Options Evaluation Report (OER)

System Security Roadmap – Technology & Human Resource Capability & capacity uplift
OER-**N2761** revision **5**

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Approvals

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Change history

Revision	Date	Amendment
1	20 July 2022	Draft prepared for external assurance by Cutler Merz
2	24 July 2022	Draft updated with revised PowerRunner cost estimates (CAPEX & OPEX) Calculations updated; Clarifications and updates to explanations and wording
3	31 July 2022	Capex and Opex updated
4	3 August 2022	Updates to Capex profile to align with updated PowerRunner Report Review comments from Regulation team actioned
5	5 October 2022	Updates to cost-benefit methodology to align with Final PowerRunner Report Inclusion of cost-benefit sensitivities Inclusion of Contingency Analysis data from 2010

Reference Documents

Author	Document	Revision
PowerRunner	System Security Roadmap Business Case Recommendations and Methodology	V1.1, 7 October 2022

Executive summary

Power system complexity in NSW is forecast to increase very significantly over the coming decade, as a result of the energy transition, particularly:

- The accelerated retirement (and reduced operation/availability) of up to 7,520 MW of coal generation capacity, reducing the share of generation from synchronous thermal generation from over 70% today, to less than 20% in 2030.
- The tripling of the proportion of generation expected to be provided from intermittent renewable sources, including the connection of over 12 GW of new renewable projects to the NSW transmission system.
- Integration of at least five Renewable Energy Zones (REZ) across NSW under the Electricity Infrastructure Investment Act 2020 (NSW), including interfaces with multiple REZ Network Operators.
- The delivery of a significant program of major transmission projects in NSW, including the requirement to take prolonged system outages for construction as well as maintenance.
- The almost tripling in capacity of distributed solar PV, significantly increasing reverse power flows from the distribution to transmission network, and reducing minimum demand levels on the transmission system.
- On-boarding of several new technologies with limited historical data and knowledge of operating performance.

These unprecedented technology and operational changes (and their occurrence in such a condensed timeframe over the next 10 years) are forecast to make it more challenging for Transgrid to plan, manage and operate the NSW power system and increase operational risk each year.

Without mitigation, this risk is forecast to increase the frequency of power system security incidents occurring on the transmission system, and result in supply interruptions – either because load shedding would be required to return the power system to a secure operating state and/or because insecure power system conditions would cause load or generation to be lost (including the possibility for cascading failures to cause catastrophic, system-wide outages).

These incidents are currently very rare because existing tools, systems and resourcing are sufficient to manage risk effectively and operate the power system securely. However, these capabilities are now considered to be operating at full capacity, and are not capable of scaling to manage forecast system conditions. An expert risk-assessment conducted for Transgrid by consultants PowerRunner concluded that unserved energy resulting from system security incidents could grow to over 9,000 MWh per annum in FY2030 under the Base (‘do nothing’) case - a 569% increase compared to the FY2022 base year. In this scenario, Transgrid may be non-compliant with its obligations under Chapters 4 and 5 of the National Electricity Rules (NER), including the requirement to operate the transmission network in a secure operating state, and to plan, design and operate the transmission network in accordance with defined power system standards. Additionally, Transgrid may not be able to meet its service level of 99.999% into the future. This case is therefore considered unacceptable.

To respond to these pressures and address this risk, an uplift in capability (technology & tools) and capacity (human resources & training) will be required, including Situational Awareness and Digital Twin technologies and an increase in staffing levels and training to support asset management, system planning and system operations. These tools have been recommended following a forward-looking capability gap analysis, based on expert assessment and a review of common and leading practice in power system operations in Australia and globally.

These tools will address the following capability gaps within Transgrid:

- Limited visibility of real-time power system conditions and incomplete system information upon which to base operational decisions about system security, particularly as the system becomes more dynamic with a growing share of intermittent renewable generation.
- Limited capability to manage the complex system outages required to facilitate the construction and commissioning of large volumes of new generators and transmission infrastructure that urgently need to be connected to the transmission network.
- Inability to scale power systems analysis and planning studies to the volumes required to connect very large numbers of new renewable projects to the transmission system and effectively plan for power system security (including the provision of new system security services including system strength) as coal generation withdraws.

Figure 1 summarises the expected escalation of power system security risks, and mitigation impacts with the application of these initiatives.

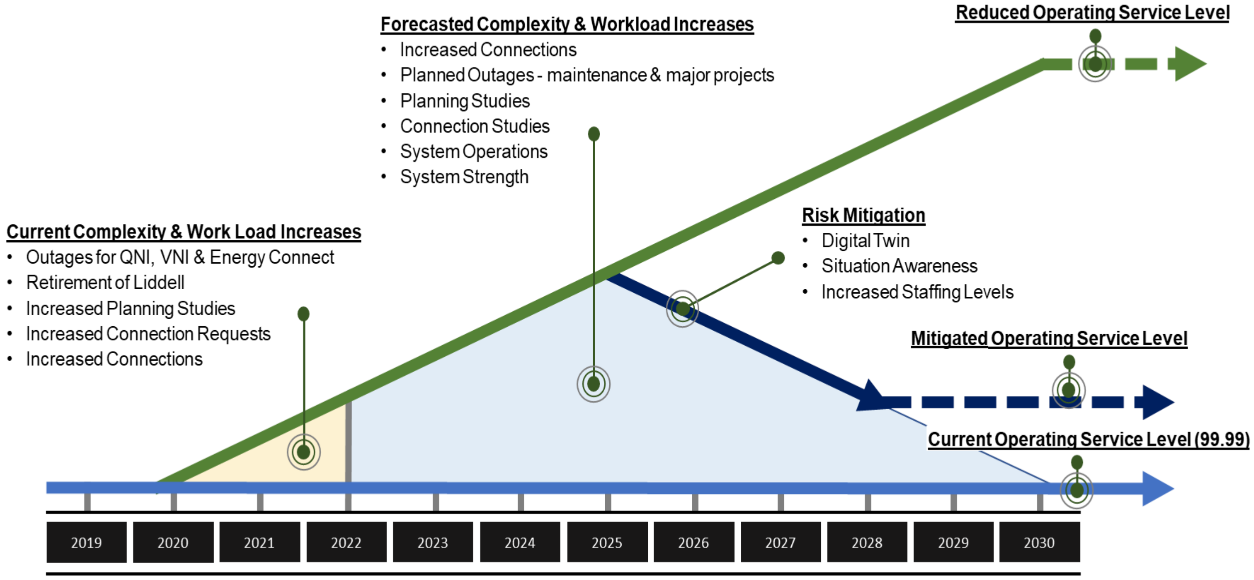

Figure 1:Indicative power system security risk escalation as a result of growing complexity with application of mitigation measures (PowerRunner)

