South Australia – Operating at 100% Renewable Energy

ElectraNet System Operability Uplift Assessment

December 2022

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Credentials

PowerRunner has deep knowledge of the electricity industry, network service providers and transmission system operations both internationally and 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 spanning over 14 countries across four continents. Internationally, PowerRunner has worked on the design and implementation of process and systems in California, 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.

Executive Summary

ElectraNet plans, builds, maintains, and operates the electricity transmission system in South Australia (SA). Its primary role is to ensure safe and reliable transmission services for South Australian consumers, transporting power from where it is generated to where it is needed.

ElectraNet also supports AEMO in maintaining overall National Electricity Market (NEM) system security as required under chapters 4 and 5 of the National Electricity Rules (NER).

SA has already reached 100% instantaneous Variable Renewable Energy (VRE)

AEMO has set a goal of being able to operate the NEM at 100% instantaneous renewable generation by 2025.

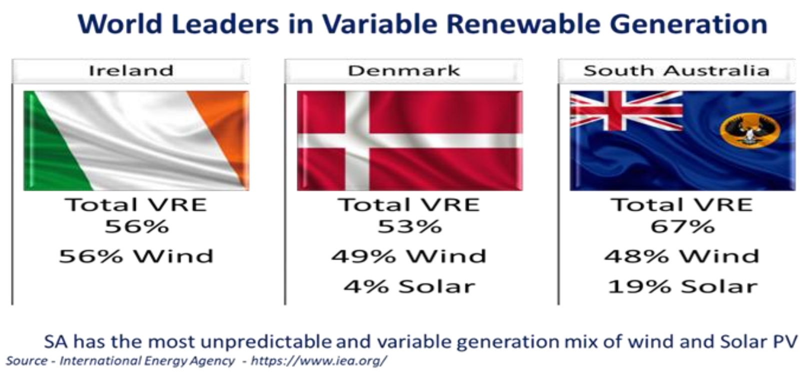
The South Australian power system was first operated at 100% instantaneous VRE in October 2021 and this is expected to happen increasingly frequently, and for longer durations, as time goes on.

A power system that experiences regular periods of 100% or more instantaneous VRE is far more complex from a planning and operational perspective than one underpinned by conventional generation. High penetration of VRE creates many more possible scenarios to be analysed in planning and operating the power system. In turn, this causes increased uncertainty as the performance of VRE technologies and transmission assets at this level of operational demand is unprecedented and unknown.

SA is a world leader in moving to 100% VRE

The SA power system has undergone dramatic change, shifting from one with approximately 20 predictable dispatchable thermal power plants to one with over 150 large VRE generators of varying sizes and technologies and more than 300,000 small distributed solar generators on domestic rooftops (DPV). These changes make SA the first gigawatt-scale system in the world to experience the complexity of operating with 100% instantaneous VRE.

The jurisdictions with high VRE penetration are underpinned by hydroelectric generation or supported by a strongly interconnected ('meshed') transmission grid. In either case this gives the network operator access to services provided by synchronous generation. SA is unique in the world in that its penetration of both wind and solar PV generation is no longer complemented by substantial synchronous generation, giving limited access to synchronous generation for network services, while significantly increasing the unpredictability of both energy supply and customer demand.



SA's use of VRE is forecast to continue to grow

SA's use of VRE is forecast to continue to grow, frequently reaching and exceeding 100% for extended periods.

The planned connection of new renewable generation, Battery Energy Storage Systems (BESS), planned maintenance and network reinforcements, and forecast minimum operational demand at close to negative 500 MW by 2028 means these challenges will persist and intensify over the next few years.

Power system risk in SA is increasing and more must be done to manage this risk

The planned changes to the SA power system, together with the compounding risk of externalities such as the extreme weather events that occurred in September 2016 and November 2022 mean that the risk of system disturbances is increasing. Based on experience of prior events, if not managed effectively, there is an elevated risk of a system disturbance will result in a loss of load, potentially escalating to a full system outage.

AEMO identified in its 2022 Integrated System Plan that:

> *"…uplifts are needed in real time monitoring, power system modelling, and control room technologies by AEMO and Network Service Providers, to ensure operational staff have the tools to maintain secure operation of the NEM power system as it transitions to significant penetrations of [VRE] including Distributed Energy Resources."*

Given the increasing use of VRE on the SA power system, ElectraNet anticipates that voltage issues, reduced system strength and performance challenges will reach unprecedented levels over the coming regulatory period. This will result in:

- Greater uncertainty regarding forecast system conditions and the need to manage a range of issues relating to voltage control and outage scheduling that are atypical, not forecast nor planned
- Increased need for expertise to analyse and respond to fast changing system conditions in near real time and real time
- A shortening of operating decision-making timeframes and margins
- A need for longer term planning solutions to mitigate operating constraints and challenges
- Increased stress on the power system and on planning and operating resources that are adequate for current system operations and planning but not for the system of the future.

Specifically, AEMO states that "system strength affects the stability and dynamics of generating systems' control systems, and the ability of the power system to both remain stable under normal conditions, and to return to steady-state conditions following a disturbance."[1]

Power system risk has been managed successfully with existing resources to date. However, there are new challenges that need to be understood and addressed to support further progress towards 100% VRE, while retaining essential system security and strength.

[1] AEMO, "Power System Requirements", 2020.

The challenges created by 100% instantaneous VRE include:

- **Unexpected system operating conditions –** system conditions are less predictable in a rapidly changing power system. More look ahead analysis based on real time system conditions is required to understand how VRE is impacting on system security
- **Voltage control** – increasing VRE, reducing minimum demands and changes in customer load characteristics (becoming more capacitive) are making voltage control more complex and challenging
- **Increased complexity of outage management –** more complex and rapidly changing system operating conditions are resulting in a decrease in available outage times and durations increasing the complexity of outage management. Shorter recall times are required when power system operating conditions change. Cancellations of planned outages at short notice has increased. This results in standdown costs and resource inefficiencies. Further, the increased likelihood of critical asset maintenance delays causes increased risk of plant failure and subsequent system disturbances.
- **Operating the system at loading levels lower than it was designed for** – as operational demand falls to very low levels for longer, the power system is increasingly vulnerable and challenging to operate.
- **Maximum, minimum, zero and negative demand** - transmission network stress points are occurring more frequently during minimum, zero and negative demand conditions in addition to the historical focus on performance under maximum demand conditions
- **Increased complexity, scale and volume of planning studies –** increase in system operating conditions that need to be considered for network planning and operations, including N-1-1 planning to consider the increased likelihood of multiple credible contingencies or credible contingencies and planned outages occurring simultaneously during network stress events.
- **Expanded limit advice** – faster and a higher volume of limit advice is required for AEMO to develop the constraint equations needed to dispatch the power system. Limit advice needs to be updated more frequently in response to changes to the network such as generation connections and major infrastructure projects.
- **Configuration and operability of protection schemes –** regular frequent reviews of protection adequacy, including for minimum fault conditions are required. Regular review, reconfiguration, and testing of special protection schemes is required. An increase in the complexity and scale of wide area protection schemes requires greater focus and attention.
- **Reduced power quality –** higher penetration of VRE inverter connections brings with it the potential for increased power quality challenges that need to be managed
- **Operating procedures –** the volume of required updates to operating instructions used by ElectraNet and AEMO to assist in real time operations, management of fault conditions and emergency management is increasing substantially
- **Volume, frequency, and complexity of data and analytics –** to maintain system security, there is a need for accurate and timely network and asset data to assess system conditions and predict the impact of network constraints for a greater range of operating scenarios (generation dispatch patterns, asset availability and network configuration). System alarms, which are a critical input to power system operations, are increasing in volume, frequency, and complexity.

