

Evolving Transgrid's Operational Technology (OT) Capability

Independent report by EPRI to evaluate Transgrid's Operational Technology (OT) Capability for operating the transmission network planned for 2030



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EPRI prepared this report in consultation with the Transgrid subject matter experts.

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EXECUTIVE SUMMARY

EPRI has been engaged by Transgrid to independently evaluate their operational and control centre capabilities and assess their preparedness for operating the New South Wales and ACT transmission networks so that they can meet the growing demands and complexities of the network in the future. This report identifies the gaps in operational capability and proposed technology investment opportunities to reduce the operational risks to the future network.

Transgrid's Network Capacity Growth

The Australian transmission system, which includes Transgrid's network, like all global power systems, is undergoing a radical evolution as it decarbonises. The generation resources that power NSW and the ACT are shifting from predominantly large, centralised, thermal, predictable and conventional generation to smaller, distributed, renewable, variable, weather-dependent resources. Because of lower capacity factors for renewable generation, more inverter-based variable renewable energy (VRE) generation is required to be connected through Transgrid's network to obtain an equivalent capacity to coal-fired generation and meet the energy demands of the network.

According to the Australian Energy Market Operator's (AEMO) 2024 Integrated System Plan (ISP), the Step Change scenario (the most likely scenario) suggests that 19 gigawatts (GW) of renewable generation is expected to connect in NSW between 2024 and 2030.

AEMO in Australia¹, along with system operators overseas are also undertaking similar investments. For example, TenneT, the system owner and operator of the transmission network in the Netherlands and in Germany are in the process of a major operational technology overhaul, including the installation of a new Energy Management System (EMS), Asset Management System (AMS) and Network Model Management System².

Transmission Operational Context

The control centre is the nerve centre of the network, where operators work 24 hours a day, 7 days a week and 365 days a year, to monitor and control the flow of power through the transmission network through their interaction with the assets on the network, in coordination with AEMO.

The number of generator operators interfacing with the Transgrid control centre has more than quadrupled between 2015 and 2024. The number of generation connections on the network has almost doubled, and this trend is expected to continue and intensify from 2025 to 2039.

This change to the transmission network has already, and will continue to result in:

- A large increase in the network footprint (e.g., more substations, more lines and transformers, more protection and control devices); all of which will increase operational data, control points and workload to operate,

¹ <https://wa.aemo.com.au/initiatives/major-programs/operations-technology-program>

² <https://www.tennet.eu/about-tennet/innovations/control-room-future>

- A large increase in the number of planned outages to facilitate connection and commissioning of transmission and generation assets in coordination with the asset development teams and AEMO,
- Increased complexity in managing the network in real-time because of bi-directional generation and demand, cross-state flows and resulting higher fluctuation in voltages requiring increased network operations supervision,
- The need for additional monitoring and control of new inverter-interfaced resources, transmission assets and energy storage solutions to maintain system strength and transmission network flexibility.

Further, the increased frequency of high impact and low probability, external events, such as more extreme weather driven by climate change, is also increasing the complexity of managing the network. This rapid growth in assets, changing network behaviours and the increasing complexity of the network are increasing the risk to system security, availability of supply (e.g., unserved energy) and decreasing the efficiency of the network (e.g., from increases in network constraints). The risk primarily manifests through increased pressure on the control centre operators to maintain the ability to accurately and promptly make sense of abnormal situations to make the right decision to maintain reliability.

With the increased network complexity associated with managing the network's growing footprint, it is expected that the frequency of cases where operators must handle rapidly developing network events will grow.

Transmission Operational Technology Context

Operational technology (the software applications to monitor and control the network) for high reliability systems such as electricity control centres, are complex to resource, procure, develop and install. Continuous operational capability uplift is required to:

- Maintain effective and efficient network monitoring of the much larger, more complex network,
- Facilitate the safe execution of an increased volume of planned and unplanned control actions to maintain network reliability,
- Operate the network as efficiently and cost-effectively as possible, by reducing consumer costs from constraints while maintaining reliability.

Investments in control room technologies such as SCADA (Supervisory Control and Data Acquisition)/EMS (Energy Management System) are required to provide operators with the functionality to operate a larger and more complex network. The question is around the extent of the technology investment required and how quickly it can be delivered. The traditional approach to operational capability uplift, in particular uplift of operational technology (OT) systems, requires irregular and large investments and long-duration projects. Investments in operational capability using this traditional approach can take many years to realise benefits and typically aren't flexible or fast enough to meet the emerging needs of the rapidly changing energy system.

However, the rapidly emerging network changes and operational challenges are driving the need for control room systems to shift from infrequent technology upgrades to continuous / regular investment to evolve and improve operational systems. Taking a holistic approach to uplifting systems and operational capability provides earlier benefits and agility to adapt to emerging needs, whilst de-risking large-scale system changes.

Scenario-based Planning for Operations

The Australian energy system is evolving so rapidly and with significant uncertainty that scenario-based plans from the AEMO ISP for demand and generation resource capacity growth projections are required (the Progressive Change, Step Change, and Green Energy Export scenarios). Holistic and agile procurement and development in operational technologies also allow for alignment with these scenario-based plans and projections for future network growth from AEMO and Transgrid planners.

Based on an assessment of the projected growth rates of renewables on the Transgrid network, particularly acute between now and the early 2030s in all AEMO-derived scenarios, Transgrid operations will face substantial challenges in the network operational domains. These challenges, if not mitigated with technology improvements, will increase risks to the network and supply to customers.

The Step Change scenario represents what AEMO's 2024 ISP considers to be the most likely (median) scenario (43%), while Progressive Change is 42%. By anchoring on the needs required for both the Step Change and Progressive Change scenarios, the two most likely scenarios, Transgrid is prepared for the most likely outcomes and can scale up in an agile way if the Green Energy Export scenario eventuates. Developing technology for the Step Change and Progressive Change scenarios represents an approximate coverage of 85% of the future energy state and can be considered the least regrettable option in the short and medium term.

Technology Solutions

To meet the operational capability uplift requirements for the Step Change and Progressive Change scenarios, the project team identified 10 operational technology solutions to be enhanced to monitor and operate the transmission network in the near future. The technology solutions are grouped into two categories: enabling technology and operational technology applications. Enabling technology represents fundamental investments required to deliver the operational technology applications.

Enabling Technology

- Data Management and Network Modelling
- EMS/SCADA Upgrade
- Training and Operational Documentation Streamlining

Operational Technology Applications

- Alarms, Visualisation, Situational Awareness Enhancements
- Operational and Environmental Forecasts and Impact Assessment
- Wide Area, High Speed Monitoring
- Smart Transmission Device Management
- System Strength, Inertia, Fault Level Monitoring
- Asset Management and Asset Health Monitoring System
- Enhanced Outage Management System (OMS)

On an ongoing basis, investment decisions should be aligned to the evolving energy system in accordance with the AEMO ISP and Transgrid's Transmission Annual Planning Report (TAPR). Table 1 sets out the key investments recommended to achieve AEMO's next ISP planning horizon of 2030.

EPRI recommend that Transgrid further detail the risk and benefits for the investment in the technologies outlined within this report. Noting that key benefit areas will be associated with reduced expected unserved energy (EUE), reduced market constraints, maintaining safety, facilitating renewable energy connections, reduced risk of asset failure and maintaining network reliability obligations.

Table 1 Proposed solutions to bridge the operational technology capability gap for Transgrid to meet AEMO's Step Change and Progressive Change scenarios

Solution	Key investment required	Desired end state by 2030 for the Step Change scenario
Data management and network modelling	Enhance operational insights with greater integration between asset, planning and operational data	Electrical and asset model integrated with operational data to provide a single view of truth
EMS/SCADA	To leverage new software functionality and use standard processing of data from the range of new energy resources	EMS/SCADA utilises standard software capabilities to improve accuracy of the EMS, increased levels of data exchange and enables enhanced situational awareness and decision-making
Training and Document Management	Modern training simulator along quicker access to knowledge within Operating Manuals	Fit for purpose training simulator. Automated search and retrieval on operating manuals
Asset Management	Integration of network operational and asset management for enhanced network utilisation	Optimal network asset utilisation in real time operations
Outage Management	Modernise OMS architecture and enhance data integration between systems and with Business to Business	Enhanced OMS with integrations to other core technology and ability to incorporate unplanned outages and dynamic issues
Operational Forecasting	The ability to utilise weather and generation resource forecasts in real time operations and to manage emergencies	Forecasts used regularly and consistently in all operational processes such as switching, voltage management
Wide Area Monitoring	A wide area monitoring system for PMU data to monitor emerging network stability risks	Ability to integrate, align operational data (SCADA, PMU, DFR, Protection, Power Quality) in one location, visualisation for decision making support and investigations
Smart Transmission Network Device Management	Utilisation of network device control management solution to optimise setpoints in operational processes	Results of smart device action in response to network issues incorporated into operational processes and technology systems
Fault Level Monitoring	Monitor the risks with fault levels and system stability in coordination with AEMO	Deployed enhanced applications for Steady State, inertia, fault level online with in-built forecast or predictive capability

Solution	Key investment required	Desired end state by 2030 for the Step Change scenario
Alarm Visualisation and Situational Awareness	Alarm rationalisation, analytics solution and more advanced system for root-cause analysis	Reduced alarm rates with increased assets, alarm flood suppression to accelerates the operator’s awareness of the root cause of the alarm

ABOUT EPRI

Founded in 1972, the Electric Power Research Institute (EPRI) is the world's preeminent independent, non-profit energy research and development organisation. With offices around the world, EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe to shape the future of energy.

EPRI's mission is to advance safe, reliable, affordable, and clean energy for society through global collaboration, science and technology innovation, and applied research.

EPRI have been engaged with research and collaboration activities in Australia for many years, and Australian partners such as AEMO, the Australian TNSPs, and CSIRO (Commonwealth Scientific and Industrial Research Organisation) have been valuable members of EPRI's global community and system operator collective. In addition, EPRI has been conducting this work in multiple jurisdictions such as Ireland, the UK, the Netherlands, Germany and Peru, further expanding its expertise in global energy system innovation.

In 2023, EPRI were engaged by Transgrid to review the operational capability and provide an independent assessment of the key operational needs, to manage the Australian network of the future.



Nonprofit

Chartered to serve the public benefit, with guidance from an independent advisory council.

Thought Leadership

Systematically and imaginatively looking ahead to identify issues, technology gaps, and broader needs that can be addressed by the electricity sector.

Independent

Objective, scientific research leading to progress in reliability, efficiency, affordability, health, safety, and the environment.

Scientific and Industry Expertise

Provide expertise in technical disciplines that bring answers and solutions to electricity generation, transmission, distribution, and end use.

Collaborative Value

Bring together our members and diverse scientific and technical sectors to shape and drive research and development in the electricity sector.