The implementation of the capability and capacity uplift will mitigate a proportion of the increased risk, including reducing the likelihood that system security incidents will occur (at all), and when they do, enabling the majority to be contained as minor or intermediate events, rather than cascading into larger (including potentially catastrophic) events. This substantially reduces expected unserved energy relative to the Base case.

An assessment of this option (Option A) compared to continued use of current processes, tools, and staffing levels (Base case) is presented in Table 1.

Table 1:Evaluation of Option A compared to Base case

Option	CAPEX PV ($m)	OPEX PV ($m) 10 year	Gross Benefits PV ($m)	Net Benefits PV ($m)
Option A: capability & capacity uplift	$74.5	$81.5	$975.3	$819.2

It is recommended to progress with the implementation of Option A (technology and capacity uplift) as soon as is reasonably possible. This option has a clear net benefit and is required to maintain compliance with Transgrid's obligations under the National Electricity Rules throughout the energy transition.

1. Need/opportunity

The energy transition in NSW is occurring at an accelerating pace. The next decade will be a period of profound transformation within the electricity system, with several factors driving increased complexity in power system planning and operations. This step change in complexity is increasing system security risk on the power system, and these risks are forecast to increase each year as renewable generation increases and coal units operate less frequently and withdraw from the market. Without mitigation:

- These risks will increase the likelihood of system security incidents occurring on the transmission network which could lead to high levels of unserved energy. These system security incidents are forecast to almost triple the volume of unserved energy from minor and intermediate events (similar in scale to what has previously been experienced on Transgrid's network) by FY2030, compared to FY2022. However, when the increased risk of catastrophic system black events is also considered, unserved energy may exceed 9,000 MWh.
- Transgrid may be non-compliant with its obligations under the National Electricity Rules (NER), including clause 4.2.6 which requires Transgrid to operate the transmission network in a secure operating state, including returning to a satisfactory operating state following a credible contingency, and clause S5.1 which requires Transgrid to plan, design and operate the transmission network in accordance with defined power system standards (for network reliability, frequency variations, voltage, voltage fluctuations, voltage unbalance, stability, etc.).

1.1. **Power system complexity is increasing**

1.1.1. Accelerated retirement of ageing coal generators

The NSW power system is currently underpinned by a fleet of coal generators which supply over 70% of generation on the transmission network. These power stations are nearing the end of their technical lives and will soon retire. In recent months, owners of NSW coal power stations have announced that they would bring forward planned retirement dates, including for the Eraring Power Station, now retiring in 2025 (7 years earlier than previously expected) and Bayswater Power Station, now retiring in 2033 (2 years earlier than previously announced, and with management commentary than this date could be further brought forward to 2030 under some circumstances). The most likely scenario in the Australian Energy Market Operator's (AEMO) 2022 Integrated System Plan ('Step Change') forecasts that 7,520 MW[1] of coal generation capacity in NSW will retire by 2032 – almost three quarters of the current capacity.

Historically, coal generators have typically operated as 'baseload' generation, with units predictably online 24 hours, 7 days a week. These units have been relied upon to provide security services to the power

[1] Includes 2000MW of Liddell Power Station capacity, which has already commenced staged retirement.

system, including system strength (fault current), inertia and voltage support. The number of units available has comfortably exceeded the minimum standard defined by AEMO for NSW (7 units), even during maintenance outages. This has provided a 'buffer' to the power system which has helped to maintain the technical operating envelope, and to quickly return the system to secure operations when incidents occur on the network (generator trips, equipment failures, weather events, etc.).

As coal generators reach the end of their technical lives, their reliability and availability is expected to decline. These units are experiencing growing operational, commercial and social license pressures as the market share of renewable generation increases. It is therefore likely that they will experience an increased rate of planned and unplanned maintenance outages, and there is potential for extended periods of economic unit decommitment during the next decade, before units officially withdraw from the market. AEMO is forecasting that by FY2025, there will be periods when the minimum number of coal units will not be available in NSW[2]. Extensive power system studies will be needed to plan the NSW system to securely operate with less thermal generation online, and to deliver the required levels of system security services from alternative sources to ensure minimum requirements can be met at all times.

As a result, conditions on the NSW power system will be more unpredictable, and it will likely spend more time operating at minimum levels of system security, rather than in surplus as has historically been the case. This increases the risk that contingency events may cause the power system to operate in an insecure state, and make it more challenging to return the power system to a secure state following an event.

1.1.2. Rapid growth in intermittent renewable generation

As coal generation retires, it is expected that renewable generation, energy storage and firm (peaking) capacity will be rapidly deployed so that there will be sufficient generation to meet demand at all times. The 2022 Integrated System Plan 'Step Change' scenario forecasts that variable renewable generation capacity in NSW (including utility scale and behind the meter) will triple, from 9.6 GW in 2022 to 29 GW in 2030. Grid-scale wind and solar capacity is forecast to grow to 17.5 GW in 2030, an increase of over 12 GW.

These forecasts are significantly higher than those presented in AEMO's 2018 and 2020 Integrated System Plans. There has been a significant shift in the industry consensus view, with more renewable capacity now expected to connect sooner. This reflects both the accelerated closure timeframes for coal generators in NSW and new policy mechanisms established to deliver the NSW Government's Electricity Infrastructure Roadmap (enabled by the Electricity Infrastructure Investment Act 2020 (NSW) ('The Act')).