An increase in skilled resource capability is needed to better understand and manage the increasing complexity, mitigate increasing operational risk, and maintain system security.

The potential consequence of cascading events for consumers is a sustained, widespread outage. Such an event would impose substantial costs on South Australian consumers and businesses. Illustratively, an outage of the average South Australian underlying demand of 1700 MW for 8 hours has an estimated cost of $460m.[2]

Operating at increasing intervals of 100% VRE and distributed generation, very low and negative operating demand and prolonged outages is heightening the risk of instability following system disturbances, safety issues, and damage to transmission assets

The challenges associated with 100% instantaneous VRE are here and now.

PowerRunner has assessed that ElectraNet's current resources in Asset Management, Network Planning, and System Operations are functioning at or above full capacity. The added complexity of several functions is over-dependent on the skills and knowledge of single individuals in an industry where skilled resources are in high demand and short supply.

To mitigate the increasing uncertainty of system conditions, planning complexity and operational risk, PowerRunner considers that ElectraNet requires an uplift of up to 26 Full Time Equivalents (FTEs) to better understand the atypical symptoms manifesting on the SA power system while continuing to take relevant actions to maintain system security as summarised in Table 1.

Table 1: ElectraNet - Summary of 100% renewables system operability uplift requirements

Capability	Function	Description	FTE
Planning	**Network planning**	Increased rate of change on the network and the potential for demand to fall to very low levels throughout the year requires much more detailed 'what if' analysis to underpin network management plans and to manage the risk of high impact low probability events.	**6-8**
	Outage management	With demand and generation being more volatile and the network more constrained during the year, much more detailed analysis of the system is needed to allow network equipment to be taken offline for maintenance and project work.	
	General Power System Risk Review	AEMO's annual General Power System Risk Review requires additional input, analysis and information from TNSPs.	
	Protection adequacy	The continued growth of inverter-based technologies on the power system increases the need for regular review of protection schemes to ensure they operate as intended to protect against power system disturbances.	
	System strength management	The recent Efficient Management of System Strength Rule includes new obligations for forward looking planning and provision of system strength services by TNSPs.	
Situational Awareness	**Dynamic monitoring**	Analysis of Phasor Measurement Unit data for improved situational awareness and early detection of network risk conditions to support operational decision making.	**5-7**
	Alarm analytics	In a more complex power system, network alarms will occur more frequently and in increasingly complex combinations. Improved alarm analytics is needed to help identify and diagnose problems as they emerge.	

2 Based on an average underlying demand of 1700 MW, calculated by averaging South Australia's forecast 2022/23 underlying yearly consumption (including the component of underlying demand supplied by rooftop solar PV and small non-scheduled generation) in AEMO's 2022 Electricity Statement of Opportunities, available at https://forecasting.aemo.com.au/Electricity/AnnualConsumption/Operational and the AER's standard Value of Customer Reliability, which is approximately $34,000/MWh

Capability	Function	Description	FTE
	Asset condition monitoring	An uplift is required in real-time monitoring, modelling, and analysis of network critical asset information, including predictive analytics.	
	System disturbance analysis	More needs to be done to investigate, analyse and learn from system disturbances given reduced 'safety margins' in a highly variable renewable system.	
Network Operations	**Control Room**	The increasing complexity and variability of system operations and risk of system disturbances places greater demands on Transmission System Operators in the control room requiring deployment of additional resources.	**8-11**
	Operations Systems Development	As the network and therefore the tools used to manage it become increasingly complex, additional SCADA engineers are required to support the tools for voltage and contingency analysis, situational awareness, and control room information systems.	
Total			**19-26**

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1. Introduction

Against a background of rapid growth in power system complexity, ElectraNet engaged PowerRunner to provide independent expert advice on the capability uplift needed to understand and manage the increasing complexity and risk of operating the SA transmission network.

The objective of PowerRunner's engagement was to assist ElectraNet in assessing the capability uplift in skilled resources needed to better understand and manage increasing planning complexity, and mitigate increasing operational risk by providing:

- global insights into trends in power system complexity
- risk analysis, and
- subject matter assistance.

The overall approach taken is illustrated in Table 2:

Table 2 – PowerRunner's approach

Activities	Outcomes
Research	• Assess local and international trends and leading practices • Review relevant global publications and industry reports, planning reports, work plans, and budgets • Leverage consultant knowledge and materials from similar projects
Workshops	• Work with relevant ElectraNet team members to workshop current state of planning and operations capabilities • Identify risks, issues, mitigations, constraints, as they relate to the changing nature of the power system and increased complexity • Facilitate an understanding of resource requirements • Present findings and recommendations
Risk Assessment	• Undertake a high-level risk assessment to evaluate the step change in complexity and risk in network planning and operations and asset management.
System Operability Uplift Assessment Report	• Develop a report highlighting the current challenges and trends on the SA power system and an assessment of the capability uplift in skilled resources needed better understand and manage increasing planning complexity, and mitigate increasing operational risk.
Consensus building consultation	• Present the key findings and recommendations to ElectraNet SMEs and Executives for input and discussion

The analysis revolves around PowerRunner's complexity risk assessment, which is provided in section 4.

Our methodology is to tabulate risks arising from growing power system complexity by reference to:

- key business functions in managing the transmission network
- major power system change drivers, observed and forecast, for the SA power system.

The impacts are defined as:

- Limited Impact on Complexity
- Moderate Increase in Complexity
- Large Increase in Complexity

Each major power system change driver describes a separate, and unique system security risk with each issue relating back to the energy transition in SA at an overarching level. These risks are independent, and therefore, cumulative in their impact on power system security and the risk of unserved energy.

This report is structured as follows:

- section 2 provides background and context
- section 3 examines the current level of power system risk in South Australia
- section 4 provides PowerRunner's analysis of the current situation and its conclusions
- section 5 provides recommendations.

