Business Case Recommendations and Methodology

System Security Road Map

Enabling the secure operation of the NSW power system at 100% instantaneous renewable energy

Disclaimer

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Version Control

Version	Release Date	Changes
1.0	31 July, 2022	Draft Publication
1.1	7 October, 2022	Final Publication

Executive Summary

Transgrid has engaged PowerRunner to assess its current asset management, network planning and network operations capabilities and recommend initiatives that address gaps and ensure that it is capable of securely planning, operating, and managing the NSW power system as it transitions towards renewable generation, and may operate at 100% instantaneous renewable generation as soon as 2025.

PowerRunner has assessed that there is growing system complexity and operational risk which if not mitigated is likely to lead to non-compliance with obligations under the National Energy Rules (NER) and an increase in minor, intermediate and catastrophic system security incidents on Transgrid's network and unserved energy – increasing each year and being 569% higher by Financial Year 2030 when compared to Financial Year 2022.

PowerRunner has recommended a suite of initiatives that Transgrid should implement to address the growing complexity and risk, comprising an uplift in capability (technology & tools) and capacity (human resources), with a total cost of $130m (Real $FY22) between Financial Year 2024 and Financial Year 2028.

The 5-year investment component of the capability uplift (technology/tools) is comprised of CAPEX of $85.0m and OPEX of $2.5m which is summarized in the table below, as well as 2023 estimated budget for Program Initiation Costs (Real $FY22).

	2024	2025	2026	2027	2028	Total 5-year (FY24-FY28)	Project initiation costs (FY2023)
Technology Development - Capex							
Total Capex Costs	$58,091,889	$17,563,793	$6,037,861	$3,187,334	$83,225	$84,964,102	$6,221,354
Maintenance & Support - Opex							
Total Opex Costs	-	-	$665,037	$931,051	$931,051	$2,527,140	

The 5-year OPEX investment component of the capacity uplift (human resources and training) is $42.3m (Real $FY22) and is summarized in the table below.

	2024	2025	2026	2027	2028	Total 5-year	2023
Technology Development - Capex							
FTE Increase	30	36	39	45	46		21
Total Opex Costs	$6,566,434	$7,797,054	$8,509,552	$9,651,809	$9,807,686	$42,332,535	$4,863,225

PowerRunner has assessed that implementing these initiatives could mitigate an increasing operational risk by 35% and 25% for capability and capacity uplift, respectively. These costs and risk mitigation factors are assessed as reasonable given the estimated impact of planned changes to the NSW energy system over the next decade:

- investment of over $27.0 billion in 12,000MW of new renewable generation
- construction of over $7.6 billion in new transmission infrastructure

- integration of 5 Renewable Energy Zones – potentially multiple transmission owners and operators
- retirement of 6,800MW of coal fired generation
- increase of distributed solar generation - reducing net customer load
- requirement of additional system services to maintain voltage control, inertia, and system strength
- the need for prolonged system outages for major projects – reducing the resilience of the power system

Findings

PowerRunner has been engaged to assess Transgrid capabilities and develop a roadmap of initiatives needed to enable the secure operation of the NSW power system at 100% instantaneous renewable energy, which, based upon conditions forecast by AEMO may occur by 2025. This has involved an intensive 4-month deep-dive review into Transgrid's network planning, asset management and operational divisions. As part of this engagement, PowerRunner has assessed the emerging complexity and operational risk and recommended inputs and methodology to be applied by Transgrid in the evaluation of the costs and benefits of the System Security Roadmap Technology and Human Resources uplift.

The overall finding is that an uplift in Transgrid capability and capacity is required, given the pace of the energy transition, the level of investment in new generation and transmission infrastructure, and the increasing complexity and risk in planning and operating the transmission system in NSW.

PowerRunner has deep knowledge of the electricity industry, network service providers and transmission system operations both internationally and in domestically. We have strong credentials in asset management, network planning and real time system operations including capabilities needed to manage the energy transition. We understand the drivers for electricity network and generation investment and the issues facing electricity markets in Australia and around the world.

PowerRunner has experience advising clients in the energy industry markets spanning over 14 countries across four continents. Internationally, PowerRunner has worked on the design and implementation of day-ahead markets in PJM, Ireland and Texas. Domestically, we have been substantially involved in the establishment, evolution and operation of both the NEM and the Western Australian electricity markets.

An operational risk-based methodology should be used – there is a step change in complexity and work volumes forecasted over the next 5 to 10-year planning horizon due to the pace of the energy transition and the planned inimitable changes in generation mix and transmission topology. PowerRunner has estimated the increased operational risk that could be expected as a result of this complexity, recommended capability and capacity uplift initiatives to address these issues, and assessed the risk mitigation that these initiatives may achieve.

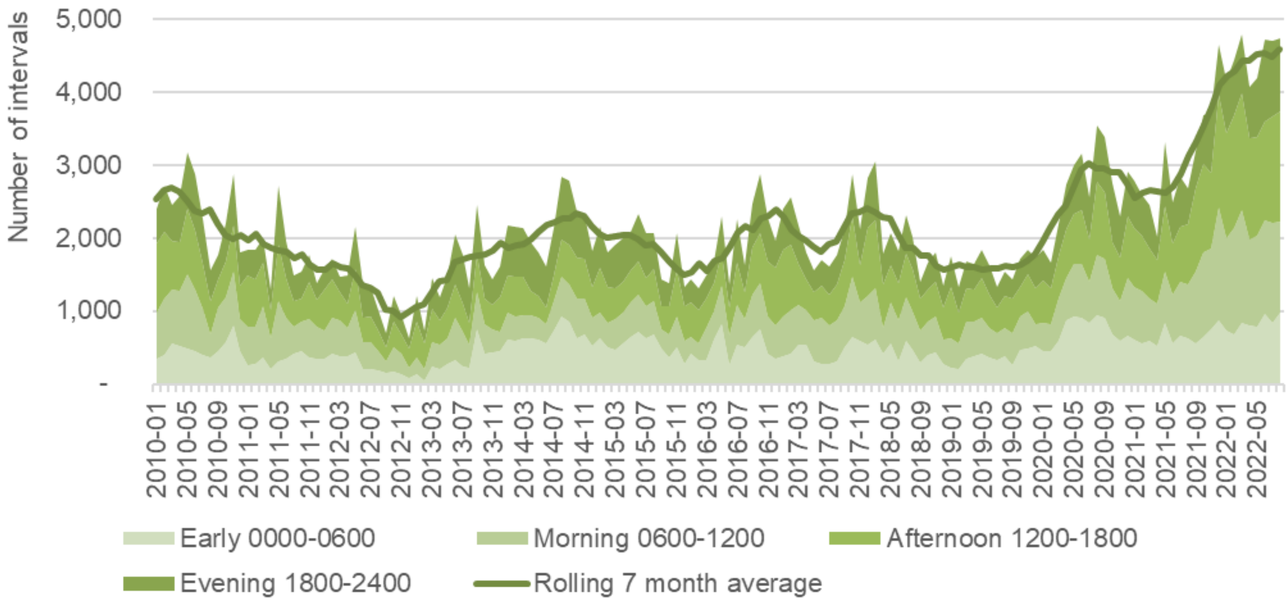
The capability and capacity uplift is needed to mitigate these risks to a reasonable level – based on outcomes of the capability assessment, Transgrid's current tools and resources are already at or above capacity. The proposed uplift is needed to reduce risks to a reasonable level and to maintain system security (including at up to 100% instantaneous renewables by 2025). The energy transition in NSW includes:

- investment of over $27.0 billion in 12,000MW of new renewable generation
- construction of over $7.6 billion in new transmission infrastructure to support AEMO's ISP
- integration of 5 Renewable Energy Zones – potentially multiple transmission owners and operators
- retirement of 6,800MW of coal fired generation
- increase of distributed solar generation - reducing net customer load,

- requirement of additional system services to maintain voltage control, inertia, and system strength
- the need for prolonged system outages for major projects – reducing the resilience of the power system

Existing operational tools and capabilities are now at full capacity – NSW is in the early stages of the energy transition, with most of the system transformation forecast to occur in the next decade. System complexity and operational risks are already increasing, and existing tools and capabilities are at capacity and unable to scale.

The NSW power system is operating closer to the edge of the power system technical envelope – the trend in the figure below shows the growth in operating intervals where at least one credible contingency would have resulted in a violation of the power system technical envelope (potential insecure network operations, and without intervention this could cause forced outages or potential escalation to a major or catastrophic system event). This shows the increasing levels of control room operator interventions that are currently required to maintain secure operations - this trend is forecast to continue as system complexity increases through the energy transition.



Operating intervals when at least one credible contingency on the NSW transmission system would have resulted in a violation of the power system technical envelope

Overwhelming acceptance of increasing complexity and operational risk – there is worldwide acceptance that the electricity industry is rapidly transitioning towards a more decentralized, renewables-based generation power system – trending to an ambition of 100% renewables. By its nature this ambition is challenging and complex for Transgrid who is obligated to:

- Maintain the safety reliability and security of the Transmission system in accordance with the NER
- Accommodate REZ connections, major projects and retirement of coal fired generation
- Deliver or procure system strength, inertia and other system security services

Greater visibility of system conditions is needed – the forecasted increase in power system complexity is heightening the risk of load shedding events, work safety issues, damage to transmission assets, environmental risks, and the distinct possibility of failing to meet compliance obligations resulting from antiquated processes, lack of skilled resources and inadequate tools to manage the step change workload. To better manage this complexity Transgrid requires greater visibility of system conditions, real time data feeds and analytics to support improved decision making along with enhanced resource requirements to support improved event simulations and modelling to deliver cost efficient contingency actions.

Relatively minor investment to maintain reasonable security level as part of a multibillion-dollar energy system investment – the current investments in the energy transition in NSW are estimated at $39.6 billion and are expected to deliver over $9.8 billion in direct benefits to consumers. The cost of the technology and capacity uplift required to ensure Transgrid can maintain reasonable system stability levels throughout these substantial changes in transmission network topology is estimated at $130m (to Financial Year 2028) – 0.33% of the overall estimated energy transition investment.

Transgrid Responsibilities

Transgrid plans, builds, maintains, and operates the high voltage electricity transmission network in NSW and the ACT, connecting generators, distributors, and major end users in accordance with the NER and jurisdictional license conditions. The NSW network is the backbone of the National Energy Market (NEM), enabling energy trading.

