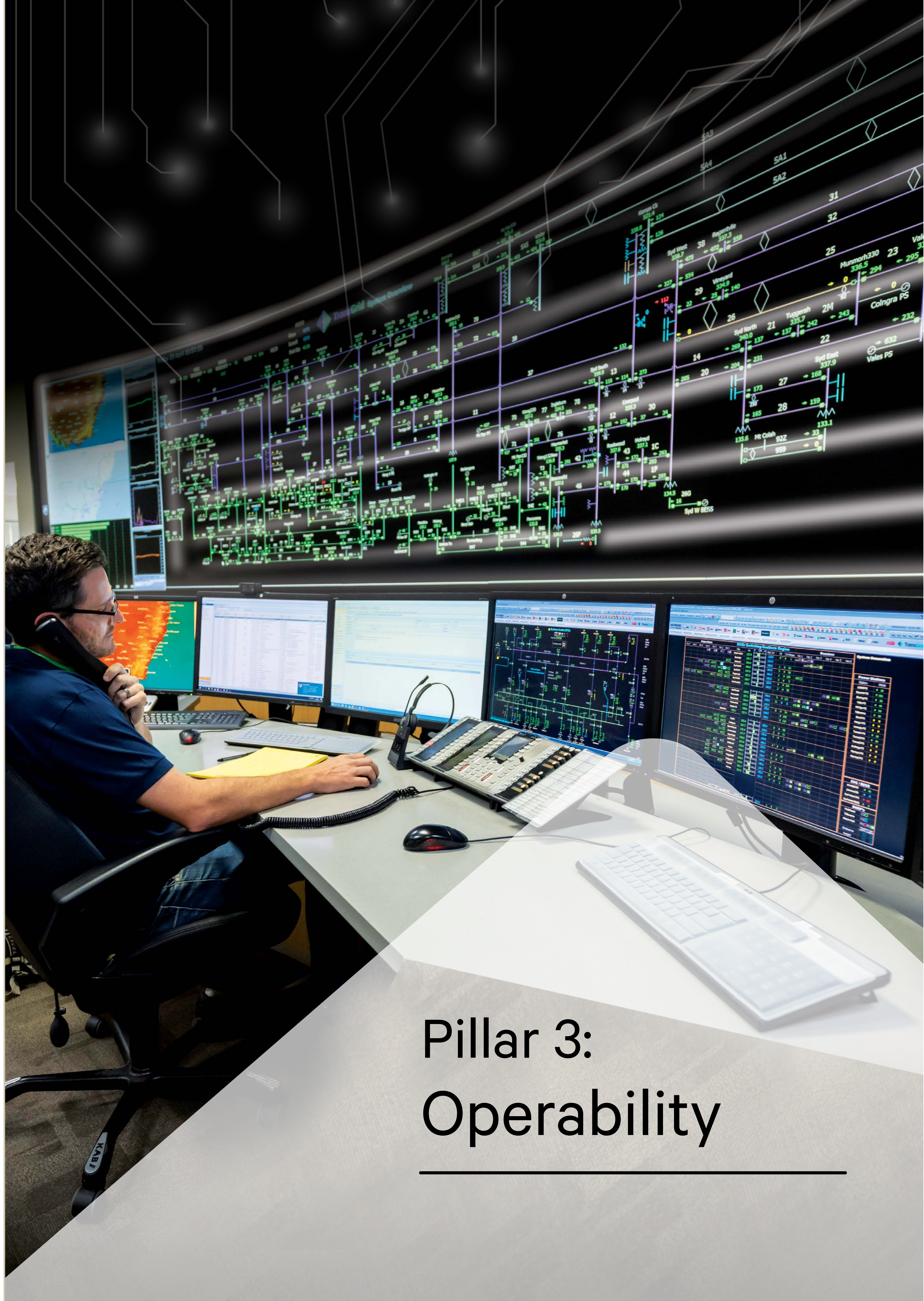
- Most grid scale batteries today are equipped with grid-following inverters, which track and 'follow' the grid's voltage reference. When the voltage waveform is distorted, particularly in areas of low system strength, grid following inverters are prone to unstable behaviour (just like grid-following renewables)
- Grid-forming, or advanced inverters, set their own internal voltage waveform reference and can synchronous with the grid or operate independently of other generation[41]. Grid-forming batteries are expected be able to provide essential system stability services that strengthen the grid by increasing the stability of the voltage waveform.
- This technology has significant potential, but more studies and real-world tests are required to assess and validate their potential. ARENA is currently supporting the rollout of eight grid scale batteries with advanced inverters, representing 2GW / 4.2GWh of capacity. This represents a tenfold increase in grid forming battery storage capacity across the NEM.[42]

41. AEMO, 2021, Application of advanced grid-scale inverters in the NEM
42. Source: ARENA, 2022, ARENA backs eight big batteries to bolster grid, https://arena.gov.au/blog/arena-backs-eight-big-batteries-to-bolster-grid/

2.8. Ongoing analysis is required

Transgrid and the broader industry must undertake further research and analysis to understand the full implications of operating the grid at up to 100% instantaneous renewables. For example, we need to assess the risk of other stability issues outlined in the ‘key system security terms’ box on page 19, such as large-disturbance instability and small signal instability. Not only will new solutions for system security be required, but the control system parameters of the remaining synchronous generators (such as coal, gas and hydro units) may need to be re-tuned.

As the proportion of renewable energy sources in the grid increases, power quality issues, such as harmonics, steady state voltage violations, and voltage flicker are expected to become more prevalent. Transgrid, AEMO and other Network Service Providers must continue to thoroughly assess and rectify potential power system security gaps as the grid transitions to renewables.



Pillar 3: Operability

Pillar 3: Operability

Planning and operating a more complex power system

"Uplifts are needed in real time monitoring, power system modelling, and control room technologies by AEMO and Network Service Providers, to ensure operational staff have the tools to maintain secure operation of the NEM power system as it transitions to significant penetrations of inverter-based resources including Distributed Energy Resources".

AEMO, 2022 Integrated System Plan

Over the next decade, an investment by Transgrid of $140 million will be needed to build new operational technology tools and $16 million per year to increase our staffing levels and training to facilitate the safe and secure transition of NSW's electricity system.

To 2033, investment in operability is projected to represent 0.2% of total electricity system spending in NSW, including on generation, storage, system security, the distribution network and consumer spending on distributed energy resources.

Investing in operability uplift is projected to deliver over $4 in benefits to consumers for every $1 spent by ensuring grid operators are equipped to deal with emerging challenges, and avoiding disruptive and costly power outages that may otherwise occur.