ACRONYMS AND ABBREVIATIONS

Acronym	
AEMO	Australian Energy Market Operator
AI	Artificial Intelligence
BTM	Behind the Meter
CBM	Condition-Based Monitoring
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DER	Distributed Energy Resources
DLR	Dynamic Line Rating
DPV	Domestic (or Distributed) Photo Voltaic
EMS	Energy Management System
EPRI	Electric Power Research Institute
EUE	Expected Unserved Energy
EV	Electric Vehicle
FACTS	Flexible AC Transmission Systems
GETS	Grid Enhancing Technologies
HSM	High Speed Monitoring
ISP	Integrated System Plan
IT	Information Technology
ML	Machine Learning
MV	Medium Voltage
NEM	National Electricity Market
ORC	Operational Readiness Centre
OT	Operational Technology
NMM	Network Model Management
PFC	Power Flow Controller
PI	Process Information
PMU	Phasor Measurement Units
PV	Photovoltaic
RACI	Responsible, Accountable, Consulted, Informed
RAS	Remedial Action Schemes
RES	Renewable Energy Sources
REZ	Renewable Energy Zones
SCADA	Supervisory Control and Data Acquisition
SE	State Estimator
SPS	Special Protection Scheme
SIPS	System Integrity Protection Schemes
SSR	System Security Roadmap
TAPR	Transmission Annual Planning Report
SSSP	System Strength Service Provider
TNSP	Transmission Network Service Provider
VRE	Variable Renewable Energy
WAMS	Wide Area Monitoring System

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1. INTRODUCTION

EPRI were engaged by Transgrid and carried out the project and report in 2024 and 2025.

Purpose and Scope of this Report

The purpose of this report is to:

- Review the drivers for changes to the Transgrid network in the coming years,
- Review the current state of Transgrid’s operational capability,
- Document the impacts on Transgrid’s operational capabilities with information technology (IT) /operational technology (OT) solutions and applications, as they meet the challenges of the projected resource growth rates in the coming years,
- Provide recommendations of the OT requirements that will be required to maintain safe and reliable operations of the NSW and ACT transmission network in the coming years.

The scope of the report is to assess Transgrid’s operational capability only associated with IT/OT technology solutions and applications.

Methodology and Structure of the Report

The methodology and process for this report is structured in four sections:

- **Drivers for Change to the Transgrid Network** – The future network growth projections are identified which will drive increased operational impacts and the need for changes in operability (section 2),
- **Operational Technology Impacts for Transgrid** – The operational impacts are defined using a structured approach considering risk, current operational capabilities, and Transgrid’s responsibilities (section 3),
- **Transgrid’s Operational Technology Capabilities** – Assess Transgrid’s functions and operational technology capabilities as they are constituted currently to manage today’s network (section 4),
- **Operational Technology Capability Gaps and Solutions** – The potential technology solutions areas to reduce operability gaps and keep pace with the rate of network change. Recommend technology uplift required to meet different levels of maturity to cater for the range of network growth scenarios (section 5).

It should be noted that any technological uplift involves people, process, data, and technology investments. This report focuses on capital investments and not the associated expenditure on people and process improvements. Transgrid should explore the associated operational expenditure, as part of an overall structured approach to planning and investing in new technologies and improvements.

Engagement and Consultation

EPRI consulted with AEMO and Australian transmission network service providers (TNSPs) to apply local and international insights from transmission system owners and operators facing similar challenges. EPRI have vast experience in impartially engaging with equivalent system operators around the world to assess operational capabilities in line with near to long-term growth projections for demand and VRE resources.

2. DRIVERS FOR CHANGE TO THE TRANSGRID NETWORK

To understand how Transgrid's transmission operability will be impacted, it is necessary to look at the internal and external drivers for growth in the network and resources in the coming years. These growth drivers will disrupt the current operational paradigm and present new challenges and risks that are discussed in Section 4.

There are seven key drivers for changes to the Transgrid transmission network and transmission networks more broadly. These are summarised in Figure 1.

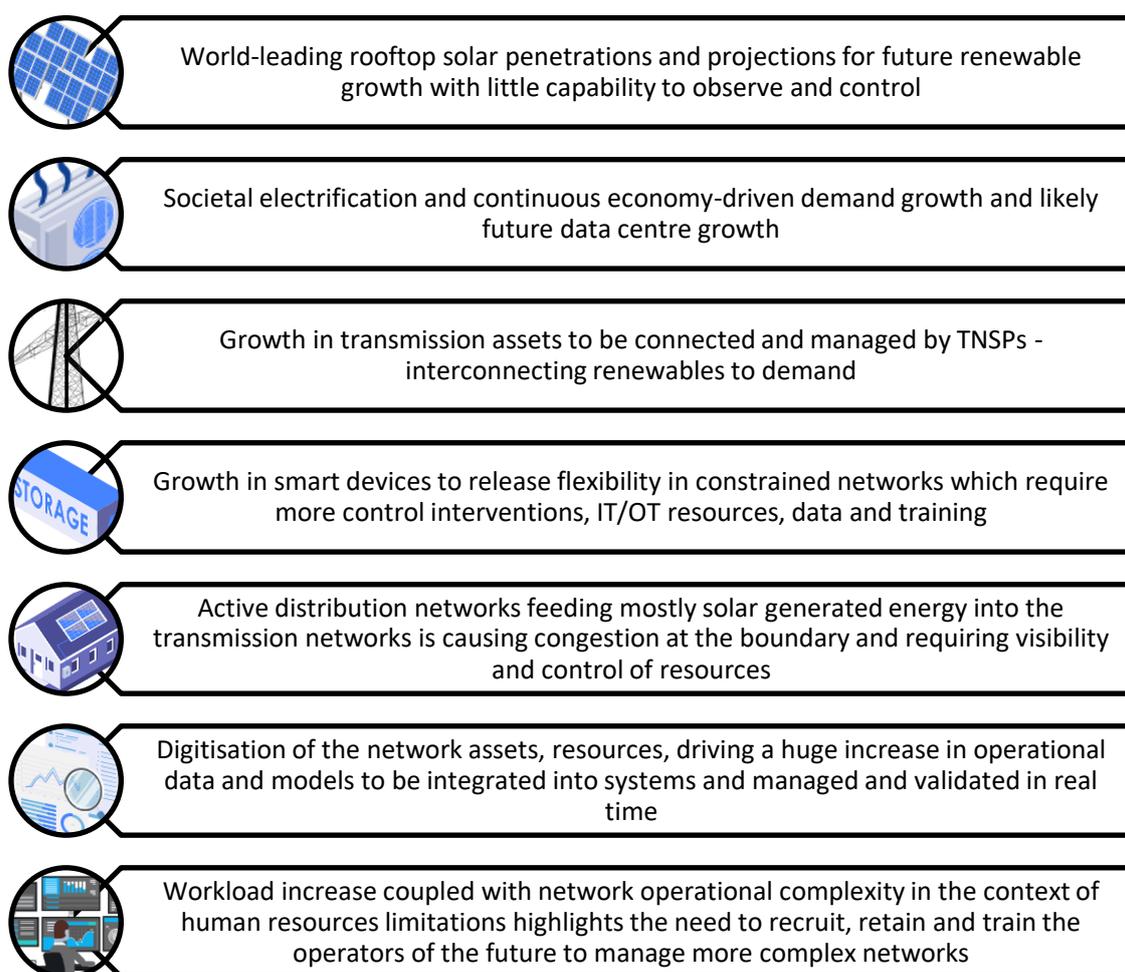


Figure 1 Summary of the external drivers faced in evolving electricity networks across the world

Australia is facing similar challenges to most other global transmission system owners and operators; however, the difference is in scale. There has been an exponential rise in solar and wind energy connected to the Australian network in the past five years and this trend is expected to continue, based on growth projections from AEMO (see Figure 2). Operational systems are developed and configured to manage the network and assets of today, not the network and assets of tomorrow. Hence, developing OT to keep pace with this exponential growth is challenge.

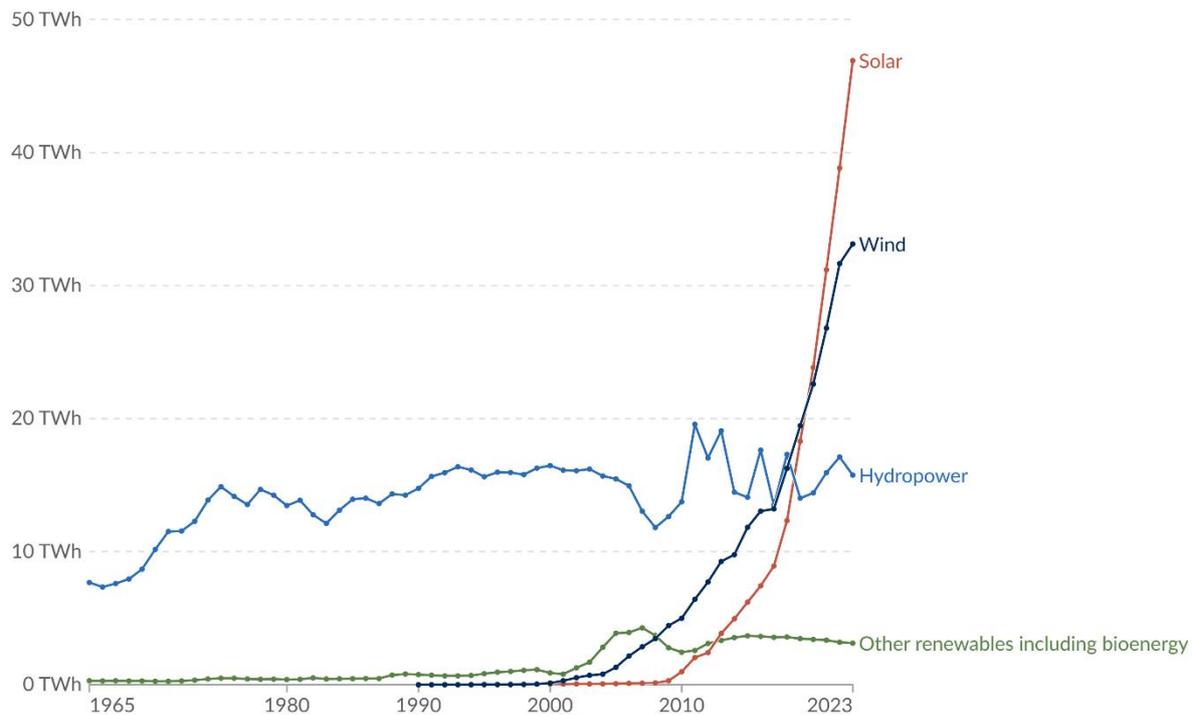


Figure 2 Modern renewable energy generation (in TWh) by source in Australia³

The following sections provide further details of key external drivers for network growth and operability challenges for Transgrid.

The Transgrid Network is Rapidly Evolving

Transgrid's network is increasing in scale and operational complexity. The key external drivers are:

- VRE resources replacing thermal generation,
- The establishment of renewable energy zones (REZs) in NSW,
- The substantial increase in transmission network assets to accommodate VRE and REZs,
- The emergence of smart transmission devices, such as power flow controllers and grid scale batteries which are now available to system operators,
- Increased interactions between transmission and various market participants such as generation, distribution and the market operator, and
- Electrification of sectors such as transport and heating, which will increase electricity demand.