There are more than 3 million homes and businesses connected to the NSW power system.

Purpose of proposed capability and capacity uplift

The purpose of the proposed capacity and capability uplift is to mitigate, as much as reasonably practicable, the risks arising from increasing power system complexity, and maintain planning and operating capabilities - in support of AEMO maintaining overall NEM system security as obligated under sections 4 and 5 of the NER. PowerRunner has assessed that failing to implement these solutions increases the risk of system events, including loss of supply to customers, with the Value Customer Reliability at $43,032/MWh.

There is an increasing risk Transgrid failing to meet its obligations under the NER. This is driven by the energy transition. The main contributors are:

Increased inverter-based generation	12,000MW of new renewable generation planned to connect to weaker parts of the network over the next 5 years – increasing customer connection, testing and energizing activities, customer inquiries, and planning studies
Outage Coordination	Outages now need to be orchestrated rather than planned – on the supply side - aging coal fired generation requires more frequent schedule maintenance are prone to unscheduled outages. On the infrastructure side – there is an increased need for prolonged system outages to allow for the construction and upgrades of major projects. When added to the business-as-usual infrastructure maintenance outages and unplanned, forced outages the complexity of system planning, and operations is increasing driving a higher than acceptable risk of system events. The construction of transmission infrastructure for QNI, Project EnergyConnect, HumeLink, VNI West, Central-West Orana REZ Transmission Link, resulting in increased planned outages which will significantly impact the resilience and reliability of the power system

Retirement of coal generation	Over 6,800MW of coal fired generation planned for retirement over the next decade impacting voltage control, inertia, and system strength. They have become both less reliable and more expensive to maintain and with the trend toward early retirement and the long lead-time for new renewable generation capacity, replacement system services, and new transmission infrastructure, the risks of supply shortfalls is substantially increasing – planning studies needed to identify impacts to system security and power quality.
Onboarding new technologies	Limited historical data and operating experience of new equipment large scale renewable equipment, synchronous condensers, power flow controls – increasing the need for trial and qualifying new equipment, staff training and updates of operational procedures and manuals.
Integration of Renewable Energy Zones	5 Renewable Energy Zones are scheduled for development over the next 8 years - This will result in multiple owners and operators that need to perform in line with their agreed operational levels which in turn increases complexity of control room operational procedures, manuals, operating decision support, communications, planning studies and outage management
Volume of regulatory changes	Currently there are 425 active market rule changes that need to be tracked and monitored for possible modifications to procedures and tools – this number is expected to increase to accommodate the changes needed to support the energy transition – this will increase regulatory involvement in screening and responding to rule changes as well as implementing of new rule changes into operations and IT systems. Rule changes will also drive changes to processes and procedures and will add further to the number of obligations that Transgrid will be required to comply to.
Electrification	An increase in demand and renewable generation resources needed to support the replacement of oil and gas in heating and transportation. This impacts connections, planning studies and control room operations to ensure that we adequately meet this growing electrification demand.
Distributed energy resources	116,000 rooftop solar installations occurred in NSW in 2021 resulting in new operating conditions - voltage swings, minimum load, limited outage windows, reduced inertia, and system strength. Bidirectional power flows are becoming more common on the distribution system.

The compounding effect of these energy transition factors is leading to additional tasks, duties, and projects that are driving a significant increase in Transgrid's regulatory obligations and workload. Without an uplift, it is unreasonable to expect that employees (at existing staffing levels) would be able to quickly produce a higher volume of work, high-quality results (despite not fully understanding or experiencing the impact of new technologies), train new resources and scale existing tools to meet more complex power system needs.

Approach

The benefits of the capability and capacity uplift relate to the mitigation potential future risks of load shedding events (or loss of load and/or generation as a result of insecure network operating conditions). These events are deemed to be caused by increasing network planning and system operations complexity. These risks, that are rare today (network incidents leading to unserved energy often occur because of asset failure or tripping rather than as a result of operator decision-making or insufficient planning analysis), but are forecasted to increase in the future due to the energy transition. Given there is no historical precedent or supporting data for this scale of industry transition, indicative estimates based on our expert judgement are the best available to establish a clear cost – benefit case, from a risk-based assessment.

PowerRunner's approach for assessing requirements and benefits was to:

- Interview relevant Transgrid managers and executives
- Conduct a capability assessment (leveraging our standard industry capability model)
- Conduct a leading practice review of system operators domestically and globally
- Utilize our industry knowledge and draw upon on materials including, regulatory obligations (NER), asset management, network planning and system operations processes, both internationally and domestically.
- Review industry publications including AEMO, AER, and AEMC materials that we deemed relevant to the scope of this deliverable.

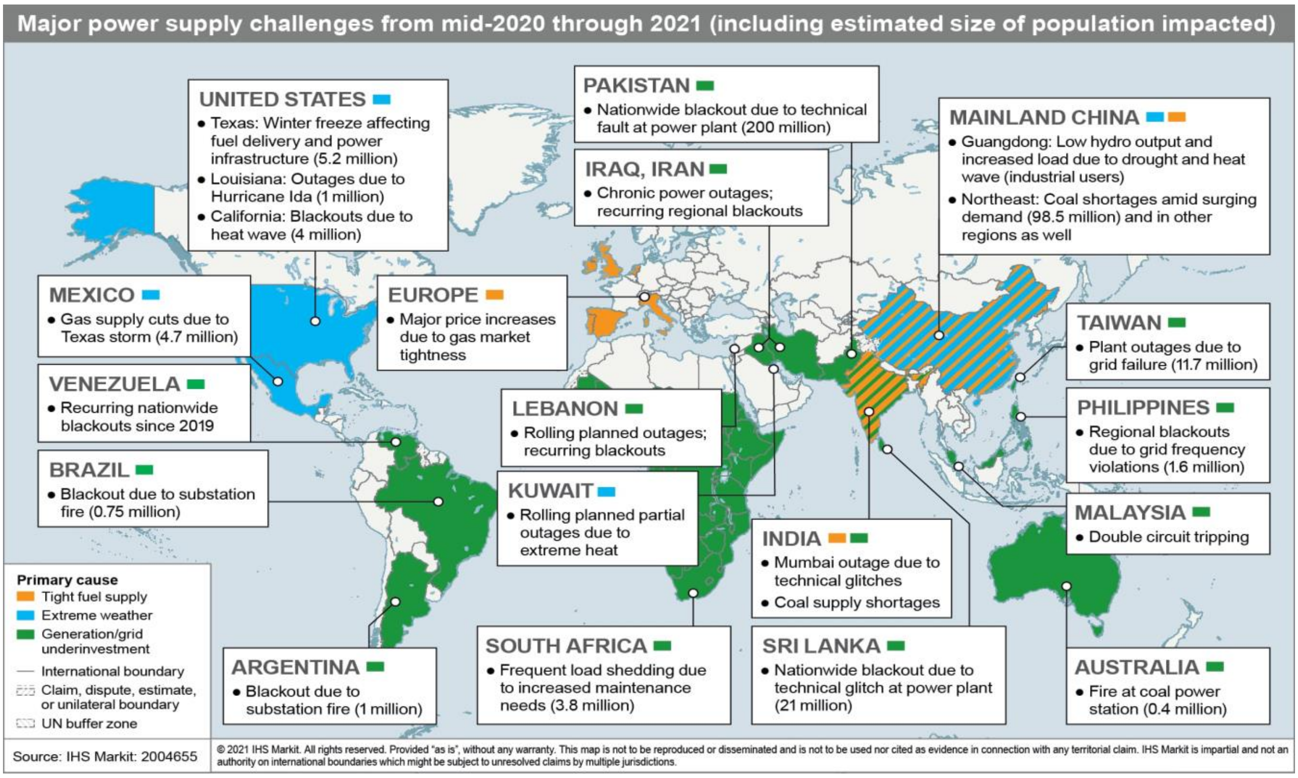
Within the context of this overall approach, specific activities included:

Planning	- Agreeing the form, content and expectations of the scope, deliverables, and timeline - Establish that no market economic assessments will be conducted
Research	- Assess local and international leading practices - Review relevant global publications and industry reports, strategic plans, planning reports, work plans, and budgets - Leverage consultant knowledge and materials from similar projects
Workshop	- Working with relevant managers and wider Transgrid SMEs to workshop current state of business capabilities, major projects, and initiatives - Identify risks, challenges, mitigations, constraints, costs, and benefits - Identifying and documenting business issues / problems that staff are experiencing - Identify relevant compliance obligations, regulations, policies, and rules - Engender consensus on business impacts of the energy transition, proposed mitigating initiatives and priorities.
Capability Assessment	- Build a capability model for Network Planning, Network Operations and Asset Management - Conduct a gap analysis between the current and the future capability needs to understand resource capacity, energy transition impacts and planning and operating risk - From the gap analysis - define and prioritize the initiatives to transition to the future sate of operations – people, processes, and tools

The approach is designed around reviewing the drivers of the step change in the network topology and related business activities, the increase in planning and operational risk and the appropriateness of the methodology and inputs to the derived benefits from mitigating these challenges.

The PowerRunner complexity risk assessment is summarized in the table below. Power system events leading to lost load are currently rare, especially network events arising from human error, inadequate system analysis or poor operational decision making, due to adequate operational tools, capability and redundancy and resilience in the system. Current tools, processes and people were determined to be already at maximum capacity, and the forecast system changes and increasing analytical workloads will reduce system redundancy and resilience and increase the risk of failure of key planning and operating processes.

Although rare, system events occurring more frequently worldwide:



In NSW the risk of system events is increasing. The suspension of the NEM in June 2022, for the first time since its inception in 1998, is an indicator of how complex the energy transition will be. In particular, the proposed outages needed for the transition, the retirement of coal generation, the connection of new generation the implementation of REZs means that in PowerRunner's opinion the risk of a system event increases significantly in the coming years.

Based on its assessment, PowerRunner forecasts that if unmitigated, the compounded effect will increase the risk of system security incidents leading to lost load on the NSW transmission system by 569% in Financial Year 2030 compared to the base year of Financial Year 2022, with the risk of minor, intermediate and catastrophic system security incidents resulting in unserved energy increasing each year that mitigation is not applied. PowerRunner has determined that historical network reliability performance is not considered a reasonable predictor for future performance, given the very significant changes in complexity that are forecast, and the emergence of power system operating conditions that have not previously been observed.