3.1. Driving complexity in the NSW power system

A grid operating at 100% instantaneous renewable energy is a fundamentally different system to plan for, operate and manage. Driving this increase in complexity over the coming decade in NSW is the:

- Accelerated retirement (and reduced operation/availability) of over 7GW of coal generation capacity, reducing the share of synchronous thermal generation from 68% today, to 17% in 2033.
- Tripling of the proportion of generation expected to be provided from intermittent renewable sources, including the connection of 17GW of new large scale renewable generation and storage to the transmission system.
- Integration of at least five renewable energy zones under the NSW Electricity Infrastructure Investment Act 2020, including interfaces with multiple renewable energy zone Network Operators.
- Delivery of a significant program of major transmission projects, including the requirement to take prolonged system outages for construction.
- Almost tripling in capacity of rooftop solar, reducing minimum demand levels and significantly increasing reverse power flows from the distribution to transmission network.
- On-boarding of new technologies with limited historical data and knowledge of operating performance, including grid-forming batteries, SmartValve technology and compressed air systems.

These unprecedented technology and operational changes (and their occurrence in such a condensed timeframe over the next decade) are making it more challenging for Transgrid to plan, manage and operate the NSW power system, and increase operational risk.

Managing the increased complexity of the NSW power system is not a future problem. The system is already more dynamic, unpredictable and is sitting closer to the edge of its secure operating envelope.

Transgrid's existing operational tools and capabilities are now at full capacity.

3.2. Transgrid's role in operating the NSW transmission system

As a Transmission Network Service Provider (TNSP), Transgrid is responsible for the safe, efficient and reliable planning, management and operation of the NSW transmission system.

We perform studies for real-time, next-day, next-week, next-month operations and plan for operations and investment many years into the future.

Our control room is constantly monitoring and interacting with transmission equipment, with generators and our direct-connected customers including distribution network operators. Operators are remotely activating and deactivating transmission equipment to ensure that power flows are stable, operating limits are not exceeded, and that sections of the grid are isolated for maintenance and the connection of new infrastructure, including renewable generators and storage.

With an eye on the immediate future, we manage system security on the transmission subsystem (132kV lines) and ensure the reliability of the high voltage network is not compromised by planned and unplanned equipment outages. We must coordinate with the market operator to ensure that generation is dispatched only where the transmission network can support it – communicating changes in the operating envelope of the transmission network to AEMO so they can appropriately dispatch generators.

We maintain our transmission assets over their entire life cycle, ensuring that the network can deliver exceptionally high reliability and safety. This involves constantly monitoring equipment for changes in operational behaviour and assessing and planning for asset maintenance and renewal.

With an eye even further ahead, we ensure that generators being added to the system are set up where and with operating parameters that the system can reliably and securely support and in anticipation of developing transmission needs.

Transgrid collaborates with AEMO, NSW Government, EnergyCo, NSW distribution networks and other transmission network service providers in adjacent jurisdictions to plan the needs of the transmission system to support forecast changes in generation and demand many years in advance in order to facilitate the energy transition for the benefit of our consumers.

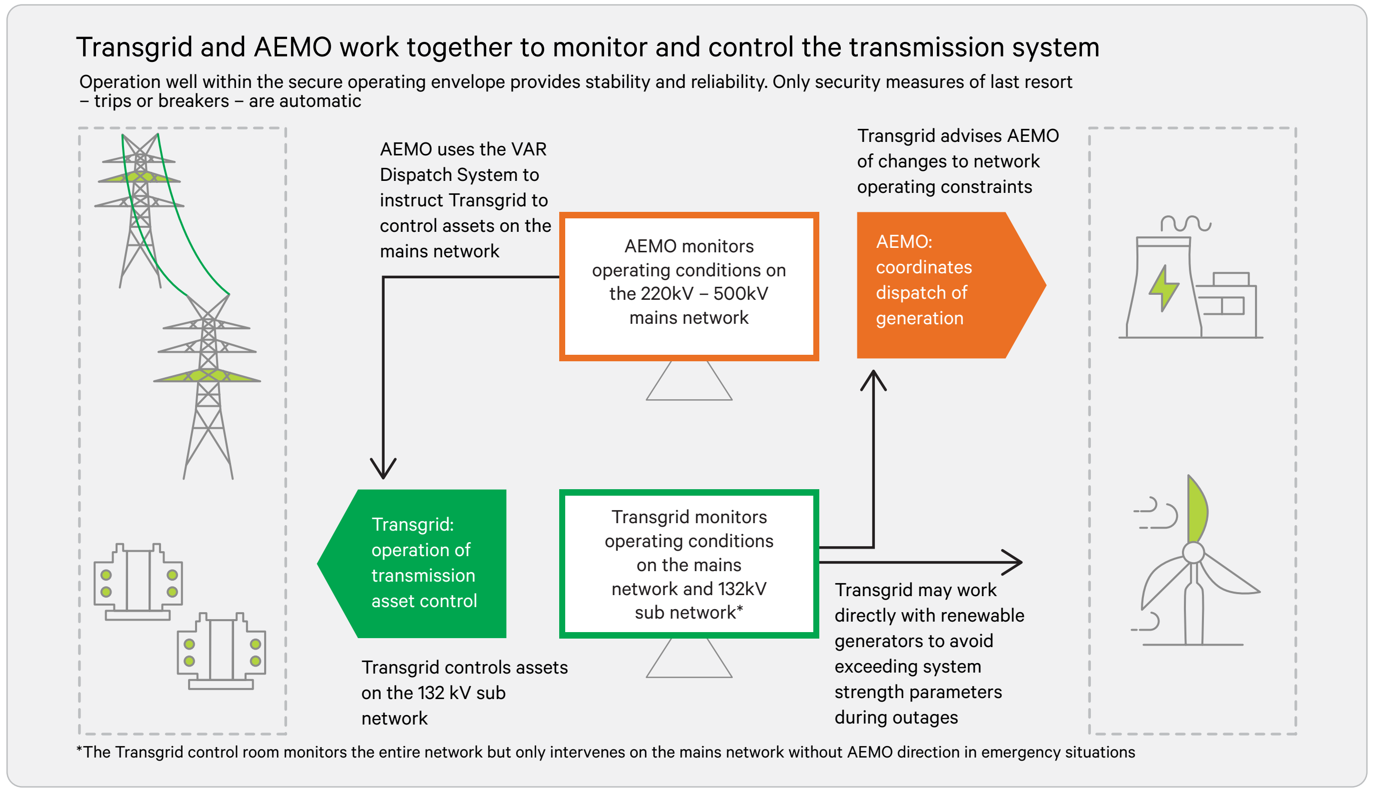


Figure 27: Transgrid and AEMO's overlapping roles for system operations

3.3. A complex network operates closer to the edge

Operating the NSW power system as it transitions towards 100% instantaneous renewable power is resulting in a grid that is sitting closer to its limits for stability and security. This requires more scrutiny from operators who must intervene more often to restore redundancy or be prepared to take rapid action on multiple network assets in the event of an unplanned outage.