Transgrid must therefore facilitate the connection very large volumes of new renewable generation capacity to the NSW transmission network, including managing a growing number of customer inquiries, connection applications as well as generator testing, energising and commissioning. Each of these stages involves detailed power system analysis to ensure that generators meet performance standards, and the power system can operate securely with them online under a range of different conditions and scenarios. Complex and unpredictable interactions between inverter-based generators, and between inverter-based generation and other system elements are possible, particularly as levels of system strength and other system security services decline. Failure to identify and mitigate these issues in the planning phase can result in system security and power quality issues once generators are operational.

With more renewable capacity connecting to the network, operating conditions on the power system will change dramatically, to become more dynamic, less stable and less predictable. By 2030, the annual contribution of generation from intermittent, weather-driven sources is forecast to grow to around 70%,

[2] AEMO 2021 System Security Report

while the proportion from thermal generation will fall to less than 20%. AEMO is forecasting that by 2025 the National Electricity Market could experience periods with up to 100% instantaneous renewable generation (typically during periods with high wind and solar availability and relatively low demand). This is an increase from a maximum of around 50% instantaneous renewable generation in FY2021[3]. By 2030, dispatch periods with 100% renewables are forecast by AEMO to be common.

1.1.3. Integration of NSW Renewable Energy Zones

The NSW Government has developed a plan to provide for the orderly transformation of the state's electricity system, including new policy mechanisms and frameworks to achieve these objectives. The NSW Electricity Infrastructure Roadmap sets out the plan for development of at least five Renewable Energy Zones (REZs) across NSW to facilitate the connection of an intended 12 GW of renewable generation capacity by 2030. These will be located in Central-West Orana, Illawarra, New England, South-West and Hunter-Central Coast regions of NSW. The Energy Corporation of NSW (EnergyCo) (a Government-controlled statutory authority) has been established to lead the delivery of NSW REZs including the coordination of REZ transmission, generation, firming and storage projects to deliver timely and coordinated investment.

Under the Act, EnergyCo will undertake a competitive procurement process to select a Network Operator to design, build, finance, maintain and operate network infrastructure for each declared REZ in NSW. Each REZ and the respective Network Operator will need to connect to, and interface with, Transgrid's transmission backbone network and operations function. This will create new operational complexities, with multiple transmission operators and new roles and responsibilities within the NSW power system – and risks to power system security if these relationships and interfaces do not perform as expected (particularly at times of power system stress).

1.1.4. Planning and construction of major transmission infrastructure projects

AEMO's 2022 Integrated System Plan identifies several Actionable, large-scale transmission projects required to be developed in NSW during the next decade. These projects need to be progressed urgently, and include:

- **HumeLink:** A 500 kV transmission upgrade connecting Project EnergyConnect and the Snowy Mountains Hydroelectric Scheme to Bannaby. The project has a delivery date of July 2026 for Stage 1 ($330 million) and Stage 2 ($2,985 million).
- **Sydney Ring:** A high capacity 500 kV transmission network to reinforce supply to Sydney, Newcastle and Wollongong load centres. The project has a delivery date of July 2027 for Northern option ($0.9 billion ± 50%) or Southern option ($2.25 billion ± 50%).
- **VNI West:** A new high capacity 500 kV double-circuit transmission line to connect Western Renewables Link (north of Ballarat) with Project EnergyConnect at Dinawan via Kerang. The project has a delivery date of July 2031 for Stage 1 ($491 million) and Stage 2 (estimated at $2.5 billion).
- **New England REZ Transmission Link:** Transmission network augmentations defined in the NSW Electricity Strategy. The project has a July 2027 delivery date and an estimated cost of $1.9 billion ± 50%).

These projects are in addition to existing transmission projects in development or under construction in NSW including Project EnergyConnect (expected commissioning July 2026), VNI Minor (November 2022), QNI Minor (mid 2023) and the Central-West Orana REZ Transmission Link (July 2025).

[3] AEMO 2021 Electricity Statement of Opportunities

Each of these major projects will have complex interactions with the existing transmission network, including the need for prolonged outages to facilitate construction, connection and commissioning. The power system will have lower levels of resilience and redundancy during outages, and extensive planning and analysis will be required to ensure that adequate levels of system reliability and security can be maintained throughout, including during contingencies.

1.1.5. Increasing penetration of distributed energy resources

Rooftop solar continues to be popular in NSW. The state has experienced five years in a row of record-high installation rates, and almost 1 GW of small-scale solar was installed in NSW 'behind the meter' in calendar year 2021 alone[4]. The 2022 Integrated System Plan forecasts that distributed solar capacity in NSW will almost triple in the next decade, from 4.4 GW in 2022, to 12.9 GW in FY2032.

As a result, minimum system demand is falling rapidly in NSW, and at a faster rate than previously expected. After being relatively stable for a number of years, minimum demand in NSW fell to 4.3 GW in FY2022, 18% lower than the previous year (5.2 GW). By 2035, NSW is likely to experience periods where operational demand on the transmission system will fall below zero. This represents a new operating paradigm with net backflow of power into the transmission system from the distribution network (rather than the traditional one-directional flow from transmission to distribution). Under these conditions, there will be challenges in managing over-voltages in the transmission network as well as keeping the minimum combination of thermal units online, as identified by AEMO as needed to maintain system security.

1.2. Operational risk on the NSW power system is increasing

Each of the drivers outlined above will drive power system complexity, and they will also have complex interactions with each other. The cumulative impact of them, and the fact that they are occurring over a condensed timeframe (10 years), will be an increase in the level of operational risk on the power system, and a step-change in the volume of analysis and decision-making needed to effectively plan, operate and manage the transmission system within Transgrid's obligations under Sections 4 and 5 of the NER.

These impacts are further compounded by the significant number of regulatory and energy market changes being progressed in parallel at the state and NEM levels, which will directly create new compliance obligations for TNSPs, or indirectly impact the evolution of the power system that Transgrid is responsible for planning, managing and operating. These changes are often designed to accommodate the energy transition (e.g. to evolve market structures for new technologies, efficiently deliver system security services and facilitate distributed energy resources) but their development and introduction at a time of significant system change will also increase uncertainty and complexity over the next 10 years.