Large increase in complexity	Moderate increase in complexity	Limited impact on complexity

		Complexity Risk Assessment: Increased risk in FY30 compared to FY22 (base year) Growth in system security events causing unserved energy					
		+12GW Largescale Renewable Capacity	NSW Renewable Energy Zones	Major Transmission Projects	Retirement of Coal Generation	Distributed solar	Cumulative Total
Focus Areas	Connections	150%	50%	100%	50%	50%	
	Planned Outages	100%	100%	150%	150%	50%	
	Forced Outages	100%	100%	100%	150%	100%	
	Planning Studies	150%	150%	150%	150%	100%	
	Operating Studies	150%	150%	150%	50%	150%	
	Testing & Commissioning	150%	100%	100%	50%	50%	
	Operating Procedures	150%	150%	100%	100%	50%	
	Voltage Control	150%	100%	150%	150%	100%	
	System Limit Analysis	150%	150%	150%	150%	50%	
	Minimum Load Conditions	150%	150%	100%	50%	150%	
	Special Protection Schemes	150%	150%	100%	150%	50%	
	System Strength	150%	150%	100%	150%	50%	
	Asset health and management	100%	100%	150%	50%	50%	
Average		**138%**	**123%**	**123%**	**108%**	**77%**	**569%**

The methodology seeks to measure the inherent planning and operational risk resulting from the increased complexity generated from the connection of 12,000MW of renewable resources, the development of 5 REZs, construction of $7.6 billion of new transmissions infrastructure and the early retirement of baseload coal units. These drivers increase the risk of potential unserved energy in NSW and the NEM. Bases the increased complexity upon orders of magnitude as estimated from factors at the nexus of the Focus Area (y-axis, table above) and major NSW initiatives in coming years (x-axis) and are defined as:

- **Limited Impact on Complexity:** the expected risk to power system security because of the increase in both quantity (i.e., more tasks within each 'Focus Area') and increased complexity of tasks to complete each focus area to a standard required to maintain the security of the NSW power system (i.e., more time, expertise and analysis required to complete each 'Focus Area') is estimated to increase by half by FY2030, as compared to FY2022. If not effectively mitigated, this risk is expected to increase the frequency of system security incidents and associated unserved energy on Transgrid's network to a limited extent.

- **Moderate Increase in Complexity:** the expected risk to power system security because of the increase in both quantity and complexity of tasks needed to complete each focus area to a standard required to maintain the security of the NSW power system is estimated to increase by double that of FY2030, as compared to FY2022. If not effectively mitigated, this risk is expected to increase the frequency of system security incidents and associated unserved energy on Transgrid's network to a moderate extent.

- **Large Increase in Complexity:** the expected risk to power system security as a result of the increase in both the quantity and complexity of tasks needed to complete each focus area to a standard required to maintain the security of the NSW power system is estimated to increase by one and a half times, or more, by FY2030, as compared to FY2022. If not effectively mitigated, this risk is expected to increase the frequency of system security incidents and associated unserved energy on Transgrid's network to a large extent.

For example, the NSW Initiative “Additional 12GW Large scale Renewable Capacity” will impact Transgrid’s ability to maintain appropriate levels of system security should by some of these resources fail to connect in a timely manner. This would impact the provision of necessary system services such as voltage control and system strength by new generation to replace the services from the retiring fossil resources. The increased risk of delays could come from the Focus Areas of “Planning Studies” that requires numerous iterations of connection studies per combination of planned resources which increases both the number of studies, as well as their complexity to prepare and run reflected in the Focus Area of “Testing and Commissioning”.

The Initiative risk increase is determined by taking the average of the Focus Area risk for each given Initiative. The complexity to Transgrid is an average to that specific Initiative’s increased risk complexity and is mutually exclusive to the other Initiatives. This is a similar calculation to technical system threat vulnerability methodologies, where the total vulnerabilities across a full system is added together and divided by the number of sub-system areas. In this case, the increased risk metric in each column (i.e., total vulnerabilities) were summed, then divided by the total number of Focus Areas (i.e., sub-systems). This average numerical value is then translated into an average increased complexity level: Large, Moderate, Limited.

The average risk values are additive across each Initiative to estimate the total increase in operational risk on Transgrid’s network as a result of increasing complexity. Each Initiative describes a separate, and unique driver of system security risk (although each issue relates back to the energy transition in NSW at an overarching level). These risks are considered to be independent, and therefore, cumulative in their impact on system security and the risk of unserved energy:

- **12GW of Renewable Capacity:** Inverter based renewable generation can have complex interaction with other generation and network elements which if not effectively planned for, designed and operated can lead to a breach of the technical envelope under system normal and in the event of credible contingencies (for example issues with oscillations, harmonics, voltage, frequency, fault ride-through etc.). Intermittent generation is more complex and dynamic to operate than synchronous thermal generation and requires more real-time intervention and decision making within Transgrid’s control rooms to maintain secure system operation. Failure of people and process in the planning and operational time horizons can lead to insecure power system operations, requiring load shedding to return the system to secure operations, or unserved energy from the tripping of load or generation under insecure power system conditions.

- **New Renewable Energy Zones:** The delivery of the NSW Electricity Strategy will involve new roles and responsibilities within the NSW power system. It will result in multiple parties with planning functions, control areas, control room operations, etc. which will require more interfaces, communications and coordination. Failure of these protocols may lead to system security incidents (from both planning and operational phases).

- **Major Transmission Projects:** The delivery of an extensive program of large transmission projects in NSW requires extensive planning studies to assess system security requirements under many scenarios and operational conditions. Construction and commissioning of this infrastructure and its connection to the existing transmission system will require prolonged planned outages for each major project, reducing capacity and redundancy of the transmission network during that period – requiring detailed planning and updates to limiting constraint equations. Failure of these studies, forecasts, planning and operational processes may lead to system security incidents, particularly during contingencies.

- **Early Retirement of Coal:** The withdrawal of coal generation (and periods of prolonged planned/unplanned generator outages) reduces the level of critical system security services in the power system (system strength, inertia, voltage control, etc.). This reduces the system security ‘buffer’ that currently exists and will lead to the power system spending more time at minimum limits – this will increase the likelihood that a credible contingency event will cause the power system to breach its technical envelope and make it more difficult to return the system to a secure operational state, increasing the risk of system security incidents and resulting unplanned energy. Rapid changes in announced generator closures, planning scenarios and forecasts requires large volumes of increasingly complex system studies to be conducted in a short period of time (e.g. for configuration and testing SPSs, new operating procedures and system strength studies) to assess potential system issues and optimise solutions (technically and economically) to address them in a timely way.

- **Distributed Solar:** Rapid uptake (faster than previously forecast) is reducing minimum operational demand on the system and causing overvoltage issues on the network. Increasing levels of distributed generation mean both load and generation is dynamic and subject to rapid changes with weather conditions – creating challenges for voltage control and frequency for system stability, as well as forward operational analysis of the intermittency of distributed solar and dynamic impact on capacity to avoid load shedding events.

Further qualitative details that contributed to the following rankings are described in the tables in the “Methodology to assess benefits of required uplift” Section, below.

Network events are defined as follows:

- **Minor:** An event impacting a limited geographic region for a short period of time and resulting in less than 100 MWh of lost load (average 11 MWh lost load per event based on Transgrid’s historical data). Historically these events occur on average 10 times per year on the Transgrid network, with common causes being equipment trips, malfunction or failure. They are typically simple issues that are able to be resolved quickly. Only a very small proportion of all minor are currently system security incidents (approximately 3%). As such, the likelihood of minor events caused by system security incidents is approximately 31%.

- **Intermediate:** Larger and/or more complex system events resulting in more than 100 MWh of lost load (average 329 MWh lost load based on Transgrid’s historical data). Historically these have been approximately 1 in 2-year events on the Transgrid network, and have been initiated by generator trips, extreme weather or equipment failures which have subsequently triggered further issues such as generator, load or transmission line trips. Currently around half of these events are system security incidents which involve the power system being outside its technical envelope leading to loss of load, or load-shedding being required to maintain or restore power system security. As such, the likelihood of intermediate events caused by system security incidents is approximately 26%.

- **Catastrophic**: A black start event covering the full NSW region. Only one black start event has occurred in the NEM since its establishment, in South Australia in September 2016. By definition, these events are system security incidents because the loss of generation and load occurs as a result of insecure power system conditions. PowerRunner has assessed that a system black in NSW is currently around a 1 in 50-year event (2% likelihood in one year).

Increased Complexity

There is an overwhelming consensus that the electricity industry is rapidly transitioning towards a more decentralized, renewables-based generation power system – trending to an ambition of 100% renewables. By its nature this ambition is challenging and complex for Transmission operators who are obligated to:

- Maintain the safety reliability and security of the Transmission system
- Accommodate REZ connections, major projects and retirement of coal fired generation
- procure system services for system strength

The challenges of complexity, and planning and operating risk associated with the energy transition is recognized in Australia and worldwide:

AEMO 2022 Integrated System Plan (ISP)	"Uplifts are needed in in real time monitoring, power system modelling, and control room technologies by AEMO and Network Service Providers, to ensure operational staff have the tools to maintain secure operation of the NEM power system as it transitions to significant penetrations of inverter-based resources including Distributed Energy Resources".
AER 2020-2025 Strategic Plan	"The nature and size of the energy transition requires significant changes to the market design and regulatory frameworks governing the sector" "Australia's energy system is rapidly changing and affecting how energy networks are used". "With over 2 million households with solar PV, DER significantly affect the operation of the energy system, and new standards are required to manage system security risks" "We must ensure revenue determinations reflect consumer preferences while at the same time preparing the regulatory framework for new types of expenditures to manage the impact of the energy transition on networks".
AEMC 2021-2025 Strategic Plan	"In a rapidly changing world we need to be smarter about the problems we tackle and how we solve them. Today's solution needs to fit with what is happening tomorrow and in 10 years' time" "Uncertainty - The pace, nature, and scale of disruption that new technologies will bring to the Australian energy sector - new technologies are already disrupting the way we use, create, deliver, sell, and store energy. This is certainly expected to continue"
ESB Post 2025 Electricity Market Design	"People are very clear about what they want from energy reform. It is reliable, affordable, lower emissions electricity. Australia has already jumped ahead of the rest of the world with more rooftop solar than anywhere. And massive penetration of low-cost, large-scale wind and solar farms has brought forward the use-by date for old thermal generators".
NSW Government	"There are more than 50 new solar, wind and energy storage projects currently progressing through planning and development processes - investment in new network infrastructure is necessary to ensure there is sufficient capacity to allow them to connect to the grid'. "Only one in 20 of the State's new generation proposals are able to connect. An overcrowded grid results in higher losses of electricity in transmission, reducing generator revenue and investor confidence".