Transgrid has already observed that the NSW power system is sitting closer to the edge of its secure operating envelope. This means the system is more likely to tip into insecure operating conditions if a credible contingency occurs. Realtime contingency analysis running in our control rooms shows the times that the loss of a generator or transmission system asset would result in a violation of the power system technical envelope. Figure 28 shows the trend of the contingency analysis results since 2010, where a sharp rise in possible violation events can be seen since the start of this decade – a trend that is projected to continue as the energy transition gathers momentum.

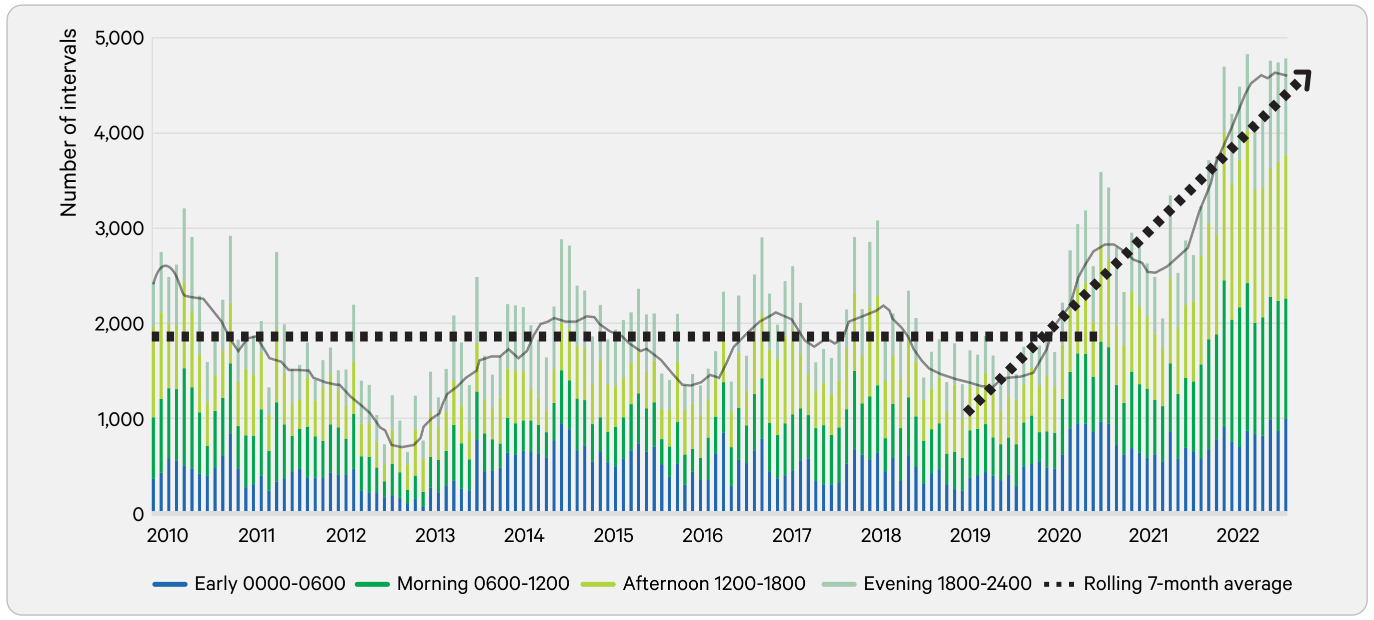


Figure 28: Operating intervals (5 minute granularity) per month when at least one credible contingency on the NSW transmission system would have resulted in a violation of the power system technical envelope, with a simplified trend overlayed

We can see evidence of the growing complexity involved in operating the transmission system.

Between
2015 & 2023

9 to 41
Increase in **Generator Operators** interfacing with our control room

4,000 to 11,000
Increase in **Data Monitoring Devices** across the network

18,000 to 36,000
Increase in **Alarm Monitoring Points**

101 to 184
Increase in generator **connections**, distribution network connections and substations connected to our network

3.4. New connections and system planning require intense scrutiny

For every large coal generator decommissioned, around 20 new wind farms would need to be connected to replace the equivalent energy output. Each new connection and major transmission project requires significant network analysis, planning, energising, testing and commissioning. This work is essential to ensure new generators and transmission assets can meet performance standards, and the power system can operate securely with them online under a range of different conditions and scenarios.

Over the past two years Transgrid has seen a rapid rise in the number of new connection applications across NSW. This will only accelerate with the NSW Government's plans for an additional 12GW of largescale renewable generation capacity to be connected by the end of this decade.

Annual connection applications **Generation capacity (MW)**

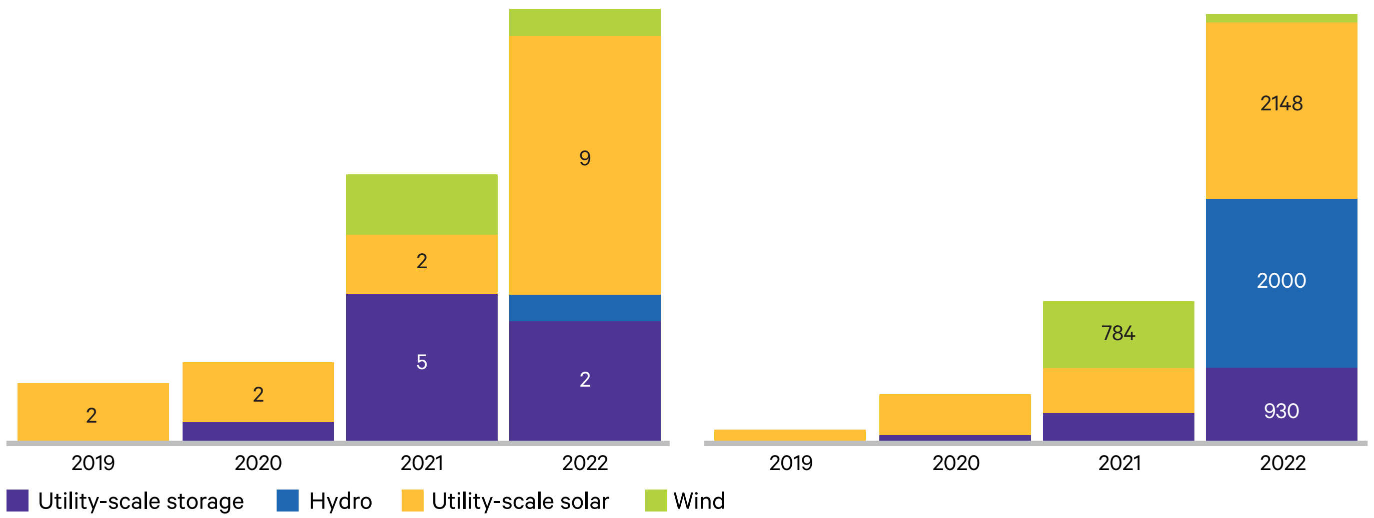


Figure 29: Connection application volumes (number of applications and capacity) in NSW between 2019-2022