New risks and requirements are emerging across the different time horizons required to plan, operate and manage the transmission system. Incorrect or incomplete analysis, information or decision making across these time horizons can result in system security incidents on the network - if generation, network assets and services do not perform as planned, or if decisions are made on an incomplete or incorrect basis. For example:

- **In the planning time horizon (years ahead):** Detailed power system and planning studies and economic assessments will be required to plan for an optimal mix of system security services (e.g. voltage control, inertia, and system strength) as coal units retire, as well as to connect and commission new renewable generation, transmission infrastructure and REZs. This will involve assessing new and novel technologies (with complex interactions and limited historical data about operating performance),

[4] Clean Energy Council (2022) Clean Energy Australia Report

integrating services provided as non-network solutions by third parties, and increasingly sophisticated demand-side technologies including electric vehicle charging, aggregated distributed resources (e.g. virtual power plants), and hydrogen production. Multiple scenarios and contingencies will need to be tested to assess power system reliability and security, and develop and optimise solutions to address emerging system risks.

- **In the operational/planning time horizon (hours/days/months ahead):** Multiple forecasts and system simulations will need to be run in the short to medium term to ensure secure operations will be maintained, factoring in availability of dispatchable generators, variable renewable generation, demand conditions and network outages.
- **In the real-time operational time horizon:** There will be an almost exponential increase in real-time operational decision-making requirements as the power system becomes more distributed, dynamic and unpredictable. Enhanced awareness and control capability in asset monitoring and grid operations are required.

1.2.1. Existing operational tools and capabilities are now at full capacity

Until recently, the planning and operation of the power system has been largely deterministic. Lack of Reserve conditions were rare and tended to occur during periods of consecutive hot days during summer months. Power system planning and operations tended to focus on single outage contingency (N-1), system peak demand, and managing voltage levels to support the balancing of supply and demand over a relatively predictable daily load profile. Existing tools, capabilities and resourcing levels reflect these conditions and requirements.

NSW is currently at the early stages of the energy transition, with the majority of the system transformation forecast to occur in the next decade. However, there are emerging signs that system complexity and risks are increasing and existing tools and capabilities are reaching their limits, with the levels of change that have been experienced to date:

- The NEM market bodies including the Australian Energy Regulator, the AEMO and the Australian Energy Markets Commission have observed that the transition of the NEM power system from large, synchronous thermal generation to inverter-based renewable generation is creating power system security challenges including more periods of low inertia, weak system strength, volatile frequency and voltage instability[5]. These impacts have mostly been observed in other jurisdictions (particularly South Australia), because NSW has historically had relatively high levels of coal generation and lower proportions of renewable generation.
- AEMO has launched its Operational Technology Roadmap which identifies gaps and proposes solutions in the system and market operations capabilities needed to enable transformative change while maintaining electricity system reliability, security and resilience. The 2022 Integrated System Plan identified that *"Uplifting System Operator and Network Service Provider capabilities in operational systems, processes, real-time monitoring, and power system modelling will be essential to have the tools to maintain secure operation of the NEM power system as it transitions to significant penetrations of inverter-based resources including DER"*.
- Transgrid has observed that the NSW power system is sitting closer to the edge of its secure operating envelope, with the system more likely to tip into insecure operating conditions if a credible contingency occurs.

[5] For example, AER (2021) State of the Energy Market 2021 and AEMC (2022) 2021 Annual Market Performance Review

Figure 1 presents the results of Transgrid's Contingency Analysis (CA) tool from 2010 to 2022. The CA tool uses the SCADA Energy Management System to run a series of load flow scenarios for predefined credible contingencies, for each 5-minute dispatch period. An alarm is raised when where the resultant network would be operating outside of the allowable technical envelope, requiring an operator to take action. In these situations, credible contingency could result in insecure network operation, and without intervention this could cause network faults with lost generation and/or load, or potential escalation to a major (or catastrophic) system event. The frequency of these alarms is therefore considered to be an indicator of system risk.

The trend in Figure 1 shows that the number of CA alarms has grown significantly in the past two years, and has more than doubled in 2022 compared to the period 2010-2020. This highlights the increasing level of responsiveness (and possibly intervention) that is already required in the Transgrid control room, and the reliance on operators making a growing number of decisions in real-time to maintain secure operations. This trend is forecast to continue as system complexity increases, and existing tools, information levels and capabilities will not be able to scale to continue to effectively manage system security risk.