Specific to Transgrid, the planned construction of $7.6 billion of new transmission infrastructure, together with the retirement of 6,800 MW of coal fired generation and the connection of 12,000 MW of renewable inverter-based generation is driving additional complexity in the topology of the NSW power system. This is increasing workload and creating scaling challenges for existing tools and processes used for asset monitoring, system planning and real-time system operations. The planning and operating risks are assessed as unacceptable and current processes and tools need to be uplifted to maintain current security service levels.

Relatively small uplift – large investment and decommissioning effort

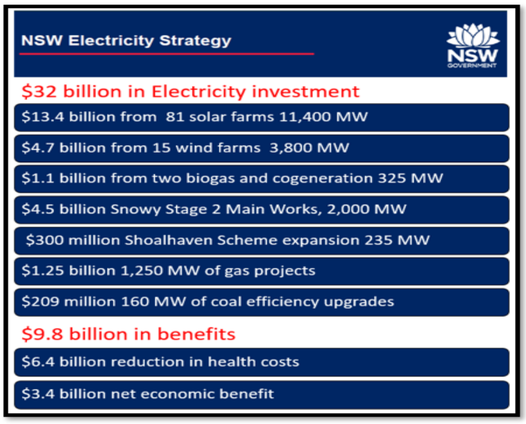
The planned investment in infrastructure and decommissioning of aging assets in the NEM over the next 10 years is ambitious. AEMO in its 2022 Integrated System Plan (ISP) forecast period to 2050, highlights the extent of this substantial investment if the form of:

- Doubling the delivered electricity to approximately from 180 to 330 terawatt hours (TWh) per year
- Coal retiring two to three times faster than anticipated
- Nine times the capacity of utility-scale Variable Renewable Energy capacity.
- Nearly five times the distributed PV capacity, and substantial growth in distributed storage.
- 46 GW / 640 GWh (gigawatt hours) of storage, in all its forms
- 7 GW of dispatchable hydro
- 9 GW of gas-fired generation in total for peak loads and firming
- Further significant Market Reforms

NSW government have indicated in their Electricity Strategy that technology and innovation are changing how we generate and use energy. In October 2018 more than 20,000 megawatts of large-scale projects were progressing through the planning system, representing more than $27 billion in potential investment, mostly in regional NSW. They specifically mention that:

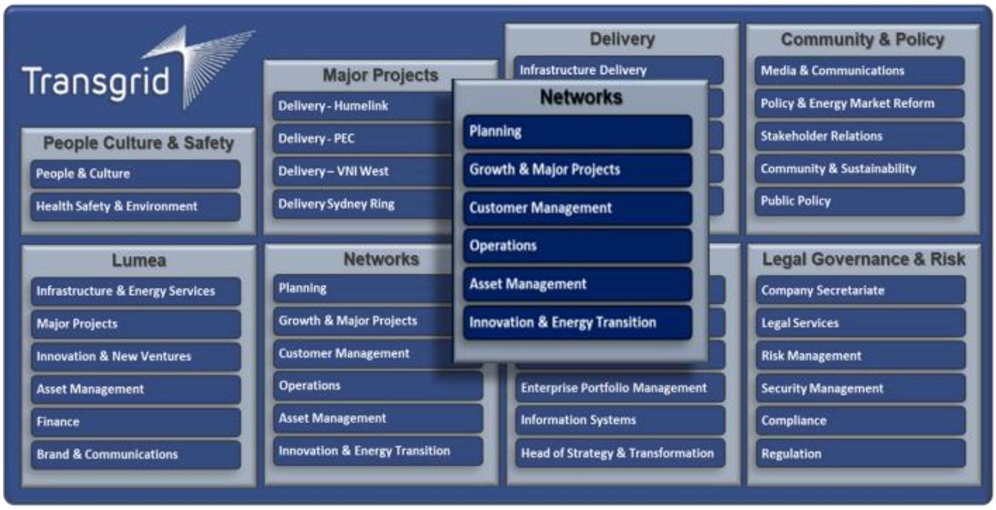
- Generation investment - The New South Wales government is driving the move to a larger renewable generation mix. The scale of investment, supported by the private sector and by the NSW Government, in renewable generation is $32 billion over the coming years. This includes $13.4 billion in solar generation, $4.7 billion in wind generation, $4.5 billion in hydro (snowy stage 2) $1.1 billion in biogas.
- Transmission investment – the planned construction of ISP projects such as Queensland – NSW Interconnector (QNI), Victoria – NSW Interconnector (VNI), EnergyConnect, Hume Link, Central-Wes Orana REZ Transmission Link – Wallor substation upgrade and Powering Sydney's Future cable replacement is scheduled for completion over the coming years. These major projects are estimated at a cost of $7.6 billion

These investments are estimated to cost a total of $39.6 billion and deliver over $9.8 billion in indirect benefits to consumers. The cost of the technology and human resources capacity uplift required to maintain current stability levels given these changes estimated at $130 million – 0.33% of the overall estimated investment.



A step change in capability requirements

The changes proposed to achieve the ambitions of the energy transition are having a profound impact on the individual capabilities required by Transgrid, and the people, processes, systems, and facilities required to support AEMO in providing system security as defined in NER. These impacted were examined using PowerRunner's standard capability model for the electricity industry:



As a result, PowerRunner has assessed that Transgrid is currently poorly positioned to assist AEMO in maintaining the power system in a secure state in the following areas:

- System operations – lack of visibility of current a future system conditions impedes Transgrid ability to support AEMO and may result in applying conservative operating limits that constrain generation dispatch. These operating decisions can contribute to inefficient market outcomes that could be avoided or minimized with the deployment of better situation awareness and digital twin technology
- Connections – delays in studies and may delay the connection of new generations in time to replace retirement of coal fired generation. This can result in supply demand shortfalls in the event of early retirement of coal generation
- Planning – delays in defining system limits, needed by AEMO to manage system dispatch can delay the connections of new assets and impact supply-demand balance

Capability and capacity uplift recommended for Transgrid

PowerRunner recommends the implementation of new technologies and tools, together with an uplift of technical expertise and staffing levels. This uplift is needed to further enhance Transgrid's capability and capacity to plan, operate and manage the transmission network consistent with the forecasted complexity and risks associated with the energy transition.

These solutions will enable Transgrid to continue to deliver its obligations under the NER as power system complexity increases and better maintain power system security. This solution is designed to provide:

- Improved visibility into system conditions to improve operating procedures and real-time decision-making. This will allow early detection of system issues, enabling operators to intervene quickly so that system events can be avoided altogether, or effectively contained so that they do not cascade into larger or more complex issues across the network.

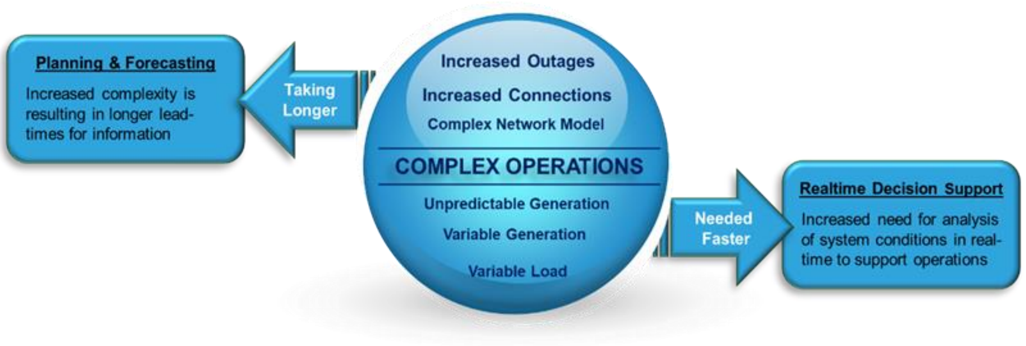
- Improved planning and management of system outages, facilitating the connection of major new transmission projects, REZs and renewable generation.
- Increased volume, quality and speed of power system and planning studies, enabling the timely connection of new renewable generators and the efficient and effective delivery of new infrastructure and services to maintain system security as coal generation retires.

Technology uplift – the table below summarizes the suite of new digital tools required, comprising a network Digital Twin, and enhanced Situational awareness and real-time decision support. The expected delivery date for these new tools is 2025, which represents the earliest practical implementation timeframe.

Initiative	Function
Digital Twin: Modelled representation of physical system	
Single Network Management Model	• Create and Maintain 'As-Built' and 'Future State' models in a central provisioning tool • As-switched models would be maintained in the distributed applications - SCADA, EMS-SE, OM, Net Planning • Tracking switching and maintaining model histories in Network Model Manager. Standardized models suitable for internal and external model sharing
Asset Registration	• Customer and Asset Registration process and workflow management application for Asset information gathering to populate downstream systems – Network Model Manager, Asset Management • Portal and workflow functionality to capture and manage asset data and connection process from connection application to energization
Data Governance & Calculation Platform	• Virtualizing disparate data sources for analysis and visualization, including IT/OT convergence - bringing together SCADA, asset information, weather information and forecasts. • Supports Single Network Model Management
Situational awareness & Real-time decision support	
Alarm Analytics	• Utilize alarm analytics to better understand system conditions and support real time decision making • Mitigate alarm overload and noise - analyse and determine root causes of alarms to better assist system operators and near time engineers. • Process alarm data to support the operational characteristics of renewables • Alarm Analytics to present operators with predictive and prescriptive decision support based upon multiple alarming scenarios
Forecasting	• Support informed measures to manage the resilience, security, and strength of the power system. • Provide accurate view of upcoming system conditions across real-time and look ahead period • Provides insight into unpredictability and variability of renewable generation
Advanced Neural Net State Estimation	• Enable probabilistic approach to real-time system operations rather than being resisted by deterministic methods • Faster solving of power flows in near and real time to support decision making - achieve an acceptable balance between computational speed and system condition accuracy • Look-Ahead Analysis - hour ahead/day ahead/ week ahead load flow analysis utilizing "as- switched" model and micro forecast information (Forward Load Flow studies) including Asset lifecycle impacts using Advanced Neural Network
Visualisation & Operations Decision Support	• Analytics and presentation of system operations data and information in the control room • Assist and support operation decision making and operating procedures. • Digital knowledge base for operational procedures, external portal for customer information such as outage details

Initiative	Function
Asset Health Decision Support	• Functionality to assist and support asset management decision making for asset health and near real time asset condition analysis

There is a growing need for detailed analysis to be conducted in near and real-time to support operational decisions. The current forecasting, planning and real time decision tool tools used to support 5-minute real-time operations are taking up to days to solve. The current tools and processes are limited in their ability to scale and are no longer fit for purpose to manage the increasing complexity and risk associated with the energy transition.