³ Ember (2024), Energy Institute – Statistical Review of World Energy, Our World in Data, <https://ourworldindata.org/grapher/modern-renewable-prod?country=~AUS>

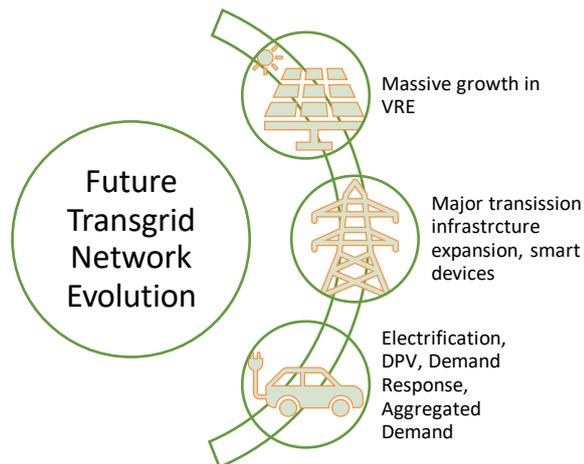


Figure 3 Future challenges to Transgrid's transmission network operability capabilities which are driving the need for an operational capability uplift

VRE resources will replace thermal generation

The generation resources on the Transgrid network are currently undergoing a transition from mostly centralised, predictable, fossil-fuelled, thermal, large, synchronous power plants to more decentralised, variable, renewable, smaller, asynchronous generation resources. New large-scale renewable energy is also being connected to the Transgrid network via Renewable Energy Zones (REZ).

AEMO ISP-projected VRE Growth Rates

The Australian energy system is evolving so rapidly that scenario-based plans and projections are required. AEMO have access to a broad set of information as supplied by the TNSPs for the future National Electricity Market (NEM) and Australian energy system more broadly, so the AEMO's 2024 ISP⁴ has been used in the methodology for this project as the best available forecast for the likely future development of the NEM.

AEMO's 2024 ISP projects three scenarios with varying degrees of VRE growth for the NEM.

- The **Progressive Change** scenario reflects slower decarbonisation beyond current commitments (42% likelihood),
- The **Step Change** scenario is the central scenario growth assumption and fulfils Australia's emission reduction commitments (43% likelihood), and
- The **Green Energy Exports** scenario (15% likelihood) reflects very strong industrial decarbonisation and low-emission energy exports.

Scenario Planning for Operations

Given operational capital limitations in the operational domain, to effectively plan IT/OT investment decisions in the operational domain, it is necessary to plan to a projected future state rather than a

⁴ AEMO Integrated System Plan 2024 <https://aemo.com.au/-/media/files/major-publications/isp/2024/2024-integrated-system-plan-isp.pdf?la=en>

forecasted state. The ISP scenarios are helpful in this regard. The Step Change scenario is the median scenario with an assessed 43% likelihood of being accurate, however planning for both the Step Change scenario and Progressive Change scenario will give an approximately 85% confidence in projected growth rates as it would encompass growth in the less ambitious Progressive Change scenario (42%). In this way, planning for both scenarios is the least regrettable decision as it covers a broader range of potential futures.

Assessing the Implications of the Step Change and Progressive Change Scenarios on Transgrid

Most of the new renewable energy (solar and wind) will be connected on the Transgrid network in the years ahead through Renewable Energy Zones (REZ). These are designated onshore and offshore spaces which efficiently feed into the transmission networks.

There are 12 REZs in NSW and the ACT. AEMO project significant growth in renewable energy capacity in the years to 2050. Figure 4 shows the projected growth rate for 8 of the 12 REZs in NSW (4 of the 12 REZ do not currently have projected renewable capacity) for the Step Change scenario. The Progressive Change scenario has a similar growth rate. The ISP data also documents existing committed capacity as of end of 2023 (when the simulations were developed).

The combination of committed and projected capacity represents a growth in renewable energy capacity connecting to the Transgrid network directly and from the REZs of approximately 19 GW between 2024 and 2030 for Step Change scenario and 18 GW for the Progressive Change scenario.

The Step Change and Progressive Change scenarios both involve similar levels of rapid change between 2024 and 2030. Given this, both scenarios have similar implications for Transgrid. For simplicity, Figure 4 shows forecasts for Step Change scenario only.

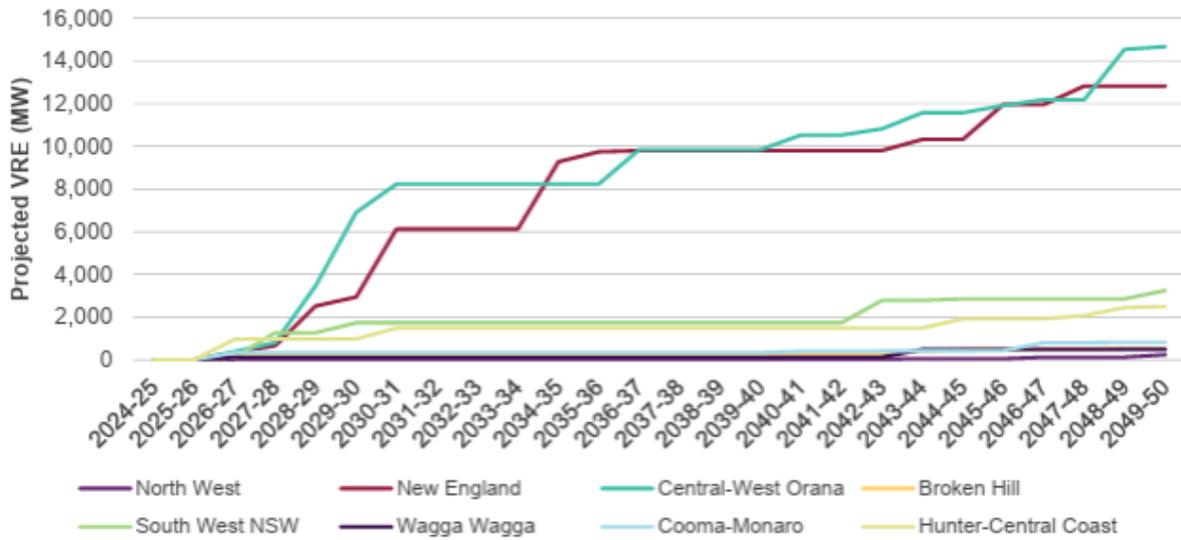


Figure 4 NSW utility-scale VRE development in REZs for the ISP Step Change Scenario (MW)⁵

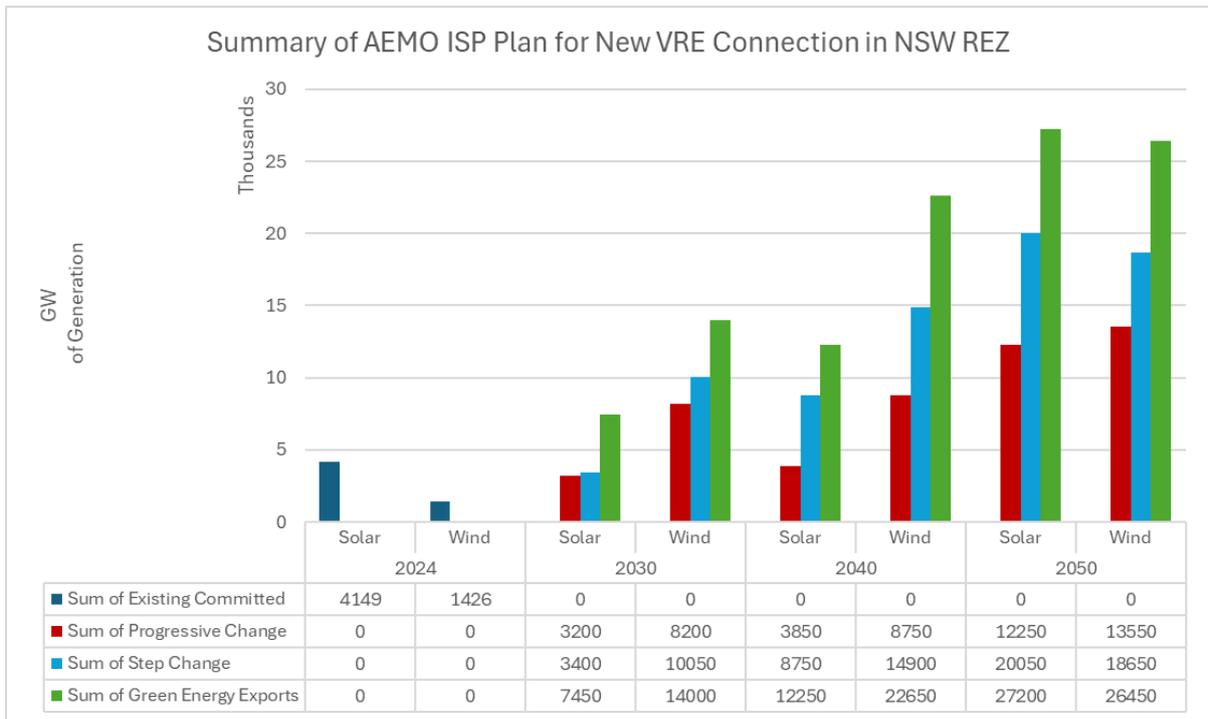


Figure 5 Summary chart of the projected quantities of VRE (GW) to be connected in the New South Wales REZ from 2024 to 2050 under the ISP scenarios

⁵ AEMO Integrated System Plan 2024 <https://aemo.com.au/-/media/files/major-publications/isp/2024/2024-integrated-system-plan-isp.pdf?la=en>

Putting the Growth Rate in Context

Only 10 countries have connected more VRE in the past five years than Transgrid is to connect in the next five years. With the exception of the Netherlands (with a population of 18 million and GDP of US\$923 billion compared to NSW with a population of 8 million and GDP of US\$440 billion), the remaining 9 countries have much larger population and GDP.

For context:

- 19 GW is the approximately 50% of the record NEM peak demand (38 GW),
- 19 GW is approximately 150% of the historical maximum peak demand in NSW (2023, 12.6 GW),
- 19 GW is 70% of the total VRE capacity added to the whole of Australia between 2019 and 2023.

Table 2 From 2019-2023 the connection of solar and wind generation in countries around the world, with the projection from 2025 to 2030 for NSW for context⁶

Country	Renewable Generation 2019-2023 (GW)
China	691.9
United States	140.6
India	55.1
Brazil	49.3
Germany	47.3
Japan	32.6
Spain	31.6
Australia	27.2
Netherlands	25.7
Vietnam	22.6
New South Wales Projection (2025-2030)	19
South Korea	18.9
Poland	18.8
France	18.2

New generation resources from REZ and associated variability of power flows will have an impact on Transgrid’s ability to efficiently operate the transmission network.