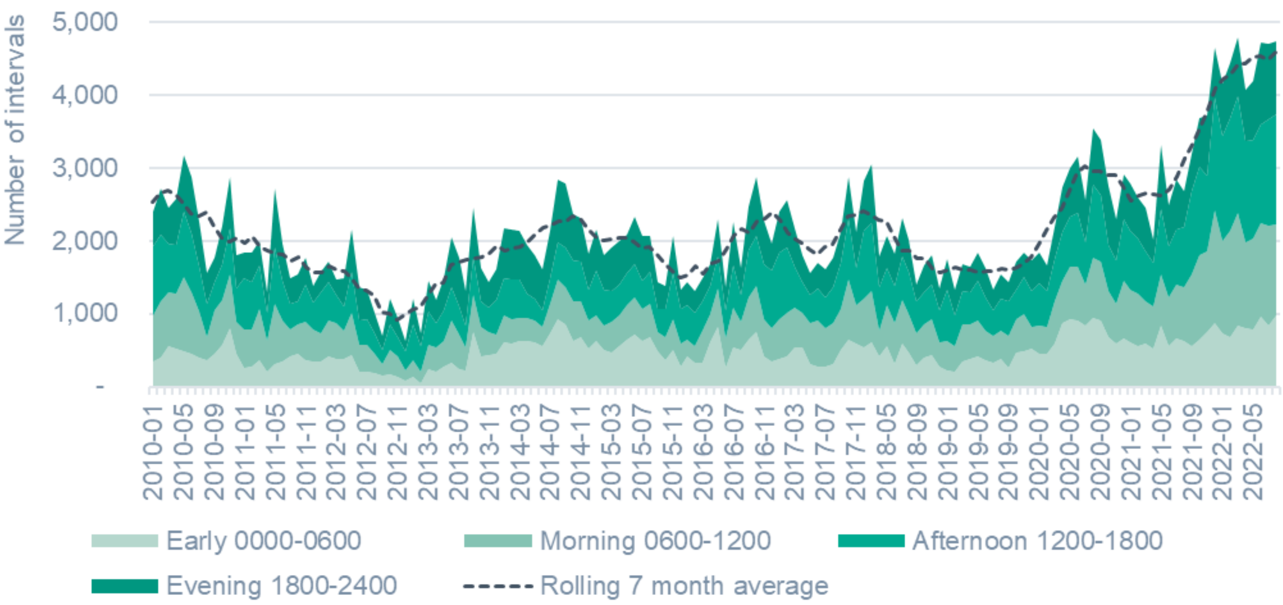

Figure 2: Operating intervals when at least one credible contingency on the NSW transmission system would have resulted in a violation of the power system technical envelope, 2010 to Aug 2023

1.3. Complexity and operational risk will increase the risk of unserved energy in NSW

Transgrid has engaged consultants PowerRunner to define, quantify and evaluate emerging system risks and the initiatives required by Transgrid to maintain power system security, considering the accelerating energy transition and growing system complexity. PowerRunner and its team have extensive global experience and expertise in power system operations, risk, power system analysis and modelling, and the design and implementation of advanced digital tools and systems. The engagement involved:

- Quantifying emerging system complexity and risks and forecasting how these will translate into a greater risk of power system security incidents, including expected unserved energy in NSW, if left unmitigated;

- Assessing Transgrid's current capabilities and undertaking a gap analysis to define the uplift in capability and capacity required to effectively plan, manage and operate the NSW power system under conditions forecast for the coming decade, including the potential for periods with 100% instantaneous renewable generation by 2025;
- Defining the tools, systems, people and processes required to uplift Transgrid's capabilities and capacity so that it can mitigate system security risks and continue to meet its obligations under the NER throughout the energy transition, including the costs and benefits of these initiatives.

Power system security incidents leading to lost load are currently rare due to adequate operational tools and redundancy and resilience in the system. In the past 19 years, Transgrid has recorded a total of 11 incidents which involved the loss of load as a result of voltage or frequency deviations, or load-shedding to maintain/restore the power system to secure operations. This represents around 6% of all network incidents resulting in lost load during the period. The vast majority of incidents occurring on Transgrid's network are the result of asset trips, equipment failure, errors or mal-operation (either within Transgrid's own asset base or those connected to our network with generation, load or distribution networks).

PowerRunner has determined that historical network performance is not 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. Current tools, processes and people were assessed by PowerRunner to be already at maximum capacity, and not capable of scaling to manage the system changes and increasing analytical requirements. As a result, the risk of failure of key planning and operating processes is expected to grow.

Figure 3 summarises the PowerRunner complexity risk assessment. The increased operational risk associated with each complexity driver was assessed across a range of focus areas, considering both the quantity and complexity (time, expertise and analytical volume) required to complete each task to a standard required to maintain NSW power system security. For each driver, the increased risk of system security incidents in FY2030 was estimated relative to FY2022 (base year) by averaging the impact on the various focus areas. Each complexity driver is an independent source of system risk, so risk factors were summed to calculate cumulative total. These risks are summarised as follows:

- **12 GW Renewable capacity added to transmission system:** Tripling of inverter-based, weather-driven renewable generation, requiring high levels of real-time decision making and intervention to maintain secure power system operation. Generation has complex interactions with each other, and other network elements requiring detailed planning and operational studies across different scenarios and conditions. Failure of planning, people and processes can lead to a breach of the network technical envelope under system normal and credible contingencies (e.g. issues with harmonics, oscillations, voltage, frequency, fault ride-through, etc.), leading to unserved energy.
- **NSW Renewable Energy Zones:** The delivery of the NSW Electricity Strategy will involve new roles and responsibilities for planning, delivering and operating different Renewable Energy Zones in NSW, which will each need to interface, communicate and coordinate with Transgrid's transmission network. Failure of these protocols (in the planning and operational phases) may lead to system security incidents and unserved energy.
- **Major Transmission Projects:** The delivery of multiple large transmission projects in NSW requires extensive planning studies to assess system security under different scenarios and operating conditions, as well as prolonged outages during the construction and commissioning stages of each project to connect to the existing transmission system – during that period, capacity and redundancy in the network will be reduced. Failure of studies, forecasts, planning and operational processes may lead to system security incidents, particularly while the network is strained and during contingencies.
- **Early retirement of coal generation:** The withdrawal of coal generation (and periods of planned/unplanned generator outages) reduces the level of system security services available in the

power system (system strength, inertia, voltage control, etc.). 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 operating state – increasing the risk of unserved energy. Regular (and rapid) changes to announced generator closure dates requires large volumes of planning studies to be conducted to assess emerging system security issues and to optimise solutions to provide services to replace those historically provided by coal (technically and economically) and deploy them in increasingly short time frames.

- **Distributed solar:** Faster uptake than was previously forecast is reducing minimum operational demand on Transgrid's network, and causing load to be more dynamic and weather-driven (as well as generation). This creates challenges for voltage and frequency control in real-time – requiring operator intervention to maintain operations within the technical envelope.

Based on its assessment, PowerRunner forecasts that if unmitigated, the compounded effect of the several complexity drivers which are all likely to occur in NSW over the same 10-year period will significantly increase the risk of system security incidents, with a corresponding increase in the risk of unserved energy. The assessment has found that unserved energy on the NSW transmission system resulting from system security incidents could increase 569% by FY2030 compared to the base year of FY2022, with the risk of minor, intermediate and catastrophic outage events increasing linearly each year that mitigation is not applied.