2. Context

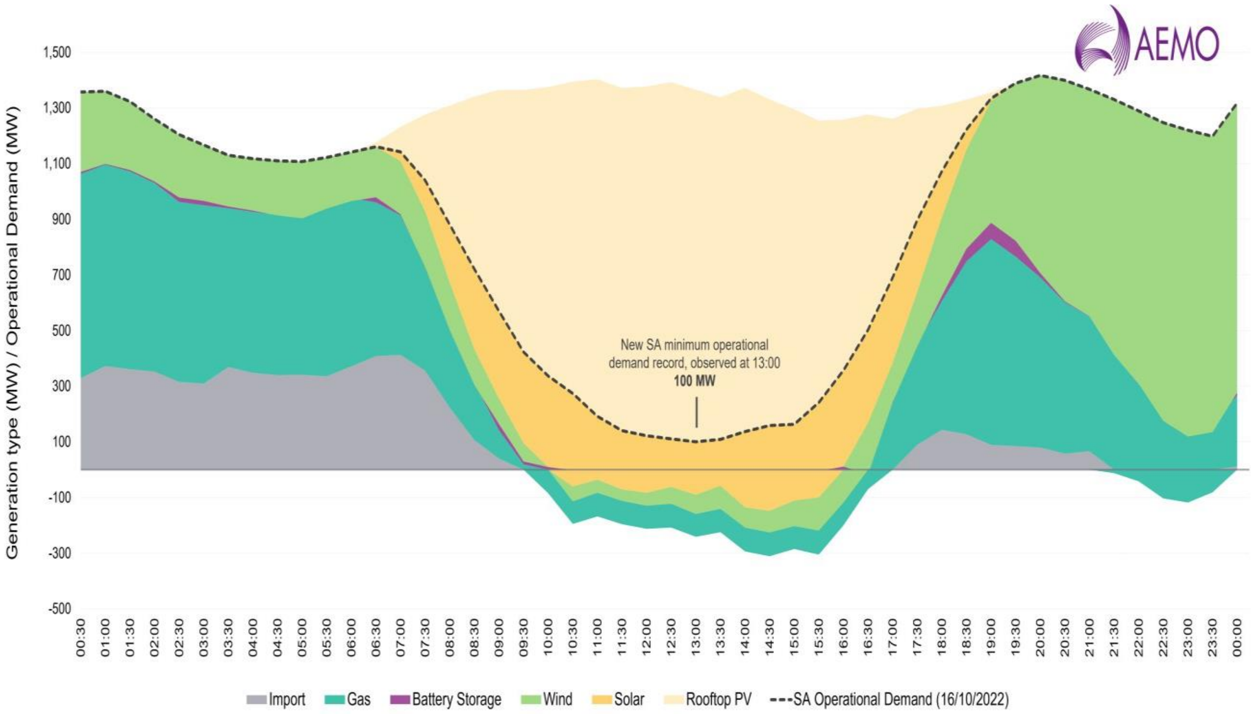
South Australia's power system is growing in complexity

1.1. SA has already reached 100% instantaneous VRE

AEMO has set a goal of being able to operate the NEM wide power system at 100% instantaneous VRE by 2025. The SA power system was first operated at 100% instantaneous VRE in October 2021 and this is expected to happen increasingly frequently, and for longer durations, as time goes on.

Figure 1 shows that, on 16 October 2022, the SA power system hit a new record minimum (half hourly) demand of 100 MW, down 88 MW from the previous record of 188 MW for a 30-minute period.

Figure 1: SA operational demand and generation mix – 16 October 2022



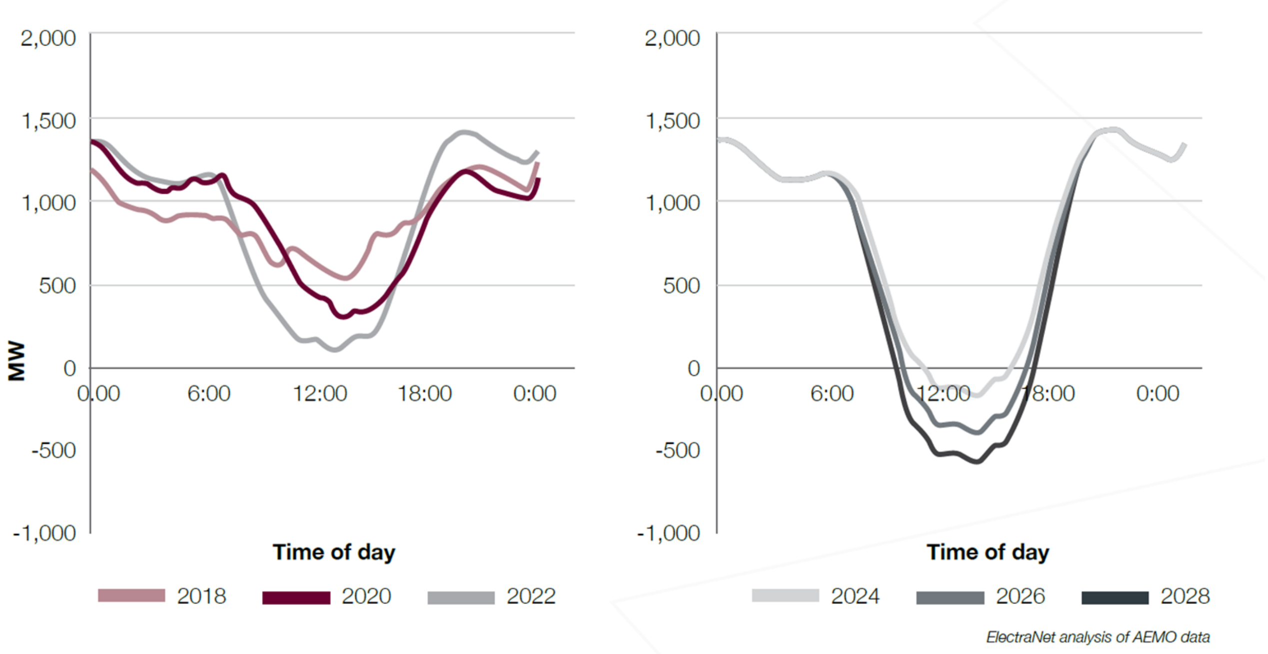
During the minimum demand period on 16 October 2022, it is estimated that rooftop solar PV output was 1,220 MW, accounting for 92% of the region's electricity demand. More than 100% of SA electricity demand was met by solar power, including large-scale solar generation, for about six hours in the middle of the day.

High penetration of VRE provides benefits to SA consumers in lower energy prices but comes with increased complexity and risk as the performance of VRE technologies and their impact on transmission assets at this level is unprecedented and unknown.