Societal Electrification

Australia is experiencing rapid growth in various aspects of societal electrification, including electric vehicles (EVs), heat pumps, and renewable energy adoption. While NSW-specific information is

⁶ Ember (2024), Energy Institute – Statistical Review of World Energy, Our World in Data, <https://ourworldindata.org/grapher/modern-renewable-prod?country=~AUS>

difficult to calculate, trends in societal electrification are expected to continue in the short and long term. The key trends for societal electrification include:

- **Electric Vehicles** – EV adoption in Australia is accelerating significantly. Specifically, NSW has a 9 per cent EV adoption, and EV sales broadly have doubled every year since 2022.
- **Heat Pumps** – In Australia, the heat pump market is growing rapidly, particularly for domestic water heating. Domestic heat pump installations increased fourfold between 2019 and 2022, and 117,000 hot water heat pumps were installed in 2023⁷. Projections suggest up to 450,000 hot water heat pumps could be sold annually by 2036.
- **Rooftop Solar** – The Clean Energy Regulator in Australia anticipates a 3 GW increase in small-scale rooftop solar capacity in 2025, continuing an established trend of Australia being the world leader in domestic, rooftop photovoltaic (PV) energy production.

Operational Capability Upgrades in Peer System Operators

A smart transmission device is a component of the network, which enhances the traditional electrical grid with advanced digital communications or other technologies. These devices use computer-based remote control and automation to improve the efficiency, reliability, and sustainability of electricity delivery. Their key features are:

- Two-way communication between the asset and the control room, allowing for real-time remote monitoring and control,
- Automatic detection and response to issues in the grid, such as outages or faults,
- Facilitate the integration of renewable energy sources like solar and wind into the grid by adjusting asset characteristics and facilitating flexible operations,
- Manage and adjust the demand for electricity during peak times to prevent overloads and reduce costs.

While demand and generation are changing rapidly, linear transmission infrastructure can take years to be planned, permitted, and constructed. To optimise investment and accelerate growth, Transgrid, like other TNSPs, is increasing flexibility in the existing transmission asset base, using smart devices for advanced power flow control to allow generation to be connected in advance of deep transmission reinforcement projects being completed.

Recent examples such as the Smart Wires SmartValve technology that has quickly created extra network capacity without upgrading transmission lines, and Remedial Action Schemes (RAS) for automated response required to manage a very dynamic network with high volume of VRE.

⁷ <https://iifir.org/en/news/main-figures-for-the-australian-heat-pump-market>

3. OPERATIONAL IMPACTS FOR TRANSGRID

The central function played by the control centre means that the changes to generation resources, network and demand will have significant operational impacts. This section discusses the operational impacts and the consequences if the impact or risks are not mitigated.

Consequences of lack of investment

It is useful to think of the operational impacts of a radically different transmission network in terms of the obligations of a TNSP. The operational impacts, risks and consequences that arise from lack of investment in operational capability are described below.

Reliability

Reliability means the ability to provide continuous, high-quality electricity supply to the electricity customers of NSW and the ACT. It can be measured operationally by EUE, measured in megawatt hours (MWh).

The challenge for TNSPs is to maintain reliability in a VRE-dominated network that is increasingly operating closer to the edge of its technical operational envelope. This is demonstrated in Figure 6, where there is a marked increase in credible contingencies that may have resulted in a violation of the power system technical envelope since 2019.

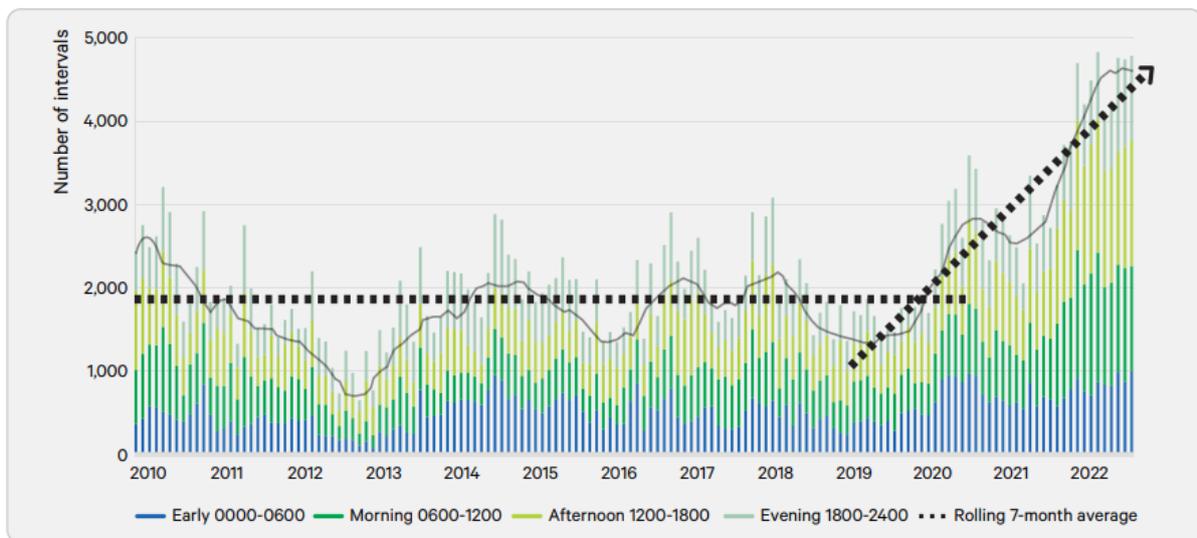


Figure 6 From the Transgrid SSR - Operating intervals (5-minute granularity) per month when at least one credible contingency on the NSW transmission system would have resulted in a violation of the power system technical envelope, with a simplified trend overlaid⁸

Transgrid's control centre has a direct influence on maintaining reliability through the ability to optimally operate the assets and to utilise inherent system redundancies. An increase in new assets, and associated operational data, in combination with VRE sources, will put pressure on network reliability. There will be an increased frequency that the network operates without redundancies, to maintain system security and to facilitate planned outages. This will ultimately lead to an increased

⁸ Transgrid System Security Roadmap, 2023, <https://www.transgrid.com.au/media/avyondr4/system-security-roadmap-2023.pdf>

risk of unserved energy when the control centre operators experience cognitive overload, temporarily lose situational awareness, or cannot act quickly enough to prevent a major network disturbance.

Resiliency

Resilience means the ability to survive major network disturbance (or IT or communications network) incidents or gracefully fail and return to normal as quickly as possible after the major network disturbance or incident. It differs from reliability, which focuses on continuous supply even for regular minor disturbances. In the control centre operational context, resiliency has two parallel but interrelated requirements:

- The network must be resilient in the event of a major network incident i.e., it must be difficult to collapse and quick to restore,
- The systems, facilities and people that make up the control centre must be resilient to failures or business continuity events.

Resilience is difficult to measure as, by design, major high impact low probability (HILP) events rarely occur. A good proxy is response/restoration times to more frequent low to medium impact incidents as small improvements of the response and restoration time for these incidents would typically equate to greater resiliency for major HILP events.

The challenge is to maintain a consistent level of resilience in a network with increasingly extreme weather exacerbated by climate change, and with increasing market participants, assets and smart devices, and greater network complexity due to the variability of generation and demand along with new asset types such as battery energy storage systems.

Transgrid's control centre has a direct influence on maintaining resilience through the ability to proactively operate the assets to maintain strong system security and be prepared for a rapid restoration response through effective procedures and training for HILP events. The increasing scale and complexity of the network mean that resiliency is more frequently challenged and restoration options more complex.

There have been well-documented major disturbances in the NEM in the past ten years that have required emergency procedures and restoration, such as the South Australian blackout in 2016, the Queensland and South Australian system separation in 2018 and the major storms in Victoria in 2024. Recommendations from these events included improved control room tools to provide better situational awareness applications and improved response during emergencies.

Efficiency

Transgrid's control centre has a direct influence on improving the efficiency of the market through the ability to minimise market constraints when taking forced and planned outages. However, the increase in planned outages due to the connection of major transmission infrastructure and renewable generation, combined with a larger network and more generators increases the workload to identify the optimal outage to minimise market constraints. Further, Transgrid will need to operate the network more conservatively to prevent overload of assets if uplift in operability does not occur.

Transgrid's operational personnel face the dual challenge of managing the transmission network efficiently while also operating prudently to protect assets from overloading. This balancing act is crucial for several reasons:

- Ensuring that network charges reflect only prudent and efficient costs,
- Effectively managing constraints to facilitate low-cost dispatch in the wholesale market, contributing to lower electricity prices,
- Protecting network assets from overload, which has become increasingly important as the network evolves and faces new pressures.

Security

Security refers to the ability to operate a secure system, primarily by ensuring that the network is operated within its limits for normal operation and for post-credible contingency events. The responsibility is shared between AEMO and Transgrid for the transmission network and can be measured by the number of violations of asset limits and the duration of violation.

The security of Transgrid's network has been impacted over the past decade as shown in **Error! Reference source not found.** The challenge is to secure the system within 30 minutes post contingency events, in an optimal way that minimises market constraints. In the coming years, due to the greater number of network connections, simulations will require more time to study the variety of potential scenarios, which may not be achieved within the 30-minute timeframe required to plan and execute the actions to re-secure. This trend of increasing security violations and threats is expected to continue with the projected connection of 19 GW of new VRE in NSW before 2030.

Safety

The network is inherently designed, maintained, and operated to be safe for employees, contractors, and the public. Transgrid's control centre has a direct and indirect influence on achieving safety requirements through the actions or inactions taken by the operators. The risk is currently managed using procedural controls, training and software systems.

Highly manual procedural controls (such as switching execution) will experience an increased safety risk in the future as the volume of planned and unplanned outages increases to facilitate outages to maintain and upgrade the network. Safety cannot be compromised, so there may be delays to planned outages and delays in restoration from unplanned outages in the more complex network of 2030 and beyond.

Factors Impacting Transgrid Operations

There are an increasing number of external factors that on a day-to-day basis will impact control centre operation. These factors include, but are not limited by:

- Frequent and unpredictable change in generation requiring voltage stability correction,
- The stable operation of the network changing fundamentally when inverter-based resources replace conventional generation,
- Facilitating increasing volumes of outage requests for connections and co-ordination of many more parties,
- Increase in management and coordination of lack of reserve planning and response with AEMO,
- Increasing volumes and duration of contingency violations and radial load feeds,
- Mid-day demand has decreased to lowest levels on record due to embedded generation in the distribution network, with reverse generation from traditional load centres. This is expected to continue.

Operational Challenges

External growth factors as documented in section 2 will drive Transgrid's transmission network growth to accommodate for increasing traffic demands and expanding capacity. This will impact on Transgrid's ability to operate in several ways and are detailed below.

Human Factors – The Operator in the Control Centre

The challenge is to continuously recruit, train and retain network operators for an environment that is experiencing rapid network growth, and increased complexity with more variability in generation and demand.

As such, the roles and career pathways of today's transmission network operators are changing. The traditional career pathway was from the field after many years of hands-on experience, to the control centre where safety, experience and intuition could be applied. While adding human resources is necessary, it is only impactful up to a point before operations become significantly segmented. This may lead to reduced situational awareness and a reduced ability to process data and analysis quickly.