The complex and unpredictable interactions of inverter-based resources – wind, solar and battery storage – coupled with the growing number of elements in the network are driving the need for increasingly sophisticated and time-consuming analysis to be undertaken. New generation facilities are being constructed in much shorter timeframes than traditional thermal generators. As connection applications grow, the team and tools to undertake detailed analysis must be scaled to meet the demand.

3.5. Asset management and operation is a delicate balance

Managing transmission assets is not a standalone process. The planned outages required to maintain existing assets and facilitate the connection of new assets must be coordinated with real-time network reliability and security needs. Outages for maintenance can only take place when there is enough redundancy in the network. Spare dispatchable generating capacity is shrinking as coal generators retire, limiting the buffer that the power system has to take planned outages. More dynamic and weather-dependent power flows also reduce the windows of high redundancy for outage planning.

In addition, the dynamic operation of the power system is changing the way our assets are used. Greater largescale renewables, declining minimum demand and increased morning and evening ramping are resulting in greater switching of network equipment, such as capacitor banks and reactive plant. Greater switching accelerates asset fatigue.

As operating patterns change, and new equipment enters the system, effective asset management will require new capabilities, including uplifts in real-time and predictive monitoring.

3.6. Capability and capacity gaps as we approach 100% instantaneous renewables

A complex energy system needs modern tools and skills. The growth in complexity is leading to capability and capacity gaps within Transgrid – gaps that must urgently be addressed if we are to continue to safely and securely operate the NSW power system. Current issues include:

- Limited visibility of real-time power system conditions and limited predictive look-ahead forecasting is creating incomplete system information on which to base operational decisions. This will become ever more problematic as the system becomes more dynamic, with a growing share of intermittent renewable generation.
- Limited capability to manage the complex system outages required to facilitate the construction and commissioning of large volumes of new generators and transmission infrastructure. This capability is essential to support urgent new connections to the transmission network.
- Difficulty in scaling power systems analysis and planning studies to the volumes required to connect very large numbers of new renewable projects to the transmission system. This capability is also required to effectively plan for power system security as coal generation withdraws.

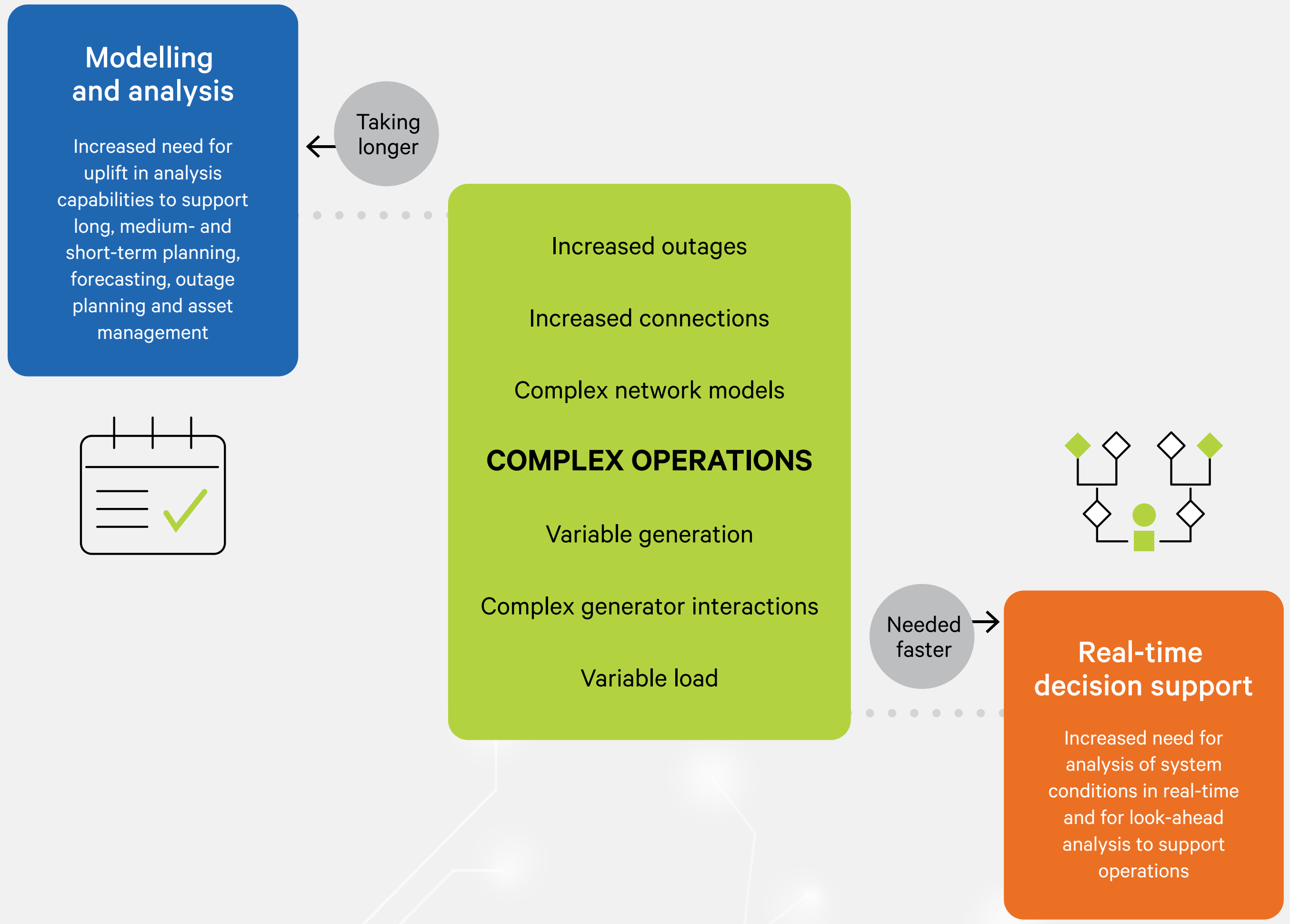


Figure 30: The growing complexity of the power system is driving capability gaps

To play our part in the clean energy transition, Transgrid must have the appropriate systems and skills to plan for, manage and operate the increasingly complex NSW power system. Failing to invest in these capabilities poses unacceptable risks to reliable and secure operation of the transmission network. In addition to delays in generation connection and more conservative operating limits constraining generation dispatch (see 1.2 The Cost of Congestion), failing to uplift capacity and capability could result in greater risks of supply losses.