AEMO forecasts that the uptake of solar PV and other forms of VRE will continue.

The SA power system is forecast to operate more frequently at negative demand and minimum demand is forecast to fall further, reaching close to negative 500 MW by 2028 as shown in Figure 2.

Figure 2: Historic and projected demand on low demand days



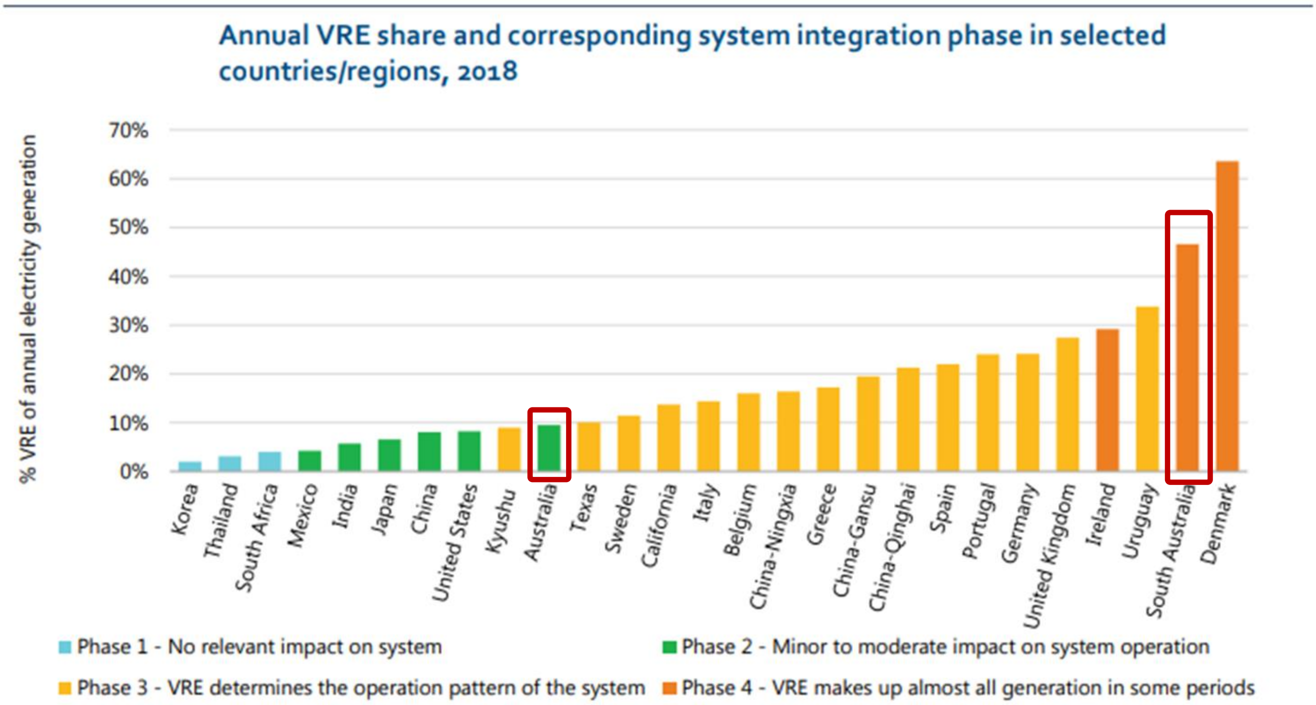
A power system that experiences regular periods of 100% instantaneous VRE is far more complex from a planning and operational perspective than one underpinned by conventional generation. High penetration of VRE creates many more possible combinations and permutations to be analysed in planning for, and operating, the power system.

1.2. SA is a world leader in moving to 100% VRE

South Australia's power system has undergone dramatic changes, shifting from one using approximately 20 predictable, dispatchable thermal power plants to one with over 150 power producers of varying sizes, utilising VRE and in which the largest aggregated generator is now DPV.

The International Energy Agency (IEA) shows SA as a world leader in VRE integration (Figure 3). Based on IEA analysis, none of the current 39 member countries are operating at 100% instantaneous VRE. Several countries have high penetrations of renewable energy; however, they are supported by synchronous hydro generation that provides inertia and system strength (as is also the case in Tasmania).

Figure 3 Annual VRE share in selected countries - IEA



Note: As of 2021-22, the annual share of VRE for SA has risen to 68%.

Source: ElectraNet Transmission Annual Planning Report, October 2022, page 19.

By way of comparison, Denmark is close to SA in terms of VRE capacity with more than 60% of its generation capacity supplied from VRE. Denmark is committed to operating at 100% renewable energy by 2050.

However, the fundamental difference between Denmark and SA is that Denmark is strongly interconnected with the highly meshed European and Scandinavian transmission systems with interconnectors to Germany, Norway, Sweden, the Netherlands, and England (planned). Denmark's import capability over these existing and planned interconnections is about 2.5 times its average demand.[3]

In contrast, SA is currently interconnected only to Victoria via two interconnectors with a combined import capability of 820 MW, about half of South Australia's average demand.[4]

When Project EnergyConnect is completed in 2025, SA will be able to import 800 MW from NSW. Total import capability will nearly enough to cover to South Australia's average underlying demand for electricity.[5]

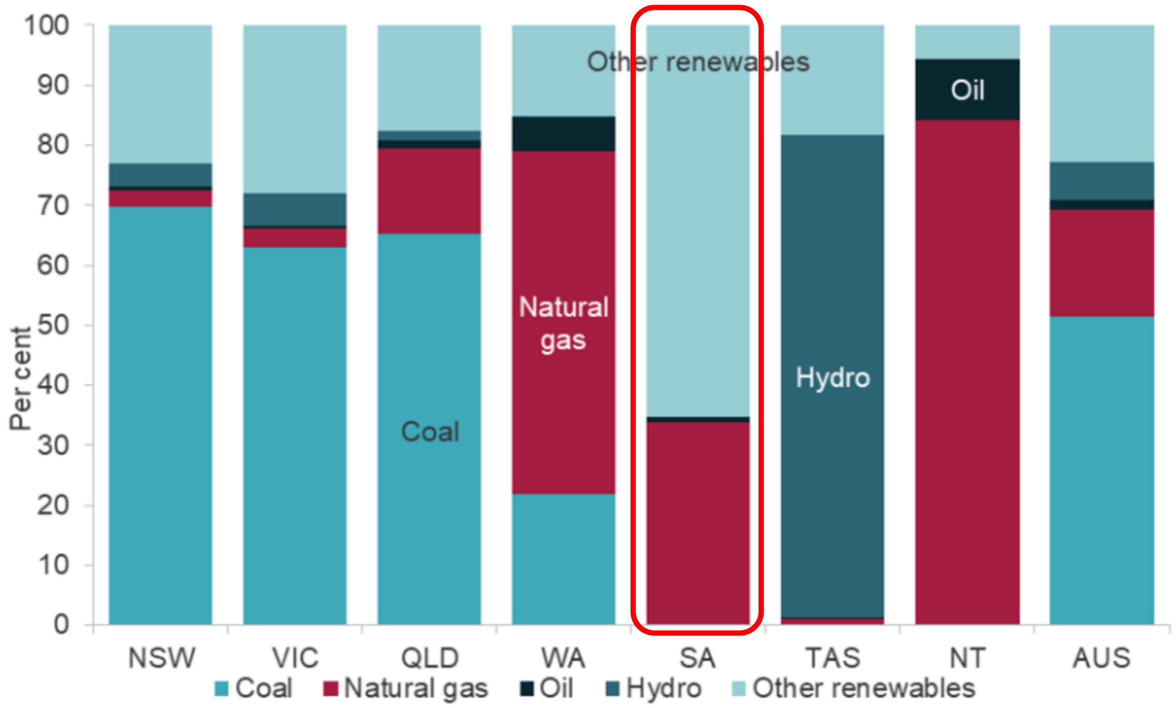
[3] Source: https://en.wikipedia.org/wiki/Electricity_sector_in_Denmark.