This issue is compounded as new staff require several years of training and on-the-job experience, which is increasingly difficult to achieve in a rapidly changing and increasingly complex transmission network without modern tools, therefore relying on the operator's experience and intuition. Some examples of uplift are outlined:

- **Training** – As the network evolves with new assets and generation resources, the structure of the network will change, and the network operational modes will shift to previously unseen patterns. This will require an increase in continuous training of operator personnel for all aspects of operational processes.
- **Network Data, Engineering Simulations and Studies** – The shifting operational nature of the Transgrid network requires more engineering data, analysis and studies which will require new systems, expertise, training, and resources in the operational planning domain.

Facilitating the Connection of VRE and New REZ

In the ISP Step Change scenario, it is assumed that there will be an additional 19 GW of VRE generation feeding into the transmission network in NSW.

New REZs will be developed across NSW and connected directly to the transmission backbone network, which will in turn require transmission network augmentations. Connecting 19 GW in the next five or so years will be a major operational challenge, straining operations resource models and increasing risks to the transmission network.

Each transmission utility-scale connection will require outages to facilitate connection and commissioning. Outages require extensive planning and simulation, coordination, and procedure development and execution. Testing and commissioning require resources to execute in real-time in parallel with normal network operations. New resources and assets will need to be integrated into technology systems and business-as-usual operational processes.

Each new connection and transmission asset will increase the asset base and the number of protection devices and alarms to be managed. Smarter technology for asset and outage

management will be required for the facilitation of connections and ultimate operation of renewables.

Operability with VRE

Adding 19 GW of new VRE in the short term will also add significant real-time network operational challenges. The variability and decentralisation of resources will change the operating dynamics of the network, leading to increasingly complex and changing operating requirements in real-time.

The withdrawal of large fossil fuel synchronous generation in the merit order to be replaced with VRE removes the primary sources of system security services that the NSW grid has relied upon for decades. The increasing deployment of new VRE will further reduce system strength, either through localised weakening of the network or as a by-product of reducing the synchronous generation on the network. This risk will be offset by the connection of synchronous condensers and other sources of system strength on the transmission network.

In addition, the quantity of distributed energy resources (DER) and domestic photovoltaic (DPV) behind the meter (primarily rooftop solar) will cause a change in how the network is operated in the middle of the day during periods of low demand.

The Transgrid System Security Roadmap

The need for operability uplift is highlighted in Transgrid's System Security Roadmap⁹. This report summarises the challenges Transgrid will face in the coming decades based on projected growth from the AEMO Integrated System Plan (ISP). There is a strategic focus on three pillars:

- **Energy Reliability** – The need to invest in and build new transmission infrastructure to facilitate connection of VRE,
- **System Security** – The need to build or contract with new assets to bolster system security following the retirement of large coal fired generators. System security is a proxy for system strength, strong voltage, and inertia,
- **Operability** – The need to improve the planning and operational capability to manage the system of the future.



⁹ Transgrid, System Security Roadmap, 2023, <https://www.transgrid.com.au/media/avyondr4/system-security-roadmap-2023.pdf>

Figure 7 The three pillars from the SSR 2023

Investments in all three SSR pillars are complementary and are required to transition towards a renewable grid. For example, investments in system security and energy reliability will increase the complexity of operating the network, thereby requiring an uplift in Transgrid's operability capabilities.

4. TRANSGRID'S OPERATIONAL CAPABILITIES

Transmission control centres are critical functions, where operators work 24/7 365 days a year to monitor and control the flow of power through transmission networks. Transgrid in its licensed role as the TNSP, work in coordination with AEMO in accordance with the National Electricity Rules (NER)¹⁰.

Transgrid's critical functions encompass, but are not limited to:

- **System monitoring and control** – Continuous, real-time surveillance of the entire network, which is essential for effective network management and rapid response to changes.
- **Fault detection and response** – When system faults occur, the control centre assesses the cause and impact, implements corrective measures, and manages power redirection to minimise service disruptions.
- **People and Asset protection** – Prevent overload of assets, which reduces risk of equipment failure and potential safety hazards.
- **Planned outage management and coordination** – Manage planned outages to facilitate scheduled maintenance and connection of new assets.

To assess the current state of Transgrid operational capability and gap in capabilities, it is first necessary to baseline the objectives at the most fundamental levels. This allows capabilities to be aligned with outcomes and strategic objectives of Transgrid.

The Concept of a Business Capability Model

The purpose of a business capability model (BCM) is to organise the resources and processes at the disposal of an organisation into a coherent map to be used in strategy development across the organisation. Capabilities are groups of processes that must be executed to meet strategic objectives. An operational capability model is a business capability model with a focus on the core operational processes and associated technologies. All companies have other capabilities, such as human resources, legal and finance, that enable the operational capabilities but are not covered in this report.

Transgrid's Operational Capability Model

In 2024, Transgrid, in collaboration with AEMO and EPRI, developed a list of the operational processes executed in the Transgrid control centre.

The processes are categorised into a shorter list of 10 overarching operational capabilities to form an operational capability model, shown in Figure 8Error! Reference source not found. and described in Table 3.

It should be noted that some of these capabilities and the operational processes that underlie the capabilities complement the processes that AEMO and other TNSPs execute. These capabilities require coordination between Transgrid, AEMO and the other TNSPs to manage the network safely, reliably and efficiently.

¹⁰ Australian National Electricity Rules (NER), <https://www.aemc.gov.au/regulation/energy-rules/national-electricity-rules>



Figure 8 Transgrid Operational Capabilities

Table 3 Overview of Transgrid’s operational capabilities

Operational capabilities	Description
Operations and analysis	Operating the network and analysing the data from the network to maintain reliability
System asset monitoring and situation awareness	Monitoring of the transmission assets such as lines, transformers and substation equipment
Asset switching and restoration	Coordination and execution of high voltage switching of the transmission assets on the network as part of planned and unplanned outages and demand restoration.
Remote incident response	Response to incidents and disturbances on the transmission network, including remote switching
Emergency/incident management	Coordinating and managing emergency incidents such as major storms, bushfires with field staff and with AEMO and DNSPs
Outage planning and coordination	Planning for transmission outages for maintenance and capital construction works in coordination with AEMO
Operational procedures and training	Developing and maintaining procedures for the safe operation of the network as it evolves, in accordance with NER and other safety obligations
Operations support	Engineering support to the operational teams such as network simulation and analysis
Operational technology	Operational technology tools (e.g. SCADA/ EMS) in the control room, to maintain continuous uptime and reliability
Facilities	Maintain safe, secure facilities and equipment to provide situational awareness to operators

Mapping Operational Capabilities to Operational Processes and Technology

Each capability has various operational processes that make up the capability in conjunction with applications, data, and human interactions. If capabilities describe ‘WHAT’ Transgrid does to serve its purpose, then the operational processes describe ‘HOW’ the capability is executed.

As part of this project, each process was mapped to the OT/software application, which facilitates the execution of the process. The core applications in the operational context are the SCADA/EMS, OMS and AMS. Each application is served by data and executed by an operator, engineer, or member of the operations staff. There can be multiple processes per capability, applications per process and data points per application.

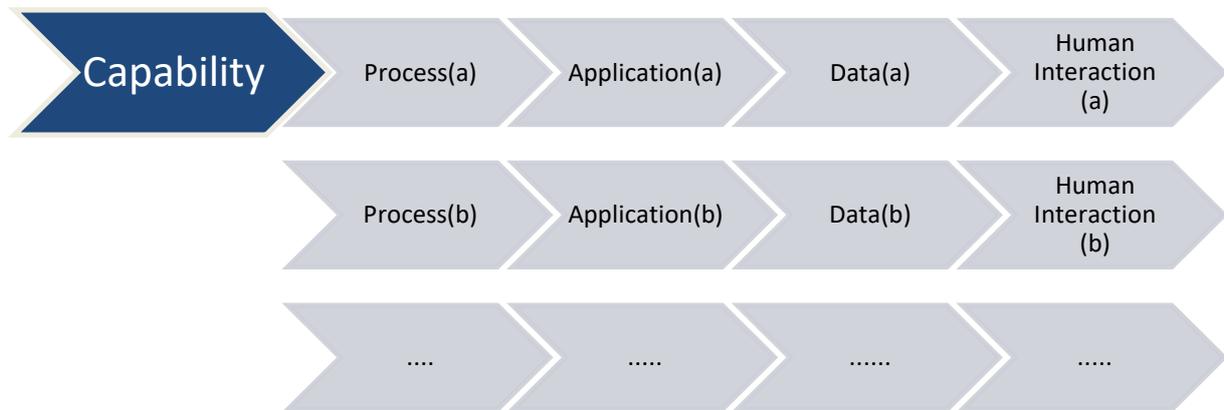


Figure 9 Graphic showing how capabilities are mapped to processes and applications and data

The assessment considered 117 operational processes that underpin Transgrid’s 10 operational capabilities, and that Transgrid’s role is either responsible or accountable for 87 of the 117 operational processes. The analysis then identified 58 operational processes that are highly impacted given the projections from the AEMO ISP and where capability uplift is required to meet the ISP Step Change targets of 2030.

Table 5 shows Transgrid’s 87 responsible or accountable operational capabilities with line of sight to technology solutions. The 58 process that are highly impacted are shown in bold with the process that are highly impacted by 2025 noted with an asterisk.