Expert analysis and advice to Transgrid suggests that, without an uplift in operational capabilities and capacity, the compound effect of increased complexity will lead to a more than five-fold increase in the risk of lost load due to operability incidents on the NSW transmission system by 2030. In addition to more frequent localised events, the chance of an extreme system black event, similar to what was experienced in South Australia in 2016, could rise. Such outages, even when localised, are not just inconvenient but represent safety issues for customers and ultimately real economic costs.

The good news is that the benefits to consumers of preventing these outages with uplifts in operational technology tools and increased headcount and training will outweigh the cost of the uplift by a factor of 5.

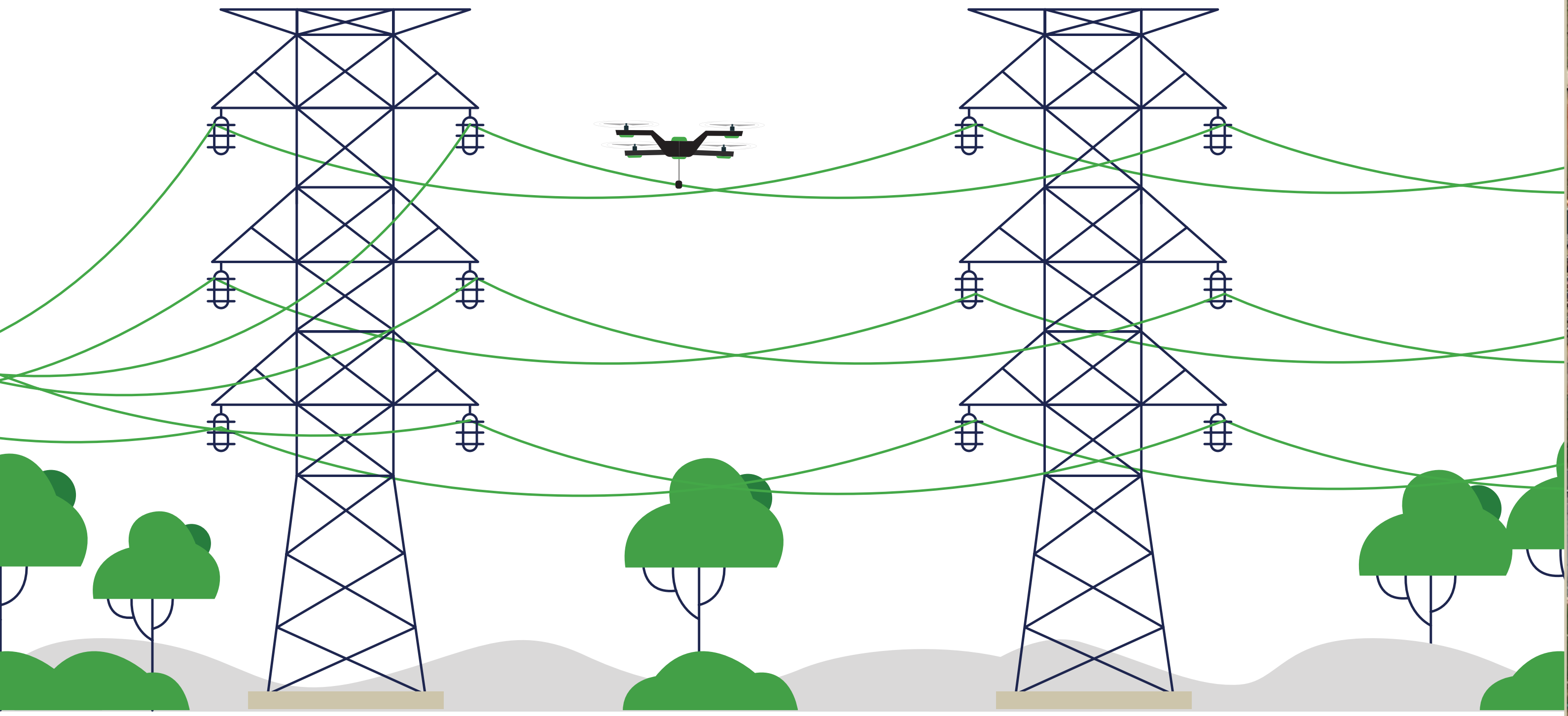
Inverter-based resources: sophisticated power for the future

Inverter-based resources such as batteries, solar and wind generators have sophisticated interactions with power networks. They can be tuned to provide all manner of system security services such as fast response reserves, frequency inertia and system strength required to keep the grid stable and operating reliably. The technology of inverters today is such that the provision of these crucial services can be provided as needed for local grid conditions and this is why some are referred to as grid forming (see page 26).

However, unlike truly synchronous generators that are self- and grid-stabilising within normal operating parameters, inverter-based resources are highly sensitive to grid conditions. This is especially true for the grid-following devices that make up the vast majority of current and future renewable resources. Rather than inherently stabilising disturbances in the grid, these devices are susceptible to larger changes and respond by disconnecting or reducing power for safety. Depending on grid conditions, this can have a stabilising or amplifying effect on disturbances.

When grid conditions change rapidly, the response of individual resources can vary wildly due both to grid topology and variation in generation due to weather. It is thus a much more complex operational process to ensure that small instabilities do not cascade into larger problems for the power system: unexpected responses can have significant consequences.

Like any highly sophisticated machine, the possible product is both more powerful and refined, but also requires a greater level of understanding and skill to achieve.



Learnings from other countries and research institutions

Maintaining operability is essential for reliable and secure power system operation.

Transgrid's high standards for operation mean that NSW has not had to endure a major power system outage to date, however recent incidents around the world have highlighted the need for improved control capabilities and situational awareness for managing power networks as renewables are added, to handle very large volumes of data and far more complex situations.