[4] ElectraNet, Transmission Annual Planning Report, page 53, available at https://www.electranet.com.au/what-we-do/network/transmission-annual-planning-reports/.

[5] This takes account of demand supplied by rooftop solar PV and small non-scheduled generation, which would be lost in a major system event.

Figure 4 compares generation by resource in calendar year 2021 to other Australian states and territories. It shows SA as the clear leader in VRE integration in Australia as well.

Figure 4: Australian electricity generation fuel mix, calendar year 2021



Source: Department of Climate Change, Energy, the Environment and Water (2022) Australian Energy Statistics, Table O

1.3. SA's use of VRE is forecast to continue to grow

AEMO has recently published the 2022 ESOO, forecasting increasing DPV and VRE connections and both higher maximum and materially lower minimum demand on the SA power system.

This confirms that the challenges, complexities, and uncertainties of operating the power system at high levels of VRE are 'here and now' and will continue over the 5-year regulatory period.

Notable changes to the topology of the SA power system are forecast as outlined in Table 3 below. In addition to substantial increases in VRE capacity, the ESOO forecasts operational demand at close to negative 500 MW by 2028.[6]

These changes and forecast operational demand levels will further exacerbate the challenges, complexities, and uncertainties of operating the SA transmission network as part of a power system at 100% VRE, which will persist and evolve over the 5-year regulatory period.

6 AEMO, 2022 ESOO, page 96. Available at https://www.aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-reliability/nem-electricity-statement-of-opportunities-esoo.

Table 3: Forecast changes in SA Power System

Change	Description
Increase in VRE connections	• 457 MW of additional VRE generation is expected to connect between summer 2021-22 and 2022-23 - predominantly wind and solar facilities at the Port Augusta Renewable Energy Park • Connection pipeline of 10 GW of new generators and battery storage
Increased distributed solar	• Approaching 2,000 MW of distributed solar on the SA power system • DPV Standards compliance is poor and is not improving, resulting in a heightened risk of DPV shake off
Solar & pumping station	• 105 MW Tailem Bend Stage 2 Solar Project - target connection in 2024 • 12 MW Mannum Adelaide Pumping Station No 3 - MAPL3 (Tungkillo) in 2025
Generation Retirements	• 683 MW of generation scheduled to retire between 2022 and 2030: – 120 MW Torrens Island A Unit 3 (currently mothballed) scheduled to retire in 2022 – 180 MW Osborne gas generator scheduled for retirement in December 2023 – 383 MW Dry Creek, Mintaro, Port Lincoln and Snuggery power stations scheduled for retirement in 2030 • A further 800 MW of generation recently announced to retire in 2026: [7] – 200 MW single Torrens Island B unit (currently mothballed) – 600 MW remainder of Torrens Island B units
Generation returns to service	• 90 MW Mintaro Power Station scheduled to return to service in January 2023
Major infrastructure	• Project Energy Connect - SA-NSW 330 kV interconnector • Integration of potentially many new loads at unprecedented scale and capability
Asset replacement	• Program of work for the replacement of aging assets
Capacitive loads	• The characteristics of load on the electricity network are changing with an observed trend in load becoming less inductive and more capacitive to the extent of about 20 MVAR per annum

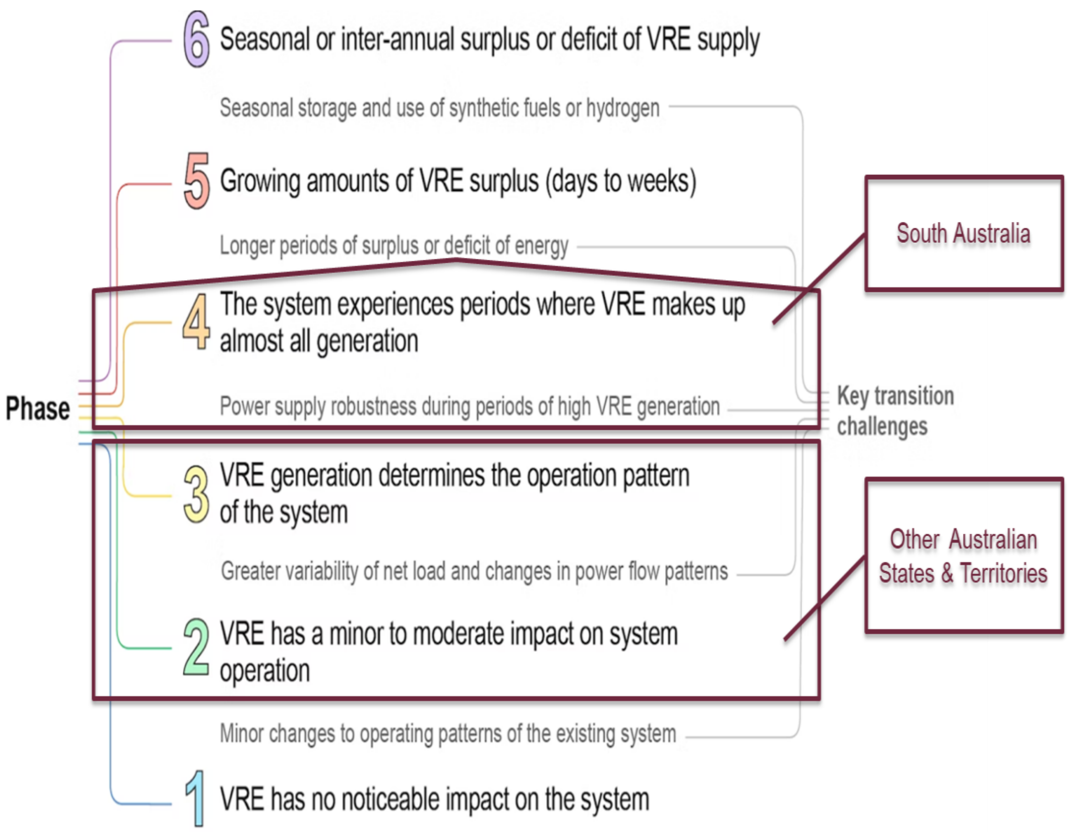
The IEA has developed a phase categorisation to illustrate the evolving penetration of VRE on power systems, as well as the related operational issues. This is shown in Figure 5.