Table 5 Transgrid’s operational capabilities line of sight to technology initiatives

Operational Capability	Process	Capability Gaps (highly impacted processes)	Technology Initiatives
Operations & Analysis	Apply constraints in dispatch	Monitoring the risks with fault levels and system stability in coordination with AEMO.	Fault Level Monitoring
	Minimum and Maximum Demand		
	Voltage Control and Reactive power scheduling		
	Under frequency load shedding schemes	Integration of all smart transmission devices into EMS	
	System Strength		
System Inertia			

Operational Capability	Process	Capability Gaps (highly impacted processes)	Technology Initiatives
	System Restart and Restoration	(response of SPS to a contingency, DLR rating overrides).	Smart Transmission Network Device Management
	Manage Contingencies		
	Intervention in the market		
	Curtailment of customers		
System Asset Monitoring and Situational Awareness	Monitor and Control Transmission Network	Current version of SCADA/EMS software does not support the range of new energy resources as a standard, nor include any new functional updates.	EMS/SCADA
	Detection of ongoing system wide issues during normal operation (eg voltage, thermal, oscillations, harmonics, system strength)		
	Alarm Monitoring and Prioritisation*	Alarm rationalisation, analytics solution and more advanced system for root-cause analysis	Alarm Visualisation and Situational Awareness
	Alarm Validation and Root Cause Analysis*		
	Manage Alarm Resolution*		
	SCADA alarm management for alarms on NSW prescribed network*	The ability to utilise weather and resource forecasts in real time operations and to manage emergencies	Operational Forecasting
	Communication with AEMO - System Issue/Risk - TG network		
	Risk assesses bushfire impacts as per PSSG for prescribed NSW network	A wide area monitoring system for PMU data to monitor emerging network stability risks	Wide Area Monitoring
	Monitor system ancillary, system strength and inertial support service availability		
	Transgrid Asset Monitoring (e.g. use of asset, low SF6)		
Communication with AEMO - Transgrid Asset Monitoring	Integration of network operational and asset management for enhanced network utilisation	Asset Management	
	Monitoring the risks with fault levels and system stability in coordination with AEMO.	Fault Level Monitoring	
Planned Asset Switching / Access Management	Manage Switching and Access Authorities for planned outage and testing	Outage management system (OMS) architecture doesn't support enhanced data integration into SCADA nor business to business (B2B)	Outage Management
	Switching of HV assets		
	Preparation of HV switching instructions for Transgrid network		
	Preparation of RNI HV switching instructions		
	Preparation of LV or protection switching instructions for Transgrid network		
	Actions to manage system operating and network security requirements for assets - Direct oversight		
	Communication with AEMO on switching Transgrid assets		
	Remote control actions e.g. remote switching		
Unplanned Asset Switching	Remote control actions e.g. remote switching of Transgrid assets	Outage management system (OMS) architecture doesn't support enhanced data integration into SCADA nor business to business (B2B)	Outage Management
	Callout of standby		
	Coordination with response on site to ensure assets safe e.g. physical isolation and earthing		

Operational Capability	Process	Capability Gaps (highly impacted processes)	Technology Initiatives
	Coordination with response on site e.g. physical isolation and earthing	The ability to utilise weather and resource forecasts in real time operations	Operational Forecasting
	Coordination with AEMO on system impacts for incident on Transgrid assets		
	Coordination with AEMO on system impacts for incident on RNI assets		
	Return to service (RTS) Transgrid assets		
	Action to return to service - physical REZ NO assets		
	Action to return to service - physical Transgrid assets		
	Switching/Isolations to enable 3rd party access (for example generator or DNSP requirements)		
	Coordination of return to service request for a Transgrid asset		
Emergency Operations	Incident Response for Transgrid network	Maintain accurate model of the network in real time and EMS/SCADA capability for new renewable related asset types	EMS/SCADA
	Incident Response for RNI		
	Power System emergency response (e.g. Load Shedding, min demand management etc)		
	Coordination on system security response requirements		
	Manage Network Emergency Response and Communications		
	Power System Emergency management Level 1/2 - NSW		
	Power System Emergency management Level 3		
	Power System Emergency management Level 4		
	Power System Emergency management Level 5		
	Communication with other parties (police, fire, RMS, rail etc.)		
Operations Support	Stability limit advice NSW	Alarm rationalisation, analytics solution and more advanced system for root-cause analysis	Alarm Visualisation and Situational Awareness
	Management of System Security and operating envelopes		
	Development of limits advice and ratings for development of the technical envelope for wider NSW network	Monitoring the risks with fault levels and system stability in coordination with AEMO.	Fault Level Monitoring
	System Restart Planning		
	Analysis of operational data (asset status)		
	Network Security and Performance Monitoring reporting for stakeholders, AEMO and customers		
	Operations Analysis and Reporting		
	Manage Technical Operational Compliance		
Outage planning to support Transgrid's AMP and project delivery programmes	Outage management system (OMS) architecture doesn't support	Outage Management	

Operational Capability	Process	Capability Gaps (highly impacted processes)	Technology Initiatives
Outage Planning and Coordination	Transmission Outage Coordination & Planning	enhanced data integration into SCADA nor business to business (B2B)	Fault Level Monitoring
	Entry of data on planned outages (and updates) into AEMO NOS		
	Preparation of limits advice and constraints for NSW for taking a planned outage in NSW network	Dynamic updating of limits advice to AEMO.	
Operational Procedures and Training	Operator Training	Operator training simulator along quicker access to knowledge within Operating Manuals	Training and Document Management
	Operational Manual Management (defining operating envelopes and actions to be taken) - AEMO Operating zone		
	High voltage safe access procedures		
	Safety Rules, training and management		
	HV asset switching procedures		
	HV outage coordination procedures		
Operational Technology	Manage Protection and Communication Systems	Optimise utilisation of network device control management solution to optimise setpoints in operational processes	Smart Transmission Network Device Management
	Manage Operational Data		
	Manage provision of real-time operational data to AEMO		
	Manage EMS availability	Alarm rationalisation, analytics solution and more advanced system for root-cause analysis	Alarm Visualisation and Situational Awareness
	Manage EMS configuration		
	Manage SCADA system availability	Current version of SCADA/EMS software does not support the range of new energy resources as a standard, nor include any new functional updates.	EMS/SCADA
	REZ network visibility in Transgrid SCADA		
	Manage SCADA system configuration (inc. field commissioning)		
	Transgrid SCADA system management Transgrid		
	Additional SCADA points creation and testing	Centralised single version of the truth operational planning, operational electrical network models, and operational data management capabilities	Data management and network modelling
	SCADA alarm configuration management for station alarms		
	Transgrid EMS design		
	Network model updates		
	Non ICCP data information standards/requirements at interface points	The ability to utilise weather and resource forecasts in real time operations	Operational Forecasting
	Manage Weather, Lightning and Bushfire Telemetry		
	Manage Control Room Telephony		
Transgrid's Network Operations Responsible Officer liaison point			
Facilities	Control Centre Facilities	Not assessed	Not assessed
	Manage Site security and CCTV systems		

5. OPERATIONAL CAPABILITY GAPS AND SOLUTIONS

Capability Upgrade Mapped to Future Energy Scenarios

Transgrid's operability capability needs to be aligned with the network as it is today and robust enough to meet the demands of the power system in the future. Aligning the operability upgrade requirements with the VRE growth projections for demand and renewables in the ISP allows Transgrid to consider the need for investment under various ISP scenarios.

Transgrid should develop operational capability for the most likely future energy scenarios – the Step Change and Progressive Change scenarios by 2030. The time element and pace of growth in the network are important considerations. The Step Change scenario projects VRE in the NSW to grow by 19 GW by 2030.

This rate of growth is likely to continue and may accelerate beyond 2030. Even if the Step Change scenario growth rates are not reached by 2030, they will be reached in the early 2030s. Time is also a factor in the need for imminent investment, as the nature of IT projects for control centres and high-reliability organisations requires many years from planning to commissioning. Also the vendor marketplace is small and stretched, as most other system operators around the world are embarking on similar capability uplift projects.

To summarise, it would not be operationally prudent to wait until the early 2030s, with accelerating growth in VRE and the transmission network, to begin the process of uplifting Transgrid's operational capability – a process which will take until the mid-late 2030s to deliver adequate solutions.

Proposed Solutions to the Capability Gaps

The capability gaps identified in the assessment summarised in section 4 can be primarily addressed by an uplift in OT and software applications used in control centres and operations departments. There are some improvements to processes and additional human resources, in addition to the new technology, that may be necessary and impactful, but the analysis of these complementary measures is beyond the scope of the project. Additionally, large, bulky software products are not just about the initial capital cost. There is also a significant cost in continuous improvement, security patching and upgrades, and general maintenance through the product life cycle.

Operational Technology Solutions

Globally, transmission companies (TNSPs, Independent System Operators, Transmission System Operators) have tried to bridge the capability gap by either:

- a. Adding more operators into real time operations and engineering in engineering support roles.
- b. Leveraging operational technology systems.

While adding human resources is necessary, it is likely to be impactful up to a point before it becomes too difficult to manage operationally and there is diminishing returns to adding more people. Therefore, this is not considered a viable solution.

Automation of processes is also a worthwhile long-term goal but retrofitting legacy technology systems to be more automated while maintaining reliability in short time frames is a very challenging task. More automated systems are long term objective requiring very extensive investment in technology capability uplift. Therefore, this is not considered a viable solution in the timeframe of the need.

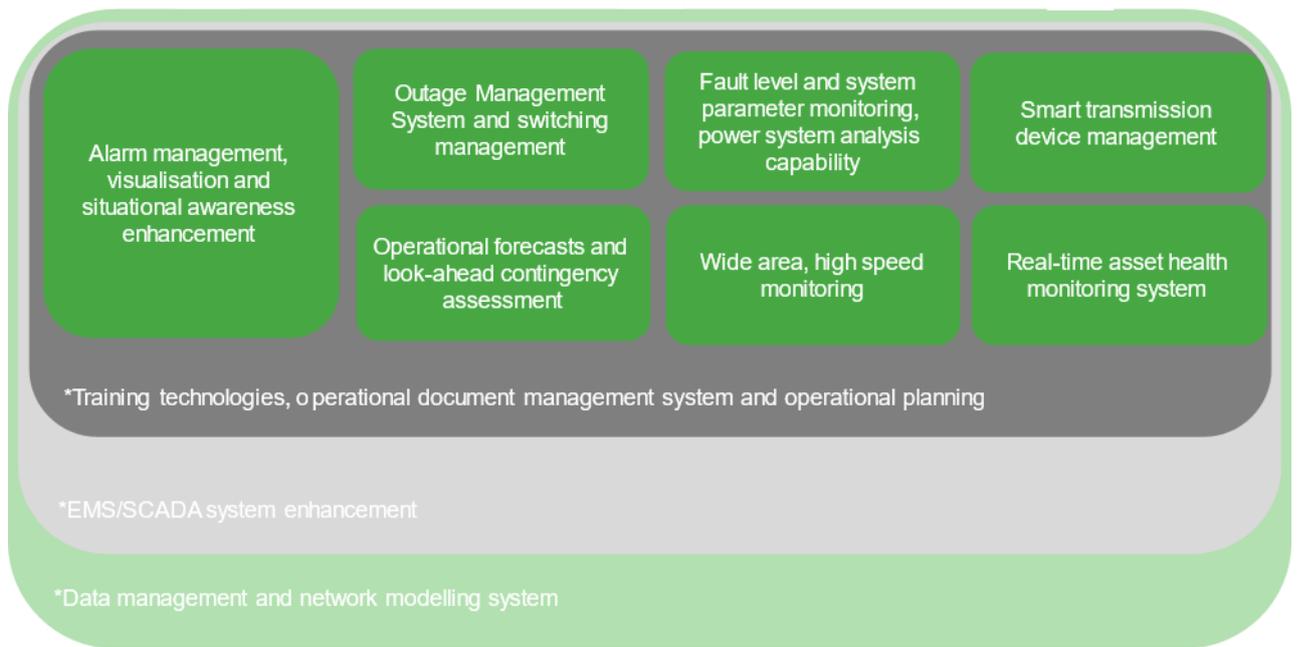
It is recommended to consider investment in the following ten operational technology solutions.