The 2020 State of Reliability study by the North American Electric Reliability Corporation (NERC) noted that every major outage since the 1960s in the United States was at least partially due to a lack of operability in the form of situational awareness or operations decisions making.[43]

Catastrophic event	Consumer impact	Escalating factors	Recommended capability and capacity
US – 2003 **North-East Blackout[44]** Network operators did not recognise deteriorating system conditions under routine contingency situations for outages. When parts of one transmission network began to trip automatically for protection, lack of planning and procedures and information mismatch with generation and interconnected network operators lead to ineffectual control actions and cascading protection trips across interconnected and interdependent networks.	• 50 million people affected and 61.8GW of generation lost • Took 4 days to restore in some parts of the US • Estimated cost to the US of $4-10 billion and $2.3 billion in lost manufacturing to Canada.	• Lack of situational awareness due to inadequate operating procedures, tools and communication between operators • Ineffective visualisation of power system conditions across control areas • Training deficiency of operators.	• Improve situational awareness • Implement real-time applications for wide-area system monitoring • Improve system modelling data and data exchange practices between network operators • Increase support and tools for decision making in operations.
US – 2011 **Arizona- California Outages[45]** During planned maintenance, the system was operating without redundancy. The loss of a single 500kV transmission line at this time initiated the event. Resultant flow redistributions, voltage deviations, and resulting overloads had a ripple effect, as transformers, transmission lines, and generating units tripped offline and initiated automatic load shedding.	• Cascading outages left 2.7 million customers without power during rush hour, some for up to 12 hours.	• Due to inadequate operations planning and real-time situational awareness, the transmission system was not being operated in a N-1 state required to prevent cascading outages in the event of a single contingency.	• Improve real-time tools to support monitoring of potential contingencies that could affect reliable operations • Improve communications among network operators to maintain situational awareness • Ensure network operators have adequate real-time tools.
UK – 2019 **Ofgem Outage[46]** A lightening strike caused a routine fault on the transmission network, disconnecting a number of small generators connected to the distribution network. Two large generators experienced technical issues and failed to provide power to the system, resulting in a large frequency dip that caused large volumes of distributed generators to disconnect. Combined power losses exceeded backup power generation capacity.	• Over 1 million people were affected • Most significant impacts seen on the rail sector • System was restored in 45 minutes.	• Some generators failed to meet their license and code requirements • Two distribution networks reconnected customers before receiving required instructions from the Electricity System Operator, jeopardising recovery of the system.	• Review and improve grid standards and planning processes for test compliance to grid codes • Improve real-time visibility of distributed generation • Improve processes and procedures for managing system operation in highly complex and changing conditions.

43. NERC, 2020, State of Reliability
44. https://www.energy.gov/oe/articles/blackout-2003-final-report-august-14-2003-blackout-united-states-and-canada-causes-and
45. https://www.nerc.com/pa/rrm/ea/Pages/September-2011-Southwest-Blackout-Event.aspx
46. https://www.ofgem.gov.uk/publications/investigation-9-august-2019-power-outage

Advice from recent local and global innovation and research efforts to improve the operation of power systems during the energy transition include:

US – NERC: State of Reliability 2020[47]	• Situational Awareness is necessary to maintain reliability, anticipate events and respond appropriately when or before events occur. • A lack of appropriate tools and data compromising situational awareness impacts operator decision making and thus system reliability.
US – FERC and ERO Real Time Assessments 2021[48]	• Significant changes to power systems are not being reflected in the collection of real-time data, adversely affecting situational awareness. • Increasing complexity is straining the ability of system operators to complete real-time assessments.
Europe – ENTSO-E **Research, Development & Innovation Roadmap 2020–2030** **2020[49]**	• Important operations innovation includes enhanced integrated Phasor Measurement Unit (PMU) usage for Wide-Area Monitoring and improved situational awareness and the development and training of AI-based decision support systems to leverage increased data. • Transmission system operators must devote resources to innovative grid design and solutions as well as new asset management approaches, including the use of sensors, the Internet of things, satellites, advanced robotics and applied machine learning for predictive asset management.
AUSTRALIA – CSIRO (for G-PST) **Control Room of the Future Research Roadmap[50]**	• As a result of transformational change, the existing systems in the control room of 2021 will not be adequate to manage the system of the future. The way the system is operated, and the way power system operators interact with the system, will have to adapt at a rapid pace. • Significant risks to the system posed by inadequate situational awareness, deficient decision-making support and cognitive overload of staff are difficult to quantify. Tasks should be automated where possible, but automation is not a panacea for operator situational awareness.

47. NERC, 2020, State of Reliability
48. FERC, 2021, FERC and ERO Enterprise Joint Report on Real-time Assessments
49. ENTSO-E, 2020, Research, Development and Innovation Roadmap 2020-2030
50. CSIRO, 2021, Australia's Global Power System Transformation (G-PST) Research Roadmap

3.7. Transgrid's plan for deploying new operational technology tools

Like other transmission operators around the world, Transgrid needs new operational technology tools to continue to plan and operate a secure power system that is accelerating towards 100% instantaneous renewables. We must adapt and evolve our processes, skills and tools to better manage growing system complexity.

Transgrid has already begun the process to deploy 25 phasor measurement units, or PMUs, to assist network visibility. These high-speed streaming devices can detect oscillations and phenomena in power systems that existing SCADA systems cannot. High-speed monitoring devices that improve data collection from the power system such as these are just a start, additional tools are required to turn new and improved visibility into improved awareness and control.

Transgrid has identified a suite of essential operational technology tools. This suite will provide an uplift that aligns with AEMO's own Operations Technology Roadmap[51] and Engineering Framework and is consistent with the experience of system and market operators globally.

The core suite of tools essential for Transgrid to plan, manage and operate an increasingly complex power system fall into two groups:

Digital twin modelled representation of the physical system

- Single network management model
- Asset registration
- Data governance and calculation platform
- Asset health decision support

Situational awareness and real-time decision support

- Alarm analytics
- Advanced forecasting
- Advanced neural net state estimate
- Visualisation and operations decision support

3.8. Digital twin: an advanced modelled representation of the physical power system

Digital twin technology is essential to improving network planning, asset management, outage and fault management and network operations in a complex power system. A digital twin is a digital replica of the power system's physical assets, processes and systems that can be used for simulation and modelling. When used in combination with sensor data, a digital twin supports real-time diagnostics of operational anomalies, understanding of system health and improved system efficiency.

Digital twins can provide asset managers, planners and control room operators with critical information that enables them to understand current and evolving system conditions and make decisions at the speed necessary to securely operate an unpredictable and intermittent power system. These tools allow operators to understand the network's rapidly changing risk profile and identify where solutions could be effectively deployed in the future.

By incorporating and using high quality data governance and 'single point of truth' data models, digital twins help to expose gaps and relationships between asset performance, network plans and system operator actions. This allows multi-criteria decision-making and enables users to test and model options and important trade-offs across operations, planning and asset management.