The purpose of the phase categorisation is to prioritise different measures to support system flexibility, identify relevant challenges and implement appropriate measures to support the system integration of VRE.

When the phase categorisation was completed in 2018: Australia was at Phase 2 collectively. However SA was at Phase 4.

[7] Announced by AGL on 24 November 2022, see https://www.agl.com.au/about-agl/media-centre/asx-and-media-releases/2022/november/torrens-island-b-power-station-to-close-in-2026.

Figure 5: IEA phase categorisation of power systems with Variable Renewable Energy



1.4. ElectraNet is one of the first TNSPs in the world to experience challenges from high VRE

Increasing VRE penetration, together with higher maximum demand, lower minimum demand and increasingly negative demand, is increasing planning complexity and exacerbating operational challenges across the SA power system.

Network planning has typically focused on preparing for credible contingencies under maximum demand conditions. There are approximately 200 credible contingencies to consider in SA, meaning that the same number of plans, and supporting studies, must be conducted.

Planning studies must now also address low, zero and negative demand conditions. These conditions are observed much more frequently than maximum demand, meaning that the possibility of more than one credible contingency occurring simultaneously needs to be considered.

This is known as N-1-1 planning and increases the necessary analysis 200-fold.

Further, it will be necessary for network planning to account for more scenarios with different combinations of generators, further increasing the volume and scale of the necessary analysis. In practice ElectraNet will now need to adopt more automated methods for completing and interpreting system studies to underpin planning.

In December 2021, AEMO identified over 300 unique potential gaps in the energy transition, in its NEM Engineering Framework Initial Roadmap.[8]

The Initial Roadmap identified that operating conditions that are expected to emerge in the next 10 years will require the power system to be deliberately engineered for a step change in capability.

[8] AEMO, NEM Engineering Framework: Initial Roadmap, December 2021. Available at https://aemo.com.au/-/media/files/initiatives/engineering-framework/2021/nem-engineering-framework-initial-roadmap.pdf.

The Initial Roadmap also highlights the scale of transformation required, with a need for the future power system to:

- support increasingly complex dynamics in the transition from mainly synchronous to mainly inverter-based resources and balance increasing volumes of VRE
- enable increasingly decentralised operation through the ongoing uptake of DPV and other distributed energy resources, and increasingly coupling with other sectors through the electrification of industry, transport and other end uses.

In the Initial Roadmap, AEMO stated that:

> *… it is critical that designing a step change in power system capability starts today, due to:*
>
> - *The extent of work and collaboration required across many areas, including technical engineering, planning, and regulatory reform*
> - *The pace of change underway and the asymmetric risk to consumers of disorderly, constrained and inefficient transition*
> - *The risks if timely action is not taken and system operators do not have the tools to securely and reliably manage new operational conditions as they emerge.*[9]

The extent to which very high levels of VRE penetration will impact the power system is unprecedented and relatively unknown, as there is limited historical performance data available. It is generally accepted that the higher the penetration of VRE the greater the challenges, complexity, and risk.

The current experience of the SA power system also identifies new challenges, and highlights where existing issues are exacerbated to levels not yet experienced elsewhere. These are summarised in Table 4.

Table 4: Power system challenges in South Australia

Challenge	Description
Unexpected system operating conditions	• System conditions are less predictable in a rapidly changing power system – for example the forecasting horizon for zero demand was until recently around 10 years away, masking the urgent need to study these system conditions • A step change in the rate of change (decline) in operational demand over the course of a day is resulting in rapidly changing system conditions • More look ahead analysis based on real time system conditions is required to understand how VRE is impacting on system security
Voltage control	• increasing VRE, reducing minimum demands and changes in customer load characteristics (becoming more capacitive) are making voltage control more complex and challenging • A step change increase in the number of intervals where emergency procedures for voltage control are activated – 1 event in 2020 has increased to 9 events in 2022 to date • Increasing persistence of voltage depressions during network faults • 5 am distribution VAR injections – cause unknown • Distribution forced outages causing voltage and oscillation issues on the transmission system

9 Initial Roadmap, page 6.

Challenge	Description
	• Transformers operating on bottom tap settings with reduced operational flexibility • Increased requests from distribution system operator for voltage support • System strength shortfalls
Increased complexity of outage management	• More equipment out of service is an indication of reduced resilience in the SA power system • Average Equipment (major plant) Out of Service per day has increased by 225% from 2016 to 2021, hence a step change in the complexity of outage management. • Increased numbers of equipment out of service per day results in a step change in complexity and scale in contingency analysis and system security assessments to support outage approvals • The increased likelihood of critical asset maintenance being delayed causes increased risk of plant failure and subsequent system disturbances • Total Equipment Out of Service per Year indicates a similar increase of 225% from 2016 to 2021. This causes a year-round step change in complexity of outage management, not limited to seasonal outage windows as was the norm historically • Increase in VRE has resulted in a decrease in available outage times and durations requiring much shorter recall times if power system operating conditions change • More planned outages cancelled at short notice are resulting in standdown costs and resource inefficiencies
Operating the system at loading levels below the level it was designed for	• As operational demand falls to very low levels for longer, the power system is increasingly vulnerable and challenging to operate • There has been a step change in days per annum with operational demand at or below 500 MW below which greater operational challenges exist – This is highlighted by the number of emergency procedures for voltage control activated - 1 event in 2020 has increased to 9 events in 2022 to date
Maximum, minimum, zero and negative demand	• Transmission network stress points are occurring more frequently during minimum, zero and negative demand conditions in addition to the historical focus on performance under maximum demand conditions • System stresses at times of minimum and maximum MVAr demand – which is no longer correlated to active power demand • Negative demand forecast at -500MW by 2028
Increased complexity, scale and volume of planning studies	• There is an increase in system operating conditions that need to be considered for network planning and operations, including N-1-1 planning to consider the increased likelihood of multiple credible contingencies occurring simultaneously (200-fold increase) • There is an increased number of credible generator and load permutations in conjunction with network configurations that need to be considered in network planning. • This includes power quality and QV analysis at the times of minimum and zero demand • Analysis of the impact of loading ramp rates on system and local voltage control under system normal and N-1-1 scenarios needs to be considered • N-1-1 contingency analysis of minimum demand and studies of high voltage, at time of zero demand, minimum demand and under minimum and maximum MVAr conditions also add to the scope of planning required