Enabling Technology

- Data Management and Network Modelling
- EMS/SCADA Upgrade
- Training and Operational Documentation Streamlining

Operational Technology Applications

- Alarms, Visualisation, Situational Awareness Enhancements
- Operational and Environmental Forecasts and Impact Assessment
- Wide Area, High Speed Monitoring
- Smart Transmission Device Management
- System Strength, Inertia, Fault Level Monitoring
- Asset Management and Asset Health Monitoring System
- Enhanced Outage Management System (OMS)



Notes: * Enabling technologies

Figure 10 Transgrid’s 10 proposed operational technology solutions

Based on this report, Transgrid should choose the optimal solutions (based on market assessment and vendor offering) to address the recommended technological uplift defined in this report.

Maturity Level

The proposed operational technologies are captured by three levels of maturity ranging from Level 1 – Basic, Level 2 – Intermediate and Level 3 - Advanced in which they can be implemented to meet the operational capability uplift requirements for the Progressive, Step and Green Energy change scenarios. The three operational technology levels of maturity have been defined from a technical perspective where each level builds upon the previous one to capture further enhancements to the operational technology capabilities.

The proposed operational technologies are introduced below and described in more detail in the tables that follow.

Enabling Applications

There are three enabling technologies – data management, EMS/SCADA and training and document management. They are considered as enabling technologies as they provide the data quality functionality required for the seven proposed technology solutions for the control centre to function. The enabling applications are required to support the implementation of the other operational technology applications.

Data management refers to the technology needed to manage operational data and models in a well-governed, streamlined, efficient and accurate manner. The operational data and models should be interoperable across all software applications. Models of the network in the EMS/SCADA should be the same as the models of the network used in simulation processes and tasks and in asset management. This technology upgrade would include the data historian for the core applications and the ability to leverage machine learning.

Network model data consists of data to represent the physical asset data, the electrical representative model data. Models are used in simulation studies in the planning domain for long-term expansion planning and in the operations domain for studies for outages and contingency analysis. The models are used in different simulation application tools and have different formats, so they may differ. Over time they may diverge as operations models need to reflect the real network but planning models represent future networks. The physical network model used for asset simulations is also separate and siloed from electrical models. The real-time operational data that parameterise the models (such as SCADA) are also in a separate software application, database, and format, not linked directly to models in external systems.

The optimal approach is to develop a 'single version of truth' model of the network in a standardised format that can be used by all simulation applications. The electrical model should link relationally to the physical model. This establishes a 'data continuum' for models from planning to operations and asset management construction and commissioning. This data continuum will allow updates to be made in one source format and passed through to all applications. This increases the efficiency of the SMEs by reducing the human resources of multi-model management and reduces model error over time. It will also enable condition-based maintenance and data analytics and machine learning in future if the model is consistently formatted and linked across domains.

The need for a single version of the truth system will be more acute with the increase in assets and generation on the network. It can be achieved by a network model management (NMM) system, available from vendors that are developed to consolidate model data and the governance around the data interconnected with simulation applications.

Data Management Maturity Levels

Data Management and Network Modelling	Current State	Level 1	Level 2	Level 3
Descriptions	<ul style="list-style-type: none"> Multiple off-line and on-line power system modelling applications are used by planning and operations teams Power system network models and asset data are a combination of manual and automated data exchange between teams at Transgrid, and external entities Operational data is maintained in operational and business data management systems 	<ul style="list-style-type: none"> Network model data governance system in place with owners Processes mapped for flows of models of the network around the company Establish standards and architecture design for centralisation of network model and operational data Network model management system developed and populated 	<ul style="list-style-type: none"> Needs listed in Level 1, and: Electrical model data aligned and integrated with time-series operational data points such as SCADA, PMU, Digital Fault Record (DFR), protection Access to data across company for planning and operational insights Data Hub for operational data for offline 'remote' access Electrical model and operational data linked to asset model to improve simulation, analytics, and process automation 	<ul style="list-style-type: none"> Needs listed in Level 2, and: Automated self-validation of the models through real time operational and sensor data and linked to simulators Artificial Intelligence/Machine Learning (AI/ML) (either on-prem or in cloud) on model and operational data to derive insights on abnormal behaviours based on training on archive data Optimised asset investment decisions
Capability Gap Addressed and Desired End State		Centralised operational planning, operational electrical network models, and operational data management capabilities	Electrical model integrated with operational data in single repository or data hub	Highest quality and currency of electrical model and operational to improve the accuracy of AI/ML capabilities

EMS/SCADA Applications Maturity Level

EMS/SCADA Enhancements	Current State	Level 1	Level 2	Level 3
Descriptions	<ul style="list-style-type: none"> Industry recognised EMS/SCADA software Base state estimation functionality Lack of standard SCADA models to manage DER and VRE Network segregation of SCADA system 	<ul style="list-style-type: none"> Enhanced state estimator in EMS. Working, accurate state estimation for transmission network Capability to process and visualise VRE and DER across the transmission network e.g. life-cycle upgrade of the EMS-SCADA 	<ul style="list-style-type: none"> Needs listed in Level 1, and: Capability to model to Medium Voltage (MV) network, on DNSP system aggregated DER at supply points Capability to model into neighbouring transmission systems 	<ul style="list-style-type: none"> Needs listed in Level 2, and: Machine learning based State Estimator (SE) where gaps exist in SE and to derive insights from operational data Full controllability of VRE/DER as agreed under instruction
Capability Gap Addressed and Desired End State		Accurate model of the network in real time and exploration of EMS/SCADA capability for managing DER	Visibility of VRE and DER at distribution level and pass through to AEMO	Controllability of DER for emergency and restoration or as delegated by AEMO

Training and Document Management Applications Maturity Level

Training and Operational Documentation Streamlining	Current State	Level 1	Level 2	Level 3
Descriptions	<ul style="list-style-type: none"> On the job (on-shift) training and more recently via use of the EMS Dispatcher Training Simulator (DTS) utilising basic functionalities Long time durations for training Documentation is disparate, not streamlined and coordinated 	<ul style="list-style-type: none"> Dedicated training competency programs for operators and operational engineers Operations readiness centre with EMS simulator and ability to integrate training environments of all technology in the control Centre. Operational documentation streamlined and standardised. All operational documents linked to technology systems and network assets LLM or equivalent for operational document search and retrieval 	<ul style="list-style-type: none"> Needs listed in Level 1, and: All technology in Operational Readiness Centre (ORC) Automatic scenario creation forms past events for training and analysis. ORC used for deployment of new software and technology upgrades. Continuous training and certification for operations support staff with and ad-hoc simulator training for operators. Integration of documents with EMS substation model for ease of access 	<ul style="list-style-type: none"> Needs listed in Level 2, and: Accurate dynamic simulation of the network in ORC simulator Training for cross energy sector domain challenges with AEMO, TNSP, DNSP, REZ operators Australia-wide certification of operators in line with industry trends
Capability Gap Addressed and Desired End State		Dedicated team and competency program for training and documentation management with early-stage ops readiness centre. Upgrade DTS and establish simulator training that supports faster operator competency progression and the ongoing training of existing operators	Enhanced operations readiness centre for training. Automated search and retrieval on ops documents	Cross sector domain training involving gas, electricity, DNSP, TNSP, AEMO, REZ

Operational Technology Applications

These group of proposed technology enhancements are to address the emerging network challenges for managing operational processes in high VRE operational scenarios. These technologies will be critical to network operation where VRE capacity at least doubles in a short space of time. This includes the management of system security, the monitoring and mitigation of power quality issues, network oscillation and smart device management and the ability to forecast for short-term outlook.

An important enabler for enhanced operational capability and one of the emerging technology applications is Wide Area, High Speed Monitoring. This has two components:

- The sensor devices on the network that monitor the network parameters (voltage and current) such as phasor measurement units (PMUs) and digital fault recorders (DFR),
- The software technology that analyses the data and is used by control Centre personnel for monitoring – such as wide area monitoring system (WAMS) or power quality monitoring.

The software technology is only as good as the quantity of sensors that feed data into the software. Increasing the number of sensors on the network would provide wider coverage across the network for the full range of power system phenomena. There are currently 5-10 PMUs on the Transgrid network. These pass data to the AEMO control centre for wide-area monitoring. As the number of installed PMUs increases across the network it will incrementally improve the proposed WAMS technology to identify network abnormalities and the root cause or primary driver of the abnormality (to be constrained). Configuration management and deployment of PMUs and DFRs will require investments.

The smart device management technology is intended to consolidate and streamline the management of inverter-interfaced transmission devices on the network for operational purposes – such as the control, setpoints and troubleshooting. In the planning and protection domains, there is also a significant challenge in managing these devices that is expected to worsen over time due to the number of different device manufacturers, their software configuration systems, the management of the bespoke design schematics, and their interaction with other technology systems. These devices are expected to proliferate further on the network in the coming years, so investment is required to manage, configure, and operate the devices as they play an increasingly important role in network operation.

Asset Management Applications Maturity Level

Asset Management and Monitoring System	Current State	Level 1	Level 2	Level 3
Descriptions	<ul style="list-style-type: none"> PI used for data analytics and to gather insights in asset monitoring centre Manual coordination between the AMC and control centre Dual PI historian architecture for asset health checking and operational limit checking Switching steps are generated automatically, manually verified and manually executed using the SCADA/EMS (where feasible), with manual reference to the switching sheet in the OMS 	<ul style="list-style-type: none"> Thresholds established for all assets for network action in coordination with AEMO Automated coordination between AMC and network control centre with alarms for action Automated notification and actions for field personnel Alarm management actions to move in control centre (24-hour monitoring) 	<ul style="list-style-type: none"> Needs listed in Level 1, and: Integration of CBM with OMS and EMS Protocols with AEMO for outage management when asset issues identified Clear notifications to network operations with risks through EMS or other systems Asset network and outage management systems integrated with consistent models Physical security monitoring integrated with asset monitoring Wide-spread coverage of all assets 	<ul style="list-style-type: none"> Needs listed in Level 2, and: Condition based maintenance for all assets based on insights in data fully integrated into operational and asset processes. Data analytics and asset monitoring algorithms used extensively in real time to optimise asset usage and outage requirements and linked procedures. Video and drone-based monitoring for anomalies. Predictive asset and management systems that identify anomalies in asset data, allowing sufficient time to act.
Capability Gap Addressed and Desired End State		Clear links and areas of responsibility between operations and asset management teams.	Initiative-taking management of assets to integrate in real time operations based on asset analytics.	Dynamically adjusted asset ratings based on Condition Based Maintenance by design for monitoring of assets.