Digital Twin – a digital representation of physical transmission assets, used for operating simulations and planning and modelling. When used in combination with sensor data, it provides an improved performance for tasks such as diagnosing operational issues, understanding system health, and improving system efficiency.

Transgrid requires the digital twin to provide the ability to test and learn how new technologies might operate in the field and allow the analysis of data from new SCADA and Phasor Measurement Unit (PMU) sensors to improve forecasts, and better understand system conditions.

Transgrid needs to run operating scenarios to test the impact of proposed connections, system strength solutions, and infrastructure investment changes to the grid. To operate a system with high penetrations of renewable generation required continuous scanning for information about current conditions of the network using machine learning to identify important signals relating to asset performance and changing system conditions. This is for Transgrid to maintain system security into the future. Transgrid requires the ability to forecast future trends to avoid stranding of network assets and to support better maintenance and real time operations. This will allow Transgrid to identify and prioritize the need for grid reinforcements, as well as how best to defer investment. The Digital Twin adds value to Transgrid by mitigating risk and complexity in the areas of:

Asset Management	Improved Asset Management for a more efficient network planning process • Assess and predict asset health using data which informs capital investment decision-making • Extend the life of high value, critical assets • Use Asset Planning models of the network to trial new concepts rather than having to physically build them, giving us a fast and low-risk option for innovation.

Outage Management	Improved maintenance schedule and more efficient network upgrades • Manage prolonged outages for major projects – reduced reliance • Reduction in outage recalls • Manage N-1-1 conditions where forced outages occur in conjunction with • Determination of maintenance schedule based on network conditions • Manage asset risk based on asset condition to reduce maintenance spend and unplanned outages
Power System Operations	Improved the security and resilience of the power system • Better understand the new and complex operational conditions • Realtime monitoring of the energy network • Advanced control room analytics will enable more efficient decision making and information display • visibility of network conditions hour/day/week look ahead - load flow analysis

Situation Awareness & Real-time decision support - is a critical requirement for Transgrid to maintain system security, anticipate events, and respond appropriately when or before system events occur. Without the appropriate tools and data, Transgrid may not have adequate visibility of system conditions impacting the quality of decisions made in near and real time – that increases the risk of a system event.

Transgrid requires additional applications and tools that provide sufficient visibility of system conditions (situational awareness) to make informed decisions and respond effectively to system events. A finding of the Report on the 2003 North American Blackout was that inadequate situational awareness has been identified as one of the contributing factors in several recent large electrical disturbances worldwide.

Situation awareness tools and people are critical to operating the power system given the increased risk and complexity, allowing:

- Protection of assets - protects and prolongs the life of both the generation and transmission assets and assists in avoiding investment in stranded assets
- Reduce the probability of system events – it is estimated that a full system blackout would impact the NSW economy. Having improved situational awareness will provide better early warning with the possibility of providing real-time contingencies analysis and support.
- Safe, secure, and reliable operations – the technology and resources outlined above are required to provide Transgrid with the critical and timely situational awareness to handle system uncertainty (such as severe weather, forced outages, minimum demand, cloud cover). Timely action will help protect transmission assets and allow Transgrid to take timely actions cost effective actions that will maintain the system security consistent with its regulatory obligations.
- Essential tools – the investment will provide Transgrid with improved analytics, models, simulation tools, and visualisations that are fast becoming to safe and secure operation of the network that is dominated by intermittent generation sources.

As the complexity and related increases in the volumes of work, are expected to continue – the risks and consequences for consumers for Transgrid not addressing the lack of visibility and situation awareness is:

- Supply shortfalls due to delays in generation connections - should fossil fuel plants retire earlier than scheduled or the build out of Reliability Energy Zones are delayed

- Reduced system security due to inefficient outage management – planned system maintenance, major infrastructure projects and consistent tight system conditions in real-time leaves limited time slots for scheduling of planned outages. Outages for prolonged period to facilitate major projects reduces system security (N-1-1 conditions) and can constrain renewable generation resources.
- Cascading outages – early retirement of coal generation, increased connections of inverter-based generation, prolonged system outages for major projects, onboarding of technologies with limited operational knowledge, increased Lack of Reserve conditions are increasing the risk of cascading outages and load shedding.
- Power system failure requiring system restart – higher risk of system failure resulting in a State-wide loss of supply.

PowerRunner has assessed that it would not be feasible to implement:

- A fully automated technology solution, without an uplift in human resourcing. This option is considered non-credible because such tools are not currently available 'off the shelf' and could not be fully developed and implemented within the timeframes required.
- A partial implementation of the technology uplift. The suite of tools is designed to be integrated and be interoperable across network planning, asset management and system operations functions. Implementing a subset of these tools will not yield the same level of efficiency or risk mitigation.

Capacity uplift with additional human resources – Operating Expenditure (OPEX) - additional resources, skill sets, and training are also required to support the increasing requirements and complexity of network planning, asset monitoring and system operations.

Summary of PowerRunner recommendations for capacity uplift

Function	Additional human resource requirements
System Operations	Control room operators, control room trainer, outage planning function, operations analysis, operations manager, asset monitoring (including asset condition monitoring, CCTV/Security, procurement of easements), SCADA connections & uplift in personnel training
System Planning	Connection studies, developing limit equations for thermal retirements, subsystem planning, power system modelling, Non-network options, new technology assessment, system strength, 100% renewable studies & uplift in personnel training
Asset Management	Minimum protection settings, digital infrastructure capacity, asset standards for new technology, transmission line capacity, outage impact analysis, asset data and systems capability, analyst, substation capacity & uplift in personnel training

The estimated incremental levels of staffing required by Transgrid to manage the energy transition, above FY22 levels, are provided in the table below.

	FY23	FY24	FY25	FY26	FY27	FY28
Estimated incremental staffing levels above FY22 levels						
Network Planning	6	9	11	12	13	13

Network Operations	4	7	11	12	14	15
Asset Management	6	6	9	11	14	14
Innovation & Energy Transition	4	5	5	4	4	4
Delivery	-	2	-	-	-	-
PMO Function	-	-	-	-	-	-
Total	**21**	**29**	**35**	**39**	**45**	**46**

Note that these figures represent Opex-based increases to deliver existing compliance obligations and do not include additional resourcing that will be required for delivery of major projects or additional functions (if any) that may be agreed with the NSW Energy Corporation to support to delivery of the NSW Electricity Strategy.

The estimated staffing and skill requirements are based on interviews and workshops with Transgrid executives, managers and team leads and PowerRunner's assessment of additional workloads and requirements for Transgrid to deliver its prescribed obligations as a result of growing power system complexity and risk. This high-level assessment considered:

- Manager and team feedback - an effective peer review and challenge of increasing workload, staffing level and skill sets. Managers were asked to justify their needs and were challenged on how realistic the staff increases and additional cost given the expected workload and complexity.
- Observing and evaluating current business activity – observing the number and complexity of planning studies associated the retirement of Eraring power station, new generation connections, planned outages, difficulty on boarding of new staff provided key insights into staffing capacity and needs.
- Staff Survey – the current Transgrid team provided consistent insight and comment on the increasing complexity of planning and operations the power system and the need for additional skill resources to maintain system security.
- Identification of key roles – understanding key roles, skills, recruitment, training and the risk of overdependency on single individuals in key positions
- PowerRunner industry experience – insights into estimated staffing needs based on similar clients.

In assessing the staffing needs PowerRunner focused on 3 key areas:

- current staffing levels and available capacity
- forecasts of expected increases in workload, and
- the operational and power system risks associated with not completing work (or not completing work to a reasonable standard)

Based on the assessment, the increase in workload was estimated in the following areas:

	Total	2023	2024	2025	2026	2027	2028
Estimated increase in work volunes							
Number of Customers	102	49	59	71	81	92	102
Number of Connections	61	8	10	12	10	11	10
Number of Connection Inquiries	122	16	20	24	20	22	20
Number of Planned Outages	84	10	14	15	15	15	15
Number of forced outages	548	96	82	85	90	95	100
Number of Planning studies	1,362	147	177	213	243	276	306
System Limit Calculations	172	24	25	30	30	33	30
Special Protection Schemes	61	8	10	12	10	11	10
Inertia control actions	115	15	20	25	20	15	20
Minimum demand Actions	153	15	20	25	28	30	35
Lack of Reserve Events	123	15	17	20	25	24	22
New technologies onboarded	15	2	3	4	3	2	1

The onboarding of new technologies, coupled with the need to develop new resources given the high demand for skilled people in the electricity industry, has elevated training to a key requirement for Transgrid to manage the increasing complexity and operational risk. This training is for existing staff as well as the capacity uplift described above.

PowerRunner has assessed necessary levels of training and recommended:

- Increase training for Transgrid's control room operators from 24h/y to 100h/y. This reflects the uplift in skillsets required due to increasing operational complexity, and because Transgrid must focus on hiring more junior resources (due to high competition for the limited existing control room operators in the industry). In comparison, AEMO currently provides 100h/y of control room operator training, and are moving to 140h/y.
- Increase training for FTEs within Network Planning, Asset Management, Innovation & Energy Transition and Network Operations (excluding control room operators) from approximately 1 day per year to 3 days per year. This uplift in training is recommended as a result of the growing complexity in the energy system (including new technologies being added, such as grid forming batteries) and due to the need to hire more junior resource.