Transgrid considers PowerRunner's assessment to be reasonable because it is largely consistent with the increasing trend observed in Figure 2, which shows that there is an increasing risk of system events leading to conditions outside of the secure operating envelope. Extrapolating the trend observed between FY17 and FY23 in Figure 2 out to FY30 suggests that contingency events with the potential to result in insecure power system operations could be 583% higher in FY2030 compared to FY2022 (quadratic relationship, R^2=0.76). The starting year of FY17 was selected as it broadly represented the period when variable renewable generation did not have implications for power system operability; in this year variable renewable generation only accounted for approximately 5% of NSW electricity generation.

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					
Focus Areas	**+12GW Largescale Renewable Capacity**	**NSW Renewable Energy Zones**	**Major Transmission Projects**	**Retirement of Coal Generation**	**Distributed solar**	**Cumulative Total**
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%**

Figure 3: PowerRunner risk escalation assessment of power system events resulting in lost load in FY2030 compared to FY2022, as a consequence of increasing power system complexity

Table 2 shows that without mitigation, the risk of unserved energy on Transgrid's network will increase significantly.

Table 2 presents a probabilistic assessment of unserved energy risk on Transgrid's network based on PowerRunner's assessment. Three categories of system events have been considered in the analysis:

1. **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). 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 are currently system security incidents (approximately 3%).
2. **Intermediate:** Larger and/or more complex system events resulting in more than 100 MWh of lost load (average 329 MWh lost load). 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.
3. **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.

Table 2 shows that without mitigation, the risk of unserved energy on Transgrid's network will increase significantly.

Table 2: Risk of unserved energy in FY2030 as a result of system security incidents compared to FY2022 based on PowerRunner assessment (with no risk mitigation applied)

Event type	Description	Typical unserved energy per event (MWh)	FY2022 (base year)		FY2030	
			Likelihood	Unserved energy (MWh)	Likelihood	Unserved energy (MWh)
Minor	Event resulting in less than 100 MWh of unserved energy. Historically system security incidents of this scale have been ~1 in 3 year events on Transgrid's network	11	31%	3	208%	23
Intermediate	Larger/more complex event resulting in up to 500 MWh of unserved energy. Historically system security incidents of this scale have been ~1 in 4 year events on Transgrid's network	329	26%	85	173%	571

Event type	Description	Typical unserved energy per event (MWh)	FY2022 (base year)		FY2030	
			Likelihood	Unserved energy (MWh)	Likelihood	Unserved energy (MWh)
Catastrophic (black start)	Full black start event in NSW, with 8-hour recovery time. Assessed by PowerRunner to be currently ~1 in 50 year event.	66,000	2%	1,316 [6]	13%	8,806
Probabilistic risk of unserved energy – system security incidents				**1,405**		**9,400**

Table 2 shows that the risk of unserved energy from minor and intermediate power system security incidents (i.e. the types of power system events that have historically occurred) will increase by over 500 MWh by FY2030 compared to FY2022, which would almost triple unserved energy in Transgrid's network (including all events and incident types) over the period. Table 2 shows the main driver of expected unserved energy over this period is the escalation in risk of a catastrophic power system incident, which is forecast to increase from a 1 in 50-year event, to an approximately 1 in 8-year event over the period.

2. Options

2.1. Base case

The base case, or 'do nothing' scenario involves Transgrid maintaining its current tools, systems and resourcing levels to plan, operate and manage the NSW power system throughout the energy system. Transgrid does not consider this option to be acceptable because:

- Increasing complexity is expected to drive a year-on-year increase in system security risk, increasing the likelihood that system security incidents will lead to unserved energy. Section **Error! Reference source not found.** describes that in this scenario, there is a risk of over 9,000 MWh of additional unserved energy in FY2030 relative to FY2022.
- Transgrid may not be able to complete analysis required to maintain secure power system operations. More analysis will be needed in real-time, but the growing complexity is increasing the time needed for analysis - current forecasting, planning and decision tool used to support 5-minute real-time operations are already 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.
- Transgrid may not be compliant with its obligations under Chapters 4 and 5 of the NER, including:
  - Clause 4.2.6 requires Transgrid to operate the transmission network in a secure operating state, including returning to a satisfactory operating state following a credible contingency
  - Clause S5.1 requires Transgrid to plan, design and operate the transmission network in accordance with defined power system standards (for network reliability, frequency variations, voltage, voltage fluctuations, voltage unbalance, stability, etc.).
- Transgrid may not have the capacity to complete the large volumes of detailed power system studies required for the timely connection of new renewable generators (including to support the NSW Government Electricity Infrastructure Roadmap), major transmission projects, and to effectively assess, plan and deliver solutions to system strength within the timeframes required. This could delay

[6] Note a NSW system black event has not occurred since NEM formation so USE figure represents a risk-based probabilistic assessment

the commissioning of generators, Renewable Energy Zones and transmission projects, with implications for system reliability and meeting the NSW Government's policy timeframes, and lead to less efficient energy market outcomes.

2.2. Option A: Uplift in technology and human resources

This option involves implementing new technologies and tools, and increasing technical expertise and staffing levels, to uplift Transgrid's capability and capacity to plan, operate and manage the transmission network. These initiatives have been recommended by PowerRunner, based on the findings from the capability and capacity gap analysis conducted for Transgrid, and are required to mitigate growing system risk during the NSW energy transition (as summarised in Section **Error! Reference source not found.**).

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 security events can be avoided altogether, or effectively contained so that they do not cascade into larger or more complex issues across the network.
- Increased volume, quality and speed of power system and planning studies, needed for the timely planning and development of new renewable generators and the efficient and effective delivery of new infrastructure and services to maintain system security as coal generation retires.
- Improved planning and management of transmission system outages, needed during the construction and commissioning of major new transmission projects, generators and Renewable Energy Zones.

2.2.1. Technology uplift

Table 3 summarises the suite of new digital tools required, comprising:

- **Network 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 will provide 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.
- **Situational awareness and real-time decision support:** A suite of applications that provide visibility of system conditions in real-time and near real-time, to enable system operators to make informed decisions and respond effectively to system events as they are occurring.

Further detail of these tools is presented in Appendix A, and an overview of how these tools uplift capability and reduce operational risk is provided in Appendix B.