Challenge	Description
Expanded limit advice	• Faster and a higher volume of limit advice is required for AEMO to develop constraint equations needed to dispatch the power system • Limit advice needs to be updated more frequently in response to changes to the network such as generation connections and major infrastructure projects
Configuration and operability of protection schemes	• Regular reviews are required of protection adequacy, including for minimum fault conditions • Regular review, reconfiguration, and testing of special protection schemes required – 20 runback, bypass, local stability, local overload, and local anti-islanding schemes, 3 SA islanding schemes, 7 auto voltage control schemes • Increase in the complexity and scale of wide area protection schemes requiring greater focus and attention • Under frequency load shedding effectiveness in critical situations is compromised by feeders with reverse power flows
Reduced power quality	• Higher penetration of VRE inverter connections brings with it the potential for increased power quality challenges to be managed • There is an increased likelihood of voltage oscillations that could cause customer load, VRE or BESS to disconnect from the network • For example, in June 2022 widespread voltage oscillations were observed throughout SA with many customers noticing their light flickering and dimming. These voltage oscillations were caused by a renewable generation source in Port Augusta resulting in multiple large industrial customers disconnecting their equipment to avoid damage • There is an increasing risk that oscillations at lower fault level substations could impact a larger number of customers with heightened power system stability risk
Operating procedures	• The volume of required updates to operating instructions used by ElectraNet and AEMO to assist in real time operations, management of fault conditions and emergency management is increasing substantially • Increased changes in system topology require more analysis, redefining and testing of system restart procedures
Volume, frequency, and complexity of data and analytics	• To maintain system security, there is a need for accurate and timely network and asset data to assess system conditions and predict the impact of network constraints for a greater range of operating scenarios (generation dispatch patterns, asset availability and network configuration) • More PMUs are being deployed across the transmission network as requested by AEMO to monitor power system conditions and performance • System alarms, a critical input to power system operations, are increasing in volume, frequency, and complexity

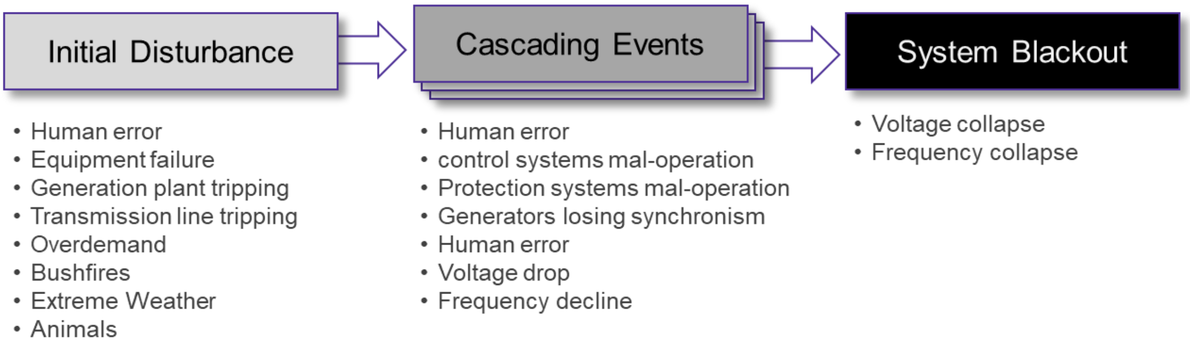
3. Power system risk in SA is increasing and more must be done to manage this risk

The atypical operating conditions and challenges currently being experienced on the SA power system, and the challenges expected soon, mean that more must be done to cope with the additional complexity of the power system.

South Australia's power system is changing, and the risk of extreme weather events, bushfires and other crises is growing. There is an increased likelihood of system disturbances occurring, more than in the past.

If a disturbance is not managed effectively, it can lead to a loss of load and, potentially, to a full system outage. The more system disturbances that occur, the higher the risk that a disturbance cascades to a lost load event or a system-wide outage based on a range of contributing factors, such as those listed in Figure 6.

Figure 6: Cascading system events



To date, the SA power system has proven to be generally robust and capable of withstanding system disturbances. However, with the changes expected in the next few years, the risk of high impact low probability power system events is increasing.

The potential consequence of cascading events for consumers is a sustained, widespread outage. Such an event would impose substantial costs on South Australian consumers and businesses. Illustratively, an outage of the average South Australian demand of 1700 MW for 8 hours has an estimated cost of $460m.[10]

The ongoing challenges and uncertainty of system conditions have caused a step change in the volume of work needed to plan and operate the SA power system.

An uplift in systems and capability is needed to manage the risk of increased system disturbances.

This has been recognised by AEMO, which stated in the [2022 Integrated System Plan] that

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

[10] Based on an average underlying demand of 1700 MW, calculated by averaging South Australia's forecast 2022/23 underlying yearly consumption (including the component of underlying demand supplied by rooftop solar PV and small non-scheduled generation) in AEMO's 2022 Electricity Statement of Opportunities, available at https://forecasting.aemo.com.au/Electricity/AnnualConsumption/Operational and the AER's standard Value of Customer Reliability, which is $34,000/MWh

4. Analysis and conclusions

PowerRunner has determined that historical network security performance is no longer a reasonable predictor for future performance, given the uncertainty and significant changes in complexity that are forecast, and the emergence of atypical power system operating conditions.

PowerRunner's complexity risk assessment is summarised in the table below. Power system events leading to lost load have been rare in the past, especially network events arising from human error, inadequate system analysis or poor operational decision making. However, this is reliant on the adequacy of operational tools, capability and redundancy and resilience in the system. These things will come under increasing pressure in the next few years.

While still rare, system events are occurring more frequently worldwide. SA has its own experience with the state wide system blackout that affected 850,000 customers on 28 September 2016 involving storm damage to electricity transmission infrastructure.

More recently, the NEM was suspended in June 2022, the first time since its inception in 1998. This was an indicator of the complexity, scale and rate of change of system conditions of the energy transition. AEMO issued over 450 Lack of Reserve (LOR) notices in May and June 2022 leading up to the market suspension. This event gives insight into the scale and complexity of system, operations in the NEM.

PowerRunner has identified that network planning and operations and asset management resources at ElectraNet are at maximum capacity. Increasing complexity in planning and operations is increasing analytical workloads.