Training costs have been assumed at $1,500 per day. The total estimated 5-year training cost for additional training of existing staff and training for new staff is $5.1m.

	FY23	FY24	FY25	FY26	FY27	FY28	FY24-28
Estimated training costs ($)							
Additional training for existing staff	768,745	768,745	768,745	768,745	768,745	768,745	**3,843,726**
Training for new staff [1]	137,213	185,490	224,138	240,922	277,410	281,010	**1,208,970**
Total	**905,958**	**954,235**	**992,883**	**1,009,668**	**1,046,155**	**1,049,755**	**5,052,696**

[1] Note that the cost of training for new staff has been included within the costs of each team, as specified below on page 22.

Costings

Technology uplift

PowerRunner has estimated the total cost of the capability (technology) uplift – plan, design, procurement build, integrate, test, deploy, including the sourcing of relevant data at $87.5 (total Capex and Opex, Financial Year 2024 to Financial Year 2028, real $FY22)

These estimates have been developed based on the following typical tasks associated with the development and deployment tools – this list is not exhaustive

- Operation of the Program Management Office and governance structure
- Develop the detailed implementation plan including approvals, key milestones, interdependencies, resourcing, and timeline.
- Create the solution requirements and signoff with relevant stakeholders
- Identify and source relevant data
- Develop and publish the Request for Tenders
- Select and engage appropriate third-party vendors
- Complete detailed requirements and design
- Design, build and augment IT hardware infrastructure
- Develop solution prototype and test
- Integrate tool with relevant legacy systems
- Build and test final version of the solution
- Implement cyber security requirements
- Trial solution
- Obtain approvals and deploy solution

	2024	2025	2026	2027	2028	Total 5-year	Project initiation costs (FY2023)
Technology Development – Capex							
Cyber Security Uplift- All Applications	$1,275,000	-	-	-	-	$1,275,000	-
Network Model Management	$11,837,187	$6,268,895	$3,718,974	$2,060,856	$83,225	$23,969,137	$1,094,106
Asset Registration	$4,415,551	$1,278,767	$1,229,925	$1,126,478	-	$8,050,721	$878,451
Data Governance & Calculation Platform	$10,335,522	$2,584,224	-	-	-	$12,919,746	$880,646
Decision Support	$5,600,577	$1,890,868	-	-	-	$7,491,445	$860,466
Forecasting	$5,504,037	$323,235	-	-	-	$5,827,272	$563,466
Alarm Analytics	$4,365,377	$308,940	$30,000	-	-	$4,704,317	$350,006
Neural Network & Stare Estimation	$9,549,220	$2,236,086	$116,889	-	-	$11,902,196	$797,106
Visualisation & Decision Support	$5,209,418	$2,672,778	$942,073	-	-	$8,824,269	$797,106
Total Capex	$58,091,889	$17,563,793	$6,037,861	$3,187,334	$83,225	$84,964,102	$6,221,354
Maintenance & Support - Opex							

Network Model Management	-	-	-	-	-	-	-
Asset Registration	-	-	$133,007	$133,007	$133,007	$399,022	-
Data Governance & Calculation Platform	-	-	$133,007	$133,007	$133,007	$399,022	-
Decision Support	-	-	$133,007	$133,007	$133,007	$399,022	-
Forecasting	-	-	$133,007	$133,007	$133,007	$399,022	-
Alarm Analytics	-	-	$133,007	$133,007	$133,007	$399,022	-
Neural Network & Stare Estimation	-	-	-	$133,007	$133,007	$266,015	-
Visualisation & Decision Support	-	-	-	$133,007	$133,007	$266,015	-
Total Opex	-	-	$665,037	$931,051	$931,051	$2,527,140	-

The estimated costs are comprised of:

- Software License: As commercial off the shelf licenses are typically not public domain and proprietary to the vendor, an experiential and benchmarking approach was taken to estimate software license costs based upon recent quotes by GE for an additional EMS module (outage management and switching), as well as global experience of major vendor contract negotiations from PowerRunner. For check and balances, a per sensor license cost, per MW license cost and per km of installed transmission line license cost metrics were calculated to benchmark to other known system license costs. Additional metrics were calculated Software cost to overall cost and Hardware cost to overall cost to compare against industry best practice and experiential large project and program software costs, as well.
- Annual Software Maintenance: Typical Annual COTS vendor software maintenance fees are between 20-25% of initial software license costs. This annualized fee was assumed to be a pre-paid cost, able to be capitalized within the first year of implementation
- Hardware: Hardware was estimated for each project based upon experiential and list cost server, switching and other associated overhead. Each hardware asset and associated assumptions were associated to each of the projects, as well as estimated timings of procurement.
- Initial Implementation: A top-down and initial bottom-up build-up of effort to implement each of the projects within the bottom-up estimate includes number and types of resources and associated duration of each to create the implementation cost estimate. The estimate also estimates the internal v. external resource composition. Costs for interfaces and automation from the new systems to Transgrid's existing cybersecurity monitoring framework has also been included.
- Ongoing Operational Costs to maintain the solutions once in Production, including:
  - Resources to maintain Applications
  - Annual Vendor Software Maintenance Costs
  - Infrastructure (Hardware) Support
  - Application Support (Operating System, Data Base licenses)

Additionally, given the scope of the capability uplift, the commencement of these initiatives is proposed to start in 2023, primarily with establishing a program management office responsible for defining project charters, governance, early requirements gathering and initial planning and procurement of resources for the project lifecycles. The estimated budget is $6.2m for FY2023.

Capacity uplift

PowerRunner has estimated a high-level total cost of the capacity (human resources & training) uplift to continue to meet NER obligations and effectively plan, manage, and operate the NSW Transmission system – based on interviews and workshops with Transgrid managers and subject matter experts at $42.3 million Financial Year 2024 to Financial Year 2028, real $FY22).

These estimates are based on the expected increase in work volumes and complexity in the following areas:

- Major Projects
- System Planning & Analysis
- Customer Management
- Innovation & Energy Transition
- Control Centre
- Operations Analysis
- Asset Monitoring
- Operations Technology
- Digital Infrastructure
- Asset Systems & Compliance
- Transmission Lines & Cables
- Analytics & Insights
- Substations
- Project Delivery

Based on these forecasted complexities and work activity increased the estimated Opex expenditure for capacity uplift by year is estimated as follows.

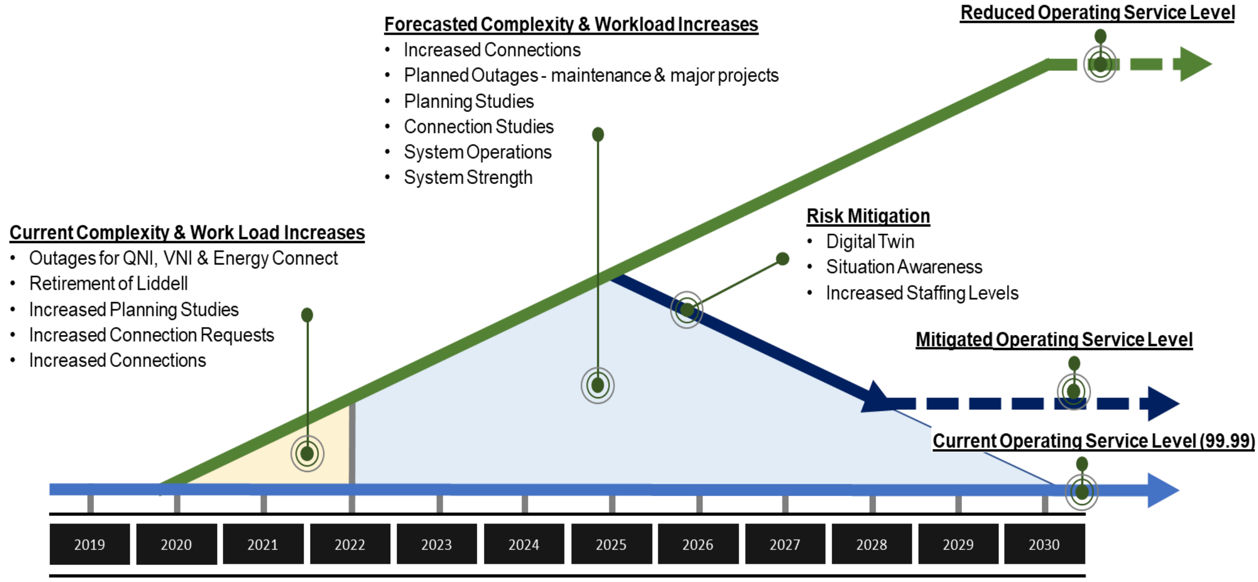
	FY2024	FY2025	FY2026	FY2027	FY2028	Total 5-year
Additional headcount and training - Opex						
Network Planning	$1,808,098	$2,081,698	$2,364,633	$2,589,555	$2,589,555	$11,433,539
Network Operations	$1,452,513	$2,195,765	$2,507,271	$2,865,705	$3,021,582	$12,042,836
Asset Management	$1,239,446	$1,751,991	$2,077,625	$2,636,525	$2,636,525	$10,342,111
Innovation & Energy Transition	$998,855	$998,855	$791,279	$791,279	$791,279	$4,371,547
Delivery	$298,776	$-	$-	$-	$-	$298,776
Project Management Office	$-	$-	$-	$-	$-	$-
Additional training for existing staff [2]	$768,745	$768,745	$768,745	$768,745	$768,745	$3,843,726
Total Opex Step Change	**$6,566,434**	**$7,797,054**	**$8,509,552**	**$9,651,809**	**$9,807,686**	**$42,332,535**

[2] Note that training costs for new staff ($1.21m over 5 years) have been included within the Opex costs for each team.

Methodology to assess benefits of required uplift

An operational risk management approach was developed by PowerRunner to quantify the benefits of the Technology and Human Resources Capacity uplift. This approach is appropriate given the step change in complexity and work volumes forecasted over the next 5 and 10 year planning horizons. This step change results in increased risk of load shedding events, work safety issues, damage to transmission assets, failure to meet compliance obligations caused by flawed processes, lack of skilled resources and inadequate tools.