Outage Management Application Maturity Level

Outage Management System	Current State	Level 1	Level 2	Level 3
Descriptions	<ul style="list-style-type: none"> Legacy in-house system for outage management fit for current purposes but may not be fit for our future purpose. OMS not integrated with EMS or AMS. Mobile switching solution based on executing steps on a switching sheet, as well as manual paper based. Network models are manually updated in the OMS to reflect the SCADA/EMS model. 	<ul style="list-style-type: none"> Risk assessment in outages based on historical fault rates to flag reliability risk and customer impacts. New OMS for managing outages on the network. Integrated with EMS to allow outage data to be viewable with network data. Reporting and analytics on outage process to identify gaps. Reduce the amount and duration of non-critical verbal communication from the control room, particularly the protocols for switching between field and control Centre. 	<ul style="list-style-type: none"> Needs listed in Level 1, and: OMS integrated with AMS so that EMS, OMS and AMS are linked EMS network model linked to outage asset model including symbols and upcoming outages Work crew resource management system and data integrated with OMS. Automated outage coordination and simulation processes. Unplanned network outages automatically linked to EMS. 	<ul style="list-style-type: none"> Needs listed in Level 2, and: Study dynamic security implications of complicated outages in coordination with AEMO. Automated outage management process for condition-based maintenance, network simulation which identifies network risks for outage combinations. Automated draft switching procedure generation for engineer/operator approval. Optimised workforce management for unplanned outages based on availability and proximity.
Capability Gap Addressed and Desired End State		New OMS to replace the existing OMS system to improve efficiency, reduce manual workload.	Smarter OMS with integrations to other core technology and ability to incorporate unplanned outages and dynamic issues.	Capability of the OMS to predictively assemble, and export planned outage scenarios for further. dynamic power system security assessments to identify outage windows of opportunity.

Operational Forecasting Application Maturity Levels

Operational and Environmental Forecasts and Impact Assessment	Current State	Level 1	Level 2	Level 3
Descriptions	<ul style="list-style-type: none"> • Web browser access to operational forecasts from AEMO for demand. • Access to observations and forecasts of weather, fire and environmental data using various web browser-based apps. 	<ul style="list-style-type: none"> • Integrate geographic information system with network operational models and data – such as SCADA. • Persistent access to AEMO op forecasts for TNSP processes such as outages and voltage management. 	<ul style="list-style-type: none"> • Needs listed in Level 1, and: • Enhanced forecast for demand from supply point. • Integrated operational and environmental forecasts with environmental GIS data. • Environmental forecasts to predict storm trajectories, participant/customer impact predictions. 	<ul style="list-style-type: none"> • Needs listed in Level 2, and: • TG developed op forecast system based on archived internal op data and open weather forecasts and rooftop PV location. • Customer/network Impact assessment of environmental activities (storm, fire) based on past event data. • Predictive environmental forecasts based on historical asset data and event archive with suggested actions.
Capability Gap Addressed and Desired End State		Easy access to forecasts to give operator visibility of potential issues as required and initial stages of integration	Forecasts used regularly and consistently in all operational processes such as switching, voltage management.	Advanced forecast capability allows predictive capability for network impacts so that they can be mitigated by operators.

Wide Area Monitoring Application Maturity Levels

Wide Area High Speed Monitoring	Current State	Level 1	Level 2	Level 3
Descriptions	<ul style="list-style-type: none"> Manual remote interrogation/download of High-Speed Monitoring (HSM) disturbance data, performed by the Asset Monitoring Centre (AMC) team. HSM not used in the control Centre. Transgrid's PMU sensor data is passed to AEMO in real-time. Protection relays manually interrogated. 	<ul style="list-style-type: none"> WAMS in TG control Centre for basic wide area monitoring for specific processes (interconnector monitoring). Automated process for protection relay and digital fault recorder interrogation and data extraction. Power quality reporting by manual triggers. 	<ul style="list-style-type: none"> Needs listed in Level 1, and: Integration of WAMS and EMS. Integration of protection relay, digital fault recorder data and SCADA. Expanded set of processes for wide area monitoring based on evolving network (phase angles for switching, state estimation enhancement etc). Automated power quality reporting and identification of sources. 	<ul style="list-style-type: none"> Needs listed in Level 2, and: PMU data on sub transmission and distribution network feeding data to WAMS. Linear state estimator down to distribution. PMUs for operational model validation. Potential for wide area monitoring and control of TG assets based on stability needs. Data analytics and machine learning on operational datasets in real time. Corrective actions to issues identified based on op data insights. Wide Area Control (WAC) for rapidly adjusting control setpoints for detected abnormal events. Mitigation actions for power quality issues.
Capability Gap Addressed and Desired End State		Deployment of WAMS in TG control centre for enhanced situational awareness with scope to expand functionality.	Ability to integrate, align all operational data (SCADA, PMU, DFR, Protection, Power Quality) in one location, visualisation for decision making support and investigations.	Using PMU data archive and real time data to gain predictive capability with corrective action suggestions for system abnormalities and unusual dynamic behaviours. Automated validation of dynamic models to improve simulations.

Smart Transmission Network Device Management Application Maturity Levels

Smart Transmission Network Device Management	Current State	Level 1	Level 2	Level 3
Descriptions	<ul style="list-style-type: none"> • Approx 50 'SPS' devices on the network of different forms. • Inconsistent control and operation techniques not integrated with EMS. • Various non-standard documentation • Lack of training 	<ul style="list-style-type: none"> • Standardised management for devices across all manufacturers and types. • Standardisation of documentation and processes for smart devices linked to EMS. • Standardised visualisation and controllability and operational data in EMS • Bespoke training on smart devices and integration with training simulator. • Methodology for integration of new devices. 	<ul style="list-style-type: none"> • Needs listed in Level 1, and: • Develop a repository for the standardisation of devices, interfaces, processes for smart devices. • Integration of all smart transmission devices into EMS (response of SPS to a contingency, DLR rating overrides). • Integration of smart device behaviours into outage management processes and systems. 	<ul style="list-style-type: none"> • Needs listed in Level 2, and: • SPS are interoperable with DLR. • Centralised controllability of smart devices from EMS for contingencies or other network issues. • Topology reconfiguration for network issues. • Automated restoration pathways for parts of the network
Capability Gap Addressed and Desired End State		Easy to understand, consistent operational processes and for smart devices.	Results of smart device action in response to network issues incorporated into operational processes and technology systems.	Automated, centralised controllability and predictive plans of smart device reactions to network issues incorporated into OT systems.

Fault Level Monitoring Application Maturity Levels

System Strength, Inertia Fault Level Monitoring	Current State	Level 1	Level 2	Level 3
Descriptions	<ul style="list-style-type: none"> No monitoring capability for system strength or inertia. Fault level monitoring application that requires a refined model and validation process. No way to assess risk or processes for control actions. No capability to model current source devices. 	<ul style="list-style-type: none"> Agreed methodology and calculation method for system strength. Refinement of the short circuit model in EMS model. Deployment of a fault level monitoring application in real time for worst case scenarios. Deployment of a basic system strength monitoring application for offline analysis. 	<ul style="list-style-type: none"> Needs listed in Level 1, and: Deployment of an inertia SS monitoring application in real time, these may be integrated or separate. Near and medium-term forecasts of system strength/inertia fault level based on outages, market, forecast data. Continuous feedback loop of SS data to planning and resource teams for future developments. 	<ul style="list-style-type: none"> Needs listed in Level 2, and: Intervention actions automatically generated for real time and forecasted deficits in system strength/inertia in coordination with AEMO. Capability to automatically deploy control actions for system strength issues, potentially using the WAC capability of PMUs.
Capability Gap Addressed and Desired End State		Basic applications for SS, inertia, and fault level monitoring to be expanded as the knowledge evolves.	Deployed enhanced applications for SS, inertia, fault level online with in-built forecast or predictive capability.	Aligning system strength with transmission network actions (either manual or automatic).

Alarm Visualisation and Situational Awareness Applications Maturity Level

Alarm Visualisation and Situational Awareness	Current State	Level 1	Level 2	Level 3
Descriptions	<ul style="list-style-type: none"> Alarms managed manually in EMS/SCADA. Manual root cause analysis using filters and operator experience. Basic, traditional visualisation style in EMS. No visualisation integration between technology systems. 	<ul style="list-style-type: none"> Rationalise, re-prioritise all alarms. Align alarms with network and asset model. Alarm analytics for monitoring. Dashboard development for all operational processes to support decision making 	<ul style="list-style-type: none"> Needs listed in Level 1, and: Abnormal alarm/operational data detection, identification. Integrated visualisations for all technology apps – weather, geography, SCADA, outages etc. Intelligent alarm processing for flood suppression based on assets. 	<ul style="list-style-type: none"> Needs listed in Level 2, and: Automated root cause analysis based on historical incidents. Recommended actions for alarms based on archive. Interlinked hierarchy of displays with redesigned videowall displays using data visualisation technology. Voice based interactions with technology systems.
Capability Gap Addressed and Desired End State		Reduce alarm rates and improve alarm root cause analysis through implementation of further alarm management techniques.	Reduced alarm rates with increased assets, alarm flood suppression to accelerates the operator’s awareness of the root cause of the alarm.	Automated detection and diagnosis of alarms. Integrated data visualisation for all technology /IT apps in control Centre.

Technology Solution Upgrade Recommendations

All the technologies require varying degrees of investment at different times, depending on how the transmission network of NSW emerges, based on projections.

The Step Change scenario is considered by AEMO to represent the most likely scenario, and the technology uplift will need eventually even if the Progressive Change scenario occurs. In this sense, uplifting Transgrid's capability by 2030 to meet the Step Change scenario represents a 'no regret' approach. **Error! Reference source not found.** below summarises the key investments recommended and the desired end state by 2030.

Table 6 Summary of the 10 identified solutions for operational capability uplift, with desired end state

Solution	Key investment required	Desired end state by 2030 for the Step Change scenario
Data management and network modelling	Comprehensive data management overhaul for assets under control	Electrical and asset model integrated with operational data to provide a single view of truth.
EMS/SCADA	To leverage new software functionality and use standard processing of data from the range of new energy resources	Visibility of VRE and DER at distribution level as required, with seamless pass through to AEMO.
Training and Document Management	Modern training simulator along quicker access to knowledge within Operating Manuals	Fit for purpose training simulator. Automated search and retrieval on operating manuals.
Asset Management	Integration of network operational and asset management for enhanced network utilisation	Optimal network asset utilisation in real time operations.
Outage Management	Modernise outage management system (OMS) architecture and enhance data integration between systems and with Business to Business	Enhanced OMS with integrations to other core technology and ability to incorporate unplanned outages and dynamic issues.
Operational Forecasting	The ability to utilise weather and resource forecasts in real time operations and to manage emergencies	Forecasts used regularly and consistently in all operational processes such as switching, voltage management.
Wide Area Monitoring	A wide area monitoring system for PMU data to monitor emerging network stability risks	Ability to integrate, align operational data (SCADA, PMU, DFR, Protection, Power Quality) in one location, visualisation for decision making support and investigations.
Smart Transmission Network Device Management	Utilisation of network device control management solution to optimise setpoints in operational processes	Results of smart device action in response to network issues incorporated into operational processes and technology systems.

Solution	Key investment required	Desired end state by 2030 for the Step Change scenario
Fault Level Monitoring	Monitor the risks with fault levels and system stability in coordination with AEMO	Deployed enhanced applications for Steady State, inertia, fault level online with in-built forecast or predictive capability.
Alarm Visualisation and Situational Awareness	Alarm rationalisation, analytics solution and more advanced system for root-cause analysis	Reduced alarm rates with increased assets, alarm flood suppression to accelerates the operator’s awareness of the root cause of the alarm.



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