The expected delivery date for these new tools is staged between FY2025 and FY2028, which represents the earliest practical implementation timeframe.

Table 3: Summary of PowerRunner recommendations for technology uplift

Initiative	Function
Digital Twin – Modeled Representation of Physical System	
Data Governance & Calculation Platform	Structuring and consolidating disparate data as a single source of truth
Asset Registration	Customer and asset registration interface, process and workflow management application which populates downstream systems
Single Network Management Model	Central source of power system data and tool for network models – Digital Twin
Situational Awareness and Real-Time Decision Support	
Alarm Analytics	Root cause detection tool to distil large quantities of information into a manageable insight to support real time decision making
Advanced Forecasting	Artificial intelligence and machine learning-based forecasting for substations and key nodes
Advanced Neural Net State Estimation	Increased visibility of network conditions hour/day/week look ahead - load flow analysis
Visualisation & Operations Decision Support	Providing actionable information to control room operators & Asset Management
Asset Health Decision Support	Support decision making on asset health and near real time asset condition analysis

The expected expenditure profile to deliver the technology uplift is presented in

It is estimated that an additional $6.2m is required in project and initiation costs, to progress to DG2 (primarily expected to be incurred in FY2023).
Table 4, as estimated by PowerRunner. The estimates have an uncertainty of ± 25% and exclude capitalised interest. Cost estimates include software licenses, software maintenance, hardware requirements, internal and external labour to implement each application initially, and ongoing operational costs to maintain solutions once in use.

It has been assumed that system capital costs will include 5 years of licensing fees for new software. From FY2029 onwards, OPEX for these tools is forecast to increase to $4.9m per annum, reflecting ongoing annual licensing and maintenance costs.

It is estimated that an additional $6.2m is required in project and initiation costs, to progress to DG2 (primarily expected to be incurred in FY2023).

Table 4: Expected cost - technology uplift ($m, FY2022) as estimated by PowerRunner

Initiative	FY24	FY25	FY26	FY27	FY28	Total (5 year)
Digital Twin						
Single Network Model Management	11.8	6.3	3.7	2.1	0.1	24.0
Asset Registration	4.4	1.3	1.2	1.1	-	8.1
Data Governance and Calculation Platform	10.3	2.6	-	-	-	12.9
Situational Awareness						
Alarm Analytics	4.4	0.3	0.03		-	4.7
Forecasting	5.5	0.3	-	-	-	5.8

Initiative	FY24	FY25	FY26	FY27	FY28	Total (5 year)
Advanced Neural Net State Estimation	9.5	2.2	0.1	-	-	11.9
Visualisation and Operational Decision Support	5.2	2.7	0.9	-	-	8.8
Asset Health Decision Support	5.6	1.9	-	-	-	7.5
Support across all applications	1.3	-	-	-	-	1.3
Total CAPEX [7]	**58.1**	**17.6**	**6.0**	**3.2**	**0.1**	**85.0**
OPEX	**-**	**-**	**0.7**	**0.9**	**0.9**	**2.5**

2.2.2. Capacity uplift with additional human resources

PowerRunner's assessment has also identified that additional resources, skill sets and training will be required to support the increasing requirements and complexity of network planning, asset monitoring and system operations. These requirements are summarised in Table 5.

Table 5: Summary of PowerRunner recommendations for capacity uplift

Function	Additional human resource requirements
System Operations (Increase of 15 FTE in FY2028)	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 (Increase of 17 FTE in FY2028)	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 (Increase of 14 FTE by 2028)	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 expected expenditure profile to deliver the human resources and training uplift is presented in Table 6. These costs are based on a bottom-up build of staffing requirements to meet Transgrid's NER obligations and to effectively plan, manage and operate the NSW transmission system (number and type of resources), and Transgrid's standard labour costing rates. Resourcing levels are assumed to increase to FY2028 and then remain at those levels.

Table 6: Expected cost - capacity uplift ($m, FY2022) as estimated by PowerRunner

Initiative	FY24	FY25	FY26	FY27	FY28	Total (5 years)
FTE increase from FY22 base year	29	35	39	45	46	
OPEX	**6.6**	**7.8**	**8.5**	**9.7**	**9.8**	**42.3**

Costs outlined in Table 6 include an uplift in training, both for existing System Operations, System Planning and Asset Management staff ($3.8m over 5 years for 144 FTEs) due to the growing complexity of the power system, and for new staff ($1.2m over 5 years for FTEs outlined in Table 6) due to the growing complexity and the need to hire and train more inexperienced staff (due to the high demand for skilled people in the electricity industry).

[7] Sum may not equal total due to rounding

2.3. Options considered and not progressed or evaluated

Three further options were considered, but were not progressed because they were not considered to be technically or economically feasible. These were:

- A much more significant uplift in staffing levels and training, without the introduction of new technology and tools. This option is not considered viable. The near-exponential increases in data management, analysis and decision-making required over the next decade mean that system risks cannot be effectively managed with additional human resources alone. Furthermore, the skill sets required are specialised and are in high demand in the employment market, so it would be highly challenging to recruit, develop, train and retain staff in the numbers that would be required.
- A fully automated technology solution that could be implemented without an uplift in human resourcing. This option is considered non-credible because such tools are not available 'off the shelf' and it is unlikely that the solution could be fully developed and implemented within the timeframes required.
- A partial implementation of the technology uplift described in Table 3. PowerRunner has specified the suite of tools to be integrated and 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.

3. Evaluation

The economic analysis undertaken for this project is a risk-based assessment which estimates the reduction in expected unserved energy under Option A (with an uplift in technology and human resources) as compared to the Base case.

Section 1.3 outlines the escalation of system security risk and resulting risk of unserved energy in the Base case, based on the complexity assessment conducted by PowerRunner.

PowerRunner has assessed that in Option A, the implementation of the technology and capacity uplift will mitigate some of this increased risk. It will prevent a proportion of system events from occurring at all, and will enable others to be contained as minor or intermediate events, rather than cascading into larger events.