The risk assessment is to ensure that Transgrid continues to plan and operate the NSW transmission system at reasonable levels of security given the increase in complexity and workload from increasing renewables penetration and other drivers of the energy transition – mitigating the increasing risk of minor, intermediate and catastrophic system events. Current performance is assessed at 99.999 of System Available Uptime.



The level of complexity and workload increase is based on the following business impacts over the Financial Year 2022 to Financial Year 2030 time period. These factors increase power system security risk (and risk of unserved energy) in two ways:

- Failure to adequately conduct studies in the planning time-horizon may lead to unexpected operational issues later on (increasing the risk of system events and unserved energy in real-time). This risk increases with the volume and complexity of analysis required, and because emerging system conditions require new types of studies to be conducted (with the methodology, input assumptions, parameters etc. not yet defined).

- Increased complexity in the operational time horizon requires a greater number of decisions to be made by operators in real-time. Current systems provide limited system visibility and incomplete information upon which these decisions can be made, increasing the risk that operator interventions will be incorrect or insufficient to maintain system security – leading to network events and unserved energy.

Complexity factor	System security risk factors

12GW of Renewable Capacity Approximately 90% addition of generation boiler plate capacity	**Analytical complexity, volume and risk** • Failure to connect in time to replace retiring coal can lead to supply shortfalls • Numerous studies required for each connecting generator • Complexity of studies is increasing due to potential generator interactions • A four-fold increase in customer inquiries experienced to date • Multiple planning model updates for new installations • Multiple models needed to reflect timing of new generation • Real-time operating procedures updated for each new generation • Training on the operation and performance of new technologies • Monitoring and acquiring performance and attributes of new technologies • Analysis and update of operating procedures based on generation performance • Reassessment of system strength requirements based on new commissioned generation • Configuration and testing SPSs to include new generation **Operational risk (real-time and near-real time horizons)** • Planned outages need to consider energization of new generation • Managing forced outages requires communication with multiple new customers • Management of generation curtailments due to outages • SCADA and telemetry connections and maintenance • Multiple stages of monitoring testing and commissioning of new generation • Operation of power system with greater share of intermittent generation more unpredictable and dynamic with greater variances in voltage and frequency.
New Renewable Energy Zones Implementation of 5 separate control areas	**Analytical complexity, volume and risk** • Additional level of joint planning • Definition of roles, responsibilities and accountabilities for planning studies **Operational risk (real-time and near-real time)** • Multiple control area operations – communication and coordination of system security • Management of seams including lop flows and voltage management • Definition of roles, responsibilities, and accountabilities in normal operations • Definition of roles, responsibilities, and accountabilities in normal system events • ICCP connectivity • Outage coordination • Management of Grid Operations safety rules • Coordination of black start events • Coordination of summer readiness planning
Major Transmission Projects Investment of $7.8 billion in new transmission infrastructure	**Analytical complexity, volume and risk** • Failure to build new infrastructure on time to replace retiring coal can lead to supply shortfall • Numerous studies required for each major project • Development of limits– required by AEMO for constraint equations for system dispatch • Contingency analysis and system operations plans • Multiple planning model updates for new infrastructure • Multiple models needed to reflect timing of new infrastructure • Real-time operating procedures updated for each major project • Assessment of potential non-network options • Analysis and update of operating procedures based on infrastructure performance in the field • Configuration and testing SPSs to include new infrastructure • Reassessment of system strength requirements based on infrastructure **Operational risk (real-time and near real-time)** • Prolonged planned outages need for each major project • Managing forced outages during prolonged planned outages • Management of generation curtailments due to prolonged outages

	• SCADA and telemetry connections and maintenance • Monitoring performance and attributes of non-wires alternatives
Early Retirement of Coal Retirement of approximately 50% of generation capacity	**Analytical complexity, volume and risk** • High risk of early retirement resulting in supply shortfall • Numerous studies for system impacts required for each retirement • Analysis and update of operating procedures based on progressive performance in the field for example increased frequency of planned and unplanned maintenance outages) • Configuration and testing SPSs to account for retirements • Reassessment of system strength requirements based on retirements **Operational risk (real-time and near real-time)** • Management of early retirement in conjunction with Prolonged planned outages • Managing forced outages in conjunction with retirements and prolonged planned outages
Distributed Solar Will become the largest generator	**Analytical complexity, volume and risk** • Multiple planning model updates for forecasted distributed solar resources • Multiple models needed to reflect timing of new solar resources • Planning studies required to assess power back flows from distribution to transmission system and solutions for over voltage • Training on the operation and performance of distributed solar on the transmission system • System security studies (system strength, frequency, voltage) and solutions for minimum operational demand periods – alternatives to minimum thermal unit combination **Operational risk (real-time and near real-time)** • Planned outages need to consider distributed energy resources • Load shedding needs to consider both load and generation shedding for voltage control and frequency • Management of minimum demand days • Management of intermittency of distributed solar • Managing minimum line ratings in periods with minimum operational demand approaching zero • Load/generation shedding to maintain minimum combination of thermal units online for system security purposes • Implementation and monitoring of distributed resource connection standards and controllability requirements
Regulatory Changes 425 regulatory changes under consideration	**Analytical complexity, volume and risk** • Growing complexity of TNSP compliance obligations to be factored into network planning, asset management and operational processes • Increased regulation to enable for new technologies • Access of distributed generation to bulk power system • Electrification of transportation and heating

Risk mitigation provided by recommended capability and capacity uplift

PowerRunner has assessed that the application of the recommended capability and capacity uplift by Transgrid will materially mitigate the increased risk to power system planning, operations and management. We estimate that the technology uplift will reduce incremental risk by 35%, and the human resources uplift will reduce risk by 25%, summing to a total risk reduction of 60% across both areas. Further detail is provided in the table below.

This reflects that the improved tools, capability and capacity is expected to:

- Prevent 60% of the increase in minor system events from occurring at all. Instead, these would be managed as contingency events, without resulting in unserved energy.

- Prevent most of the increase in intermediate and catastrophic events, by preventing network issues cascading to larger and more complex system events (which take longer to resolve and/or result in higher levels of unserved energy). 60% of intermediate events are estimated to step down to minor, and 60% of catastrophic events are estimated to step down to intermediate.

The detailed breakdown of the reduction in operational risk due to capability and capacity uplift is shown below.

	Technology Uplift (control measures)	**Capacity Uplift** (control measures)	**Technology Uplift Reduced Risk**	**Capacity Uplift Reduced Risk**	**Brief Description of Justification** (Tools)	**Brief Description of Justification** (People)
Connections	Network Model Management, Asset Registration	Network Planning Team Network Operations Team	20%	-	A coordinated Network Management Model (NMM) architecture-based, underpinned by the Common Information Model (CIM) data model, provides a feasible and realistic method to efficiently manage network model data originating from multiple sources and going to multiple consuming applications Offers sizable potential benefits in reduced engineering labor and increased accuracy of utility network models. It can provide the network model infrastructure architecture on which forward-looking transmission planning and operating applications will be built.	Additional headcount recovered directly from connecting generators
Planned Outages	- Single Network Model Management, - Forecasting - Neural Net State Estimation	- Network Operations Team - Asset Management	40%	40%	Provides a provisioning tool for 'As-built' network models. The as-switched models would be maintained in the distributed apps (SCADA, EMS-SE, OM, Network Planning) in the short term. Tracking switching and maintaining history in NMM may be done in a future phase. Provides standardized models that are suitable for internal and external model sharing, expediting studies for planned outages. Customer and Asset Registration process and workflow management application for Asset information gathering to populate downstream systems (NMM, Asset Management), expediting setup time planned outage coordination studies Look-Ahead Analysis entailing hour ahead - day ahead - week ahead load flow analysis utilizing "as- switched" models and micro forecast information (Forward Load Flow studies) Includes Asset lifecycle impacts using Advanced Neural Network help power flow studies assess planned outage impacts	Construction of ~$7 billion in new transmission infrastructure requires a number of prolonged planned transmission outages - reducing system resilience and strength. The compounded risk of planned outages for major projects, planned outages for maintenance and forced outages that can occur at any time is increasing Prolonged planned outages require constraint modelling, updating of constraint equations, and updating of system operating procedures - failures to do so increases the risk of system events in real time or operating the system overly conservatively that could constrain renewable generation Additional resources are needed to ensure system operating and constraint equations are updated and to conduct in a timely ,manner contingency analysis and system operating plans taking account of N-1-1 scenarios.
Forced Outages	- Forecasting, - Visualisation & Operational Decision Support, - Alarm Analytics - Neural Net State Estimation	- Network Operations Team - Asset Management	20%	30%	Provides a provisioning tool for 'As-built' network models. The as-switched models would be maintained in the distributed apps (SCADA, EMS-SE, OM, Network Planning) in the short term. Tracking switching and maintaining history in NMM may be done in a future phase. Provides standardized models that are suitable for internal and external model sharing, expediting studies for planned outages. Customer and Asset Registration process and workflow management application for Asset information gathering to populate downstream systems (NMM, Asset Management), expediting setup time planned outage coordination studies Look-Ahead Analysis entailing hour ahead - day ahead - week ahead load flow analysis utilizing "as- switched" models and micro forecast information (Forward Load Flow	The likelihood of forced outages on the transmission system and from coal fired generation is increasing due to increased complexity Construction of ~$7 billion in new transmission infrastructure requires a number of prolonged planned outages - reducing system resilience and strength The compounded risk of planned outages for major projects, planned outages for maintenance and forced outages that can occur at any time is increasing Additional resources are needed to conduct contingency analysis and system operating plans taking account of N-1-1 scenarios