PowerRunner has concluded that there is an immediate need for ElectraNet to better understand the increasing network planning and operating complexity and risk to system security. This will involve conducting detailed studies and analysis in long, near and real-time to support system security at 100% VRE.

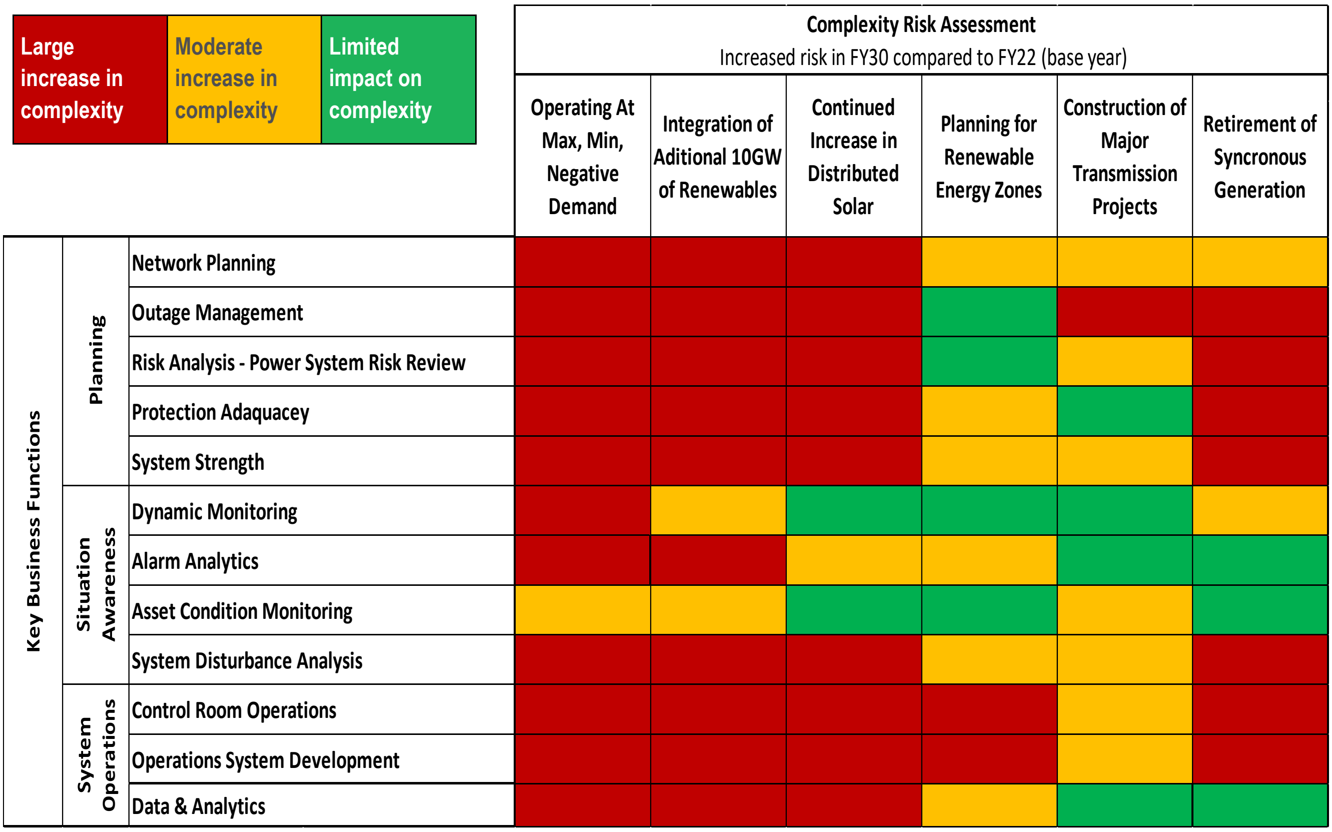
In broad terms, the future power system will be an environment in which it takes longer to produce key information but, at the same time, the information is needed faster. This can only be offset by increasing planning and analytical resources.

PowerRunner has undertaken a complexity risk assessment as shown in Figure 7 below.

Based on the risk assessment, PowerRunner forecasts that if unmitigated, the compounding effect of increased complexity across key business functions will increase the risk of power system disturbances on the SA transmission system during the coming regulatory period.

Without mitigation, there would be an increased risk of minor, intermediate and catastrophic system security incidents resulting in expected unserved energy increasing each year that mitigation is not applied.

Figure 7: Risk assessment



PowerRunner forecasts that, if unmitigated, the increased risk of disturbances on the SA transmission network arising from the risk factors identified above would lead to substantially increased potential for load shedding and major system disruption.

5. Recommendation

Given the risk assessment and the areas in which additional capability is required, PowerRunner recommends a capability uplift (human resources), to further enhance ElectraNet's capability to understand, plan, operate and manage the SA transmission network in a power system increasingly operating with 100% instantaneous VRE.

To address these requirements PowerRunner recommends a capability uplift (human resources) of up to 26 FTE as set out in Table 5.

Table 5: Required capability uplift

Capability	Function	Description	FTE
Planning	Network planning	Increased rate of change on the network and the potential for demand to fall to very low levels throughout the year requires much more detailed 'what if' analysis to underpin network management plans and to manage the risk of high impact low probability events.	6-8
	Outage management	With demand and generation being more volatile and the network more constrained during the year, much more detailed analysis of the system is needed to allow network equipment to be taken offline for maintenance and project work.	
	General Power System Risk Review	AEMO's annual General Power System Risk Review requires additional input, analysis and information from TNSPs.	
	Protection adequacy	The continued growth of inverter-based technologies on the power system increases the need for regular review of protection schemes to ensure they operate as intended to protect against power system disturbances.	
	System strength management	The recent Efficient Management of System Strength Rule includes new obligations for forward looking planning and provision of system strength services by TNSPs.	
Situational Awareness	Dynamic monitoring	Analysis of Phasor Measurement Unit data for improved situational awareness and early detection of network risk conditions to support operational decision making.	5-7
	Alarm analytics	In a more complex power system, network alarms will occur more frequently and in increasingly complex combinations. Improved alarm analytics is needed to help identify and diagnose problems as they emerge.	
	Asset condition monitoring	An uplift is required in real-time monitoring, modelling, and analysis of network critical asset information, including predictive analytics.	
	System disturbance analysis	More needs to be done to investigate, analyse and learn from system disturbances given reduced 'safety margins' in a highly variable renewable system.	
Network Operations	Control Room	The increasing complexity and variability of system operations and risk of system disturbances places greater demands on Transmission System Operators in the control room requiring deployment of additional resources.	8-11
	Operations Systems Development	As the network and therefore the tools used to manage it become increasingly complex, additional SCADA engineers are required to support the tools for voltage and contingency analysis, situational awareness, and control room information systems.	
Total			**19-26**