Digital twin: modelled representation of physical system

Single Network Management Model Improved management of data models	• Centralised 'As-Built' and 'Future State' models • Tracks and maintains model histories • Provides standardised models suitable for internal and external sharing
Asset Registration Simplifies and streamlines collection of data and manual interactions	• Provides workflow functionality for the registration processes. • Capture and manage asset data across the entire connection process • Supply data to other systems eg the Network Model Manager and Asset Health Decision Support
Data Governance and Calculation Platform Ensures a 'single point of truth' for data	• Amalgamates disparate data sources across business units and operational functions, such as SCADA, asset information, weather information and forecasts
Asset Health Decision Support Improves asset management	• Supports asset management decision making with near real-time asset condition analysis

51. AEMO's "Operations Technology Roadmap is required to uplift operational capability to allow AEMO manage the complex system of the future." AEMO, 2022, Operations Technology Roadmap

3.9. Improved situational awareness and decision support for the Transgrid control rooms

Substantial power outages happen when grid operators cannot contain and resolve small issues quickly.

Grid control rooms must ensure that the power system operates securely, within a complex technical envelope. This requires situational awareness and decision support tools to allow operators to anticipate system changes, assess the potential impact on system security and respond appropriately when or before system events occur.

By giving operators the right tools based on the digital twin, improved real-time network visibility, and with enhanced training, we can reduce the cognitive load currently being experienced in Transgrid's control rooms.

> It's like using a paper map to navigate, versus having Google maps telling you where you are and exactly what's happening ahead of you – in real time.

Operators will be able to visualise vast volumes of rapidly changing data, enabling faster and more accurate decisions to keep the power system operating within a secure technical envelope under more complex and dynamic conditions.

More details of the situational awareness and decision support tools required are presented below.

Situational awareness and decision support tools

Alarm Analytics Reduce the cognitive load for operators responding to alarms	• Triage alarm data to better understand system conditions • Present operators with predictive and prescriptive decision support
Advanced Forecasting Better forecasting to stay ahead of developing situations	• Provides an accurate view of upcoming system conditions across real-time and look ahead periods • Supports informed decisions to manage the resilience, security, and strength of the power system
Advanced Neural Net State Estimation Data driven 'what if' analysis on future network conditions	• Rapidly solves power flows in near and real-time through machine learning rather than power system modelling • Provides look-ahead analysis on possible system conditions in future operating periods to support decision making
Visualisation & Operations Decision Support Improve efficiency and accuracy of operator analysis, decisions, and actions	• Uses analytics to visualise operations data and information in the control room, to assist operational decision making • Provides a digital knowledge base for operational procedures and feeds an external portal for customer information such as outage details

Transgrid has assessed the requirements to uplift its operational technologies to manage a more complex and variable energy system. Building the state-of-the-art tools to support control room operations requires investment in the underlying digital structure. The improved data modelling and handling capabilities of the digital twin and associated governance outlined above are essential to support greater volumes of data and more advanced analytical tools. The packages of capability uplift outlined in this chapter are not and/or options; both are required to operate the NSW power system safely and securely in the coming decade.

A staged investment of $140 million in the next decade is required to ensure our control room operators, planners and asset managers have the tools needed to continue to effectively plan, manage and operate our power system. This includes capital investment in new tools and systems, and ongoing operational and licensing costs.

3.10. Growing our human capital and capabilities

The transmission system is growing and becoming more complex. We must grow in response.

To date, Transgrid has been managing growing system risks using existing teams and resources, however this is not sustainable on an ongoing basis into the future.

New technology and processes are not themselves a solution to maintaining quality work under the pressures of increased complexity and volume. Additional resources, skillsets and training will be required to support the increasing requirements and complexity of network planning, asset monitoring and system operations and to maintain our current quality and speed of work during the clean energy transition.

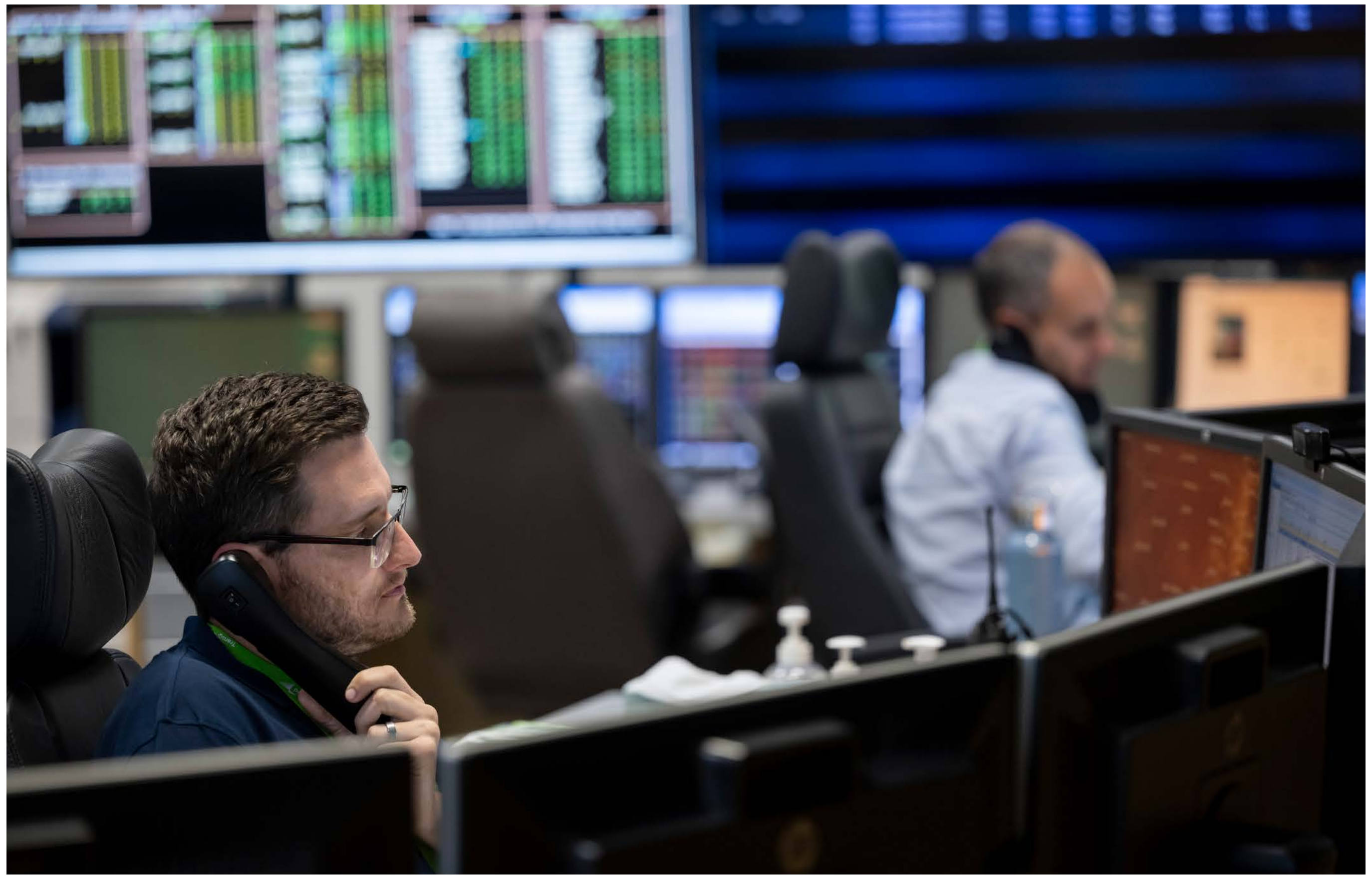
Transgrid requires increased resourcing levels to support NSW's rapid energy transition and unlock capacity to:

- Manage a more complex and volatile system using probabilistic planning and real-time operations
- Connect a higher volume of renewable generators
- Deliver system reliability and resilience as the grid transitions to operations at up to 100% instantaneous renewables

Transgrid estimates that it will need an uplift that will reach approximately $16 million per year by FY2028 to increase headcount and training. The table below highlights total resources gaps that must be filled, beyond what is required for just ensuring operability (e.g. additional connection engineers).

Function	Additional human resource requirements	Growth in staff numbers
Network Operations	Control room operations, outage planning, operations analysis, asset monitoring, SCADA management and training uplift	72 extra staff required by FY2028
Network Planning	Connection studies, subsystem planning, non-network option assessments, system security planning, 100% instantaneous renewable studies and training uplift	52 extra staff required by FY2028
Asset Management	Digital infrastructure capacity, asset standards for new technology, asset management for new transmission line and substation capacity, outage management analysis and training uplift	34 extra staff required by FY2028

Our control room is a case in point for increased training requirements. Expert advice to Transgrid recommends a four-fold increase in training for control room operators, to enable them manage increased operational complexity, new equipment and use the new tools. This is essential to maintain system security and reliability. Effective grid operation results in less undelivered energy, increased utilisation of renewable resources, more efficient use of transmission infrastructure and lower risk of catastrophic system failure.



We're making the clean energy transition possible

The NSW power system is rapidly accelerating towards a renewable dominated grid. AEMO projects that by 2025 there could be short periods where there will be sufficient renewable energy generation to meet demand, and this will become common by the end of this decade.

To continue to provide safe and reliable power to millions of Australians, Transgrid is proactively preparing for the challenges and opportunities of the clean energy transition. Key insights identified in this report include:

- It will be technically possible to operate the NSW power system at 100% instantaneous renewables, so long as the foundational pre-requisites of energy reliability, system security and operability are in place. These are not negotiable.
- System complexity is not a 'future problem' but is already making the power system difficult to operate and increasing risks to consumers.
- An urgent acceleration will be required to put these investments and capabilities in place for when they are needed. Failure to do so will increase costs for customers and increase risk to reliability.
- A 'step change' in organisational capability is required to meet this challenge in system planners and operators, not incremental evolution. Traditional regulatory frameworks and business processes are designed for a 'steady state' power system and may not be fit for purpose to deliver transformational change.
- The rapid pace of change and new frontiers will require a focused, innovative and flexible collaboration between system planners, operators, market bodies and policy makers to quickly assess and solve new challenges that emerge, and ensure reliable and secure electricity supplies in the best interests of consumers.

As this paper explains, Transgrid must:

- Accelerate the delivery of key transmission projects to support **energy reliability** as coal generators retire.
  - This will require $14 billion in investment in the next decade.
- Deliver new and essential **system security** capacity to decouple system security services from coal generation and keep the power system within its secure operating envelope without fossil-fuelled generation.
  - This will require the deployment of $2.2 billion of new system security infrastructure (and/or equivalent services) in the next decade.
  - System security equipment and services are projected to represent 1.5% of total electricity system costs in NSW to 2033.
- Invest in uplifting our operational technology tools, staffing levels and training to ensure the continued **operability** of a more complex and dynamic power system.
  - In the next 10 years this will require an investment of $140 million to uplift our tools and $16 million per year for people and training.
  - Operability uplift is projected to represent 0.2% of total electricity system costs in NSW to 2033.

Delivering on these three essential pillars will enable the NSW transmission system to respond to and thrive in our new energy landscape, providing clean, reliable and affordable electricity to Australians.

Disclaimer

The **System Security Roadmap** is prepared and made available by Transgrid solely for information purposes. It is made available on the understanding that Transgrid and/or its employees, agents and consultants are not engaged in rendering professional advice. Nothing in this document is a recommendation in respect of any possible investment. The information in this document reflects the projections, proposals and opinions adopted by Transgrid as at 21 June 2023, other than where otherwise specifically stated. Those projections, proposals and opinions may change at any time without notice. Anyone considering the information contained within this document at any time should independently seek the latest projections, proposals and opinions.

This document includes information obtained from public sources. That information has been adopted in good faith without further enquiry or verification. The document does not purport to contain all of the information that AEMO, a prospective investor, Registered Participant or potential participant in the NEM, or any other person or interested parties may require for making decisions. In preparing this document it is not possible, nor is it intended, for Transgrid to have regard to the investment objectives, financial situation and particular needs of each person or organisation which reads or uses this document.

In all cases, anyone proposing to use the information in this document should:

- Independently verify and check the currency, accuracy, completeness, reliability and suitability of that information;
- Obtain independent and specific advice from appropriate experts or other sources.

Accordingly, Transgrid makes no representations or warranty as to the currency, accuracy, reliability, completeness or suitability for particular purposes of the information in this document. Persons reading or utilising this System Security Roadmapacknowledge and accept that Transgrid and/or its employees, agents and consultants have no liability for any direct, indirect, special, incidental or consequential damage (including liability to any person by reason of negligence or negligent misstatement) for any damage resulting from, arising out of or in connection with, reliance upon statements, opinions, information or matter (expressed or implied) arising out of, contained in or derived from, or for any omissions from the information in this document, except insofar as liability under any NSW and Commonwealth statute cannot be excluded.

Find out more at:
1800 222 537
transgrid.com.au

Transgrid