The risk mitigation factors for technology and capability uplift are presented in Table 7, along with other parameters used in the economic evaluation. These factors should be summed to determine the total risk mitigation factor. PowerRunner's risk mitigation assessment has been reproduced as Appendix B.

PowerRunner has determined that in Option A, the risk of system security incidents resulting in unserved energy is reduced as follows (applying the total risk mitigation factor):

- **Minor:** 60% of the increase in minor system security incidents forecast in the Base case are prevented.
- **Intermediate:** 60% of the increase in intermediate incidents forecast in the Base case are experienced instead as minor events, with the uplift in capability and capacity enabling them to be contained and quickly resolved.
- **Catastrophic:** 60% of the increase in catastrophic incidents forecast in the Base case are experienced instead as intermediate events, with the uplift in capability and capacity preventing cascading failures and widespread outages.

Over the 10-year assessment period, Option A has a total of 33,951 MWh less expected unserved energy than the Base case.

Table 7: Parameters used in economic evaluation

Parameter	Description	Value used
Discount rate	Interest rate used to determine the present value of future costs and benefits	5.5%
Discount year	The year that dollar values are discounted to	FY 2022
Base year	The year that dollar value outputs are expressed in real terms	FY 2022 dollars
Value of Consumer Reliability (VCR)	The value that consumers place on reliable electricity supplies across outage scenarios. The value is based on AER 2019 VCR Review, escalated to FY2022 dollars based on inflation rate of 2.16%	$43,032
Period of analysis	Number of years included in economic analysis with remaining capital value assumed to be nil at the end of the analysis period.	10 years (FY2024 – FY2033)

3.1. Economic evaluation results

The economic evaluation results for Option A are summarised in Table 8. Option A demonstrates a positive net economic benefit.

Table 8: Economic evaluation (PV, $million)

Option	CAPEX PV ($m)	OPEX PV ($m) 10 year	Gross Benefits PV ($m)	Net Benefits PV ($m)
Option A: capability & capacity uplift	$74.5	$81.5	$975.3	$819.2

3.2. Sensitivities

Transgrid has tested the sensitivity of net benefits to variations in underlying assumptions, as summarised in Table 9. All the other assumptions/inputs have remained the same, including CAPEX and OPEX costs and the VCR.

Sensitivity results show that the net benefits of Option A is robust across a range of sensitivities tested, with the exception when the implications of catastrophic events (system black) are excluded. Based on international examples of blackouts[8], PowerRunner believes it is appropriate to consider the growing risk of catastrophic events.

[8] The US-Canada Power System Outage Task Force (2004) found that the common factors in every major outage in the US and Canada between 1965 and 2003 included the inability of system operators to forecast events on the system, failure to ensure the system operation was within safe limits, ineffective communication and inadequate training of operating personnel (link). The events of California's 24-hour blackout (link) in 2011 and the UK's national blackout (link) in 2019 cascaded from minor incidents to blackouts in part because of a lack of analytics and situational awareness in control rooms. Therefore, the consequences of a lack of information and training of grid controllers can be catastrophic.

Table 9: Economic evaluation sensitivities on Option A (PV, $million)

Sensitivity	Description	Net Benefits PV ($m)
1. Incident likelihood reduced by 50%	Risk escalation for minor, intermediate & catastrophic system events reduced by half, for each year to 2030, compared to base case (therefore the increase in risks in FY30 is 285%, compared to PowerRunner's assessed 569%, on a FY22 base).	$331.6
2. Mitigation reduced by 50%	Effectiveness of proposed controls (capability and capacity uplift) to mitigate risk reduced by half (across minor, intermediate & catastrophic events) compared to base case (therefore controls reduce the risk by 30%, not 60% as assess by PowerRunner).	$331.6
3. Incident likelihood & mitigation reduced by 50%	Combination of sensitivities 1 & 2	$87.8
4. Catastrophic events excluded	Benefits calculation only includes mitigation of minor and intermediate events (not system black).	-$96.0
5. 2.3% discount rate	Cost benefit is calculated with a discount rate of 2.3%. All other inputs/assumptions reflect the base case.	$1,046.8
6. 7.5% discount rate	Cost benefit is calculated with a discount rate of 7.5%. All other inputs/assumptions reflect the base case.	$706.7

4. Optimal Timing

PowerRunner has found that Transgrid's existing capabilities to plan, manage and operate the NSW power system (while suitable for current conditions) are already operating at full capacity and are not capable of being scaled to manage power system security into the future. Without an uplift in capabilities, power system security incidents are projected to increase.

Results show that the greatest net benefits are achieved when mitigation commences as soon as possible, with the earliest practical delivery date expected to be 2025 (as modelled in Option A). This is confirmed through an assessment of the delay of Option A by 1 year, to FY26. In this assessment, the net benefit drops by $49.6m to $769.6m.

5. Recommendation

It is recommended to progress with the implementation of Option A (technology and capacity uplift) as soon as is reasonably possible. These initiatives:

- Mitigate the growing risk that power system complexity will result in system security incidents leading to high levels of expected unserved energy.
- Are required for Transgrid to continue to comply with its obligations under Chapters 4 and 5 of the NER.

The economic assessment shows that there is a clear net benefit of $819.2m relative to the Base case.

Option A involves capital expenditure of $85.0 million, and an increase in operating expenditure totalling $118.6 million over the 10-year assessment period from FY2024 to FY2033 (in non-escalated 2021/22 dollars).

Appendix A – PowerRunner specification for technology uplift

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

Appendix B – PowerRunner risk mitigation assessment

Reduction in operational risk due to technology, people and training

	Technology Uplift (control measures)	Capacity Uplift (control measures)	Reduction in Operational Risk due to technology uplift	Reduction in Operational Risk due to capacity uplift	Brief Description of Justification (tools)	Brief Description of Justification (people)
Connections	- Single 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 studies) Includes Asset lifecycle impacts using Advanced Neural Network help power flow studies assess planned outage impacts	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
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 the timescales in which we operate.	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 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 - Alarm Analytics - Neural Net State Estimation	- 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 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	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.
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 visualisation 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%**			