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Planning Studies	- Single Network Model Management - Forecasting	- Network Planning Team - Network Operations Team - Asset Management - Innovation & Energy Transition	30%	40%	Key for all forward-looking functions, feeding into system planning, and operations real-time decisions Forecasting Temporal and Geographic Granular Transmission bus forecasts in Support of Network Planning and Operations, - probabilistic scenario- based Outage Management support. Planning studies incorporating the latest and most accurate transmission substation loads, given the dynamism of connected downstream assets, is critical to planning and security studies	The retirement of 5,600MW of baseload coal fired generation to FY30 under the ISP Step change scenario and the connection of 12,000MW of largescale renewable generation in NSW is a step change in the generation mix New technologies being connected to the power system have no historical performance data making it difficult to forecast how they will impact voltage, system strength and overall power system security. The likely early retirement of coal fired generation requires a range of complex planning studies to understand the impact on power system security and power quality Additional resources are required to maintain the quality and timeliness of (& the increasing demand for) planning studies and mitigate the risk of flawed investment decisions or stranding of assets
Operating Studies	- Single Network Model Management - Forecasting - Neural Net State Estimation	- Network Planning Team - Network Operations Team - Asset Management - Innovation & Energy Transition	40%	40%	Provides near time (4 weeks - hour ahead) assessment of system conditions. Supports the approval of outages Utilises the as-switched models maintained in the distributed apps (SCADA, EMS-SE, OM, Net Planning) in the short term. Tracking switching and maintaining history in NMM may be done in a future phase. Provides standardized models that are suitable for internal and external model sharing, expediting studies for planned outages. Customer and Asset Registration process and workflow management application for Asset information gathering to populate downstream systems (NMM, Asset Management), expediting setup time planned outage coordination studies Look-Ahead Analysis entailing hour ahead - day ahead - week ahead load flow analysis utilizing "as- switched" models and micro forecast information (Forward Load Flow studies) Includes Asset lifecycle impacts using Advanced Neural Network help power flow studies assess planned outage impacts	The approval of outages ~4 week in advanced is necessary to plan and coordinate contractors, equipment and supplies - cancelling outages is costly and delays planned maintenance and construction of major projects Prolonged planned outages are becoming more frequent to accommodate major projects and upgrades The increasing complexity of the power system means more and faster decisions are required on real-time - this necessitates better planning in near time additional resources are needed to maintain the current engineering support for the control room and to ensure timely and appropriate approval of system outages
Testing & Commissioning	- Asset Registration - Data Governance and Calculation Platform	- Network Planning Team - Network Operations Team - Asset Management	20%	-	An Asset Registration process coordinates registration of energy assets, simplifies the entry of data through a user-friendly interface to increase registration compliance, improve the reliability of data and improve the efficiency of data collection. This improves the quality of data used asset management and the planning and operations tools Reduces the administrative burden for customers and helps with the delivery of a consolidated asset register for all energy system assets. Automate where possible data capture making it easier for field staff to enter/capture data while reducing the need for double keying Data Governance and Calculation platform virtualizes disparate data sources for analysis and visualization, including IT/OT convergence, bringing together SCADA, asset information, weather information and forecasts.	Additional headcount recovered directly from connecting generators
Operating Procedures	- Data Governance & Calculation Platform - Visualisation & Operational Decision Support	- Network Operations Team	40%	20%	Transforming the business into a data-driven business will require in-depth change. We already have pockets of data analytics and data management expertise across the business today, but we need to bring them together and build on that community to drive a proper change. Transgrid will use data to provide rapid and automated predictive insights, providing value for system operation and planning. This includes data analysis, new functionality and modelling capabilities that use machine learning algorithms and AI to deliver business efficiencies. When combined with knowledge of statistics and neural networks this will improve our use of data throughout	12 GW of new renewable generation through 5 Renewable energy Zones results in several customer connections that require the operating procedures to be updated The likely retirement of 6,500MW of baseload coal fired generation by FY30 - each retirement will require the operating procedures to be updated Prolonged planned outages are becoming more frequent to accommodate major projects and upgrades - these outages require updates to the operating procedures

					the timescales in which we operate.	Additional resources are needed to maintain the current quality and ensure timely and accurate update of operating procedures
Voltage Control	- Visualisation and Operational Decision Support, - Forecasting, Alarm Analytics - Neural Net State Estimation	- Network Operations Team	40%	20%	Improved, location-specific visibility of transmission constrained areas where there is likely to be thermal and voltage issues. Improved tools to monitor and assess congestion in real time, with active decision support for the operators to identify and mitigate risks using network flexibility. Improved methodology and tools for modelling. Consistency and validation in dynamic models. Enhanced monitoring and decision support for operation of new network technology, devices, (Static Compensators, Static VAR Controllers, Reactors, Power Flow Controllers, Phase Shifting) enhanced transformer control. Enhanced and streamlined control and monitoring of Interconnection links and visualizations for the areas they will connect. Utilization of overload cable capacity based on loading and asset failure rates. The philosophy of operation should move to "predictive and preventative" from "curative and restorative".	12 GW of new renewable generation through 5 Renewable energy Zones results in several customer connections that require the operating procedures to be updated The likely retirement of 6,500MW of baseload coal fired generation by FY30 - each retirement will impact voltage control Prolonged planned outages are becoming more frequent to accommodate major projects and upgrades - these outages impacts voltage control Additional resources are needed to ensure there are appropriate plans and procedures in place to maintain system voltage
System Limit Analysis	- Visualisation and Operational Decision Support - Forecasting - Alarm Analytics - Neural Net State Estimation	- Network Planning Team - Network Operations Team - Innovation & Energy Transition	40%	40%	Improved, location-specific visibility of transmission constrained areas where there is likely to be thermal and voltage issues. Improved tools to monitor and assess congestion in real time, with active decision support for the operators to identify and mitigate risks using network flexibility. Improved methodology and tools for modelling. Consistency and validation in dynamic models. Enhanced monitoring and decision support for operation of new network technology, devices, (Static Compensators, Static VAR Controllers, Reactors, Power Flow Controllers, Phase Shifting) enhanced transformer control. Enhanced and streamlined control and monitoring of Interconnection links and visualizations for the areas they will connect. Utilization of overload cable capacity based on loading and asset failure rates. The philosophy of operation should move to "predictive and preventative" from "curative and restorative".	System limits are a key input to constraint equations that are used by AEMO for system dispatch Construction of ~$7 billion in new transmission infrastructure - each major project will require a reassessment of limits 12 GW of new renewable generation through 5 Renewable energy Zones results in re assessment of system limits The likely retirement of 6,500MW of baseload coal fired generation by FY30 - each retirement requires an update of system limits Prolonged planned outages are becoming more frequent to accommodate major projects and upgrades - these outages impacts voltage control Additional resources are needed to maintain the to ensure there are appropriate plans and procedures in pace to maintain system voltage
Minimum Load Conditions	- Visualisation and Operational Decision Support - Forecasting - Alarm Analytics - Neural Net State Estimation	- Network Planning Team - Network Operations Team - Innovation & Energy Transition	40%	30%	Improved, location-specific visibility of transmission constrained areas where there is likely to be thermal and voltage issues. Improved tools to monitor and assess congestion in real time, with active decision support for the operators to identify and mitigate risks using network flexibility. Improved methodology and tools for modelling. Consistency and validation in dynamic models. Enhanced monitoring and decision support for operation of new network technology, devices, (Static Compensators, Static VAR Controllers, Reactors, Power Flow Controllers, Phase Shifting) enhanced transformer control. Enhanced and streamlined control and monitoring of Interconnection links and visualizations for the areas they will connect. Utilization of overload cable capacity based on loading and asset failure rates. The philosophy of operation should move to "predictive and preventative" from "curative and restorative".	Driven by a strong update in rooftop PV, minimum load conditions are dropping much faster than expected. This is leading difficult planning and operating decision. Additional resources are needed to plan for and operate the transmission system with periods of very low demand, which correspond to the lowest levels of coal generation and therefore lower system security services in the grid (exacerbating risks to the system)
Special Protection Schemes	- Single Network Model Management - Visualisation and Operational Decision Support - Forecasting	- Network Planning Team - Network Operations Team	40%	10%	The combination of alarm data, visualization and forecasting are needed to assist in minimizing the management of the power system using SPSs - this will optimize grid capacity Better real time visibility of system conditions	Special protection schemes are being deployed to increase the efficiency of the transmission system. SPS require detailed power system model and lead to increased complexity in the control room, requiring additional resources to support it.

	- Alarm Analytics - Neural Net State Estimation				will allow operators to minimize then effectiveness of SPS windows. Smart alarm capabilities will improve situational awareness for Control Room Operators. Using Artificial Intelligence, the smart alarm capability filters out nuisance and redundant alarms and will escalate critical alarms making operator actions more efficient. The alarm system can provide improved situational awareness quicker thus allowing for less costly contingency actions Corrective actions can be automated reducing the need for manual intervention. The alarming functionality provides instantaneous situational awareness and supplements the State Estimation functionality Improved situational awareness will mitigate the risk of system events. The system will provide audit trails to demonstrate our compliance more ably to alarm management processes	
System Strength	- Single Network Model Management - Visualisation and Operational Decision Support - Forecasting - Alarm Analytics - Neural Net State Estimation	- Network Planning Team - Network Operations Team - Innovation & Energy Transition	40%	30%	System Strength will need to be calculated dynamically as topology and system conditions change. May be done within the EMS or other real-time operations system with the correct data available. In system strength shortage conditions, corrective action will need to be taken. Look-ahead analysis, like forecasting can also predict system strength shortfalls prior to real-time, thereby alleviating potential abnormal operations by giving operators more time to study contingency options. The combination of solutions, in particular enhanced visualization and operational decision support tools will be needed to calculate the dynamic real-time system strength metrics and forecasted metrics	As the number of coal generators online falls as coal generators retires, the provision of system strength falls. Lower system strength results in more volatile conditions (on a contingency), increasing the complexity in the control room. In addition, detailed planning is required for operational strategies to be assessed as a result of falling fault levels. Accountability for system strength provision is a new obligation for TNSPs under the market rules. Additional resources are needed to monitor, calculate and procure system strength requirement and ensure regulatory compliance
Asset health and management	- Asset Registration - Single Network Model Management - Data Governance and Calculation Platform	- Asset Management	40%	30%	The combination of Single Network Model Management and Data Governance Platform will provide intuitive access on key asset information on our network so we can support our stakeholders better. Staff will be able to interrogate data spatially and temporally to consider current loading or various future scenarios that will support better more efficient decision making. As the data models in the Digital Twin become more established we can then further overlay other complimentary datasets and enabling efficient information sharing between parties.	Increasing the real-time understanding of the age profile and performance levels of assets is key to operating the transmission system effectively. Given the amount of new technologies and the complexity of the transmission network - Additional resources are needed to monitor, asset health to ensure the system can operate at full capacity
Average estimated reduction in additional risk			**35%**	**25%**		
Total estimated reduction in additional risk			**60%**			